PROJ coordinate transformation software library

Release 9.3.1

PROJ contributors

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### 11.2 Geodetic TIFF grids (GTG)

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### 12 Community

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PROJ is a generic coordinate transformation software that transforms geospatial coordinates from one coordinate reference system (CRS) to another. This includes cartographic projections as well as geodetic transformations. PROJ is released under the X/MIT open source license.

PROJ includes command line applications for easy conversion of coordinates from text files or directly from user input. In addition to the command line utilities, PROJ also exposes an application programming interface, or API in short. The API lets developers use the functionality of PROJ in their own software without having to implement similar functionality themselves.

PROJ started purely as a cartography application letting users convert geodetic coordinates into projected coordinates using a number of different cartographic projections. Over the years, as the need has become apparent, support for datum shifts has slowly worked its way into PROJ as well. Today PROJ supports more than a hundred different map projections and can transform coordinates between datums using all but the most obscure geodetic techniques.

1.1 Citation

To cite PROJ in publications use:


A BibTeX entry for LaTeX users is

```latex
@Manual{,
  title = {{PROJ} coordinate transformation software library},
  author = {{PROJ contributors}},
  organization = {Open Source Geospatial Foundation},
  year = {2023},
  url = {https://proj.org/},
  doi = {10.5281/zenodo.5884394},
}
```
1.2 License

PROJ uses the MIT license. The software was initially released by the USGS in the public domain. When Frank Warmerdam took over the development of PROJ it was moved under the MIT license. The full text of the license follows, and can also be found in the file COPYING, at the top level of the source distribution package.

All source, data files and other contents of the PROJ package are available under the following terms. Note that the PROJ 4.3 and earlier was "public domain" as is common with US government work, but apparently this is not a well defined legal term in many countries. Frank Warmerdam placed everything under the following MIT style license because he believed it is effectively the same as public domain, allowing anyone to use the code as they wish, including making proprietary derivatives.

Initial PROJ 4.3 public domain code was put as Frank Warmerdam as copyright holder, but he didn't mean to imply he did the work. Essentially all work was done by Gerald Evenden.

Copyright information can be found in source files.

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CHAPTER
TWO

NEWS

2.1 9.3.1 Release Notes

December 1st 2023

2.1.1 Updates

• Update to EPSG 10.098 (#3968)
• Update ESRI objects to v3.2.0 (#3944)

2.1.2 Bug fixes

• ITRF2008: fix wrong sign for dry parameter of EURA and EURA_T (#3870)
• Fix build error with MSVC 2019 in /std:c++20 on NN_NO_CHECK() (#3872)
• ESRI WKT import: normalize GCS_unknown to unknown and D_unknown to unknown (#3874)
• CoordinateOperationFactory(): deal with CompoundToCompound with a horizontal similarity transformation and a ballpark vertical (#3881)
• Ellipsoid::isEquivalentTo(): fix so that an ellipsoid of semi-major axis A (and non-zero inv flattening) isn't equivalent to a sphere of radius A (#3882)
• isEquivalentTo(): make a datum name 'unknown' equivalent to another one (#3883)
• cs2cs: fix handling of input coordinates in grad (#3886)
• Make setargv.obj available on Universal Windows Platform (#3891)
• Allow opening proj.db with a URI (#3892)
• createOperations(): fix GeogCRS 3D with TOWGS84 to geocentric CRS (#3915)
• Fix test suite so that it can pass with ENABLE_TIFF=OFF (#3916)
• GeographicBoundingBox::intersects(): avoid infinite recursion and stack overflow on invalid bounding boxes (#3919)
• Fix importing '+proj=topocentric ... +type=crs' by using a geocentric CRS as the base CRS (#3924)
• Allow LOCAL_CS with 3 axes (#3928)
• WKT1 parser: in non-strict mode, accept missing UNIT[] in GEOGCS, GEOCCS, PROJCS and VERT_CS elements (#3933)
• `createOperations()`: fix issue with a obscure case involving CompoundCRS of unknown horizontal datum + boundCRS of vertical (#3934)
• `createOperations()`: fix bad PROJ pipeline when converting between Geog3D with non-metre height to CompoundCRS (#3943)
• `createOperations()`: Fix possible null dereference on invalid WKT input (#3946)
• `proj_factor()`: fix when input is a compound CRS of a projected CRS (#3950)
• `pj_get_suggested_operation()`: tune it to give correct result for RGAF09 to RAF 1991 / UTM zone 20N + Guadeloupe 1988 height transformation (#3954)
• Move static NameSpace::GLOBAL definition in static.cpp to avoid `static initialization fiasco` (#3956)
• horner: allow arbitrary input type of coordinate (#3961)

2.2 9.3.0 Release Notes

September 1st 2023

2.2.1 Updates

• Add C++ API to transform coordinate (#3705)
• CMake: add PROJ_DB_CACHE_DIR (#3711)
• Implement EPSG:1026 Mercator (Spherical) method (#3741)
• CMake: remove useless cross-compiling related checks (#3747)
• Add mapping of Equidistant Conic to new EPSG:1119 method (#3812)
• Implement proposal001 from Planetary DWG from OGC (#3816)
• Add option in `proj` CLI to use a CRS (#3825)
• `proj_factors()`: make it work with projected CRS with non-metre unit and/or northing/easting axis order (#3826)
• `PROJ_DEBUG`: make ON an alias of 2, and OFF of 1 (#3835)
• Database: update to EPSG 10.094 (#3847)

2.2.2 Bug fixes

• GeographicBoundingBox::intersection(): avoid infinite recursion and stack overflow on invalid bounding boxes (#3748)
• Various fixes related to concatenated operations (#3820)
• Projected CRS identification: fix crash when the base CRS is a non-geographic geodetic CRS (#3830)
• Avoid C++ exceptions to be thrown (and caught) when parsing strings like `+proj=longlat +datum=WGS84 +type=crs` (#3834)
• BUG: Handle prefix whitespace when guessing WKT dialect (#3841)
• `proj_alter_id()`: make it replace an existing ID instead of appending a new one (#3846)
• bonne: fix inverse map projection computations when `lat_1 < 0` (#3849)
• WKT1 ESRI import/export: fix GCS name for EPSG:8353 S-JTSK_[JTSK03]_Krovak_East_North (#3851)

2.3 9.2.1 Release Notes

June 1st 2023

2.3.1 Database updates

• Add alias for old ESRI datum/CRS names of EPSG:8353 S_JTSK_JTSK03_Krovak_East_North (#3678)
• Pseudo Mercator now supported with IAU CRS's (#3645)
• Updated to EPSG 10.088 (#3731)

2.3.2 Bug fixes

• Fixed build errors with Cygwin (#3642)
• PROJ string CRS parser: make sure that PROJ arguments of the rotated string are kept in the WKT representation (#3656)
• Fix slowness on proj_trans() when doing WGS 84 <--> NAD83 conversions (#3661)
• vgridshift/gridshift: accept hydroid_height as valid band description (#3675)
• WKT/PROJJSON: import/export accuracy of ConcatenatedOperation (#3676)
• Coordinate operation factory: count identified concatenated operations as a single step (#3677)
• EngineeringCRS: make `proj_create_engineering_crs()` set a datum name and relax isEquivalentTo() comparisons (#3685)
• PROJJSON: fix import/export of integer parameter value, and deal with interpolation CRS parameters in conversions (#3695)
• CMake: avoid imbalanced cmake_policy push/pop if TIFF or CURL dependency cannot be found (#3697)
• proj_create_crs_to_crs(): restore transformation selection behaviour of PROJ 9.1 when grids are missing (#3707)
• ESRI WKT: improve roundtrip of name and definition for UPS WGS84 CRS (#3720)
• CRS instantiation from PROJ.4 string: set 'Unknown based on XXXX ellipsoid' datum name when instantiating from known +a, +rf (#3727)
• cs2cs / proj_create_crs_to_crs(): fix regression with geocentric CRS (#3729)
• proj_trans(): set PROJ_ERR_COORD_TRANSFM_NO_OPERATION error when failing in ONLY_BEST=YES mode (#3730)
• tinshift: raise maximum size of JSON file to 100 MB (#3736)
2.4 9.2.0 Release Notes

March 1st 2023

2.4.1 Updates

- Database
  - EPSG updated to EPSG 10.082 (#3609)
  - ESRI objects updated to v3.1.0 (#3575)
  - Added Slovenian geoid model SLO-VRP2016/Koper (#3610)

- Projections
  - Added generic Space Oblique Mercator (#3338)
  - Inverse eck4: Add checks for projection domain (#3625)

- Transformations
  - Added support for NADCON5 grids and transformation method (#3510)
  - Added option ONLY_BEST=YES (#3535)
    - When enabled only use the best possible transformation between two CRS's can be instantiated. If the best possible transformations can't be instantiated it will fail instead of opting for the next best transformation.
    - With ONLY_BEST=YES a transformation will fail if a needed grid is unavailable.
    - The option can be toggled in proj.ini and with --only-best in cs2cs.
  - Implement 'Similarity transformation' (EPSG:9621) and import related transformations from EPSG (#3578)
  - Optimise transformations between GDA94, GDA2020 and WGS84 (#3621)

- Performance improvements
  - Pass PJ_COORD by reference for fwd4d() and inv4d() callbacks (#3503)
  - Improved of inverse meridian length calculations (#3516)
  - Avoid very poor performance on a geographic CRS whose datum name is the alias of an official one (#3624)

- Well-Known Text improvements
  - Support WKT:2019 COORDINATEMETADATA[] construct (#2711)
  - implement alterCSTLinearUnit() for CompoundCRS (#3325)
  - Implement alterCSTLinearUnit() for BoundCRS (#3327)
  - Added PJ_TYPE_DERIVED_PROJECTED_CRS (#3488)
  - Added support for ISO19111 CoordinateMetadata class (#3562)
  - Update WKT import to support WKT2 corrigendum (#3573)
  - WKT import: Make axis direction and range meaning enumeration case insensitive as mandated by spec (#3577)
  - Implement AffineCS and handle it in WKT (#3579)
  - WKT1 parser: Support inf as inverse flattening value (#3626)

- PROJJSON
– Version number changed to 0.6
– Added an additional optional source_crs property in abridged_transformation (#3454)
– Added support for ISO19111 CoordinateMetadata class (#3562)
– Implement AffineCS and handle it in PROJJSON (#3579)

• C/C++ API
  – C API: add proj_get_domain_count(), proj_get_area_of_use_ex() and proj_get_scope_ex() (#3588)
  – Added explicit NaN handling to proj_trans() and gie (#3603)

DEPRECATIONS
The following functions have been deprecated and will be removed in a future version.
– C API function proj_rtodms(). Use proj_rtodms2() instead (#3431)
– C experimental API function proj_create_conversion_tunisia_mapping_grid(). Use proj_create_conversion_tunisia_mining_grid() instead (#3559)
– C++ API function createTunisiaMapingGrid(). Use createTunisiaMiningGrid() instead (#3559)

• CMake
  – Added uninstall target (#3362)
  – Adopted use of TIFF:TIFF and CURL::libcurl targets (#3374)

• Security improvements
  – Replaced uses of sprintf() with the safer snprintf() (#3421, #3431)

• Various other improvements
  – Implemented platform independent mutex for better results on lesser used platforms (#3425)
  – Improved name and remarks in descriptions of some vertical transformations (#3334)
  – Implemented stricter matching by name to avoid false positives (#3487)
  – Improved numerical accuracy of the meridian length calculations and its inverse (#3516)
  – Added PROJ_IGNORE_CELESTIAL_BODY=YES environment variable that allows better matching of non-earth shaped ellipsoids to other celestial bodies (#3569)

2.4.2 Bug fixes

• rtodms(): fix potential buffer overflow not dealt with (#3441)
• NetworkFile::open(): fix memory leak in unlikely error code path (#3443)
• When importing LOCAL_CS["foo"], generates a non-empty name for the datum (#3491)
• Avoid unit mix-up in CRS::alterCSLinearUnit() for DerivedProjectedCRS (#3499)
• WKT to PROJ conversions: Map 'Lambert Azimuthal Equal Area (Spherical)' to +proj=laea +R_A (#3526)
• ProjectedCRS::identify(): Relax trust in id/authority in definition to identify (#3532)
• Fix instantiation of http://www.opengis.net/def/crs/IAU/2015/xxx URNs (#3569)
• Fix proj_normalize_for_visualization() on a transformation with FORCE_OVERb=YES (#3570)
• `createBoundCRSToWGS84IfPossible()`: Do not report `+towgs84` for a CRS with multiple extents, such as EPSG:6316 (#3587)

• `pj_get_suggested_operation()`: handle longitudes outside of [-180,180] for coordinate operation selection (#3595)

• WKT1 parser: only emit warning when encountering invalid UNKNOWN WKT1 axis direction (#3618)

• `projinfo`: fix long option name --source-crs (#3601)

### 2.5 9.1.1 Release Notes

*December 1st 2022*

#### 2.5.1 Updates

• Database: register `at_bev_AT_GIS_GRID_2021_09_28` grid (#3442)

#### 2.5.2 Bug fixes

• Implement `alterGeodeticCRS` and `stripVerticalComponent` for `DerivedProjected` (#3482)

• Various improvements to handling of `DerivedProjectedCRS` (#3482, #3477, #3342, #3319, #3317)

• Add missing `<cstdint>` includes (#3459)

• `cs2cs`: better validate value of `-W` option (#3453)

• `DatabaseContext::lookForGridInfo()`: fix caching of filenames and set correct URLs (#3448)

• Database: register in `grid_alternatives` grids from PROJ-data that have no corresponding transformation record (#3446)

• `cass` projection: fix forward computation of easting (#3433)

• Implement Geographic/Vertical Offset conversions (#3413)

• `vandg` projection: handle `+over` to extend the validity domain outside of `[long]>180deg` (#3427)

• `eqdc` projection: avoid floating point division by zero in non-nominal case (#3415)

• `createOperations()`: fix issues when transforming between `Geog3D` and `DerivedGeog3D` CRS with Geographic3D offsets method (#3411)

• `VerticalCRS::isEquivalentTo()`: do not consider `VerticalCRS` and `DerivedVerticalCRS` as equivalent (#3408)

• `cct` and `cs2cs`: Avoid problems when encountering UTF-8 BOM `` characters at beginning of input files (#3395)

• `createFromUserInput()`: Improved lookup when approximate name is provided (#3371)

• `projinfo` / `cs2cs`: auto promotion to 3D of CRS specified by name (#3367)

• `findsOpsInRegistryWithIntermediate()`: make it work when source/target geodetic CRS has no known id (#3365)

• `createOperations()`: emulate PROJ < 6 behavior when doing geocentric <-> geographic transformation between datum with unknown transformation (#3361)
• Fix issue when transforming from/into a WKT2 Bound VerticalCRS with a 'Geographic3D to GravityRelated-Height' method (#3355)
• **proj_normalize_for_visualization()**: take into account FORCE_OVER property from source operation (#3350)
• Link geodtest against libm when available (#3341)

## 2.6 9.1.0 Release Notes

*September 1st 2022*

### 2.6.1 Updates

- **Database:**
  - Database: update to EPSG v10.074 (#3273)
  - Update ESRI objects to version 3.0.0 (#3257)
  - Generate null transformation between geodetic/vertical datum ensemble and its members (#3266)
  - Add fk delete cascade to database tables for improved customizability of the database (#3237)
  - Add Svalbard geoid grid no_kv_arcgp-2006-sk to grid alternatives (#3292)
  - Added French grid fr_ign_RAF20 to grid alternatives (#3228)
- **WKT & PROJJSON:**
  - WKT2 parser: allow unit-less PARAMETER for coordinate operations (#3271)
  - WKT and PROJJSON adjustments (#3234)
  - Bump PROJJSON to v0.5 (#3216)
    - Change order of horizontal and vertical operations when dealing with WKT1 / PROJ4 compound CRS (#3127)
- **Coordinate Operations:**
  - Implement Vertical Offset and slope transformation method (#3200)
  - Add Interrupted Mollweide (land and ocean view) projections (#3139)
  - Add invertible Horner polynomials (#3133)
- **Optimizations:**
  - NTv2 and GTX grid readers: add a cache of lines to speed-up (#3241)
  - IComparable::isEquivalentTo() optimizations (#3233)
- **Various Updates:**
  - createOperations() / proj_trans(): better take into account area of interest name / do not only keep first returned coordinate operation (#3282)
  - createOperations(): take into account axis unit and inversion of target DerivedProjectedCRS (#3281)
  - Allow a Compound CRS with derived projected (#3283)
  - Make "Vertical Offset and Slope" method usable as a deriving conversion of a DerivedVerticalCRS (#3270)
– PROJ pipeline generator: recognize opposite Helmert transformations using a different convention (#3265)
– createOperations(): prefer simpler pipelines / affects WGS 84 to GDA94/GDA2020 (#3248)
– Make it possible to determine which grid files were actually used during a transformation (#3180)
– Transformation: no longer do vertical trasnformation when doing compound CRS to 2D CRS / add --3d to cs2cs (#3119)
– Deprecate PROJ4 CMake name (#3094)
– Use GNUInstallDirs for CMake install locations (#3100)
– Introduce PROJ_DATA` environment variable to deprecate PROJ_LIB (#3253)

2.6.2 Bug fixes

• projinfo: fix crash on --list-crs when proj.db cannot be opened (#3290)
• getCRSInfoList(): fix retrieval of projected_crs given by text_definition only (#3289)
• WKT parser: fix issue when parsing some WKT1 with Hotine_Oblique_Mercator_Azimuth_Center and ignoring rectified_grid_angle (#3280)
• WKT1 import: better deal when the angular unit of the GEOGCS[] of the PROJCS[] doesn't match the one from the database (#3274)
• createOperations(): avoid potential infinite recursions (#3264)
• WKT ESRI: fix related to projected CRS export and add support for geographic 3D CRS with LINUNIT node (#3256)
• proj_grid_info(): make it work again with remote grids (#3239)
• createOperations(): fix projected CRS with non-metre horiz&vertical unit and towgs84 to gencentric CRS (#3231)
• createOperations(): fix infinite recursion in a complex case (#3226)

2.7 9.0.1 Release Notes

June 15th 2022

2.7.1 Database updates

• Update to EPSG 10.064 (#3208)
• Add OGC:CRS84h (WGS 84 longitude-latitude-height) (#3155)
2.7.2 Bug fixes

- Use CMAKE_INSTALL_MANDIR to override default (#3081)
- Increase MAX_ITER so Mollweide forward projection works near the poles (#3082)
- Fix wrong results with SQLite 3.38.0 (#3091)
- Fix issue when transforming from/to BoundCRS of 3D CRS with non-Greenwich prime meridian, created from WKT (#3098)
- Fix issues with WKT of concatenated operations (#3105)
- CMake: fix installation of proj.pc on Windows (#3109)
- createOperations(): fix issue in transformation northing, easting projected CRS -> +proj=longlat +lon_wrap (#3110)
- unitconvert: round to nearest date when converting to yyyymmd (#3111)
- Fix comparison of GeodeticReferenceFrame vs DynamicGeodeticReferenceFrame (#3120)
- createOperations(): fix transformation involving CompoundCRS, ToWGS84 and PROJ4_GRIDS (#3124)
- Fix datum names when importing from PROJ4 crs strings (affects some transformations using geoidgrids) (#3129)
- Deal with PARAMETER["EPSG code for Interpolation CRS",crs_code] (#3149)
- createOperations(): fix CompoundCRS[BoundCRS[ProjectedCRS],BoundCRS[VerticalCRS]] to Geog3DCrs (#3151)
- ITRF2014: fix ITRF2014:ITRF88,ITRF94 and ITRF96 definitions (#3159)
- createBoundCRSToWGS84IfPossible(): improve selection logic to generate +towgs84= taking into account extent (#3160)
- createOperations(): fix some complex cases involving TOWGS84 and CompoundCRS (#3163)
- Fix CMake CURL dependency (#3185)
- WKT import: deal with Projected CRS that is a mix of WKT1:GDAL / WKT1:ESRI (#3189)
- createOperations(): fix/improve result of 'BD72 + Ostend height' to 'WGS84+EGM96 height' (#3199)
- Identifier::isEquivalentName(): fix when ending by '+' which could indirectly cause an infinite stack call in master (#3202)
- WKT import: correctly deal with absence of Latitude_Of_Origin parameter in WKT1 ESRI with Stereographic projection (#3212)
- PROJJSON parser: do not error out if a datum ensemble member is unknown in the database (#3223)

2.8 9.0.0 Release Notes

March 1st 2022
2.8.1 Breaking Changes

- Support for the autotools build system has been removed (#3027) See RFC7 for details: https://proj.org/community/rfc/rfc-7.html

2.8.2 Updates

- Database updates:
  - ESRI projection engine db to version 12.9 (#2943)
  - EPSG v10.054 (#3051)
  - Vertical grid files for PL-geoid-2011, Polish geoid model (#2960)
  - Belgian geoid model hBG18 to grid alternatives (#3044)
- Add new option to `proj_create_crs_to_crs_from_pj()` method to force +over on transformation operations (#2914)
- Specify CMAKE_INSTALL_RPATH for macOS; use -rpath LDFLAGS for tests (#3009)
- Implement Geographic3D to Depth/Geog2D+Depth as used by ETRS89 to CD Norway depth (#3010)
- Allow PROJ_LIB paths wrapped with double quotes (#3031)
- Use external gtest by default when possible (#3035)
- CMake: make BUILD_SHARED_LIBS=ON the default even on Windows (#3042)
- proj.ini: add a ca_bundle_path variable (#3049)

2.8.3 Bug fixes

- Fix extremely long parsing time on hostile PROJ strings (#2968)
- CMake: fix warning with external googletest (#2980)
- `proj_get_crs_info_list_from_database()`: report PJ_TYPE_GEODETIC_CRS for IAU_2015 -ocentric geodetic CRS (#3013)
- peirce_q: rename +type parameter wrongly introduced in 8.2.1 to +shape (#3014)
- Set more precise error code for parsing errors in `proj_create()` (#3037)
- `createOperations()`: fix transformations from/to a BoundCRS of a DerivedGeographicCRS coming from WKT (#3046)
- Better deal with importing strings like +init=epsg:XXXX +over (#3055)
- Fix importing CRS definition with +proj=peirce_q and +shape different from square or diamond (#3057)
2.9 8.2.1 Release Notes

January 1st 2022

2.9.1 Updates

- Database updated with EPSG v. 10.041 (#2974)

2.9.2 Bug fixes

- BoundCRS WKT import: fix setting of name (#2917)
- PROJStringFormatter::toString(): avoid invalid iterator increment (#2932)
- Ensure CApi test are cross-platform (#2934)
- createOperations(): do not stop at the first operation in the PROJ namespace for vertical transformations (#2937)
- createOperationsCompoundToCompound(): fix null pointer dereference when connection to proj.db doesn’t exist. (#2938)
- Fix windows.h conflict with Criterion::STRICT (#2950)
- Cache result of proj_get_type() to help for performance of proj_factors() (#2967)
- createOperations(): improvement for "NAD83(CSRS) + CGVD28 height" to "NAD83(CSRS) + CGVD2013(CGG2013) height" (#2977)
- WKT1 import: correctly deal with missing rectified_grid_angle parameter (#2986)
- Fix and additional options for Peirce Quincuncial projections (#2978)
- Fix build with Intel C++ compiler (#2995)

2.10 8.2.0 Release Notes

November 1st 2021

2.10.1 Announcements

From PROJ 9.0.0 and onwards CMake will be the only build system bundled with the PROJ package. As a consequence support for Autotools builds will stop when the 8.2 branch of PROJ reaches end of life. We encourage everyone to adjust their build workflows as soon as possible and report any discrepancies discovered between Autotools and CMake builds.

Details about the build system unification can be found in PROJ RFC 7: Drop Autotools, maintain CMake.

Note also that the "CMake: revise handling of symbol export and static builds" change mentioned below may require changes for users of the library on Windows.
2.10.2 Updates

- Added the S2 projection (#2749)
- Added support for Degree Sign on input (#2791)
- ESRI WKT: add support for import/export of (non interrupted) Goode Homolosine (#2827)
- Make filemanager aware of UWP Win32 API (#2831)
- Add proj_create_conversion_pole_rotation_netcdf_cf_convention() to address netCDF datasets using a pole rotation method (#2835)
- Emit better debug message when a grid isn’t found (#2838)
- Add support for GeodeticCRS using a Spherical planetocentric coordinate system (#2847)
- PROJJSON: support additional properties allowed in id object (version, authority_citation, uri) for parity with WKT2:2019 (#2850)
- Database layout modified to include "anchor" field to geodetic_datum and vertical_datum tables, consequently database layout version is increased to 1.2 (#2859)
- proj_factors(): accept P to be a projected CRS (#2868)
- Add IAU_2015 CRS definitions (#2876)
- CRS::extractGeodeticCRS(): implement for DerivedProjectedCRS (#2877)
- Added proj_trans_bounds() (#2882)
- CMake: add a BUILD_APPS to be able to disable build of all applications (#2895)
- CMake: generate invproj/invgeod binaries (symlinks on Unix, copy otherwise) (#2897)
- CMake build: add generate_wkt1_parser and generate_wkt2_parser manual target, and logic to detect when they must be run (#2900)
- Add fallback strategy for tinshift transform to use closest triangle for points not in any (#2907)
- Database: update to EPSG v10.038 (#2910)
- CMake: revise handling of symbol export and static builds (#2912)
  
  This requires changes for users of static builds on Windows that do not use CMake config files. The empty PROJ_DLL= definition must now be defined when building against a static build of PROJ. For users of dynamic builds on Windows, the PROJ_MSVC_DLL_IMPORT definition is no longer needed.

2.10.3 Bug fixes

- Fix O(n^2) performance patterns where n is the number of steps of a pipeline (#2820)
- Detect ESRI WKT better in certain circumstances (#2823)
- Fix performance issue on pipeline instantiation of huge (broken) pipelines (#2824)
- Make sure to re-order projection parameters according to their canonical order if needed (#2842)
- Fix database access across fork() when SQLite3 doesn't use pread[64]() (#2845)
- Fix error in implementation of Inverse ellipsoidal orthographic projection that cause convergence to sometimes fail (#2853)
- Fix handling of edge-case coordinates in inverse ortho ellipsoidal oblique (#2855)
• `proj_normalize_for_visualization()`: set input and output units when there are several alternative transformations (#2867)
• CRS::identify(): fix ignoring CS order when identifying a geodetic CRS by a PROJ string with just the ellipsoid (#2881)
• Fix CRS Equality with PROJ parameter order (#2887)
• WKT concatenated operation parsing: fix when a axis order reversal conversion is the first or last operation (#2891)
• WKT1 parser: recognize Lambert_Conformal_Conic as projection name for LCC 1SP or 2SP (#2893)
• CMake: Always build gie if testing is requested (#2899)
• Geographic 3D CRS: allow to export to WKT1:ESRI if only the GEOGCS is known (and thus extrapolating a VERTCS) (#2902)
• lib_proj.cmake: add a PROJ::proj alias and add BUILD_INTERFACE include directories, so that proj can be used as a subdirectory of a larger project (#2913)

2.11 8.1.1 Release Notes

September 1st 2021

2.11.1 Updates

• EPSG Database updated to version 10.028 (#2773)

2.11.2 Bug Fixes

• Include algorithm header file to avoid build errors on Alpine Linux (#2769)
• CMake: fix installation of executables on iOS (#2766)
• Associate extents to transformations of CRS’s that include GEOIDMODEL (#2769)
• Logging: avoid some overhead when logging is not enabled (#2775)
• ortho: remove useless and invalid log trace (#2777)
• CMake: remove external nlohmann_json from INTERFACE_LINK_LIBRARIES target (#2781)
• createOperations(): fix SourceTargetCRSExtentUse::NONE mode (#2783)
• GeoTIFF grid reading: perf improvements (#2788)
• Conversion::createUTM(): avoid integer overflow (#2796)
• Inverse laea ellipsoidal: return PROJ_ERR_COORD_TRANSFM_OUTSIDE_PROJECTION_DOMAIN when appropriate (#2801)
• Make sure that proj_crs_promote_to_3D() returns a derived CRS (#2806)
• createOperations(): fix missing deg<-->rad conversion when transforming with a CRS that has a fallback-to-PROJ4-string behavior and is a BoundCRS of a GeographicCRS (#2808)
• WKT2 import/export: preserve PROJ.4 CRS extension string in REMARKS[] (#2812)
• BoundCRS: accept importing/exporting in WKT2 and PROJJSON the scope/area/extent/id attributes (#2815)
• ConcatenatedOperation::fixStepsDirection(): fix bad chaining of steps when inverse map projection is involved in non-final step (#2819)

#2.12 8.1.0 Release Notes

July 1st 2021

#2.12.1 Updates

• Database
  – Update to EPSG v10.027 (#2751)
  – Decrease DB size by using WITHOUT ROWID tables (#2730) (#2647)
  – Add a ANALYZE step during proj.db creation allowing for faster lookups (#2729)
  – Added a PROJ.VERSION metadata entry (#2646)
  – Added NGO48 (EPSG:4273) to ETRS89 (EPSG:4258) triangulation-based transformation (#2554)
  – Additions to the norwegian NKG2020 transformation (#2548)
  – ESRI projection database updated to version 12.8 (#2717)

• API additions
  – Added proj_get_geoid_models_from_database() function that returns a list of geoid models available for a given CRS (#2681)
  – Added :c:func:proj_get_celestial_body_list_from_database() that returns a list of celestial bodies in the PROJ database (#2667)
  – Added proj_get_celestial_body_name() (#2662)

• Various improvements
  – proj_trans() / cs2cs: If two operations have the same accuracy, use the one that is contained within a larger one (#2750)
  – Share SQLite database handle among all contexts (#2738)
  – Added proj/internal/mutex.hpp as compat layer for mingw32 for std::mutex (#2736)
  – projsync: make it filter out files not intended for the current version (#2725)
  – Improvements related to DerivedVerticalCRS using Change Unit and Height/Depth reversal methods (#2696)
  – Update internal nlohmann/json to 3.9.1, and add a CMake option to be able to use external nlohmann/json (#2686)
  –createFromUserInput(): change name of CRS built from URN combined references to match the convention of EPSG projected CRS (#2677)
  – Parse compound id with two authorities, like ESRI:103668+EPSG:5703 (#2669)
  – Added projinfo option option --list-crs (supports --area) (#2663)
  – Added support for hyperbolic Cassini-Soldner (#2637)
  – Added capability to get SQL statements to add custom CRS in the database (#2577)
2.12.2 Bug fixes

- Fix 'Please include winsock2.h before windows.h' warning with msys (#2692)
- Minor changes to address lint in geodesic.c (#2752)
- BoundCRS::identify(): avoid incompatible transformation for WKT1 / TOWGS84 export (#2747)
- proj_create(): do not open proj.db if string is a PROJ string, even if proj_context_set_autoclose_database() has been set (#2735)
- Fix export of transformation to PROJ string in a particular situation where CompoundCRS are involved (#2721)

2.13 8.0.1 Release Notes

May 5th 2021

2.13.1 Updates

- Database: update to EPSG v10.018 (#2636)
- Add transformations for CHGeo2004, Swiss geoid model (#2604)
- Additions to the norwegian NKG2020 transformation (#2600)

2.13.2 Bug fixes

- pj_vlog(): fix buffer overflow in case of super lengthy error message (#2693)
- Revert "proj_create_crs_to_crs_from_pj(): do not use PROJ_SPATIAL_CRITERION_PARTIAL_INTERSECTION if area is specified" (#2679)
- UTM: error out when value of +zone= is not an integer (#2672)
- getCRSInfoList(): make result order deterministic (by increasing auth_name, code) (#2661)
- createOperation(): make sure no to discard deprecated operations if the replacement uses an unknown grid (#2623)
- Fix build on Solaris 11.4 (#2621)
- Add mapping of ESRI Equal.Area projection method to EPSG (#2612)
- Fix incorrect EPGS extent code for EPSG:7789>EPSG:4976 NKG transformation (#2599)
- fix wrong capitalization of CHENyx06_ETRS.gsb (#2597)
- createOperations(): improve handling of vertical transforms when when compound CRSs are used (#2592)
- CRS::promoteTo3D(): propagate the extent from the 2D CRS (#2589)
- createFromCRSCodesWithIntermediates(): improve performance when there is no match (#2583)
- Fix proj_clone() to work on 'meta' coordinate operation PJ* objects that can be returned by proj_create_crs_to_crs() (#2582)
- add PROJ_COMPUTE_VERSION, PROJ_VERSION_NUMBER, PROJ_AT_LEAST_VERSION macros (#2581)
- Make proj_lp_dist() and proj_geod() work on a PJ* CRS object (#2570)
- Fix gcc 11 -Wunusednull compilation warnings (#2559)
• Fix use of uninitialized memory in gie tests (#2558)
• createOperations(): fix incorrect height transformation between 3D promoted RGF93 and CH1903+ (#2555)

2.14 8.0.0 Release Notes

March 1st 2021

With the release of PROJ 8 the proj_api.h API is finally removed. See Version 4 to 6 API Migration for more info on how to migrate from the old to the proj.h API.

With the removal of proj_api.h it has been possible to simplify error codes and messages given by the software. The error codes are exposed in the API.

Several improvements has been made to the command line utilities as well as tweaks in the underlying API.

2.14.1 Updates

• Public header file proj_api.h removed (#837)
• Improved accuracy of the Mercator projection (#2397)
• Copyright statement wording updated (#2417)
• Allow cct to instantiate operations via object codes or names (#2419)
• Allow @filename syntax in cct (#2420)
• Added Geocentric to topocentric conversion (+proj=topocentric) (#2444)
• Update GeographicLib to version 1.51 (#2445)
• Added option to allow export of Geographic/Projected 3D CRS in WKT1_GDAL (#2450)
• Added --area and --bbox options in cs2cs to restrict candidate coordinate operations (#2466)
• Added build time option to make PROJ_LIB env var tested last (#2476)
• Added --authority switch in cs2cs to control where coordinate operations are looked for. C API function proj_create_crs_to_crs_from_pj() updated accordingly (#2477)
• Error codes revised and exposed in the public API (#2487)
• Added --accuracy options to projinfo. C API function proj_create_crs_to_crs_from_pj() updated accordingly (#2488)
• Added proj_crs_is_derived() function to C API (#2496)
• Enabled linking against static cURL on Windows (#2514)
• Updated ESRI CRS database to 12.7 (10.8.1/2.6) (#2519)
• Allow a WKT BoundCRS to use a PROJ string transformation (#2521)
• Update to EPSG v10.015 (#2539)
• Default log level set to PJ_LOG_ERROR (#2542)
• CMake installs a pkg-config file proj.pc, where supported (#2547)
2.14.2 Bug fixes

- Do not restrict longitude to [-90;90] range in spherical transverse Mercator forward projection (#2471)
- createOperations(): fix Compound to Geog3D/Projected3D CRS with non-metre ellipsoidal height (#2500)
- Avoid error messages to be emitted log level is set to PJ_LOG_NONE (#2527)
- Close database connection when autoclose set to True (#2532)

2.15 7.2.1 Release Notes

January 1st 2021

2.15.1 Updates

- Add metadata with the version number of the database layout (#2474)
- Split coordinateoperation.cpp and test_operation.cpp in several parts (#2484)
- Update to EPSG v10.008 (#2490)
- Added the NKG 2008 and 2020 transformations in proj.db (#2495)

2.15.2 Bug fixes

- Set CURL_ENABLED definition on projinfo build (#2405)
- createBoundCRSToWGS84IfPossible(): make it return same result with a CRS built from EPSG code or WKTI (#2412)
- WKTI2 parsing: several fixes related to map projection parameter units (#2428)
- createOperation(): make it work properly when one of the CRS is a BoundCRS of a DerivedGeographicCRS (+proj=ob_tran +o_proj=lonlat +towgs84=....) (#2441)
- WKTI parsing: fix ingestion of WKTI with a Geocentric CRS as the base of the projected CRS (#2443)
- GeographicCRS::isEquivalentTo(EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS): make it work when comparing easting,northing,up and northing,easting,up (#2446)
- createOperation(): add a ballpark vertical transformation when dealing with GEOIDMODEL[] (#2449)
- Use same arguments to printf format string for both radians and degrees in output by cct (#2453)
- PRIMEM WKTI handling: fixes on import for 'sexagesimal DMS' or from WKTI:GDAL/ESRI when GEOGCS UNIT != Degree; morph to ESRI the PRIMEM name on export (#2455)
- createObjectsFromName(): in exact match, make looking for 'ETRS89 / UTM zone 32N' return only the exact match (#2462)
- Inverse tmrc spherical: fix wrong sign of latitude when lat_0 is used (#2469)
- Add option to allow export of Geographic/Projected 3D CRS in WKTI_GDAL (#2470)
- Fix building proj.db with SQLite built with -DSQLITE_DQS=0 (#2480)
- Include JSON Schema files in CMake builds (#2485)
- createOperations(): fix inconsistent chaining exception when transforming from BoundCRS of projected CRS based on NTF Paris to BoundCRS of geog CRS NTF Paris (#2486)
2.16 7.2.0 Release Notes

November 1st 2020

2.16.1 Updates

- **Command line tools**
  - Add multi-line PROJ string export capability, and use it by default in `projinfo` (unless `--single-line` is specified) (#2381)

- **Coordinate operations**
  - *Colombia Urban* projection, implementing an EPSG projection method used by a number of projected CRS in Colombia (#2395)
  - *Triangulated Irregular Network based transformation* for triangulation-based transformations (#2344)
  - Added ellipsoidal formulation of *Orthographic* (#2361)

- **Database**
  - Update to EPSG 10.003 and make code base robust to dealing with WKT CRS with DatumEnsemble (#2370)
  - Added Finland tinshift operations (#2392)
  - Added transformation from JGD2011 Geographic 3D to JGD2011 height using GSIGEO2011 (#2393)
  - Improve CompoundCRS identification and name morphing in VerticalCRS with ESRI WKT1 (#2386)
  - Added OGC:CRS27 and OGC:CRS83 CRS entries for NAD27 and NAD83 in longitude, latitude order (#2350)

- **API**
  - Added temporal, engineering, and parametric datum `PJ_TYPE` enumerations (#2274)
  - Various improvements to context handling (#2329, #2331)
  - `proj_create_vertical_crs_ex()`: add an `ACCURACY` option to provide an explicit accuracy, or derive it from the grid name if it is known (#2342)
  - `proj_crs_create_bound_crs_to_WGS84()`: make it work on verticalCRS/compoundCRS such as EPSG:4326+5773 and EPSG:4326+3855 (#2365)
  - `promoteTo3D()`: add a remark with the original CRS identifier (#2369)
  - Added `proj_context_clone()` (#2383)

2.16.2 Bug fixes

- Avoid core dumps when copying contexts in certain scenarios (#2324)
- `proj_trans()`: reset errno before attempting a retry with a new coordinate operation (#2353)
- PROJJSON schema corrected to allow prime meridians values with explicitly stating a unit (degrees assumed) (#2354)
- Adjust `createBoundCRSToWGS84IfPossible()` and operation filtering (for POSGAR 2007 to WGS84 issues) (#2357)
- `createOperations()`: several fixes affecting NAD83 -> NAD83(2011) (#2364)
• WKT2:2019 import/export: handle DATUM (at top level object) with PRIMEM
• WKT1_ESRI: fix import and export of CompoundCRS (#2389)

2.17 7.1.1 Release Notes

September 1st 2020

2.17.1 Updates

• Added various Brazilian grids to the database (#2277)
• Added geoid file for Canary Islands to the database (#2312)
• Updated EPSG database to version 9.8.15 (#2310)

2.17.2 Bug fixes

• WKT parser: do not raise warning when parsing a WKT2:2015 TIMECRS whose TIMEUNIT is at the CS level, and not inside (#2281)
• Parse '+proj=something_not_latlong +vunits=' without +geoidgrids as a Projected3D CRS and not a compound CRS with a unknown datum (#2289)
• C API: Avoid crashing due to missing SANITIZE_CTX() in entry points (#2293)
• CMake build: Check "target_clones" before use (#2297)
• PROJ string export of +proj=krovak +czech: make sure we export +czech... (#2301)
• Helmert 2D: do not require a useless +convention= parameter (#2305)
• Fix a few spelling errors ("vgridshit" vs. "vgridshift") (#2307)
• Fix ability to identify EPSG:2154 as a candidate for 'RGF93_Lambert_93' (#2316)
• WKT importer: tune for Oracle WKT and 'Lambert Conformal Conic' (#2322)
• Revert compiler generated Fused Multiply Addition optimized routines (#2328)

2.18 7.1.0 Release Notes

July 1st 2020

2.18.1 Updates

• New transformations
  – Add a +proj=defmodel transformation for multi-component time-based deformation models (#2206):
• New projections
  – Add square conformal projections from libproject (#2148):
    * Adams Hemisphere in a Square
    * Adams World in a Square I
* Adams World in a Square II
* Guyou
* Peirce Quincuncial

- Adams Square II: map ESRI WKT to PROJ string, and implement iterative inverse method (#2157)
- Added Interrupted Goode Homolosine (Oceanic View) projection (#2226)
- Add Winkel II inverse by generic inversion of forward method (#2243)

• Database

- Update to EPSG 9.8.12, ESRI 10.8.1 and import scope and remarks for conversion (#2238) (#2267)
- Map the Behrmann projection to cae when converting ESRI CRSes (#1986)
- Support conversion of Flat_Polar_Quartic projection method (#1987)
- Register 4 new Austrian height grids (see https://github.com/OSGeo/PROJ-data/pull/13) and handle 'Vertical Offset by Grid Interpolation (BEV AT)' method (#1989)
- Add ESRI projection method mappings for Mercator_Variant_A, Mercator_Variant_B and Transverse_Cylindrical_Equal_Area and various grid mappings (#2020) (#2195)
- Map ESRI Transverse_Mercator_Complex to Transverse Mercator (#2040)
- Register grids for New Caledonia (see https://github.com/OSGeo/PROJ-data/pull/16) (#2051) (#2239)
- Register NZGD2000 -> ITRF96 transformation for NZGD2000 database (#2248)
- Register geoid file for UK added (see https://github.com/OSGeo//PROJ-data/pull/25) (#2250)
- Register Slovakian geoid transformations with needed code changes (#2259)
- Register Spanish SPED2ETV2 grid for ED50->ETRS89 (#2261)

• API

- Add API function `proj_get_units_from_database()` (#2065)
- Add API function `proj_get_suggested_operation()` (#2068)
- Add API functions `proj_degree_input()` and `proj_degree_output()` (#2144)
- Moved `proj_context_get_url_endpoint()` & `proj_context_get_user_writable_directory()` from proj_experimental.h to proj.h (#2162)
- `createFromUserInput()`: allow compound CRS with the 2 parts given by names, e.g. 'WGS 84 + EGM96 height' (#2126)
- `createOperations()`: when converting CompoundCRS<-->Geographic3DCrs, do not use discard change of ellipsoidal height if a Helmert transformation is involved (#2227)

• Optimizations

- tmerc/utm: add a `+algo=auto/evenden_snyder/poder_engsager` parameter (#2030)
- Extended tmerc (Poder/Engsager): speed optimizations (#2036)
- Approximate tmerc (Snyder): speed optimizations (#2039)
- `pj_phi2()`: speed-up computation (and thus inverse ellipsoidal Mercator and LCC) (#2052)
- Inverse cart: speed-up computation by 33% (#2145)
- Extended tmerc: speed-up forward path by ~5% (#2147)

• Various
PROJ coordinate transformation software library, Release 9.3.1

- Follow PDAL’s CMake RPATH strategy (#2009)
- WKT import/export: add support for WKT1_ESRI VERTCS syntax (#2024)
- projinfo: add a --hide-ballpark option (#2127)
- gie: implement a strict mode with <gie-strict> </gie-strict> (#2168)
- Allow importing WKT1 COMPD_CS with a VERT_DATUM[Ellipsoid,2002] (#2229)
- Add runtime checking that sqlite3 is >= 3.11 (#2235)

2.18.2 Bug fixes

- createOperations(): do not remove ballpark transformation if there are only grid based operations, even if they cover the whole area of use (#2155)
- createFromProjString(): handle default parameters of '+krovak +type=crs', and handle +czech correctly (#2200)
- ProjectedCRS::identify(): fix identification of EPSG:3059 (#2215)
- Database: add a 'WGS84' alias for the EPSG:4326 CRS (#2218)
- Fixes related to CompoundCRS and BoundCRS (#2222)
- Avoid 2 warnings about missing database indices (#2223)
- Make projinfo --3d --boundcrs-to-wgs84 work better (#2224)
- Many fixes regarding BoundCRS, CompoundCRS, Geographic3D CRS with non-metre units (#2234)
- Fix identification of (one of the) ESRI WKT formulations of EPSG:3035 (#2240)
- Avoid using deprecated and removed Windows API function with Mingw32 (#2246)
- normalizeForVisualization(): make it switch axis for EPSG:5482 (RSRGD2000 / RSPS2000) (#2256)
- Fix access violation in proj_context_get_database_metadata() (#2260)

2.19 7.0.1 Release Notes

May 1st 2020

2.19.1 Updates

- Database: update to EPSG v9.8.9 (#2141)

2.19.2 Bug fixes

- Make tests independent of proj-datumgrid (#1995)
- Add missing projection property tables (#1996)
- Avoid crash when running against SQLite3 binary built with -DSQLITE_OMIT_AUTOINIT (#1999)
- createOperations(): fix wrong pipeline generation with CRS that has +nadgrids= and +pm= (#2002)
- Fix bad copy&replace pattern on HEALPix and rHEALPix projection names (#2007)
• createUnitOfMeasure(): use full double resolution for the conversion factor (#2014)
• Update README with info on PROJ-data (#2015)
• utm/ups: make sure to set errno to PJD_ERR_ELLIPSOID_USE_REQUIRED if +es==0 (#2045)
• data/Makefile.am: remove bashism (#2048)
• ProjectedCRS::identify(): tune it to better work with ESRI WKT representation of EPSG:2193 (#2059)
• Fix build with gcc 4.8.5 (#2066)
• Autotools/pkg-conf: Define datarootdir (#2069)
• cs2cs: don't require +to for '{source_crs} {target_crs} filename...' syntax (#2081)
• CMake: fix bug with find_package(PROJ) with macOS (#2082)
• ESRI WKT import/identification: special case for NAD_1983_HARN_StatePlane_Colorado_North_FIPS_0501
  with Foot_US unit (#2088)
• ESRI WKT import/identification: special case for NAD_1983_HARN_StatePlane_Colorado_North_FIPS_0501
  with Foot_US unit (#2089)
• EngineeringCRS: when exporting to WKT1_GDAL, output unit and axis (#2092)
• Use jtsk03-jtsk horizontal grid from CDN (#2098)
• CMake: prefer to use use PROJ_SOURCE_DIR and PROJ_BINARY_DIR (#2100)
• Fix wrong grids file name in esri.sql (#2104)
• Fix identification of projected CRS whose name is close but not strictly equal to a ESRI alias (#2106)
• Fix working of Helmert transform between the horizontal part of 2 compoundCRS (#2111)
• Database: fix registration of custom entries of grid_transformation_custom.sql for geoid grids (#2114)
• ESRI_WKT ingestion: make sure to identify to non-deprecated EPSG entry when possible (#2119)
• Make sure that importing a Projected 3D CRS from WKT:2019 keeps the base geographic CRS as 3D (#2125)
• createOperations(): improve results of compoundCRS to compoundCRS case (#2131)
• hgridshift/vgridshift: defer grid opening when grid has already been opened (#2132)
• Resolve a few shadowed declaration warnings (#2142)
• ProjectedCRS identification: deal with switched 1st/2nd std parallels for LCC_2SP(#2153)
• Fix Robinson inverse projection (#2154)
• createOperations(): do not remove ballpark transformation if there are only grid based operations, even if
  they cover the whole area of use (#2156)
• createFromCoordinateReferenceSystemCodes(): ‘optimization’ to avoid using C++ exceptions (#2161)
• Ingestion of WKT1_GDAL: correctly map ‘Cylindrical_Equal_Area’ (#2167)
• Add limited support for non-conformant WKT1 LAS COMPD_CS[] (#2172)
• PROJ4 string import: take into correctly non-metre unit when the string looks like the one for WGS 84 / Pseudo
  Mercator (#2177)
• io.hpp: avoid dependency to proj_json_streaming_writer.hpp (#2184)
• Fix support of WKT1_GDAL with netCDF rotated pole formulation (#2186)
2.20 6.3.2 Release Notes

May 1st 2020

2.20.1 Bug fixes

- `validateParameters()`: fix false-positive warning on Equidistant Cylindrical (#1947)
- `proj_create_crs_to_cr()`: avoid potential reprojection failures when reprojecting area of use to source and target CRS (#1993)
- `createOperations()`: fix wrong pipeline generation with CRS that has `+nadgrids=` and `+pm=` (#2003)
- Fix bad copy&replace pattern on HealPix and rHealPix projection names (#2006)
- `createUnitOfMeasure()`: use full double resolution for the conversion factor (#2013)
- `data/Makefile.am`: remove bashism (#2047)
- `:cpp:func:ProjectedCRS::identify`: tune it to better work with ESRI WKT representation of EPSG:2193 (#2058)
- EngineeringCRS: when exporting to WKT1_GDAL, output unit and axis (#2091)
- Add missing entries in grid_alternatives for Portugal grids coming from ESRI entries (#2103)
- Fix working of Helmert transform between the horizontal part of 2 compoundCRS (#2110)
- ESRI_WKT ingestion: make sure to identify to non-deprecated EPSG entry when possible (#2118)
- Make sure that importing a Projected 3D CRS from WKT:2019 keeps the base geographic CRS as 3D (#2124)
- `createOperations()`: improve results of compoundCRS to compoundCRS case (#2130)
- PROJ4 string import: take into correctly non-metre unit when the string looks like the one for WGS 84 / Pseudo Mercator (#2178)
- Fix support of WKT1_GDAL with netCDF rotated pole formulation (#2187)
- `io.hpp`: avoid dependency to `proj_json_streaming_writer.hpp` (#2188)

2.21 7.0.0 Release Notes

March 1st 2020

The major feature in PROJ 7 is significantly improved handling of gridded models. This was implemented in PROJ RFC 4: Remote access to grids and GeoTIFF grids. The main features of the RFC4 work is that PROJ now implements a new grid format, Geodetic TIFF grids, for exchanging gridded transformation models. In addition to the new grid format, PROJ can now also access grids online using a data store in the cloud.

The grids that was previously available via the proj-datumgrid packages are now available in two places:

1. As a single combined data archive including all available resource files
2. From the cloud via https://cdn.proj.org

In addition, provided with PROJ is a utility called projsync that can be used download grids from the data store in the cloud.

The use of the new grid format and the data from the cloud requires that PROJ is build against libtiff and libcurl. Both are optional dependencies to PROJ but it is highly encouraged that the software is build against both.
PROJ coordinate transformation software library, Release 9.3.1

**Warning:** PROJ 7 will be last major release version that includes the `proj_api.h` header. The functionality in `proj_api.h` is deprecated and only supported in maintenance mode. It is inferior to the functionality provided by functions in the `proj.h` header and all projects still relying on `proj_api.h` are encouraged to migrate to the new API in `proj.h`. See [Version 4 to 6 API Migration](#) for more info on how to migrate from the old to the new API.

### 2.21.1 Updates

- Added new file access API to `proj.h` [#866]
- Updated the name of the most recent version of the WKT2 standard from WKT2_2018 to WKT2_2019 to reflect the proper name of the standard [#1585]
- Improvements in transformations from/to WGS 84 (Gxxxx) realizations and vertical <-> geog transformations [#1608]
- Update to version 1.50 of the geodesic library [#1629]
- Promote `proj_assign_context()` to `proj.h` from `proj_experimental.h` [#1630]
- Add rotation support to the HEALPix projection [#1638]
- Add C function `proj_crs_create_bound_vertical_crs()` [#1689]
- Use Win32 Unicode APIs and expect all strings to be UTF-8 [#1765]
- Improved name aliases lookup [#1827]
- CMake: Employ better use of CTest with the `BUILD_TESTING` option [#1870]
- Grid correction: fix handling grids spanning antimeridian [#1882]
- Remove legacy CMake target name `proj` [#1883]
- `projinfo` add `--searchpaths` switch [#1892]
- Add `+proj=set operation` to set component(s) of a coordinate to a fixed value [#1896]
- Add EPSG records for 'Geocentric translation by Grid Interpolation (IGN)' (`gr3df97a.txt`) and map them to new `+proj=xyzgridshift` [#1897]
- Remove null grid file as it is now a special hardcoded case in grid code [#1898]
- Add `projsync` utility [#1903]
- Make PROJ the CMake project name [#1910]
- Use relative directory to locate PROJ resource files [#1921]

### 2.21.2 Bug fixes

- Horizontal grid shift: fix failures on points slightly outside a subgrid [#209]
- Fix ASAN issue with SQLite3VFS class [#1902]
- Tests: force use of bash for `proj_add_test_script_sh` [#1905]
2.21.3 Breaking changes

- Reject NTV2 files where GS_TYPE != SECONDS (#1294)
- On Windows the name of the library is now fixed to proj.lib instead of encoding the version number in the library name (#1581)
- Require C99 compiler (#1624)
- Remove deprecated JNI bindings (#1825)
- Remove -ld option from proj and cs2cs (#1844)
- Increase CMake minimum version from 3.5 to 3.9 (#1907)

2.22 6.3.1 Release Notes

February 11th 2020

2.22.1 Updates

- Update the EPSG database to version 9.8.6
- Database: add mapping for gg10_smv2.mnt and gg10_sbv2.mnt French grids
- Database: add mapping for TOR27CSv1.GSB

2.22.2 Bug fixes

- Fix wrong use of derivingConversionRef() that caused issues with use of +init=epsg:XXXX by GDAL (affecting R spatial libraries) or in MapServer
- fix exporting CoordinateSystem to PROJ JSON with ID
- projinfo: use No. abbreviation instead of UTF-8 character (#1828)
- CompoundCRS::identify(): avoid exception when horiz/vertical part is a BoundCRS
- createOperations(): fix dealing with projected 3D CRS whose Z units != metre
- WKT1_GDAL export: limit datum name massaging to names matching EPSG (#1835)
- unitconvert with mjd time format: avoid potential integer overflow (ossfuzz 20072)
- ProjectedCRS::identify(): fix wrong identification of some ESRI WKT linked to units
- Database: add a geoid_like value for proj_method column of grid_alternatives, fix related entries and simplify/robustify logic to deal with EPSG 'Geographic3D to GravityRelatedHeight' methods
- Fix ingestion of +proj=cea with +k_0 (#1881)
- Fix performance issue, affecting PROJ.4 string generation of EPSG:7842 (#1913)
- Fix identification of ESRI-style datum names starting with D_ but without alias (#1911)
- cart: Avoid discontinuity at poles in the inverse case (#1906)
- Various updates to make regression test suite pass with gcc on i386 (#1906)
2.23 6.3.0 Release Notes

January 1st 2020

2.23.1 Updates

- Database: tune accuracy of Canadian NTv1 file w.r.t NTv2 (#1812)
- Modify verbosity level of some debug/trace messages (#1811)
- projinfo: no longer call createBoundCRSToWGS84IfPossible() for WKT1:GDAL (#1810)
- proj_trans(): add retry logic to select other transformation if the best one fails. (#1809)
- BoundCRS::identify(): improvements to discard CRS that aren't relevant (#1802)
- Database: update to IGNF v3.1.0 (#1785)
- Build: Only export symbols if building DLL (#1773)
- Database: update ESRI entries with ArcGIS Desktop version 10.8.0 database (#1762)
- createOperations(): chain operations whose middle CRSs are not identical but have the same datum (#1734)
- import/export PROJJSON: support a interpolation_crs key to geoid_model (#1732)
- Database: update to EPSG v9.8.4 (#1725)
- Build: require SQLite 3.11 (#1721)
- Add support for GEOIDMODEL (#1710)
- Better filtering based on extent and performance improvements (#1709)

2.23.2 Bug fixes

- Horizontal grid shift: fix issue on iterative inverse computation when switching between (sub)grids (#1797)
- createOperations(): make filtering out of 'uninteresting' operations less aggressive (#1788)
- Make EPSG:102100 resolve to ESRI:102100 (#1786)
- ob_tran: restore traditional handling of +to_meter with pj_transform() and proj utility (#1783)
- CRS identification: use case insensitive comparison for authority name (#1780)
- normalizeForVisualization() and other methods applying on a ProjectedCRS: do not mess the deriving-Conversion object of the original object (#1746)
- createOperations(): fix transformation computation from/to a CRS with +geoidgrids and +vunits != m (#1731)
- Fix proj_assign_context()/pj_set_ctx() with pipelines and alternative coord operations (#1726)
- Database: add an auxiliary concatenated_operation_step table to allow arbitrary number of steps (#1696)
- Fix errors running gie-based tests in Debug mode on Window (#1688)
2.24 6.2.1 Release Notes

November 1st 2019

2.24.1 Updates

- Update the EPSG database to version 9.8.2

2.24.2 Bug fixes

- Fixed erroneous spelling of "Potsdam" (#1573)
- Calculate y-coordinate correctly in Bertin 1953 in all cases (#1579)
- `proj_create_crs_to_crs_from_pj()`: make the PJ* arguments const PJ* (#1583)
- `PROJStringParser::createFromPROJString()`: avoid potential infinite recursion (#1574)
- Avoid core dump when setting `ctx==NULL` in functions `proj_coordoperation_is_instantiable()` and `proj_coordoperation_has_ballpark_transformation()` (#1590)
- `createOperations()`: fix conversion from/to PROJ.4 CRS strings with non-ISO-kosher options and `+towgs84/+nadgrids` (#1602)
- `proj_trans_generic()`: properly set coordinate time to `HUGE_VAL` when no value is passed to the function (#1604)
- Fix support for `+proj=ob_tran +o_proj=lonlat/latlong/latlon` instead of only allowing `+o_proj=longlat` (#1601)
- Improve backwards compatibility of vertical transforms (#1613)
- Improve emulation of deprecated `+init` style initialization (#1614)
- `cs2cs`: autopromote CRS to 3D when there's a mix of 2D and 3D (#1563)
- Avoid divisions by zero in odd situations (#1620)
- Avoid compile error on Solaris (#1639)
- `proj_create_crs_to_crs()`: fix when there are only transformations with ballpark steps (#1643)
- PROJ string CRS ingester: recognize more unit-less parameters, and general handling of `+key=string_value` parameters (#1645)
- Only call pkg-config in configure when necessary (#1652)
- Azimuthal Equidistant: for spherical forward path, go to higher precision ellipsoidal case when the point coordinates are super close to the origin (#1654)
- `proj_create_crs_to_crs()`: remove elimination of Ballpark operations that caused transformation failures in some cases (#1665)
- `createOperations()`: allow transforming from a compoundCRS of a bound verticalCRS to a 2D CRS (#1667)
- Avoid segfaults in case of out-of-memory situations (#1679)
- `createOperations()`: fix double vertical unit conversion from CompoundCRS to other CRS when the horizontal part of the projected CRS uses non-metre unit (#1683)(#1683)
- `importFromWkt()`: fix axis orientation for non-standard ESRI WKTS (#1690)
2.25 6.2.0 Release Notes

September 1st 2019

2.25.1 Updates

- Introduced PROJJSON, a JSON encoding of WKT2 (#1547)
- Support CRS instantiation of OGC URN's (#1505)
- Expose scope and remarks of database objects (#1537)
- EPSG Database updated to version 9.7.0 (#1558)
- Added C API function proj_grid_get_info_from_database() (#1494)
- Added C API function proj_operation_factory_context_set_discard_superseded() (#1534)
- Added C API function proj_context_set_autoclose_database() (#1566)
- Added C API function proj_create_crs_to_crs_from_pj() (#1567)
- Added C API function proj_cleanup() (#1569)

2.25.2 Bug Fixes

- Fixed build failure on Solaris systems (#1554)

2.26 6.1.1 Release Notes

July 1st 2019

2.26.1 Updates

- Update EPSG registry to version 9.6.3 (#1485)

2.26.2 Bug Fixes

- Take the passed authority into account when identifying objects (#1466)
- Avoid exception when transforming from NAD83 to projected CRS using NAD83(2011) (#1477)
- Avoid off-by-one reading of name argument if name of resource file has length 1 (#11489)
- Do not include PROJ_LIB in proj_info().searchpath when context search path is set (#1498)
- Use correct delimiter for the current platform when parsing PROJ_LIB (#1497)
- Do not confuse 'ID74' CRS with WKT2 ID[] node (#1506)
- WKT1 importer: do case insensitive comparison for axis direction (#1509)
- Avoid compile errors on GCC 4.9.3 (#1512)
- Make sure that pipelines including +proj=ob_tran can be created (#1526)
2.27 6.1.0 Release Notes

May 15th 2019

2.27.1 Updates

- Include custom ellipsoid definitions from QGIS (#1137)
- Add `–k ellipsoid` option to projinfo (#1338)
- Make cs2cs support 4D coordinates (#1355)
- WKT2 parser: update to OGC 18-010r6 (#1360 #1366)
- Update internal version of googletest to v1.8.1 (#1361)
- Database update: EPSG v9.6.2 (#1462), IGNF v3.0.3, ESRI 10.7.0 and add operation_version column (#1368)
- Add `proj_normalize_for_visualization()` that attempts to apply axis ordering as used by most GIS applications and PROJ <6 (#1387)
- Added noop operation (#1391)
- Paths set by user take priority over PROJ_LIB for search paths (#1398)
- Reduced database size (#1438)
- add support for compoundCRS and concatenatedOperation named from their components (#1441)

2.27.2 Bug fixes

- Have `gie` return non-zero code when file can't be opened (#1312)
- CMake cross-compilation fix (#1316)
- Use 1st eccentricity instead of 2nd eccentricity in Molodensky (#1324)
- Make sure to include grids when doing Geocentric to CompoundCRS with nadgrids+geoidgrids transformations (#1326)
- Handle coordinates outside of bbox better (#1333)
- Enable system error messages in command line automatically in builds (#1336)
- Make sure to install projinfo man page with CMake (#1347)
- Add data dir to pkg-config file proj.pc (#1348)
- Fix GCC 9 warning about useless `std::move()` (#1352)
- Grid related fixes (#1369)
- Make sure that ISO19111 C++ code sets pj_errno on errors (#1405)
- vgridshift: handle longitude wrap-around for grids with 360deg longitude extent (#1429)
- `projcs2cs`: validate value of `-f` parameter to avoid potential crashes (#1434)
- Many division by zero and similar bug fixes found by OSS Fuzz.
2.28 6.0.0 Release Notes

March 1st 2019

PROJ 6 has undergone extensive changes to increase its functional scope from a cartographic projection engine with so-called "early-binding" geodetic datum transformation capabilities to a more complete library supporting coordinate transformations and coordinate reference systems.

As a foundation for other enhancements, PROJ now includes a C++ implementation of the modelisation proposed by the ISO-19111:2019 standard / OGC Abstract Specification Topic 2: "Referencing By Coordinates", for geodetic reference frames (datums), coordinate reference systems and coordinate operations. Construction and query of those geodetic objects is available through a new C++ API, and also accessible for the most part from bindings in the C API. Those geodetic objects can be imported and exported from and into the OGC Well-Known Text format (WKT) in its different variants: ESRI WKT, GDAL WKT 1, WK2:2015 (ISO 19162:2015) and WK2:2018 (ISO 19162:2018). Import and export of CRS objects from and into PROJ strings is also supported. This functionality was previously available in the GDAL software library (except WK2 support which is a new feature), and is now an integral part of PROJ.

A unified database of geodetic objects, coordinate reference systems and their metadata, and coordinate operations between those CRS is now available in a SQLite3 database file, proj.db. This includes definitions imported from the IOGP EPSG dataset (v9.6.0 release), the IGNF (French national mapping agency) geodetic registry and the ESRI projection engine database. PROJ is now the reference software in the "OSGeo C stack" for this CRS and coordinate operation database, whereas previously this functionality was spread over PROJ, GDAL and libgeotiff, and used CSV or other adhoc text-based formats.

Late-binding coordinate operation capabilities, that takes metadata such as area of use and accuracy into account, has been added. This can avoid in a number of situations the past requirement of using WGS84 as a pivot system, which could cause unneeded accuracy loss, or was not doable at all sometimes when transformation to WGS84 was not available. Those late-binding capabilities are now used by the proj_create_crs_to_crs() function and the cs2cs utility.

A new command line utility, projinfo, has been added to query information about a geodetic object of the database, import and export geodetic objects from/into WKT and PROJ strings, and display coordinate operations available between two CRSs.

2.28.1 Updates

- Removed projects.h as a public interface (#835)
- Deprecated the proj_api.h interface. The header file is still available but will be removed with the next major version release of PROJ. It is now required to define ACCEPT_USE_OF_DEPRECATED_PROJ_API_H before the interface can be used (#836)
- Removed support for the nmake build system (#838)
- Removed support for the proj_def.dat defaults file (#201)
- C++11 required for building PROJ (#1203)
- Added build dependency on SQLite 3.7 (#1175)
- Added projinfo command line application (#1189)
- Added many functions to proj.h for handling ISO19111 functionality (#1175)
- Added C++ API exposing ISO19111 functionality (#1175)
- Updated cs2cs to use late-binding features (#1182)
- Removed the nad2bin application. Now available in the proj-datumgrid git repository (#1236)
• Removed support for Chebyshev polynomials in `proj` (#1226)
• Removed `proj_geocentric_latitude()` from `proj.h` API (#1170)
• Changed behavior of `proj`: Now only allow initialization of projections (#1162)
• Changed behavior of `merc`: Now defaults to the Extended Transverse Mercator algorithm (etmerc). Old implementation available by adding `+approx` (#404)
• Changed behavior: Default ellipsoid now set to GRS80 (was WGS84) (#1210)
• Allow multiple directories in `PROJ_LIB` environment variable (#1281)
• Added Lambert Conic Conformal (2SP Michigan) projection (#1142)
• Added Bertin1953 projection (#1133)
• Added Tobler-Mercator projection (#1153)
• Added Molodensky-Badekas transform (#1160)
• Added `push` and `pop` coordinate operations (#1250)
• Removed `+t_obs` parameter from helmert and deformation (#1264)
• Added `+dt` parameter to deformation as replacement for removed `+t_obs` (#1264)

2.28.2 Bug fixes

• Read `+towgs84` values correctly on locales not using dot as comma separator (#1136)
• Fixed file offset for reading of shift values in NTv1 files (#1144)
• Avoid problems with PTHREAD_MUTEX_RECURSIVE when using CMake (#1158)
• Avoid raising errors when setting ellipsoid flattening to zero (#1191)
• Fixed lower square calculations in `rHealpix` projection (#1206)
• Allow Molodensky transform parameters to be zero (#1194)
• Fixed wrong parameter in ITRF2000 init file (#1240)
• Fixed use of grid paths including spaces (#1152)
• Robinson: fix wrong values for forward path for latitudes >= 87.5, and fix inaccurate inverse method (#1172)

2.29 PROJ 5.2.0

September 15th 2018
2.29.1 Updates

- Added support for deg, rad and grad in unitconvert (#1054)
- Assume +t_epoch as time input when not otherwise specified (#1065)
- Added inverse Lagrange projection (#1058)
- Added +multiplier option to vgridshift (#1072)
- Added Equal Earth projection (#1085)
- Added "require_grid" option to gie (#1088)
- Replace transpose option of Helmert transform with +convention. From now on the convention used should be explicitly written. An error will be returned when using the +transpose option (#1091)
- Improved numerical precision of inverse spherical Mercator projection (#1105)
- cct will now forward text after coordinate input to output stream (#1111)

2.29.2 Bug fixes

- Do not pivot over WGS84 when doing cs2cs-emulation with geocent (#1026)
- Do not scan past the end of the read data in pj_ctx_fgets() (#1042)
- Make sure proj_errno_string() is available in DLL (#1050)
- Respect +to_meter setting when doing cs2cs-emulation (#1053)
- Fixed unit conversion factors for geod (#1075)
- Fixed test failures related to GCC 8 (#1084)
- Improved handling of +geoe flag (#1093)
- Calculate correct projection factors for Webmercator (#1095)
- cs2cs now always outputs degrees when transformed coordinates are in angular units (#1112)

2.30 PROJ 5.1.0

June 1st 2018

2.30.1 Updates

- Function proj_errno_string() added to proj.h API (#847)
- Validate units between pipeline steps and ensure transformation sanity (#906)
- Print help when calling cct and gie without arguments (#907)
- CITATION file added to source distribution (#914)
- Webmercator operation added (#925)
- Enhanced numerical precision of forward spherical Mercator near the Equator (#928)
- Added --skip-lines option to cct (#923)
- Consistently return NaN values on NaN input (#949)
• Removed unused src/org_proj4_Projections.h file (#956)
• Java Native Interface bindings updated (#957, #969)
• Horizontal and vertical gridshift operations extended to the temporal domain (#1015)

### 2.30.2 Bug fixes

• Handle NaN float cast overflow in PJ_robin.c and nad_intr.c (#887)
• Avoid overflow when Horner order is unreasonably large (#893)
• Avoid unwanted NaN conversions in etmerc (#899)
• Avoid memory failure in gie when not specifying x,y,z in gie files (#902)
• Avoid memory failure when +sweep is initialized incorrectly in geos (#908)
• Return HUGE_VAL on erroneous input in ortho (#912)
• Handle commented lines correctly in cct (#933)
• Avoid segmentation fault when transformation coordinates outside grid area in deformation (#934)
• Avoid doing false easting/northing adjustments on cartesian coordinates (#936)
• Thread-safe creation of proj mutex (#954)
• Avoid errors when setting up geos with +lat_0!=0 (#986)
• Reset errno when running proj in verbose mode (#988)
• Do not interpolate node values at nodata value in vertical grid shifts (#1004)
• Restrict Horner degrees to positive integer values to avoid memory allocation issues (#1005)

### 2.31 PROJ 5.0.1

March 1st 2018

### 2.31.1 Bug fixes

• Handle ellipsoid change correctly in pipelines when +towgs84=0,0,0 is set (#881)
• Handle the case where nad_table2_init returns NULL (#883)
• Avoid shadowed declaration errors with old gcc (#880)
• Expand +datum properly in pipelines (#872)
• Fail gracefully when incorrect headers are encountered in grid files (#875)
• Improve roundtrip stability in pipelines using +towgs84 (#871)
• Fixed typo in gie error codes (#861)
• Numerical stability fixes to the geodesic package (#826 & #843)
• Make sure that transient errors are returned correctly (#857)
• Make sure that locally installed header files are not used when building PROJ (#849)
• Fix inconsistent parameter names in proj.h/proj_4D_api.c (#842)
• Make sure `+vunits` is applied (#833)
• Fix incorrect Web Mercator transformations (#834)

2.32 PROJ 5.0.0

February 1st 2018

This version of PROJ introduces some significant extensions and improvements to (primarily) the geodetic functionality of the system.

The main driver for introducing the new features is the emergence of dynamic reference frames, the increasing use of high accuracy GNSS, and the related growing demand for accurate coordinate transformations. While older versions of PROJ included some geodetic functionality, the new framework lays the foundation for turning PROJ into a generic geospatial coordinate transformation engine.

The core of the library is still the well established projection code. The new functionality is primarily exposed in a new programming interface and a new command line utility, `cct` (for "Coordinate Conversion and Transformation"). The old programming interface is still available and can - to some extent - use the new geodetic transformation features.

The internal architecture has also seen many changes and much improvement. So far, these improvements respect the existing programming interface. But the process has revealed a need to simplify and reduce the code base, in order to support sustained active development.

Therefore we have scheduled regular releases over the coming years which will gradually remove the old programming interface.

This will cause breaking changes with the next two major version releases, which will affect all projects that depend on PROJ (cf. section "deprecations" below).

The decision to break the existing API has not been easy, but has ultimately been deemed necessary to ensure the long term survival of the project. Not only by improving the maintainability immensely, but also by extending the potential user (and hence developer) community.

The end goal is to deliver a generic coordinate transformation software package with a clean and concise code base appealing to both users and developers.

2.32.1 Versioning and naming

For the first time in more than 25 years the major version number of the software is changed. The decision to do this is based on the many new features and new API. While backwards compatibility remains - except in a few rare corner cases - the addition of a new and improved programming interface warrants a new major release.

The new major version number unfortunately leaves the project in a bit of a conundrum regarding the name. For the majority of the life-time of the product it has been known as PROJ.4, but since we have now reached version 5 the name is no longer aligned with the version number.

Hence we have decided to decouple the name from the version number and from this version and onwards the product will simply be called PROJ.

In recognition of the history of the software we are keeping PROJ.4 as the name of the organizing project. The same project team also produces the datum-grid package.

In summary:
• The PROJ.4 project provides the product PROJ, which is now at version 5.0.0.
• The foundational component of PROJ is the library libproj.
• Other PROJ components include the application proj, which provides a command line interface to libproj.
• The PROJ.4 project also distributes the datum-grid package, which at the time of writing is at version 1.6.0.

2.32.2 Updates

• Introduced new API in proj.h.
  – The new API is orthogonal to the existing proj_api.h API and the internally used projects.h API.
  – The new API adds the ability to transform spatiotemporal (4D) coordinates.
  – Functions in the new API use the proj_ namespace.
  – Data types in the new API use the PJ_ namespace.
• Introduced the concept of "transformation pipelines" that makes possible to do complex geodetic transformations of coordinates by daisy chaining simple coordinate operations.
• Introduced cct, the Coordinate Conversion and Transformation application.
• Introduced gie, the Geospatial Integrity Investigation Environment.
  – Selftest invoked by -C flag in proj has been removed
  – Ported approx. 1300 built-in selftests to gie format
  – Ported approx. 1000 tests from the gigs test framework
  – Added approx. 200 new tests
• Adopted terminology from the OGC/ISO-19100 geospatial standards series. Key definitions are:
  – At the most generic level, a coordinate operation is a change of coordinates, based on a one-to-one relationship, from one coordinate reference system to another.
  – A transformation is a coordinate operation in which the two coordinate reference systems are based on different datums, e.g. a change from a global reference frame to a regional frame.
  – A conversion is a coordinate operation in which both coordinate reference systems are based on the same datum, e.g. change of units of coordinates.
  – A projection is a coordinate conversion from an ellipsoidal coordinate system to a plane. Although projections are simply conversions according to the standard, they are treated as separate entities in PROJ as they make up the vast majority of operations in the library.
• New operations
  – The pipeline operator (pipeline)
  – Transformations
    * Helmert transform (helmert)
    * Horner real and complex polynomial evaluation (horner)
    * Horizontal gridshift (hgridshift)
    * Vertical gridshift (vgridshift)
    * Molodensky transform (molodensky)
    * Kinematic gridshift with deformation model (deformation)
  – Conversions
    * Unit conversion (unitconvert)
PROJ coordinate transformation software library, Release 9.3.1

* Axis swap (axisswap)

- Projections
  * Central Conic projection (ccon)

- Significant documentation updates, including
  - Overhaul of the structure of the documentation
  - A better introduction to the use of PROJ
  - A complete reference to the new API
  - A complete rewrite of the section on geodesic calculations
  - Figures for all projections

- New "free format" option for operation definitions, which permits separating tokens by whitespace when specifying key/value-pairs, e.g. proj = merc lat_0 = 45.

- Added metadata to init-files that can be read with the proj_init_info() function in the new proj.h API.

- Added ITRF2000, ITRF2008 and ITRF2014 init-files with ITRF transformation parameters, including plate motion model parameters.

- Added ellipsoid parameters for GSK2011, PZ90 and "danish". The latter is similar to the already supported andrae ellipsoid, but has a slightly different semimajor axis.

- Added Copenhagen prime meridian.

- Updated EPSG database to version 9.2.0.

- Geodesic library updated to version 1.49.2-c.

- Support for analytical partial derivatives has been removed.

- Improved performance in Winkel Tripel and Aitoff.

- Introduced pj_has_inverse() function to proj_api.h. Checks if an operation has an inverse. Use this instead of checking whether P->inv exists, since that can no longer be relied on.

- ABI version number updated to 13:0:0.

- Removed support for Windows CE.

- Removed the VB6 COM interface.

2.32.3 Bug fixes

- Fixed incorrect convergence calculation in Lambert Conformal Conic. (#16)

- Handle ellipsoid parameters correctly when using +nadgrids=null. (#22)

- Return correct latitude when using negative northings in Transverse Mercator. (#138)

- Return correct result at origin in inverse Mod. Stereographic of Alaska. (#161)

- Return correct result at origin in inverse Mod. Stereographic of 48 U.S. (#162)

- Return correct result at origin in inverse Mod. Stereographic of 50 U.S. (#163)

- Return correct result at origin in inverse Lee Oblated Stereographic. (#164)

- Return correct result at origin in inverse Miller Oblated Stereographic. (#165)

- Fixed scaling and wrap-around issues in Oblique Cylindrical Equal Area. (#166)
• Corrected a coefficient error in inverse Transverse Mercator. (#174)
• Respect -r flag when calling proj with -V. (#184)
• Remove multiplication by 2 at the equator error in Stereographic projection. (#194)
• Allow +alpha=0 and +gamma=0 when using Oblique Mercator. (#195)
• Return correct result of inverse Oblique Mercator when alpha is between 90 and 270. (#331)
• Avoid segmentation fault when accessing point outside grid. (#396)
• Avoid segmentation fault on NaN input in Robin inverse. (#463)
• Very verbose use of proj (-V) on Windows is fixed. (#484)
• Fixed memory leak in General Oblique Transformation. (#497)
• Equations for meridian convergence and partial derivatives have been corrected for non-conformal projections. (#526)
• Fixed scaling of cartesian coordinates in pj_transform(). (#726)
• Additional bug fixes courtesy of Google's OSS-Fuzz program
Source code for the current and previous releases can be downloaded from https://download.osgeo.org/proj/
Documentation in PDF and zipped HTML can be downloaded using the flyout menu on the left side of the browser window from https://proj.org/

3.1 Current Release

- **2023-12-01** proj-9.3.1.tar.gz (md5)
- **2023-12-01** proj-data-1.16.tar.gz

Note: The proj-datumgrid packages have been deprecated with PROJ 7.0.0. The proj-data package should be used with PROJ 7.0.0 and newer.

The proj-datumgrid packages should be used with PROJ releases from the 5.x and 6.x branches.

3.2 Past Releases

- **2023-09-01** proj-9.3.0.tar.gz
- **2023-06-01** proj-9.2.1.tar.gz
- **2023-03-01** proj-9.2.0.tar.gz
- **2022-12-01** proj-9.1.1.tar.gz
- **2022-09-01** proj-9.1.0.tar.gz
- **2022-06-15** proj-9.0.1.tar.gz
- **2022-03-01** proj-9.0.0.tar.gz
- **2022-01-01** proj-8.2.1.tar.gz
- **2021-11-01** proj-8.2.0.tar.gz
- **2021-09-01** proj-8.1.1.tar.gz
- **2021-07-01** proj-8.1.0.tar.gz
- **2021-05-05** proj-8.0.1.tar.gz
- **2021-03-01** proj-8.0.0.tar.gz
• 2021-01-01 proj-7.2.1.tar.gz
• 2020-11-01 proj-7.2.0.tar.gz
• 2020-09-01 proj-7.1.1.tar.gz
• 2020-07-01 proj-7.1.0.tar.gz
• 2020-05-01 proj-6.3.2.tar.gz
• 2020-05-01 proj-7.0.1.tar.gz
• 2020-03-01 proj-7.0.0.tar.gz
• 2020-02-11 proj-6.3.1.tar.gz
• 2020-01-01 proj-6.3.0.tar.gz
• 2019-11-01 proj-6.2.1.tar.gz
• 2019-09-01 proj-6.2.0.tar.gz
• 2019-07-01 proj-6.1.1.tar.gz
• 2019-05-15 proj-6.1.0.tar.gz
• 2019-03-01 proj-6.0.0.tar.gz
• 2018-09-15 proj-5.2.0.tar.gz
• 2018-06-01 proj-5.1.0.tar.gz
• 2018-04-01 proj-5.0.1.tar.gz
• 2018-03-01 proj-5.0.0.tar.gz
• 2016-09-02 proj-4.9.3.tar.gz
• 2015-09-13 proj-4.9.2.tar.gz
• 2015-03-04 proj-4.9.1.tar.gz
• 2023-06-01 proj-data-1.14.tar.gz
• 2023-03-01 proj-data-1.13.tar.gz
• 2022-12-01 proj-data-1.12.tar.gz
• 2022-09-01 proj-data-1.11.tar.gz
• 2022-06-15 proj-data-1.10.tar.gz
• 2022-03-01 proj-data-1.9.tar.gz
• 2021-11-01 proj-data-1.8.tar.gz
• 2021-07-01 proj-data-1.7.tar.gz
• 2021-05-05 proj-data-1.6.tar.gz
• 2021-03-01 proj-data-1.5.tar.gz
• 2021-01-01 proj-data-1.4.tar.gz
• 2020-11-01 proj-data-1.3.tar.gz
• 2020-09-01 proj-data-1.2.tar.gz
• 2020-05-01 proj-data-1.1.tar.gz
• 2020-03-01 proj-data-1.0.tar.gz
• 2018-09-15 proj-datumgrid-1.8.zip
• 2020-03-01 proj-datumgrid-europe-1.6.zip
• 2020-03-01 proj-datumgrid-north-america-1.4.zip
• 2020-03-01 proj-datumgrid-oceania-1.2.zip
• 2019-03-01 proj-datumgrid-world-1.0.zip
• 2018-03-01 proj-datumgrid-1.7.zip
• 2016-09-11 proj-datumgrid-1.6.zip
• 2019-09-01 proj-datumgrid-europe-1.5.zip
• 2019-09-01 proj-datumgrid-europe-1.4.zip
• 2019-07-01 proj-datumgrid-europe-1.3.zip
• 2019-03-01 proj-datumgrid-europe-1.2.zip
• 2018-09-15 proj-datumgrid-europe-1.1.zip
• 2018-03-01 proj-datumgrid-europe-1.0.zip
• 2019-03-01 proj-datumgrid-north-america-1.3.zip
• 2019-03-01 proj-datumgrid-north-america-1.2.zip
• 2018-09-15 proj-datumgrid-north-america-1.1.zip
• 2018-03-01 proj-datumgrid-north-america-1.0.zip
• 2018-03-01 proj-datumgrid-oceania-1.1.zip
• 2018-03-01 proj-datumgrid-oceania-1.0.zip
CHAPTER
FOUR

INSTALLATION

These pages describe how to install PROJ on your computer without compiling it yourself. Below are guides for installing on Windows, Linux and Mac OS X. This is a good place to get started if this is your first time using PROJ. More advanced users may want to compile the software themselves.

4.1 Installation from package management systems

4.1.1 Cross platform

PROJ is also available via cross platform package managers.

4.1.1.1 Conda

The conda package manager includes several PROJ packages. We recommend installing from the conda-forge channel:

```
conda install -c conda-forge proj
```

Using conda you can also install the PROJ data package. Here's how to install the proj-data package:

```
conda install -c conda-forge proj-data
```

Available is also the legacy packages proj-datumgrid-europe, proj-datumgrid-north-america, proj-datumgrid-oceania and proj-datumgrid-world.

**Tip:** Read more about the various datumgrid packages available [here](#).

4.1.1.2 Docker

A Docker image with just PROJ binaries and a full compliment of grid shift files is available on DockerHub. Get the package with:

```
docker pull osgeo/proj
```
4.1.2 Windows

The simplest way to install PROJ on Windows is to use the OSGeo4W software distribution. OSGeo4W provides easy access to many popular open source geospatial software packages. After installation you can use PROJ from the OSGeo4W shell. To install PROJ do the following:

**Note:** If you have already installed software via OSGeo4W on your computer, or if you have already installed QGIS on your computer, it is likely that PROJ is already installed. Type "OSGeo4W Shell" in your start menu and check whether that gives a match.

1. Download the 64 bit installer.
2. Run the OSGeo4W setup program.
4. Select "Install from Internet" and press Next.
5. Select a installation directory. The default suggestion is fine in most cases. Press Next.
6. Select "Local package directory". The default suggestion is fine in most cases. Press Next.
7. Select "Direct connection" and press Next.
8. Choose the download.osgeo.org server and press Next.
9. Find "proj" under "Commandline_Utilities" and click the package in the "New" column until the version you want to install appears.
10. Press next to install PROJ.

You should now have a "OSGeo" menu in your start menu. Within that menu you can find the "OSGeo4W Shell" where you have access to all the OSGeo4W applications, including proj.

For those who are more inclined to the command line, steps 2--10 above can be accomplished by executing the following command:

```
C:\temp\osgeo4w-setup.exe -q -k -r -A -s https://download.osgeo.org/osgeo4w/v2/ -P proj
```

4.1.3 Linux

How to install PROJ on Linux depends on which distribution you are using. Below is a few examples for some of the more common Linux distributions:

4.1.3.1 Debian

On Debian and similar systems (e.g. Ubuntu) the APT package manager is used:

```
sudo apt-get install proj-bin
```
4.1.3.2 Fedora

On Fedora the dnf package manager is used:

```bash
sudo dnf install proj
```

4.1.3.3 Red Hat

On Red Hat based system packages are installed with yum:

```bash
sudo yum install proj
```

4.1.4 Mac OS X

On OS X PROJ can be installed via the Homebrew package manager:

```bash
brew install proj
```

PROJ is also available from the MacPorts system:

```bash
sudo ports install proj
```

4.2 Compilation and installation from source code

The classic way of installing PROJ is via the source code distribution. The most recent version is available from the download page.

The following guides show how to compile and install the software using CMake.

---

**Note:** Support for Autotools was maintained until PROJ 8.2 (see PROJ RFC 7: Drop Autotools, maintain CMake). PROJ 9.0 and later releases only support builds using CMake.

---

4.2.1 Build requirements

- C99 compiler
- C++11 compiler
- CMake >= 3.9
- SQLite3 >= 3.11: headers and library for target architecture, and sqlite3 executable for build architecture.
- libtiff >= 4.0 (optional but recommended)
- curl >= 7.29.0 (optional but recommended)
4.2.2 Build steps

With the CMake build system you can compile and install PROJ on more or less any platform. After unpacking the source distribution archive step into the source- tree:

```
cd proj-9.3.1
```

Create a build directory and step into it:

```
mkdir build
cd build
```

From the build directory you can now configure CMake, build and install the binaries:

```
cmake ..
cmake --build .
cmake --build . --target install
```

On Windows, one may need to specify generator:

```
cmake -G "Visual Studio 15 2017" ..
```

If the SQLite3 dependency is installed in a custom location, specify the paths to the include directory and the library:

```
cmake -DSQLITE3_INCLUDE_DIR=/opt/SQLite/include -DSQLITE3_LIBRARY=/opt/SQLite/lib/"libsqlite3.so ..
```

Alternatively, the custom prefix for SQLite3 can be specified:

```
cmake -DCMAKE_PREFIX_PATH=/opt/SQLite ..
```

Tests are run with:

```
ctest
```

With a successful install of PROJ we can now install data files using the `projsync` utility:

```
projsync --system-directory
```

which will download all resource files currently available for PROJ. If less than the entire collection of resource files is needed the call to `projsync` can be modified to suit the users needs. See `projsync` for more options.

**Note:** The use of `projsync` requires that network support is enabled (the default option). If the resource files are not installed using `projsync` PROJ will attempt to fetch them automatically when a transformation needs a specific data file. This requires that `PROJ_NETWORK` is set to `ON`.

As an alternative on systems where network access is disabled, the `proj-data` package can be downloaded and its content decompressed into one of the directories where PROJ looks for resources

Starting with PROJ 9.2, a `uninstall` target is available to remove files installed by the `install` target:

```
cmake --build . --target uninstall
```
4.2.3 CMake configure options

Options to configure a CMake are provided using `-D<var>=<value>`. All cached entries can be viewed using `cmake -LAH` from a build directory.

**BUILD_APPS=ON**

Build PROJ applications. Default is ON. Control the default value for BUILD_CCT, BUILD_CS2CS, BUILD_GEOD, BUILD_GIE, BUILD_PROJ, BUILD_PROJINFO and BUILD_PROJSYNC. Note that changing its value after having configured once will not change the value of the individual BUILD_CCT, ... options.

Changed in version 8.2.

**BUILD_CCT=ON**

Build `cct`, default is the value of BUILD_APPS.

**BUILD_CS2CS=ON**

Build `cs2cs`, default is the value of BUILD_APPS.

**BUILD_GEOD=ON**

Build `geod`, default is the value of BUILD_APPS.

**BUILD_GIE=ON**

Build `gie`, default is the value of BUILD_APPS.

**BUILD_PROJ=ON**

Build `proj`, default is the value of BUILD_APPS.

**BUILD_PROJINFO=ON**

Build `projinfo`, default is the value of BUILD_APPS.

**BUILD_PROJSYNC=ON**

Build `projsync`, default is the value of BUILD_APPS.

**BUILD_SHARED_LIBS**

Build PROJ library shared. Default is ON. See also the CMake documentation for `BUILD_SHARED_LIBS`.

Changed in version 7.0: Renamed from `BUILD_LIBPROJ_SHARED`

---

**Note:** before PROJ 9.0, the default was OFF for Windows builds.

**BUILD_TESTING=ON**

CTest option to build the testing tree, which also downloads and installs Googletest. Default is ON, but can be turned OFF if tests are not required.

Changed in version 7.0: Renamed from `PROJ_TESTS`

**CMAKE_BUILD_TYPE**

Choose the type of build, options are: None (default), Debug, Release, RelWithDebInfo, or MinSizeRel. See also the CMake documentation for `CMAKE_BUILD_TYPE`.

---

**Note:** A default build is not optimized without specifying `-DCMAKE_BUILD_TYPE=Release` (or similar) during configuration, or by specifying `--config Release` with CMake multi-configuration build tools (see example below).
CMAKE_C_COMPILER
C compiler. Ignored for some generators, such as Visual Studio.

CMAKE_C_FLAGS
Flags used by the C compiler during all build types. This is initialized by the CFLAGS environment variable.

CMAKE_CXX_COMPILER
C++ compiler. Ignored for some generators, such as Visual Studio.

CMAKE_CXX_FLAGS
Flags used by the C++ compiler during all build types. This is initialized by the CXXFLAGS environment variable.

CMAKE_INSTALL_PREFIX
Default for Windows is based on the environment variable OSGEO4W_ROOT (if set), otherwise is c:/OSGeo4W. Default for Unix-like is /usr/local/.

ENABLE_IPO=OFF
Build library using the compiler's interprocedural optimization (IPO), if available, default OFF. Changed in version 7.0: Renamed from ENABLE_LTO.

EXE_SQLITE3
Path to an sqlite3 or sqlite3.exe executable.

SQLITE3_INCLUDE_DIR
Path to an include directory with the sqlite3.h header file.

SQLITE3_LIBRARY
Path to a shared or static library file, such as sqlite3.dll, libsqlite3.so, sqlite3.lib or other name.

ENABLE_CURL=ON
Enable CURL support, default ON.

CURL_INCLUDE_DIR
Path to an include directory with the curl directory.

CURL_LIBRARY
Path to a shared or static library file, such as libcurl.dll, libcurl.so, libcurl.lib, or other name.

ENABLE_TIFF=ON
Enable TIFF support to use PROJ-data resource files, default ON.

TIFF_INCLUDE_DIR
Path to an include directory with the tiff.h header file.

TIFF_LIBRARY_RELEASE
Path to a shared or static library file, such as tiff.dll, libtiff.so, tiff.lib, or other name. A similar variable TIFF_LIBRARY_DEBUG can also be specified to a similar library for building Debug releases.

USE_CCACHE=OFF
Configure CMake to use ccache (or clcache for MSVC) to build C/C++ objects.

PROJ_DB_CACHE_DIR
Path to an existing directory used to cache proj.db to speed-up subsequent builds without modifications to source SQL files.
4.2.4 Building on Windows with vcpkg and Visual Studio 2017 or 2019

This method is the preferred one to generate Debug and Release builds.

4.2.4.1 Install git

Install git

4.2.4.2 Install Vcpkg

Assuming there is a c:\dev directory

```
cd c:\dev
git clone https://github.com/Microsoft/vcpkg.git

cd vcpkg
.ootstr-vcpkg.bat
```

4.2.4.3 Install PROJ dependencies

```
vcpkg install sqlite3[core,tool] tiff curl --triplet=x86-windows
vcpkg install sqlite3[core,tool] tiff curl --triplet=x64-windows
```

Note: The tiff and curl dependencies are only needed since PROJ 7.0

4.2.4.4 Checkout PROJ sources

```
cd c:\dev

git clone https://github.com/OSGeo/PROJ.git
```

4.2.4.5 Build PROJ

```
cd c:\dev\PROJ
mkdir build_vs2019

cd build_vs2019

cmake -DCMAKE_TOOLCHAIN_FILE=C:\dev\vcpkg\scripts\buildsystems\vcpkg.cmake ..
cmake --build . --config Debug -j 8
```
4.2.4.6 Run PROJ tests

```
cd c:\dev\PROJ\build_vs2019
cctest -V --build-config Debug
```

4.2.5 Building on Windows with Conda dependencies and Visual Studio 2017 or 2019

Variant of the above method but using Conda for SQLite3, TIFF and CURL dependencies. It is less appropriate for Debug builds of PROJ than the method based on vcpkg.

4.2.5.1 Install git

Install git

4.2.5.2 Install miniconda

Install miniconda

4.2.5.3 Install PROJ dependencies

Start a Conda enabled console and assuming there is a c:\dev directory

```
cd c:\dev
cconda create --name proj
cconda activate proj
cconda install sqlite libtiff curl cmake
```

Note: The libtiff and curl dependencies are only needed since PROJ 7.0

4.2.5.4 Checkout PROJ sources

```
cd c:\dev
git clone https://github.com/OSGeo/PROJ.git
```

4.2.5.5 Build PROJ

From a Conda enabled console

```
cconda activate proj
cd c:\dev\PROJ
call "C:\Program Files (x86)\Microsoft Visual Studio\2017\Community\VC\Auxiliary\Build\vcvars64.bat"
cmake -S . -B _build.vs2019 -DCMAKE_LIBRARY_PATH:FILEPATH="%CONDA_PREFIX%/Library/lib" -DCMAKE_INCLUDE_PATH:FILEPATH="%CONDA_PREFIX%/Library/include" cmake --build _build.vs2019 --config Release -j 8
```
4.2.5.6 Run PROJ tests

```
cd c:\dev\PROJ
cd _build.vs2019
ctest -V --build-config Release
```
The main purpose of PROJ is to transform coordinates from one coordinate reference system to another. This can be achieved either with the included command line applications or the C API that is a part of the software package.

5.1 Quick start

Coordinate transformations are defined by, what in PROJ terminology is known as, "proj-strings". A proj-string describes any transformation regardless of how simple or complicated it might be. The simplest case is projection of geodetic coordinates. This section focuses on the simpler cases and introduces the basic anatomy of the proj-string. The complex cases are discussed in Geodetic transformation.

A proj-string holds the parameters of a given coordinate transformation, e.g.

```
+proj=merc +lat_ts=56.5 +ellps=GRS80
```

I.e. a proj-string consists of a projection specifier, +proj, a number of parameters that applies to the projection and, if needed, a description of a datum shift. In the example above geodetic coordinates are transformed to projected space with the Mercator projection with the latitude of true scale at 56.5 degrees north on the GRS80 ellipsoid. Every projection in PROJ is identified by a shorthand such as merc in the above example.

By using the above projection definition as parameters for the command line utility proj we can convert the geodetic coordinates to projected space:

```
$ proj +proj=merc +lat_ts=56.5 +ellps=GRS80
```

If called as above proj will be in interactive mode, letting you type the input data manually and getting a response presented on screen. proj works as any UNIX filter though, which means that you can also pipe data to the utility, for instance by using the echo command:

```
$ echo 55.2 12.2 | proj +proj=merc +lat_ts=56.5 +ellps=GRS80
3399483.80 752085.60
```

PROJ also comes bundled with the cs2cs utility which is used to transform from one coordinate reference system to another. Say we want to convert the above Mercator coordinates to UTM, we can do that with cs2cs:

```
$ echo 3399483.80 752085.60 | cs2cs +proj=merc +lat_ts=56.5 +ellps=GRS80 +to +proj=utm +zone=32
6103992.36 1924052.47 0.00
```

Notice the +to parameter that separates the source and destination projection definitions.

If you happen to know the EPSG identifiers for the two coordinates reference systems you are transforming between you can use those with cs2cs:
In the above example we transform geodetic coordinates in the WGS84 reference frame to UTM zone 32N coordinates in the ETRS89 reference frame. UTM coordinates

$ echo 56 12 | cs2cs +init=epsg:4326 +to +init=epsg:25832
231950.54 1920310.71 0.00

5.2 Cartographic projection

The foundation of PROJ is the large number of projections available in the library. This section is devoted to the generic parameters that can be used on any projection in the PROJ library.

Below is a list of PROJ parameters which can be applied to most coordinate system definitions. This table does not attempt to describe the parameters particular to particular projection types. These can be found on the pages documenting the individual projections.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+a</td>
<td>Semimajor radius of the ellipsoid axis</td>
</tr>
<tr>
<td>+axis</td>
<td>Axis orientation</td>
</tr>
<tr>
<td>+b</td>
<td>Semiminor radius of the ellipsoid axis</td>
</tr>
<tr>
<td>+ellps</td>
<td>Ellipsoid name (see proj -le)</td>
</tr>
<tr>
<td>+k</td>
<td>Scaling factor (deprecated)</td>
</tr>
<tr>
<td>+k_0</td>
<td>Scaling factor</td>
</tr>
<tr>
<td>+lat_0</td>
<td>Latitude of origin (in degree if no angular unit specified)</td>
</tr>
<tr>
<td>+lon_0</td>
<td>Central meridian (in degree if no angular unit specified)</td>
</tr>
<tr>
<td>+lon_wrap</td>
<td>Center longitude to use for wrapping (see below)</td>
</tr>
<tr>
<td>+over</td>
<td>Allow longitude output outside -180 to 180 range, disables wrapping (see below)</td>
</tr>
<tr>
<td>+pm</td>
<td>Alternate prime meridian (typically a city name, see below)</td>
</tr>
<tr>
<td>+proj</td>
<td>Projection name (see proj -1)</td>
</tr>
<tr>
<td>+units</td>
<td>Horizontal coordinate system units (meters, US survey feet, etc.)</td>
</tr>
<tr>
<td>+vunits</td>
<td>Vertical coordinate system units.</td>
</tr>
<tr>
<td>+x_0</td>
<td>False easting (always in meters)</td>
</tr>
<tr>
<td>+y_0</td>
<td>False northing (always in meters)</td>
</tr>
</tbody>
</table>

In the sections below most of the parameters are explained in details.

5.2.1 Units

Horizontal coordinate system units can be specified using the +units keyword with a symbolic me for a unit (i.e. us-ft). Alternatively the translation to meters can be specified with the +to_meter keyword (i.e. 0.304800609601219 for US feet). The -lu argument to cs2cs or proj can be used to list symbolic unit names. The default unit for projected coordinates is the meter. A few special projections deviate from this behavior, most notably the latlong pseudo-projection that returns degrees. Note that this does not affect the units of linear parameters such as +x_0 or +y_0 which should always be specified in meters.

Vertical (Z) units can be specified using the +vunits keyword with a symbolic name for a unit (i.e. us-ft). Alternatively the translation to meters can be specified with the +vto_meter keyword (i.e. 0.304800609601219 for US feet). The -lu argument to cs2cs or proj can be used to list symbolic unit names. If no vertical units are specified, the vertical units will default to be the same as the horizontal coordinates.
Note: proj does not handle vertical units at all and hence the +vto_meter argument will be ignored.

Scaling of output units can be done by applying the +k_0 argument (unitless). The returned coordinates are scaled by the value assigned with the +k_0 parameter. This parameter is only used by projections that mention using it, and its exact effect is projection dependent.

Input units for angular parameters (+lon_0, +lat_0, etc.) are interpreted to be decimal degrees by convention. Explicit specification of input angular units can be accomplished by adding the appropriate suffix to input values.

<table>
<thead>
<tr>
<th>Suffix</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>Decimal degrees</td>
</tr>
<tr>
<td>D</td>
<td>°</td>
</tr>
<tr>
<td>r</td>
<td>Radians</td>
</tr>
<tr>
<td>R</td>
<td></td>
</tr>
</tbody>
</table>

Example of use. The longitude of the central meridian +lon_0=90, can also be expressed more explicitly with units of decimal degrees as +lon_0=90d or in radian units as +lon_0=1.570796r (approximately).

5.2.2 False Easting/Northing

Virtually all coordinate systems allow for the presence of a false easting (+x_0) and northing (+y_0). Note that these values are always expressed in meters even if the coordinate system is some other units. Some coordinate systems (such as UTM) have implicit false easting and northing values.

5.2.3 Longitude Wrapping

By default PROJ wraps output longitudes in the range -180 to 180. The +over switch can be used to disable the default wrapping which is done at a low level in pj_inv(). This is particularly useful with projections like the Equidistant Cylindrical (Plate Carrée) or Mercator where it could be desirable for X values past -20000000 (roughly) to continue past -180 instead of wrapping to +180.

Note however that for most projections where the 180 meridian does not project to a straight line, +over will have no effect or will not lead to expected results.

The +lon_wrap option can be used to provide an alternative means of doing longitude wrapping. It has only effect with operations that output angular coordinates, such as +proj=longlat The argument to this option is a center longitude. So +lon_wrap=180 means wrap longitudes in the range 0 to 360.

```sh
$ echo -1 0 cs2cs +proj=longlat +to +proj=longlat +lon_wrap=180
359dE    0dN 0.000
```

Note that +over does not disable +lon_wrap.
5.2.4 Prime Meridian

A prime meridian may be declared indicating the offset between the prime meridian of the declared coordinate system and that of Greenwich. A prime meridian is declared using the "pm" parameter, and may be assigned a symbolic name, or the longitude of the alternative prime meridian relative to Greenwich.

Currently prime meridian declarations are not used by the pj_inv() and pj_fwd() calls. Consequently the user utility cs2cs does honour prime meridians but the proj user utility ignores them.

The following predeclared prime meridian names are supported. These can be listed using with cs2cs -lm.

<table>
<thead>
<tr>
<th>Meridian</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>greenwich</td>
<td>0dE</td>
</tr>
<tr>
<td>lisbon</td>
<td>9d07'54.862&quot;W</td>
</tr>
<tr>
<td>paris</td>
<td>2d20'14.025&quot;E</td>
</tr>
<tr>
<td>bogota</td>
<td>7d40'51.3&quot;E</td>
</tr>
<tr>
<td>madrid</td>
<td>3d41'16.48&quot;W</td>
</tr>
<tr>
<td>rome</td>
<td>12d27'8.4&quot;E</td>
</tr>
<tr>
<td>bern</td>
<td>7d26'22.5&quot;E</td>
</tr>
<tr>
<td>jakarta</td>
<td>10d48'27.79&quot;E</td>
</tr>
<tr>
<td>ferro</td>
<td>17d40'W</td>
</tr>
<tr>
<td>brussels</td>
<td>4d22'4.71&quot;E</td>
</tr>
<tr>
<td>stockholm</td>
<td>18d3'29.8&quot;E</td>
</tr>
<tr>
<td>athens</td>
<td>23d42'58.815&quot;E</td>
</tr>
<tr>
<td>oslo</td>
<td>10d43'22.5&quot;E</td>
</tr>
</tbody>
</table>

Example of use. The location long=0, lat=0 in the greenwich based lat/long coordinates is translated to lat/long coordinates with Madrid as the prime meridian.

```
cs2cs +proj=latlong +datum=WGS84 +to +proj=latlong +datum=WGS84 +pm=madrid
0 0
3d41'16.48"E 0dN 0.000
```

5.2.5 Axis orientation

Starting in PROJ 4.8.0, the +axis argument can be used to control the axis orientation of the coordinate system. The default orientation is "easting, northing, up" but directions can be flipped, or axes flipped using combinations of the axes in the +axis switch. The values are:

- "e" - Easting
- "w" - Westing
- "n" - Northing
- "s" - Southing
- "u" - Up
- "d" - Down

They can be combined in +axis in forms like:

- +axis=enu - the default easting, northing, elevation.
- +axis=neu - northing, easting, up - useful for "lat/long" geographic coordinates, or south orientated transverse mercator.
• +axis=wnu - westing, northing, up - some planetary coordinate systems have "west positive" coordinate systems

Note: The +axis argument does not work with the proj command line utility.

### 5.2.6 Order of applications of parameters

In the forward direction (from geodetic to projected coordinates), steps are performed in the following order:

- subtracting prime meridian (+pm) to input coordinate longitude
- subtracting central meridian (+lon_0) to input coordinate longitude
- normalizing input coordinate longitude to [-180, 180], unless +over is specified
- application of map projection formula on a spheroid of radius 1 and with the eccentricity of the target spheroid specified. Includes taking into account projection parameters such as +k_0, +lat_0, and other projection specific parameters
- scaling of output x, y values by the semimajor axis
- addition of false easting +x_0 to x and false northing +y_0 to y
- scaling of output x, y by the output horizontal unit (+units / +to_meter)
- scaling of output z by the output vertical unit (+vunits / +vto_meter)
- application of axis orientation and order (+axis)

This is implemented mostly in fwd.cpp

For the reverse direction (from projected coordinates to geodetic coordinates), reverse steps are performed in the reverse order.

### 5.3 Geodetic transformation

PROJ can do everything from the most simple projection to very complex transformations across many reference frames. While originally developed as a tool for cartographic projections, PROJ has over time evolved into a powerful generic coordinate transformation engine that makes it possible to do both large scale cartographic projections as well as coordinate transformation at a geodetic high precision level. This chapter delves into the details of how geodetic transformations of varying complexity can be performed.

In PROJ, two frameworks for geodetic transformations exists, the PROJ 4.x/5.x / cs2cs / pj_transform() framework and the transformation pipelines framework. The first is the original, and limited, framework for doing geodetic transforms in PROJ. The latter is a newer addition that aims to be a more complete transformation framework. Both are described in the sections below. Large portions of the text are based on [EversKnudsen2017].

Before describing the details of the two frameworks, let us first remark that most cases of geodetic transformations can be expressed as a series of elementary operations, the output of one operation being the input of the next. E.g. when going from UTM zone 32, datum ED50, to UTM zone 32, datum ETRS89, one must, in the simplest case, go through 5 steps:

1. Back-project the UTM coordinates to geographic coordinates
2. Convert the geographic coordinates to 3D cartesian geocentric coordinates
3. Apply a Helmert transformation from ED50 to ETRS89
4. Convert back from cartesian to geographic coordinates
5. Finally project the geographic coordinates to UTM zone 32 planar coordinates.

### 5.3.1 Transformation pipelines

The homology between the above steps and a Unix shell style pipeline is evident. It is there the main architectural inspiration behind the transformation pipeline framework. The pipeline framework is realized by utilizing a special "projection", that takes as its user supplied arguments, a series of elementary operations, which it strings together in order to implement the full transformation needed. Additionally, a number of elementary geodetic operations, including Helmert transformations, general high order polynomial shifts and the Molodensky transformation are available as part of the pipeline framework. In anticipation of upcoming support for full time-varying transformations, we also introduce a 4D spatiotemporal data type, and a programming interface (API) for handling this.

The Molodensky transformation converts directly from geodetic coordinates in one datum, to geodetic coordinates in another datum, while the (typically more accurate) Helmert transformation converts from 3D cartesian to 3D cartesian coordinates. So when using the Helmert transformation one typically needs to do an initial conversion from geodetic to cartesian coordinates, and a final conversion the other way round, to arrive at the desired result. Fortunately, this three-step compound transformation has the attractive characteristic that each step depends only on the output of the immediately preceding step. Hence, we can build a geodetic-to-geodetic Helmert transformation by tying together the outputs and inputs of 3 steps (geodetic-to-cartesian → Helmert → cartesian-to-geodetic), pipeline style. The pipeline driver, makes this kind of chained transformations possible. The implementation is compact, consisting of just one pseudo-projection, called `pipeline`, which takes as its arguments strings of elementary projections (note: "projection" is the, slightly misleading, PROJ term used for any kind of transformation). The pipeline pseudo projection is supplemented by a number of elementary transformations, all in all providing a framework for building high accuracy solutions for a wide spectrum of geodetic tasks.

As a first example, let us take a look at the iconic geodetic → Cartesian → Helmert → geodetic case (steps 2 to 4 in the example in the introduction). (Note, for the rest of this book the "+"s are removed from the examples.) In PROJ it can be implemented as

```
proj=pipeline
step proj=cart ellps=intl
step proj=helmert convention=coordinate_frame
  x=-81.0703 y=-89.3603 z=-115.7526
  rx=-0.48488 ry=-0.02436 rz=-0.41321 s=-0.540645
step proj=cart inv ellps=GRS80
```

The pipeline can be expanded at both ends to accommodate whatever coordinate type is needed for input and output: In the example below, we transform from the deprecated Danish System 45, a 2D system with some tension in the original defining network, to UTM zone 33, ETRS89. The tension is reduced using a polynomial transformation (the init=./s45b... step, s45b.pol is a file containing the polynomial coefficients), taking the S45 coordinates to a technical coordinate system (TC32), defined to represent "UTM zone 32 coordinates, as they would look if the Helmert transformation between ED50 and ETRS89 was perfect". The TC32 coordinates are then converted back to geodetic(ED50) coordinates, using an inverse UTM projection, further to cartesian(ED50), then to cartesian(ETRS89), using the relevant Helmert transformation, and back to geodetic(ETRS89), before finally being projected onto the UTM zone 33, ETRS89 system. All in all a 6 step pipeline, implementing a transformation with centimeter level accuracy from a deprecated system with decimeter level tensions.

```
proj=pipeline
step init=./s45b.pol:s45b_tc32
step proj=utm inv ellps=intl zone=32
step proj=cart ellps=intl
step proj=helmert convention=coordinate_frame
  x=-81.0703 y=-89.3603 z=-115.7526
  rx=-0.48488 ry=-0.02436 rz=-0.41321 s=-0.540645
```

(continues on next page)
step proj=cart inv ellps=GRS80
step proj=utm ellps=GRS80 zone=33

With the pipeline framework spatiotemporal transformation is possible. This is possible by leveraging the time dimension in PROJ that enables 4D coordinates (three spatial components and one temporal component) to be passed through a transformation pipeline. In the example below a transformation from ITRF93 to ITRF2000 is defined. The temporal component is given as GPS weeks in the input data, but the 14-parameter Helmert transform expects temporal units in decimal years. Hence the first step in the pipeline is the unitconvert pseudo-projection that makes sure the correct units are passed along to the Helmert transform. Most parameters of the Helmert transform are taken from [Altamimi2002], except the epoch which is the epoch of the transformation. The last step in the pipeline is converting the coordinate timestamps back to GPS weeks.

`proj=pipeline
step proj=unitconvert t_in=gps_week t_out=decimalyear
step proj=helmert convention=coordinate_frame
   x=0.0127 y=0.0065 z=-0.0209 s=0.00195
   rx=0.00039 ry=-0.00080 rz=0.00114
   dx=-0.0029 dy=-0.0002 dz=-0.0006 ds=0.00001
   drx=0.00011 dry=0.00019 drz=-0.00007
   t_epoch=1988.0
step proj=unitconvert t_in=decimalyear t_out=gps_week`

### 5.3.2 PROJ 4.x/5.x paradigm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+datum</td>
<td>Datum name (see <code>proj -ld</code>)</td>
</tr>
<tr>
<td>+geoid-grids</td>
<td>Filename of GTX grid file to use for vertical datum transforms</td>
</tr>
<tr>
<td>+geoid_crs</td>
<td>(Added in PROJ 9.1) Value can be &quot;WGS84&quot; or &quot;horizontal_crs&quot;. Only used if geoidgrids is specified.</td>
</tr>
<tr>
<td>+nadgrids</td>
<td>Filename of NTv2 grid file to use for datum transforms</td>
</tr>
<tr>
<td>+towgs84</td>
<td>3 or 7 term datum transform parameters</td>
</tr>
<tr>
<td>+to_meter</td>
<td>Multiplier to convert map units to 1.0m</td>
</tr>
<tr>
<td>+vto_meter</td>
<td>Vertical conversion to meters</td>
</tr>
</tbody>
</table>

**Warning:** This section documents the behavior of PROJ 4.x and 5.x. In PROJ 6.x, `cs2cs` has been reworked to use `proj_create_crs_to_crs()` internally, with late binding capabilities, and thus is no longer constrained to using WGS84 as a pivot (also called as early binding method). When `cs2cs` of PROJ 6 is used with PROJ 4 expanded strings to describe the CRS, including `+towgs84`, `+nadgrids` and `+geoidgrids`, it will generally give the same results as earlier PROJ versions. When used with AUTHORITY:CODE CRS descriptions, it may return different results.

The `cs2cs` framework in PROJ 4 and 5 delivers a subset of the geodetic transformations available with the pipeline framework. Coordinate transformations done in this framework were transformed in a two-step process with WGS84 as a pivot datum. That is, the input coordinates are transformed to WGS84 geodetic coordinates and then transformed...
from WGS84 coordinates to the specified output coordinate reference system, by utilizing either the Helmert transform, datum shift grids or a combination of both. Datum shifts can be described in a proj-string with the parameters +towgs84, +nadgrids and +geoidgrids. An inverse transform exists for all three and is applied if specified in the input proj-string. The most common is +towgs84, which is used to define a 3- or 7-parameter Helmert shift from the input reference frame to WGS84. Exactly which realization of WGS84 is not specified, hence a fair amount of uncertainty is introduced in this step of the transformation. With the +nadgrids parameter a non-linear planar correction derived from interpolation in a correction grid can be applied. Originally this was implemented as a means to transform coordinates between the North American datums NAD27 and NAD83, but corrections can be applied for any datum for which a correction grid exists. The inverse transform for the horizontal grid shift is "dumb", in the sense that the correction grid is applied verbatim without taking into account that the inverse operation is non-linear. Similar to the horizontal grid correction, +geoidgrids can be used to perform grid corrections in the vertical component. Both grid correction methods allow inclusion of more than one grid in the same transformation.

The +geoid_crs=WGS84/horizontal_crs parameter was added in PROJ 9.1 to solve an ambiguity that has been rampant for a long time. Before PROJ 6, the interpolation CRS of the geoid transformation was assumed to be the one of the horizontal CRS. Starting with PROJ 6, this was inadvertently changed to be WGS84.

When transforming from a CRS that specifies a horizontal datum shift with +towgs84 or +nadgrids, and a vertical one with +geoidgrids with +geoid_crs=horizontal_crs, to WGS84, the vertical transformation is done before the horizontal one.

```bash
$ projinfo -s "+proj=longlat +ellps=GRS80 +nadgrids=@foo +geoidgrids=@bar +geoid_crs=horizontal_crs +type=crs" -t EPSG:4979 -o PROJ -q

+proj=pipeline
  +step +proj=unitconvert +xy_in=deg +xy_out=rad
  +step +proj=vgridshift +grids=@bar +multiplier=1
  +step +proj=hgridshift +grids=@foo
  +step +proj=unitconvert +xy_in=rad +z_in=m +xy_out=deg +z_out=m
  +step +proj=axisswap +order=2,1

Conversely, when +geoid_crs=WGS84 (or omitting it with PROJ >= 6), the horizontal transformation is done before the vertical one.

```
```bash
$ projinfo -s "+proj=longlat +ellps=GRS80 +nadgrids=@foo +geoidgrids=@bar +geoid_crs=WGS84 +type=crs" -t EPSG:4979 -o PROJ -q

+proj=pipeline
  +step +proj=unitconvert +xy_in=deg +xy_out=rad
  +step +proj=hgridshift +grids=@foo
  +step +proj=vgridshift +grids=@bar +multiplier=1
  +step +proj=unitconvert +xy_in=rad +xy_out=deg
  +step +proj=axisswap +order=2,1

In contrast to the transformation pipeline framework, transformations with the cs2cs framework in PROJ 4 and 5 were expressed as two separate proj-strings. One proj-string to WGS84 and one from WGS84. Together they form the mapping from the source coordinate reference system to the destination coordinate reference system. When used with the cs2cs the source and destination CRS's are separated by the special +to parameter.

The following example demonstrates converting from the Greek GGRS87 datum to WGS84 with the +towgs84 parameter.

```bash
cs2cs +proj=latlong +ellps=GRS80 +towgs84=-199.87,74.79,246.62 +to +proj=latlong +datum=WGS84
20 35
20d0'5.467"E 35d0'9.575"N 0.000
```
PROJ coordinate transformation software library, Release 9.3.1

With PROJ 6, you can simply use the following:

**Note:** With PROJ 6, the order of coordinates for EPSG geographic coordinate reference systems is latitude first, longitude second.

```plaintext
cs2cs "GGRS87" "WGS 84"
35 20
35d0'9.575"N 20d0'5.467"E 0.000

cs2cs EPSG:4121 EPSG:4326
35 20
35d0'9.575"N 20d0'5.467"E 0.000
```

The EPSG database provides this example for transforming from WGS72 to WGS84 using an approximated 7 parameter transformation.

```plaintext
cs2cs +proj=latlong +ellps=WGS72 +towgs84=0,0,4.5,0,0,0.554,0.219
   +to +proj=latlong +datum=WGS84
4 55
4d0'0.554"E 55d0'0.09"N 0.000
```

With PROJ 6, you can simply use the following (note the reversed order for latitude and longitude)

```plaintext
cs2cs "WGS 72" "WGS 84"
55 4
55d0'0.09"N 4d0'0.554"E 0.000

cs2cs EPSG:4322 EPSG:4326
55 4
55d0'0.09"N 4d0'0.554"E 0.000
```

### 5.3.3 Grid Based Datum Adjustments

In many places (notably North America and Australia) national geodetic organizations provide grid shift files for converting between different datums, such as NAD27 to NAD83. These grid shift files include a shift to be applied at each grid location. Actually grid shifts are normally computed based on an interpolation between the containing four grid points.

PROJ supports use of grid files for shifting between various reference frames. The grid shift table formats are CTable, NTv1 (the old Canadian format), and NTv2 (.gsb - the new Canadian and Australian format).

The text in this section is based on the cs2cs framework. Gridshifting is of course also possible with the pipeline framework. The major difference between the two is that the cs2cs framework is limited to grid mappings to WGS84, whereas with transformation pipelines it is possible to perform grid shifts between any two reference frames, as long as a grid exists.

Use of grid shifts with cs2cs is specified using the +nadgrids keyword in a coordinate system definition. For example:

```plaintext
% cs2cs +proj=latlong +ellps=clrk66 +nadgrids=ntv1_can.dat \
   +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 50
EOF
111d0'2.952"W 50d0'0.111"N 0.000
```

5.3. Geodetic transformation
In this case the /usr/local/share/proj/ntv1_can.dat grid shift file was loaded, and used to get a grid shift value for the selected point.

It is possible to list multiple grid shift files, in which case each will be tried in turn till one is found that contains the point being transformed.

```bash
cs2cs +proj=latlong +ellps=clrk66 \
    +nadgrids=conus,alaska,hawaii,stgeorge,stlrnc,stpaul \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 44
EOF
111d0'2.788"W 43d59'59.725"N 0.000
```

### 5.3.3.1 Skipping Missing Grids

The special prefix `@` may be prefixed to a grid to make it optional. If it not found, the search will continue to the next grid. Normally any grid not found will cause an error. For instance, the following would use the ntv2_0.gsb file if available, otherwise it would fallback to using the ntv1_can.dat file.

```bash
cs2cs +proj=latlong +ellps=clrk66 +nadgrids=@ntv2_0.gsb,ntv1_can.dat \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 50
EOF
111d0'3.006"W 50d0'0.103"N 0.000
```

### 5.3.3.2 The null Grid

A special null grid shift file is distributed with PROJ. This file provides a zero shift for the whole world. It may be listed at the end of a nadgrids file list if you want a zero shift to be applied to points outside the valid region of all the other grids. Normally if no grid is found that contains the point to be transformed an error will occur.

```bash
cs2cs +proj=latlong +ellps=clrk66 +nadgrids=conus,null \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 45
EOF
111d0'3.006"W 50d0'0.103"N 0.000
```

```bash
cs2cs +proj=latlong +ellps=clrk66 +nadgrids=conus,null \
    +to +proj=latlong +ellps=GRS80 +datum=NAD83 << EOF
-111 44
-111 55
EOF
111d0'2.788"W 43d59'59.725"N 0.000
111dW 55dN 0.000
```

For more information see the chapter on *Other transformation grids.*
5.3.3 Caveats

- Where grids overlap (such as conus and ntv1_can.dat for instance) the first found for a point will be used regardless of whether it is appropriate or not. So, for instance, \texttt{+nadgrids=ntv1_can.dat,conus} would result in the Canadian data being used for some areas in the northern United States even though the conus data is the approved data to use for the area. Careful selection of files and file order is necessary. In some cases border spanning datasets may need to be pre-segmented into Canadian and American points so they can be properly grid shifted.

- Additional detail on the grid shift being applied can be found by setting the PROJ_DEBUG environment variable to a value. This will result in output to stderr on what grid is used to shift points, the bounds of the various grids loaded and so forth.

5.4 Ellipsoids

An ellipsoid is a mathematically defined surface which approximates the \textit{geoid}: the surface of the Earth's gravity field, which is approximately the same as mean sea level.

![Ellipsoid with best fit to the local region](image1.png)

![Ellipsoid with global best fit to the geoid](image2.png)

![The geoid](image3.png)

A complete ellipsoid definition comprises a size (primary) and a shape (secondary) parameter.

Fig. 1: Global and local fitting of the ellipsoid

A complete ellipsoid definition comprises a size (primary) and a shape (secondary) parameter.
5.4.1 Ellipsoid size parameters

+R=<value>
  Radius of the sphere, \( R \).
+a=<value>
  Semi-major axis of the ellipsoid, \( a \).

5.4.2 Ellipsoid shape parameters

+rf=<value>
  Reverse flattening of the ellipsoid, \( 1/f \).
+f=<value>
  Flattening of the ellipsoid, \( f \).
+es=<value>
  Eccentricity squared, \( e^2 \).
+e=<value>
  Eccentricity, \( e \).
+b=<value>
  Semi-minor axis, \( b \).

The ellipsoid definition may be augmented with a spherification flag, turning the ellipsoid into a sphere with features defined by the ellipsoid.

5.4.3 Ellipsoid spherification parameters

+R_A
  A sphere with the same surface area as the ellipsoid.
+R_V
  A sphere with the same volume as the ellipsoid.
+R_C
  New in version 9.3.0.
  A sphere whose radius is the radius of the conformal sphere at \( \phi_0 \).
+R_a
  A sphere with \( R = (a + b)/2 \) (arithmetic mean).
+R_g
  A sphere with \( R = \sqrt{ab} \) (geometric mean).
+R_h
  A sphere with \( R = 2ab/(a + b) \) (harmonic mean).
+R_lat_a=<phi>
  A sphere with \( R \) being the arithmetic mean of the corresponding ellipsoid at latitude \( \phi \).
+R_lat_g=<phi>
  A sphere with \( R \) being the geometric mean of the corresponding ellipsoid at latitude \( \phi \).

If +R is given as size parameter, any shape and spherification parameters given are ignored.
5.4.4 Built-in ellipsoid definitions

The `+ellps=xxx` parameter provides both size and shape for a number of built-in ellipsoid definitions. Default is GRS80 if not given.

<table>
<thead>
<tr>
<th>ellps</th>
<th>Parameters</th>
<th>Datum name</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRS80</td>
<td>a=6378137.0 rf=298.257222101</td>
<td>GRS 1980 (IUGG, 1980)</td>
</tr>
<tr>
<td>airy</td>
<td>a=6377563.396 b=6356256.910</td>
<td>Airy 1830</td>
</tr>
<tr>
<td>bessel</td>
<td>a=6377397.155 rf=299.1528128</td>
<td>Bessel 1841</td>
</tr>
<tr>
<td>clerk66</td>
<td>a=6378206.4 b=6356583.8</td>
<td>Clarke 1866</td>
</tr>
<tr>
<td>intl</td>
<td>a=6378388.0 rf=298.3</td>
<td>International 1909 (Hayford)</td>
</tr>
<tr>
<td>WGS60</td>
<td>a=6378165.0 rf=298.3</td>
<td>WGS 60</td>
</tr>
<tr>
<td>WGS66</td>
<td>a=6378145.0 rf=298.25</td>
<td>WGS 66</td>
</tr>
<tr>
<td>WGS72</td>
<td>a=6378135.0 rf=298.26</td>
<td>WGS 72</td>
</tr>
<tr>
<td>WGS84</td>
<td>a=6378137.0 rf=298.257223563</td>
<td>WGS 84</td>
</tr>
<tr>
<td>sphere</td>
<td>a=6370997.0 b=6370997.0</td>
<td>Normal Sphere (r=6370997)</td>
</tr>
</tbody>
</table>

If size and shape are given as `+ellps=xxx`, later shape and size parameters are are taken into account as modifiers for the built-in ellipsoid definition.

While this may seem strange, it is in accordance with historical PROJ behavior. It can e.g. be used to define coordinates on the ellipsoid scaled to unit semimajor axis by specifying `+ellps=xxx +a=1`

5.4.5 Transformation examples

Spherical earth with radius 7000km:

```
+proj=latlon +R=7000000
```

Using the GRS80 ellipsoid:

```
+proj=latlon +ellps=GRS80
```

Expressing ellipsoid by semi-major axis and reverse flattening ($1/f$):

```
+proj=latlon +a=6378137.0 +rf=298.25
```

Spherical earth based on volume of ellipsoid

```
+proj=latlon +a=6378137.0 +rf=298.25 +R_V
```

5.5 Environment variables

PROJ can be controlled by setting environment variables. Most users will have a use for the `PROJ_DATA`.

On UNIX systems environment variables can be set for a shell-session with:

```
$ export VAR="some variable"
```

or it can be set for just one command line call:

```
```

5.5. Environment variables 67
$ VAR="some variable" ./cmd

Environment variables on UNIX are usually removed with the unset command:

$ unset VAR

On windows systems environment variables can be set in the command line with:

> set VAR="some variable"

VAR will be available for the entire session, unless it is unset. This is done by setting the variable with no content:

> set VAR=

**PROJ_DATA**

Prior to PROJ 9.1, this environment variable was called PROJ_LIB. This older name is still supported in PROJ 9.1 as a fallback, but support for it may be removed in future release.

The location of PROJ resource files.

Starting with PROJ 6, multiple directories can be specified. On Unix, they should be separated by the colon (:) character. On Windows, by the semi-colon (;) character.

PROJ is hardcoded to look for resource files in other locations as well, amongst those are the installation directory (usually share/proj under the PROJ installation root) and the current folder.

You can also set the location of the resource files using proj_context_set_search_paths() in the proj.h API header.

Changed in version 6.1.0: Starting with PROJ version 6.1.0, the paths set by proj_context_set_search_paths() will have priority over the PROJ_DATA to allow for multiple versions of PROJ resource files on your system without conflicting.

**PROJ_AUX_DB**

New in version 8.1.0.

To set the path to one or several auxiliary SQLite3 databases of structure identical to the main proj.db database and that can contain additional object (CRS, transformation, ...) definitions. If several paths are provided, they must be separated by the colon (:) character on Unix, and on Windows, by the semi-colon (;) character.

**PROJ_DEBUG**

Set the debug level of PROJ.

The following levels are available: - 0: no message. - 1: error messages only (default). - 2: same as 1, with debug messages. - 3: same as 2, with verbose messages. - 4: same as 3, with very verbose messages.

Starting with PROJ 9.3, ON can be used as an alias for 2, and OFF as an alias for 1.

**PROJ_NETWORK**

New in version 7.0.0.

If set to ON, enable the capability to use remote grids stored on CDN (Content Delivery Network) storage, when grids are not available locally. Alternatively, the proj_context_set_enable_network() function can be used.

**PROJ_NETWORK_ENDPOINT**

New in version 7.0.0.

Define the endpoint of the CDN storage. Normally defined through the proj.ini configuration file locale in PROJ_DATA. Alternatively, the proj_context_set_url_endpoint() function can be used.
PROJ_CURL_CA_BUNDLE

New in version 7.2.0.

Define a custom path to the CA Bundle file. This can be useful if curl and PROJ_NETWORK are enabled. Alternatively, the proj_curl_set_ca_bundle_path() function can be used.

5.6 Known differences between versions

Once in a while, a new version of PROJ causes changes in the existing behavior. In this section we track deliberate changes to PROJ that break from previous behavior. Most times that will be caused by a bug fix. Unfortunately, some bugs have existed for so long that their faulty behavior is relied upon by software that uses PROJ.

Behavioural changes caused by new bugs are not tracked here, as they should be fixed in later versions of PROJ.

5.6.1 Version 4.6.0

The default datum application behavior changed with the 4.6.0 release. PROJ will now only apply a datum shift if both the source and destination coordinate system have valid datum shift information.

The PROJ 4.6.0 Release Notes states

MAJOR: Rework pj_transform() to avoid applying ellipsoid to ellipsoid transformations as a datum shift when no datum info is available.

5.6.2 Version 5.0.0

5.6.2.1 Longitude wrapping when using custom central meridian

By default PROJ wraps output longitudes in the range -180 to 180. Previous to PROJ 5, this was handled incorrectly when a custom central meridian was set with +lon_0. This caused a change in sign on the resulting easting as seen below:

```
$ proj +proj=merc +lon_0=110 <<EOF
-70 0
290 0
EOF
20037508.34 0.00
-20037508.34 0.00
```

From PROJ 5 on onwards, the same input now results in same coordinates, as seen from the example below where PROJ 5 is used:

```
$ proj +proj=merc +lon_0=110 <<EOF
-70 0
290 0
EOF
-20037508.34 0.00
-20037508.34 0.00
```

The change is made on the basis that \( \lambda = 290^\circ \) is a full rotation of the circle larger than \( \lambda = -70^\circ \) and hence should return the same output for both.

Adding the +over flag to the projection definition provides the old behavior.

5.6. Known differences between versions
5.6.3 Version 6.0.0

5.6.3.1 Removal of proj_def.dat

Before PROJ 6, the proj_def.dat was used to provide general and per-projection parameters, when +no_defs was not specified. It has now been removed. In case, no ellipsoid or datum specification is provided in the PROJ string, the default ellipsoid is GRS80 (was WGS84 in previous PROJ versions).

5.6.3.2 Changes to deformation

Reversed order of operation

In the initial version of the deformation operation the time span between $t_{obs}$ and $t_e$ was determined by the expression

$$dt = t_e - t_{obs}$$

With version 6.0.0 this has been reversed in order to behave similarly to the Helmert operation, which determines time differences as

$$dt = t_{obs} - t_e$$

Effectively this means that the direction of the operation has been reversed, so that what in PROJ 5 was a forward operation is now an inverse operation and vice versa.

Pipelines written for PROJ 5 can be migrated to PROJ 6 by adding +inv to forward steps involving the deformation operation. Similarly +inv should be removed from inverse steps to be compatible with PROJ 6.

Removed +t_obs parameter

The +t_obs parameter was confusing for users since it effectively overwrote the observation time in input coordinates. To make it more clear what is the operation is doing, users are now required to directly specify the time span for which they wish to apply a given deformation. The parameter +dt has been added for that purpose. The new parameter is mutually exclusive with +t_epoch. +dt is used when deformation for a set amount of time is needed and +t_epoch is used (in conjunction with the observation time of the input coordinate) when deformation from a specific epoch to the observation time is needed.

5.6.4 Version 6.3.0

5.6.4.1 projinfo

Before PROJ 6.3.0, WKT1:GDAL was implicitly calling --boundcrs-to-wgs84, to add a T0WGS84[] node in some cases. This is no longer the case.
5.6.5 Version 7.0.0

5.6.5.1 proj

Removed -ld option from application, since it promoted use of deprecated parameters like +towgs and +datum.

5.6.5.2 cs2cs

Removed -ld option from application, since it promoted use of deprecated parameters like +towgs and +datum.

5.6.5.3 UTF-8 adoption

The value of all path, filenames passed to PROJ through function calls, PROJ strings or environment variables should be encoded in UTF-8.

5.7 Network capabilities

New in version 7.0.

PROJ 7.0 has introduced, per PROJ RFC 4: Remote access to grids and GeoTIFF grids, the capability to work with grid files that are not installed on the local machine where PROJ is executed.

This enables to transparently download the parts of grids that are needed to perform a coordinate transformation.

5.7.1 CDN of GeoTIFF grids

Files are accessed by default through a CDN (Content Delivery Network), accessible through https://cdn.proj.org, that contains Geodetic TIFF grids (GTG) datasets which are mirrored and managed by the https://github.com/OSGeo/PROJ-data/ GitHub project. Files in the CDN are designed to be used by PROJ 7 or later, but any software project wishing to use the CDN for shifting support are encouraged to participate in the project and leverage the CDN.

5.7.2 How to enable network capabilities?

This capability assumes that PROJ has been build against libcurl, and that the user authorizes network access.

Authorizing network access can be done in multiple ways:

- enabling / uncommenting the network = on line of proj.ini
- defining the PROJ_NETWORK environment variable to ON
- or using the proj_context_set_enable_network() with a enabled = TRUE value.

Note: Instead of using the libcurl implementation, an application using the PROJ API can supply its own network implementation through C function callbacks with proj_context_set_network_callbacks(). Enabling network use must still be done with one of the above mentioned method.
5.7.3 Setting endpoint

When this is enabled, and a grid is not found in the various locations where resource files are looked for, PROJ will then attempt at loading the file from a remote server, which defaults to https://cdn.proj.org in proj.ini. This location can be changed with the PROJ_NETWORK_ENDPOINT environment variable or with proj_context_set_url_endpoint().

5.7.4 Caching

To avoid repeated access to network, a local cache of downloaded chunks of grids is implemented as SQLite3 database, cache.db, stored in the PROJ user writable directory.

This local caching is enabled by default (can be changed in proj.ini or with proj_grid_cache_set_enable()). The default maximum size of the cache is 300 MB, which is more than half of the total size of grids available, at time of writing. This size can also be customized in proj.ini or with proj_grid_cache_set_max_size().

5.7.5 Download API

When on-demand loading of grid is not desirable, the PROJ API also offers the capability to download whole grids in the PROJ user writable directory by using the proj_is_download_needed() and proj_download_file() functions.

5.7.6 Download utility

projsync is a tool for downloading resource files.

5.7.7 Mirroring

If you are able, you are encouraged to mirror the grids via AWS S3 command line:

```
aws s3 sync s3://cdn.proj.org .
```

If direct S3 access is not possible, you can also use wget to locally mirror the data:

```
wget --mirror https://cdn.proj.org/
```

5.7.8 Acknowledgments

The s3://cdn.proj.org bucket is hosted by the Amazon Public Datasets program. CDN services are provided by the AWS Public Dataset team via CloudFront.
Bundled with PROJ comes a set of small command line utilities. The *proj* program is limited to converting between geographic and projection coordinates within one datum. The *cs2cs* program operates similarly, but allows translation between any pair of definable coordinate systems, including support for datum transformation. The *geod* program provides the ability to do geodesic (great circle) computations. *gie* is the program used for regression tests in PROJ. *cct*, a 4D equivalent to the *proj* program, performs transformation coordinate systems on a set of input points. *projinfo* performs queries for geodetic objects and coordinate operations. *projsync* is a tool for synchronizing PROJ datum and transformation support data.

### 6.1 cct

#### 6.1.1 Synopsis

```
cct [-cIostvz [args]] +opt[=arg] ... file ...
```

or

```
cct [-cIostvz [args]] {object_definition} file ...
```

Where `{object_definition}` is one of the possibilities accepted by `proj_create()`, provided it expresses a coordinate operation

- a proj-string,
- a WKT string,
- an object code (like "EPSG:1671" "urn:ogc:def:coordinateOperation:EPSG::1671"),
- an object name. e.g. "ITRF2014 to ETRF2014 (1)". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
- a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
- a PROJJSON string. The jsonschema is at [https://proj.org/schemas/v0.4/projjson.schema.json](https://proj.org/schemas/v0.4/projjson.schema.json)

New in version 8.0.0.

**Note:** Before version 8.0.0 only proj-strings could be used to instantiate operations in *cct*.

or

```
cct [-cIostvz [args]] {object_reference} file ...
```
where \{object\_reference\} is a filename preceded by the '@' character. The file referenced by the {object\_reference} must contain a valid {object\_definition}.

New in version 8.0.0.

### 6.1.2 Description

cct is a 4D equivalent to the proj projection program, performs transformation coordinate systems on a set of input points. The coordinate system transformation can include translation between projected and geographic coordinates as well as the application of datum shifts.

The following control parameters can appear in any order:

- **-c \(<x,y,z,t>\)**
  Specify input columns for (up to) 4 input parameters. Defaults to 1,2,3,4.

- **-d \(<n>\)**
  New in version 5.2.0.
  Specify the number of decimals to round to in the output.

- **-I**
  Do the inverse transformation.

- **-o \(<output\_file\_name>, --output=<output\_file\_name>\)**
  Specify the name of the output file.

- **-t \(<time>, --time=<time>\)**
  Specify a fixed observation time to be used for all input data.

- **-z \(<height>, --height=<height>\)**
  Specify a fixed observation height to be used for all input data.

- **-s \(<n>, --skip-lines=<n>\)**
  New in version 5.1.0.
  Skip the first \(n\) lines of input. This applies to any kind of input, whether it comes from STDIN, a file or interactive user input.

- **-v, --verbose**
  Write non-essential, but potentially useful, information to stderr. Repeat for additional information (-vv, -vvv, etc.)

- **--version**
  Print version number.

The +opt arguments are associated with coordinate operation parameters. Usage varies with operation.

cct is an acronym meaning Coordinate Conversion and Transformation.

The acronym refers to definitions given in the OGC 08-015r2/ISO-19111 standard “Geographical Information -- Spatial Referencing by Coordinates”, which defines two different classes of coordinate operations:

**Coordinate Conversions**, which are coordinate operations where input and output datum are identical (e.g. conversion from geographical to cartesian coordinates) and

**Coordinate Transformations**, which are coordinate operations where input and output datums differ (e.g. change of reference frame).
6.1.3 Use of remote grids

New in version 7.0.0.

If the PROJ_NETWORK environment variable is set to ON, cct will attempt to use remote grids stored on CDN (Content Delivery Network) storage, when they are not available locally.

More details are available in the Network capabilities section.

6.1.4 Examples

1. The operator specs describe the action to be performed by cct. So the following script

```bash
echo 12 55 0 0 | cct +proj=utm +zone=32 +ellps=GRS80
```

will transform the input geographic coordinates into UTM zone 32 coordinates. Hence, the command

```bash
echo 12 55 | cct -z0 -t0 +proj=utm +zone=32 +ellps=GRS80
```

Should give results comparable to the classic proj command

```bash
echo 12 55 | proj +proj=utm +zone=32 +ellps=GRS80
```

2. Convert geographical input to UTM zone 32 on the GRS80 ellipsoid:

```bash
cct +proj=utm +ellps=GRS80 +zone=32
```

3. Roundtrip accuracy check for the case above:

```bash
cct +proj=pipeline +proj=utm +ellps=GRS80 +zone=32 +step +step +inv
```

4. As (2) but specify input columns for longitude, latitude, height and time:

```bash
cct -c 5,2,1,4 +proj=utm +ellps=GRS80 +zone=32
```

5. As (2) but specify fixed height and time, hence needing only 2 cols in input:

```bash
cct -t 0 -z 0 +proj=utm +ellps=GRS80 +zone=32
```

6. Auxiliary data following the coordinate input is forwarded to the output stream:

```bash
$ echo 12 56 100 2018.0 auxiliary data | cct +proj=merc
1335833.8895 7522963.2411 100.0000 2018.0000 auxiliary data
```

7. Coordinate operation referenced through its code

```bash
$ echo 3541657.3778 948984.2343 5201383.5231 2020.5 | cct EPSG:8366
3541657.9112 948983.7503 5201383.2482 2020.5000
```

8. Coordinate operation referenced through its name

```bash
$ echo 3541657.3778 948984.2343 5201383.5231 2020.5 | cct "ITRF2014 to ETRF2014 (1)"
3541657.9112 948983.7503 5201383.2482 2020.5000
```
6.1.5 Background

cct also refers to Carl Christian Tscherning (1942--2014), professor of Geodesy at the University of Copenhagen, mentor and advisor for a generation of Danish geodesists, colleague and collaborator for two generations of global geodesists, Secretary General for the International Association of Geodesy, IAG (1995--2007), fellow of the American Geophysical Union (1991), recipient of the IAG Levallois Medal (2007), the European Geosciences Union Vening Meinesz Medal (2008), and of numerous other honours.

cct, or Christian, as he was known to most of us, was recognized for his good mood, his sharp wit, his tireless work, and his great commitment to the development of geodesy -- both through his scientific contributions, comprising more than 250 publications, and by his mentoring and teaching of the next generations of geodesists.

As Christian was an avid Fortran programmer, and a keen Unix connoisseur, he would have enjoyed to know that his initials would be used to name a modest Unix style transformation filter, hinting at the tireless aspect of his personality, which was certainly one of the reasons he accomplished so much, and meant so much to so many people.

Hence, in honour of cct (the geodesist) this is cct (the program).

6.2 cs2cs

6.2.1 Synopsis

cs2cs [-eEfIlrstvwW [args]]

[[--area <name_or_code>] | [--bbox <west_long,south_lat,east_long,north_lat>]]

[--authority <name>] [--3d]

[--accuracy <accuracy>] [--only-best[=yes|no]] [--no-ballpark]

{source_crs} {target_crs})

where {source_crs} or {target_crs} is one of the possibilities accepted by proj_create(), provided it expresses a CRS

- a proj-string,
- a WKT string,
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
- a CRS name and a coordinate epoch, separated with '@'. For example "ITRF2014@2025.0". (added in 9.2)
- a OGC URN combining references for compound coordinate reference systems (e.g. "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" or custom abbreviated syntax "EPSG:2393+5717"),
- a OGC URN combining references for projected or derived CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)". "urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ:ENh,coordinateOperation:EPSG::16031" (added in 6.2)
- a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
- a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.4/projjson.schema.json (added in 6.2)
• a compound CRS made from two object names separated with "+", e.g. "WGS 84 + EGM96 height"
(added in 7.1)

New in version 6.0.0.

Note: before 7.0.1, it was needed to add +to between {source_crs} and {target_crs} when adding a filename

6.2.2 Description

cs2cs performs transformation between the source and destination cartographic coordinate reference system on a set of input points. The coordinate reference system transformation can include translation between projected and geographic coordinates as well as the application of datum shifts.

The following control parameters can appear in any order:

-I
Method to specify inverse translation, convert from +to coordinate system to the primary coordinate system defined.

-t<a>
Where a specifies a character employed as the first character to denote a control line to be passed through without processing. This option applicable to ASCII input only. (# is the default value).

-d <n>
New in version 5.2.0.
Specify the number of decimals to round to in the output.

-e <string>
Where string is an arbitrary string to be output if an error is detected during data transformations. The default value is a three character string: *\t*.

-E
Causes the input coordinates to be copied to the output line prior to printing the converted values.

-l[-id]>
List projection identifiers that can be selected with +proj. cs2cs -l=id gives expanded description of projection id, e.g. cs2cs -l=merc.

-1p
List of all projection id that can be used with the +proj parameter. Equivalent to cs2cs -l.

-1P
Expanded description of all projections that can be used with the +proj parameter.

-1e
List of all ellipsoids that can be selected with the +ellps parameters.

-1u
List of all distance units that can be selected with the +units parameter.

-r
This option reverses the order of the first two expected inputs from that specified by the CRS to the opposite order. The third coordinate, typically height, remains third.
-s
This option reverses the order of the first two expected outputs from that specified by the CRS to the opposite order. The third coordinate, typically height, remains third.

-f <format>
Where format is a printf format string to control the form of the output values. For inverse projections, the output will be in degrees when this option is employed. If a format is specified for inverse projection the output data will be in decimal degrees. The default format is “%.2f” for forward projection and DMS for inverse.

-w<n>
Where n is the number of significant fractional digits to employ for seconds output (when the option is not specified, -w3 is assumed).

-W<n>
Where n is the number of significant fractional digits to employ for seconds output. When -W is employed the fields will be constant width with leading zeroes. Valid range: -W0 through -W8.

-v
Causes a listing of cartographic control parameters tested for and used by the program to be printed prior to input data.

--area <name_or_code>
New in version 8.0.0.
Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The area of interest can be specified either as a name (e.g "Denmark - onshore") or a AUTHORITY:CODE (EPSG:3237). This option is mutually exclusive with --bbox.

--bbox <west_long,south_lat,east_long,north_lat>
New in version 8.0.0.
Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The area of interest is specified as a bounding box with geographic coordinates, expressed in degrees in an unspecified geographic CRS. west_long and east_long should be in the [-180,180] range, and south_lat and north_lat in the [-90,90]. west_long is generally lower than east_long, except in the case where the area of interest crosses the antimeridian.

--only-best[=yes|=no]
New in version 9.2.0.
Force cs2cs to only use the best transformation known by PROJ. cs2cs will return an error if a grid needed for the best transformation is missing.
Best transformation should be understood as the most accurate transformation available among all relevant for the point to transform, and if all known grids required to perform such transformation were accessible (either locally or through network).
Note that the default value for this option can be also set with the PROJ_ONLY_BEST_DEFAULT environment variable, or with the only_best_default setting of proj.ini (--only-best when specified overrides such default value).

--no-ballpark
New in version 8.0.0.
Disallow any coordinate operation that is, or contains, a Ballpark transformation.
--accuracy <accuracy>
New in version 8.0.0.
Sets the minimum desired accuracy for candidate coordinate operations.

--authority <name>
New in version 8.0.0.
This option can be used to restrict the authority of coordinate operations looked up in the database. When not specified, coordinate operations from any authority will be searched, with the restrictions set in the authority_to_authority_preference database table related to the authority of the source/target CRS themselves. If authority is set to any, then coordinate operations from any authority will be searched if authority is a non-empty string different of any, then coordinate operations will be searched only in that authority namespace (e.g EPSG).

This option is mutually exclusive with --bbox.

--3d
New in version 9.1.
"Promote" 2D CRS(s) to their 3D version, where the vertical axis is the ellipsoidal height in metres, using the ellipsoid of the base geodetic CRS. Depending on PROJ versions and the exact nature of the CRS involved, especially before PROJ 9.1, a mix of 2D and 3D CRS could lead to 2D or 3D transformations. Starting with PROJ 9.1, both CRS need to be 3D for vertical transformation to possibly happen.

The cs2cs program requires two coordinate reference system (CRS) definitions. The first (or primary) is defined based on all projection parameters not appearing after the +to argument. All projection parameters appearing after the +to argument are considered the definition of the second CRS. If there is no second CRS defined, a geographic CRS based on the datum and ellipsoid of the source CRS is assumed. Note that the source and destination CRS can both of same or different nature (geographic, projected, compound CRS), or one of each and may have the same or different datums.

When using a WKT definition or a AUTHORITY:CODE, the axis order of the CRS will be enforced. So for example if using EPSG:4326, the first value expected (or returned) will be a latitude.

Internally, cs2cs uses the proj_create_crs_to_crs() function to compute the appropriate coordinate operation, so implementation details of this function directly impact the results returned by the program.

The environment parameter PROJ_DATA establishes the directory for resource files (database, datum shift grids, etc.)

One or more files (processed in left to right order) specify the source of data to be transformed. A - will specify the location of processing standard input. If no files are specified, the input is assumed to be from stdin. For input data the two data values must be in the first two white space separated fields and when both input and output are ASCII all trailing portions of the input line are appended to the output line.

Input geographic data (longitude and latitude) must be in DMS or decimal degrees format and input cartesian data must be in units consistent with the ellipsoid major axis or sphere radius units. Output geographic coordinates will normally be in DMS format (use -f %%.12f for decimal degrees with 12 decimal places), while projected (cartesian) coordinates will be in linear (meter, feet) units.
6.2.2.1 Use of remote grids

New in version 7.0.0.

If the PROJ_NETWORK environment variable is set to ON, cs2cs will attempt to use remote grids stored on CDN (Content Delivery Network) storage, when they are not available locally.

More details are available in the Network capabilities section.

6.2.3 Examples

6.2.3.1 Using PROJ strings

The following script

```
$ cs2cs +proj=latlong +datum=NAD83 +to +proj=utm +zone=10 +datum=NAD27 -r <<EOF
45°15'33.1" 111.5W
45d15.551666667N -111d30 '+45.2591944444 111d30'000w
EOF
```

will transform the input NAD83 geographic coordinates into NAD27 coordinates in the UTM projection with zone 10 selected. The geographic values of this example are equivalent and meant as examples of various forms of DMS input. The x-y output data will appear as three lines of:

```
1402285.93  5076292.58  0.00
```

To get those exact values, you have need to have all current grids installed (in that instance the NADCON5 us_noaa_nadcon5_nad27_nad83_1986_conus.tif grid) locally or use networking capabilities mentioned above.

To make sure you will get the optimal result, you may add --only-best. Assuming the above mentioned grid is not available,

```
$ echo -111.5 45.25919444444 | cs2cs --only-best +proj=latlong +datum=NAD83 +to +proj=utm+
˓→+zone=10 +datum=NAD27
```

would return:

```
Attempt to use coordinate operation axis order change (2D) + Inverse of NAD27 to NAD83␣˓→(7) + axis order change (2D) + UTM zone 10N failed. Grid us_noaa_nadcon5_nad27_nad83␣˓→1986_conus.tif is not available. Consult https://proj.org/resource_files.html for␣˓→guidance.
```

Otherwise, if you don’t have the grid available and you don’t specify --only-best:

```
$ echo -111.5 45.25919444444 | cs2cs --only-best +proj=latlong +datum=NAD83 +to +proj=utm+
˓→+zone=10 +datum=NAD27
```

would return:

```
1402224.57  5076275.42  0.00
```

which is the result when the NAD27 and NAD83 datums are dealt as identical, which is an approximation at a level of several tens of metres.
6.2.3.2 Using EPSG CRS codes

Transforming from WGS 84 latitude/longitude (in that order) to UTM Zone 31N/WGS 84

```
cs2cs EPSG:4326 EPSG:32631 <<EOF
45N 2E
EOF
```

outputs

```
421184.70 4983436.77 0.00
```

6.2.3.3 Using EPSG CRS names

Transforming from WGS 84 latitude/longitude (in that order) with EGM96 height to UTM Zone 31N/WGS 84 with WGS84 ellipsoidal height

```
echo 45 2 0 | cs2cs "WGS 84 + EGM96 height" "WGS 84 / UTM zone 31N" --3d
```

outputs

```
421184.70 4983436.77 50.69
```

Note: To get those exact values, you have need to have the EGM96 grid installed locally or use networking capabilities mentioned above.

6.3 geod

6.4 invgeod

6.4.1 Synopsis

```
geod +ellps=<ellipse> [-afIIptWw [args]] [-opt[=arg] ...] file ...
invgeod +ellps=<ellipse> [-afIIptWw [args]] [-opt[=arg] ...] file ...
```

6.4.2 Description

`geod` (direct) and `invgeod` (inverse) perform geodesic (Great Circle) computations for determining latitude, longitude and back azimuth of a terminus point given a initial point latitude, longitude, azimuth and distance (direct) or the forward and back azimuths and distance between an initial and terminus point latitudes and longitudes (inverse). The results are accurate to round off for \(|f| < 1/50\), where \(f\) is flattening.

`invgeod` may not be available on all platforms; in this case use `geod -I` instead.

The following command-line options can appear in any order:
-I
Specifies that the inverse geodesic computation is to be performed. May be used with execution of geod as an alternative to invgeod execution.

-a
Latitude and longitudes of the initial and terminal points, forward and back azimuths and distance are output.

-t<a>
Where a specifies a character employed as the first character to denote a control line to be passed through without processing.

-le
Gives a listing of all the ellipsoids that may be selected with the +ellps= option.

-lu
Gives a listing of all the units that may be selected with the +units= option. (Default units are meters.)

-f <format>
Where format is a printf format string to control the output form of the geographic coordinate values. The default mode is DMS.

-F <format>
Where format is a printf format string to control the output form of the distance value. The default mode is "%.3f".

-w<n>
Where n is the number of significant fractional digits to employ for seconds output (when the option is not specified, -w3 is assumed).

-W<n>
Where n is the number of significant fractional digits to employ for seconds output. When -W is employed the fields will be constant width with leading zeroes.

-p
This option causes the azimuthal values to be output as unsigned DMS numbers between 0 and 360 degrees. Also note -f.

The +opt command-line options are associated with geodetic parameters for specifying the ellipsoidal or sphere to use. The options are processed in left to right order from the command line. Reentry of an option is ignored with the first occurrence assumed to be the desired value.

One or more files (processed in left to right order) specify the source of data to be transformed. A - will specify the location of processing standard input. If no files are specified, the input is assumed to be from stdin.

For direct determinations input data must be in latitude, longitude, azimuth and distance order and output will be latitude, longitude and back azimuth of the terminus point. Latitude, longitude of the initial and terminus point are input for the inverse mode and respective forward and back azimuth from the initial and terminus points are output along with the distance between the points.

Input geographic coordinates (latitude and longitude) and azimuthal data must be in decimal degrees or DMS format and input distance data must be in units consistent with the ellipsoid major axis or sphere radius units. The latitude must lie in the range [-90d,90d]. Output geographic coordinates will be in DMS (if the -f switch is not employed) to 0.001" with trailing, zero-valued minute-second fields deleted. Output distance data will be in the same units as the ellipsoid or sphere radius.

The Earth's ellipsoidal figure may be selected in the same manner as program proj by using +ellps=, +a=, +es=, etc. geod may also be used to determine intermediate points along either a geodesic line between two points or along an arc of specified distance from a geographic point. In both cases an initial point must be specified with +lat_1=lat and
+lon_1=long parameters and either a terminus point +lat_2=lat and +lon_2=long or a distance and azimuth from the initial point with +S=distance and +A=azimuth must be specified.

If points along a geodesic are to be determined then either +n_S=integer specifying the number of intermediate points and/or +del_S=distance specifying the incremental distance between points must be specified.

To determine points along an arc equidistant from the initial point both +del_A=angle and +n_A=integer must be specified which determine the respective angular increments and number of points to be determined.

### 6.4.3 Examples

The following script determines the geodesic azimuths and distance in U.S. statute miles from Boston, MA, to Portland, OR:

```bash
geod +ellps=clrk66 -I +units=us-mi <<EOF
42d15'N 71d07'W 45d31'N 123d41'W
EOF
```

which gives the results:

```
-66d31'50.141" 75d39'13.083" 2587.504
```

where the first two values are the azimuth from Boston to Portland, the back azimuth from Portland to Boston followed by the distance.

An example of forward geodesic use is to use the Boston location and determine Portland’s location by azimuth and distance:

```bash
geod +ellps=clrk66 +units=us-mi <<EOF
42d15'N 71d07'W -66d31'50.141" 2587.504
EOF
```

which gives:

```
45d31'0.003"N 123d40'59.985"W 75d39'13.094"
```

Note: Lack of precision in the distance value compromises the precision of the Portland location.

### 6.4.4 Further reading

1. GeographicLib.
3. A geodesic bibliography.
6.5 gie

6.5.1 Synopsis

gie [ -hovql [ args ] ] file[s]

6.5.2 Description

gie, the Geospatial Integrity Investigation Environment, is a regression testing environment for the PROJ transformation library. Its primary design goal is to be able to perform regression testing of code that are a part of PROJ, while not requiring any other kind of tooling than the same C compiler already employed for compiling the library.

-h, --help
   Print usage information

-o <file>, --output <file>
   Specify output file name

-v, --verbose
   Verbose: Provide non-essential informational output. Repeat -v for more verbosity (e.g. -vv)

-q, --quiet
   Quiet: Opposite of verbose. In quiet mode not even errors are reported. Only interaction is through the return code (0 on success, non-zero indicates number of FAILED tests)

-l, --list
   List the PROJ internal system error codes

--version
   Print version number

Tests for gie are defined in simple text files. Usually having the extension .gie. Test for gie are written in the purpose-build command language for gie. The basic functionality of the gie command language is implemented through just 3 command verbs: operation, which defines the PROJ operation to test, accept, which defines the input coordinate to read, and expect, which defines the result to expect.

A sample test file for gie that uses the three above basic commands looks like:

```gie
--------------------------------------------
Test output of the UTM projection
--------------------------------------------
operation +proj=utm +zone=32 +ellps=GRS80
--------------------------------------------
accept 12 55
expect 691_875.632_14 6_098_907.825_05
</gie>
```

Parsing of a gie file starts at <gie> and ends when </gie> is reached. Anything before <gie> and after </gie> is not considered. Test cases are created by defining an operation which accept an input coordinate and expect an output coordinate.
Because gie tests are wrapped in the `<gie>/</gie>` tags it is also possible to add test cases to custom made `init files`. The tests will be ignore by PROJ when reading the init file with `+init` and `gie` ignores anything not wrapped in `<gie>/</gie>`.

`gie` tests are defined by a set of commands like `operation`, `accept` and `expect` in the example above. Together the commands make out the `gie` command language. Any line in a `gie` file that does not start with a command is ignored. In the example above it is seen how this can be used to add comments and styling to `gie` test files in order to make them more readable as well as documenting what the purpose of the various tests are.

Below the `gie command language` is explained in details.

### 6.5.3 Examples

1. Run all tests in a file with all debug information turned on

```
gie -vvvv corner-cases.gie
```

2. Run all tests in several files

```
gie foo bar
```

### 6.5.4 gie command language

**operation `<+args>`**

Define a PROJ operation to test. Example:

```
operation proj=utm zone=32 ellps=GRS80
  # test 4D function
  accept 12 55 0 0
  expect 691875.63214 6098907.82501 0 0
  # test 2D function
  accept 12 56
  expect 687071.4391 6210141.3267
```

**accept `<x y [z [t]]>`**

Define the input coordinate to read. Takes test coordinate. The coordinate can be defined by either 2, 3 or 4 values, where the first two values are the x- and y-components, the 3rd is the z-component and the 4th is the time component. The number of components in the coordinate determines which version of the operation is tested (2D, 3D or 4D). Many coordinates can be accepted for one `operation`. For each `accept` an accompanying `expect` is needed.

Note that `gie` accepts the underscore (_) as a thousands separator. It is not required (in fact, it is entirely ignored by the input routine), but it significantly improves the readability of the very long strings of numbers typically required in projected coordinates.

See `operation` for an example.

**expect `<x y [z [t]]>` | `<error code>`**

Define the expected coordinate that will be returned from accepted coordinate passed though an operation. The expected coordinate can be defined by either 2, 3 or 4 components, similarly to `accept`. Many coordinates can be expected for one `operation`. For each `expect` an accompanying `accept` is needed.

See `operation` for an example.
In addition to expecting a coordinate it is also possible to expect a PROJ error code in case an operation can’t be created. This is useful when testing that errors are caught and handled correctly. Below is an example of that tests that the pipeline operator fails correctly when a non-invertible pipeline is constructed.

```
operation  proj=pipeline step
proj=urm5 n=0.5 inv
expect    failure pjd_err_malformed_pipeline
```

See `gie --list` for a list of error codes that can be expected.

**tolerance** <tolerance>

The `tolerance` command controls how much accepted coordinates can deviate from the expected coordinate. This is handy to test that an operation meets a certain numerical tolerance threshold. Some operations are expected to be accurate within millimeters where others might only be accurate within a few meters. `tolerance` should

```
operation  proj=merc
# test coordinate as returned by `echo 12 55 | proj +proj=merc`
tolerance  1 cm
accept     12 55
expect     1335833.89 7326837.72

# test that the same coordinate with a 50 m false easting as determined
# by `echo 12 55 |proj +proj=merc +x_0=50` is still within a 100 m
# tolerance of the unaltered coordinate from proj=merc
tolerance  100 m
accept     12 55
expect     1335883.89 7326837.72
```

The default tolerance is 0.5 mm. See `proj -lu` for a list of possible units.

**roundtrip** <n> <tolerance>

Do a roundtrip test of an operation. `roundtrip` needs a `operation` and a `accept` command to function. The accepted coordinate is passed to the operation first in it's forward mode, then the output from the forward operation is passed back to the inverse operation. This procedure is done n times. If the resulting coordinate is within the set tolerance of the initial coordinate, the test is passed.

Example with the default 100 iterations and the default tolerance:

```
operation  proj=merc
accept     12 55
roundtrip
```

Example with count and default tolerance:

```
operation  proj=merc
accept     12 55
roundtrip  10000
```

Example with count and tolerance:

```
operation  proj=merc
accept     12 55
roundtrip  10000 5 mm
```
direction <direction>

The direction command specifies in which direction an operation is performed. This can either be forward or inverse. An example of this is seen below where it is tested that a symmetrical transformation pipeline returns the same results in both directions.

```plaintext
operation proj=pipeline zone=32 step
  proj=utm ellps=GRS80 step
  proj=utm ellps=GRS80 inv
tolerance 0.1 mm
accept 12 55 0 0
expect 12 55 0 0

# Now the inverse direction (still same result: the pipeline is symmetrical)
direction inverse
expect 12 55 0 0
```

The default direction is "forward".

ignore <error code>

This is especially useful in test cases that rely on a grid that is not guaranteed to be available. Below is an example of that situation.

```plaintext
operation proj=hgridshift +grids=nzgd2kgrid0005.gsb ellps=GRS80
tolerance 1 mm
ignore pjd_err_failed_to_load_grid
accept 172.99892181021551 -45.001620431954613
expect 173 -45
```

See gie --list for a list of error codes that can be ignored.

require_grid <grid_name>

Checks the availability of the grid <grid_name>. If it is not found, then all accept(expect) pairs until the next operation will be skipped. require_grid can be repeated several times to specify several grids whose presence is required.

echo <text>

Add user defined text to the output stream. See the example below.

```plaintext
<gie>
  echo ** Mercator projection tests **
  operation +proj=merc
  accept 0 0
  expect 0 0
</gie>
```

which returns

```
Reading file 'test.gie'
** Mercator projection test **

 total: 1 tests succeeded, 0 tests skipped, 0 tests failed.
```
skip

Skip any test after the first occurrence of skip. In the example below only the first test will be performed. The second test is skipped. This feature is mostly relevant for debugging when writing new test cases.

```<gie>
operation proj=merc
accept 0 0
expect 0 0
skip
accept 0 1
expect 0 110579.9
</gie>```

### 6.5.5 Strict mode

New in version 7.1.

A stricter variant of normal gie syntax can be used by wrapping gie commands between `<gie-strict>` and `</gie-strict>`. In strict mode, comment lines must start with a sharp character. Unknown commands will be considered as an error. A command can still be split on several lines, but intermediate lines must end with the space character followed by backslash to mark the continuation.

```<gie-strict>
# This is a comment. The following line with multiple repeated characters too
# A command on several lines must use " \ " continuation
operation proj=hgridshift +grids=nzgd2kgird0005.gsb \
  ellps=GRS80
tolerance 1 mm
ignore pjd_err_failed_to_load_grid
accept 172.999892181021551 -45.001620431954613
expect 173 -45
</gie-strict>```

### 6.5.6 Background

More importantly than being an acronym for "Geospatial Integrity Investigation Environment", gie were also the initials, user id, and USGS email address of Gerald Ian Evenden (1935--2016), the geospatial visionary, who, already in the 1980s, started what was to become the PROJ of today.

Gerald's clear vision was that map projections are just special functions. Some of them rather complex, most of them of two variables, but all of them just special functions, and not particularly more special than the \( \sin() \), \( \cos() \), \( \tan() \), and \( \text{hypot()} \) already available in the C standard library.

And hence, according to Gerald, they should not be particularly much harder to use, for a programmer, than the \( \sin() \)'s, \( \tan() \)'s and \( \text{hypot()} \)'s so readily available.

Gerald's ingenuity also showed in the implementation of the vision, where he devised a comprehensive, yet simple, system of key-value pairs for parameterising a map projection, and the highly flexible \( PJ \) struct, storing run-time compiled versions of those key-value pairs, hence making a map projection function call, \( \text{pj_fwd}(PJ, \text{point}) \), as easy as a traditional function call like \( \text{hypot}(x,y) \).

While today, we may have more formally well defined metadata systems (most prominent the OGC WKT2 representation), nothing comes close being as easily readable ("human compatible") as Gerald's key-value system. This system
in particular, and the PROJ system in general, was Gerald's great gift to anyone using and/or communicating about geodata.

It is only reasonable to name a program, keeping an eye on the integrity of the PROJ system, in honour of Gerald.

So in honour, and hopefully also in the spirit, of Gerald Ian Evenden (1935--2016), this is the Geospatial Integrity Investigation Environment.

### 6.6 proj

### 6.7 invproj

#### 6.7.1 Synopsis

```
proj [-bEfiIlmorsStTvVwW] [args][[+opt[=arg] ...] | {crs}] file ...
invproj [-bEfiIlmorsStTvVwW] [args][[+opt[=arg] ...] | {crs}] file ...
```

#### 6.7.2 Description

`proj` and `invproj` perform respective forward and inverse conversion of cartographic data to or from cartesian data with a wide range of selectable projection functions.

`invproj` may not be available on all platforms; in this case use `proj -I` instead.

The following control parameters can appear in any order

- `-b`
  Special option for binary coordinate data input and output through standard input and standard output. Data is assumed to be in system type double floating point words. This option is to be used when `proj` is a child process and allows bypassing formatting operations.

- `-d <n>`
  New in version 5.2.0: Specify the number of decimals to round to in the output.

- `-i`
  Selects binary input only (see `-b`).

- `-I`
  Alternate method to specify inverse projection. Redundant when used with `invproj`.

- `-o`
  Selects binary output only (see `-b`).

- `-t<a>`
  Where `a` specifies a character employed as the first character to denote a control line to be passed through without processing. This option applicable to ASCII input only. (# is the default value).

- `-e <string>`
  Where `string` is an arbitrary string to be output if an error is detected during data transformations. The default value is a three character string: **
  Note that if the `-b`, `-i` or `-o` options are employed, an error is returned as HUGE_VAL value for both return values.
-E
Causes the input coordinates to be copied to the output line prior to printing the converted values.

-1<[-id]>
List projection identifiers that can be selected with +proj. 
proj -1=id gives expanded description of projection id, e.g. 
proj -1=merc.

-lp
List of all projection id that can be used with the +proj parameter. Equivalent to 
proj -1.

-lP
Expanded description of all projections that can be used with the +proj parameter.

-le
List of all ellipsoids that can be selected with the +ellps parameters.

-lu
List of all distance units that can be selected with the +units parameter.

-r
This option reverses the order of the expected input from longitude-latitude or x-y to latitude-longitude or y-x.

-s
This option reverses the order of the output from x-y or longitude-latitude to y-x or latitude-longitude.

-S
Causes estimation of meridional and parallel scale factors, area scale factor and angular distortion, and maximum 
and minimum scale factors to be listed between <> for each input point. For conformal projections meridional 
and parallel scales factors will be equal and angular distortion zero. Equal area projections will have an area 
factor of 1.

-m <mult>
The cartesian data may be scaled by the mult parameter. When processing data in a forward projection mode the 
cartesian output values are multiplied by mult otherwise the input cartesian values are divided by mult before 
inverse projection. If the first two characters of mult are 1/ or 1: then the reciprocal value of mult is employed.

-f <format>
Where format is a printf format string to control the form of the output values. For inverse projections, the output 
will be in degrees when this option is employed. The default format is "%.2f" for forward projection and DMS 
for inverse.

-w<n>
Where n is the number of significant fractional digits to employ for seconds output (when the option is not 
specified, -w3 is assumed).

-W<n>
Where n is the number of significant fractional digits to employ for seconds output. When -W is employed the 
fields will be constant width with leading zeroes.

-v
Causes a listing of cartographic control parameters tested for and used by the program to be printed prior to input 
data.

-V
This option causes an expanded annotated listing of the characteristics of the projected point. -v is implied with 
this option.
The +opt run-line arguments are associated with cartographic parameters. Additional projection control parameters may be contained in two auxiliary control files: the first is optionally referenced with the +init=file:id and the second is always processed after the name of the projection has been established from either the run-line or the contents of +init file. The environment parameter PROJ_DATA establishes the default directory for a file reference without an absolute path. This is also used for supporting files like datum shift files.

New in version 9.3.0: {crs} is one of the possibilities accepted by ::proj_create(), provided it expresses a projected CRS, like a WKT string, an object code (like "EPSG:32632") a PROJJSON string, etc. The projection computed will be those of the map projection implied by the transformation from the base geographic CRS of the projected CRS to the projected CRS.

One or more files (processed in left to right order) specify the source of data to be converted. A - will specify the location of processing standard input. If no files are specified, the input is assumed to be from stdin. For ASCII input data the two data values must be in the first two white space separated fields and when both input and output are ASCII all trailing portions of the input line are appended to the output line.

Input geographic data (longitude and latitude) must be in DMS or decimal degrees format and input cartesian data must be in units consistent with the ellipsoid major axis or sphere radius units. Output geographic coordinates will be in DMS (if the -w switch is not employed) and precise to 0.001" with trailing, zero-valued minute-second fields deleted.

### 6.7.3 Example

The following script

```
proj +proj=utm +zone=12 -r <<EOF
  45d15'33.1" 111.5W
  45d15.551666667N -111d30.452591944444 111d30'000w
EOF
```

will perform UTM zone 12 forward projection. The default +ellps=GRS80 is used as no +ellps was specified. The geographic values of this example are equivalent and meant as examples of various forms of DMS input. The x-y output data will appear as three lines of:

```
460770.43  5011865.86
```

This other example

```
proj EPSG:6421 -V <<EOF
-120 35.8
EOF
```

Will perform the projection of the coordinates in "NAD83(2011)/California zone 4" (EPSG:6421) into its geographic system, "NAD83(2011)" showing the expanded annotated listing. The output will appear as:

```
#Lambert Conformal Conic
# Conic, SphEll
# lat_l= and lat_2= or lat_0, k_0=
# +proj=lcc +lat_0=35.3333333333333 +lon_0=-119 +lat_1=37.25 +lat_2=36
# +x_0=2000000 +y_0=500000 +ellps=GRS80
# Final Earth figure: ellipsoid
# Major axis (a): 6378137.000
# 1/flattening: 298.257222
# squared eccentricity: 0.006694380023
Longitude: 120dW [-120 ]
```

(continues on next page)
Latitude: 35d48'N [35.8]
Easting (x): 1909606.87
Northing (y): 552253.58
Meridian scale (h): 1.00004382 (0.004382 % error)
Parallel scale (k): 1.00004382 (0.004382 % error)
Areal scale (s): 1.00008765 (0.008765 % error)
Angular distortion (ω): 0.000
Meridian/Parallel angle: 90.00000
Convergence: -0d35'47.714" [-0.59658715]
Max-min (Tissot axis a-b) scale error: 1.00004 1.00004

6.8 projinfo

6.8.1 Synopsis

projinfo
[-o formats] [-k crs|operation|datum|ensemble|ellipsoid] [--summary] [-q]
[[-area name_or_code] | [-bbox west_long,south_lat,east_long,north_lat]]
[--spatial-test contains|intersects]
[--crs-extent-use none|both|intersection|smallest]
[--grid-check none|discard_missing|sort|known_available]
[--pivot-crs always|if_no_direct_transformation|never|[auth:code[,auth:code]*]]
[--show-superseded] [--hide-ballpark] [--accuracy {accuracy}]
[--allow-ellipsoidal-height-as-vertical-crs]
[--boundcrs-to-wgs84]
[--authority name]
[--main-db-path path] [--aux-db-path path]*
[--dump-db-structure]
[--identify] [--3d]
[--output-id AUTH:CODE]
[--c-ify] [--single-line]
--searchpaths | --remote-data|
--list-crs [list-crs-filter]|
--dump-db-structure [{object_definition} | {object_reference}]|
{object_definition} | {object_reference} | (-s {srs_def} -t {srs_def})

where {object_definition} or {srs_def} is one of the possibilities accepted by proj_create()

• a proj-string,
• a WKT string,
• an object code (like "EPSG:4326", "urn:ogc:def:crs:EPSG::4326",
  "urn:ogc:def:coordinateOperation:EPSG::1671"),
• an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not
guaranteed, heuristics are applied to determine the appropriate best match.
• a CRS name and a coordinate epoch, separated with '@'. For example "ITRF2014@2025.0". (added in 9.2)
• a OGC URN combining references for compound coordinate reference systems (e.g. "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" or custom abbreviated syntax "EPSG:2393+5717"),
• a OGC URN combining references for references for projected or derived CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)": "urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031" (added in 6.2)
• a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
• a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.4/projjson.schema.json (added in 6.2)
• a compound CRS made from two object names separated with "+". e.g. "WGS 84 + EGM96 height" (added in 7.1)

{object_reference} is a filename preceded by the '@' character. The file referenced by the {object_reference} must contain a valid {object_definition}.

6.8.2 Description

projinfo is a program that can query information on a geodetic object, coordinate reference system (CRS) or coordinate operation, when the -s and -t options are specified, and display it under different formats (PROJ string, WKT string or PROJJSON string).

It can also be used to query coordinate operations available between two CRS.

The program is named with some reference to the GDAL gdalsrsinfo utility that offers partly similar services.

The following control parameters can appear in any order:

-o formats

formats is a comma separated combination of: all, default, PROJ, WKT_ALL, WKT2:2015, WKT2:2019, WKT1:GDAL, WKT1:ESRI, PROJJSON, SQL.

Except all and default, other formats can be preceded by - to disable them.

**Note:** WKT2_2019 was previously called WKT2_2018.

**Note:** Before PROJ 6.3.0, WKT1:GDAL was implicitly calling --boundcrs-to-wgs84. This is no longer the case.

**Note:** When SQL is specified, --output-id must be specified.

-k crs|operation|datum|ensemble|ellipsoid

When used to query a single object with a AUTHORITY:CODE, determines the (k)ind of the object in case there are CRS, coordinate operations or ellipsoids with the same CODE. The default is crs.

--summary

When listing coordinate operations available between 2 CRS, return the result in a summary format, mentioning only the name of the coordinate operation, its accuracy and its area of use.
Note: only used for coordinate operation computation

-q
Turn on quiet mode. Quiet mode is only available for queries on single objects, and only one output format
is selected. In that mode, only the PROJ, WKT or PROJJSON string is displayed, without other introduction
output. The output is then potentially compatible of being piped in other utilities.

--area name_or_code
Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The
area of interest can be specified either as a name (e.g "Denmark - onshore") or a AUTHORITY:CODE (EPSG:3237)
This option is exclusive of --bbox.

Note: only used for coordinate operation computation

--bbox west_long,south_lat,east_long,north_lat
Specify an area of interest to restrict the results when researching coordinate operations between 2 CRS. The
area of interest is specified as a bounding box with geographic coordinates, expressed in degrees in a unspecified
geographic CRS. west_long and east_long should be in the [-180,180] range, and south_lat and north_lat in the
[-90,90]. west_long is generally lower than east_long, except in the case where the area of interest crosses the
antimeridian.

Note: only used for coordinate operation computation

--spatial-test contains|intersects
Specify how the area of use of coordinate operations found in the database are compared to the area of use
specified explicitly with --area or --bbox, or derived implicitly from the area of use of the source and target
CRS. By default, projinfo will only keep coordinate operations whose are of use is strictly within the area of
interest (contains strategy). If using the intersects strategy, the spatial test is relaxed, and any coordinate
operation whose area of use at least partly intersects the area of interest is listed.

Note: only used for coordinate operation computation

--crs-extent-use none|both|intersection|smallest
Specify which area of interest to consider when no explicit one is specified with --area or --bbox options. By
default (smallest strategy), the area of use of the source or target CRS will be looked, and the one that is the
smallest one in terms of area will be used as the area of interest. If using none, no area of interest is used. If using
both, only coordinate operations that relate (contain or intersect depending of the --spatial-test strategy)
to the area of use of both CRS are selected. If using intersection, the area of interest is the intersection of the
bounding box of the area of use of the source and target CRS

Note: only used for coordinate operation computation

--grid-check none|discard_missing|sort|known_available
Specify how the presence or absence of a horizontal or vertical shift grid required for a coordinate operation
affects the results returned when researching coordinate operations between 2 CRS. The default strategy is sort
(if PROJ_NETWORK is not defined). In that case, all candidate operations are returned, but the actual availability
of the grids is used to determine the sorting order. That is, if a coordinate operation involves using a grid that
is not available in the PROJ resource directories (determined by the PROJ_DATA environment variable), it will
be listed in the bottom of the results. The none strategy completely disables the checks of presence of grids and this returns the results as if all the grids where available. The discard_missing strategy discards results that involve grids not present in the PROJ resource directories. The known_available strategy discards results that involve grids not present in the PROJ resource directories and that are not known of the CDN. This is the default strategy is PROJ_NETWORK is set to OFF.

**Note:** only used for coordinate operation computation

--pivot-crs always|if_no_direct_transformation|never|{auth:code[,auth:code]*}

Determine if intermediate (pivot) CRS can be used when researching coordinate operation between 2 CRS. A typical example is the WGS84 pivot. By default, projinfo will consider any potential pivot if there is no direct transformation (if_no_direct_transformation). If using the never strategy, only direct transformations between the source and target CRS will be used. If using the always strategy, intermediate CRS will be considered even if there are direct transformations. It is also possible to restrict the pivot CRS to consider by specifying one or several CRS by their AUTHORITY:CODE.

**Note:** only used for coordinate operation computation

--show-superseded

When enabled, coordinate operations that are superseded by others will be listed. Note that supersession is not equivalent to deprecation: superseded operations are still considered valid although they have a better equivalent, whereas deprecated operations have been determined to be erroneous and are not considered at all.

**Note:** only used for coordinate operation computation

--hide-ballpark

New in version 7.1.

Hides any coordinate operation that is, or contains, a Ballpark transformation

**Note:** only used for coordinate operation computation

--accuracy {accuracy}

New in version 8.0.

Sets the minimum desired accuracy for returned coordinate operations.

**Note:** only used for coordinate operation computation

--allow-ellipsoidal-height-as-vertical-crs

New in version 8.0.

Allows exporting a geographic or projected 3D CRS as a compound CRS whose vertical CRS represents the ellipsoidal height.

**Note:** only used for CRS, and with WKT1:GDAL output format
--boundcrs-to-wgs84
When specified, this option researches a coordinate operation from the base geographic CRS of the single CRS, source or target CRS to the WGS84 geographic CRS, and if found, wraps those CRS into a BoundCRS object. This is mostly to be used for early-binding approaches.

--authority name
Specify the name of the authority into which to restrict looks up for objects, when specifying an object by name or when coordinate operations are computed. The default is to allow all authorities.

When used with SQL output, this restricts the authorities to which intermediate objects can belong to (the default is EPSG and PROJ). Note that the authority of the --output-id option will also be implicitly added.

--main-db-path path
Specify the name and path of the database to be used by projinfo. The default is proj.db in the PROJ resource directories.

--aux-db-path path
Specify the name and path of auxiliary databases, that are to be combined with the main database. Those auxiliary databases must have a table structure that is identical to the main database, but can be partly filled and their entries can refer to entries of the main database. The option may be repeated to specify several auxiliary databases.

--identify
When used with an object definition, this queries the PROJ database to find known objects, typically CRS, that are close or identical to the object. Each candidate object is associated with an approximate likelihood percentage. This is useful when used with a WKT string that lacks an EPSG identifier, such as ESRI WKT1. This might also be used with PROJ strings. For example, +proj=utm +zone=31 +datum=WGS84 +type=crs will be identified with a likelihood of 70% to EPSG:32631

--dump-db-structure
New in version 8.1.
Outputs the sequence of SQL statements to create a new empty valid auxiliary database. This option can be specified as the only switch of the utility. If also specifying a CRS object and the --output-id option, the definition of the object as SQL statements will be appended.

--list-crs [list-crs-filter]
New in version 8.1.
Outputs a list (authority name:code and CRS name) of the filtered CRSs from the database. If no filter is provided all authority names and types of non deprecated CRSs are dumped. list-crs-filter is a comma separated combination of: allow Deprecated, geodetic, geocentric, geographic, geographic_2d, geographic_3d, vertical, projected, compound. Affected by options --authority, --area, --bbox and --spatial-test
A visual alternative is the webpage CRS Explorer.

--3d
New in version 6.3.
"Promote" 2D CRS(s) to their 3D version, where the vertical axis is the ellipsoidal height in metres, using the ellipsoid of the base geodetic CRS. Depending on PROJ versions and the exact nature of the CRS involved, especially before PROJ 9.1, a mix of 2D and 3D CRS could lead to 2D or 3D transformations. Starting with PROJ 9.1, both CRS need to be 3D for vertical transformation to possibly happen.

--output-id=AUTH:NAME
New in version 8.1.
Identifier to assign to the object (for SQL output).
It is strongly recommended that new objects should not be added in common registries, such as EPSG, ESRI, IAU, etc. Users should use a custom authority name instead. If a new object should be added to the official EPSG registry, users are invited to follow the procedure explained at https://epsg.org/dataset-change-requests.html.

Combined with `--dump-db-structure`, users can create auxiliary databases, instead of directly modifying the main proj.db database. See the example how to export to an auxiliary database.

Those auxiliary databases can be specified through `proj_context_set_database_path()` or the `PROJ_AUX_DB` environment variable.

--c-ify
For developers only. Modify the string output of the utility so that it is easy to put those strings in C/C++ code

--single-line
Output PROJ, WKT or PROJJSON strings on a single line, instead of multiple indented lines by default.

--searchpaths
New in version 7.0.
Output the directories into which PROJ resources will be looked for (if not using C API such as `proj_context_set_search_paths()` that will override them.

--remote-data
New in version 7.0.
Display information regarding if Network capabilities is enabled, and the related URL.

### 6.8.3 Examples

1. Query the CRS object corresponding to EPSG:4326

```
projinfo EPSG:4326
```

Output:

```
PROJ.4 string:
+proj=longlat +datum=WGS84 +no_defs +type=crs

WKT2:2019 string:
GEOGCRS["WGS 84",
    DATUM["World Geodetic System 1984",
        ELLIPSOID["WGS 84",6378137,298.257223563,LENGTHUNIT["metre",1]]],
    PRIMEM["Greenwich",0],
    ANGLEUNIT["degree",0.0174532925199433]],
CS[ellipsoidal,2],
    AXIS["geodetic latitude (Lat)",north,
        ORDER[1],
        ANGLEUNIT["degree",0.0174532925199433]],
    AXIS["geodetic longitude (Lon)",east,
        ORDER[2],
        ANGLEUNIT["degree",0.0174532925199433]],
USAGE[
    SCOPE["unknown"],
    AREA["World"],
    (continues on next page)
```
2. List the coordinate operations between NAD27 (designed with its CRS name) and NAD83 (designed with its EPSG code 4269) within an area of interest

```
projinfo -s NAD27 -t EPSG:4269 --area "USA - Missouri"
```

Output:

```
DERIVED_FROM(EPSG):1241, NAD27 to NAD83 (1), 0.15 m, USA - CONUS including EEZ

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1 +step +proj=unitconvert \
  +xy_in=deg +xy_out=rad +step +proj=hgridshift +grids=conus \
  +step +proj=unitconvert +xy_in=rad +xy_out=deg +step +proj=axisswap +order=2,1

WKT2:2019 string:
COORDINATEOPERATION["NAD27 to NAD83 (1)",
SOURCECRS[
  GEOGCRS["NAD27",
  DATUM["North American Datum 1927",
    ELLIPSOID["Clarke 1866",6378206.4,294.978698213898,
      LENGTHUNIT["metre",1]],
    PRIMEM["Greenwich",0,
      ANGLEUNIT["degree",0.0174532925199433]],
    CS[ellipsoidal,2],
      AXIS["geodetic latitude (Lat)",north,
        ORDER[1],
        ANGLEUNIT["degree",0.0174532925199433]],
      AXIS["geodetic longitude (Lon)",east,
        ORDER[2],
        ANGLEUNIT["degree",0.0174532925199433]]],
  TARGETCRS[
    GEOGCRS["NAD83",
    DATUM["North American Datum 1983",
      ELLIPSOID["GRS 1980",6378137,298.257222101,
        LENGTHUNIT["metre",1]],
      PRIMEM["Greenwich",0,
        ANGLEUNIT["degree",0.0174532925199433]],
      CS[ellipsoidal,2],
        AXIS["geodetic latitude (Lat)",north,
          ORDER[1],
          ANGLEUNIT["degree",0.0174532925199433]],
        AXIS["geodetic longitude (Lon)",east,
          ORDER[2],
          ANGLEUNIT["degree",0.0174532925199433]]],
    METHOD["CTABLE2"],
    PARAMETERFILE["Latitude and longitude difference file","conus"],
    OPERATIONACCURACY[0.15],
    USAGE[
      SCOPE["unknown"],
```
3. Export an object as a PROJJSON string

```bash
projinfo GDA94 -o PROJJSON -q
```

Output:

```json
{
   "type": "GeographicCRS",
   "name": "GDA94",
   "datum": {
      "type": "GeodeticReferenceFrame",
      "name": "Geocentric Datum of Australia 1994",
      "ellipsoid": {
         "name": "GRS 1980",
         "semi_major_axis": 6378137,
         "inverse_flattening": 298.257222101
      }
   },
   "coordinate_system": {
      "subtype": "ellipsoidal",
      "axis": [
         {
            "name": "Geodetic latitude",
            "abbreviation": "Lat",
            "direction": "north",
            "unit": "degree"
         },
         {
            "name": "Geodetic longitude",
            "abbreviation": "Lon",
            "direction": "east",
            "unit": "degree"
         }
      ]
   },
   "area": "Australia - GDA",
   "bbox": {
      "south_latitude": -60.56,
      "west_longitude": 93.41,
      "north_latitude": -8.47,
      "east_longitude": 173.35
   },
   "id": {
      "authority": "EPSG",
      "code": 4283
   }
}
```

4. Exporting the SQL statements to insert a new CRS in an auxiliary database.
# Get the SQL statements for a custom CRS
projinfo "+proj=merc +lat_ts=5 +datum=WGS84 +type=crs +title=my_crs" --output-id HOBU:MY_CRS -o SQL -q > my_crs.sql
cat my_crs.sql

# Initialize an auxiliary database with the schema of the reference database
echo ".schema" | sqlite3 /path/to/proj.db | sqlite3 aux.db

# Append the content of the definition of HOBU:MY_CRS
sqlite3 aux.db < my_crs.db

# Check that everything works OK
projinfo --aux-db-path aux.db HOBU:MY_CRS

or more simply:

# Create an auxiliary database with the definition of a custom CRS.
projinfo "+proj=merc +lat_ts=5 +datum=WGS84 +type=crs +title=my_crs" --output-id HOBU:MY_CRS --dump-db-structure | sqlite3 aux.db

# Check that everything works OK
projinfo --aux-db-path aux.db HOBU:MY_CRS

Output:

```
INSERT INTO geodetic_crs VALUES('HOBU','GEODETIC_CRS_MY_CRS','unknown','','geographic 2D
  EPSG','6424','EPSG','6326',NULL,0);
INSERT INTO usage VALUES('HOBU','USAGE_GEODETIC_CRS_MY_CRS','geodetic_crs','HOBU',
  'GEODETIC_CRS_MY_CRS','PROJ','EXTENT_UNKNOWN','PROJ','SCOPE_UNKNOWN');
INSERT INTO conversion VALUES('HOBU','CONVERSION_MY_CRS','unknown','','EPSG','9805',
  'Mercator (variant B)','EPSG','8823','Latitude of 1st standard parallel',5,'EPSG','9122
  EPSG','8802','Longitude of natural origin',0,'EPSG','9122','EPSG','8806','False_e
  easting',0,'EPSG','9001','EPSG','8807','False northing',0,'EPSG','9001',NULL,NULL,NULL,
  NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,NULL,0);
INSERT INTO usage VALUES('HOBU','USAGE_CONVERSION_MY_CRS','conversion','HOBU',
  'CONVERSION_MY_CRS','PROJ','EXTENT_UNKNOWN','PROJ','SCOPE_UNKNOWN');
INSERT INTO projected_crs VALUES('HOBU','MY_CRS','my_crs','','EPSG','4400','HOBU',
  'GEODETIC_CRS_MY_CRS','HOBU','CONVERSION_MY_CRS',NULL,0);
INSERT INTO usage VALUES('HOBU','USAGE_PROJECTED_CRS_MY_CRS','projected_crs','HOBU','MY_
  => CRS','PROJ','EXTENT_UNKNOWN','PROJ','SCOPE_UNKNOWN');
```

PROJ.4 string:
+proj=merc +lat_ts=5 +lon_0=0 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs +type=crs

WK2:2019 string:
PROJCRS["my_crs",
  BASEGEOGCRS["unknown",
    ENSEMBLE["World Geodetic System 1984 ensemble",
      MEMBER["World Geodetic System 1984 (Transit)"]],
      MEMBER["World Geodetic System 1984 (G730)"]],
    MEMBER["World Geodetic System 1984 (G873)"]],
  MEMBER["World Geodetic System 1984 (G1150)"]],
  MEMBER["World Geodetic System 1984 (G1674)"],

(continues on next page)
MEMBER["World Geodetic System 1984 (G1762)",
ELLIPSOID["WGS 84",6378137,298.257223563,
LENGTHUNIT["metre",1]],
ENSEMBLEACCURACY[2,0],
PRIMEM["Greenwich",0,
ANGLEUNIT["degree",0.0174532925199433],
ID["HOBU","GEODETIC_CRS_MY_CRS"],
CONVERSION["unknown",
METHOD["Mercator (variant B)",
ID["EPSG",9805]],
PARAMETER["Latitude of 1st standard parallel",5,
ANGLEUNIT["degree",0.0174532925199433],
ID["EPSG",8823]],
PARAMETER["Longitude of natural origin",0,
ANGLEUNIT["degree",0.0174532925199433],
ID["EPSG",8802]],
PARAMETER["False easting",0,
LENGTHUNIT["metre",1],
ID["EPSG",8806]],
PARAMETER["False northing",0,
LENGTHUNIT["metre",1],
ID["EPSG",8807]]],
CS[Cartesian,2],
AXIS["(E)",east,
ORDER[1],
LENGTHUNIT["metre",1]],
AXIS["(N)",north,
ORDER[2],
LENGTHUNIT["metre",1]],
ID["HOBU","MY_CRS"]

5. Get the WKT representation of EPSG:25832 in the WKT1:GDAL output format and on a single line

```
projinfo -o WKT1:GDAL --single-line EPSG:25832
```

Output:

```
WKT1:GDAL string:
PROJCS["ETRS89 / UTM zone 32N",GEOGCS["ETRS89",DATUM["European Terrestrial Reference_
 System_1989",SPHEROID["GRS 1980",6378137,298.257222101,AUTHORITY["EPSG","7019"]],
 AUTHORITY["EPSG","6258"]],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532925199433,AUTHORITY["EPSG","9122"]],AUTHORITY["EPSG","4258"]],PROJECTION["Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",9],PARAMETER["scale_factor",0.9996],PARAMETER["false_easting",500000],PARAMETER["false_northing",0],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AXIS["Easting",EAST],AXIS["Northing",NORTH],AUTHORITY["EPSG","25832"]]
```
6.9 projsync

6.9.1 Synopsis

projsync
  [--endpoint URL]
  [--local-geojson-file FILENAME]
  ([--user-writable-directory] | [--system-directory] | [--target-dir DIRNAME])
  [--bbox west_long,south_lat,east_long,north_lat]
  [--spatial-test contains|intersects]
  [--source-id ID] [--area-of-use NAME]
  [--file NAME]
  [--all] [--exclude-world-coverage]
  [--quiet | --verbose] [--dry-run] [--list-files]
  [--no-version-filtering]

6.9.2 Description

projsync is a program that downloads remote resource files into a local directory. This is an alternative to downloading a proj-data-X.Y.Z archive file, or using the on-demand networking capabilities of PROJ.

The following control parameters can appear in any order:

--endpoint URL
  Defines the URL where to download the master files.geojson file and then the resource files. Defaults to the value set in proj.ini

--local-geojson-file FILENAME
  Defines the filename for the master GeoJSON files that references resources. Defaults to ${endpoint}/files.geojson

--user-writable-directory
  Specifies that resource files must be downloaded in the user writable directory. This is the default.

--system-directory
  Specifies that resource files must be downloaded in the ${installation_prefix}/share/proj directory. The user launching projsync should make sure it has writing rights in that directory.

--target-dir DIRNAME
  Directory into which resource files must be downloaded.

--bbox west_long,south_lat,east_long,north_lat
  Specify an area of interest to restrict the resources to download. The area of interest is specified as a bounding box with geographic coordinates, expressed in degrees in a unspecified geographic CRS. west_long and east_long should be in the [-180,180] range, and south_lat and north_lat in the [-90,90]. west_long is generally lower than east_long, except in the case where the area of interest crosses the antimeridian.

--spatial-test contains|intersects
  Specify how the extent of the resource files are compared to the area of use specified explicitly with --bbox. By default, any resource files whose extent intersects the value specified by --bbox will be selected. If using the contains strategy, only resource files whose extent is contained in the value specified by --bbox will be selected.
--source-id ID
   Restrict resource files to be downloaded to those whose source_id property contains the ID value. Specifying ? as ID will list all possible values.

--area-of-use NAME
   Restrict resource files to be downloaded to those whose area_of_use property contains the NAME value. Specifying ? as NAME will list all possible values.

--file NAME
   Restrict resource files to be downloaded to those whose name property contains the NAME value. Specifying ? as NAME will list all possible values.

--all
   Ask to download all files.

--exclude-world-coverage
   Exclude files which have world coverage.

-q / --quiet
   Quiet mode

--verbose
   New in version 8.1.
   Verbose mode (more than default)

--dry-run
   Simulate the behavior of the tool without downloading resource files.

--list-files
   List file names, with the source_id and area_of_use properties.

--no-version-filtering
   New in version 8.1.
   By default, projsync only downloads files that are compatible of the PROJ_DATA.VERSION metadata of proj.db, taking into account the version_added and version_removed properties of entries in files.geojson. When specifying this switch, all files referenced in files.geojson will be candidate (combined with other filters).

At least one of --list-files, --file, --source-id, --area-of-use, --bbox or --all must be specified.

Options --file, --source-id, --area-of-use and --bbox are combined with a AND logic.

### 6.9.3 Examples

1. Download all resource files

   projsync --all

2. Download resource files covering specified point and attributed to an agency

   projsync --source-id fr_ign --bbox 2,49,2,49
Coordinate operations in PROJ are divided into three groups: Projections, conversions and transformations. Projections are purely cartographic mappings of the sphere onto the plane. Technically projections are conversions (according to ISO standards), though in PROJ projections are distinguished from conversions. Conversions are coordinate operations that do not exert a change in reference frame. Operations that do exert a change in reference frame are called transformations.

7.1 Projections

Projections are coordinate operations that are technically conversions but since projections are so fundamental to PROJ we differentiate them from conversions.

Projections map the spherical 3D space to a flat 2D space.

7.1.1 Adams Hemisphere in a Square

<table>
<thead>
<tr>
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<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Global</td>
</tr>
<tr>
<td>Alias</td>
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</tr>
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<tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.1.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Fig. 1: proj-string: +proj=adams_hemi
Example: \( +\text{lon}_0=1.570796r \)

See *Projection Units* for more information.

\[ +R=\text{value} \]

Radius of the sphere, given in meters. If used in conjunction with \(+\text{ellps}\), \(+R\) takes precedence.

See *Ellipsoid size parameters* for more information.

\[ +\text{x}_0=\text{value} \]

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\[ +\text{y}_0=\text{value} \]

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.2 Adams World in a Square I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<tr>
<td>Alias</td>
<td>adams_ws1</td>
</tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.2.1 Parameters

**Note:** All parameters are optional.

\[ +\text{lon}_0=\text{value} \]

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \( +\text{lon}_0=1.570796r \)

See *Projection Units* for more information.
Fig. 2: proj-string: +proj=adams_ws1
PROJ coordinate transformation software library, Release 9.3.1

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.3 Adams World in a Square II

<table>
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</tr>
</thead>
<tbody>
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<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>adams_ws2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.3.1 Parameters

Note: All parameters are optional.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.
Fig. 3: proj-string: +proj=adams_ws2
\[ +x_0 = \text{<value>} \]
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

\[ +y_0 = \text{<value>} \]
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

### 7.1.4 Albers Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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<td>Alias</td>
<td>aea</td>
</tr>
<tr>
<td>Domain</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 4: proj-string: `+proj=aea +lat_1=29.5 +lat_2=42.5`
7.1.4.1 Options

Required

+lat_1=<value>
First standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_1=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_2=1.570796r
See Projection Units for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Default to 0.0.

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Default to 0.0.

7.1.5 Azimuthal Equidistant

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
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<td>Available forms</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.5.1 Options

Note: All options are optional for the Azimuthal Equidistant projection.

+guam
Use Guam ellipsoidal formulas. Only accurate near the Island of Guam ($\lambda \approx 144.5^\circ$, $\phi \approx 13.5^\circ$)

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

Default to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_0=1.570796r

See Projection Units for more information.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Default to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Fig. 5: proj-string: +proj=aeqd
Example: \( +\text{lon}_0=1.570796r \)

See *Projection Units* for more information.

\[ +x_0=\text{<value>} \]

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\[ +y_0=\text{<value>} \]

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\[ +\text{ellps}=\text{<value>} \]

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

\[ +R=\text{<value>} \]

Radius of the sphere, given in meters. If used in conjunction with \(+\text{ellps}\), \(+R\) takes precedence.

See *Ellipsoid size parameters* for more information.

### 7.1.6 Airy

The Airy projection is an azimuthal minimum error projection for the region within the small or great circle defined by an angular distance, \( \phi_b \), from the tangency point of the plane \((\lambda_0, \phi_0)\).

<table>
<thead>
<tr>
<th>Classification</th>
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</tr>
</thead>
<tbody>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td><strong>Output type</strong></td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.6.1 Options

\[ +\text{lat}_b \]

Angular distance from tangency point of the plane \((\lambda_0, \phi_0)\) where the error is kept at minimum.

*Defaults to 90° (suitable for hemispherical maps).*

\[ +\text{no_cut} \]

Do not cut at hemisphere limit
Fig. 6: proj-string: +proj=airy
+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_0=1.570796r
See Projection Units for more information.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

7.1.7 Aitoff

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1. Projections
### 7.1.7.1 Parameters

**Note:** All parameters for the projection are optional.

```plaintext
+lon_0=<value>
```

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See [Projection Units](#) for more information.

```plaintext
+R=<value>
```

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See [Ellipsoid size parameters](#) for more information.

```plaintext
+x_0=<value>
```

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

```plaintext
+y_0=<value>
```

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.8 Modified Stereographic of Alaska

<table>
<thead>
<tr>
<th>Classification</th>
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</tr>
</thead>
<tbody>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 8: proj-string: +proj=alsk
7.1.8.1 Options

**Note:** All options are optional for the projection.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

+ellps=<value>
The name of a built-in ellipsoid definition.
See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.
*Defaults to "GRS80".*

### 7.1.9 Apian Globular I

![Image](Fig. 9: proj-string: +proj=apian)

<table>
<thead>
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<th>Miscellaneous</th>
</tr>
</thead>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.9.1 Options

**Note:** All options are optional for the Apian Globular projection.

`+lat_0=<value>`

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_0=1.570796r`

See *Projection Units* for more information.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.10 August Epicycloidal

<table>
<thead>
<tr>
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<th>Miscellaneous</th>
</tr>
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<tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 10: proj-string: +proj=august

7.1.10.1 Parameters

**Note:** All options are optional for the August Epicycloidal projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
PROJ coordinate transformation software library, Release 9.3.1

See *Projection Units* for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

### 7.1.11 Bacon Globular

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Defined area</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 11: proj-string: +proj=bacon
7.1.11.1 Parameters

**Note:** All parameters are optional for the Bacon Globular projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

**Defaults** to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

**Defaults** to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

**Defaults** to 0.0.

7.1.12 Bertin 1953

New in version 6.0.0.

<table>
<thead>
<tr>
<th>Classification</th>
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<tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

The Bertin 1953 projection is intended for making world maps. Created by Jacques Bertin in 1953, this projection was the go-to choice of the French cartographic school when they wished to represent phenomena on a global scale. The projection was formulated in 2017 by Philippe Rivière for visionscarto.net.
7.1.12.1 Usage

The Bertin 1953 projection has no special options. Its rotation parameters are fixed. Here is an example of a forward projection with scale 1:

```
$ echo 122 47 | proj +proj=bertin1953 +R=1
0.72 0.73
```

7.1.12.2 Parameters

**Note:** All parameters for the projection are optional.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.12.3 Further reading


7.1.13 Bipolar conic of western hemisphere

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>bipc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 13: proj-string: `+proj=bipc +ns`
7.1.13.1 Parameters

Note: All options are optional for the Bipolar Conic projection.

+ns
Return non-skewed cartesian coordinates.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.14 Boggs Eumorphic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>boggs</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1. Projections
7.14.1 Parameters

Note: All options are optional for the Boggs Eumorphic projection.

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
   
   Defaults to 0.0.

   Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

   Example: +lon_0=1.570796r

   See Projection Units for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

   See Ellipsoid size parameters for more information.

+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

   Defaults to 0.0.

+y_0=<value>
   False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

   Defaults to 0.0.
7.1.15 Bonne (Werner lat_1=90)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>bonne</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Figure 15: proj-string: +proj=bonne +lat_1=10](image)

7.1.15.1 Parameters

**Required**

+lat_1=<value>

First standard parallel.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_1=1.570796r

See *Projection Units* for more information.
Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -1e for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.16 Cal Coop Ocean Fish Invest Lines/Stations

The CalCOFI pseudo-projection is the line and station coordinate system of the California Cooperative Oceanic Fisheries Investigations program, known as CalCOFI, for sampling offshore of the west coast of the U.S. and Mexico.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Only valid for the west coast of USA and Mexico</td>
</tr>
<tr>
<td>Alias</td>
<td>calcofi</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
The coordinate system is based on the Mercator projection with units rotated -30 degrees from the meridian so that they are oriented with the coastline of the Southern California Bight and Baja California. Lines increase from Northwest to Southeast. A unit of line is 12 nautical miles. Stations increase from inshore to offshore. A unit of station is equal to 4 nautical miles. The rotation point is located at line 80, station 60, or 34.15 degrees N, -121.15 degrees W, and is depicted by the red dot in the figure. By convention, the ellipsoid of Clarke 1866 is used to calculate CalCOFI coordinates.

The CalCOFI program is a joint research effort by the U.S. National Oceanic and Atmospheric Administration, University of California Scripps Oceanographic Institute, and California Department of Fish and Game. Surveys have been conducted for the CalCOFI program since 1951, creating one of the oldest and most scientifically valuable joint oceanographic and fisheries data sets in the world. The CalCOFI line and station coordinate system is now used by several other programs including the Investigaciones Mexicanas de la Corriente de California (IMECOCAL) program offshore of Baja California. The figure depicts some commonly sampled locations from line 40 to line 156.7 and offshore to station 120. Blue numbers indicate line (bottom) or station (left) numbers along the grid. Note that lines spaced at approximate 3-1/3 intervals are commonly sampled, e.g., lines 43.3 and 46.7.
7.1.16.1 Usage

A typical forward CalCOFI projection would be from long/lat coordinates on the Clark 1866 ellipsoid. For example:

```
proj +proj=calcofi +ellps=clrk66 -E <<EOF
-121.15 34.15
EOF
```

Output of the above command:

```
-121.15 34.15 80.00 60.00
```

The reverse projection from line/station coordinates to long/lat would be entered as:

```
proj +proj=calcofi +ellps=clrk66 -I -E -f "%.2f" <<EOF
80.0 60.0
EOF
```

Output of the above command:

```
80.0 60.0 -121.15 34.15
```

7.1.16.2 Options

Note: All options are optional for the CalCOFI projection.

+ellps=<value>

The name of a built-in ellipsoid definition.

See Ellipsoids for more information, or execute `proj -le` for a list of built-in ellipsoid names.

Defaults to "GRS80".

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

7.1.16.3 Mathematical definition

The algorithm used to make conversions is described in [EberHewitt1979] with a few corrections reported in [Weber-Moore2013].
7.1.16.4 Further reading

1. General information about the CalCOFI program
2. The Investigaciones Mexicanas de la Corriente de California

7.1.17 Cassini (Cassini-Soldner)

Although the Cassini projection has been largely replaced by the Transverse Mercator, it is still in limited use outside the United States and was one of the major topographic mapping projections until the early 20th century.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse and oblique cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, Spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the central meridian with long, narrow areas</td>
</tr>
<tr>
<td>Alias</td>
<td>cass</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.17.1 Usage

There has been little usage of the spherical version of the Cassini, but the ellipsoidal Cassini-Soldner version was adopted by the Ordnance Survey for the official survey of Great Britain during the second half of the 19th century [Steers1970]. Many of these maps were prepared at a scale of 1:2,500. The Cassini-Soldner was also used for the detailed mapping of many German states during the same period.

Example using EPSG 30200 (Trinidad 1903, units in clark's links):

```bash
$ echo 0.17453293 -1.08210414 | proj +proj=cass
+lat_0=10.44166666666667 +lon_0=-61.33333333333334
+x_0=86501.46392051999 +y_0=65379.0134283
+a=6378293.645208759 +b=6356617.987679838
+to_meter=0.201166195164
66644.94 82536.22
```

Example using EPSG 3068 (Soldner Berlin):

```bash
$ echo 13.5 52.4 | proj +proj=cass
+lat_0=52.41864827777778 +lon_0=13.62720366666667
+x_0=40000 +y_0=10000 +ellps=bessel
31343.05 7932.76
```
Fig. 16: proj-string: +proj=cass
7.1.17.2 Options

Note: All options are optional for the Cassini projection.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_0=1.570796r
See Projection Units for more information.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -1e for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.
+hyperbolic

Use modified form of the standard Cassini-Soldner projection known as the Hyperbolic Cassini-Soldner. This is used in particular for the "Vanua Levu Grid" of the island of Vanua Levu, Fiji (EPSG:3139)

7.1.17.3 Mathematical definition

The formulas describing the Cassini projection are taken from [Snyder1987].

$\phi_0$ is the latitude of origin that match the center of the map (default to 0). It can be set with +lat_0.

Spherical form

Forward projection

\[
x = \arcsin(\cos(\phi) \sin(\lambda))
\]
\[
y = \arctan 2(\tan(\phi), \cos(\lambda)) - \phi_0
\]

Inverse projection

\[
\phi = \arcsin(\sin(y + \phi_0) \cos(x))
\]
\[
\lambda = \arctan 2(\tan(x), \cos(y + \phi_0))
\]

Ellipsoidal form

Forward projection

\[
N = (1 - e^2 \sin^2(\phi))^{-1/2}
\]
\[
T = \tan^2(\phi)
\]
\[
A = \lambda \cos(\phi)
\]
\[
C = \frac{e^2}{1 - e^2 \cos^2(\phi)}
\]
\[
x = N(A - T A^3/6 - (8 - T + 8C)T A^5/120)
\]
\[
y = M(\phi) - M(\phi_0) + N \tan(\phi)(A^2/2 + (5 - T + 6C)A^4/24)
\]

and $M()$ is the meridional distance function.
Inverse projection

\[
\phi' = M^{-1}(M(\phi_0) + y)
\]

if \(\phi' = \frac{\pi}{2}\) then \(\phi = \phi'\) and \(\lambda = 0\)
otherwise evaluate \(T\) and \(N\) above using \(\phi'\) and

\[
R = (1 - e^2)(1 - e^2 \sin^2 \phi')^{-3/2}
\]
\[
D = x / N
\]
\[
\phi = \phi' - \tan \phi' \frac{N}{R} \left( \frac{D^2}{2} - (1 + 3T) \frac{D^4}{24} \right)
\]
\[
\lambda = \frac{(D - T \frac{D^3}{3} + (1 + 3T)T \frac{D^5}{15})}{\cos \phi'}
\]

7.1.17.4 Further reading

1. Wikipedia
2. EPSG, POSC literature pertaining to Coordinate Conversions and Transformations including Formulas

7.1.18 Central Cylindrical

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>cc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.18.1 Parameters

Note: All parameters are optional for the Central Cylindrical projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
Fig. 17: proj-string: +proj=cc
See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.19 Central Conic

New in version 5.0.0.

This is central (centrographic) projection on cone tangent at *option:lat_1* latitude, identical with conic() projection from *mapproj* R package.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the standard parallel</td>
</tr>
<tr>
<td>Alias</td>
<td>ccon</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 18: proj-string: `+proj=ccon +lat_1=52 +lon_0=19`
7.1.19.1 Usage

This simple projection is rarely used, as it is not equidistant, equal-area, nor conformal.

An example of usage (and the main reason to implement this projection in proj4) is the ATPOL geobotanical grid of Poland, developed in Institute of Botany, Jagiellonian University, Krakow, Poland in 1970s [Zajac1978]. The grid was originally handwritten on paper maps and further copied by hand. The projection (together with strange Earth radius) was chosen by its creators as the compromise fit to existing maps during first software development in DOS era. Many years later it is still de facto standard grid in Polish geobotanical research.

The ATPOL coordinates can be achieved with the following parameters:

```
+proj=ccon +lat_1=52 +lon_0=19 +axis=esu +a=6390000 +x_0=330000 +y_0=-350000
```

For more information see [Komsta2016] and [Verey2017].

7.1.19.2 Parameters

Required

+lat_1=<value>
Standard parallel of projection.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

 Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

 Defaults to 0.0.
7.1.19.3 Mathematical definition

Forward projection

\[ r = \cot \phi_0 - \tan(\phi - \phi_0) \]
\[ x = r \sin(\lambda \sin \phi_0) \]
\[ y = \cot \phi_0 - r \cos(\lambda \sin \phi_0) \]

Inverse projection

\[ y = \cot \phi_0 - y \]
\[ \phi = \phi_0 - \tan^{-1}(\sqrt{x^2 + y^2} - \cot \phi_0) \]
\[ \lambda = \frac{\tan^{-1}\sqrt{x^2 + y^2}}{\sin \phi_0} \]

7.1.19.4 Reference values

For ATPOL to WGS84 test, run the following script:

```bash
#!/bin/bash
cat << EOF | src/cs2cs -v -f "%E" +proj=ccon +lat_1=52 +lat_0=52 +lon_0=19 +axis=esu␣
˓→+a=6390000 +x_0=330000 +y_0=-350000 +to +proj=longlat
0 0
0 700000
700000 0
700000 700000
330000 350000
EOF
```

It should result with

```
1.384023E+01 5.503040E+01 0.000000E+00
1.451445E+01 4.877385E+01 0.000000E+00
2.478271E+01 5.500352E+01 0.000000E+00
2.402761E+01 4.875048E+01 0.000000E+00
1.900000E+01 5.200000E+01 0.000000E+00
```

Analogous script can be run for reverse test:

```bash
cat << EOF | src/cs2cs -v -f "%E" +proj=longlat +to +proj=ccon +lat_1=52 +lat_0=52 +lon_␣˓→0=19 +axis=esu +a=6390000 +x_0=330000 +y_0=-350000
24 55
15 49
24 49
19 52
EOF
```
and it should give the following results:

```
6.500315E+05  4.106162E+03  0.000000E+00
3.707419E+04  6.768262E+05  0.000000E+00
6.960534E+05  6.722946E+05  0.000000E+00
3.300000E+05  3.500000E+05  0.000000E+00
```

### 7.1.20 Equal Area Cylindrical

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>cea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 19: proj-string: `+proj=cea`

#### 7.1.20.1 Named specializations

The Equal Area Cylindrical projection is sometimes known under other names when it is instantiated with particular values of the `lat_ts` parameter:

<table>
<thead>
<tr>
<th>Name</th>
<th>lat_ts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lambert cylindrical equal-area</td>
<td>0</td>
</tr>
<tr>
<td>Behrmann</td>
<td>30</td>
</tr>
<tr>
<td>Gall-Peters</td>
<td>45</td>
</tr>
</tbody>
</table>
7.1.20.2 Parameters

Note: All parameters are optional for the Equal Area Cylindrical projection.

+lat_ts=<value>
Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +k_0 if both options are used together.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_ts=1.570796r
See Projection Units for more information.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+k_0=<value>
Scale factor. Determines scale factor used in the projection.
Defaults to 1.0.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
+\text{\texttt{y_0}}=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the
projection method). Always in meters.

\textit{Defaults to 0.0.}

\textbf{Note:} \texttt{lat\_ts} and \texttt{k\_0} are mutually exclusive. If \texttt{lat\_ts} is specified, it is equivalent to setting \texttt{k\_0} to \[
\frac{\cos \phi_t}{\sqrt{1-e^2 \sin^2 \phi_t}}
\]

### 7.1.20.3 Further reading

1. Wikipedia: Lambert cylindrical equal-area
2. Wikipedia: Gall-Peters
3. Wikipedia: Behrmann

### 7.1.21 Chamberlin Trimetric

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>chamb</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.21.1 Parameters

**Required**

\textbf{Note:} Control points should be oriented clockwise.

+\texttt{lat\_1}=<value>

Latitude of the first control point.

+\texttt{lon\_1}=<value>

Longitude of the first control point.

+\texttt{lat\_2}=<value>

Latitude of the second control point.

+\texttt{lon\_2}=<value>

Longitude of the second control point.

+\texttt{lat\_3}=<value>

Latitude of the third control point.

+\texttt{lon\_3}=<value>

Longitude of the third control point.
Fig. 20: proj-string: +proj=chamb +lat_1=10 +lon_1=30 +lon_2=40
Optional

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.22 Collignon

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>collg</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 21: proj-string: `+proj=collg`
7.1.22.1 Parameters

**Note:** All parameters are optional for the Collignon projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.23 Colombia Urban

New in version 7.2.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse ellipsoidal projection</td>
</tr>
<tr>
<td>Alias</td>
<td>col_urban</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

From [IOGP2018]:

The capital cites of each department in Colombia use an urban projection for large scale topographic mapping of the urban areas. It is based on a plane through the origin at an average height for the area, eliminating the need for corrections to engineering survey observations.

`proj-string: +proj=col_urban`
7.1.23.1 Parameters

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_0=1.570796r
See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
 Defaults to "GRS80".

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

+h_0=<value>
Projection plane origin height (in metre)
 Defaults to 0.0.
7.1.24 Compact Miller

The Compact Miller projection is a cylindrical map projection with a height-to-width ratio of 0.6:1.

See [Jenny2015]

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>comill</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 22: proj-string: +proj=comill

7.1.24.1 Parameters

Note: All parameters are optional for projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

7.1. Projections
PROJ coordinate transformation software library, Release 9.3.1

See Projection Units for more information.

\[ +R=\text{value} \]

Radius of the sphere, given in meters. If used in conjunction with +ellps, \(+R\) takes precedence.

See Ellipsoid size parameters for more information.

\[ +x_0=\text{value} \]

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

\[ +y_0=\text{value} \]

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

### 7.1.25 Craster Parabolic (Putnins P4)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>crast</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 23: proj-string: +proj=crast
7.1.25.1 Parameters

**Note:** All parameters are optional for the Craster Parabolic projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.26 Denoyer Semi-Elliptical

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>denoy</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.26.1 Parameters

Note: All parameters are optional for the Denoyer Semi-Elliptical projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
7.1.27 Eckert I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eck1</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 25: proj-string: `+proj=eck1`

\[
x = 2\sqrt{2/3\pi}\lambda(1 - |\phi|/\pi)
\]

\[
y = 2\sqrt{2/3\pi}\phi
\]

7.1.27.1 Parameters

**Note:** All parameters are optional for the Eckert I projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

7.1. Projections
+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

### 7.1.28 Eckert II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eck2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 26: proj-string: +proj=eck2
7.1.28.1 Parameters

Note: All parameters are optional for the Eckert II projection.

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
   Defaults to 0.0.

   Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
   Example: +lon_0=1.570796r
   See Projection Units for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   See Ellipsoid size parameters for more information.

+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
   Defaults to 0.0.

+y_0=<value>
   False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
   Defaults to 0.0.

7.1.29 Eckert III

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eck3</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1. Projections
7.1.29.1 Parameters

Note: All parameters are optional for the Eckert III projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.30 Eckert IV

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eck4</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 28: proj-string: +proj=eck4

\[ x = \lambda (1 + \cos \phi) / \sqrt{2 + \pi} \]

\[ y = 2\phi / \sqrt{2 + \pi} \]

7.1.30.1 Parameters

**Note:** All parameters are optional for the Eckert IV projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
PROJ coordinate transformation software library, Release 9.3.1

See *Projection Units* for more information.

\[ +R=<value> \]

Radius of the sphere, given in meters. If used in conjunction with \(+\text{ellps}\), \(+R\) takes precedence.

See *Ellipsoid size parameters* for more information.

\[ +x_0=<value> \]

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\[ +y_0=<value> \]

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.31 Eckert V

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eck5</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 29: proj-string: \(+\text{proj}=\text{eck5}\)
### 7.1.31.1 Parameters

**Note:** All parameters are optional for the Eckert V projection.

#### +lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

#### +R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

#### +x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

#### +y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.32 Eckert VI

<table>
<thead>
<tr>
<th><strong>Classification</strong></th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available forms</strong></td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td><strong>Defined area</strong></td>
<td>Global</td>
</tr>
<tr>
<td><strong>Alias</strong></td>
<td>eck6</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>2D</td>
</tr>
<tr>
<td><strong>Input type</strong></td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td><strong>Output type</strong></td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.32.1 Parameters

**Note:** All parameters are optional for the Eckert VI projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.33 Equidistant Cylindrical (Plate Carrée)

The simplest of all projections. Standard parallels ($0^\circ$ when omitted) may be specified that determine latitude of true scale ($k=h=1$).

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the equator</td>
</tr>
<tr>
<td>Alias</td>
<td>eqc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 31: proj-string: `+proj=eqc`

### 7.1.33.1 Usage

Because of the distortions introduced by this projection, it has little use in navigation or cadastral mapping and finds its main use in thematic mapping. In particular, the plate carrée has become a standard for global raster datasets, such as Celestia and NASA World Wind, because of the particularly simple relationship between the position of an image pixel on the map and its corresponding geographic location on Earth.

The following table gives special cases of the cylindrical equidistant projection.

<table>
<thead>
<tr>
<th>Projection Name</th>
<th>(lat ts=) $\phi_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain/Plane Chart</td>
<td>$0^\circ$</td>
</tr>
<tr>
<td>Simple Cylindrical</td>
<td>$0^\circ$</td>
</tr>
<tr>
<td>Plate Carrée</td>
<td>$0^\circ$</td>
</tr>
<tr>
<td>Ronald Miller—minimum overall scale distortion</td>
<td>$37^\circ30'$</td>
</tr>
<tr>
<td>E.Grafarend and A.Niermann</td>
<td>$42^\circ$</td>
</tr>
<tr>
<td>Ronald Miller—minimum continental scale distortion</td>
<td>$43^\circ30'$</td>
</tr>
<tr>
<td>Gall Isographic</td>
<td>$45^\circ$</td>
</tr>
<tr>
<td>Ronald Miller Equirectangular</td>
<td>$50^\circ30'$</td>
</tr>
<tr>
<td>E.Grafarend and A.Niermann minimum linear distortion</td>
<td>$61^\circ7'$</td>
</tr>
</tbody>
</table>
Example using EPSG 32662 (WGS84 Plate Carrée):

```
$ echo 2 47 | proj +proj=eqc +ellps=WGS84
222638.98 5232016.07
```

Example using Plate Carrée projection with true scale at latitude 30° and central meridian 90°W:

```
$ echo -88 30 | proj +proj=eqc +lat_ts=30 +lon_0=90w
192811.01 3339584.72
```

### 7.1.33.2 Parameters

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

**+lat_0=<value>**

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_0=1.570796r`

See *Projection Units* for more information.

**+lat_ts=<value>**

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over `+k_0` if both options are used together.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_ts=1.570796r`

See *Projection Units* for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

+ellps=<value>
The name of a built-in ellipsoid definition.
 See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
 Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
 See Ellipsoid size parameters for more information.

7.1.33.3 Mathematical definition
The formulas describing the Equidistant Cylindrical projection are all taken from [Snyder1987].

$\phi_{ts}$ is the latitude of true scale, that mean the standard parallels where the scale of the projection is true. It can be set with +lat_ts.

$\phi_0$ is the latitude of origin that match the center of the map. It can be set with +lat_0.

Forward projection

\[ x = \lambda \cos \phi_{ts} \]
\[ y = \phi - \phi_0 \]

Inverse projection

\[ \lambda = \frac{x}{\cos \phi_{ts}} \]
\[ \phi = y + \phi_0 \]
7.1.33.4 Further reading

1. Wikipedia
2. Wolfram Mathworld

7.1.34 Equidistant Conic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>eqdc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 32: proj-string: +proj=eqdc +lat_1=55 +lat_2=60
7.1.34.1 Parameters

Required

\texttt{+lat\_1}=<value>

First standard parallel.

\textit{Defaults to 0.0.}

\textbf{Note:} The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lat\_1=1.570796r}

See \textit{Projection Units} for more information.

\texttt{+lat\_2}=<value>

Second standard parallel.

\textit{Defaults to 0.0.}

\textbf{Note:} The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lat\_2=1.570796r}

See \textit{Projection Units} for more information.

Optional

\texttt{+lon\_0}=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

\textit{Defaults to 0.0.}

\textbf{Note:} The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lon\_0=1.570796r}

See \textit{Projection Units} for more information.

\texttt{+ellps}=<value>

The name of a built-in ellipsoid definition.

See \textit{Ellipsoids} for more information, or execute \texttt{proj -1e} for a list of built-in ellipsoid names.

\textit{Defaults to "GRS80".}

\texttt{+R}=<value>

Radius of the sphere, given in meters. If used in conjunction with \texttt{+ellps}, \texttt{+R} takes precedence.

See \textit{Ellipsoid size parameters} for more information.

7.1. Projections
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.35 Equal Earth

New in version 5.2.0.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudo cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>equearth</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

The Equal Earth projection is intended for making world maps. Equal Earth is a projection inspired by the Robinson projection, but unlike the Robinson projection retains the relative size of areas. The projection was designed in 2018 by Bojan Savric, Tom Patterson and Bernhard Jenny [Savric2018].
7.1.35.1 Usage

The Equal Earth projection has no special options. Here is an example of an forward projection on a sphere with a radius of 1 m:

```
$ echo 122 47 | proj +proj=eqearth +R=1
1.55 0.89
```

7.1.35.2 Parameters

**Note:** All parameters for the projection are optional.

```
+lon_0=<value>
```

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

```
+ellps=<value>
```

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

```
+R=<value>
```

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

```
+x_0=<value>
```

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

```
+y_0=<value>
```

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.35.3 Further reading


7.1.36 Euler

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>euler</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 34: proj-string: +proj=euler +lat_1=67 +lat_2=75
7.1.36.1 Parameters

Required

+lat_1=<value>
First standard parallel.

 sodom for 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow
the value with the "r" character.

Example: +lat_1=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.

 sodom for 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow
the value with the "r" character.

Example: +lat_2=1.570796r
See Projection Units for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning
depend on the projection method).

 sodom for 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow
the value with the "r" character.

Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection
method). Always in meters.

 sodom for 0.0.
+\texttt{y}_0=\texttt{<value>}

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.37 Fahey

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>fahey</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 35: proj-string: \texttt{+proj=fahey}
7.1.37.1 Parameters

Note: All parameters are optional for the Fahey projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.38 Foucaut

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>fouc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.38.1 Parameters

Note: All parameters are optional for the Foucaut projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
$+y_0=<\text{value}>$

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.39 Foucaut Sinusoidal

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>fouc_s</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 37: proj-string: `+proj=fouc_s`

The $y$-axis is based upon a weighted mean of the cylindrical equal-area and the sinusoidal projections. Parameter $n = n$ is the weighting factor where $0 \leq n \leq 1$.

$$
x = \lambda \cos \phi / (n + (1 - n) \cos \phi) \\
y = n\phi + (1 - n) \sin \phi
$$

For the inverse, the Newton-Raphson method can be used to determine $\phi$ from the equation for $y$ above. As $n \to 0$ and $\phi \to \pi/2$, convergence is slow but for $n = 0$, $\phi = \sin^3 y$

#### 7.1.39.1 Parameters

**Note:** All parameters are optional for the Foucaut Sinusoidal projection.

$+n=<\text{value}>$

Weighting factor. Value should be in the interval 0-1.

$+\text{lon}_0=<\text{value}>$

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.40 Gall (Gall Stereographic)

The Gall stereographic projection, presented by James Gall in 1855, is a cylindrical projection. It is neither equal-area nor conformal but instead tries to balance the distortion inherent in any projection.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse and oblique cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, Spherical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>gall</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.40.1 Usage

The need for a world map which avoids some of the scale exaggeration of the Mercator projection has led to some commonly used cylindrical modifications, as well as to other modifications which are not cylindrical. The earliest common cylindrical example was developed by James Gall of Edinburgh about 1855 (Gall, 1885, p. 119-123). His meridians are equally spaced, but the parallels are spaced at increasing intervals away from the Equator. The parallels of latitude are actually projected onto a cylinder wrapped about the sphere, but cutting it at lats. 45° N. and S., the point of perspective being a point on the Equator opposite the meridian being projected. It is used in several British atlases, but seldom in the United States. The Gall projection is neither conformal nor equal-area, but has a blend of various features. Unlike the Mercator, the Gall shows the poles as lines running across the top and bottom of the map.

Note: The Gall projection must not be confused with the Gall-Peters one, the later being a specialization of Equal Area Cylindrical.
Example using Gall Stereographic

$ echo 9 51 | proj +proj=gall
708432.90 5193386.36

Example using Gall Stereographic (Central meridian 90°W)

$ echo 9 51 | proj +proj=gall +lon_0=90w
7792761.91 5193386.36

7.1.40.2 Parameters

**Note:** All parameters for the projection are optional.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`
See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters. 

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+ellps=<value>

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute *proj -le* for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

### 7.1.40.3 Mathematical definition

The formulas describing the Gall Stereographic are all taken from [Snyder1993].

#### Spherical form

**Forward projection**

\[ x = \frac{\lambda}{\sqrt{2}} \]
\[ y = (1 + \frac{\sqrt{2}}{2}) \tan(\phi/2) \]

**Inverse projection**

\[ \phi = 2 \arctan\left( \frac{y}{1 + \frac{\sqrt{2}}{2}} \right) \]
\[ \lambda = \sqrt{2}x \]
7.1.40.4 Further reading

1. Wikipedia

7.1.41 Geostationary Satellite View

The geos projection pictures how a geostationary satellite scans the earth at regular scanning angle intervals.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>geos</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 39: proj-string: +proj=geos +h=35785831.0 +lon_0=-60 +sweep=y
7.1.41.1 Usage

In order to project using the geos projection you can do the following:

```
proj +proj=geos +h=35785831.0
```

The required argument `h` is the viewing point (satellite position) height above the earth.

The projection coordinate relate to the scanning angle by the following simple relation:

```
scanning_angle (radians) = projection_coordinate / h
```

**Note on sweep angle**

The viewing instrument on-board geostationary satellites described by this projection have a two-axis gimbal viewing geometry. This means that the different scanning positions are obtained by rotating the gimbal along a N/S axis (or `y`) and a E/W axis (or `x`).

In the image above, the outer-gimbal axis, or sweep-angle axis, is the N/S axis (`y`) while the inner-gimbal axis, or fixed-angle axis, is the E/W axis (`x`).
This example represents the scanning geometry of the Meteosat series satellite. However, the GOES satellite series use the opposite scanning geometry, with the E/W axis (x) as the sweep-angle axis, and the N/S (y) as the fixed-angle axis.

The sweep argument is used to tell PROJ which on which axis the outer-gimbal is rotating. The possible values are x or y, y being the default. Thus, the scanning geometry of the Meteosat series satellite should take sweep as y, and GOES should take sweep as x.

### 7.1.41.2 Parameters

**Required**

+\texttt{h}=<value>

Height of the view point above the Earth and must be in the same units as the radius of the sphere or semimajor axis of the ellipsoid.

**Optional**

+\texttt{sweep}=<axis>

Sweep angle axis of the viewing instrument. Valid options are "x" and "y".

*Defaults to "y".*

+\texttt{lon\_0}=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lon\_0=1.570796r}

See *Projection Units* for more information.

+\texttt{R}=<value>

Radius of the sphere, given in meters. If used in conjunction with \texttt{+ellps}, \texttt{+R} takes precedence.

See *Ellipsoid size parameters* for more information.

+\texttt{ellps}=<value>

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute \texttt{proj -le} for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

+\texttt{x\_0}=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.42 Ginsburg VIII (TsNIIGAiK)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>gins8</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 40: proj-string: +proj=gins8
7.1.42.1 Parameters

**Note:** All parameters are optional for the Ginsburg VIII projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See *Projection Units* for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

7.1.43 General Sinusoidal Series

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>gn_sinu</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 41: proj-string: +proj=gn_sinu +m=2 +n=3

7.1.43.1 Parameters

Note: All parameters are optional for the General Sinusoidal Series projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.44 Gnomonic

For a sphere, the gnomonic projection is a projection from the center of the sphere onto a plane tangent to the center point of the projection. This projects great circles to straight lines. For an ellipsoid, it is the limit of a doubly azimuthal projection, a projection where the azimuths from 2 points are preserved, as the two points merge into the center point. In this case, geodesics project to approximately straight lines (these are exactly straight if the geodesic includes the center point). For details, see Section 8 of [Karney2013].

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Within a quarter circumference of the center point</td>
</tr>
<tr>
<td>Alias</td>
<td>gnom</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 42: proj-string: +proj=gnom +lat_0=90 +lon_0=-50 +R=6.4e6
7.1.44.1 Parameters

Note: All parameters are optional for the Gnomonic projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_0=1.570796r
See Projection Units for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -1e for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.
7.1.45 Goode Homolosine

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>goode</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 43: proj-string: +proj=goode

7.1.45.1 Parameters

Note: All parameters are optional for the Goode Homolosine projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.
PROJ coordinate transformation software library, Release 9.3.1

+\(x_0\)=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+\(y_0\)=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.46 Modified Stereographic of 48 U.S.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>The lower 48 states of the U.S.</td>
</tr>
<tr>
<td>Alias</td>
<td>gs48</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Fig. 44: proj-string: +proj=gs48](image)

### 7.1.46.1 Parameters

**Note:** All parameters are optional for the projection.

+\(\text{ellps}=<\text{value}>\)

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.47 Modified Stereographic of the 50 U.S. states

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>All 50 states of the U.S.</td>
</tr>
<tr>
<td>Alias</td>
<td>gs50</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 45: proj-string: `+proj=gs50`
7.1.47.1 Parameters

Note: All parameters are optional for the projection.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
Defaults to "GRS80".

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.48 Guyou

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>guyou</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.48.1 Parameters

Note: All parameters are optional.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.
Fig. 46: proj-string: +proj=guyou
+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.49 Hammer & Eckert-Greifendorff

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>hammer</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 47: proj-string: +proj=hammer
7.1.49.1 Parameters

Note: All parameters are optional for the projection.

\+W=<value>
Set to 0.5 for the Hammer projection and 0.25 for the Eckert-Greifendorff projection. \+W has to be larger than zero.  
Defaults to 0.5.

\+M=<value>
\+M has to be larger than zero.  
Defaults to 1.0.

\+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).  
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.  
Example: \+lon_0=1.570796r
See Projection Units for more information.

\+R=<value>
Radius of the sphere, given in meters. If used in conjunction with \+ellps, \+R takes precedence.  
See Ellipsoid size parameters for more information.

\+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.  
Defaults to 0.0.

\+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.  
Defaults to 0.0.

7.1.50 Hatano Asymmetrical Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>hatano</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.50.1 Parameters

**Note:** All parameters for the projection are optional.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
Mathematical Definition

Forward

\[
\begin{align*}
  x &= 0.85\lambda \cos \theta \\
  y &= C_y \sin \theta \\
  P(\theta) &= 2\theta + \sin 2\theta - C_p \sin \phi \\
  P'(\theta) &= 2(1 + \cos 2\theta) \\
  \theta_0 &= 2\phi
\end{align*}
\]

<table>
<thead>
<tr>
<th>Condition</th>
<th>( C_y )</th>
<th>( C_p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>For ( \phi &gt; 0 )</td>
<td>1.75859</td>
<td>2.67595</td>
</tr>
<tr>
<td>For ( \phi &lt; 0 )</td>
<td>1.93052</td>
<td>2.43763</td>
</tr>
</tbody>
</table>

For \( \phi = 0 \), \( y \leftarrow 0 \), and \( x \leftarrow 0.85\lambda \).

Further reading

1. Compare Map Projections
2. Mathworks

7.1.51 HEALPix

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
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<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>healpix</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
The HEALPix projection is area preserving and can be used with a spherical and ellipsoidal model. It was initially developed for mapping cosmic background microwave radiation. The image below is the graphical representation of the mapping and consists of eight isomorphic triangular interrupted map graticules. The north and south contains four in which straight meridians converge polewards to a point and unequally spaced horizontal parallels. HEALPix provides a mapping in which points of equal latitude and equally spaced longitude are mapped to points of equal latitude and equally spaced longitude with the module of the polar interruptions.

7.1.51.1 Usage

To run a forward HEALPix projection on a unit sphere model, use the following command:

```
proj +proj=healpix +a=1 -E <<EOF
0 0
EOF
# output
0 0 0.00 0.00
```

7.1.51.2 Parameters

**Note:** All parameters for the projection are optional.

+rot_xy

New in version 6.3.0.

Rotation of the HEALPix map in degrees. A positive value results in a clockwise rotation around \((x_0, y_0)\) in the cartesian / projected coordinate space.

*Defaults to 0.0.*
+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+ellps=<value>
The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

### 7.1.51.3 Further reading

1. NASA
2. Wikipedia

### 7.1.52 rHEALPix

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>rhealpix</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
rHEALPix is a projection based on the HEALPix projection. The implementation of rHEALPix uses the HEALPix projection. The rHEALPix combines the peaks of the HEALPix into a square. The square's position can be translated and rotated across the x-axis which is a novel approach for the rHEALPix projection. The initial intention of using rHEALPix in the Spatial Computation Engine Science Collaboration Environment (SCENZGrid).

### 7.1.52.1 Usage

To run a rHEALPix projection (on the default GRS80 ellipsoidal model,) use the following command:

```
proj +proj=rhealpix +north_square=2 -E << EOF
> 55 12
> EOF
55 12   6115727.86   1553840.13
```

- **EOF**
- **55 12**
- **6115727.86**
- **1553840.13**
7.1.52.2 Parameters

**Note:** All parameters for the projection are optional.

+**north_square**

Position of the north polar square. Valid inputs are 0--3.

*Defaults to 0.0.*

+**south_square**

Position of the south polar square. Valid inputs are 0--3.

*Defaults to 0.0.*

+**lon_0**=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+**ellps**=<value>

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute *proj -le* for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

+**x_0**=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+**y_0**=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

7.1.52.3 Further reading

1. NASA
2. Wikipedia
### 7.1.53 Interrupted Goode Homolosine

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>igh</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

The Interrupted Goode Homolosine projection is an equal-area composite projection intended for making world maps. Low latitudes are comprised of six separate Sinusoidal projection regions, and high latitudes are comprised of six separate Mollweide (homolographic) projections. The transition latitude is at 40d 44’ 11.8”, where the Sinusoidal and Mollweide scales are equal. The lobes in this projection are chosen to emphasize the land area of the Earth. This projection was first published in 1925 by J. P. Goode [Goode1925].

#### 7.1.53.1 Parameters

**Note:** All parameters are optional for the projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.
+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

### 7.1.54 Interrupted Goode Homolosine (Oceanic View)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>igh_o</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

The Interrupted Goode Homolosine (Oceanic View) projection is an equal-area composite projection intended for making maps of the Earth's oceans. Low latitudes are comprised of six separate Sinusoidal projection regions, and high latitudes are comprised of six separate Mollweide (homolographic) projections. The transition latitude is at 40d 44' 11.8", where the Sinusoidal and Mollweide scales are equal. The lobes in this projection are chosen to emphasize the ocean area of the Earth when used with a central longitude of -160 degrees. This projection was first published in 1925 by J. P. Goode [Goode1925].
7.1.54.1 Parameters

**Note:** All parameters are optional for the projection. A value of \( +\text{lon}_0=-160 \) is recommended.

`+\text{lon}_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the ”r” character.

Example: `+\text{lon}_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with \(+\text{ellps}, +R\) takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

7.1.55 Interrupted Mollweide

The Interrupted Mollweide projection is an equal-area projection intended for making world maps. The projection is comprised of six separate Mollweide (homolographic) projection regions. In contrast with the Interrupted Goode Homolosine projection, there is no transition latitude, which gives greater continuity at the cost of greater equatorial distortion. The lobes in this projection are chosen to emphasize the land area of the Earth. This projection was first published in 1919 by J. P. Goode [Goode1919].
7.1.55.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
### 7.1.56 Interrupted Mollweide (Oceanic View)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>imoll_o</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

The Interrupted Mollweide (Oceanic View) projection is an equal-area projection intended for making maps of the Earth's oceans. The projection is comprised of six separate Mollweide (homolographic) projection regions. In contrast with the Interrupted Goode Homolosine (Oceanic View) projection, there is no transition latitude, which gives greater continuity at the cost of greater equatorial distortion. The lobes in this projection are chosen to emphasize the ocean area of the Earth when used with a central longitude of -160 degrees. This projection was first published in 1919 by J. P. Goode [Goode1919].

#### 7.1.56.1 Parameters

**Note:** All parameters are optional for the projection. A value of +lon_0=-160 is recommended.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
PROJ coordinate transformation software library, Release 9.3.1

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters. 

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters. 

*Defaults to 0.0.*

### 7.1.57 International Map of the World Polyconic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudoconical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>imw_p</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 53: proj-string: +proj=imw_p +lat_1=30 +lat_2=-40
7.1.57.1 Parameters

Required

+lat_1=<value>
First standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_1=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_2=1.570796r
See Projection Units for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters. 

_Defaults to 0.0._

### 7.1.58 Icosahedral Snyder Equal Area

Snyder’s Icosahedral Equal Area map projections on polyhedral globes for the dodecahedron and truncated icosahedron offer relatively low scale and angular distortion. The equations involved are relatively straight-forward, and for certain instructional tools and databases, the projections are useful for world maps. The interruptions remain a disadvantage, as with any low-error projection system applied to the entire globe [Snyder1992].

<table>
<thead>
<tr>
<th>Classification</th>
<th>Polyhedral, equal area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward, spherical</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>isea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

_Snyder_’s Figure 12 for pole orientation [Snyder1992].

---

**Fig. 54: proj-string: +proj=isea**

### 7.1.58.1 Parameters

**Note:** All parameters are optional for the projection.

_+orient=<string>_  
Can be set to either _isea_ or _pole_. See Snyder’s Figure 12 for pole orientation [Snyder1992].

_Defaults to isea_
+azi=<value>
    Azimuth.
    Defaults to 0.0

+aperture=<value>
    Defaults to 3.0

+resolution=<value>
    Defaults to 4.0

+mode=<string>
    Can be either plane, di, dd or hex.
    Defaults to plane

+lon_0=<value>
    Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
    Defaults to 0.0.

    **Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

    Example: +lon_0=1.570796r

    See *Projection Units* for more information.

+lat_0=<value>
    Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
    Defaults to 0.0.

    **Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

    Example: +lat_0=1.570796r

    See *Projection Units* for more information.

+R=<value>
    Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

    See *Ellipsoid size parameters* for more information.

+x_0=<value>
    False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
    Defaults to 0.0.

+y_0=<value>
    False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
    Defaults to 0.0.
7.1.59 Kavrayskiy V

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>kav5</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 55: proj-string: +proj=kav5

Note: This projection name may also be transliterated as Kavraisky V.

Created by Soviet cartographer Vladimir V. Kavrayskiy in 1933 [Snyder1993].

7.1.59.1 Parameters

Note: All parameters are optional for the Kavrayskiy V projection.

+lons_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

7.1. Projections
+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.60 Kavrayskiy VII

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>kav7</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Note: This projection name may also be transliterated as Kavraisky VII.

Created by Soviet cartographer Vladimir V. Kavrayskiy in 1939 [Snyder1993].

Fig. 56: proj-string: +proj=kav7
7.1.60.1 Parameters

Note: All parameters are optional for the Kavrayskiy VII projection.

+lon_0=<value>
  Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
  Defaults to 0.0.

  Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
  Example: +lon_0=1.570796r
  See Projection Units for more information.

+R=<value>
  Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
  See Ellipsoid size parameters for more information.

+x_0=<value>
  False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.

+y_0=<value>
  False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.

7.1.61 Krovak

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but more accurate around Czechoslovakia</td>
</tr>
<tr>
<td>Alias</td>
<td>krovak</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 57: proj-string: +proj=krovak
7.1.61.1 Parameters

Note: All parameters are optional for the Krovak projection.
The latitude of pseudo standard parallel is hardcoded to 78.5° and the ellipsoid to Bessel.

+czech
Reverse the sign of the output coordinates, as is tradition in the Czech Republic.

+lon_0=<value>
Longitude of projection center.
Defaults to 24°50' (24.8333333333333)

+lat_0=<value>
Latitude of projection center.
Defaults to 49.5

+k_0=<value>
Scale factor. Determines scale factor used in the projection.
Defaults to 0.9999

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.62 Laborde

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but more accurate around Madagascar</td>
</tr>
<tr>
<td>Alias</td>
<td>labrd</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1. Projections
Fig. 58: proj-string: +proj=labrd +lon_0=40 +lat_0=-10
7.1.62.1 Parameters

Required

+lat_0=<value>
Latin of projection center. Must not be zero.

Optional

+azi=<value>
Azimuth of the central line.
Defaults to 0.0

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.63 Lambert Azimuthal Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>laea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 59: proj-string: +proj=laea
7.1.63.1 Parameters

**Note:** All parameters are optional.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
 Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See *Projection Units* for more information.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
 Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_0=1.570796r
See *Projection Units* for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.
 Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.
7.1.64 Lagrange

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>lagrng</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 60: proj-string: +proj=lagrng
7.1.64.1 Parameters

**Note:** All parameters are optional for the projection.

+\(W\)=<value>

The factor +\(W\) is the ratio of the difference in longitude from the central meridian to the ascending circle meridian to 90. +\(W\) must be a positive value.

*Defaults to 2.0*

+\(\text{lon}_0\)=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +\(\text{lon}_0=1.570796r\)

See *Projection Units* for more information.

+\(\text{lat}_1\)=<value>

First standard parallel.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +\(\text{lat}_1=1.570796r\)

See *Projection Units* for more information.

+\(\text{ellps}\)=<value>

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute *proj -le* for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

+\(R\)=<value>

Radius of the sphere, given in meters. If used in conjunction with +\(\text{ellps}\), +\(R\) takes precedence.

See *Ellipsoid size parameters* for more information.

+\(x_0\)=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.65 Larrivee

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>larr</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 61: proj-string: +proj=larr
### 7.1.65.1 Parameters

**Note:** All parameters are optional for the Larrivee projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.66 Laskowski

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>lask</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.66.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.67 Lambert Conformal Conic

A Lambert Conformal Conic projection (LCC) is a conic map projection used for aeronautical charts, portions of the State Plane Coordinate System, and many national and regional mapping systems. It is one of seven projections introduced by Johann Heinrich Lambert in 1772.

It has several different forms: with one and two standard parallels (referred to as 1SP and 2SP in EPSG guidance notes). Additionally we provide "2SP Michigan" form which is very similar to normal 2SP, but with a scaling factor on the ellipsoid (given as \( k_0 \) parameter). It is implemented as per EPSG Guidance Note 7-2 (version 54, August 2018, page 25). It is used in a few systems in the EPSG database which justifies adding this otherwise non-standard projection.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal conic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal. One or two standard parallels (1SP and 2SP). &quot;LCC 2SP Michigan&quot; form can be used by setting ( +k_0 ) parameter to specify ellipsoid scale.</td>
</tr>
<tr>
<td>Defined area</td>
<td>Best for regions predominantly east–west in extent and located in the middle north or south latitudes.</td>
</tr>
<tr>
<td>Alias</td>
<td>lcc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 63: proj-string: \(+proj=lcc +lon_0=-90 +lat_1=33 +lat_2=45\)
7.1.67.1 Parameters

Required

+lat_1=<value>
First standard parallel.
 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_1=1.570796r
See Projection Units for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_0=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.
 Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_2=1.570796r
See *Projection Units* for more information.

+ellps=<value>

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+k_0=<value>

This parameter can represent two different values depending on the form of the projection. In LCC 1SP it determines the scale factor at natural origin. In LCC 2SP Michigan it determines the ellipsoid scale factor.

*Defaults to 1.0.*

7.1.6.7 Further reading

1. Wikipedia
2. Wolfram Mathworld
3. John P. Snyder "Map projections: A working manual" (pp. 104-110)
4. ArcGIS documentation on "Lambert Conformal Conic"
5. EPSG Guidance Note 7-2 (version 54, August 2018, page 25)

7.1.68 Lambert Conformal Conic Alternative

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
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<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>lcca</td>
</tr>
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<td>Domain</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1. Projections
7.1.68.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_0=1.570796r

See Projection Units for more information.
+ellps=<value>
The name of a built-in ellipsoid definition.

See Ellipsoids for more information, or execute proj -1e for a list of built-in ellipsoid names.

Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.69 Lambert Equal Area Conic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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</tr>
<tr>
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<tr>
<td>Alias</td>
<td>leac</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 65: proj-string: +proj=leac
7.1.69.1 Parameters

Note: All parameters are optional for the Lambert Equal Area Conic projection.

+lat_1=<value>
First standard parallel.

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_1=1.570796r

See Projection Units for more information.

+south
Sets the second standard parallel to 90°S. When the flag is off the second standard parallel is set to 90°N.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.

See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.

Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.70 Lee Oblated Stereographic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.70.1 Parameters

**Note:** All parameters are optional for the projection.

`+ellps=<value>`

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

7.1.71 Loximuthal

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 66: proj-string: +proj=lee_os
7.1.71.1 Parameters

**Note:** All parameters are optional for the Loximuthal projection.

`+lat_1=<value>`

First standard parallel.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_1=1.570796r`

See *Projection Units* for more information.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

 Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

 Defaults to 0.0.

### 7.1.72 Space oblique for LANDSAT

Space oblique for LANDSAT is a specialization of *Space Oblique Mercator* which specifies the appropriate ascending longitude, inclination angle, and orbital period for Landsat satellites, based on their satellite designation / id and path number.

"Paths" are the repeating ground tracks that are traced by sun-synchronous satellites like those of the Landsat program.

<table>
<thead>
<tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 68: proj-string: +proj=lsat +lat_1=-60 +lat_2=60 +lsat=2 +path=2
7.1.72.1 Parameters

Required

+lsat=<value>
Landsat satellite used for the projection. Value between 1 and 5.

+path=<value>
Selected path of satellite. Value between 1 and 253 when +lsat is set to 1, 2 or 3, otherwise valid input is between 1 and 233.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.

See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.

Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.72.2 Further reading

1. Landsat Wikipedia
2. Space Oblique Mercator Projection

7.1.73 McBryde-Thomas Flat-Polar Sine (No. 1)

<table>
<thead>
<tr>
<th>Classification</th>
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</tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 69: proj-string: +proj=mbt_s

7.1.73.1 Parameters

Note: All parameters are optional for the McBryde-Thomas Flat-Polar Sine projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.74 McBryde-Thomas Flat-Pole Sine (No. 2)

<table>
<thead>
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</tr>
</thead>
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<td>Available forms</td>
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<tr>
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<td>Global</td>
</tr>
<tr>
<td>Alias</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 70: proj-string: +proj=mbt_fps
7.1.74.1 Parameters

Note: All parameters are optional.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.75 McBride-Thomas Flat-Polar Parabolic

<table>
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</tr>
</thead>
<tbody>
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<td>Defined area</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 71: proj-string: +proj=mbtfpp

### 7.1.75.1 Parameters

**Note:** All parameters are optional.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with *+ellps*, *+R* takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.76 McBryde-Thomas Flat-Polar Quartic

<table>
<thead>
<tr>
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<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 72: proj-string: +proj=mbtfpq

7.1.76.1 Parameters

**Note:** All parameters are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.
+\textit{x}_0 = \textit{value} \\
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters. \\
\textit{Defaults} to 0.0.

\textit{y}_0 = \textit{value} \\
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters. \\
\textit{Defaults} to 0.0.

### 7.1.77 McBryde-Thomas Flat-Polar Sinusoidal

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
<th>Available forms</th>
<th>Forward and inverse, spherical and ellipsoidal</th>
<th>Defined area</th>
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<th>2D</th>
<th>Input type</th>
<th>Geodetic coordinates</th>
<th>Output type</th>
<th>Projected coordinates</th>
</tr>
</thead>
</table>

**Fig. 73: proj-string: \texttt{+proj=mbtfps}**

#### 7.1.77.1 Parameters

**Note:** All parameters are optional for the McBryde-Thomas Flat-Polar Sinusoidal projection.

\textit{lon}_0 = \textit{value} \\
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method). \\
\textit{Defaults} to 0.0.
Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.78 Mercator

The Mercator projection is a cylindrical map projection that originates from the 16th century. It is widely recognized as the first regularly used map projection. It is a conformal projection in which the equator projects to a straight line at constant scale. The projection has the property that a rhumb line, a course of constant heading, projects to a straight line. This makes it suitable for navigational purposes.

### Classification
Conformal cylindrical

### Available forms
Forward and inverse, spherical and ellipsoidal

### Defined area
Global, but best used near the equator

### Alias
merc

### Domain
2D

### Input type
Geodetic coordinates

### Output type
Projected coordinates

#### 7.1.78.1 Usage

Applications should be limited to equatorial regions, but is frequently used for navigational charts with latitude of true scale (+lat_ts) specified within or near chart’s boundaries. It is considered to be inappropriate for world maps because of the gross distortions in area; for example the projected area of Greenland is larger than that of South America, despite the fact that Greenland’s area is \( \frac{1}{8} \) that of South America [Snyder1987].

Example using latitude of true scale:

```
$ echo 56.35 12.32 | proj +proj=merc +lat_ts=56.5
3470306.37 759599.90
```

Example using scaling factor:
Fig. 74: proj-string: +proj=merc
echo 56.35 12.32 | proj +proj=merc +k_0=2
12545706.61  2746073.80

Note that \texttt{+lat\_ts} and \texttt{+k\_0} are mutually exclusive. If used together, \texttt{+lat\_ts} takes precedence over \texttt{+k\_0}.

### 7.1.78.2 Parameters

**Note:** All parameters for the projection are optional.

\texttt{+lat\_ts}=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over \texttt{+k\_0} if both options are used together.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lat\_ts=1.570796r}

See *Projection Units* for more information.

\texttt{+k\_0}=<value>

Scale factor. Determines scale factor used in the projection.

*Defaults to 1.0.*

\texttt{+lon\_0}=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lon\_0=1.570796r}

See *Projection Units* for more information.

\texttt{+x\_0}=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\texttt{+y\_0}=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
+ellps=<value>
   The name of a built-in ellipsoid definition.
   See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.
   Defaults to "GRS80".

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   See *Ellipsoid size parameters* for more information.

7.1.78.3 Mathematical definition

**Spherical form**

For the spherical form of the projection we introduce the scaling factor:

\[ k_0 = \cos \phi_{ts} \]

**Forward projection**

\[ x = k_0 R \lambda; \quad y = k_0 R \psi \]

\[ \psi = \ln \tan \left( \frac{\pi}{4} + \frac{\phi}{2} \right) \]

\[ = \sinh^{-1} \tan \phi \]

The quantity \( \psi \) is the isometric latitude.

**Inverse projection**

\[ \lambda = \frac{x}{k_0 R}; \quad \psi = \frac{y}{k_0 R} \]

\[ \phi = \frac{\pi}{2} - 2 \tan^{-1} \exp(-\psi) \]

\[ = \tan^{-1} \sinh \psi \]

**Ellipsoidal form**

For the ellipsoidal form of the projection we introduce the scaling factor:

\[ k_0 = m(\phi_{ts}) \]

where

\[ m(\phi) = \frac{\cos \phi}{\sqrt{1 - e^2 \sin^2 \phi}} \]

\( a m(\phi) \) is the radius of the circle of latitude \( \phi \).
**Forward projection**

\[
\begin{align*}
  x &= k_0 a \lambda; \quad y = k_0 a \psi \\
  \psi &= \ln \tan \left( \frac{\pi}{4} + \frac{\phi}{2} \right) - \frac{1}{2} e \ln \left( \frac{1 + e \sin \phi}{1 - e \sin \phi} \right) \\
  &= \sinh^{-1} \tan \phi - e \tanh^{-1} (e \sin \phi)
\end{align*}
\]

**Inverse projection**

\[
\begin{align*}
  \lambda &= \frac{x}{k_0 a}; \quad \psi = \frac{y}{k_0 a}
\end{align*}
\]

The latitude \( \phi \) is found by inverting the equation for \( \psi \). This follows the method given by [Karney2011tm]. Start by introducing the conformal latitude

\[
\chi = \tan^{-1} \sinh \psi
\]

The tangents of the latitudes \( \tau = \tan \phi \) and \( \tau' = \tan \chi = \sinh \psi \) are related by

\[
\tau' = \tau \sqrt{1 + \sigma^2} - \sigma \sqrt{1 + \tau^2}
\]

where

\[
\sigma = \sinh \left( e \tanh^{-1} (e \tau / \sqrt{1 + \tau^2}) \right)
\]

This is obtained by taking the sinh of the equation for \( \psi \) and using the multiple argument formula. The equation for \( \tau' \) can be solved to give \( \tau \) using Newton’s method using \( \tau = \tau' / (1 - e^2) \) as an initial guess and with the needed derivative given by

\[
\frac{d\tau'}{d\tau} = \frac{1 - e^2}{1 + (1 - e^2)\tau^2} \sqrt{1 + \tau^2} \sqrt{1 + \tau'^2}
\]

This converges after no more than 2 iterations. Finally set \( \phi = \tan^{-1} \tau \).

### 7.1.78.4 Further reading

1. Wikipedia
2. Wolfram Mathworld

### 7.1.79 Miller Oblated Stereographic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>mil_os</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 75: proj-string: +proj=mil_os
7.1.79.1 Parameters

Note: All parameters are optional for the projection.

+ellps=<value>
  The name of a built-in ellipsoid definition.
  See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
  Defaults to "GRS80".

+x_0=<value>
  False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.

+y_0=<value>
  False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.

7.1.80 Miller Cylindrical

The Miller cylindrical projection is a modified Mercator projection, proposed by Osborn Maitland Miller in 1942. The latitude is scaled by a factor of $\frac{4}{5}$, projected according to Mercator, and then the result is multiplied by $\frac{5}{4}$ to retain scale along the equator.

<table>
<thead>
<tr>
<th>Classification</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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</tr>
<tr>
<td>Defined area</td>
<td>Global, but best used near the equator</td>
</tr>
<tr>
<td>Alias</td>
<td>mill</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.80.1 Usage

The Miller Cylindrical projection is used for world maps and in several atlases, including the National Atlas of the United States (USGS, 1970, p. 330-331) [Snyder1987].

Example using Central meridian 90°W:

```
$ echo -100 35 | proj +proj=mill +lon_0=90w
-1113194.91   4061217.24
```
Fig. 76: proj-string: +proj=mill

7.1.80.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
   Defaults to 0.0.

   Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
   Example: +lon_0=1.570796r
   See Projection Units for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   See Ellipsoid size parameters for more information.

+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
   Defaults to 0.0.
+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

### 7.1.80.3 Mathematical definition

The formulas describing the Miller projection are all taken from [Snyder1987].

**Forward projection**

\[
x = \lambda
\]

\[
y = 1.25 \times \ln \left[ \tan \left( \frac{\pi}{4} + 0.4 \times \phi \right) \right]
\]

**Inverse projection**

\[
\lambda = x
\]

\[
\phi = 2.5 \times \left( \arctan \left[ e^{0.8 \times y} \right] - \frac{\pi}{4} \right)
\]

### 7.1.80.4 Further reading

1. Wikipedia

### 7.1.81 Space oblique for MISR

Space oblique for MISR is a specialization of *Space Oblique Mercator* which specifies the appropriate ascending longitude, inclination angle, and orbital period for Multi-angle Imaging Spectroradiometer (MISR) orbits, based on the path number for the orbit.

"Paths" are the repeating ground tracks that are traced by sun-synchronous satellites like Terra on which the MISR instrument is aboard.

<table>
<thead>
<tr>
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<tr>
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<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>misrsom</td>
</tr>
<tr>
<td>Domain</td>
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<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 77: proj-string: +proj=misrsom +path=1
7.1.81.1 Parameters

Required

+path=<value>
Selected path of satellite. Value between 1 and 233.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See *Projection Units* for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

1. MISR Wikipedia
2. Terra Wikipedia
3. Space Oblique Mercator Projection
7.1.82 Mollweide

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
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</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
<td>Alias</td>
<td>moll</td>
</tr>
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<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 78: proj-string: +proj=moll

7.1.82.1 Parameters

Note: All parameters are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.
\[+x_0=\text{value}\]

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\[+y_0=\text{value}\]

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.83 Murdoch I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
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<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 79: proj-string: `+proj=murd1 +lat_1=30 +lat_2=50`
7.1.83.1 Parameters

Required

+lat_1=<value>
First standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_1=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_2=1.570796r
See Projection Units for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.84 Murdoch II

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>murd2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 80: proj-string: `+proj=murd2 +lat_1=30 +lat_2=50`
7.1.84.1 Parameters

Required

+lat_1=<value>
First standard parallel.
Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_1=1.570796r

See *Projection Units* for more information.

+lat_2=<value>
Second standard parallel.
Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_2=1.570796r

See *Projection Units* for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
+\texttt{y}_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

\textit{Defaults to 0.0.}

## 7.1.85 Murdoch III

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>murd3</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Figure 81: proj-string: +proj=murd3 +lat_1=30 +lat_2=50](image)

Fig. 81: proj-string: +proj=murd3 +lat_1=30 +lat_2=50
7.1.85.1 Parameters

Required

+lat_1=<value>
First standard parallel.

_Defaults to 0.0._

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: _+lat_1=1.570796r_

See _Projection Units_ for more information.

+lat_2=<value>
Second standard parallel.

_Defaults to 0.0._

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: _+lat_2=1.570796r_

See _Projection Units_ for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

_Defaults to 0.0._

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: _+lon_0=1.570796r_

See _Projection Units_ for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with _+ellps_, _+R_ takes precedence.

See _Ellipsoid size parameters_ for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

_Defaults to 0.0._
+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

 Defaults to 0.0.

7.1.86 Natural Earth

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudo cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>natearth</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 82: proj-string: +proj=natearth

The Natural Earth projection is intended for making world maps. A distinguishing trait is its slightly rounded corners fashioned to emulate the spherical shape of Earth. The meridians (except for the central meridian) bend acutely inward as they approach the pole lines, giving the projection a hint of three-dimensionality. This bending also suggests that the meridians converge at the poles instead of truncating at the top and bottom edges. The distortion characteristics of the Natural Earth projection compare favorably to other world map projections.
7.1.86.1 Usage

The Natural Earth projection has no special options so usage is simple. Here is an example of an inverse projection on a sphere with a radius of 7500 m:

```
$ echo 3500 -8000 | proj -I +proj=natearth +a=7500
37d54'6.091"E  61d23'4.582"S
```

7.1.86.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.86.3 Further reading

1. Wikipedia
7.1.87 Natural Earth II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudo cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
<td>Alias</td>
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<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 83: proj-string: +proj=natearth2

The Natural Earth II projection is intended for making world maps. At high latitudes, meridians bend steeply toward short pole lines resulting in a map with highly rounded corners that resembles an elongated globe.

See [Savric2015]

7.1.87.1 Parameters

**Note:** All parameters for the projection are optional.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.88 Nell

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
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<td>Domain</td>
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<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Fig. 84: proj-string: +proj=nell](image_url)
7.1.88.1 Parameters

**Note:** All parameters are optional.

`+lon_0=<value>`
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

**Example:** `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`
Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.89 Nell-Hammer

<table>
<thead>
<tr>
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<th>Pseudocylindrical</th>
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<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.89.1 Parameters

Note: All parameters are optional.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

**+y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.90 Nicolosi Globular

<table>
<thead>
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<th>Pseudoconical</th>
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</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 86: proj-string: +proj=nicol

7.1.90.1 Parameters

**Note:** All parameters are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.
\( +x_0 = \langle \text{value} \rangle \)

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\( +y_0 = \langle \text{value} \rangle \)

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.91 Near-sided perspective

The near-sided perspective projection simulates a view from a height \( h \) similar to how a satellite in orbit would see it.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal. Neither conformal nor equal area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, although for one hemisphere at a time.</td>
</tr>
<tr>
<td>Alias</td>
<td>nsper</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.91.1 Parameters

**Required**

\( +h = \langle \text{value} \rangle \)

Height of the view point above the Earth and must be in the same units as the radius of the sphere or semimajor axis of the ellipsoid.

**Optional**

\( +\text{lon}_0 = \langle \text{value} \rangle \)

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \( +\text{lon}_0=1.570796r \)

See *Projection Units* for more information.
Fig. 87: proj-string: +proj=nsper +h=3000000 +lat_0=-20 +lon_0=145
+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
 Defaults to 0.0.

---

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_0=1.570796r

See *Projection Units* for more information.

---

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

---

### 7.1.92 New Zealand Map Grid (EPSG:27200)

#### 7.1.92.1 Parameters

---

**Note:** All standard projection parameters are hard-coded for this projection.

---

### 7.1.93 General Oblique Transformation

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>ob_tran</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 88: proj-string: +proj=nzmg
7.1.93.1 Usage

All of the projections of spherical library can be used as an oblique projection by means of the General Oblique Transformation. The user performs the oblique transformation by selecting the oblique projection +proj=ob_tran, specifying the translation factors, +o_lat_p and +o_lon_p, and the projection to be used, +o_proj. In the example of the Fairgrieve projection, the latitude and longitude of the North pole of the unrotated geographic CRS, \( \alpha \) and \( \beta \) respectively, expressed in the rotated geographic CRS, are to be placed at 45\(^\circ\)N and 90\(^\circ\)W and the Mollweide projection is used. Because the central meridian of the translated coordinates will follow the \( \beta \) meridian it is necessary to translate the translated system so that the Greenwich meridian will pass through the center of the projection by offsetting the central meridian.

The final control for this projection is:

\[
+\text{proj}=\text{ob_tran} +\text{o_proj}=\text{moll} +\text{o_lat_p}=40 +\text{o_lon_p}=50 +\text{lon}_0=60
\]

7.1.93.2 Parameters

**Required**

+o_proj=<projection>

Oblique projection.

In addition to specifying an oblique projection, how to rotate the projection should be specified. This is done in one of three ways: Define a new pole, rotate the projection about a given point or define a new "equator" spanned by two points on the sphere. See the details below.
New pole

+o_lat_p=<latitude>
   Latitude of the North pole of the unrotated source CRS, expressed in the rotated geographic CRS.

+o_lon_p=<longitude>
   Longitude of the North pole of the unrotated source CRS, expressed in the rotated geographic CRS.

Rotate about point

+o_alpha=<value>
   Angle to rotate the projection with.

+o_lon_c=<value>
   Longitude of the point the projection will be rotated about.

+o_lat_c=<value>
   Latitude of the point the projection will be rotated about.

New "equator" points

+o_lon_1=<value>
   Longitude of first point.

+o_lat_1=<value>
   Latitude of first point.

+o_lon_2=<value>
   Longitude of second point.

+o_lat_2=<value>
   Latitude of second point.

Optional

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

   *Defaults to 0.0.*

   **Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

   Example: +lon_0=1.570796r

   See *Projection Units* for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

   See *Ellipsoid size parameters* for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.94 Oblique Cylindrical Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>ocea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 90: proj-string: +proj=ocea

7.1.94.1 Parameters

Required

For the Oblique Cylindrical Equal Area projection a pole of rotation is needed. The pole can be defined in two ways: By a point and azimuth or by providing two points that make up the pole.
**Point & azimuth**

+lonc=<value>
   Longitude of rotational pole point.

+alpha=<value>
   Angle of rotational pole.

**Two points**

+lon_1=<value>
   Longitude of first point.

+lat_1=<value>
   Latitude of first point.

+lon_2=<value>
   Longitude of second point.

+lat_2=<value>
   Latitude of second point.

**Optional**

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
   
   *Defaults to 0.0.*

   **Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

   Example: +lon_0=1.570796r

   See *Projection Units* for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   
   See *Ellipsoid size parameters* for more information.

+k_0=<value>
   Scale factor. Determines scale factor used in the projection.
   
   *Defaults to 1.0.*

+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
   
   *Defaults to 0.0.*
+\textit{y}_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

\textit{Defaults to 0.0.}

### 7.1.95 Oblated Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>oea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Described in [Snyder1988].

#### 7.1.95.1 Parameters

**Required**

+\textit{m}=<value>

+\textit{n}=<value>

**Optional**

+\textit{theta}=<value>

+\textit{lon}_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

\textit{Defaults to 0.0.}

\textbf{Note:} The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lon}_0=1.570796r

See \textit{Projection Units} for more information.

+\textit{R}=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +\textit{R} takes precedence.

See \textit{Ellipsoid size parameters} for more information.
Fig. 91: proj-string: +proj=aea +m=1 +n=2
\[ x_0 = \text{value} \]

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\[ y_0 = \text{value} \]

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.96 Oblique Mercator

The Oblique Mercator projection is a cylindrical map projection that closes the gap between the Mercator and the Transverse Mercator projections.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, but reasonably accurate only within 15 degrees of the oblique central line</td>
</tr>
<tr>
<td>Alias</td>
<td>omerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 92: proj-string: `+proj=omerc +lat_1=45 +lat_2=55`

Figuratively, the cylinder used for developing the Mercator projection touches the planet along the Equator, while that of the Transverse Mercator touches the planet along a meridian, i.e. along a line perpendicular to the Equator.

The cylinder for the Oblique Mercator, however, touches the planet along a line at an arbitrary angle with the Equator. Hence, the Oblique Mercator projection is useful for mapping areas having their greatest extent along a direction that is neither north-south, nor east-west.

The Mercator and the Transverse Mercator projections are both limiting forms of the Oblique Mercator: The Mercator projection is equivalent to an Oblique Mercator with central line along the Equator, while the Transverse Mercator is equivalent to an Oblique Mercator with central line along a meridian.
For the sphere, the construction of the Oblique Mercator projection can be imagined as "tilting the cylinder of a plain Mercator projection", so the cylinder, instead of touching the equator, touches an arbitrary great circle on the sphere. The great circle is defined by the tilt angle of the central line, hence putting land masses along that great circle near the centre of the map, where the Equator would go in the plain Mercator case.

The ellipsoidal case, developed by Hotine, and refined by Snyder [Snyder1987] is more complex, involving initial steps projecting from the ellipsoid to another curved surface, the "aposphere", then projection from the aposphere to the skew uv-plane, before finally rectifying the skew uv-plane onto the map XY plane.

### 7.1.96.1 Usage

The tilt angle (azimuth) of the central line can be given in two different ways. In the first case, the azimuth is given directly, using the option +alpha and defining the centre of projection using the options +lonc and +lat_0. In the second case, the azimuth is given indirectly by specifying two points on the central line, using the options +lat_1, +lon_1, +lat_2, and +lon_2.

Example: Verify that the Mercator, and Transverse Mercator (on a sphere), projections are limiting forms of the Oblique Mercator

```bash
$ echo 12 55 | proj +proj=merc +ellps=GRS80
1335833.89 7326837.71

$ echo 12 55 | proj +proj=omerc +alpha=90 +ellps=GRS80
1335833.89 7326837.71

$ echo 12 55 | proj +proj=omerc +alpha=0 +R=6400000
766869.97 6209742.96

$ echo 12 55 | proj +proj=tmerc +R=6400000
766869.97 6209742.96
```

Example: Second case - indirectly given azimuth

```bash
$ echo 12 55 | proj +proj=omerc +lon_1=-1 +lat_1=1 +lon_2=0 +lat_2=0 +ellps=GRS80
349567.57 6839490.50
```

Example: An approximation of the Danish "System 34" from [Rittri2012]

```bash
$ echo 10.536498003 56.229892362 | cs2cs +proj=longlat +ellps=GRS80 +to +proj=omerc ...
˓→+axis=wnu +lonc=9.46 +lat_0=56.1333333 +x_0=-266906.229 +y_0=189617.957 +k=0.9999537 ...
˓→+alpha=-0.76324 +gamma=0 +ellps=GRS80
200000.13 199999.89
```

The input coordinate represents the System 34 datum point "Agri Bavnehoj", with coordinates (200000, 200000) by definition. So at the datum point, the approximation is off by about 17 cm. This use case represents a datum shift from a cylinder projection on an old, slightly misaligned datum, to a similar projection on a modern datum.
7.1.96.2 Parameters

Central point and azimuth method

+alpha=<value>

Azimuth of centerline clockwise from north at the center point of the line. If +gamma is not given then +alpha determines the value of +gamma.

+gamma=<value>

Azimuth of centerline clockwise from north of the rectified bearing of centre line. If +alpha is not given, then +gamma is used to determine +alpha.

If specifying only +gamma without +alpha, the maximum value of the absolute value of +gamma is a function of the absolute value of +lat_0, equal to 90 − |\phi_0| on a sphere and slightly above on a non-spherical ellipsoid.

+lonc=<value>

Longitude of the projection centre. Note that this value is used to override the +lon_0 parameter, so the latter should not be specified as it would get ignored.

+lat_0=<value>

Latitude of the projection centre.

Two point method

+lon_1=<value>

Longitude of first point.

+lat_1=<value>

Latitude of first point.

+lon_2=<value>

Longitude of second point.

+lat_2=<value>

Latitude of second point.

Optional

+no_rot

No rectification (not "no rotation" as one may well assume). Do not take the last step from the skew uv-plane to the map XY plane.

Note: This option is probably only marginally useful, but remains for (mostly) historical reasons.

+no_off

Do not offset origin to center of projection.

+k_0=<value>

Scale factor. Determines scale factor used in the projection.

Defaults to 1.0.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.
+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

7.1.97 Ortelius Oval

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>ortel</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 93: proj-string: +proj=ortel

7.1.97.1 Parameters

Note: All parameters are optional.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
 Defaults to 0.0.
**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.98 Orthographic

The orthographic projection is a perspective azimuthal projection centered around a given latitude and longitude.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, although only one hemisphere can be seen at a time</td>
</tr>
<tr>
<td>Alias</td>
<td>ortho</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

**Note:** Before PROJ 7.2, only the spherical formulation was implemented. If wanting to replicate PROJ < 7.2 results with newer versions, the ellipsoid must be forced to a sphere, for example by adding a `+f=0` parameter.

This projection method corresponds to EPSG:9840.

#### 7.1.98.1 Parameters

**Note:** All parameters for the projection are optional.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*
Fig. 94: proj-string: +proj=ortho
7.1.99 Patterson

The Patterson projection is a cylindrical map projection designed for general-purpose mapmaking.

See [Patterson2014]
### Classification
Cylindrical

### Available forms
Forward and inverse, spherical projection

### Defined area
Global

### Alias
patterson

### Domain
2D

### Input type
Geodetic coordinates

### Output type
Projected coordinates

---

**Fig. 95: proj-string: +proj=patterson**

### 7.1.99.1 Parameters

**Note:** All parameters are optional for projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

---

Chapter 7. Coordinate operations
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
*Defaults to 0.0.*

### 7.1.100 Perspective Conic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>pconic</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 96: proj-string: +proj=pconic +lat_1=25 +lat_2=75
7.1.100.1 Parameters

Required

+lat_1=<value>
First standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_1=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_2=1.570796r
See Projection Units for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.101 Peirce Quincuncial

The Peirce Quincuncial projection is a conformal map projection that transforms the circle of the northern hemisphere into a square, and the southern hemisphere split into four triangles arranged around the square to form a quincunx. The resulting projection is a regular diamond shape or can be rotated to form a square. The resulting tile can be infinitely tessellated. Though this implementation defaults to a central meridian of 0, it is more common to use a central meridian of around 25 to optimise the distortions. Peirce’s original published map from 1879 used a central meridian of approx -70. The diamond and square versions can be produced using the `+shape=diamond` and `+shape=square` options respectively. This implementation includes an alternative lateral projection which places hemispheres side-by-side (`+shape=horizontal` or `+shape=vertical`). Combined with a general oblique transformation, this can be used to produced a Grieger Triptychial projection (see example below).

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>peirce_q</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.101.1 Parameters

**Note:** All parameters are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+shape=square/diamond/horizontal/vertical/nhemisphere/shemisphere

New in version 9.0.

*Defaults to diamond.*
Fig. 97: proj-string: +proj=peirce_q +lon_0=25 +shape=square
Fig. 98: proj-string: +proj=peirce_q +lon_0=25 +shape=diamond

Fig. 99: proj-string: +proj=peirce_q +lon_0=25 +shape=horizontal
Fig. 100: proj-string: +proj=pipeline +step +proj=ob_tran +o_proj=peirce_q +o_lat_p=-45 +o_lon_p=45 +o_type=horizontal +o_scrollx=-0.25 +step +proj=affine +s11=-1 +s12=0 +s21=0 +s22=-1

**Warning:** This option was wrongly introduced introduced in 8.2.1 with the type name, which was inap-propriate as it conflicted with the +type=crs general hint.

Indicates the shape of transformation applied to the southern hemisphere: square and diamond represent the traditional quincuncial form suggested by Peirce with the southern hemisphere divided into 4 triangles and reflected outward from the northern hemisphere. The square shape is rotated by 45 degrees to produce the conventional square presentation. The origin lies at the centre of the square or diamond.

By contrast, the horizontal and vertical forms reflect the southern hemisphere laterally across the x or y axis respectively to produce a rectangular form. The origin lies at the centre of the rectangle.

The other two types, nhemisphere and shemisphere, discard latitudes of less than 0 or more than 0, respectively, to allow single hemispheres to be selected. The origin lies at the centre of the square or diamond.

**+scrollx=<value>**

For horizontal shape allows a scalar circular scroll of resulting x coordinates to shift sections of the projection to the other horizontal side of the map.

*Defaults to 0.0. Must be a scale between -1.0 and 1.0.*

**+scrolly=<value>**

For vertical shape allows a scalar circular scroll of resulting y coordinates to shift sections of the projection to the other vertical side of the map.

*Defaults to 0.0. Must be a scale between -1.0 and 1.0.*

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+\(y_0=x\) = <value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.102 Polyconic (American)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudoconical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>poly</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 101: proj-string: +proj=poly
7.1.102.1 Parameters

Note: All parameters are optional for projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.103 Putnins P1

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
<td>Alias</td>
<td>putp1</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.103.1 Parameters

**Note:** All parameters are optional for the Putnins P1 projection.

```bash
+lon_0=<value>
```

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

```bash
+R=<value>
```

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

```bash
+x_0=<value>
```

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

```bash
+y_0=<value>
```

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.104 Putnins P2

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Forward and inverse, spherical projection</td>
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<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>putp2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 103: proj-string: +proj=putp2

7.1.104.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Default to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Default to 0.0.

7.1.105 Putnins P3

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
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<td>Alias</td>
<td>putp3</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 104: proj-string: +proj=putp3

7.1.105.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Default to 0.0.

7.1. Projections
Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.106 Putnins P3'

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
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<td>putp3p</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 105: proj-string: +proj=putp3p
7.1.106.1 Parameters

**Note:** All parameters are optional for the projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

7.1.107 Putnins P4'

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
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</thead>
<tbody>
<tr>
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<td>Forward and inverse, spherical projection</td>
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<tr>
<td>Alias</td>
<td>putp4p</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.107.1 Parameters

**Note:** All parameters are optional for the projection.

**+lon₀=**<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon₀=1.570796r

See *Projection Units* for more information.

**+R=**<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x₀=**<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y₀=**<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.108 Putnins P5

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>putp5</td>
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<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Fig. 107: proj-string: +proj=putp5](image)

7.1.108.1 Parameters

**Note:** All parameters are optional for the projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.109 Putnins P5'

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>putp5p</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 108: proj-string: +proj=putp5p

7.1.109.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.
**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

### 7.1.110 Putnins P6

<table>
<thead>
<tr>
<th><strong>Classification</strong></th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available forms</strong></td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td><strong>Defined area</strong></td>
<td>Global</td>
</tr>
<tr>
<td><strong>Alias</strong></td>
<td>putp6</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>2D</td>
</tr>
<tr>
<td><strong>Input type</strong></td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td><strong>Output type</strong></td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

![Fig. 109: proj-string: +proj=putp6](image)
7.1.110.1 Parameters

**Note:** All parameters are optional for the projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

7.1.111 Putnins P6'

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available forms</strong></td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td><strong>Defined area</strong></td>
<td>Global</td>
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<td><strong>Alias</strong></td>
<td>putp6p</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>2D</td>
</tr>
<tr>
<td><strong>Input type</strong></td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td><strong>Output type</strong></td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.111.1 Parameters

**Note:** All parameters are optional for the projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.112 Quartic Authalic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 111: proj-string: +proj=qua_aut

7.1.112.1 Parameters

Note: All parameters are optional for the Quartic Authalic projection.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
_Devaults to 0.0._

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
_Devaults to 0.0._

7.1.113 Quadrilateralized Spherical Cube

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

The purpose of the Quadrilateralized Spherical Cube (QSC) projection is to project a sphere surface onto the six sides of a cube:
For this purpose, other alternatives can be used, notably Gnomonic or HEALPix. However, QSC projection has the following favorable properties:

It is an equal-area projection, and at the same time introduces only limited angular distortions. It treats all cube sides equally, i.e. it does not use different projections for polar areas and equatorial areas. These properties make QSC projection a good choice for planetary-scale terrain rendering. Map data can be organized in quadtree structures for each cube side. See [LambersKolb2012] for an example.

The QSC projection was introduced by [ONeilLaubscher1976], building on previous work by [ChanONeil1975]. For clarity: The earlier QSC variant described in [ChanONeil1975] became known as the COBE QSC since it was used by the NASA Cosmic Background Explorer (COBE) project; it is an approximately equal-area projection and is not the same as the QSC projection.

See also [CalabrettaGreisen2002] Sec. 5.6.2 and 5.6.3 for a description of both and some analysis.

In this implementation, the QSC projection projects onto one side of a circumscribed cube. The cube side is selected by choosing one of the following six projection centers:

| +lat_0=0 | +lon_0=0 | front cube side |
| +lat_0=0 | +lon_0=90 | right cube side |
| +lat_0=0 | +lon_0=180 | back cube side |
| +lat_0=0 | +lon_0=-90 | left cube side |
| +lat_0=90 | top cube side |
| +lat_0=-90 | bottom cube side |
Furthermore, this implementation allows the projection to be applied to ellipsoids. A preceding shift to a sphere is performed automatically; see [LambersKolb2012] for details.

7.1.113.1 Usage

The following example uses QSC projection via GDAL to create the six cube side maps from a world map for the WGS84 ellipsoid:

```bash
gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=0" \ 
  -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137 \ 
  worldmap.tif frontside.tif

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=90" \ 
  -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137 \ 
  worldmap.tif rightside.tif

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=180" \ 
  -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137 \ 
  worldmap.tif backside.tif

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=0 +lon_0=-90" \ 
  -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137 \ 
  worldmap.tif leftside.tif

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=90 +lon_0=0" \ 
  -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137 \ 
  worldmap.tif topside.tif

gdalwarp -t_srs "+wktext +proj=qsc +units=m +ellps=WGS84 +lat_0=-90 +lon_0=0" \ 
  -wo SOURCE_EXTRA=100 -wo SAMPLE_GRID=YES -te -6378137 -6378137 6378137 6378137 \ 
  worldmap.tif bottomside.tif
```

Explanation:

- QSC projection is selected with `+wktext +proj=qsc`.
- The WGS84 ellipsoid is specified with `+ellps=WGS84`.
- The cube side is selected with `+lat_0=... +lon_0=...`.
- The `-wo` options are necessary for GDAL to avoid holes in the output maps.
- The `-te` option limits the extends of the output map to the major axis diameter (from `-radius` to `+radius` in both x and y direction). These are the dimensions of one side of the circumscribing cube.

The resulting images can be laid out in a grid like below.
7.1.113.2 Parameters

Note: All parameters for the projection are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+lat_0=<value>

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

Defaults to 0.0.
Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_0=1.570796r

See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.

See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.

Defaults to "GRS80".

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.113.3 Further reading
1. Wikipedia
2. NASA

7.1.114 Robinson

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>robin</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.114.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.
**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

---

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

---

### 7.1.115 Roussilhe Stereographic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>rouss</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.1.115.1 Parameters

**Note:** All parameters are optional for the projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+ellps=<value>`

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.116 Rectangular Polyconic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudoconical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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<td>Global</td>
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<tr>
<td>Alias</td>
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</tr>
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<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 114: proj-string: +proj=rpoly

7.1.116.1 Parameters

Note: All parameters are optional for the projection.

+lat_ts=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +k_0 if both options are used together.

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_ts=1.570796r

See Projection Units for more information.
+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See *Projection Units* for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

### 7.1.117 S2

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
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<td>Alias</td>
<td>s2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

New in version 8.2.

The S2 projection, like the Quadrilateralized Spherical Cube (QSC) projection, projects a sphere surface onto the six sides of a cube:
S2 was created by Google to represent geographic data on the whole earth. The documentation can be found at S2 Geometry. It works by first projecting a point on the sphere to a face of the cube. These are called u,v-coordinates, and they are in \([-1,1] \times [-1,1]\). This step is followed by a non-linear transformation to normalize the area of rectangles on the sphere. There are three different choices available for this transformation, meaning that S2 is a family of projections. The final output is in s,t-coordinates, which are in \([0,1] \times [0,1]\). See the comments in S2 Code for an explanation of the tradeoff between speed and area-preservation. Note that the projection is azimuthal when "none" or "linear" is selected for the area-normalization, but it is not azimuthal when "quadratic" or "tangent" is chosen. See S2’s Earthcube page to visualize the unfolded cube and the orientation of each face.

In this implementation, the cube side is selected by choosing one of the following six projection centers:

| +lat_0=0 +lon_0=0 | front cube side |
| +lat_0=0 +lon_0=90 | right cube side |
| +lat_0=0 +lon_0=180 | back cube side |
| +lat_0=0 +lon_0=90 | left cube side |
| +lat_0=90 | top cube side |
| +lat_0=-90 | bottom cube side |

The specific transformation can be chosen with the UVtoST parameter:
Furthermore, this implementation allows the projection to be applied to ellipsoids. A preceding shift to a sphere is performed automatically; see [LambersKolb2012] for details. The output of the projection is in $s,t$-coordinates ($[0,1] \times [0,1]$), so only the eccentricity of the ellipse is taken into account: the absolute value of the axes does not affect the output.

### 7.1.117.1 Usage

The following example uses S2 on the right face:

```bash
echo 90 0 | proj +proj=s2 +lat_0=0 +lon_0=90 +ellps=WGS84 +UVtoST=linear 0.5 0.5
```

Explanation:

- S2 projection is selected with `+proj=s2`.
- The WGS84 ellipsoid is specified with `+ellps=WGS84`.
- The cube side is selected with `+lat_0=... +lon_0=...`
- The normalization transformation is selected with `+UVtoST=...`

### 7.1.117.2 Parameters

**Note:** All parameters for the projection are optional.

#### +lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

#### +lat_0=<value>

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*
**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_0=1.570796r`

See *Projection Units* for more information.

+**ellps=<value>**

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

+**UVtoST=<value>**

The area-normalization transformation. Choose from {linear, quadratic, tangent, none}

*Defaults to "quadratic".*

+**x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+**y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.117.3 Further reading

1. S2’s Website

### 7.1.118 Spherical Cross-track Height

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse.</td>
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<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
<td>Alias</td>
<td>sch</td>
</tr>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>3D coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

proj-string: `+proj=sch +plat_0=XX +plon_0=XX +phdg_0=XX`

The SCH coordinate system is a sensor aligned coordinate system developed at JPL (Jet Propulsion Laboratory) for radar mapping missions.

See [Hensley2002]
7.1.18.1 Parameters

**Required**

+plat_0=<value>
  Peg latitude (in degree)
+plon_0=<value>
  Peg longitude (in degree)
+phdg_0=<value>
  Peg heading (in degree)

**Optional**

+h_0=<value>
  Average height (in metre)
  Defaults to 0.0.
+lon_0=<value>
  Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
  Defaults to 0.0.

  **Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

  Example: +lon_0=1.570796r

  See [Projection Units](#) for more information.

+x_0=<value>
  False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.

+y_0=<value>
  False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.

+ellps=<value>
  The name of a built-in ellipsoid definition.
  See [Ellipsoids](#) for more information, or execute `proj -le` for a list of built-in ellipsoid names.
  Defaults to "GRS80".

+R=<value>
  Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
  See [Ellipsoid size parameters](#) for more information.
7.1.119 Sinusoidal (Sanson-Flamsteed)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
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<tr>
<td>Defined area</td>
<td>Global</td>
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<tr>
<td>Alias</td>
<td>sinu</td>
</tr>
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<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

MacBryde and Thomas developed generalized formulas for several of the pseudocylindricals with sinusoidal meridians:

\[
x = C\lambda(m + \cos\theta)/(m + 1)
\]

\[
y = C\theta
\]

\[
C = \sqrt{(m + 1)/n}
\]

7.1.119.1 Parameters

**Note:** All parameters are optional for the Sinusoidal projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: \(+\text{lon}_0=1.570796r\)

See *Projection Units* for more information.

\(+R=\text{value}\)

Radius of the sphere, given in meters. If used in conjunction with \(+\text{ellps}, +R\) takes precedence.

See *Ellipsoid size parameters* for more information.

\(+x_0=\text{value}\)

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

\(+y_0=\text{value}\)

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.120 Space Oblique Mercator (SOM)

The Space Oblique Mercator (SOM) projection is a generalization of the Oblique Mercator projection, itself an (oblique) aspect of the Mercator projection with origins in the 16th century. In the previously available map projections, ground tracks of satellites traced curved lines which complicated their use in representing satellite remote sensing data. In response, SOM was specifically designed to represent satellite ground tracks as straight lines. This had the effect of minimizing distortions of data along a ground track and allowing satellite data to be represented accurately as a rectangular array.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
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<td>Global</td>
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<td>Domain</td>
<td>2D</td>
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<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.120.1 Parameters

**Required**

\(+\text{asc}_\text{lon}=\text{value}\)

Longitude of the ascending node for the orbit (decimal degrees).

\(+\text{inc}_\text{angle}=\text{value}\)

Inclination (vertical tilt) of the orbit with respect to the reference plane, measured at the ascending node (decimal degrees).

\(+\text{ps}_\text{rev}=\text{value}\)

Time required for a single orbit (days).
Fig. 116: proj-string: 
+proj=som +inc_angle=98.303820000243860022 +ps_rev=0.06866666666666667 +asc_lon=64.412896137498847793
(gives same results as: +proj=som +inc_angle=1.7157253262878522 +ps_rev=0.06866666666666667 +asc_lon=1.1242171183417042r)
Note:
To specify asc_lon or inc_angle in radians (instead of degrees). Follow the value with the "r" character.
As an example, to specify the ascending longitude as 1.1242171183417042 radians (~64.4129 decimal degrees): +asc_lon=1.1242171183417042r.
For more information see projections usage.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+ellps=<value>
The name of a built-in ellipsoid definition.
See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
Defaults to "GRS80".

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
7.1.120.2 Further reading

2. USGS Report on Space Oblique Mercator Mathematical Development

7.1.121 Swiss Oblique Mercator

![Map of Europe showing Swiss Oblique Mercator projection]

Fig. 117: proj-string: +proj=somerc

7.1.121.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.
**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+ellps=<value>`

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+k_0=<value>`

Scale factor. Determines scale factor used in the projection.

*Defaults to 1.0.*

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.122 Stereographic

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
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<td>Alias</td>
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<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 118: proj-string: +proj=stere +lat_0=90 +lat_ts=75
### 7.1.122.2 Parameters

**Note:** All parameters are optional for the projection.

**+lat_0=<value>**

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \(+lat_0=1.570796r\)

See *Projection Units* for more information.

**+lat_ts=<value>**

Defines the latitude where scale is not distorted. It is only taken into account for Polar Stereographic formulations (+lat_0 = +/- 90 ), and then defaults to the +lat_0 value. If set to a value different from +/- 90, it takes precedence over +k_0 if both options are used together.

**+k_0=<value>**

Scale factor. Determines scale factor used in the projection.

*Defaults to 1.0.*

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \(+lon_0=1.570796r\)

See *Projection Units* for more information.

**+ellps=<value>**

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute *proj -le* for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.123 Oblique Stereographic Alternative

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
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<tr>
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<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

*Fig. 119: proj-string: +proj=sterea +lat_0=90*
7.1.123.1 Parameters

**Note:** All parameters are optional for the projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

**+lat_0=<value>**

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_0=1.570796r`

See *Projection Units* for more information.

**+ellps=<value>**

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
7.1.124 Gauss-Schreiber Transverse Mercator (aka Gauss-Laborde Reunion)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conformal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>gstmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 120: proj-string: +proj=gstmerc

7.1.124.1 Parameters

Note: All parameters are optional for the projection.

+k_0=<value>
Scale factor. Determines scale factor used in the projection.
Defaults to 1.0.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+lat_0=<value>
Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).
Defaults to 0.0.
**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_0=1.570796r`

See *Projection Units* for more information.

`+ellps=<value>`

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

Defaults to "GRS80".

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

### 7.1.125 Transverse Central Cylindrical

<table>
<thead>
<tr>
<th><strong>Classification</strong></th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available forms</strong></td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td><strong>Defined area</strong></td>
<td>Global</td>
</tr>
<tr>
<td><strong>Alias</strong></td>
<td>tcc</td>
</tr>
<tr>
<td><strong>Domain</strong></td>
<td>2D</td>
</tr>
<tr>
<td><strong>Input type</strong></td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td><strong>Output type</strong></td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.125.1 Parameters

**Note:** All parameters are optional for the projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.
Fig. 121: proj-string: +proj=tcc

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.126 Transverse Cylindrical Equal Area

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>tcea</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.126.1 Parameters

**Note:** All parameters are optional for the projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+k_0=<value>`

Scale factor. Determines scale factor used in the projection.

*Defaults to 1.0.*

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
Fig. 122: proj-string: +proj=tcea
7.1.127  Times

See [Snyder1993], p.213-214.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>times</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 123: proj-string: +proj=times

7.1.127.1 Parameters

**Note:** All parameters are optional for projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.128 Tissot

7.1.128.1 Parameters

Required

+lat_1=<value>
First standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_1=1.570796r
See Projection Units for more information.

+lat_2=<value>
Second standard parallel.
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lat_2=1.570796r
See Projection Units for more information.
Fig. 124: proj-string: 
+proj=tissot +lat_1=60 +lat_2=65
Optional

```
+lon_0=<value>
```

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

```
+R=<value>
```

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

```
+x_0=<value>
```

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

```
+y_0=<value>
```

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.129 Transverse Mercator

The transverse Mercator projection in its various forms is the most widely used projected coordinate system for world topographical and offshore mapping. It is a conformal projection in which a chosen meridian projects to a straight line at constant scale.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse and oblique cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical and ellipsoidal</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, with full accuracy within 3900 km of the central meridian</td>
</tr>
<tr>
<td>Alias</td>
<td>tmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Prior to the development of the Universal Transverse Mercator coordinate system, several European nations demonstrated the utility of grid-based conformal maps by mapping their territory during the interwar period. Calculating the distance between two points on these maps could be performed more easily in the field (using the Pythagorean theorem) than was possible using the trigonometric formulas required under the graticule-based system of latitude and longitude. In the post-war years, these concepts were extended into the Universal Transverse Mercator/Universal Polar Stereographic (UTM/UPS) coordinate system, which is a global (or universal) system of grid-based maps.

The following table gives special cases of the Transverse Mercator projection.

<table>
<thead>
<tr>
<th>Projection Name</th>
<th>Areas</th>
<th>Central meridian</th>
<th>Zone width</th>
<th>Scale Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Mercator</td>
<td>World wide</td>
<td>Various</td>
<td>less than 1000 km</td>
<td>Various</td>
</tr>
<tr>
<td>Transverse Mercator south oriented</td>
<td>Southern Africa</td>
<td>2° intervals E of 11°E</td>
<td>2°</td>
<td>1.000</td>
</tr>
<tr>
<td>UTM North hemisphere</td>
<td>World wide equator to 84°N</td>
<td>6° intervals E &amp; W of 3°E &amp; W</td>
<td>Usually 6°, wider for Norway and Svalbard</td>
<td>0.9996</td>
</tr>
<tr>
<td>UTM South hemisphere</td>
<td>World wide north of 80°S to equator</td>
<td>6° intervals E &amp; W of 3°E &amp; W</td>
<td>Always 6°</td>
<td>0.9996</td>
</tr>
<tr>
<td>Gauss-Kruger</td>
<td>Former USSR, Yugoslavia, Germany, S. America, China</td>
<td>Various, according to area</td>
<td>Usually less than 6°, often less than 4°</td>
<td>1.0000</td>
</tr>
<tr>
<td>Gauss Boaga</td>
<td>Italy</td>
<td>Various, according to area</td>
<td>6°</td>
<td>0.9996</td>
</tr>
</tbody>
</table>

Example using Gauss-Kruger on Germany area (aka EPSG:31467)

```bash
$ echo 9 51 | proj +proj=tmerc +lon_0=9 +x_0=3500000 +ellps=bessel 3500000.00 5651505.56
```

7.1.29.1 Usage

Fig. 125: proj-string: +proj=tmerc
Example using Gauss Boaga on Italy area (EPSG:3004)

```bash
$ echo 15 42 | proj +proj=tmerc +lon_0=15 +k_0=0.9996 +x_0=2520000 +ellps=intl
2520000.00 4649858.60
```

### 7.1.129.2 Parameters

**Note:** All parameters for the projection are optional.

**+approx**

New in version 6.0.0.

Use the Evenden-Snyder algorithm described below under "Legacy ellipsoidal form". It is faster than the default algorithm, but is less accurate and diverges beyond 3° from the central meridian.

**+algo=auto/evenden_snyder/poder_engsager**

New in version 7.1.

Selects the algorithm to use. The hardcoded value and the one defined in proj.ini default to poder_engsager; that is the most precise one.

When using auto, a heuristics based on the input coordinate to transform is used to determine if the faster Evenden-Snyder method can be used, for faster computation, without causing an error greater than 0.1 mm (for an ellipsoid of the size of Earth)

Note that **+approx** and **+algo** are mutually exclusive.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: **+lon_0=1.570796r**

See *Projection Units* for more information.

**+lat_0=<value>**

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: **+lat_0=1.570796r**

See *Projection Units* for more information.
+ellps=<value>
   The name of a built-in ellipsoid definition.
   See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
   Defaults to "GRS80".
+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   See Ellipsoid size parameters for more information.
+k_0=<value>
   Scale factor. Determines scale factor used in the projection.
   Defaults to 1.0.
+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
   Defaults to 0.0.
+y_0=<value>
   False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
   Defaults to 0.0.

7.1.129.3 Mathematical definition

The formulation given here for the Transverse Mercator projection is due to Krüger [Krueger1912] who gave the series expansions accurate to $n^4$, where $n = (a - b)/(a + b)$ is the third flattening. These series were extended to sixth order by Engsager and Poder in [Poder1998] and [Engsager2007]. This gives full double-precision accuracy within 3900 km of the central meridian (about 57% of the surface of the earth) [Karney2011tm]. The error is less than 0.1 mm within 7000 km of the central meridian (about 89% of the surface of the earth).

This formulation consists of three steps: a conformal projection from the ellipsoid to a sphere, the spherical transverse Mercator projection, rectifying this projection to give constant scale on the central meridian.

The scale on the central meridian is $k_0$ and is set by +k_0.

Option +lon_0 sets the central meridian; in the formulation below $\lambda$ is the longitude relative to the central meridian.

Options +lat_0, +x_0, and +y_0 serve to translate the projected coordinates so that at $(\phi, \lambda) = (\phi_0, \lambda_0)$, the projected coordinates are $(x, y) = (x_0, y_0)$. To simplify the formulas below, these options are set to zero (their default values).

Because the projection is conformal, the formulation is most conveniently given in terms of complex numbers. In particular, the unscaled projected coordinates $\eta$ (proportional to the easting, $x$) and $\xi$ (proportional to the northing, $y$) are combined into the single complex quantity $\zeta = \xi + i\eta$, where $i = \sqrt{-1}$. Then any analytic function $f(\zeta)$ defines a conformal mapping (this follows from the Cauchy-Riemann conditions).
Spherical form

Because the full (ellipsoidal) projection includes the spherical projection as one of the components, we present the spherical form first with the coordinates tagged with primes, \( \phi' \), \( \lambda' \), \( \zeta' = \xi' + i\eta' \), \( x' \), \( y' \), so that they can be distinguished from the corresponding ellipsoidal coordinates (without the primes). The projected coordinates for the sphere are given by

\[
x' = k_0 R\eta'; \quad y' = k_0 R\xi'
\]

Forward projection

\[
\begin{align*}
\zeta' &= \tan^{-1}\left(\frac{\tan \phi'}{\cos \lambda'}\right) \\
\eta' &= \sinh^{-1}\left(\frac{\sin \lambda'}{\sqrt{\tan^2 \phi' + \cos^2 \lambda'}}\right)
\end{align*}
\]

Inverse projection

\[
\begin{align*}
\phi' &= \tan^{-1}\left(\frac{\sin \xi'}{\sqrt{\sinh^2 \eta' + \cos^2 \xi'}}\right) \\
\lambda' &= \tan^{-1}\left(\frac{\sinh \eta'}{\cos \xi'}\right)
\end{align*}
\]

Ellipsoidal form

The projected coordinates are given by

\[
\begin{align*}
\zeta &= \xi + i\eta; \quad x = k_0 A\eta; \quad y = k_0 A\xi \\
A &= \frac{a}{1 + n} \left(1 + \frac{1}{4}n^2 + \frac{1}{64}n^4 + \frac{1}{256}n^6\right)
\end{align*}
\]

The series for conversion between ellipsoidal and spherical geographic coordinates and ellipsoidal and spherical projected coordinates are given in matrix notation where \( S(\theta) \) and \( N \) are the row and column vectors of length 6

\[
S(\theta) = \begin{pmatrix} \sin 2\theta & \sin 4\theta & \sin 6\theta & \sin 8\theta & \sin 10\theta & \sin 12\theta \end{pmatrix}
\]

\[
N = \begin{pmatrix} n & n^2 & n^3 & n^4 & n^5 & n^6 \end{pmatrix}
\]

and \( C_{a,\beta} \) are upper triangular \( 6 \times 6 \) matrices.
Relation between geographic coordinates

\[ \chi' = \lambda \]

\[ \phi' = \tan^{-1} \sinh(\sin^{-1} \phi - e \tanh^{-1}(e \sin \phi)) \]

Instead of using this analytical formula for \( \phi' \), the conversions between \( \phi \) and \( \phi' \) use the series approximations:

\[
\phi' = \phi + S(\phi) \cdot C_{\chi, \phi} \cdot N \\
\phi = \phi' + S(\phi') \cdot C_{\phi, \chi} \cdot N
\]

\[
C_{\chi, \phi} = \begin{pmatrix}
-2 & 2 & 45 & 96 & 312 & 32 & 12 & 2 & 4642 \\
3 & -16 & 15 & 73 & 45 & 375 & 373 & 630 & 314 \\
15 & -15 & 14 & 58 & 37 & 348 & 346 & 630 & 315 \\
257 & 1237 & 630 & 314 & 1401 & 735 & 375 & 32 & 4642 \\
964 & 45 & 375 & 373 & 630 & 314 & 1401 & 735 & 32 \end{pmatrix}
\]

\[
C_{\phi, \chi} = \begin{pmatrix}
2 & -2 & 56 & -3 & -8 & 116 & 26 & 2 \frac{2854}{6757} \\
3 & -3 & 15 & 56 & 116 & 26 & 2 \frac{2854}{6757} \\
15 & -15 & 14 & 58 & 37 & 348 & 346 & 630 & 315 \\
423 & 1237 & 630 & 314 & 1401 & 735 & 375 & 32 \frac{2854}{6757} \\
964 & 45 & 375 & 373 & 630 & 314 & 1401 & 735 & 32 \end{pmatrix}
\]

Here \( \phi' \) is the conformal latitude (sometimes denoted by \( \chi \)) and \( C_{\chi, \phi} \) and \( C_{\phi, \chi} \) are the coefficients in the trigonometric series for converting between \( \phi \) and \( \chi \).

Relation between projected coordinates

\[ \zeta = \zeta' + S(\zeta') \cdot C_{\mu, \chi} \cdot N \\
\zeta' = \zeta + S(\zeta) \cdot C_{\chi, \mu} \cdot N \]

\[
C_{\mu, \chi} = \begin{pmatrix}
\frac{1}{2} & -2 & 48 & -\frac{1}{3} & -12 & 13 & 18 & 7891 \\
48 & -12 & 13 & 18 & 7891 & 7891 & 7891 & 7891 \\
13 & 18 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
18 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 \end{pmatrix}
\]

\[
C_{\chi, \mu} = \begin{pmatrix}
-\frac{1}{2} & -\frac{2}{3} & -\frac{2}{3} & -\frac{2}{3} & -\frac{2}{3} \frac{5}{6} & -\frac{5}{6} & -\frac{5}{6} \\
48 & 48 & 48 & 48 & 48 & 48 & 48 \\
13 & 13 & 13 & 13 & 13 & 13 & 13 \\
18 & 18 & 18 & 18 & 18 & 18 & 18 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 & 7891 & 7891 & 7891 & 7891 & 7891 & 7891 \\
7891 \end{pmatrix}
\]

On the central meridian (\( \lambda = \lambda' = 0 \)), \( \zeta' = \phi' \) is the conformal latitude \( \chi \) and \( \zeta \) plays the role of the rectifying latitude (sometimes denoted by \( \mu \)). \( C_{\mu, \chi} \) and \( C_{\chi, \mu} \) are the coefficients in the trigonometric series for converting between \( \chi \) and \( \mu \).
Legacy ellipsoidal form

The formulas below describe the algorithm used when giving the `+approx` option. They are originally from [Snyder1987], but here quoted from [Evenden1995] and [Evenden2005]. These are less accurate than the formulation above and are only valid within about 5 degrees of the central meridian. Here $M(\phi)$ is the meridional distance.

**Forward projection**

\[
N = \frac{k_0}{(1 - e^2 \sin^2 \phi)^{1/2}}
\]

\[
R = \frac{k_0(1 - e^2)}{(1 - e^2 \sin^2 \phi)^{3/2}}
\]

\[
t = \tan \phi
\]

\[
\eta = \frac{e^2}{1 - e^2 \cos^2 \phi}
\]

\[
x = k_0 \lambda \cos \phi
\]

\[
x + \frac{k_0 \lambda^3 \cos^3 \phi}{3!} (1 - t^2 + \eta^2)
\]

\[
x + \frac{k_0 \lambda^5 \cos^5 \phi}{5!} (5 - 18t^2 + t^4 + 14\eta^2 - 58t^2\eta^2)
\]

\[
x + \frac{k_0 \lambda^7 \cos^7 \phi}{7!} (61 - 479t^2 + 179t^4 - t^6)
\]

\[
y = M(\phi)
\]

\[
y + \frac{k_0 \lambda^2 \sin \phi \cos \phi}{2!}
\]

\[
y + \frac{k_0 \lambda^4 \sin \phi \cos^3 \phi}{4!} (5 - t^2 + 9\eta^2 + 4\eta^4)
\]

\[
y + \frac{k_0 \lambda^6 \sin \phi \cos^5 \phi}{6!} (61 - 58t^2 + t^4 + 270\eta^2 - 330t^2\eta^2)
\]

\[
y + \frac{k_0 \lambda^8 \sin \phi \cos^7 \phi}{8!} (1385 - 3111t^2 + 543t^4 - t^6)
\]

**Inverse projection**

\[
\phi_1 = M^{-1}(y)
\]

\[
N_1 = \frac{k_0}{(1 - e^2 \sin^2 \phi_1)^{1/2}}
\]

\[
R_1 = \frac{k_0(1 - e^2)}{(1 - e^2 \sin^2 \phi_1)^{3/2}}
\]

\[
t_1 = \tan(\phi_1)
\]

\[
\eta_1 = \frac{e^2}{1 - e^2 \cos^2 \phi_1}
\]
\[ \phi = \phi_1 - \frac{t_1 x^2}{2! R_1 N_1} + \frac{t_1 x^4}{4! R_1 N_1^3} (5 + 3t_1^2 + \eta_1^2 - 4\eta_1^4 - 9\eta_1^2 t_1^2) - \frac{t_1 x^6}{6! R_1 N_1^5} (61 + 90t_1^2 + 46\eta_1^2 + 45t_1^4 - 252\eta_1^2 t_1^2) + \frac{t_1 x^8}{8! R_1 N_1^7} (1385 + 3633t_1^2 + 4095t_1^4 + 1575t_1^6) \]

\[ \lambda = \frac{x}{\cos \phi_1} - \frac{x^3}{3! \cos \phi_1} (1 + 2t_1^2 + \eta_1^2) + \frac{x^5}{5! \cos \phi_1} (5 + 6\eta_1^2 + 28t_1^2 - 3\eta_1^2 + 8t_1^2 \eta_1^2) - \frac{x^7}{7! \cos \phi_1} (61 + 662t_1^2 + 1320t_1^4 + 720t_1^6) \]

### 7.1.129.4 Further reading
1. [Wikipedia](#)

### 7.1.130 Tobler-Mercator

New in version 6.0.0.

Equal area cylindrical projection with the same latitudinal spacing as Mercator projection.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical equal area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical only</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global, conventionally truncated at about 80 degrees north and south</td>
</tr>
<tr>
<td>Alias</td>
<td>tobmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

#### 7.1.130.1 Usage

The inappropriate use of the Mercator projection has declined but still occasionally occurs. One method of contrasting the Mercator projection is to present an alternative in the form of an equal area projection. The map projection derived here is thus not simply a pretty Christmas tree ornament: it is instead a complement to Mercator’s conformal navigation anamorphosis and can be displayed as an alternative. The equations for the new map projection preserve the latitudinal stretching of the Mercator while adjusting the longitudinal spacing. This allows placement of the new map adjacent to that of Mercator. The surface area, while drastically warped, maintains the correct magnitude.
Fig. 126: proj-string: +proj=tobmerc

### 7.1.130.2 Parameters

**Note:** All parameters for the projection are optional.

#### +k_0=<value>

Scale factor. Determines scale factor used in the projection.

*Defaults to 1.0.*

#### +lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

#### +x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

7.1.130.3 Mathematical definition

The formulas describing the Tobler-Mercator are taken from Waldo Tobler’s article [Tobler2018]

Spherical form

For the spherical form of the projection we introduce the scaling factor:

\[ k_0 = \cos^2 \phi_{ts} \]

Forward projection

\[ x = k_0 \lambda \]
\[ y = k_0 \ln \left( \tan \left( \frac{\pi}{4} + \frac{\phi}{2} \right) \right) \]

Inverse projection

\[ \lambda = \frac{x}{k_0} \]
\[ \phi = \frac{\pi}{2} - 2 \arctan \left( e^{-y/k_0} \right) \]

7.1.131 Two Point Equidistant

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>tpeqd</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 127: proj-string: +proj=tpeqd +lat_1=60 +lat_2=65
### 7.1.131.1 Parameters

**Note:** All parameters are optional for the projection.

```plaintext
+lon_1=<value>
  Longitude of first point.
+lat_1=<value>
  Latitude of first point.
+lon_2=<value>
  Longitude of second point.
+lat_2=<value>
  Latitude of second point.
+R=<value>
  Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
  See Ellipsoid size parameters for more information.
+x_0=<value>
  False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.
+y_0=<value>
  False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
  Defaults to 0.0.
```

### 7.1.132 Tilted perspective

Tilted Perspective is similar to *Near-sided perspective* (nsper) in that it simulates a perspective view from a height. Where nsper projects onto a plane tangent to the surface, Tilted Perspective orients the plane towards the direction of the view. Thus, extra parameters specifying azimuth and tilt are required beyond nsper’s h. As with nsper, lat_0 & lon_0 are also required for satellite position.
Fig. 128: proj-string: +proj=tpers +h=5500000 +lat_0=40
7.1. Parameters

**Required**

+h=<value>

Height of the viewpoint above the Earth and must be in the same units as the radius of the sphere or semimajor axis of the ellipsoid.

**Optional**

+azi=<value>

Bearing in degrees away from north.

*Defaults to 0.0.*

+tilt=<value>

Angle in degrees away from nadir.

*Defaults to 0.0.*

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

---

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

---

+lat_0=<value>

Latitude of natural origin, latitude of false origin or latitude of projection centre (naming and meaning depend on the projection method).

*Defaults to 0.0.*

---

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_0=1.570796r

See *Projection Units* for more information.

---

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.133 Universal Polar Stereographic

Fig. 129: proj-string: +proj=ups
7.1.133.1 Parameters

**Note:** All parameters are optional for the projection.

**+south**
South polar aspect.

**+lon\_0=<value>**
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

**+ellps=<value>**
The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

**+R=<value>**
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

**+x\_0=<value>**
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y\_0=<value>**
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

7.1.134 Urmaev V

7.1.134.1 Parameters

**Required parameters**

**+n=<value>**
Set the $n$ constant. Value between 0 and 1.
Fig. 130: proj-string: `+proj=urm5 +n=0.9 +alpha=2 +q=4`
Optional parameters

+\(q\)=<value>
Set the \(q\) constant.

+\(\text{alpha}\)=<value>
Set the \(\alpha\) constant.

+\(\text{lon}_0\)=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +\(\text{lon}_0=1.570796r\)

See *Projection Units* for more information.

+\(\text{ellps}\)=<value>
The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

+\(R\)=<value>
Radius of the sphere, given in meters. If used in conjunction with +\(\text{ellps}\), +\(R\) takes precedence.

See *Ellipsoid size parameters* for more information.

+\(x_0\)=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+\(y_0\)=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.135 Urmaev Flat-Polar Sinusoidal

#### 7.1.135.1 Parameters

**Note:** All parameters are optional for the projection.

+\(n\)=<value>
Set the \(n\) constant. Value between 0 and 1.
+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.
7.1.136 Universal Transverse Mercator (UTM)

The Universal Transverse Mercator is a system of map projections divided into sixty zones across the globe, with each zone corresponding to 6 degrees of longitude.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Transverse cylindrical, conformal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, ellipsoidal only</td>
</tr>
<tr>
<td>Defined area</td>
<td>Within the used zone, but transformations of coordinates in adjacent zones can be expected to be accurate as well</td>
</tr>
<tr>
<td>Alias</td>
<td>utm</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

UTM projections are really the *Transverse Mercator* to which specific parameters, such as central meridians, have been applied. The Earth is divided into 60 zones each generally 6° wide in longitude. Bounding meridians are evenly divisible by 6°, and zones are numbered from 1 to 60 proceeding east from the 180th meridian from Greenwich with minor exceptions [Snyder1987].

Fig. 132: UTM zones.
7.1.136.1 Usage

Convert geodetic coordinate to UTM Zone 32 on the northern hemisphere:

```
$ echo 12 56 | proj +proj=utm +zone=32
687071.44
6210141.33
```

Convert geodetic coordinate to UTM Zone 59 on the southern hemisphere:

```
$ echo 174 -44 | proj +proj=utm +zone=59 +south
740526.32
5123750.87
```

7.1.136.2 Parameters

Required

+zone=<value>

Select which UTM zone to use. Can be a value between 1-60.

Optional

+south

Add this flag when using the UTM on the southern hemisphere.

+approx

New in version 6.0.0.

Use faster, less accurate algorithm for the Transverse Mercator.

+algo=auto/evenden_snyder/poder_engsager

New in version 7.1.

Selects the algorithm to use. The hardcoded value and the one defined in `proj.ini` default to `poder_engsager`, that is the most precise one.

When using auto, a heuristics based on the input coordinate to transform is used to determine if the faster Evenden-Snyder method can be used, for faster computation, without causing an error greater than 0.1 mm (for an ellipsoid of the size of Earth)

Note that `+approx` and `+algo` are mutually exclusive.

+ellps=<value>

The name of a built-in ellipsoid definition.

See `Ellipsoids` for more information, or execute `proj -le` for a list of built-in ellipsoid names.

Defaults to "GRS80".
### 7.1.136.3 Further reading

1. Wikipedia

#### 7.1.137 van der Grinten (I)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>vandg</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 133: proj-string: +proj=vandg
7.1.137.1 Parameters

**Note:** All parameters are optional for the projection.

**+lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \(+\text{lon}_0=1.570796r\)

See *Projection Units* for more information.

**+R=<value>**

Radius of the sphere, given in meters. If used in conjunction with \(+\text{ellps}\), \(+R\) takes precedence.

See *Ellipsoid size parameters* for more information.

**+x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

**+y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.138 van der Grinten II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>vandg2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 134: proj-string: \texttt{+proj=vandg2}
7.1.138.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.139 van der Grinten III

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>vandg3</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 135: proj-string: +proj=vandg3
## 7.1.139.1 Parameters

**Note:** All parameters are optional for the projection.

### +lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

### +R=<value>

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

### +x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### +y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

## 7.1.140 van der Grinten IV

### Classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Miscellaneous</th>
</tr>
</thead>
</table>

### Available forms

- Forward spherical projection

### Defined area

- Global

### Alias

- vandg4

### Domain

- 2D

### Input type

- Geodetic coordinates

### Output type

- Projected coordinates
7.1.140.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
   Defaults to 0.0.

   Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
   Example: +lon_0=1.570796r
   See Projection Units for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   See Ellipsoid size parameters for more information.

+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
   Defaults to 0.0.
+"y_0"=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.141 Vitkovsky I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>vitk1</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 137: proj-string: +proj=vitk1 +lat_1=45 +lat_2=55
7.1.141.1 Parameters

Required

+lat_1=<value>
First standard parallel.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_1=1.570796r

See *Projection Units* for more information.

+lat_2=<value>
Second standard parallel.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_2=1.570796r

See *Projection Units* for more information.

Optional

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*
+y₀=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

7.1.142 Wagner I (Kavrayskiy VI)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag1</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 138: proj-string: +proj=wag1

Note: This projection name may also be transliterated as Kavraisky VI.

7.1.142.1 Parameters

Note: All parameters are optional for the projection.

+lon₀=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
 Defaults to 0.0.
Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

7.1.143 Wagner II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 139: proj-string: +proj=wag2
\[ x = 0.92483 \lambda \cos \theta \]
\[ y = 1.38725 \theta \]
\[ \sin \theta = 0.88022 \sin(0.8855 \phi) \]

### 7.1.143.1 Parameters

**Note:** All parameters are optional for the projection.

+**lon_0=<value>**

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+**R=<value>**

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+**x_0=<value>**

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+**y_0=<value>**

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.144 Wagner III

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag3</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 140: proj-string: \texttt{+proj=wag3}

\[
x = \left[ \cos \phi_{ts} / \cos(2\phi_{ts}/3) \right] \lambda \cos(2\phi/3)
\]
\[
y = \phi
\]

7.1.144.1 Parameters

\textbf{Note:} All parameters are optional for the projection.

\texttt{+lat_ts=<value>}

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over \texttt{+k_0} if both options are used together.

\textit{Defaults to 0.0}.

\textbf{Note:} The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lat_ts=1.570796r}

See \textit{Projection Units} for more information.

\texttt{+lon_0=<value>}

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

\textit{Defaults to 0.0}.

\textbf{Note:} The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: \texttt{+lon_0=1.570796r}
See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.145 Wagner IV

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag4</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 141: proj-string: +proj=wag4
7.1.145.1 Parameters

**Note:** All parameters are optional.

+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See *Projection Units* for more information.

+R=<value>

Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See *Ellipsoid size parameters* for more information.

+x_0=<value>

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

+y_0=<value>

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

*Defaults to 0.0.*

### 7.1.146 Wagner V

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag5</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
7.146.1 Parameters

Note: All parameters are optional.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r

See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.147 Wagner VI

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag6</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 143: proj-string: `+proj=wag6`

7.1.147.1 Parameters

**Note:** All parameters are optional for the Wagner VI projection.

`+lon_0=<value>`

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.
+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
 Defaults to 0.0.

7.1.148 Wagner VII

<table>
<thead>
<tr>
<th>Classification</th>
<th>Azimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wag7</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 144: proj-string: +proj=wag7
7.1.149 Web Mercator / Pseudo Mercator

New in version 5.1.0.

The Web Mercator / Pseudo Mercator projection is a cylindrical map projection. This is a variant of the regular Mercator projection, except that the computation is done on a sphere, using the semi-major axis of the ellipsoid.

From Wikipedia:

This projection is widely used by the Web Mercator, Google Web Mercator, Spherical Mercator, WGS 84 Web Mercator[1] or WGS 84/Pseudo-Mercator is a variant of the Mercator projection and is the de facto standard for Web mapping applications. [...] It is used by virtually all major online map providers [...] Its official EPSG identifier is EPSG:3857, although others have been used historically.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cylindrical (non conformant if used with ellipsoid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>webmerc</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

7.1.149.1 Usage

Example:

```bash
$ echo 2 49 | proj +proj=webmerc +datum=WGS84
222638.98 6274861.39
```

7.1.149.2 Parameters

**Note:** All parameters for the projection are optional, except the ellipsoid definition, which is WGS84 for the typical use case of EPSG:3857. In which case, the other parameters are set to their default 0 value.

```bash
+ellps=<value>

The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute *proj -le* for a list of built-in ellipsoid names.

*Defaults to "GRS80".*
```

```bash
+lon_0=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

*Defaults to 0.0.*
```

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`
PROJ coordinate transformation software library, Release 9.3.1

See Projection Units for more information.

+x_<0>=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_<0>=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

7.1.149.3 Mathematical definition

The formulas describing the Mercator projection are all taken from G. Evenden's libproj manuals [Evenden2005].

Forward projection

\[ x = \lambda \]
\[ y = \ln \left( \tan \left( \frac{\pi}{4} + \frac{\phi}{2} \right) \right) \]

Inverse projection

\[ \lambda = x \]
\[ \phi = \frac{\pi}{2} - 2 \arctan \left( e^{-y} \right) \]

7.1.149.4 Further reading

1. Wikipedia

7.1.150 Werenskiold I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>weren</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>
Fig. 145: proj-string: +proj=weren

7.1.150.1 Parameters

Note: All parameters are optional for the projection.

+lon_0=<value>
   Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
   
   Defaults to 0.0.

   Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.
   
   Example: +lon_0=1.570796r

   See Projection Units for more information.

+R=<value>
   Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
   
   See Ellipsoid size parameters for more information.

+x_0=<value>
   False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
   
   Defaults to 0.0.

+y_0=<value>
   False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
   
   Defaults to 0.0.
### 7.1.151 Winkel I

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wink1</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 146: proj-string: +proj=wink1

#### 7.1.151.1 Parameters

**Note:** All parameters are optional for the projection.

+\(\text{lat}_\text{ts}\)=<value>

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over +\(k_\theta\) if both options are used together.

*Defaults to 0.0.*

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +\(\text{lat}_\text{ts}=1.570796r\)

See *Projection Units* for more information.

+\(\text{lon}_\theta\)=<value>

Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
 Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lon_0=1.570796r`

See *Projection Units* for more information.

`+R=<value>`

Radius of the sphere, given in meters. If used in conjunction with `+ellps`, `+R` takes precedence.

See *Ellipsoid size parameters* for more information.

`+x_0=<value>`

False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

`+y_0=<value>`

False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

### 7.1.152 Winkel II

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudocylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse, spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wink2</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

### 7.1.152.1 Parameters

**Note:** All parameters are optional for the projection.

`+lat_ts=<value>`

Latitude of true scale. Defines the latitude where scale is not distorted. Takes precedence over `+k_0` if both options are used together.

Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: `+lat_ts=1.570796r`
PROJ coordinate transformation software library, Release 9.3.1

Fig. 147: proj-string: +proj=wink2

See Projection Units for more information.

+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See Projection Units for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.

See Ellipsoid size parameters for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.

Defaults to 0.0.
7.1.153 Winkel Tripel

<table>
<thead>
<tr>
<th>Classification</th>
<th>Pseudoazimuthal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available forms</td>
<td>Forward and inverse spherical projection</td>
</tr>
<tr>
<td>Defined area</td>
<td>Global</td>
</tr>
<tr>
<td>Alias</td>
<td>wintri</td>
</tr>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected coordinates</td>
</tr>
</tbody>
</table>

Fig. 148: proj-string: +proj=wintri

7.1.153.1 Parameters

Note: All parameters are optional for the projection.

+lat_1=<value>
First standard parallel.

Defaults to 0.0.

Note: The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lat_1=1.570796r

See Projection Units for more information.
+lon_0=<value>
Central meridian/longitude of natural origin, longitude of origin or longitude of false origin (naming and meaning depend on the projection method).
Defaults to 0.0.

**Note:** The default convention is to interpret this value as decimal degrees. To specify radians instead, follow the value with the "r" character.

Example: +lon_0=1.570796r
See *Projection Units* for more information.

+R=<value>
Radius of the sphere, given in meters. If used in conjunction with +ellps, +R takes precedence.
See *Ellipsoid size parameters* for more information.

+x_0=<value>
False easting, easting at false origin or easting at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

+y_0=<value>
False northing, northing at false origin or northing at projection centre (naming and meaning depend on the projection method). Always in meters.
Defaults to 0.0.

### 7.2 Conversions

Conversions are coordinate operations in which both coordinate reference systems are based on the same datum. In PROJ projections are differentiated from conversions.

#### 7.2.1 Axis swap

New in version 5.0.0.
Change the order and sign of 2,3 or 4 axes.

<table>
<thead>
<tr>
<th>Alias</th>
<th>axisswap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D or 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

Each of the possible four axes are numbered with 1--4, such that the first input axis is 1, the second is 2 and so on. The output ordering is controlled by a list of the input axes re-ordered to the new mapping.
7.2.1.1 Usage

Reversing the order of the axes:

+proj=axisswap +order=4,3,2,1

Swapping the first two axes (x and y):

+proj=axisswap +order=2,1,3,4

The direction, or sign, of an axis can be changed by adding a minus in front of the axis-number:

+proj=axisswap +order=1,-2,3,4

It is only necessary to specify the axes that are affected by the swap operation:

+proj=axisswap +order=2,1

7.2.1.2 Parameters

+order=<list>

Ordered comma-separated list of axis, e.g. +order=2,1,3,4. Adding a minus in front of an axis number results in a change of direction for that axis, e.g. southward instead of northward.

Required.

7.2.2 Geodetic to cartesian conversion

New in version 5.0.0.

Convert geodetic coordinates to cartesian coordinates (in the forward path).

<table>
<thead>
<tr>
<th>Alias</th>
<th>cart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geocentric cartesian coordinates</td>
</tr>
</tbody>
</table>

This conversion converts geodetic coordinate values (longitude, latitude, elevation above ellipsoid) to their geocentric (X, Y, Z) representation, where the first axis (X) points from the Earth centre to the point of longitude=0, latitude=0, the second axis (Y) points from the Earth centre to the point of longitude=90, latitude=0 and the third axis (Z) points to the North pole.

7.2.2.1 Usage

Convert geodetic coordinates to cartesian (uses default +ellps=GRS80):

```
echo 17.7562015132 45.3935192042 133.12 2017.8 | cct +proj=cart 4272922.1553 1368283.0597 4518261.3501 2017.8000
```
7.2.2 Parameters

+ellps=<value>

   The name of a built-in ellipsoid definition.
   See Ellipsoids for more information, or execute proj -1e for a list of built-in ellipsoid names.
   Defaults to "GRS80".

7.2.3 Geocentric Latitude

New in version 5.0.0.

Convert from Geodetic Latitude to Geocentric Latitude (in the forward path).

<table>
<thead>
<tr>
<th>Alias</th>
<th>geoc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geocentric angular coordinates</td>
</tr>
</tbody>
</table>

The geodetic (or geographic) latitude (also called planetographic latitude in the context of non-Earth bodies) is the angle between the equatorial plane and the normal (vertical) to the ellipsoid surface at the considered point. The geodetic latitude is what is normally used everywhere in PROJ when angular coordinates are expected or produced.

The geocentric latitude (also called planetocentric latitude in the context of non-Earth bodies) is the angle between the equatorial plane and a line joining the body centre to the considered point.

Note: This conversion must be distinguished from the Geodetic to cartesian conversion which converts geodetic coordinates to geocentric coordinates in the cartesian domain.
7.2.3.1 Mathematical definition

The formulas describing the conversion are taken from [Snyder1987] (equation 3-28)
Let \( \phi' \) to be the geocentric latitude and \( \phi \) the geodetic latitude, then

\[
\phi' = \arctan \left[ (1 - e^2) \tan(\phi) \right]
\]

The geocentric latitude is consequently lesser (in absolute value) than the geodetic latitude, except at the equator and the poles where they are equal.
On a sphere, they are always equal.

7.2.3.2 Usage

Converting from geodetic latitude to geocentric latitude:

```
+proj=geoc
```

Converting from geocentric latitude to geodetic latitude:

```
+proj=pipeline +step +proj=geoc +inv
```

7.2.3.3 Parameters

```
+ellps=<value>
```

The name of a built-in ellipsoid definition.

See **Ellipsoids** for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

7.2.4 Lat/long (Geodetic alias)

Passes geodetic coordinates through unchanged.

<table>
<thead>
<tr>
<th>Aliases</th>
<th>latlon, latlong, lonlat, longlat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates</td>
</tr>
</tbody>
</table>

**Note:** Can not be used with the `proj` application.
7.2.4.1 Parameters

No parameters will affect the output of the operation if used on its own. However, the parameters below can be used in a declarative manner when used with cs2cs or in a transformation pipeline.

+ellps=<value>
   The name of a built-in ellipsoid definition.
   See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.
   Defaults to "GRS80".

+datum=<value>
   Declare the datum used with the coordinates. Available options are: WGS84, GGRS87, NAD38, NAD27, potsdam, carthage, hermannskogel, ire65, nzgd49, OSGB336.

   Note: The +datum option is primarily available to support the legacy use of PROJ.4 strings as CRS descriptors and should in most cases be avoided.

+towgs84=<list>
   A list of three or seven comma separated Helmert parameters that maps the input coordinates to the WGS84 datum.

7.2.5 No operation

New in version 6.1.0.

Pass a coordinate through unchanged.

The no operation is a dummy operation that returns whatever is passed to it as seen in this example:

$ echo 12 34 56 78 | cct +proj=noop
12.0000 34.0000 56.0000 78.0000

The operation has no options and default options will not affect the output.

7.2.6 Pop coordinate value to pipeline stack

New in version 6.0.0.

Retrieve components of a coordinate that was saved in a previous pipeline step.
This operation makes it possible to retrieve coordinate components that was saved in previous pipeline steps. A retrieved coordinate component is loaded, or popped, from a memory stack that is part of a pipeline. The pipeline coordinate stack is inspired by the stack data structure that is commonly used in computer science. There are four stacks available: One for each coordinate dimension. The dimensions, or coordinate components, are numbered 1--4. It is only possible to move data to and from the stack within the same coordinate component number. Values can be saved to the stack by using the push operation.

If the pop operation is used by itself, e.g. not in a pipeline, it will function as a no-operation that passes the coordinate through unchanged. Similarly, if no coordinate component is available on the stack to be popped the operation does nothing.

### 7.2.6.1 Examples

A common use of the push and pop operations is in 3D Helmert transformations where only the horizontal components are needed. This is often the case when combining heights from a legacy vertical reference with a modern geocentric reference. Below is an example of such a transformation, where the horizontal part is transformed with a Helmert operation but the vertical part is kept exactly as the input was.

```
$ echo 12 56 12.3 2020 | cct +proj=pipeline \
  +step +proj=push +v_3 \
  +step +proj=cart +ellps=GRS80 \
  +step +proj=helmert +x=3000 +y=1000 +z=2000 \
  +step +proj=cart +ellps=GRS80 +inv \
  +step +proj=pop +v_3 \
12.0056753463 55.9866540552 12.3000 2000.0000
```

Note that the third coordinate component in the output is the same as the input.

The same transformation without the push and pop operations would look like this:

```
$ echo 12 56 12.3 2020 | cct +proj=pipeline \
  +step +proj=cart +ellps=GRS80 \
  +step +proj=helmert +x=3000 +y=1000 +z=2000 \
  +step +proj=cart +ellps=GRS80 +inv \
12.0057 55.9867 3427.7404 2000.0000
```

Here the vertical component is adjusted significantly.

### 7.2.6.2 Parameters

+ v_1

Retrieves the first coordinate component from the pipeline stack

+ v_2

Retrieves the second coordinate component from the pipeline stack

+ v_3

Retrieves the third coordinate component from the pipeline stack

+ v_4

Retrieves the fourth coordinate component from the pipeline stack
7.2.6.3 Further reading

1. Stack data structure on Wikipedia

7.2.7 Push coordinate value to pipeline stack

New in version 6.0.0.

Save components of a coordinate from one step of a pipeline and make it available for retrieving in another pipeline step.

<table>
<thead>
<tr>
<th>Alias</th>
<th>push</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

This operations allows for components of coordinates to be saved for application in a later step. A saved coordinate component is moved, or pushed, to a memory stack that is part of a pipeline. The pipeline coordinate stack is inspired by the stack data structure that is commonly used in computer science. There's four stacks available: One four each coordinate dimension. The dimensions, or coordinate components, are numbered 1--4. It is only possible to move data to and from the stack within the same coordinate component number. Values can be moved off the stack again by using the pop operation.

If the push operation is used by itself, e.g. not in a pipeline, it will function as a no-operation that passes the coordinate through unchanged.

7.2.7.1 Examples

A common use of the push and pop operations is in 3D Helmert transformations where only the horizontal components are needed. This is often the case when combining heights from a legacy vertical reference with a modern geocentric reference. Below is a an example of such a transformation, where the horizontal part is transformed with a Helmert operation but the vertical part is kept exactly as the input was.

```bash
$ echo 12 56 12.3 2020 | cct +proj=pipeline \
+step +proj=push +v_3 \
+step +proj=cart \
+step +proj=helmert +x=3000 +y=1000 +z=2000 \
+step +proj=cart +inv \
+step +proj=pop +v_3

12.0056753463 55.9866540552 12.3000 2000.0000
```

Note that the third coordinate component in the output is the same as the input.

The same transformation without the push and pop operations would look like this:

```bash
$ echo 12 56 12.3 2020 | cct +proj=pipeline \
+step +proj=cart \
+step +proj=helmert +x=3000 +y=1000 +z=2000 \
+step +proj=cart +inv

12.0057 55.9867 3427.7404 2000.0000
```

Here the vertical component is adjusted significantly.
7.2.7.2 Parameters

+\text{v}_1

Stores the first coordinate component on the pipeline stack

+\text{v}_2

Stores the second coordinate component on the pipeline stack

+\text{v}_3

Stores the third coordinate component on the pipeline stack

+\text{v}_4

Stores the fourth coordinate component on the pipeline stack

7.2.7.3 Further reading

1. Stack data structure on Wikipedia

7.2.8 Set coordinate value

New in version 7.0.0.

Set component(s) of a coordinate to a fixed value.

<table>
<thead>
<tr>
<th>Alias</th>
<th>set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

This operation allows for components of coordinates to be set to a fixed value. This may be useful in pipeline when a step requires some component, typically an elevation or a date, to be set to a fixed value.

7.2.8.1 Example

In the ETRS89 to Dutch RD with NAP height transformation, the used ellipsoidal height for the Helmert transformation is not the NAP height, but the height is set to 0 m. This is an unconventional trick to get the same results as when the effect of the Helmert transformation is included in the horizontal NTv2 grid. For the forward transformation from ETRS89 to RD with NAP height, we need to set the ellipsoidal ETRS89 height for the Helmert transformation to the equivalent of 0 m NAP. This is 43 m for the centre of the Netherlands and this value can be used as an approximation elsewhere (the effect of this approximation is below 1 mm for the horizontal coordinates, in an area up to hundreds of km outside the Netherlands).

The $+\text{proj}=\text{set} +\text{v}_3=0$ close to the end of the pipeline is to make it usable in the reverse direction.

```
$ cct -t 0 -d 4 +proj=pipeline \
  +step +proj=unitconvert +xy_in=deg +xy_out=rad \
  +step +proj=axisswap +order=2,1 \
  +step +proj=vgridshift +grids=nlgeo2018.gtx \
  +step +proj=push +v_3 \n  +step +proj=set +v_3=43 \n  +step +proj=cart \
  +step +proj=helmert +x=-565.7346 +y=-50.4058 +z=-465.2895 +rx=-0.395023 +ry=0.
```

(continues on next page)
330776 +rz=-1.876073 +s=-4.07242 +convention=coordinate_frame +exact 
+step +proj=cart +inv +ellps=bessel 
+step +proj=hgridshift +inv +grids=rdcorr2018.gsb,null 
+step +proj=sterea +lat_0=52.156160556 +lon_0=5.387638889 +k=0.9999079 +x_0=155000
+y_0=463000 +ellps=bessel 
+step +proj=set +v_3=0 
+step +proj=pop +v_3

7.2.8.2 Parameters

+v_1=value
   Set the first coordinate component to the specified value

+v_2=value
   Set the second coordinate component to the specified value

+v_3=value
   Set the third coordinate component to the specified value

+v_4=value
   Set the fourth coordinate component to the specified value

7.2.9 Geocentric to topocentric conversion

New in version 8.0.0.

Convert geocentric coordinates to topocentric coordinates (in the forward path).

<table>
<thead>
<tr>
<th>Alias</th>
<th>topocentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geocentric cartesian coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Topocentric cartesian coordinates</td>
</tr>
</tbody>
</table>

This operation converts geocentric coordinate values (X, Y, Z) to topocentric (E/East, N/North, U/Up) values. This is also sometimes known as the ECEF (Earth Centered Earth Fixed) to ENU conversion.

Topocentric coordinates are expressed in a frame whose East and North axis form a local tangent plane to the Earth's ellipsoidal surface fixed to a specific location (the topocentric origin), and the Up axis points upwards along the normal to that plane.
The topocentric origin is a required parameter of the conversion, and can be expressed either as geocentric coordinates ($X_0, Y_0$ and $Z_0$) or as geographic coordinates ($\text{lat}_0, \text{lon}_0, h_0$).

When conversion between geographic and topocentric coordinates is desired, the topocentric conversion must be preceded by the *Geodetic to cartesian conversion* conversion to perform the initial geographic to geocentric coordinates conversion.

The formulas used come from the "Geocentric/topocentric conversions" paragraph of [IOGP2018]. *+proj=topocentric* alone corresponds to the EPSG:9836 conversion method, *+proj=cart* followed by *+proj=topocentric* corresponds to EPSG:9837.
7.2.9.1 Usage

Convert geocentric coordinates to topocentric coordinates, with the topocentric origin specified in geocentric coordinates:

```
    echo 3771793.968 140253.342 5124304.349 2020 | \\
    cct -d 3 +proj=topocentric +X_0=3652755.3058 +Y_0=319574.6799 +Z_0=5201547.3536 -189013.869 -128642.040 -4220.171 2020.0000
```

Convert geographic coordinates to topocentric coordinates, with the topocentric origin specified in geographic coordinates:

```
    echo 2.12955 53.80939444 73 2020 | cct -d 3 +proj=pipeline \\
    +step +proj=cart \\
    +step +proj=topocentric +lon_0=5 +lat_0=55 +h_0=200 -189013.869 -128642.040 -4220.171 2020.0000
```

7.2.9.2 Parameters

+**ellps**=<value>

    The name of a built-in ellipsoid definition.

    See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

    Defaults to "GRS80".

**Topocentric origin described as geocentric coordinates**

**Note:** The below options are mutually exclusive with the ones to express the origin as geographic coordinates.

+**X_0**=<value>

    Geocentric X value of the topocentric origin (in metre)

+**Y_0**=<value>

    Geocentric Y value of the topocentric origin (in metre)

+**Z_0**=<value>

    Geocentric Z value of the topocentric origin (in metre)

**Topocentric origin described as geographic coordinates**

**Note:** The below options are mutually exclusive with the ones to express the origin as geocentric coordinates.

+**lat_0**=<value>

    Latitude of topocentric origin (in degree)
+lon_0=<value>
    Longitude of topocentric origin (in degree)

+h_0=<value>
    Ellipsoidal height of topocentric origin (in metre)
    Defaults to 0.0.

7.2.10 Unit conversion

New in version 5.0.0.

Convert between various distance, angular and time units.

<table>
<thead>
<tr>
<th>Alias</th>
<th>unitconvert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D or 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

There are many examples of coordinate reference systems that are expressed in other units than the meter. There are also many cases where temporal data has to be translated to different units. The `unitconvert` operation takes care of that.

Many North American systems are defined with coordinates in feet. For example in Vermont:

```
+proj=pipeline \
+step +proj=tmerc +lat_0=42.5 +lon_0=-72.5 +k_0=0.999964286 +x_0=500000.00001016 \
+step +proj=unitconvert +xy_out=us-ft
```

Often when working with GNSS data the timestamps are presented in GPS-weeks, but when the data transformed with the `helmert` operation timestamps are expected to be in units of decimalyears. This can be fixed with `unitconvert`:

```
+proj=pipeline \
+step +proj=unitconvert +t_in=gps_week +t_out=decimalyear \
+step +proj=helmert +epoch=2000.0 +t_obs=2017.5 ...
```

7.2.10.1 Parameters

+xy_in=<unit> or <conversion_factor>
    Horizontal input units. See Distance units and Angular units for a list of available units. Default: meter. <conversion_factor> is the conversion factor from the input unit to metre for linear units, or to radian for angular units. Default if not given: meters.

+xy_out=<unit> or <conversion_factor>
    Horizontal output units. See Distance units and Angular units for a list of available units. Default: meter. <conversion_factor> is the conversion factor from the output unit to metre for linear units, or to radian for angular units. Default if not given: meters.

+z_in=<unit> or <conversion_factor>
    Vertical output units. See Distance units and Angular units for a list of available units. <conversion_factor> is the conversion factor from the input unit to metre for linear units, or to radian for angular units.
+z_out=<unit> or <conversion_factor>

Vertical output units. See Distance units and Angular units for a list of available units. <conversion_factor> is the conversion factor from the output unit to metre for linear units, or to radian for angular units.

+t_in=<unit>

Temporal input units. See Time units for a list of available units.

+t_out=<unit>

Temporal output units. See Time units for a list of available units.

### 7.2.10.2 Distance units

In the table below all distance units supported by PROJ are listed. The same list can also be produced on the command line with `proj` or `cs2cs`, by adding the `-lu` flag when calling the utility.

<table>
<thead>
<tr>
<th>Label</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>km</td>
<td>Kilometer</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>dm</td>
<td>Decimeter</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>kmi</td>
<td>International Nautical Mile</td>
</tr>
<tr>
<td>in</td>
<td>International Inch</td>
</tr>
<tr>
<td>ft</td>
<td>International Foot</td>
</tr>
<tr>
<td>yd</td>
<td>International Yard</td>
</tr>
<tr>
<td>mi</td>
<td>International Statute Mile</td>
</tr>
<tr>
<td>fath</td>
<td>International Fathom</td>
</tr>
<tr>
<td>ch</td>
<td>International Chain</td>
</tr>
<tr>
<td>link</td>
<td>International Link</td>
</tr>
<tr>
<td>us-in</td>
<td>U.S. Surveyor's Inch</td>
</tr>
<tr>
<td>us-ft</td>
<td>U.S. Surveyor's Foot</td>
</tr>
<tr>
<td>us-yd</td>
<td>U.S. Surveyor's Yard</td>
</tr>
<tr>
<td>us-ch</td>
<td>U.S. Surveyor's Chain</td>
</tr>
<tr>
<td>us-mi</td>
<td>U.S. Surveyor's Statute Mile</td>
</tr>
<tr>
<td>ind-yd</td>
<td>Indian Yard</td>
</tr>
<tr>
<td>ind-ft</td>
<td>Indian Foot</td>
</tr>
<tr>
<td>ind-ch</td>
<td>Indian Chain</td>
</tr>
</tbody>
</table>

### 7.2.10.3 Angular units

New in version 5.2.0.

In the table below all angular units supported by PROJ `unitconvert` are listed.

<table>
<thead>
<tr>
<th>Label</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>deg</td>
<td>Degree</td>
</tr>
<tr>
<td>grad</td>
<td>Grad</td>
</tr>
<tr>
<td>rad</td>
<td>Radian</td>
</tr>
</tbody>
</table>
7.2.10.4 Time units

In the table below all time units supported by PROJ are listed.

<table>
<thead>
<tr>
<th>Label</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>mjd</td>
<td>Modified Julian date</td>
</tr>
<tr>
<td>decimalyear</td>
<td>Decimal year</td>
</tr>
<tr>
<td>gps_week</td>
<td>GPS Week</td>
</tr>
<tr>
<td>yyyymmdd</td>
<td>Date in yyyymmdd format</td>
</tr>
</tbody>
</table>

Note: When converting time units from a date-only format (yyyymmdd), PROJ assumes a time value of 00:00 midnight. When converting time units to a date-only format, PROJ rounds to the nearest date at 00:00 midnight. That is, any time values less than 12:00 noon will round to 00:00 on the same day. Time values greater than or equal to 12:00 noon will round to 00:00 on the following day.

7.3 Transformations

Transformations coordinate operation in which the two coordinate reference systems are based on different datums.

7.3.1 Affine transformation

New in version 6.0.0.

The affine transformation applies translation and scaling/rotation terms on the x,y,z coordinates, and translation and scaling on the temporal coordinate.

<table>
<thead>
<tr>
<th>Alias</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>affine</td>
<td>affine</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Domain</th>
<th>Input type</th>
<th>Output type</th>
</tr>
</thead>
<tbody>
<tr>
<td>4D</td>
<td>XYZT</td>
<td>XYZT</td>
</tr>
</tbody>
</table>

By default, the parameters are set for an identity transforms. The transformation is reversible unless the determinant of the sji matrix is 0, or tscale is 0

This can be used to implement:

- EPSG "Affine parametric transformation" of code 9624 by setting $A0$, $A1$, $A2$, $B0$, $B1$, $B2$ EPSG parameters to respectively $xoff$, $s11$, $s12$, $yoff$, $s21$, $s21$ PROJ parameters.

- EPSG "Similarity transformation" of code 9621 by setting:
  - $xoff$ to $X_{T0}$
  - $yoff$ to $Y_{T0}$
  - $s11$ to $M \cos \theta$
  - $s12$ to $M \sin \theta$
  - $s21$ to $-M \sin \theta$
  - $s22$ to $M \cos \theta$
where:

- \(X_{T0}\) is the first ordinate of the origin point of the source CRS expressed in the target CRS.
- \(Y_{T0}\) is the second ordinate of the origin point of the source CRS expressed in the target CRS.
- \(M\) is the multiplication factor applied to coordinates in the source CRS to obtain the correct scale of the target CRS.
- \(\theta\) is the angle about which the axes of the source CRS need to be rotated to coincide with the axes of the target CRS, counter-clockwise being positive.

### 7.3.1.1 Parameters

**Optional**

\[+xoff=<value>\]
Offset in X. Default value: 0

\[+yoff=<value>\]
Offset in Y. Default value: 0

\[+zoff=<value>\]
Offset in Z. Default value: 0

\[+toff=<value>\]
Offset in T. Default value: 0

\[+s11=<value>\]
Rotation/scaling term. Default value: 1

\[+s12=<value>\]
Rotation/scaling term. Default value: 0

\[+s13=<value>\]
Rotation/scaling term. Default value: 0

\[+s21=<value>\]
Rotation/scaling term. Default value: 0

\[+s22=<value>\]
Rotation/scaling term. Default value: 1

\[+s31=<value>\]
Rotation/scaling term. Default value: 0

\[+s32=<value>\]
Rotation/scaling term. Default value: 0

\[+s33=<value>\]
Rotation/scaling term. Default value: 1

\[+tscale=<value>\]
Time scaling term. Default value: 1
Mathematical description

$$\begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}^{dest} = \begin{bmatrix} xoff \\ yoff \\ zoff \\ toff \end{bmatrix} + \begin{bmatrix} s_{11} & s_{12} & s_{13} & 0 \\ s_{21} & s_{22} & s_{23} & 0 \\ s_{31} & s_{32} & s_{33} & 0 \\ 0 & 0 & 0 & t\text{scale} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ T \end{bmatrix}^{source}$$  \quad (7.1)

7.3.2 Multi-component time-based deformation model

New in version 7.1.0.

<table>
<thead>
<tr>
<th>Alias</th>
<th>defmodel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input type</td>
<td>Geodetic or projected coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic or projected coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Available forms</td>
<td>Forward and inverse</td>
</tr>
</tbody>
</table>

The defmodel transformation can be used to represent most deformation models currently in use, in particular for areas subject to complex deformation, including large scale secular crustal deformation near plate boundaries and vertical deformation due to Glacial Isostatic Adjustment (GIA). These can often be represented by a constant velocity model. Additionally, many areas suffer episodic deformation events such as earthquakes and aseismic slow slip event.

The transformation relies on a "master" JSON file, describing general metadata on the deformation model, its spatial and temporal extent, and listing spatial components whose values are stored in Geodetic TIFF grids (GTG). The valuation of each component is modulated by a time function (constant, step, reverse step, velocity, piecewise, exponential).

All details on the content of this JSON file are given in the Proposal for encoding of a Deformation Model.

If input coordinates are given in the geographic domain (resp. projected domain), the output will also be in the geographic domain (resp. projected domain). The domain should be the corresponding to the source_crs metadata of the model.

This transformation is a generalization of the Kinematic datum shifting utilizing a deformation model transformation.

7.3.2.1 Parameters

**Required**

+model=<filename>

Filename to the JSON master file for the deformation model. This file must validate against the deformation_model.schema.json JSON schema.
7.3.2.2 Example

Transforming a point with the LINZ NZGD2000 deformation model:

```
echo 166.7133850980 -44.5105886020 293.3700 2007.689 |
cct +proj=defmodel +model=nzgd2000-20180701.json
```

7.3.3 Kinematic datum shifting utilizing a deformation model

New in version 5.0.0.

Perform datum shifts means of a deformation/velocity model.

<table>
<thead>
<tr>
<th>Alias</th>
<th>deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input type</td>
<td>Cartesian coordinates (spatial), decimalyears (temporal).</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates (spatial), decimalyears (temporal).</td>
</tr>
<tr>
<td>Domain</td>
<td>4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates</td>
</tr>
</tbody>
</table>

The deformation operation is used to adjust coordinates for intraplate deformations. Usually the transformation parameters for regional plate-fixed reference frames such as the ETRS89 does not take intraplate deformation into account. It is assumed that tectonic plate of the region is rigid. Often times this is true, but near the plate boundary and in areas with post-glacial uplift the assumption breaks. Intraplate deformations can be modelled and then applied to the coordinates so that they represent the physical world better. In PROJ this is done with the deformation operation.

Starting with PROJ 7.0, it is recommended to store both the horizontal and vertical velocities in a single GeoTIFF file (Geodetic TIFF grids (GTG)). Grid values are expected to be in units of mm/year. Using GDAL for construction of new grids is recommended. Prior to PROJ 7.0, the horizontal grid used to be stored in CTable2 format and the vertical grid in the GTX format. Both grids GDAL both reads and writes both file formats.

More complex deformations can be done with the Multi-component time-based deformation model transformation.

7.3.3.1 Example

In [Hakli2016] coordinate transformation including a deformation model is described. The paper describes how coordinates from the global ITRFxx frames are transformed to the local Nordic realisations of ETRS89. Scandinavia is an area with significant post-glacial rebound. The deformations from the post-glacial uplift is not accounted for in the official ETRS89 transformations so in order to get accurate transformations in the Nordic countries it is necessary to apply the deformation model. The transformation from ITRF2008 to the Danish realisation of ETRS89 is in PROJ described as:

```
proj = pipeline ellps = GRS80
# ITRF2008@t_obs -> ITRF2000@t_obs
step init = ITRF2008:ITRF2000
# ITRF2000@t_obs -> ETRF2000@t_obs
step proj=helmert t_epoch = 2000.0 convention=position_vector
  x = 0.054 rx = 0.000891 drx = 8.1e-05
  y = 0.051 ry = 0.00539 dry = 0.00049
  z = -0.048 rz = -0.008712 drz = -0.000792
# ETRF2000@t_obs -> NKG_ETRF00@2000.0
step proj = deformation t_epoch = 2000.0
```

(continues on next page)
grids = ./eur_nkg_nkgrf03vel_realigned.tif
inv
# NKG_ETRF@2000.0 -> ETRF92@2000.0
step proj=helmert convention=position_vector s = -0.009420e
  x = 0.03863  rx = 0.00617753
  y = 0.147    ry = 5.064e-05
  z = 0.02776  rz = 4.729e-05
# ETRF92@2000.0 -> ETRF92@1994.704
step proj = deformation dt = -5.296
  grids = ./eur_nkg_nkgrf03vel_realigned.tif

From this we can see that the transformation from ITRF2008 to the Danish realisation of ETRS89 is a combination of Helmert transformations and adjustments with a deformation model. The first use of the deformation operation is:

```plaintext
proj = deformation t_epoch = 2000.0 grids = ./eur_nkg_nkgrf03vel_realigned.tif
```

Here we set the central epoch of the transformation, 2000.0. The observation epoch is expected as part of the input coordinate tuple. The deformation model is described by a single grid, specified with `+grids`.

### 7.3.3.2 Parameters

#### +grids=<list>

New in version 7.0.0.

Comma-separated list of grids to load. If a grid is prefixed by an `@` the grid is considered optional and PROJ will not complain if the grid is not available.

Grids should be in GeoTIFF format (*Geodetic TIFF grids (GTG)*) with the first 3 components being respectively the easting, northing and up velocities in mm/year. Setting the Description and Unit Type GDAL band metadata items is strongly recommended, so that gdalinfo reports:

```plaintext
Band 1 Block=... Type=Float32, ColorInterp=Gray
  Description = east_velocity
  Unit Type: mm/year
Band 2 Block=... Type=Float32, ColorInterp=Undefined
  Description = north_velocity
  Unit Type: mm/year
Band 3 Block=... Type=Float32, ColorInterp=Undefined
  Description = up_velocity
  Unit Type: mm/year
```

**Note:** `+grids` is mutually exclusive with `+xy_grids` and `+z_grids`

#### +t_epoch=<value>

Central epoch of transformation given in decimal years. Will be used in conjunction with the observation time from the input coordinate to determine `dt` as used in eq. (7.1) below.

**Note:** `+t_epoch` is mutually exclusive with `+dt`
+dt=<value>

New in version 6.0.0.

dt as used in eq. (7.1) below. Is useful when no observation time is available in the input coordinate or when a deformation for a specific timespan needs to be applied in a transformation. dt is given in units of decimal years.

Note: +dt is mutually exclusive with +t_epoch

+xy_grids=<list>

Deprecated since version 7.0.

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will not complain if the grid is not available.

Grids for the horizontal component of a deformation model is expected to be in CTable2 format.

Note: +xy_grids is mutually exclusive with +grids

+z_grids=<list>

Deprecated since version 7.0.

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will not complain if the grid is not available.

Grids for the vertical component of a deformation model is expected to be in either GTX format.

Note: +z_grids is mutually exclusive with +grids

7.3.3.3 Mathematical description

Mathematically speaking, application of a deformation model is simple. The deformation model is represented as a grid of velocities in three dimensions. Coordinate corrections are applied in cartesian space. For a given coordinate, \((X, Y, Z)\), velocities \((V_X, V_Y, V_Z)\) can be interpolated from the gridded model. The time span between \(t_{\text{obs}}\) and \(t_c\) determine the magnitude of the coordinate correction as seen in eq. (7.1) below.

\[
\begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix}_B = \begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix}_A + (t_{\text{obs}} - t_c) \begin{pmatrix}
V_X \\
V_Y \\
V_Z \\
\end{pmatrix}
\]

(7.1)

 Corrections are done in cartesian space.

Coordinates of the gridded model are in ENU (east, north, up) space because it would otherwise require an enormous 3 dimensional grid to handle the corrections in cartesian space. Keeping the correction in lat/long space reduces the complexity of the grid significantly. Consequently though, the input coordinates needs to be converted to lat/long space when searching for corrections in the grid. This is done with the cart operation. The converted grid corrections can then be applied to the input coordinates in cartesian space. The conversion from ENU space to cartesian space is done in the following way:

\[
\begin{pmatrix}
X \\
Y \\
Z \\
\end{pmatrix} = \begin{pmatrix}
- \sin \phi \cos \lambda N - \sin \lambda E + \cos \phi \cos \lambda U \\
- \sin \phi \sin \lambda N + \sin \lambda E + \cos \phi \sin \lambda U \\
\cos \phi N + \sin \phi U \\
\end{pmatrix}
\]

(7.1)

where \(\phi\) and \(\lambda\) are the latitude and longitude of the coordinate that is searched for in the grid. \((E, N, U)\) are the grid values in ENU-space and \((X, Y, Z)\) are the corrections converted to cartesian space.
7.3.3.4 See also

1. Behavioural changes from version 5 to 6

7.3.4 Geographic offsets

New in version 6.0.0.

The Geographic offsets transformation adds an offset to the geographic longitude, latitude coordinates, and an offset to the ellipsoidal height.

<table>
<thead>
<tr>
<th>Alias</th>
<th>geogoffset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
</tbody>
</table>

This method is normally only used when low accuracy is tolerated. It is documented as coordinate operation method code 9619 (for geographic 2D) and 9660 (for geographic 3D) in the EPSG dataset ([IOGP2018])

It can also be used to implement the method Geographic2D with Height Offsets (code 9618) by noting that the input vertical component is a gravity-related height and the output vertical component is the ellipsoid height (dh being the geoid undulation).

It can also be used to implement the method Vertical offset (code 9616)

The reverse transformation simply consists in subtracting the offsets.

This method is a conveniency wrapper for the more general Affine transformation.

7.3.4.1 Examples

Geographic offset from the old Greek geographic 2D CRS to the newer GGRS87 CRS:

```
+proj=geogoffset +dlon=0.28 +dlat=-5.86
```

Conversion from Tokyo + JSLD69 height to WGS 84:

```
+proj=geogoffset +dlon=-13.97 +dlat=7.94 +dh=26.9
```

Conversion from Baltic 1977 height to Black Sea height:

```
+proj=geogoffset +dh=0.4
```

7.3.4.2 Parameters

Optional

```
+dlon=<value>
```

  Offset in longitude, expressed in arc-second, to add.

```
+dlat=<value>
```

  Offset in latitude, expressed in arc-second, to add.
+dh=<value>
  Offset in height, expressed in meter, to add.

### 7.3.5 General grid shift

New in version 9.2.0.

Translation of geodetic coordinates using a grid shift.

<table>
<thead>
<tr>
<th>Alias</th>
<th>gridshift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D and 3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
</tbody>
</table>

The transformation may apply horizontal geodetic offsetting and/or vertical (ellipsoidal or orthometric height) offsetting, depending on the type of the grid(s).

This is a generalization of the *Horizontal grid shift* and *Vertical grid shift* methods, that may be used in particular for US NADCON5 grids that contain both horizontal geodetic and ellipsoidal height offsets.

#### 7.3.5.1 Example

Transformation of a point from NAD83(NSRS2007) to NAD83(2011) on conterminous USA using a NADCON5 grid that contains horizontal and ellipsoidal height offsets.

```bash
+proj=gridshift +grids=us_noaa_nadcon5_nad83_2007_nad83_2011_conus.tif
```

**Parameters**

**Required**

+grids=<list>
  Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will not complain if the grid is not available.

  Grids must be in GeoTIFF format (*Geodetic TIFF grids (GTG)*) and have an explicit TYPE metadata item whose value is HORIZONTAL_OFFSET, GEOGRAPHIC_3D_OFFSET, ELLIPSOIDAL_HEIGHT_OFFSET, VERTICAL_OFFSET_GEOGRAPHIC_TO_VERTICAL or VERTICAL_OFFSET_VERTICAL_TO_VERTICAL.

**Optional**

+interpolation=bilinear/biquadratic
  Default is bilinear, unless the grid contains a `interpolation_method` metadata item specifying the method. Biquadratic is typically used for NADCON5 grids, and is defined in NOAA Technical Memorandum NOS NGS 84 - Biquadratic Interpolation

+no_z_transform
  If specified, vertical coordinate transformation will be skipped.
7.3.6 Helmert transform

The Helmert transformation changes coordinates from one reference frame to another by means of 3-, 4- and 7-parameter shifts, or one of their 6-, 8- and 14-parameter kinematic counterparts.

<table>
<thead>
<tr>
<th>Alias</th>
<th>helmert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D and 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Cartesian coordinates (spatial), decimalyears (temporal).</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates (spatial), decimalyears (temporal).</td>
</tr>
<tr>
<td>Input type</td>
<td>Cartesian coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates</td>
</tr>
</tbody>
</table>

The Helmert transform, in all its various incarnations, is used to perform reference frame shifts. The transformation operates in cartesian space. It can be used to transform planar coordinates from one datum to another, transform 3D cartesian coordinates from one static reference frame to another or it can be used to do fully kinematic transformations from global reference frames to local static frames.

All of the parameters described in the table above are marked as optional. This is true as long as at least one parameter is defined in the setup of the transformation. The behavior of the transformation depends on which parameters are used in the setup. For instance, if a rate of change parameter is specified a kinematic version of the transformation is used.

The kinematic transformations require an observation time of the coordinate, as well as a central epoch for the transformation. The latter is usually documented alongside the rest of the transformation parameters for a given transformation. The central epoch is controlled with the parameter \( t_{\text{epoch}} \). The observation time is given as part of the coordinate when using PROJ's 4D-functionality.

7.3.6.1 Examples

Transforming coordinates from NAD72 to NAD83 using the 4 parameter 2D Helmert:

```
proj=helmert convention=coordinate_frame x=-9597.3572 y=.6112 s=0.304794780637 theta=-1.244048
```

Simplified transformations from ITRF2008/IGS08 to ETRS89 using 7 parameters:

```
proj=helmert convention=coordinate_frame x=0.67678 y=0.65495 z=-0.52827 rx=-0.022742 ry=0.012667 rz=0.022704 s=-0.01070
```

Transformation from \( \text{ITRF2000} \) to \( \text{ITRF93} \) using 15 parameters:

```
proj=helmert convention=position_vector x=0.0127 y=0.0065 z=-0.0209 s=0.00195
dx=-0.0029 dy=-0.0002 dz=-0.0006 ds=0.00001
rx=-0.00039 ry=0.00080 rz=-0.00114
drx=-0.00011 dry=-0.00019 drz=0.00007
t_epoch=1988.0
```
7.3.6.2 Parameters

**Note:** All parameters are optional but at least one should be used, otherwise the operation will return the coordinates unchanged.

**Convention**=coordinate_frame/position_vector

Indicates the convention to express the rotational terms when a 3D-Helmert / 7-parameter more transform is involved. As soon as a rotational parameter is specified (one of \(rx\), \(ry\), \(rz\), \(drx\), \(dry\), \(drz\)), convention is required.

The two conventions are equally popular and a frequent source of confusion. The coordinate frame convention is also described as an clockwise rotation of the coordinate frame. It corresponds to EPSG method code 1032 (in the geocentric domain) or 9607 (in the geographic domain). The position vector convention is also described as an anticlockwise (counter-clockwise) rotation of the coordinate frame. It corresponds to as EPSG method code 1033 (in the geocentric domain) or 9606 (in the geographic domain).

This parameter is ignored when only a 3-parameter (translation terms only: \(x\), \(y\), \(z\)), 4-parameter (3-parameter and \(theta\)) or 6-parameter (3-parameter and their derivative terms) is used.

The result obtained with parameters specified in a given convention can be obtained in the other convention by negating the rotational parameters (\(rx\), \(ry\), \(rz\), \(drx\), \(dry\), \(drz\))

**Note:** This parameter obsoletes transpose which was present in PROJ 5.0 and 5.1, and is forbidden starting with PROJ 5.2

\(+x=<value>\)
Translation of the x-axis given in meters.

\(+y=<value>\)
Translation of the y-axis given in meters.

\(+z=<value>\)
Translation of the z-axis given in meters.

\(+s=<value>\)
Scale factor given in ppm.

\(+rx=<value>\)
X-axis rotation in the 3D Helmert given arc seconds.

\(+ry=<value>\)
Y-axis rotation in the 3D Helmert given in arc seconds.

\(+rz=<value>\)
Z-axis rotation in the 3D Helmert given in arc seconds.

\(+theta=<value>\)
Rotation angle in the 2D Helmert given in arc seconds.

\(+dx=<value>\)
Translation rate of the x-axis given in m/year.

\(+dy=<value>\)
Translation rate of the y-axis given in m/year.
+dz=<value>
Translation rate of the z-axis given in m/year.

+ds=<value>
Scale rate factor given in ppm/year.

+drx=<value>
Rotation rate of the x-axis given in arc seconds/year.

+dry=<value>
Rotation rate of the y-axis given in arc seconds/year.

+drz=<value>
Rotation rate of the y-axis given in arc seconds/year.

+t_epoch=<value>
Central epoch of transformation given in decimal year. Only used spatiotemporal transformations.

+exact
Use exact transformation equations.

See (7.6)

7.3.6.3 Mathematical description

In the notation used below, \( \hat{P} \) is the rate of change of a given transformation parameter \( P \). \( \hat{P} \) is the kinematically adjusted version of \( P \), described by

\[
\hat{P} = P + \hat{P} (t - t_{central})
\]

(7.1)

where \( t \) is the observation time of the coordinate and \( t_{central} \) is the central epoch of the transformation. Equation (7.1) can be used to propagate all transformation parameters in time.

Superscripts of vectors denote the reference frame the coordinates in the vector belong to.

2D Helmert

The simplest version of the Helmert transform is the 2D case. In the 2-dimensional case only the horizontal coordinates are changed. The coordinates can be translated, rotated and scaled. Translation is controlled with the \( x \) and \( y \) parameters. The rotation is determined by \( \theta \) and the scale is controlled with the \( s \) parameters.

Note: The scaling parameter \( s \) is unitless for the 2D Helmert, as opposed to the 3D version where the scaling parameter is given in units of ppm.

Mathematically the 2D Helmert is described as:

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix}^B =
\begin{bmatrix}
T_x \\
T_y
\end{bmatrix} + s
\begin{bmatrix}
\cos \theta & \sin \theta \\
-\sin \theta & \cos \theta
\end{bmatrix}
\begin{bmatrix}
X \\
Y
\end{bmatrix}^A
\]

(7.2)

(7.2) can be extended to a time-varying kinematic version by adjusting the parameters with (7.1) to (7.2), which yields the kinematic 2D Helmert transform:

\[
\begin{bmatrix}
X \\
Y
\end{bmatrix}^B =
\begin{bmatrix}
\dot{T}_x \\
\dot{T}_y
\end{bmatrix} + s(t)
\begin{bmatrix}
\cos \dot{\theta} & \sin \dot{\theta} \\
-\sin \dot{\theta} & \cos \dot{\theta}
\end{bmatrix}
\begin{bmatrix}
X \\
Y
\end{bmatrix}^A
\]

(7.2)

All parameters in (7.2) are determined by the use of (7.1), which applies the rate of change to each individual parameter for a given timespan between \( t \) and \( t_{central} \).
3D Helmert

The general form of the 3D Helmert is

\[ V^B = T + (1 + s \times 10^{-6}) R V^A \]  

(7.2)

Where \( T \) is a vector consisting of the three translation parameters, \( s \) is the scaling factor and \( R \) is a rotation matrix. \( V^A \) and \( V^B \) are coordinate vectors, with \( V^A \) being the input coordinate and \( V^B \) is the output coordinate.

In the Position Vector convention, we define \( R_x = \text{radians} \ (rx) \), \( R_y = \text{radians} \ (ry) \) and \( R_z = \text{radians} \ (rz) \)

In the Coordinate Frame convention, \( R_x = -\text{radians} \ (rx) \), \( R_y = -\text{radians} \ (ry) \) and \( R_z = -\text{radians} \ (rz) \)

The rotation matrix is composed of three rotation matrices, one for each axis.

\[ R_X = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos R_x & -\sin R_x \\ 0 & \sin R_x & \cos R_x \end{bmatrix} \]  

(7.2)

\[ R_Y = \begin{bmatrix} \cos R_y & 0 & \sin R_y \\ 0 & 1 & 0 \\ -\sin R_y & 0 & \cos R_y \end{bmatrix} \]  

(7.3)

\[ R_Z = \begin{bmatrix} \cos R_z & -\sin R_z & 0 \\ \sin R_z & \cos R_z & 0 \\ 0 & 0 & 1 \end{bmatrix} \]  

(7.4)

The three rotation matrices can be combined in one:

\[ R = R_X R_Y R_Z \]  

(7.5)

For \( R \), this yields:

\[
\begin{bmatrix}
\cos R_y \cos R_z & -\cos R_x \sin R_z + \sin R_x \sin R_z & \sin R_x \sin R_z + \cos R_y \cos R_z \\
\sin R_x \sin R_y - \cos R_y \cos R_z & \cos R_x \cos R_y + \sin R_x \sin R_y & -\sin R_x \cos R_y - \cos R_x \sin R_y \\
-\sin R_y & \sin R_x \cos R_z & \cos R_x \cos R_z \\
\end{bmatrix}
\]  

(7.6)

Using the small angle approximation the rotation matrix can be simplified to

\[ R = \begin{bmatrix} 1 & 0 & 0 \\ R_z & 1 & -R_x \\ -R_y & R_x & 1 \end{bmatrix} \]  

(7.7)

Which allow us to express the most common version of the Helmert transform, using the approximated rotation matrix:

\[
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + (1 + s \times 10^{-6}) \begin{bmatrix} 1 & -R_z & R_y \\ R_z & 1 & -R_x \\ -R_y & R_x & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A
\]  

(7.7)

If the rotation matrix is transposed, or the sign of the rotation terms negated, the rotational part of the transformation is effectively reversed. This is what happens when switching between the 2 conventions position_vector and coordinate_frame.

Applying (7.1) we get the kinematic version of the approximated 3D Helmert:

\[
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^B = \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + (1 + s \times 10^{-6}) \begin{bmatrix} 1 & -\dot{R}_z & \dot{R}_y \\ \dot{R}_z & 1 & -\dot{R}_x \\ -\dot{R}_y & \dot{R}_x & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}^A
\]  

(7.7)
The Helmert transformation can be applied without using the rotation parameters, in which case it becomes a simple translation of the origin of the coordinate system. When using the Helmert in this version equation (7.2) simplifies to:

\[
\begin{bmatrix}
X_B \\
Y_B \\
Z_B
\end{bmatrix} = \begin{bmatrix}
T_x \\
T_y \\
T_z
\end{bmatrix} + \begin{bmatrix}
X_A \\
Y_A \\
Z_A
\end{bmatrix}
\]  
(7.7)

That after application of (7.1) has the following kinematic counterpart:

\[
\begin{bmatrix}
X_B \\
Y_B \\
Z_B
\end{bmatrix} = \begin{bmatrix}
\dot{T}_x \\
\dot{T}_y \\
\dot{T}_z
\end{bmatrix} + \begin{bmatrix}
X_A \\
Y_A \\
Z_A
\end{bmatrix}
\]  
(7.7)

### 7.3.7 Horner polynomial evaluation

New in version 5.0.0.

Changed in version 9.1.0: Iterative polynomial inversion

<table>
<thead>
<tr>
<th>Alias</th>
<th>horner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D and 3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic and projected coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic and projected coordinates</td>
</tr>
</tbody>
</table>

The Horner polynomial evaluation scheme is used for transformations between reference frames where one or both are inhomogeneous or internally distorted. This will typically be reference frames created before the introduction of space geodetic techniques such as GPS.

Horner polynomials, or Multiple Regression Equations as they are also known as, have their strength in being able to create complicated mappings between coordinate reference frames while still being lightweight in both computational cost and disk space used.

PROJ implements two versions of the Horner evaluation scheme: Real and complex polynomial evaluation. Below both are briefly described. For more details consult [Ruffhead2016] and [IOGP2018].

The polynomial evaluation in real number space is defined by the following equations:

\[
\Delta X = \sum_{i,j} u_{i,j} U^i V^j
\]

\[
\Delta Y = \sum_{i,j} v_{i,j} U^i V^j
\]

where

\[
U = X_{in} - X_{origin}
\]

\[
V = Y_{in} - Y_{origin}
\]

and \(u_{i,j}\) and \(v_{i,j}\) are coefficients that make up the polynomial.

The final coordinates are determined as

\[
X_{out} = X_{in} + \Delta X
\]

\[
Y_{out} = Y_{in} + \Delta Y
\]

(7.9)
The inverse transform is the same as the above but requires a different set of coefficients. If only the forward set of coefficients and origin is known the inverse transform can be done by iteratively solving a system of equations. By writing (7.7) as:

\[
\begin{bmatrix}
\Delta X \\
\Delta Y
\end{bmatrix} = \begin{bmatrix} u_{0,0} \\ v_{0,0} \end{bmatrix} + \begin{bmatrix} u_{0,1} + u_{0,2}U + ... \\ v_{1,0} + v_{1,1}V + v_{2,0}U + ... \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix} + \begin{bmatrix} u_{1,0} + u_{1,1}U + u_{2,0}V + ... \\ v_{0,1} + v_{0,2}U + ... \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix}
\]

\[
\begin{bmatrix}
\Delta X \\
\Delta Y
\end{bmatrix} = \begin{bmatrix} u_{0,0} \\ v_{0,0} \end{bmatrix} + \begin{bmatrix} MA & MB \\ MC & MD \end{bmatrix} \begin{bmatrix} U \\ V \end{bmatrix}
\]

\[
\begin{bmatrix}
U \\
V
\end{bmatrix} = \begin{bmatrix} MA & MB \\ MC & MD \end{bmatrix}^{-1} \begin{bmatrix} \Delta X - u_{0,0} \\ \Delta Y - v_{0,0} \end{bmatrix}
\]

We can iteratively solve with initial values of \(U = 0\) and \(V = 0\) and find \(U\) and \(V\).

**Note:** This iterative inverse transformation is a more general solution to *reversible polynomials of degree n* as presented in [IOGP2019]. These can provide a satisfactory solution in a single step when certain conditions are met.

Evaluation of the complex polynomials are defined by the following equations:

\[
\Delta X + i\Delta Y = \sum_{j=1}^{n} (c_{2j-1} + ic_{2j})(U + iV)^j \tag{7.10}
\]

Where \(n\) is the degree of the polynomial. \(U\) and \(V\) are defined as in (7.8) and the resulting coordinates are again determined by (7.9). Complex polynomials can be solved iteratively similar to real polynomials.

### 7.3.7.1 Examples

Mapping between Danish TC32 and ETRS89/UTM zone 32 using polynomials in real number space:

- `+proj=horner`
- `+ellps=intl`
- `+range=500000`
- `+fwd_origin=877605.269066,6125810.306769`
- `+inv_origin=877605.760036,6125811.281773`
- `+deg=4`
- `+fwd_u=8.7760574982e+05,9.9999752475e+00,-2.8817299305e-10,-5.5627059451e-15,1.9107771273e-18,3.615590993e-10,-2.042430315e-18,1.429091719e-15,5.3886155968e-19,-1.0167505000e-18`
- `+inv_u=8.7760574982e+06,9.9999752475e+00,-2.8817299305e-10,-5.5627059451e-15,1.9107771273e-18,3.615590993e-10,-2.042430315e-18,1.429091719e-15,5.3886155968e-19,-1.0167505000e-18`

Mapping between Danish System Storebælt and ETRS89/UTM zone 32 using complex polynomials:
PROJ coordinate transformation software library, Release 9.3.1

7.3.7.2 Parameters

Setting up Horner polynomials requires many coefficients being explicitly written, even for polynomials of low degree. For this reason it is recommended to store the polynomial definitions in an *init file* for easier writing and reuse.

**Required**

Below is a list of required parameters that can be set for the Horner polynomial transformation. As stated above, the transformation takes to forms, either using real or complex polynomials. These are divided into separate sections below. Parameters from the two sections are mutually exclusive, that is parameters describing real and complex polynomials can't be mixed.

- **+ellps=<value>**
  - The name of a built-in ellipsoid definition.
  - See *Ellipsoids* for more information, or execute *proj -le* for a list of built-in ellipsoid names.
  - *Defaults to "GRS80".*

- **+deg=<value>**
  - Degree of polynomial

- **+fwd_origin=<northing,easting>**
  - Coordinate of origin for the forward mapping

**Real polynomials**

The following parameters has to be set if the transformation consists of polynomials in real space. Each parameter takes a comma-separated list of coefficients. The number of coefficients is governed by the degree, \( d \), of the polynomial:

\[
N = \frac{(d+1)(d+2)}{2}
\]

- **+fwd_u=<u_11,u_12,\ldots,u_ij,\ldots,u_mn>**
  - Coefficients for the forward transformation i.e. latitude to northing as described in (7.7).

- **+fwd_v=<v_11,v_12,\ldots,v_ij,\ldots,v_mn>**
  - Coefficients for the forward transformation i.e. longitude to easting as described in (7.7).
Complex polynomials

The following parameters has to be set if the transformation consists of polynomials in complex space. Each parameter takes a comma-separated list of coefficients. The number of coefficients is governed by the degree, \( d \), of the polynomial:

\[
N = 2d + 2
\]

\( +\text{fwd}\_c=<c_1,c_2,...,c_N> \)

Coefficients for the complex forward transformation as described in (7.10).

Optional

\( +\text{inv}\_\text{origin}=<\text{northing},\text{easting}> \)

Changed in version 9.1.0.

Coordinate of origin for the inverse mapping. Without this option iterative polynomial evaluation is used for the inverse transformation.

\( +\text{inv}\_u=<u_{11},u_{12},...,u_{ij},...,u_{mn}> \)

Changed in version 9.1.0.

Coefficients for the inverse transformation i.e. latitude to northing as described in (7.7). Only applies for real polynomials. Without this option iterative polynomial evaluation is used for the inverse transformation.

\( +\text{inv}\_v=<v_{11},v_{12},...,v_{ij},...,v_{mn}> \)

Changed in version 9.1.0.

Coefficients for the inverse transformation i.e. longitude to easting as described in (7.7). Only applies for real polynomials. Without this option iterative polynomial evaluation is used for the inverse transformation.

\( +\text{inv}\_c=<c_1,c_2,...,c_N> \)

Changed in version 9.1.0.

Coefficients for the complex inverse transformation as described in (7.10). Only applies for complex polynomials. Without this option iterative polynomial evaluation is used for the inverse transformation.

\( +\text{range}=<\text{value}> \)

Radius of the region of validity.

\( +\text{uneg} \)

Express latitude as southing. Only applies for complex polynomials.

\( +\text{vneg} \)

Express longitude as westing. Only applies for complex polynomials.

\( +\text{inv}\_\text{tolerance}=<\text{value}> \)

New in version 9.1.0.

Only applies to cases of iterative inversion. The procedure converges to the correct results with each step. Iteration stops when the result differs from the previous calculated result by less than \(<\text{value}>\). \(<\text{value}>\) should be the same units as \( U \) and \( V \) of (7.8)

Defaults to 0.001.
7.3.8 Molodensky transform

New in version 5.0.0.

The Molodensky transformation resembles a Helmert transform with zero rotations and a scale of unity, but converts directly from geodetic coordinates to geodetic coordinates, without the intermediate shifts to and from cartesian geocentric coordinates, associated with the Helmert transformation. The Molodensky transformation is simple to implement and to parametrize, requiring only the 3 shifts between the input and output frame, and the corresponding differences between the semimajor axes and flattening parameters of the reference ellipsoids. Due to its algorithmic simplicity, it was popular prior to the ubiquity of digital computers. Today, it is mostly interesting for historical reasons, but nevertheless indispensable due to the large amount of data that has already been transformed that way [EversKnudsen2017].

<table>
<thead>
<tr>
<th>Alias</th>
<th>molodensky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
</tbody>
</table>

The Molodensky transform can be used to perform a datum shift from coordinate \((\phi_1, \lambda_1, h_1)\) to \((\phi_2, \lambda_2, h_2)\) where the two coordinates are referenced to different ellipsoids. This is based on three assumptions:

1. The cartesian axes, \(X, Y, Z\), of the two ellipsoids are parallel.
2. The offset, \(\delta X, \delta Y, \delta Z\), between the two ellipsoid are known.
3. The characteristics of the two ellipsoids, expressed as the difference in semimajor axis \((\delta a)\) and flattening \((\delta f)\), are known.

The Molodensky transform is mostly used for transforming between old systems dating back to the time before computers. The advantage of the Molodensky transform is that it is fairly simple to compute by hand. The ease of computation come at the cost of limited accuracy.

A derivation of the mathematical formulas for the Molodensky transform can be found in [Deakin2004].

### 7.3.8.1 Examples

The abridged Molodensky:

```
proj=molodensky a=6378160 rf=298.25 da=-23 df=-8.120449e-8 dx=-134 dy=-48 dz=149
```

The same transformation using the standard Molodensky:

```
proj=molodensky a=6378160 rf=298.25 da=-23 df=-8.120449e-8 dx=-134 dy=-48 dz=149
```
7.3.8.2 Parameters

**Required**

+da=<value>
Difference in semimajor axis of the defining ellipsoids.

+df=<value>
Difference in flattening of the defining ellipsoids.

+dx=<value>
Offset of the X-axes of the defining ellipsoids.

+dy=<value>
Offset of the Y-axes of the defining ellipsoids.

+dz=<value>
Offset of the Z-axes of the defining ellipsoids.

+ellps=<value>
The name of a built-in ellipsoid definition.

See *Ellipsoids* for more information, or execute `proj -le` for a list of built-in ellipsoid names.

*Defaults to "GRS80".*

**Optional**

+abridged
Use the abridged version of the Molodensky transform.

7.3.9 Molodensky-Badekas transform

New in version 6.0.0.

The Molodensky-Badekas transformation changes coordinates from one reference frame to another by means of a 10-parameter shift.

**Note:** It should not be confused with the *Molodensky transform* transform which operates directly in the geodetic coordinates. Molodensky-Badekas can rather be seen as a variation of *Helmert transform*.

<table>
<thead>
<tr>
<th>Alias</th>
<th>molobadekas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Cartesian coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates</td>
</tr>
</tbody>
</table>

The Molodensky-Badekas transformation is a variation of the *Helmert transform* where the rotational terms are not directly applied to the ECEF coordinates, but on cartesian coordinates relative to a reference point (usually close to Earth surface, and to the area of use of the transformation). When px = py = pz = 0, this is equivalent to a 7-parameter Helmert transformation.
7.3.9.1 Example

Transforming coordinates from La Canoa to REGVEN:

```
proj=molobadekas convention=coordinate_frame
    x=-270.933 y=115.599 z=-360.226 rx=-5.266 ry=-1.238 rz=2.381
    s=-5.109 px=2464351.59 py=-5783466.61 pz=974809.81
```

7.3.9.2 Parameters

**Note:** All parameters (except convention) are optional but at least one should be used, otherwise the operation will return the coordinates unchanged.

**+convention=coordinate_frame/position_vector**

Indicates the convention to express the rotational terms when a 3D-Helmert / 7-parameter more transform is involved.

The two conventions are equally popular and a frequent source of confusion. The coordinate frame convention is also described as an clockwise rotation of the coordinate frame. It corresponds to EPSG method code 1034 (in the geocentric domain) or 9636 (in the geographic domain) The position vector convention is also described as an anticlockwise (counter-clockwise) rotation of the coordinate frame. It corresponds to as EPSG method code 1061 (in the geocentric domain) or 1063 (in the geographic domain).

The result obtained with parameters specified in a given convention can be obtained in the other convention by negating the rotational parameters \((rx, ry, rz)\)

**+x=<value>**

Translation of the x-axis given in meters.

**+y=<value>**

Translation of the y-axis given in meters.

**+z=<value>**

Translation of the z-axis given in meters.

**+s=<value>**

Scale factor given in ppm.

**+rx=<value>**

X-axis rotation given arc seconds.

**+ry=<value>**

Y-axis rotation given in arc seconds.

**+rz=<value>**

Z-axis rotation given in arc seconds.

**+px=<value>**

Coordinate along the x-axis of the reference point given in meters.

**+py=<value>**

Coordinate along the y-axis of the reference point given in meters.

**+pz=<value>**

Coordinate along the z-axis of the reference point given in meters.
7.3.9.3 Mathematical description

In the Position Vector convention, we define \( R_x = \text{radians} \,(r_x), R_y = \text{radians} \,(r_y) \) and \( R_z = \text{radians} \,(r_z) \)

In the Coordinate Frame convention, \( R_x = -\text{radians} \,(r_x), R_y = -\text{radians} \,(r_y) \) and \( R_z = -\text{radians} \,(r_z) \)

\[
\begin{bmatrix}
X_{\text{output}} \\
Y \\
Z
\end{bmatrix} = \begin{bmatrix} T_x + P_x \\
T_y + P_y \\
T_z + P_z
\end{bmatrix} + (1 + s \times 10^{-6}) \begin{bmatrix}
1 & -R_z & R_y \\
R_z & 1 & -R_x \\
-R_y & R_x & 1
\end{bmatrix} \begin{bmatrix}
X_{\text{input}} - P_x \\
Y_{\text{input}} - P_y \\
Z_{\text{input}} - P_z
\end{bmatrix}
\] (7.11)

7.3.10 Horizontal grid shift

New in version 5.0.0.

Change of horizontal datum by grid shift.

<table>
<thead>
<tr>
<th>Alias</th>
<th>hgridshift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D and 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
</tbody>
</table>

The horizontal grid shift is done by offsetting the planar input coordinates by a specific amount determined by the loaded grids. The simplest use case of the horizontal grid shift is applying a single grid:

```
+proj=hgridshift +grids=nzgr2kgrid0005.gsb
```

More than one grid can be loaded at the same time, for instance in case the dataset needs to be transformed spans several countries. In this example grids of the continental US, Alaska and Canada is loaded at the same time:

```
+proj=hgridshift +grids=@conus,@alaska,@ntv2_0.gsb,@ntv_can.dat
```

The @ in the above example states that the grid is optional, in case the grid is not found in the PROJ search path. The list of grids is prioritized so that grids in the start of the list takes precedence over the grids in the back of the list.

PROJ supports GeoTIFF (Geodetic TIFF grids (GTG)), CTable2 and NTv2 files for horizontal grid corrections. Details about all three formats can be found in the GDAL documentation and/or driver source code. GDAL reads and writes all three formats. Using GDAL for construction of new grids is recommended.

To apply as well ellipsoidal height differences sometimes present in some grids (such as US NADCON5 grids), use the General grid shift method.

7.3.10.1 Temporal gridshifting

New in version 5.1.0.

By initializing the horizontal gridshift operation with a central epoch, it can be used as a step function applying the grid offsets only if a coordinate is transformed from an epoch before grids central epoch to an epoch after. This is handy in transformations where it is necessary to handle deformations caused by seismic activity.

The central epoch of the grid is controlled with \( ^t_{\text{epoch}} \) and the final epoch of the coordinate is set with \( ^t_{\text{final}} \). The observation epoch of the coordinate is part of the coordinate tuple.

Suppose we want to model the deformation of the 2008 earthquake in Iceland in a transformation of data from 2005 to 2009:
 Temporal gridshifting is especially powerful in transformation pipelines where several gridshifts can be chained together, effectively acting as a series of step functions that can be applied to a coordinate that is propagated through time. In the following example we establish a pipeline that allows transformation of coordinates from any given epoch up until the current date, applying only those gridshifts that have central epochs between the observation epoch and the final epoch:

```
+proj=pipeline +t_final=now
+step +proj=hgridshift +grids=earthquake_1.gsb +t_epoch=2010.421
+step +proj=hgridshift +grids=earthquake_2.gsb +t_epoch=2013.853
+step +proj=hgridshift +grids=earthquake_3.gsb +t_epoch=2017.713
```

**Note:** The special epoch *now* is used when specifying the final epoch with +t_final. This results in coordinates being transformed to the current date. Additionally, +t_final is used as a global pipeline parameter, which means that it is applied to all the steps in the pipeline.

In the above transformation, a coordinate with observation epoch 2009.32 would be subject to all three gridshift steps in the pipeline. A coordinate with observation epoch 2014.12 would only be offset by the last step in the pipeline.

### 7.3.10.2 Parameters

**Required**

+grids=<list>

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will not complain if the grid is not available.

Grids are expected to be in GeoTIFF (Geodetic TIFF grids (GTG)) or NTv2 format (or CTable2 for legacy grids)

**Optional**

+t_epoch=<time>

Central epoch of the transformation.

New in version 5.1.0.

+t_final=<time>

Final epoch that the coordinate will be propagated to after transformation. The special epoch now can be used instead of writing a specific period in time. When now is used, it is replaced internally with the epoch of the transformation. This means that the resulting coordinate will be slightly different if carried out again at a later date.

New in version 5.1.0.
7.3.11 Triangulated Irregular Network based transformation

New in version 7.2.0.

<table>
<thead>
<tr>
<th>Alias</th>
<th>tinshift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input type</td>
<td>Projected or geographic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>Output type</td>
<td>Projected or geographic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>Domain</td>
<td>2D or 3D</td>
</tr>
<tr>
<td>Available forms</td>
<td>Forward and inverse</td>
</tr>
</tbody>
</table>

The `tinshift` transformation takes one mandatory argument, `file`, that points to a JSON file, which contains the triangulation and associated metadata. Input and output coordinates must be geographic or projected coordinates. Depending on the content of the JSON file, horizontal, vertical or both components of the coordinates may be transformed.

The transformation is invertible, with the same computational complexity than the forward transformation.

7.3.11.1 Parameters

Required

`+file=<filename>`

Filename to the JSON file for the TIN.

7.3.11.2 Example

Transforming a point with the Finland EPSG:2393 ("KKJ / Finland Uniform Coordinate System") projected CRS to EPSG:3067 ("ETRS89 / TM35FIN(E,N)"

```bash
$ echo 3210000.0000 6700000.0000 0 2020 | cct +proj=tinshift +file=./triangle_kkj.json
209948.3217 6697187.0009 0.0000 2020
```

Algorithm

Internally, `tinshift` ingest the whole file into memory. It is considered that triangulation should be small enough for that.

When a point is transformed, one must find the triangle into which it falls into. Instead of iterating over all triangles, we build a in-memory quadtree to speed-up the identification of candidates triangles.

To determine if a point falls into a triangle, one computes its 3 barycentric coordinates from its projected coordinates, \( \lambda_i \) for \( i = 1, 2, 3 \). They are real values (in the [0,1] range for a point inside the triangle), giving the weight of each of the 3 vertices of the triangles.

Once those weights are known, interpolating the target horizontal coordinate is a matter of doing the linear combination of those weights with the target horizontal coordinates at the 3 vertices of the triangle \( (X_t, Y_t) \):

\[
X_{target} = X_t * \lambda_1 + X_t * \lambda_2 + X_t * \lambda_3 \\
Y_{target} = Y_t * \lambda_1 + Y_t * \lambda_2 + Y_t * \lambda_3
\]
This interpolation is exact at the vertices of the triangulation, and has linear properties inside each triangle. It is completely equivalent to other formulations of triangular interpolation, such as

\[
X_{\text{target}} = A + X_{\text{source}} \cdot B + Y_{\text{source}} \cdot C
\]
\[
Y_{\text{target}} = D + X_{\text{source}} \cdot E + Y_{\text{source}} \cdot F
\]

where the A, B, C, D, E, F constants (for a given triangle) are found by solving the 2 systems of 3 linear equations, constraint by the source and target coordinate pairs of the 3 vertices of the triangle:

\[
X_{t_i} = A + X_{s_i} \cdot B + Y_{s_i} \cdot C
\]
\[
Y_{t_i} = D + X_{s_i} \cdot E + Y_{s_i} \cdot F
\]

Similarly for a vertical coordinate transformation, where \(Z_{\text{off}_i}\) is the vertical offset at each vertex of the triangle:

\[
Z_{\text{target}} = Z_{\text{source}} + Z_{\text{off}_1} \cdot \lambda_1 + Z_{\text{off}_2} \cdot \lambda_2 + Z_{\text{off}_3} \cdot \lambda_3
\]

Constraints on the triangulation

No check is done on the consistence of the triangulation. It is highly recommended that triangles do not overlap each other (when considering the source coordinates or the forward transformation, or the target coordinates for the inverse transformation), otherwise which triangle will be selected is unspecified. Besides that, the triangulation does not need to have particular properties (like being a Delaunay triangulation)

File format

The triangulation is stored in a text-based format, using JSON as a serialization.

Below a minimal example, from the KKJ to ETRS89 transformation, with just a single triangle:

```json
{
    "file_type": "triangulation_file",
    "format_version": "1.0",
    "name": "Name",
    "version": "Version",
    "publication_date": "2018-07-01T00:00:00Z",
    "license": "Creative Commons Attribution 4.0 International",
    "description": "Test triangulation",
    "authority": {
        "name": "Authority name",
        "url": "http://example.com",
        "address": "Adress",
        "email": "test@example.com"
    },
    "links": [
        {
            "href": "https://example.com/about.html",
            "rel": "about",
            "type": "text/html",
            "title": "About"
        },
        {
            "href": "https://example.com/download",
```
So after the generic metadata, we define the input and output CRS (informative only), and that the transformation affects
horizontal components of coordinates. We name the columns of the vertices and triangles arrays. We defined
the source and target coordinates of each vertex, and define a triangle by referring to the index of its vertices in the
vertices array.

More formally, the specific items for the triangulation file are:

**input_crs**
String identifying the CRS of source coordinates in the vertices. Typically EPSG:XXXX. If the transformation is for
vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX
is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89
transformation, this is EPSG:2393 (KKJ / Finland Uniform Coordinate System). The input coordinates
are assumed to be passed in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude
for geographic coordinates and easting, northing for projected coordinates.

**output_crs**
String identifying the CRS of target coordinates in the vertices. Typically EPSG:XXXX. If the transformation is for
vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX
is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89
transformation, this is EPSG:3067 ("ETRS89/TM35FIN(E,N)"). The output coordinates will be returned in the
"normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and
easting, northing for projected coordinates.

**transformed_components**
Array which may contain one or two strings: "horizontal" when horizontal components of the coordinates are
transformed and/or "vertical" when the vertical component is transformed.

**fallback_strategy**
String identifying how to treat points that do not fall into any of the specified triangles. This item is available
for format_version >= 1.1. Possible values are none, nearest_side and nearest_centroid. The default
is none and signifies, that points that fall outside the specified triangles are not transformed. This is also the
behavior for `format_version` before 1.1. If `fallback_strategy` is set to `nearest_side`, then points that do not fall into any triangle are transformed according to the triangle closest to them by euclidean distance. If `fallback_strategy` is set to `nearest_centroid`, then points that do not fall into any triangle are transformed according to the triangle with the closest centroid (intersection of its medians).

**vertices_columns**
Specify the name of the columns of the rows in the `vertices` array. There must be exactly as many elements in `vertices_columns` as in a row of `vertices`. The following names have a special meaning: `source_x`, `source_y`, `target_x`, `target_y`, `source_z`, `target_z` and `offset_z`. `source_x` and `source_y` are compulsory. `source_x` is for the source longitude (in degree) or easting. `source_y` is for the source latitude (in degree) or northing. `target_x` and `target_y` are compulsory when `horizontal` is specified in `transformed_components`. (`source_z` and `target_z`) or `offset_z` are compulsory when `vertical` is specified in `transformed_components`.

**triangles_columns**
Specify the name of the columns of the rows in the `triangles` array. There must be exactly as many elements in `triangles_columns` as in a row of `triangles`. The following names have a special meaning: `idx_vertex1`, `idx_vertex2`, `idx_vertex3`. They are compulsory.

**vertices**
An array whose items are themselves arrays with as many columns as described in `vertices_columns`.

**triangles**
An array whose items are themselves arrays with as many columns as described in `triangles_columns`. The value of the `idx_vertexN` columns must be indices (between 0 and len(`vertices`) - 1) of items of the `vertices` array.

A JSON schema is available for this file format.

### 7.3.12 Vertical Offset And Slope

New in version 9.1.0.

The Vertical Offset And Slope offsets transformation adds an offset to an orthometric height, taking account a constant offset and a inclined plane, defined by its slope along latitude and longitude axis.

<table>
<thead>
<tr>
<th>Alias</th>
<th>vertoffset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
<tr>
<td>output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical)</td>
</tr>
</tbody>
</table>

It is documented as coordinate operation method code 1046 in the EPSG dataset ([IOGP2018]). It is typically used in Europe, to relate national vertical systems to pan-European vertical systems (EVRF2000, EVRF2007).

#### 7.3.12.1 Examples

Vertical offset from LN02 height to EVRF2000 height with horizontal coordinates in ETRS89:

```
+proj=vertoffset +lat_0=46.9166666666666666 +lon_0=8.18333333333334 \
+dh=-0.245 +slope_lat=-0.210 +slope_lon=-0.032
```
7.3.12.2 Parameters

Required

+lat_0=<value>
Latitude of origin of the inclined plane.

+lon_0=<value>
Longitude of origin of the inclined plane

+dh=<value>
Offset in height, expressed in meter, to add.

+slope_lat=<value>
Slope parameter in the latitude domain, expressed in arc-seconds.

+slope_lon=<value>
Slope parameter in the longitude domain, expressed in arc-seconds.

+ellps=<value>
The name of a built-in ellipsoid definition.

See Ellipsoids for more information, or execute proj -le for a list of built-in ellipsoid names.

Defaults to "GRS80".

7.3.12.3 Formula

The $Z_{dest}$ destination elevation is obtained from the $Z_{src}$ source elevation with:

$$Z_{dest} = Z_{src} + (dh + slope_{lat} \times \rho_0 \times (\phi - \phi_0) + slope_{lon} \times \nu_0 \times (\lambda - \lambda_0) \times \cos(\phi))$$  \hspace{1cm} (7.11)

where:

- $dh$, $slope_{lat}$ and $slope_{lon}$ are the above mentioned parameters
- $\lambda_0, \phi_0$ is the longitude, latitude of the point of origin of the inclinate plane (+lon_0, +lat_0)
- $\lambda, \phi$ is the longitude, latitude of the point to evaluate
- $\rho_0$ is the radius of curvature of the meridian at latitude $\phi_0$
- $\nu_0$ is the radius of curvature on the prime vertical (i.e. perpendicular to the meridian) at latitude $\phi_0$

The reverse formula is:

$$Z_{src} = Z_{dest} - (dh + slope_{lat} \times \rho_0 \times (\phi - \phi_0) + slope_{lon} \times \nu_0 \times (\lambda - \lambda_0) \times \cos(\phi))$$  \hspace{1cm} (7.12)

7.3.13 Vertical grid shift

New in version 5.0.0.

Change Vertical datum change by grid shift

<table>
<thead>
<tr>
<th>Alias</th>
<th>vgridshift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D and 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
<tr>
<td>Output type</td>
<td>Geodetic coordinates (horizontal), meters (vertical), decimalyear (temporal)</td>
</tr>
</tbody>
</table>
The vertical grid shift is done by offsetting the vertical input coordinates by a specific amount determined by the loaded grids. The simplest use case of the horizontal grid shift is applying a single grid. Here we change the vertical reference from the ellipsoid to the global geoid model, EGM96:

```
+proj=vgridshift +grids=egm96_15.gtx
```

More than one grid can be loaded at the same time, for instance in the case where a better geoid model than the global is available for a certain area. Here the gridshift is set up so that the local DVR90 geoid model takes precedence over the global model:

```
+proj=vgridshift +grids=@dvr90.gtx,egm96_15.gtx
```

The `@` in the above example states that the grid is optional, in case the grid is not found in the PROJ search path. The list of grids is prioritized so that grids in the start of the list takes precedence over the grids in the back of the list.

PROJ supports the GeoTIFF (Geodetic TIFF grids (GTG)) and GTX file formats for vertical grid corrections. Details about all the formats can be found in the GDAL documentation. GDAL both reads and writes the format. Using GDAL for construction of new grids is recommended.

### 7.3.13.1 Temporal gridshifting

New in version 5.1.0.

By initializing the vertical gridshift operation with a central epoch, it can be used as a step function applying the grid offsets only if a coordinate is transformed from an epoch before grids central epoch to an epoch after. This is handy in transformations where it is necessary to handle deformations caused by seismic activity.

The central epoch of the grid is controlled with `+t_epoch` and the final epoch of the coordinate is set with `+t_final`. The observation epoch of the coordinate is part of the coordinate tuple.

Suppose we want to model the deformation of the 2008 earthquake in Iceland in a transformation of data from 2005 to 2009:

```
echo 63.992 -21.014 10.0 2005.0 | cct +proj=vgridshift +grids=iceland2008.gtx +t_epoch=2008.4071 +t_final=2009.0
```

Note: The timestamp of the resulting coordinate is still 2005.0. The observation time is always kept unchanged as it would otherwise be impossible to do the inverse transformation.

Temporal gridshifting is especially powerful in transformation pipelines where several gridshifts can be chained together, effectively acting as a series of step functions that can be applied to a coordinate that is propagated through time. In the following example we establish a pipeline that allows transformation of coordinates from any given epoch up until the current date, applying only those gridshifts that have central epochs between the observation epoch and the final epoch:

```
+proj=pipeline +t_final=now
+step +proj=vgridshift +grids=earthquake_1.gtx +t_epoch=2010.421
+step +proj=vgridshift +grids=earthquake_2.gtx +t_epoch=2013.853
+step +proj=vgridshift +grids=earthquake_3.gtx +t_epoch=2017.713
```

Note: The special epoch `now` is used when specifying the final epoch with `+t_final`. This results in coordinates being transformed to the current date. Additionally, `+t_final` is used as a global pipeline parameter, which means
that it is applied to all the steps in the pipeline.

In the above transformation, a coordinate with observation epoch 2009.32 would be subject to all three gridshift steps in the pipeline. A coordinate with observation epoch 2014.12 would only by offset by the last step in the pipeline.

### 7.3.13.2 Parameters

#### Required

**+grids=<list>**

Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will the not complain if the grid is not available.

Grids are expected to be in GeoTIFF (Geodetic TIFF grids (GTG)) or GTX formats.

#### Optional

**+t_epoch=<time>**

Central epoch of the transformation.

New in version 5.1.0.

**+t_final=<time>**

Final epoch that the coordinate will be propagated to after transformation. The special epoch now can be used instead of writing a specific period in time. When now is used, it is replaced internally with the epoch of the transformation. This means that the resulting coordinate will be slightly different if carried out again at a later date.

New in version 5.1.0.

**+multiplier=<value>**

Specify the multiplier to apply to the grid value in the forward transformation direction, such that:

\[
Z_{\text{target}} = Z_{\text{source}} + \text{multiplier} \times \text{gridvalue}
\]

(7.13)

The multiplier can be used to control whether the gridvalue should be added or subtracted, and if unit conversion must be done (the multiplied gridvalue must be expressed in metre).

Note that the default is -1.0 for historical reasons.

New in version 5.2.0.

### 7.3.14 Geocentric grid shift

New in version 7.0.0.

Geocentric translation using a grid shift

<table>
<thead>
<tr>
<th>Alias</th>
<th>xyzgridshift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>3D</td>
</tr>
<tr>
<td>Input type</td>
<td>Cartesian coordinates</td>
</tr>
<tr>
<td>Output type</td>
<td>Cartesian coordinates</td>
</tr>
</tbody>
</table>
Perform a geocentric translation by bilinear interpolation of \(dx, dy, dz\) translation values from a grid. The grid is referenced against either the 2D geographic CRS corresponding to the input (or sometimes output) CRS.

This method is described (in French) in [NTF_88] and as EPSG operation method code 9655 in [IOGP2018] (§2.4.4.1.1 France geocentric interpolation).

The translation in the grids are added to the input coordinates in the forward direction, and subtracted in the reverse direction. By default (if \(grid\_ref=input\_crs\)), in the forward direction, the input coordinates are converted to their geographic equivalent to directly read and interpolate from the grid. In the reverse direction, an iterative method is used to be able to find the grid locations to read. If \(grid\_ref=output\_crs\) is used, then the reverse strategy is applied: iterative method in the forward direction, and direct read in the reverse direction.

### 7.3.14.1 Example

NTF to RGF93 transformation using \(gr3df97a.tif\) grid

```
+proj=pipeline
  +step +proj=push +v_3
  +step +proj=cart +ellps=clrk80ign
  +step +proj=xyzgridshift +grids=gr3df97a.tif +grid\_ref=output\_crs
  +step +proj=cart +inv
  +step +proj=pop +v_3
```

**Parameters**

The ellipsoid parameters should be the ones consistent with \(grid\_ref\). They are used to perform a geocentric to geographic conversion to find the translation parameters.

**Required**

- **\(\texttt{+ellps=<value>}\)**
  
The name of a built-in ellipsoid definition.
  
  See [Ellipsoids](#) for more information, or execute `proj -le` for a list of built-in ellipsoid names.
  
  *Defaults to "GRS80".*

- **\(\texttt{+grids=<list>}\)**
  
  Comma-separated list of grids to load. If a grid is prefixed by an @ the grid is considered optional and PROJ will not complain if the grid is not available.

  Grids are expected to be in GeoTIFF format ([Geodetic TIFF grids (GTG)](#)). If no metadata is provided, the first, second and third samples are assumed to be the geocentric translation along X, Y and Z axis respectively, in metres.
Optional

+grid_ref= input_crs/output_crs

Specify in which CRS the grid is referenced to. The default value is input_crs. That is the grid is referenced in the geographic CRS corresponding to the input geocentric CRS.

If output_crs is specified, the grid is referenced in the geographic CRS corresponding to the output geocentric CRS. This is for example the case for the French gr3df97a.tif grid converting from NTF to RGF93, but referenced against RGF93. Thus in the forward direction (NTF->RGF93), an iterative method is used to find the appropriate shift.

+multiplier=<value>

Specify the multiplier to apply to the grid values. Defaults to 1.0

7.4 The pipeline operator

New in version 5.0.0.

Construct complex operations by daisy-chaining operations in a sequential pipeline.

<table>
<thead>
<tr>
<th>Alias</th>
<th>pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>2D, 3D and 4D</td>
</tr>
<tr>
<td>Input type</td>
<td>Any</td>
</tr>
<tr>
<td>Output type</td>
<td>Any</td>
</tr>
</tbody>
</table>

Note: See the section on Geodetic transformation for a more thorough introduction to the concept of transformation pipelines in PROJ.

With the pipeline operation it is possible to perform several operations after each other on the same input data. This feature makes it possible to create transformations that are made up of more than one operation, e.g. performing a datum shift and then applying a suitable map projection. Theoretically any transformation between two coordinate reference systems is possible to perform using the pipeline operation, provided that the necessary coordinate operations in each step is available in PROJ.

A pipeline is made up of a number of steps, with each step being a coordinate operation in itself. By connecting these individual steps sequentially we end up with a concatenated coordinate operation. An example of this is a transformation from geodetic coordinates on the GRS80 ellipsoid to a projected system where the east-west and north-east axes has been swapped:

```
+proj=pipeline +ellps=GRS80 +step +proj=merc +step +proj=axisswap +order=2,1
```

Here the first step is applying the Mercator projection and the second step is applying the Axis swap conversion. Note that the +ellps=GRS80 is specified before the first occurrence of +step. This means that the GRS80 ellipsoid is used in both steps, since any parameter stated before the first occurrence of +step is treated as a global parameter and is transferred to each individual steps.
7.4.1 Rules for pipelines

1. Pipelines must consist of at least one step.

```
+proj=pipeline
```

Will result in an error.

2. Pipelines can only be nested if the nested pipeline is defined in an init file.

```
+proj=pipeline
+step +proj=pipeline +step +proj=merc +step +proj=axisswap +order=2,1
+step +proj=unitconvert +xy_in=m +xy_out=us-ft
```

Results in an error, while

```
+proj=pipeline
+step +init=predefined_pipelines:projectandswap
+step +proj=unitconvert +xy_in=m +xy_out=us-ft
```

does not.

3. Pipelines without a forward path can’t be constructed.

```
+proj=pipeline +step +inv +proj=urm5
```

Will result in an error since Urmaev V does not have an inverse operation defined.

4. Parameters added before the first `+step` are global and will be applied to all steps.

In the following the GRS80 ellipsoid will be applied to all steps.

```
+proj=pipeline +ellps=GRS80
+step +proj=cart
+step +proj=helmert +x=10 +y=3 +z=1
+step +proj=cart +inv
+step +proj=merc
```

5. Units of operations must match between steps.

New in version 5.1.0.

The output units of step \( n \) must match the expected input unit of step \( n+1 \). E.g., you can’t pass an operation that outputs projected coordinates to an operation that expects angular units (degrees). An example of such a unit mismatch is displayed below.

```
+proj=pipeline
+step +proj=merc # Mercator outputs projected coordinates
+step +proj=robin # The Robinson projection expects angular input
```
7.4.2 Parameters

7.4.2.1 Required

+step
Separate each step in a pipeline.

7.4.2.2 Optional

+inv
Invert a step in a pipeline.

+omit_fwd
New in version 6.3.0.
Skip a step of the pipeline when it is followed in the forward path.

The following example shows a combined use of push and pop operators, with omit_fwd and omit_inv options, to implement a vertical adjustment that must be done in an interpolation CRS that is different from the horizontal CRS used in input and output. omit_fwd in the forward path avoid a useless inverse horizontal transformation and relies on the pop operator to restore initial horizontal coordinates. omit_inv serves the similar purpose when the pipeline is executed in the reverse direction

```
+proj=pipeline
+step +proj=unitconvert +xy_in=deg +xy_out=rad
+step +proj=push +v_1 +v_2
+step +proj=hgridshift +grids=nvhpgn.gsb +omit_inv
+step +proj=vgridshift +grids=g1999u05.gtx +multiplier=1
+step +inv +proj=hgridshift +grids=nvhpgn.gsb +omit_fwd
+step +proj=pop +v_1 +v_2
+step +proj=unitconvert +xy_in=rad +xy_out=deg
```

+omit_inv
New in version 6.3.0.
Skip a step of the pipeline when it is followed in the reverse path.

7.5 Computation of coordinate operations between two CRS

Author
Even Rouault

Last Updated
2023-08-26
### 7.5.1 Introduction

When using `projinfo -s {crs_def} -t {crs_def}. cs2cs {crs_def} {crs_def}` or the underlying `proj_create_crs_to_crs()` or `proj_create_operations()` functions, PROJ applies an algorithm to compute one or several candidate coordinate operations, that can be expressed as a PROJ pipeline to transform between the source and the target CRS. This document is about the description of this algorithm that finds the actual operations to apply to be able later to perform transform coordinates. So this is mostly about metadata management around coordinate operation methods, and not about the actual mathematics used to implement those methods. As a matter of fact with PROJ 6, there are about 60 000 lines of code dealing with "metadata" management (including conversions between PROJ strings, all CRS WKT variants), to be compared to 30 000 for the purely computation part.

This document is meant as a plain text explanation of the code for developers, but also as a in-depth examination of what happens under the hood for curious PROJ users. It is important to keep in mind that it is not meant to be the ultimate source of truth of how coordinate operations should be computed. There are clearly implementation choices and compromises that can be questioned.

Let us start with an example to research operations between the NAD27 and NAD83 geographic CRS:

```shell
$ projinfo -s NAD27 -t NAD83 --summary --spatial-test intersects --grid-check none

Candidate operations found: 10
DERIVED_FROM(EPSG):1312, NAD27 to NAD83 (3), 1.0 m, Canada
DERIVED_FROM(EPSG):1313, NAD27 to NAD83 (4), 1.5 m, Canada - NAD27, at least one grid.
DERIVED_FROM(EPSG):1241, NAD27 to NAD83 (1), 0.15 m, USA - CONUS including EEZ
DERIVED_FROM(EPSG):1243, NAD27 to NAD83 (2), 0.5 m, USA - Alaska including EEZ
DERIVED_FROM(EPSG):1573, NAD27 to NAD83 (6), 1.5 m, Canada - Quebec, at least one grid.
EPSG:1462, NAD27 to NAD83 (5), 1.0 m, Canada - Quebec, at least one grid missing
EPSG:9111, NAD27 to NAD83 (9), 1.5 m, Canada - Saskatchewan, at least one grid missing
unknown id, Ballpark geographic offset from NAD27 to NAD83, unknown accuracy, World, has
ballpark transformation
EPSG:8555, NAD27 to NAD83 (7), 0.15 m, USA - CONUS and GoM, at least one grid missing
EPSG:8549, NAD27 to NAD83 (8), 0.5 m, USA - Alaska, at least one grid missing
```

The algorithm involves many cases, so we will progress in the explanation from the most simple case to more complex ones. We document here the working of this algorithm as implemented in PROJ 8.0.0. The results of some examples might also be quite sensitive to the content of the PROJ database and the PROJ version used.

From a code point of view, the entry point of the algorithm is the C++ `osgeo::proj::operation::CoordinateOperation::createOperations()` method.

It combines several strategies:

- look up in the PROJ database for available operations
- consider the pair (source CRS, target CRS) to synthetize operations depending on the nature of the source and target CRS.
7.5.2 Geographic CRS to Geographic CRS, with known identifiers

With the above example of two geographic CRS, that have an identified identifier, (projinfo internally resolves NAD27 to EPSG:4267 and NAD83 to EPSG:4269) the algorithm will first search in the coordinate operation related tables of the proj.db if there are records that list direct transformations between the source and the target CRS. The transformations typically involve Helmert-style operations or datum shift based on grids (more esoteric operations are possible).

A request similar to the following will be emitted:

```
$ sqlite3 proj.db "SELECT auth_name, code, name, method_name, accuracy FROM coordinate_operation_view WHERE 
source_crs_auth_name = 'EPSG' AND 
source_crs_code = '4267' AND 
target_crs_auth_name = 'EPSG' AND 
target_crs_code = '4269';"
```

As we have found direct transformations, we will not attempt any more complicated research. One can note in the above result set that a ESRI:108003 operation was found, but as the source and target CRS are in the EPSG registry, and there are operations between those CRS in the EPSG registry itself, transformations from other authorities will be ignored (except if they are in the PROJ authority, which can be used as an override).

As those results all involve operations that does not have a perfect accuracy and that does not cover the area of use of the 2 CRSs, a ‘Ballpark geographic offset from NAD27 to NAD83’ operation is synthetized by PROJ (see Ballpark transformation)

7.5.3 Filtering and sorting of coordinate operations

The last step is to filter and sort results in order of relevance.

The filtering takes into account the following criteria to decide which operations must be retained or discarded:

- a minimum accuracy that the user might have expressed,
- an area of use on which the coordinate operation(s) must apply
- if the absence of grids needed by an operation must result in discarding it.

The sorting algorithm determines the order of relevance of the operations we got. A comparison function compares pair of operations to determine which of the two is the most relevant. This is implemented by the operator \( \odot \) method of the SortFunction structure. When comparing two operations, the following criteria are used. The tests are performed in the order they are listed below:

1. consider as more relevant an operation that can be expressed as a PROJ operation string (the database might list operations whose method is not (yet) implemented by PROJ)
2. if both operations evaluate identically with respect to the above criterion, consider as more relevant an operation that does not include a synthetic ballpark vertical transformation (occurs when there is a geoid model).
3. if both operations evaluate identically with respect to the above criterion, consider as more relevant an operation that does not include a synthetic ballpark horizontal transformation.

4. consider as more relevant an operation that refers to shift grids that are locally available.

5. consider as more relevant an operation that refers to grids that are available in one of the proj-datumgrid packages, but not necessarily locally available.

6. consider as more relevant an operation that has a known accuracy.

7. if two operations have unknown accuracy, consider as more relevant an operation that uses grid(s) if the other one does not (grid based operations are assumed to be more precise than operations relying on a few parameters).

8. consider as more relevant an operation whose area of use is larger (note: the computation of the area of use is approximate, based on a bounding box).

9. consider as more relevant an operation that has a better accuracy.

10. in case of same accuracy, consider as more relevant an operation that does not use grids (operations that use only parameters will be faster).

11. consider as more relevant an operation that involves less transformation steps (transformation steps considered are the ones listed in the WKT output, not PROJ pipeline steps).

12. and for completeness, if two operations are comparable given all the above criteria, consider as more relevant the one which has the shorter name, and if they have the same length, consider as more relevant the one whose name comes last in lexicographic order (e.g. "FOO to BAR (3)" will have higher precedence than "FOO to BAR (2)"

Note: `proj_trans()`, on the results returned by `proj_create_crs_to_crs()`, will not necessarily use the operation that is listed in first position due to the above algorithm. `proj_trans()` has more context, since it has the coordinate to transform, so it can compare this coordinate to the area of use of operations. Typically, the above criteria will favor an operation that has a larger area of use over another one with a smaller area, due to it being more generally applicable. But once coordinates are known, `proj_trans()` can select an operation with a smaller area of use that applies to the coordinate to transform.

### 7.5.4 Geodetic/geographic CRS to Geodetic/geographic CRS, without known identifiers

In a number of situations, the source and/or target CRS do not have an identifier (WKT without identifier, PROJ string, ..) The first step is to try to find in the `proj.db` a CRS of the same nature of the CRS to identify and whose name exactly matches the one provided to the `createOperations()` method. If there is exactly one match and that the CRS are "computationally" equivalent, then use the code of the CRS for further computations.

If this search did not succeed, or if the previous case with known CRS identifiers did not result in matches in the database, the search will be based on the datums. That is, a list of geographic CRS whose datum matches the datum of the source and target CRS is searched for in the database (by querying the `geodetic_crs` database table). If the datum has a known identifier, we will use it, otherwise we will look for an equivalent datum in the database based on the datum name.

Let's consider the case where the datum of the source CRS is EPSG:6171 "Reseau Geodesique Francais 1993" and the datum of the target CRS is EPSG:6258 "European Terrestrial Reference System 1989". For EPSG:6171, there are 10 matching (non-deprecated) geodetic CRSs:

- EPSG:4171, RGF93, geographic 2D
- EPSG:4964, RGF93, geocentric
PROJ coordinate transformation software library, Release 9.3.1

- EPSG:4965, RGF93, geographic 3D
- EPSG:7042, RGF93 (lon-lat), geographic 3D
- EPSG:7084, RGF93 (lon-lat), geographic 2D
- IGNF:RGF93, RGF93 cartesiennes geocentriques, geocentric
- IGNF:RGF93GDD, RGF93 geographiques (dd), geographic 2D
- IGNF:RGF93GEO, RGF93 cartesiennes geocentriques, geocentric
- IGNF:RGF93GEODD, RGF93 geographiques (dd), geographic 3D
- IGNF:RGF93G, RGF93 cartesiennes geocentriques, geocentric
- IGNF:RGF93GEO, RGF93 geographiques (dms), geographic 2D

The first three entries from the EPSG dataset are typical: for each datum, one can define a geographic 2D CRS (latitude, longitude), a geographic 3D CRS (latitude, longitude, ellipsoidal height) and a geocentric one. For that particular case, the EPSG dataset has also included two extra definitions corresponding to a longitude, latitude, [ellipsoidal height] coordinate system, as found in the official French IGNF registry. This IGNF registry has also definitions for a geographic 2D CRS (with an extra subtlety with an entry using decimal degree as unit and another one degree-minute-second), geographic 3D and geocentric.

For EPSG:6258, there are 7 matching (non-deprecated) geodetic CRSs:

- EPSG:4258, ETRS89, geographic 2D
- EPSG:4936, ETRS89, geocentric
- EPSG:4937, ETRS89, geographic 3D
- IGNF:ETRS89, ETRS89 cartesiennes geocentriques, geocentric
- IGNF:ETRS89G, ETRS89 geographiques (dms), geographic 2D
- IGNF:ETRS89GEO, ETRS89 geographiques (dms), geographic 3D
- ESRI:104129, GCS_EUREF_FIN, geographic 2D

So the 3 typical EPSG entries, 3 equivalent (with long, lat ordering for the geographic CRS) and one from the ESRI registry;

PROJ can now test 10 x 7 different combinations of source x target CRSs, using the database searching method explained in the previous section. As soon as one of this combination returns at least one non-ballpark combination, the result set coming from that combination is used. PROJ will then add before that transformation a conversion between the source CRS and the first intermediate CRS, and will add at the end a conversion between the second intermediate CRS and the target CRS. Those conversions are conversion between geographic 2D and geographic 3D CRS or geographic 2D/3D and geocentric CRS.

This is done by the createOperationsWithDatumPivot() method.

So if transforming between EPSG:7042, RGF93 (lon-lat), geographic 3D and EPSG:4936, ETRS89, geocentric, one get the following concatenated operation, chaining an axis order change, the null geocentric translation between RGF93 and ETRS89 (EPSG:1591), and a conversion between geographic and geocentric coordinates. This concatenated operation is assumed to have a perfect accuracy as both the initial and final operations are conversions, and the middle transformation accounts for the fact that the RGF93 datum is one realization of ETRS89, so they are equivalent for most purposes.

```
$ projinfo -s EPSG:7042 -t EPSG:4936
Candidate operations found: 1
-------------------------------------
Operation No. 1:
```

(continues on next page)
unknown id, axis order change (geographic3D horizontal) + RGF93 to ETRS89 (1) $\rightarrow$
Conversion from ETRS89 (geog2D) to ETRS89 (geocentric), 0 m, France

PROJ string:
\begin{verbatim}
+proj=pipeline +step +proj=unitconvert +xy_in=deg +xy_out=rad +step +proj=cart $\rightarrow$
+ellps=GRS80
\end{verbatim}

WKT2:2019 string:
\begin{verbatim}
CONCATENATEDOPERATION["axis order change (geographic3D horizontal) + RGF93 to ETRS89 (1) $\rightarrow$
Conversion from ETRS89 (geog2D) to ETRS89 (geocentric),

SOURCECRS[
  GEOCRS["RGF93 (lon-lat)",
    [...] ID["EPSG",7042]],

TARGETCRS[
  GEODCRS["ETRS89",
    [...] ID["EPSG",4936]],

STEP[
  CONVERSION["axis order change (geographic3D horizontal)",
    METHOD["Axis Order Reversal (Geographic3D horizontal)",
      ID["EPSG",9844]],
    ID["EPSG",15499]],

STEP[
  COORDINATEOPERATION["RGF93 to ETRS89 (1)",
    [...] METHOD["Geocentric translations (geog2D domain)",
      ID["EPSG",9603]],
    PARAMETER["X-axis translation",0,
      LENGTHUNIT["metre",1],
      ID["EPSG",8605]],
    PARAMETER["Y-axis translation",0,
      LENGTHUNIT["metre",1],
      ID["EPSG",8606]],
    PARAMETER["Z-axis translation",0,
      LENGTHUNIT["metre",1],
      ID["EPSG",8607]],
    OPERATIONACCURACY[0.0],
    ID["EPSG",1591],
    REMARK["May be taken as approximate transformation RGF93 to WGS 84 - see code 1671."]]],

STEP[
  CONVERSION["Conversion from ETRS89 (geog2D) to ETRS89 (geocentric)",
    METHOD["Geographic/geocentric conversions",
      ID["EPSG",9602]]],

USAGE[
  SCOPE["unknown"],
  AREA["France"],
  BBOX[41.15,-9.86,51.56,10.38]]
\end{verbatim}

7.5. Computation of coordinate operations between two CRS
7.5.5 Geodetic/geographic CRS to Geodetic/geographic CRS, without direct transformation

Still considering transformations between geodetic/geographic CRS, but let's consider that the lookup in the database for a transformation between the source and target CRS (possibly going through the "equivalent" CRS based on the same datum as detailed in the previous section) leads to an empty set.

Of course, as most operations are invertible, one first tries to do a lookup switching the source and target CRS, and inverting the resulting operation(s):

```
$ projinfo -s NAD83 -t NAD27 --spatial-test intersects --summary

Candidate operations found: 10
INVERSE(DERIVED_FROM(EPSG)):1312, Inverse of NAD27 to NAD83 (3), 2.0 m, Canada
INVERSE(DERIVED_FROM(EPSG)):1313, Inverse of NAD27 to NAD83 (4), 1.5 m, Canada - NAD27
INVERSE(DERIVED_FROM(EPSG)):1241, Inverse of NAD27 to NAD83 (1), 0.15 m, USA - CONUS,
  including EEZ
INVERSE(DERIVED_FROM(EPSG)):1243, Inverse of NAD27 to NAD83 (2), 0.5 m, USA - Alaska,
  including EEZ
INVERSE(DERIVED_FROM(EPSG)):1573, Inverse of NAD27 to NAD83 (6), 1.5 m, Canada - Quebec,
  at least one grid missing
INVERSE(EPSG):1462, Inverse of NAD27 to NAD83 (5), 2.0 m, Canada - Quebec, at least one
  grid missing
INVERSE(EPSG):9111, Inverse of NAD27 to NAD83 (9), 1.5 m, Canada - Saskatchewan, at
  least one grid missing
unknown id, Ballpark geographic offset from NAD83 to NAD27, unknown accuracy, World, has
  ballpark transformation
INVERSE(EPSG):8555, Inverse of NAD27 to NAD83 (7), 0.15 m, USA - CONUS and GoM, at least
  one grid missing
INVERSE(EPSG):8549, Inverse of NAD27 to NAD83 (8), 0.5 m, USA - Alaska, at least one
  grid missing
```

That was an easy case. Now let's consider the transformation between the Australian CRS AGD84 and GDA2020. There is no direct transformation from AGD84 to GDA2020, or in the reverse direction, even when considering alternative geodetic CRS based on the underlying datums. PROJ will then do a cross-join in the coordinate_operation_view table to find the tuples (op1, op2) of coordinate operations such that:

- **SOURCE_CRS = op1.source_crs AND op1.target_crs = op2.source_crs AND op2.target_crs = TARGET_CRS**
- **SOURCE_CRS = op1.source_crs AND op1.target_crs = op2.target_crs AND op2.source_crs = TARGET_CRS**
- **SOURCE_CRS = op1.target_crs AND op1.source_crs = op2.source_crs AND op2.target_crs = TARGET_CRS**
- **SOURCE_CRS = op1.target_crs AND op1.source_crs = op2.target_crs AND op2.source_crs = TARGET_CRS**

Depending on which case is selected, op1 and op2 should be reversed, before being concatenated.

This logic is implemented by the `findsOpsInRegistryWithIntermediate()` method.

Assuming that the proj-datumgrid-oceania package is installed, we get the following results for the AGD84 to GDA2020 coordinate operations lookup:

```
$ projinfo -s AGD84 -t GDA2020 --spatial-test intersects --summary

```

(continues on next page)
Candidate operations found: 4

-------------------------------------
Operation No. 1:

unknown id, AGD84 to GDA94 (5) + GDA94 to GDA2020 (1), 0.11 m, Australia - AGD84

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1
   +step +proj=unitconvert +xy_in=deg +xy_out=rad
   +step +proj=hgridshift +grids=National_84_02_07_01.gsb
   +step +proj=push +v_3
   +step +proj=cart +ellps=GRS80
   +step +proj=helmert +x=0.06155 +y=-0.01087 +z=-0.04019
      +rx=-0.0394924 +ry=-0.0327221 +rz=-0.0328979
      +s=-0.009994 +convention=coordinate_frame
   +step +inv +proj=cart +ellps=GRS80
   +step +proj=pop +v_3
   +step +proj=unitconvert +xy_in=rad +xy_out=deg
   +step +proj=axisswap +order=2,1

-------------------------------------
Operation No. 2:

unknown id, AGD84 to GDA94 (2) + GDA94 to GDA2020 (1), 1.01 m, Australia - AGD84

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1
   +step +proj=unitconvert +xy_in=deg +xy_out=rad
   +step +proj=push +v_3
   +step +proj=cart +ellps=aust_SA
   +step +proj=helmert +x=-117.763 +y=-51.51 +z=139.061
      +rx=-0.292 +ry=-0.443 +rz=-0.277 +s=-0.191
      +convention=coordinate_frame
   +step +proj=helmert +x=0.06155 +y=-0.01087 +z=-0.04019
      +rx=-0.0394924 +ry=-0.0327221 +rz=-0.0328979
      +s=-0.009994 +convention=coordinate_frame
   +step +inv +proj=cart +ellps=GRS80
   +step +proj=pop +v_3
   +step +proj=unitconvert +xy_in=rad +xy_out=deg
   +step +proj=axisswap +order=2,1

-------------------------------------
Operation No. 3:

unknown id, AGD84 to GDA94 (5) + GDA94 to GDA2020 (2), 0.15 m, unknown domain of validity

PROJ string:
+proj=pipeline +step +proj=axisswap +order=2,1
   +step +proj=unitconvert +xy_in=deg +xy_out=rad
   +step +proj=hgridshift +grids=National_84_02_07_01.gsb
   +step +proj=hgridshift +grids=GDA94_GDA2020_conformal_and_distortion.gsb
   +step +proj=unitconvert +xy_in=rad +xy_out=deg

(continues on next page)
One can see that the selected intermediate CRS that has been used is GDA94. This is a completely novel behavior of PROJ 6 as opposed to the logic of PROJ.4 where datum transformations implied using EPSG:4326 / WGS 84 has the mandatory datum hub. PROJ 6 no longer hardcodes it as the mandatory datum hub, and relies on the database to find the appropriate hub(s). Actually, WGS 84 has been considered during the above lookup, because there are transformations between AGD84 and WGS 84 and WGS 84 and GDA2020. However those have been discarded in a step which we did not mention previously: just after the initial filtering of results and their sorting, there is a final filtering that is done. In the list of sorted results, given two operations A and B that have the same area of use, if B has an accuracy lower than A, and A does not use grids, or all the needed grids are available, then B is discarded.

If one forces the datum hub to be considered to be EPSG:4326, ones gets:

```
$ projinfo -s AGD84 -t GDA2020 --spatial-test intersects --pivot-crs EPSG:4326 -o PROJ
```

Candidate operations found: 2

Operation No. 1:

unknown id, AGD84 to WGS 84 (7) + Inverse of GDA2020 to WGS 84 (2), 4 m, Australia → AGD84

PROJ string:

```
+proj=pipeline +step +proj=axisswap +order=2,1 \
+step +proj=unitconvert +xy_in=deg +xy_out=rad \
+step +proj=hgridshift +grids=National_84_02_07_01.gsb \
+step +proj=hgridshift +grids=GDA94_GDA2020_conformal.gsb \
+step +proj=unitconvert +xy_in=rad +xy_out=deg \
+step +proj=axisswap +order=2,1
```

Operation No. 2:

unknown id, AGD84 to WGS 84 (9) + Inverse of GDA2020 to WGS 84 (2), 4 m, Australia → AGD84

```
+proj=pipeline +step +proj=axisswap +order=2,1 \
+step +proj=unitconvert +xy_in=deg +xy_out=rad \
+step +proj=push +v_3 \
+step +proj=cart +ellps=aust_SA \
+step +proj=helmert +x=-117.763 +y=-51.51 +z=139.061 \
+rx=-0.292 +ry=-0.443 +rz=-0.277 \
+s=-0.191 +convention=coordinate_frame \
+inv +proj=cart +ellps=GRS80 \
+step +proj=pop +v_3 \
+step +proj=unitconvert +xy_in=rad +xy_out=deg \
+step +proj=axisswap +order=2,1
```

(continues on next page)
Those operations are less accurate, since WGS 84 is assumed to be equivalent to GDA2020 with an accuracy of 4 metre. This is an instance demonstrating that using WGS 84 as a hub systematically can be sub-optimal.

There are still situations where the attempt to find a hub CRS does not work, because there is no such hub. This can occur for example when transforming from GDA94 to the latest realization at time of writing of WGS 84, WGS 84 (G1762). There are transformations between WGS 84 (G1762). Using the above described techniques, we would only find one non-ballpark operation taking the route: 1. Conversion from GDA94 (geog2D) to GDA94 (geocentric): synthetized by PROJ 2. Inverse of ITRF2008 to GDA94 (1): from EPSG 3. Inverse of WGS 84 (G1762) to ITRF2008 (1): from EPSG 4. Conversion from WGS 84 (G1762) (geocentric) to WGS 84 (G1762): synthetized by PROJ

This is not bad, but the global validity area of use is "Australia - onshore and EEZ", whereas GDA94 has a larger area of use. There is another road that can be taken by going through GDA2020 instead of ITRF2008. The GDA94 to GDA2020 transformations operate on the respective geographic CRS, whereas GDA2020 to WGS 84 (G1762) operate on the geocentric CRS. Consequently, GDA2020 cannot be identifier as a hub by a "simple" self-join SQL request on the coordinate operation table. This requires to do the join based on the datum referenced by the source and target CRS of each operation rather than the source and target CRS themselves. When there is a match, PROJ inserts the required conversions between geographic and geocentric CRS to have a consistent concatenated operation, like the following: 1. GDA94 to GDA2020 (1): from EPSG 2. Conversion from GDA2020 (geog2D) to GDA2020 (geocentric): synthetized by PROJ 3. GDA2020 to WGS 84 (G1762) (1): from EPSG 4. Conversion from WGS 84 (G1762) (geocentric) to WGS 84 (G1762) (geog2D): synthetized by PROJ

7.5.6 Projected CRS to any target CRS

This actually extends to any Derived CRS, whose Projected CRS is a well-known particular case. Such transformations are done in 2 steps:

1. Use the inverse conversion of the derived CRS to its base CRS, typically an inverse map projection.
2. Find transformations from this base CRS to the target CRS. If the base CRS is the target CRS, this step can be skipped.

$ projinfo -s EPSG:32631 -t RGF93

Candidate operations found: 1
--------------
Operation No. 1:
unknown id, Inverse of UTM zone 31N + Inverse of RGF93 to WGS 84 (1), 1 m, France

PROJ string:
+proj=pipeline +step +inv +proj=utm +zone=31 +ellps=WGS84 +step +proj=unitconvert +xy_in=rad +xy_out=deg +step +proj=axisswap +order=2,1

This is implemented by the createOperationsDerivedTo method

For the symmetric case, source CRS to a derived CRS, the above algorithm is applied by switching the source and target CRS, and then inverting the resulting operation(s). This is mostly a matter of avoiding to write very similar code
PROJ coordinate transformation software library, Release 9.3.1

twice. This logic is also applied to all below cases when considering the transformation between 2 different types of objects.

7.5.7 Vertical CRS to a Geographic CRS

Such transformation is normally not meant as being used as standalone by PROJ users, but as an internal computation step of a Compound CRS to a target CRS.

In cases where we are lucky, the PROJ database will have a transformation registered between those:

```
$ projinfo -s "NAVD88 height" -t "NAD83(2011)" -o PROJ --spatial-test intersects
Candidate operations found: 11
-------------------------------------
Operation No. 1:
INVERSE(DERIVED_FROM(EPSG)):9229, Inverse of NAD83(2011) to NAVD88 height (3), 0.015 m, USA - CONUS - onshore
PROJ string:
+proj=vgridshift +grids=g2018u0.gtx +multiplier=1
```

But in cases where there is no match, the createOperationsVertToGeog method will be used to synthetize a ballpark vertical transformation, just taking care of unit changes, and axis reversal in case the vertical CRS was a depth rather than a height. Of course the results of such an operation are questionable, hence the ballpark qualifier and a unknown accuracy advertized for such an operation.

7.5.8 Vertical CRS to a Vertical CRS

Overall logic is similar to the above case. There might be direct operations in the PROJ database, involving grid transformations or simple offsets. The fallback case is to synthetize a ballpark transformation.

This is implemented by the createOperationsVertToVert method

```
$ projinfo -s "NGVD29 depth (ftUS)" -t "NAVD88 height" --spatial-test intersects -o PROJ
Candidate operations found: 3
-------------------------------------
Operation No. 1:
unknown id, Inverse of NGVD29 height (ftUS) to NGVD29 depth (ftUS) + NGVD29 height (ftUS) to NGVD29 height (m) + NGVD29 height (m) to NAVD88 height (3), 0.02 m, USA - CONUS east of 89°W - onshore
PROJ string:
+proj=pipeline +step +proj=axisswap +order=1,2,-3 +step +proj=unitconvert +z_in=us-ft +z_out=m +step +proj=vgridshift +grids=vertcone.gtx +multiplier=0.001
```

(continues on next page)
PROJ coordinate transformation software library, Release 9.3.1

PROJ string:
+proj=pipeline +step +proj=axisswap +order=1,2,-3 +step +proj=unitconvert +z_in=us-ft +z_→out=m +step +proj=vgridshift +grids=vertconc.gtx +multiplier=0.001

Operation No. 3:
unknown id, Inverse of NGVD29 height (ftUS) to NGVD29 depth (ftUS) + NGVD29 height → (ftUS) to NGVD29 height (m) + NGVD29 height (m) to NAVD88 height (1), 0.02 m, USA - CONUS west of 107°W - onshore

PROJ string:
+proj=pipeline +step +proj=axisswap +order=1,2,-3 +step +proj=unitconvert +z_in=us-ft +z_→out=m +step +proj=vgridshift +grids=vertconw.gtx +multiplier=0.001

7.5.9 Compound CRS to a Geographic CRS

A typical example of a Compound CRS is a CRS made of a geographic or projected CRS as the horizontal component, and a vertical CRS. E.g. "NAD83 + NAVD88 height"

When the horizontal component of the compound source CRS is a projected CRS, we first look for the operation from this source CRS to another compound CRS made of the geographic CRS base of the projected CRS, like "NAD83 / California zone 1 (ftUS) + NAVD88 height" to "NAD83 + NAVD88 height", which ultimately goes to one of the above described case. Then we can consider the transformation from a compound CRS made of a geographic CRS to another geographic CRS.

It first starts by the vertical transformations from the vertical CRS of the source compound CRS to the target geographic CRS, using the strategy detailed in Vertical CRS to a Geographic CRS.

What we did not mention is that when there is not a transformation registered between the vertical CRS and the target geographic CRS, PROJ attempts to find transformations between that vertical CRS and any other geographic CRS. This is clearly an approximation. If the research of the vertical CRS to the target geographic CRS resulted in operations that use grids that are not available, as another approximation, we research operations from the vertical CRS to the source geographic CRS for the vertical component.

Once we got those more or less accurate vertical transformations, we must consider the horizontal transformation(s). The algorithm iterates over all found vertical transformations and look for their target geographic CRS. This will be used as the interpolation CRS for horizontal transformations. PROJ will then look for available transformations from the source geographic CRS to the interpolation CRS and from the interpolation CRS to the target geographic CRS.

There is then a 3-level loop to create the final set of operations chaining together:

- the horizontal transformation from the source geographic CRS to the interpolation CRS
- the vertical transformation from the source vertical CRS to the interpolation CRS
- the horizontal transformation from the interpolation CRS to the target geographic CRS.

This is implemented by the createOperationsCompoundToGeog method.

Example:

$ projinfo -s "NAD83(NSRS2007) + NAVD88 height" -t "WGS 84 (G1762)" --spatial-test intersects --summary

(continues on next page)
Candidate operations found: 21
unknown id, Inverse of NAD83(NRS2007) to NAVD88 height (1) + NAD83(NRS2007) to WGS 84...
unknown id, Inverse of NAD83(HARN) to NAD83(NRS2007) (1) + Inverse of NAD83(HARN) to...
unknown id, Inverse of NAD83(HARN) to NAVD88 height (7) + NAD83(HARN) to WGS 84 (1) + WGS...
7.5.10 CompoundCRS to CompoundCRS

There is some similarity with the previous paragraph. We first research the vertical transformations between the two vertical CRS.

1. If there is such a transformation, be it direct, or if both vertical CRS relate to a common intermediate CRS. If it has a registered interpolation geographic CRS, then it is used. Otherwise we fallback to the geographic CRS of the source CRS.

Finally, a 3-level loop to create the final set of operations chaining together:

- the horizontal transformation from the source CRS to the interpolation CRS
- the vertical transformation
- the horizontal transformation from the interpolation CRS to the target CRS.

Example:

```bash
$ projinfo -s "NAD27 + NGVD29 height (ftUS)" -t "NAD83 + NAVD88 height" --spatial-test intersects --summary

Candidate operations found: 20
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (1), 0.17 m, USA - CONUS east of 89°W - onshore
unknown id, NGVD29 height (ftUS) to NAVD88 height (2) + NAD27 to NAD83 (1), 0.17 m, USA - CONUS 89°W-107°W - onshore
unknown id, NGVD29 height (ftUS) to NAVD88 height (1) + NAD27 to NAD83 (1), 0.17 m, USA - CONUS west of 107°W - onshore
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (3), 1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (2) + NAD27 to NAD83 (3), 1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (1) + NAD27 to NAD83 (3), 1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (5), 1.02 m, unknown domain of validity
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (6), 1.52 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height (3) + NAD27 to NAD83 (7), 1.52 m, unknown domain of validity, at least one grid missing
```

(continues on next page)
unknown id, NGVD29 height (ftUS) to NAVD88 height \( (2) \) + NAD27 to NAD83 \( (9) \), ↦ 1.52 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height \( (1) \) + NAD27 to NAD83 \( (9) \), ↦ 1.52 m, unknown domain of validity, at least one grid missing
unknown id, NGVD29 height (ftUS) to NAVD88 height \( (3) \) + Ballpark geographic, ↦ offset from NAD27 to NAD83, unknown accuracy, USA - CONUS east of 89°W ↦ onshore, has ballpark transformation
unknown id, NGVD29 height (ftUS) to NAVD88 height \( (2) \) + Ballpark geographic, ↦ offset from NAD27 to NAD83, unknown accuracy, USA - CONUS 89°W-107°W ↦ onshore, has ballpark transformation
unknown id, NGVD29 height (ftUS) to NAVD88 height \( (1) \) + Ballpark geographic, ↦ offset from NAD27 to NAD83, unknown accuracy, USA - CONUS west of 107°W ↦ onshore, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + NAD27 to NAD83 \( (1) \), unknown accuracy, ↦ USA - CONUS including EEZ, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + NAD27 to NAD83 \( (3) \), unknown accuracy, ↦ Canada, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + NAD27 to NAD83 \( (4) \), unknown accuracy, ↦ Canada - NAD27, has ballpark transformation
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + NAD27 to NAD83 \( (5) \), unknown accuracy, ↦ Canada - Quebec, has ballpark transformation, at least one grid missing
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + NAD27 to NAD83 \( (6) \), unknown accuracy, ↦ Canada - Quebec, has ballpark transformation, at least one grid missing
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + NAD27 to NAD83 \( (9) \), unknown accuracy, ↦ Canada - Saskatchewan, has ballpark transformation, at least one grid missing
unknown id, Transformation from NGVD29 height (ftUS) to NAVD88 height, ↦ (ballpark vertical transformation) + Ballpark geographic offset from, ↦ NAD27 to NAD83, unknown accuracy, World, has ballpark transformation

2. Otherwise, when there is no such transformation, we decompose into 3 steps:

• transform from the source CRS to the geographic 3D CRS corresponding to it
• transform from the geographic 3D CRS corresponding to the source CRS to the geographic 3D CRS corresponding to the target CRS
• transform from the geographic 3D CRS corresponding to the target CRS to the target CRS.

Example:

```
$ projinfo -s "WGS 84 + EGM96 height" -t "ETRS89 + Belfast height" --spatial-test intersects --summary
```

Candidate operations found: 7
unknown id, Inverse of WGS 84 to EGM96 height \( (1) \) + Inverse of ETRS89 to, ↦ WGS 84 \( (1) \) + ETRS89 to Belfast height \( (2) \), 2.014 m, UK - Northern Ireland, ↦ onshore

(continues on next page)
unknown id, Inverse of WGS 84 to EGM96 height (1) + Inverse of ETRS89 to...
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset...
unknown id, Inverse of WGS 84 to EGM96 height (1) + Null geographic offset...
Example:

```
$ projinfo -s "+proj=tmerc +lat_0=49 +lon_0=-2 +k=0.9996012717 +x_0=400000 +y_0=-100000 -ellps=airy +towgs84=446.448,-125.157,542.06,0.15,0.247,0.842,-20.489 +units=m +type=crs" -t ETRS89 -o PROJ
```

Candidate operations found: 1

Operation No. 1:

unknown id, Inverse of unknown + Transformation from unknown to WGS84 + Inverse of ETRS89 to WGS 84 (1), unknown accuracy, Europe - ETRS89

PROJ string:

```
+proj=pipeline +step +inv +proj=tmerc +lat_0=49 +lon_0=-2 +k=0.9996012717 +x_0=400000 +y_0=-100000 +ellps=airy +towgs84=446.448,-125.157,542.06,0.15,0.247,0.842,-20.489 +units=m +type=crs
```

There are other situations with BoundCRS, involving vertical transformations, or transforming to other objects than a geographic CRS, but the curious reader will have to inspect the code for the actual gory details.

### 7.5.12 Using Derived Projected for source or target CRS

The WKT2 tag DERIVEDPROJCRS can be useful to define a customized CRS adding a DERIVINGCONVERSION to apply a conversion on top of the projection. It can be also done inside a Compound CRS. One use case is to describe a local CRS produced in a site calibration, as explained in [JimenezShaw2023].

Using the WKT2 from that paper (stored in wkt2.txt file for readability) we would get this:

```
projinfo -s EPSG:6319 -t "`cat wkt2.txt`" -o proj
```

Candidate operations found: 1

Operation No. 1:

unknown id, Inverse of Transformation from Ellipsoid (metre) to NAD83(2011) (ballpark vertical transformation, without ellipsoid height to vertical height correction) + Conv Vertical Offset and Slope + Transverse Mercator + Affine transformation as PROJ-based, unknown accuracy, World, has ballpark transformation

PROJ string:

```
+proj=pipeline +step +axisswap +order=2,1 +step +unitconvert +xy_in=deg +xy_out=rad +step +verbose +lat_0=41.2305352787143 +lon_0=-73.1815861874286 +dh=31.0121985701957 +slope_lat=-6.1257285218232 +slope_lon=-2.67487863214139 +step +tmerc +lat_0=41.2305352787143 +lon_0=-73.1815861874286 +k=1 +x_0=0 +y_0=0 +ellps=GRS80 +step +affine +xoff=265262.95287 +yoff=196619.27389 +s11=1.00003994119 +s12=0.00548156923529 +s21=-0.00548156923529 +s22=1.00003994119
```
CHAPTER EIGHT

RESOURCE FILES

A number of files containing preconfigured transformations and default parameters for certain projections are bundled with the PROJ distribution. Init files contain preconfigured proj-strings for various coordinate reference systems and the defaults file contains default values for parameters of select projections.

In addition to the bundled init files the PROJ project also distributes a number of packages containing transformation grids and additional init files not included in the main PROJ package.

8.1 Where are PROJ resource files looked for?

PROJ will attempt to locate its resource files - database, transformation grids or init files - from several directories. The following paths are checked in order:

- For resource files that have an explicit relative or absolute path, the directory specified in the filename.
- Path resolved by the callback function set with the proj_context_set_file_finder(). If it is set, the next tests will not be run.
- Path(s) set with the proj_context_set_search_paths(). If set, the next tests will not be run.
- New in version 7.0.
  The PROJ user writable directory, which is:
  - on Windows, ${LOCALAPPDATA}/proj
  - on macOS, ${HOME}/Library/Application Support/proj
  - on other platforms (Linux), ${XDG_DATA_HOME}/proj if XDG_DATA_HOME is defined. Else ${HOME}/.local/share/proj
- Path(s) set with by the environment variable PROJ_DATA. Prior to PROJ 9.1, this environment variable was called PROJ_LIB. This older name is still supported in PROJ 9.1 as a fallback, but support for it may be removed in future release. On Linux/macOS/Unix, use : to separate paths. On Windows, ;
- New in version 7.0.
  The ..share/proj/ and its contents are found automatically at run-time if the installation respects the build structure. That is, the binaries and proj.dll/libproj.so are installed under ../bin/ or ../lib/, and resource files are in ../share/proj/.
- A path built into PROJ as its resource installation directory (whose value is $(pkgdatadir) for builds using the Makefile build system or ${CMAKE_INSTALL_PREFIX}/${DATADIR} for CMake builds). Note, however, that since this is a hard-wired path setting, it only works if the whole PROJ installation is not moved somewhere else.
**Note:** If PROJ is built with the `PROJ_DATA_ENV_VAR_TRIED_LAST` CMake option (called `PROJ_LIB_ENV_VAR_TRIED_LAST` before PROJ 9.1), then this hard-wired path will be tried before looking at the environment variable `PROJ_DATA`.

- The current directory

When networking capabilities are enabled, either by API with the `proj_context_set_enable_network()` function or when the `PROJ_NETWORK` environment variable is set to `ON`, PROJ will attempt to use remote grids stored on CDN (Content Delivery Network) storage.

### 8.2 proj.db

A proj installation includes a SQLite database of transformation information that must be accessible for the library to work properly. The library will print an error if the database can't be found.

The database may be customized/reduced by deleting entries not relevant for a certain use-case. An example for a simple SQL script removing all entries not related to 'WGS 84' ellipsoid:

```
PRAGMA FOREIGN_KEYS=1;
DELETE FROM ellipsoid WHERE name != 'WGS 84';
-- clean up table usage
DELETE FROM usage WHERE (object_table_name, object_auth_name, object_code) IN (SELECT object_table_name, object_auth_name, object_code FROM usage WHERE NOT EXISTS (SELECT 1 FROM object_view o WHERE o.table_name = object_table_name AND o.auth_name = object_auth_name AND o.code = object_code));
VACUUM;
PRAGMA foreign_key_check;
```

### 8.3 proj.ini

New in version 7.0.

proj.ini is a text configuration file, mostly dedicated at setting up network related parameters.

Its default content is:

```
[generic]
; Lines starting by ; are commented lines.
;
; Network capabilities disabled by default.
; Can be overridden with the PROJ_NETWORK=ON environment variable.
; Cf https://proj.org/en/latest/usage/network.html
; Valid values = on, off
network = off

; Endpoint of the Content Delivery Network where remote resources might
; be accessed. Only used if network access is allowed (cf above "network"
```
8.4 Transformation grids

Grid files are important for shifting and transforming between datums.

PROJ supports CTable2, NTv1 and NTv2 files for horizontal grid corrections and the GTX file format for vertical corrections. Details about the formats can be found in the GDAL documentation. GDAL reads and writes all formats. Using GDAL for construction of new grids is recommended.
8.5 External resources and packaged grids

8.5.1 proj-data

The proj-data package is a collection of all the resource files that are freely available for use with PROJ. The package is maintained on GitHub and the contents of the package are show-cased on the PROJ CDN. The contents of the package can be installed using the projsync package or by downloading the zip archive of the package and unpacking in the PROJ_DATA directory.

8.5.2 proj-datumgrid

Note: The packages described below can be used with PROJ 7 and later but are primarily meant to be used with PROJ 6 and earlier versions. The proj-datumgrid series of packages are not maintained anymore and are only kept available for legacy purposes.

For a functioning build of PROJ prior to version 7, installation of the proj-datumgrid is needed. If you have installed PROJ from a package system chances are that this will already be done for you. The proj-datumgrid package provides transformation grids that are essential for many of the predefined transformations in PROJ. Which grids are included in the package can be seen on the proj-datumgrid repository as well as descriptions of those grids. This is the main grid package and the only one that is required. It includes various older grids that is mostly needed for legacy reasons. Without this package, the test suite fails miserably.

8.5.3 Regional packages

In addition to the default proj-datumgrid package regional packages are also distributed. These include grids and init files that are valid within the given region. The packages are divided into geographical regions in order to keep the needed disk space by PROJ at a minimum. Some users may have a use for resource files covering several regions in which case they can download more than one.

At the moment three regional resource file packages are distributed:

- Europe
- Oceania
- North America

If someone supplies grids relevant for Africa, South-America, Asia or Antarctica we will create new regional packages. Click the links to jump to the relevant README files for each package. Details on the content of the packages maintained there.

Tip: To download the various datumgrid packages head to the download section.
8.5.4 World package

The world package includes grids that have global extent, e.g. the global geoid model EGM08.

8.5.5 -latest packages

All packages above come in different versions, e.g., proj-datumgrid-1.8 or proj-datumgrid-europe-1.4. The -latest packages are symbolic links to the latest version of a given package. That means that the link https://download.osgeo.org/proj/proj-datumgrid-north-america-latest.zip is equivalent to https://download.osgeo.org/proj/proj-datumgrid-north-america-1.2.zip (as of the time of writing this).

8.6 Other transformation grids

Below is a list of grid resources for various countries which are not included in the grid distributions mentioned above.

8.6.1 Free grids

The following is a list of grids distributed under a free and open license.

8.6.1.1 Hungary

Hungarian grid ETRS89 - HD72/EOV (epsg:23700), both horizontal and elevation grids

8.6.2 Non-Free Grids

Not all grid shift files have licensing that allows them to be freely distributed, but can be obtained by users through free and legal methods.

8.6.2.1 Austria

Overview of Austrian grids and other resources related to the local geodetic reference.

8.6.2.2 Brazil

Brazilian grids for datums Corrego Alegre 1961, Corrego Alegre 1970-72, SAD69 and SAD69(96)

8.6.2.3 Netherlands

Dutch grid (Registration required before download)
8.6.2.4 Portugal

Portuguese grids for ED50, Lisbon 1890, Lisbon 1937 and Datum 73

8.6.2.5 South Africa

South African grid (Cape to Hartebeesthoek94 or WGS84)

8.6.2.6 Spain

Spanish grids for ED50.

8.6.3 HTDP

This section describes the use of the crs2crs2grid.py script and the HTDP (Horizontal Time Dependent Positioning) grid shift modelling program from NGS/NOAA to produce PROJ compatible grid shift files for fine grade conversions between various NAD83 epochs and WGS84. Traditionally PROJ has treated NAD83 and WGS84 as equivalent and failed to distinguish between different epochs or realizations of those datums. At the scales of much mapping this is adequate but as interest grows in high resolution imagery and other high resolution mapping this is inadequate. Also, as the North American crust drifts over time the displacement between NAD83 and WGS84 grows (more than one foot over the last two decades).

8.6.3.1 Getting and building HTDP

The HTDP modelling program is written in FORTRAN. The source and documentation can be found on the HTDP page at http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml

On Linux systems it will be necessary to install GFortran or some Fortran compiler. For Ubuntu something like the following should work.

```
apt-get install gfortran
```

To compile the program do something like the following to produce the binary htdp from the source code.

```
gfortran htdp.for -o htdp
```

8.6.3.2 Getting crs2crs2grid.py

The crs2crs2grid.py script can be found at https://github.com/OSGeo/gdal/blob/master/swig/python/gdal-utils/osgeo_utils/samples/crs2crs2grid.py

The script depends on having the GDAL Python bindings operational; if they are not you will get an error such as:

```
Traceback (most recent call last):
  File "./crs2crs2grid.py", line 37, in <module>
    from osgeo import gdal, gdal_array, osr
ImportError: No module named osgeo
```
8.6.3.3 Usage

```bash
chr2crs2grid.py <src_crs_id> <src_crs_date> <dst_crs_id> <dst_crs_year>
    [-griddef <ul_lon> <ul_lat> <ll_lon> <ll_lat> <lon_count> <lat_count>]
    [-htdp <path_to_exe>] [-wrkdir <dirpath>] [-kfw]
    -o <output_grid_name>
```

- **griddef**: by default the following values for roughly the continental USA at a six minute step size are used:
  -127 50 -66 25 251 611
- **kfw**: keep working files in the working directory for review.

```bash
```

The goal of `crs2crs2grid.py` is to produce a grid shift file for a designated region. The region is defined using the `-griddef` switch. When missing a continental US region is used. The script creates a set of sample points for the grid definition, runs `htdp` against it and then parses the resulting points and computes a point by point shift to encode into the final grid shift file. By default it is assumed that `htdp` is in the executable path. If not, please provide the path to the executable using the `-htdp` switch.

The `htdp` program supports transformations between many CRSes and for each (or most?) of them you need to provide a date at which the CRS is fixed. The full set of CRS IDs available in the HTDP program are:

<table>
<thead>
<tr>
<th>Number</th>
<th>CRS Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NAD_83(2011) (North America tectonic plate fixed)</td>
</tr>
<tr>
<td>29</td>
<td>NAD_83(CORS96) (NAD_83(2011) will be used)</td>
</tr>
<tr>
<td>30</td>
<td>NAD_83(2007) (NAD_83(2011) will be used)</td>
</tr>
<tr>
<td>2</td>
<td>NAD_83(PA11) (Pacific tectonic plate fixed)</td>
</tr>
<tr>
<td>31</td>
<td>NAD_83(PACP00) (NAD 83(PA11) will be used)</td>
</tr>
<tr>
<td>3</td>
<td>NAD_83(MA11) (Mariana tectonic plate fixed)</td>
</tr>
<tr>
<td>32</td>
<td>NAD_83(MARP00) (NAD_83(MA11) will be used)</td>
</tr>
<tr>
<td>4</td>
<td>WGS_72</td>
</tr>
<tr>
<td>5</td>
<td>WGS_84(transit) = NAD_83(2011)</td>
</tr>
<tr>
<td>6</td>
<td>WGS_84(G730) = ITRF92</td>
</tr>
<tr>
<td>7</td>
<td>WGS_84(G873) = ITRF96</td>
</tr>
<tr>
<td>8</td>
<td>WGS_84(G1150) = ITRF2000</td>
</tr>
<tr>
<td>9</td>
<td>PNEOS_90 = ITRF90</td>
</tr>
<tr>
<td>10</td>
<td>NEOS_90 = ITRF90</td>
</tr>
<tr>
<td>11</td>
<td>SIO/MIT_92 = ITRF91</td>
</tr>
<tr>
<td>12</td>
<td>ITRF88</td>
</tr>
<tr>
<td>13</td>
<td>ITRF89</td>
</tr>
<tr>
<td>14</td>
<td>ITRF90</td>
</tr>
<tr>
<td>15</td>
<td>ITRF91</td>
</tr>
<tr>
<td>16</td>
<td>ITRF92</td>
</tr>
<tr>
<td>17</td>
<td>ITRF93</td>
</tr>
<tr>
<td>18</td>
<td>ITRF94 = ITRF96</td>
</tr>
<tr>
<td>19</td>
<td>ITRF96</td>
</tr>
<tr>
<td>20</td>
<td>ITRF97</td>
</tr>
<tr>
<td>21</td>
<td>IGS97 = ITRF97</td>
</tr>
<tr>
<td>22</td>
<td>ITRF2000</td>
</tr>
<tr>
<td>23</td>
<td>IGS00 = ITRF2000</td>
</tr>
<tr>
<td>24</td>
<td>IGB00 = ITRF2000</td>
</tr>
<tr>
<td>25</td>
<td>ITRF2005</td>
</tr>
<tr>
<td>26</td>
<td>IGS05 = ITRF2005</td>
</tr>
<tr>
<td>27</td>
<td>ITRF2008</td>
</tr>
<tr>
<td>28</td>
<td>IGS08 = ITRF2008</td>
</tr>
</tbody>
</table>

The typical use case is mapping from NAD83 on a particular date to WGS84 on some date. In this case the source CRS Id "29" (NAD_83(CORS96)) and the destination CRS Id is "8 (WGS_84(G1150)). It is also necessary to select the source and destination date (epoch). For example:

```bash
```

The output is a CTable2 format grid shift file suitable for use with PROJ (4.8.0 or newer). It might be utilized something like:

8.6. Other transformation grids

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8.6.3.4 See Also

- [http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml](http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.shtml) - NGS/NOAA page about the HTDP model and program. Source for the HTDP program can be downloaded from here.

8.7 Init files

Init files are used for preconfiguring proj-strings for often used transformations, such as those found in the EPSG database. Most init files contain transformations from a given coordinate reference system to WGS84. This makes it easy to transform between any two coordinate reference systems with `cs2cs`. Init files can however contain any proj-string and don’t necessarily have to follow the `cs2cs` paradigm where WGS84 is used as a pivot datum. The ITRF init file is a good example of that.

A number of init files come pre-bundled with PROJ but it is also possible to add your own custom init files. PROJ looks for the init files in the directory listed in the `PROJ_DATA` environment variable.

The format of init files is an identifier in angled brackets and a proj-string:

```
<3819> +proj=longlat +ellps=bessel
+to+eq=595.48,121.69,515.35,4.115,-2.9383,0.853,-3.408 +no_defs <>
```

The above example is the first entry from the `epsg` init file. So, this is the coordinate reference system with ID 3819 in the EPSG database. Comments can be inserted by prefixing them with a “#”. With version 4.10.0 a new special metadata entry is now accepted in init files. It can be parsed with a function from the public API. The metadata entry in the `epsg` init file looks like this at the time of writing:

```
<metadata> +version=9.0.0 +origin=EPSG +lastupdate=2017-01-10
```

Pre-configured proj-strings from init files are used in the following way:

```
$ cs2cs -v +proj=latlong +to+init=epsg:3819
   # ---- From Coordinate System ----
   #Lat/long (Geodetic alias)
   # +proj=latlong +ellps=WGS84
   # ---- To Coordinate System ----
   #Lat/long (Geodetic alias)
   # +init=epsg:3819 +proj=longlat +ellps=bessel
   # +to+eq=595.48,121.69,515.35,4.115,-2.9383,0.853,-3.408 +no_defs
```

It is possible to override parameters when using `+init`. Just add the parameter to the proj-string alongside the `+init` parameter. For instance by overriding the ellipsoid as in the following example

```
+init=epsg:25832 +ellps=intl
```

where the Hayford ellipsoid is used instead of the predefined GRS80 ellipsoid.

It is also possible to add additional parameters not specified in the init file, for instance by adding a central epoch when applying the ITRF2014:NOAM plate motion model:
PROJ coordinate transformation software library, Release 9.3.1

+init=ITRF2014:NOAM +t_epoch=2010.0

which then expands to

+proj=helmert +drx=0.000024 +dry=-0.000694 +drz=-0.000063 +convention=position_vector +t_epoch=2010.0

Below is a list of the init files that are packaged with PROJ.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL27</td>
<td>Great Lakes Grids</td>
</tr>
<tr>
<td>ITRF2000</td>
<td>Full set of transformation parameters between ITRF2000 and other ITRF's</td>
</tr>
<tr>
<td>ITRF2008</td>
<td>Full set of transformation parameters between ITRF2008 and other ITRF's</td>
</tr>
<tr>
<td>ITRF2014</td>
<td>Full set of transformation parameters between ITRF2014 and other ITRF's</td>
</tr>
<tr>
<td>nad27</td>
<td>State plane coordinate systems, North American Datum 1927</td>
</tr>
<tr>
<td>nad83</td>
<td>State plane coordinate systems, North American Datum 1983</td>
</tr>
</tbody>
</table>
CHAPTER NINE

GEODESIC CALCULATIONS

9.1 Introduction

Consider an ellipsoid of revolution with equatorial radius $a$, polar semi-axis $b$, and flattening $f = (a - b)/a$. Points on the surface of the ellipsoid are characterized by their latitude $\phi$ and longitude $\lambda$. (Note that latitude here means the geographical latitude, the angle between the normal to the ellipsoid and the equatorial plane).

The shortest path between two points on the ellipsoid at $(\phi_1, \lambda_1)$ and $(\phi_2, \lambda_2)$ is called the geodesic. Its length is $s_{12}$ and the geodesic from point 1 to point 2 has forward azimuths $\alpha_1$ and $\alpha_2$ at the two end points. In this figure, we have $\lambda_{12} = \lambda_2 - \lambda_1$.

A geodesic can be extended indefinitely by requiring that any sufficiently small segment is a shortest path; geodesics are also the straightest curves on the surface.

9.2 Solution of geodesic problems

Traditionally two geodesic problems are considered:

- the direct problem — given $\phi_1, \lambda_1, \alpha_1, s_{12}$, determine $\phi_2, \lambda_2, \alpha_2$.
- the inverse problem — given $\phi_1, \lambda_1, \phi_2, \lambda_2$, determine $s_{12}, \alpha_1, \alpha_2$.

PROJ incorporates C library for Geodesics. This library provides routines to solve the direct and inverse geodesic problems. Full double precision accuracy is maintained provided that $|f| < \frac{1}{50}$.

The interface to the geodesic routines differ in two respects from the rest of PROJ:

- angles (latitudes, longitudes, and azimuths) are in degrees (instead of in radians);
- the shape of ellipsoid is specified by the flattening $f$; this can be negative to denote a prolate ellipsoid; setting $f = 0$ corresponds to a sphere, in which case the geodesic becomes a great circle.

PROJ also includes a command line tool, `geod(1)`, for performing simple geodesic calculations.
9.3 Additional properties

The routines also calculate several other quantities of interest

- $S_{12}$ is the area between the geodesic from point 1 to point 2 and the equator; i.e., it is the area, measured counterclockwise, of the quadrilateral with corners $(\phi_1, \lambda_1)$, $(0, \lambda_1)$, $(0, \lambda_2)$, and $(\phi_2, \lambda_2)$. It is given in meters$^2$.
- $m_{12}$, the reduced length of the geodesic is defined such that if the initial azimuth is perturbed by $d\alpha_1$ (radians) then the second point is displaced by $m_{12} d\alpha_1$ in the direction perpendicular to the geodesic. $m_{12}$ is given in meters. On a curved surface the reduced length obeys a symmetry relation, $m_{12} + m_{21} = 0$. On a flat surface, we have $m_{12} = S_{12}$.
- $M_{12}$ and $M_{21}$ are geodesic scales. If two geodesics are parallel at point 1 and separated by a small distance $d\tau$, then they are separated by a distance $M_{12} d\tau$ at point 2. $M_{21}$ is defined similarly (with the geodesics being parallel to one another at point 2). $M_{12}$ and $M_{21}$ are dimensionless quantities. On a flat surface, we have $M_{12} = M_{21} = 1$.
- $\sigma_{12}$ is the arc length on the auxiliary sphere. This is a construct for converting the problem to one in spherical trigonometry. The spherical arc length from one equator crossing to the next is always $180^\circ$.

If points 1, 2, and 3 lie on a single geodesic, then the following addition rules hold:

- $s_{13} = s_{12} + s_{23}$,
- $\sigma_{13} = \sigma_{12} + \sigma_{23}$,
- $S_{13} = S_{12} + S_{23}$,
- $m_{13} = m_{12} M_{23} + m_{23} M_{21}$,
- $M_{13} = M_{12} M_{23} - (1 - M_{12} M_{21}) m_{23} / m_{12}$,
- $M_{31} = M_{32} M_{21} - (1 - M_{23} M_{32}) m_{12} / m_{23}$.

9.4 Multiple shortest geodesics

The shortest distance found by solving the inverse problem is (obviously) uniquely defined. However, in a few special cases there are multiple azimuths which yield the same shortest distance. Here is a catalog of those cases:

- $\phi_1 = -\phi_2$ (with neither point at a pole). If $\alpha_1 = \alpha_2$, the geodesic is unique. Otherwise there are two geodesics and the second one is obtained by setting $[\alpha_1, \alpha_2] \leftarrow [\alpha_2, \alpha_1]$, $[M_{12}, M_{21}] \leftarrow [M_{21}, M_{12}]$, $S_{12} \leftarrow -S_{12}$. (This occurs when the longitude difference is near $\pm 180^\circ$ for oblate ellipsoids.)
- $\lambda_2 = \lambda_1 \pm 180^\circ$ (with neither point at a pole). If $\alpha_1 = 0^\circ$ or $\pm 180^\circ$, the geodesic is unique. Otherwise there are two geodesics and the second one is obtained by setting $[\alpha_1, \alpha_2] \leftarrow [-\alpha_1, -\alpha_2]$, $S_{12} \leftarrow -S_{12}$. (This occurs when $\phi_2$ is near $-\phi_1$ for prolate ellipsoids.)
- Points 1 and 2 at opposite poles. There are infinitely many geodesics which can be generated by setting $[\alpha_1, \alpha_2] \leftarrow [\alpha_1, \alpha_2] + [\delta, -\delta]$, for arbitrary $\delta$. (For spheres, this prescription applies when points 1 and 2 are antipodal.)
- $s_{12} = 0$ (coincident points). There are infinitely many geodesics which can be generated by setting $[\alpha_1, \alpha_2] \leftarrow [\alpha_1, \alpha_2] + [\delta, \delta]$, for arbitrary $\delta$. 

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9.5 Area of a polygon

The area of a geodesic polygon can be determined by summing $-S_{12}$ for successive edges of the polygon ($S_{12}$ is negated so that clockwise traversal of a polygon gives a positive area). However, if the polygon encircles a pole, the sum must be adjusted by $\pm A/2$, where $A$ is the area of the full ellipsoid, with the sign chosen to place the result in $(-A/2, A/2)$.

9.6 Background

The algorithms implemented by this package are given in [Karney2013] (addenda) and are based on [Bessel1825] and [Helmert1880]; the algorithm for areas is based on [Danielsen1989]. These improve on the work of [Vincenty1975] in the following respects:

- The results are accurate to round-off for terrestrial ellipsoids (the error in the distance is less than 15 nanometers, compared to 0.1 mm for Vincenty).
- The solution of the inverse problem is always found. (Vincenty's method fails to converge for nearly antipodal points.)
- The routines calculate differential and integral properties of a geodesic. This allows, for example, the area of a geodesic polygon to be computed.

Additional background material is provided in GeographicLib's geodesic bibliography, Wikipedia's article "Geodesics on an ellipsoid", and [Karney2011] (errata).
These pages are primarily focused towards developers either contributing to the PROJ project or using the library in their own software.

## 10.1 Development practices

### 10.1.1 Commit messages

Commit messages should indicate a component name (e.g., a driver name), a short description, and when relevant, a reference to an issue (with `fixes #` if it actually fixes it)

```
COMPONENT_NAME: fix bla bla (fixes #1234)
Details here...
```

### 10.1.2 Commit hooks

PROJ provides pre-commit hooks to run code linters before a commit is made. The hooks are cloned with the repository and can be installed using `pre-commit`:

```
python -m pip install pre-commit
pre-commit install
```

Once installed, the hooks can be run manually via `pre-commit run --all-files`.

### 10.1.3 Blame ignore file

Due to whole-tree code reformatting done during PROJ 9.2 development, `git blame` information might be misleading. To avoid that, you need to modify your git configuration as following to ignore the revision of the whole-tree reformatting:

```
git config blame.ignoreRevsFile .git-blame-ignore-revs
```
10.2 Quick start for C API usage

This is a short introduction to the PROJ C API. In the following section we create two simple programs that illustrate how to transform points between two different coordinate systems, and how to convert between projected and geodetic (geographic) coordinates for a single coordinate system. Explanations for individual code snippets and the full programs are provided.

See the following sections for more in-depth descriptions of different parts of the PROJ API or consult the API reference for specifics.

Before the PROJ API can be used it is necessary to include the `<proj.h>` header file. Here `<stdio.h>` is also included so we can print some text to the screen:

```c
#include <proj.h>
#include <stdio.h>
```

Let's declare a few variables that will be used later in the program. Each variable will be discussed below. See the reference for more info on data types.

```c
PJ_CONTEXT *C;
PJ *P;
PJ *norm;
PJ_COORD a, b;
```

For use in multi-threaded programs the `PJ_CONTEXT` threading-context is used. In this particular example it is not needed, but for the sake of completeness we demonstrate its use here.

```c
C = proj_context_create();
```

Next we create the `PJ` transformation object `P` with the function `proj_create_crs_to_crs()`.

```c
P = proj_create_crs_to_crs(
    C, "EPSG:4326", "+proj=utm +zone=32 +datum=WGS84", /* or EPSG:32632 */
    NULL);

if (0 == P) {
    fprintf(stderr, "Failed to create transformation object.\n");
    return 1;
}
```

Here we have set up a transformation from geographic coordinates to UTM zone 32N. In general, this is a transformation between two different coordinate reference systems (one of which is here in geographic coordinates). The related function `proj_create()` can be used to set up transformations that are not available through the PROJ database, for instance for converting geodetic coordinates to a custom definition of a map projection.

`proj_create_crs_to_crs()` takes as its arguments:

- the threading context `C` created above,
- a string that describes the source coordinate reference system (CRS),
- a string that describes the target CRS and
- an optional description of the area of use.

It is recommended to create one threading context per thread used by the program. This ensures that all `PJ` objects created in the same context will be sharing resources such as error-numbers and loaded grids.
If you are sure that \( P \) will only be used by a single program thread, you may pass \texttt{NULL} for the threading context. This will assign the default thread context to \( P \).

The strings for the source and target CRS may be any of:

- PROJ strings, e.g. \texttt{+proj=longlat +datum=WGS84 +type=crs},
- CRS identified by their code, e.g. \texttt{EPSG:4326} or \texttt{urn:ogc:def:crs:EPSG::4326}, or
- a well-known text (WKT) string, e.g.:

\begin{verbatim}
GEOGCRS["WGS 84",
  DATUM["World Geodetic System 1984",
    ELLIPSOID["WGS 84",6378137,298.257223563,
      LENGTHUNIT["metre",1]],
    PRIMEM["Greenwich",0,]
      ANGLEUNIT["degree",0.0174532925199433]],
  CS[ellipsoidal,2],
  AXIS["geodetic latitude (Lat)",north,
    ORDER[1],
    ANGLEUNIT["degree",0.0174532925199433]],
  AXIS["geodetic longitude (Lon)",east,
    ORDER[2],
    ANGLEUNIT["degree",0.0174532925199433]],
  USAGE[
    SCOPE["unknown"],
    AREA["World"],
    BBOX[\texttt{-90,-180,90,180}],
    ID["EPSG",4326]]
\end{verbatim}

**Warning**: The use of PROJ strings to describe a CRS is not recommended. One of the main weaknesses of PROJ strings is their inability to describe a geodetic datum, other than the few ones hardcoded in the \texttt{+datum} parameter.

\texttt{proj_create_crs_to_crs()} will return a pointer to a \texttt{PJ} object, or a null pointer in the case of an error. The details of the error can be retrieved using \texttt{proj_context_errno()}. See Error handling for further details.

Now that we have a normalized transformation object in \( P \), we can use it with \texttt{proj_trans()} to transform coordinates from the source CRS to the target CRS, but first we will discuss the interpretation of coordinates.

By default, a \texttt{PJ} transformation object accepts coordinates expressed in the units and axis order of the source CRS, and returns transformed coordinates in the units and axis order of the target CRS.

For most geographic CRS, the units will be in degrees. In rare cases, such as EPSG:4807 / NTF (Paris), this can be grads. For geographic CRS defined by the EPSG authority, the order of coordinates is latitude first, longitude second. When using a PROJ string, the order is the reverse; longitude first, latitude second.

For projected CRS, the units may vary (metre, us-foot, etc.). For projected CRS defined by the EPSG authority, and with EAST / NORTH directions, the order might be easting first, northing second, or the reverse. When using a PROJ string, the order will be easting first, northing second, except if the \texttt{+axis} parameter modifies it.

If you prefer to work with a uniform axis order, regardless of the axis orders mandated by the source and target CRS, you can use the \texttt{proj_normalize_for_visualization()} function.

\texttt{proj_normalize_for_visualization()} takes a threading context and an existing \texttt{PJ} object, and generates from it a new \texttt{PJ} that accepts as input and returns as output coordinates using the traditional GIS order. That is, longitude followed by latitude, optionally followed by elevation and time for geographic CRS, and easting followed by northing for most projected CRS.
Next we create a `PJ_COORD` coordinate object, using the function `proj_coord()`. The following example creates a coordinate for 55°N 12°E (Copenhagen). Because we have normalized the transformation object with `proj_normalize_for_visualization()`, the order of coordinates is longitude followed by latitude, and the units are degrees.

```c
a = proj_coord(12, 55, 0, 0);
```

Now we are ready to transform the coordinate into UTM zone 32, using the function `proj_trans()`.

```c
b = proj_trans(P, PJ_FWD, a);
printf("easting: %.3f, northing: %.3f\n", b.enu.e, b.enu.n);
```

`proj_trans()` takes as its arguments:
- a `PJ` transformation object,
- a `PJ_DIRECTION` direction, and
- the `PJ_COORD` coordinate to transform.

The direction argument can be one of:
- `PJ_FWD` -- "forward" transformation from source CRS to target CRS.
- `PJ_IDENT` -- "identity", return the source coordinate unchanged.
- `PJ_INV` -- "inverse" transformation from target CRS to source CRS.

It returns the new transformed `PJ_COORD` coordinate.

We can perform the transformation in reverse (from UTM zone 32 back to geographic) as follows:

```c
b = proj_trans(P, PJ_INV, b);
printf("longitude: %g, latitude: %g\n", b.lp.lam, b.lp.phi);
```

Before ending the program, we need to release the memory allocated to our objects:

```c
proj_destroy(P);
proj_context_destroy(C); /* may be omitted in the single threaded case */
```

A complete compilable version of the example code can be seen below:

```c
#include <proj.h>
#include <stdio.h>

int main(void) {
    PJ_CONTEXT *C;
    PJ *P;
    PJ *norm;
```

(continues on next page)
The following example illustrates how to convert between a CRS and geodetic coordinates for that CRS.

```c
#include <math.h>
#include <proj.h>
#include <stdio.h>

int main(void) {

    // a coordinate union representing Copenhagen: 55d N, 12d E */
    // Given that we have used proj_normalize_for_visualization(), the order */
    // of coordinates is longitude, latitude, and values are expressed in */
    // degrees. */
    a = proj_coord(12, 55, 0, 0);

    /* transform to UTM zone 32, then back to geographical */
    b = proj_trans(P, PJ_FWD, a);
    printf("easting: %.3f, northing: %.3f\n", b.enu.e, b.enu.n);

    b = proj_trans(P, PJ_INV, b);
    printf("longitude: %g, latitude: %g\n", b.lp.lam, b.lp.phi);

    /* Clean up */
    proj_destroy(P);
    proj_context_destroy(C); /* may be omitted in the single threaded case */
    return 0;
}
```

The following example illustrates how to convert between a CRS and geodetic coordinates for that CRS.
/* Create the context. */
/* You may set C=PJ_DEFAULT_CTX if you are sure you will */
/* use PJ objects from only one thread */
PJ_CONTEXT *C = proj_context_create();

/* Create a projection. */
PJ *P = proj_create(C, "+proj=utm +zone=32 +datum=WGS84 +type=crs");

if (0 == P) {
    fprintf(stderr, "Failed to create transformation object.\n"
    return 1;
}

/* Get the geodetic CRS for that projection. */
PJ *G = proj_crs_get_geodetic_crs(C, P);

/* Create the transform from geodetic to projected coordinates.*/
PJ_AREA *A = NULL;
const char *const *options = NULL;
PJ *G2P = proj_create_crs_to_crs_from_pj(C, G, P, A, options);

/* Longitude and latitude of Copenhagen, in degrees. */
double lon = 12.0, lat = 55.0;

/* Prepare the input */
PJCOORD c_in;  
c_in.lpzt.z = 0.0;
c_in.lpzt.t = HUGE_VAL; // important only for time-dependent projections
   c_in.lp.lam = lon;
c_in.lp.phi = lat;
   printf("Input longitude: %g, latitude: %g (degrees)\n", c_in.lp.lam,
      c_in.lp.phi);

/* Compute easting and northing */
PJCOORD c_out = proj_trans(G2P, PJ_FWD, c_in);
   printf("Output easting: %g, northing: %g (meters)\n", c_out.enu.e,
      c_out.enu.n);

/* Apply the inverse transform */
PJCOORD c_inv = proj_trans(G2P, PJ_INV, c_out);
   printf("Inverse applied. Longitude: %g, latitude: %g (degrees)\n", c_inv.lp.lam,
      c_inv.lp.phi);

/* Clean up */
proj_destroy(P);
proj_destroy(G);
proj_destroy(G2P);
proj_context_destroy(C); /* may be omitted in the single threaded case */
return 0;
10.3 Quick start for C++ API usage

This is a short introduction to the PROJ C++ API. In the following section we create a simple program that illustrate how to transform points between two different coordinate systems.

Note: the essential osgeo::proj::operation::CoordinateOperation::coordinateTransformer() method was only added in PROJ 9.3. For earlier versions, coordinate operations must be exported as a PROJ string with the osgeo::proj::operation::CoordinateOperation::exportToPROJ() method, and passed to proj_create() to instance a PJ* object to use with proj_trans() (cf the Quick start for C API usage). The use of the C API proj_create_crs_to_crs() might still be easier to let PROJ automatically select the "best" coordinate operation when several ones are possible, as the corresponding automation is not currently available in the C++ API.

Before the PROJ API can be used it is necessary to include the various header files:

```cpp
#include <cassert>
#include <cmath> // for HUGE_VAL
#include <iomanip> // for std::setprecision()
#include <iostream>
#include "proj/coordinateoperation.hpp"
#include "proj/crs.hpp"
#include "proj/io.hpp"
#include "proj/util.hpp" // for nn_dynamic_pointer_cast

using namespace NS_PROJ::crs;
using namespace NS_PROJ::io;
using namespace NS_PROJ::operation;
using namespace NS_PROJ::util;
```

For convenience, we also declare using a few namespaces:

```cpp
using namespace NS_PROJ::crs;
using namespace NS_PROJ::io;
using namespace NS_PROJ::operation;
using namespace NS_PROJ::util;
```

We start by creating a database context (osgeo::proj::io::DatabaseContext) with the default settings to find the PROJ database.

```cpp
auto dbContext = DatabaseContext::create();
```

We then instantiate a generic authority factory (osgeo::proj::io::AuthorityFactory), that is not tied to a particular authority, to be able to get transformations registered by different authorities. This can only be used for a osgeo::proj::operation::CoordinateOperationContext, and not to instantiate objects of the database which are all tied to a non-generic authority.

```cpp
auto authFactory = AuthorityFactory::create(dbContext, std::string());
```

We create a coordinate operation context, that can be customized to amend the way coordinate operations are computed. Here we ask for default settings, as we have a coordinate operation that just involves a "simple" map projection in the same datum.

```cpp
auto coord_op_ctxt = CoordinateOperationContext::create(authFactory, nullptr, 0.0);
```

We instantiate a authority factory for EPSG related objects.

```cpp
auto authFactoryEPSG = AuthorityFactory::create(dbContext, "EPSG");
```

We instantiate the source CRS from its code: 4326, for WGS 84 latitude/longitude.
auto sourceCRS = authFactoryEPSG->createCoordinateReferenceSystem("4326");

We instantiate the source CRS from its PROJ.4 string (it would be possible to instantiate it from its 32631 code, similarly to above), and cast the generic osgeo::proj::util::BaseObject to the osgeo::proj::crs::CRS class required later.

auto targetCRS = 
    NN_CHECK_THROW(nn_dynamic_pointer_cast<CRS>(createFromUserInput( 
        "+proj=utm +zone=31 +datum=WGS84 +type=crs", dbContext)));

Warning: The use of PROJ strings to describe a CRS is not recommended. One of the main weaknesses of PROJ strings is their inability to describe a geodetic datum, other than the few ones hardcoded in the +datum parameter.

We ask for the list of operations available to transform from the source to the target CRS with the osgeo::proj::operation::CoordinateOperationFactory::createOperations() method.

auto list = CoordinateOperationFactory::create()->createOperations( 
    sourceCRS, targetCRS, coord_op_ctxt);

We check that we got a non-empty list of operations. The list is sorted from the most relevant to the less relevant one. Cf Filtering and sorting of coordinate operations for more details on the sorting of those operations. For a transformation between a projected CRS and its base CRS, like we do here, there will be only one operation.

assert(!list.empty());

We create an execution context (must only be used by one thread at a time) with the proj_context_create() function.

PJ_CONTEXT *ctx = proj_context_create();

We create a coordinate transformer (osgeo::proj::operation::CoordinateTransformer) from the first operation of the list:

auto transformer = list[0]->coordinateTransformer(ctx);

We can now transform a point with the osgeo::proj::operation::CoordinateTransformer::transform() method. Note that the the expected input values should be passed in the order and the unit of the successive axis of the input CRS. Similarly the values returned in the v[] array of the output PJ_COORD are in the order and the unit of the successive axis of the output CRS. For coordinate operations involving a time-dependent operation, coord.v[3] is the decimal year of the coordinate epoch of the input (or HUGE_VAL to indicate none).

PJ_COORD c = {{
    49.0, // latitude in degree
    2.0, // longitude in degree
    0.0, // z ordinate. unused
    HUGE_VAL // time ordinate. unused
}];

c = transformer->transform(c);

and output the result:
std::cout << std::fixed << std::setprecision(3);
std::cout << "Easting: " << c.v[0] << std::endl; // should be 426857.988
std::cout << "Northing: " << c.v[1] << std::endl; // should be 5427937.523

We need to clean up the PJ_CONTEXT handle before exiting with the `proj_context_destroy()` function.

```cpp
proj_context_destroy(ctx);
```

A complete compilable version of the example code can be seen below:

```cpp
#include <cassert>
#include <cmath> // for HUGE_VAL
#include <iomanip> // for std::setprecision()
#include <iostream>
#include "proj/coordinateoperation.hpp"
#include "proj/crs.hpp"
#include "proj/io.hpp"
#include "proj/util.hpp" // for nn_dynamic_pointer_cast

using namespace NS_PROJ::crs;
using namespace NS_PROJ::io;
using namespace NS_PROJ::operation;
using namespace NS_PROJ::util;

int main(void) {
    auto dbContext = DatabaseContext::create();

    // Instantiate a generic authority factory, that is not tied to a particular
    // authority, to be able to get transformations registered by different
    // authorities. This can only be used for CoordinateOperationContext.
    auto authFactory = AuthorityFactory::create(dbContext, std::string());

    // Create a coordinate operation context, that can be customized to amend
    // the way coordinate operations are computed. Here we ask for default
    // settings.
    auto coord_op_ctxt =
        CoordinateOperationContext::create(authFactory, nullptr, 0.0);

    // Instantiate a authority factory for EPSG related objects.
    auto authFactoryEPSG = AuthorityFactory::create(dbContext, "EPSG");

    // Instantiate source CRS from EPSG code
    auto sourceCRS = authFactoryEPSG->createCoordinateReferenceSystem("4326");

    // Instantiate target CRS from PROJ.4 string (commented out, the equivalent
    // from the EPSG code)
    // auto targetCRS =
    //    authFactoryEPSG->createCoordinateReferenceSystem("32631");
    auto targetCRS =
        NN_CHECK_THROW(nn_dynamic_pointer_cast<CRS>(createFromUserInput(
            "+proj=utm +zone=31 +datum=WGS84 +type=crs", dbContext)));
```
// List operations available to transform from EPSG:4326
// (WGS 84 latitude/longitude) to EPSG:32631 (WGS 84 / UTM zone 31N).
auto list = CoordinateOperationFactory::create()->createOperations(
    sourceCRS, targetCRS, coord_op_ctxt);

// Check that we got a non-empty list of operations
// The list is sorted from the most relevant to the less relevant one.
// Cf
// https://proj.org/operations/operations_computation.html#filtering-and-sorting-of-
// coordinate-operations
// for more details on the sorting of those operations.
// For a transformation between a projected CRS and its base CRS, like
// we do here, there will be only one operation.
assert(!list.empty());

// Create an execution context (must only be used by one thread at a time)
PJ_CONTEXT *ctx = proj_context_create();

// Create a coordinate transformer from the first operation of the list
auto transformer = list[0]->coordinateTransformer(ctx);

// Perform the coordinate transformation.
PJ_COORD c = {{
    49.0,  // latitude in degree
    2.0,  // longitude in degree
    0.0,  // z ordinate. unused
    HUGE_VAL  // time ordinate. unused
}};

// Display result
std::cout << std::fixed << std::setprecision(3);
std::cout << "Easting: " << c.v[0] << std::endl;  // should be 426857.988
std::cout << "Northing: " << c.v[1] << std::endl; // should be 5427937.523

// Destroy execution context
proj_context_destroy(ctx);

return 0;
10.4 Error handling

PROJ maintains an internal error state, which is local to a PJ_CONTEXT thread context.

See Quick start for C API usage for more information about how to create and use a thread context object.

If you receive an abnormal return from a PROJ API function (e.g. a NULL pointer) you may wish to discover more information about the error.

In this case you can make a call to proj_context_errno(), passing in your thread context. This will return an integer error code.

If the error code is zero, the last PROJ operation was deemed successful and no error has been detected.

If the error code is non-zero, an error has been detected. You can pass your thread context together with this error code to proj_context_errno_string() to retrieve a string describing the error condition.

A basic example showing how a C program might catch and report errors follows:

Listing 1: errorhandling.c

```c
#include <stdio.h>
#include <proj.h>

int main (void) {
    PJ_CONTEXT *c;
    PJ *p;
    int errno;
    const char *errstr;
    c = proj_context_create();
    p = proj_create_crs_to_crs(c, "EPSG:4326", "EPSG:3857", NULL);
    if (p == 0) {
        /* Something is wrong, let's try to get details ... */
        errno = proj_context_errno(c);
        if (errno == 0) {
            /* This should be impossible. */
            fprintf(stderr, "Failed to create transformation, reason unknown.\n");
        } else {
            errstr = proj_context_errno_string(c, errno);
            fprintf(stderr, "Failed to create transformation: %s.\n", errstr);
        }
        proj_context_destroy(c);
        return 1;
    }

    /* transformation object is valid, do work ... */

    proj_destroy(p);
    proj_context_destroy(c);
    return 0;
}
```
10.5 Reference

10.5.1 Macros

**PROJ_VERSION_MAJOR**
Major version number, e.g. 8 for PROJ 8.0.1

**PROJ_VERSION_MINOR**
Minor version number, e.g. 0 for PROJ 8.0.1

**PROJ_VERSION_PATCH**
Patch version number, e.g. 1 for PROJ 8.0.1

**PROJ_COMPUTE_VERSION** (maj, min, patch)
New in version 8.0.1.
Compute the version number from the major, minor and patch numbers.

**PROJ_VERSION_NUMBER**
New in version 8.0.1.
Total version number, equal to

\[
\text{PROJ\_COMPUTE\_VERSION}(\text{PROJ\_VERSION\_MAJOR}, \text{PROJ\_VERSION\_MINOR}, \\
\text{PROJ\_VERSION\_PATCH})
\]

**PROJ_AT_LEAST_VERSION** (maj, min, patch)
New in version 8.0.1.
Macro that returns true if the current PROJ version is at least the version specified by (maj,min,patch)
Equivalent to

\[
\text{PROJ\_VERSION\_NUMBER} \geq \text{PROJ\_COMPUTE\_VERSION}(\text{maj, min, patch})
\]

10.5.2 Data types

This section describes the numerous data types in use in PROJ. As a rule of thumb PROJ data types are prefixed with `PJ_`, or in one particular case, is simply called `PJ`. A few notable exceptions can be traced back to the very early days of PROJ when the `PJ_` prefix was not consistently used.

10.5.2.1 Transformation objects

**type PJ**
Object containing everything related to a given projection or transformation. As a user of the PROJ library you are only exposed to pointers to this object and the contents is hidden behind the public API. `PJ` objects are created with `proj_create()` and destroyed with `proj_destroy()`.

**type PJ\_DIRECTION**
Enumeration that is used to convey in which direction a given transformation should be performed. Used in transformation function call as described in the section on transformation functions.
Forward transformations are defined with the `:c:`

```c
typedef enum proj_direction {
    PJ_FWD = 1, /* Forward */
    PJ_IDENT = 0, /* Do nothing */
    PJ_INV = -1 /* Inverse */
} PJ_DIRECTION;
```
enumerator PJ_FWD
Perform transformation in the forward direction.

enumerator PJ_IDENT
Identity. Do nothing.

enumerator PJ_INV
Perform transformation in the inverse direction.

type PJ_CONTEXT
Context objects enable safe multi-threaded usage of PROJ. Each PJ object is connected to a context (if not specified, the default context is used). All operations within a context should be performed in the same thread. PJ_CONTEXT objects are created with proj_context_create() and destroyed with proj_context_destroy().

type PJ_AREA
New in version 6.0.0.
Opaque object describing an area in which a transformation is performed.
It is used with proj_create_crs_to_crs() to select the best transformation between the two input coordinate reference systems.

10.5.2.2 2 dimensional coordinates

Various 2-dimensional coordinate data types.

type PJ_LP
Geodetic coordinate, latitude and longitude. Usually in radians.

typedef struct { double lam, phi; } PJ_LP;

double PJ_LP.lam
Longitude. Lambda.

double PJ_LP.phi
Latitude. Phi.

type PJ_XY
2-dimensional cartesian coordinate.

typedef struct { double x, y; } PJ_XY;

double PJ_XY.x
Easting.

double PJ_XY.y
Northing.

type PJ_UV
2-dimensional generic coordinate. Usually used when contents can be either a PJ_XY or PJ_LP.

typedef struct {double u, v; } PJ_UV;

double PJ_UV.u
Longitude or easting, depending on use.
double PJ_UV.v
    Latitude or northing, depending on use.

### 10.5.2.3 3 dimensional coordinates

The following data types are the 3-dimensional equivalents to the data types above.

**type PJ_LPZ**

3-dimensional version of `PJ_LP`. Holds longitude, latitude and a vertical component.

```c
typedef struct { double lam, phi, z; } PJ_LPZ;
```

double PJ_LPZ.lam
    Longitude. Lambda.
double PJ_LPZ.phi
    Latitude. Phi.
double PJ_LPZ.z
    Vertical component.

**type PJ_XYZ**

Cartesian coordinate in 3 dimensions. Extension of `PJ_XY`.

```c
typedef struct { double x, y, z; } PJ_XYZ;
```

double PJ_XYZ.x
    Easting or the X component of a 3D cartesian system.
double PJ_XYZ.y
    Northing or the Y component of a 3D cartesian system.
double PJ_XYZ.z
    Vertical component or the Z component of a 3D cartesian system.

**type PJ_UVW**

3-dimensional extension of `PJ_UV`.

```c
typedef struct { double u, v, w; } PJ_UVW;
```

double PJ_UVW.u
    Longitude or easting, depending on use.
double PJ_UVW.v
    Latitude or northing, depending on use.
double PJ_UVW.w
    Vertical component.
10.5.2.4 Spatiotemporal coordinate types

The following data types are extensions of the triplets above into the time domain.

type PJ_LPZT

Spatiotemporal version of \textit{PJ\_LPZ}.

\begin{verbatim}
typedef struct {
  double lam;
  double phi;
  double z;
  double t;
} PJ_LPZT;
\end{verbatim}

double PJ_LPZT.lam
Longitude.

double PJ_LPZT.phi
Latitude

double PJ_LPZT.z
Vertical component.

double PJ_LPZT.t
Time component.

type PJ_XYZT

Generic spatiotemporal coordinate. Useful for e.g. cartesian coordinates with an attached time-stamp.

\begin{verbatim}
typedef struct {
  double x;
  double y;
  double z;
  double t;
} PJ_XYZT;
\end{verbatim}

double PJ_XYZT.x
Easting or the X component of a 3D cartesian system.

double PJ_XYZT.y
Northing or the Y component of a 3D cartesian system.

double PJ_XYZT.z
Vertical or the Z component of a 3D cartesian system.

double PJ_XYZT.t
Time component.

type PJ_UVWT

Spatiotemporal version of \textit{PJ\_UVW}.

\begin{verbatim}
typedef struct { double u, v, w, t; } PJ_UVWT;
\end{verbatim}

double PJ_UVWT.e
First horizontal component.
double PJ_UVWT.n
   Second horizontal component.
double PJ_UVWT.w
   Vertical component.
double PJ_UVWT.t
   Temporal component.

10.5.2.5 Ancillary types for geodetic computations

type PJ_OPK
   Rotations, for instance three euler angles.
   
   typedef struct { double o, p, k; } PJ_OPK;

   double PJ_OPK.o
      First rotation angle, omega.
   double PJ_OPK.p
      Second rotation angle, phi.
   double PJ_OPK.k
      Third rotation angle, kappa.

type PJ_ENU
   East, north and up components.
   
   typedef struct { double e, n, u; } PJ_ENU;

   double PJ_ENU.e
      East component.
   double PJ_ENU.n
      North component.
   double PJ_ENU.u
      Up component.

type PJ_GEOD
   Geodesic length, forward and reverse azimuths.
   
   typedef struct { double s, a1, a2; } PJ_GEOD;

   double PJ_GEOD.s
      Geodesic length.
   double PJ_GEOD.a1
      Forward azimuth.
   double PJ_GEOD.a2
      Reverse azimuth.
10.5.2.6 Complex coordinate types

type PJCOORD

General purpose coordinate union type, applicable in two, three and four dimensions. This is the default coordinate datatype used in PROJ.

typedef union {
  double v[4];
  PJ_XYZT xzty;
  PJ_UVWT uvwt;
  PJ_LPZT lpzt;
  PJ_GEOD geod;
  PJ_OPK opk;
  PJ_ENU enu;
  PJ_XYZ xyz;
  PJ_UVW uvw;
  PJ_LPZ lpz;
  PJ_XY xy;
  PJ_UV uv;
  PJ_LP lp;
} PJCOORD ;

double v[4]
  Generic four-dimensional vector.

PJ_XYZT PJ_COORD.xzty
  Spatiotemporal cartesian coordinate.

PJ_UVWT PJ_COORD.uvwt
  Spatiotemporal generic coordinate.

PJ_LPZT PJ_COORD.lpzt
  Longitude, latitude, vertical and time components.

PJ_GEOD PJ_COORD.geod
  Geodesic length, forward and reverse azimuths.

PJ_OPK PJ_COORD.opk
  Rotations, for instance three euler angles.

PJ_ENU PJ_COORD.enu
  East, north and up components.

PJ_XYZ PJ_COORD.xyz
  3-dimensional cartesian coordinate.

PJ_UVW PJ_COORD.uvw
  3-dimensional generic coordinate.

PJ_LPZ PJ_COORD.lpz
  Longitude, latitude and vertical component.

PJ_XY PJ_COORD.xy
  2-dimensional cartesian coordinate.
**PJ_UV** PJCOORD.uv
2-dimensional generic coordinate.

**PJ_LP** PJCOORD.lp
Longitude and latitude.

### 10.5.2.7 Projection derivatives

The type `PJ_FACTORS` represents various cartographic properties, such as scale factors, angular distortion and meridian convergence. It is calculated with the `proj_factors()` function.

```c
typedef struct {
    double meridional_scale;
    double parallel_scale;
    double areal_scale;
    double angular_distortion;
    double meridian_parallel_angle;
    double meridian_convergence;
    double tissot_semimajor;
    double tissot_semiminor;
    double dx_dlam;
    double dx_dphi;
    double dy_dlam;
    double dy_dphi;
} PJ_FACTORS;
```

double PJ_FACTORS.meridional_scale
Meridional scale at coordinate \((\lambda, \phi)\).

double PJ_FACTORS.parallel_scale
Parallel scale at coordinate \((\lambda, \phi)\).

double PJ_FACTORS.areal_scale
Areal scale factor at coordinate \((\lambda, \phi)\).

double PJ_FACTORS.angular_distortion
Angular distortion at coordinate \((\lambda, \phi)\).

double PJ_FACTORS.meridian_parallel_angle
Meridian/parallel angle, \(\theta'\), at coordinate \((\lambda, \phi)\).

double PJ_FACTORS.meridian_convergence
Meridian convergence at coordinate \((\lambda, \phi)\). Sometimes also described as *grid declination*.

double PJ_FACTORS.tissot_semimajor
Maximum scale factor.

double PJ_FACTORS.tissot_semiminor
Minimum scale factor.
double PJ_FACTORS.\textit{dx_dlam}
Partial derivative $\frac{\partial x}{\partial \lambda}$ of coordinate $(\lambda, \phi)$.

double PJ_FACTORS.\textit{dy_dlam}
Partial derivative $\frac{\partial y}{\partial \lambda}$ of coordinate $(\lambda, \phi)$.

double PJ_FACTORS.\textit{dx_dphi}
Partial derivative $\frac{\partial x}{\partial \phi}$ of coordinate $(\lambda, \phi)$.

double PJ_FACTORS.\textit{dy_dphi}
Partial derivative $\frac{\partial y}{\partial \phi}$ of coordinate $(\lambda, \phi)$.

10.5.2.8 List structures

type \textit{PJ\_OPERATIONS}
Description a PROJ operation

\begin{verbatim}
struct PJ_OPERATIONS {
    const char *id;    /* operation keyword */
    PJ *(*proj)(PJ *); /* operation entry point */
    char *const *descr; /* description text */
};
\end{verbatim}

cost char *\textit{id}
Operation keyword.

\textit{PJ *}(*op)(PJ *)
Operation entry point.

char *const *\textit{descr}
Description of operation.

type \textit{PJ\_ELLPS}
Description of ellipsoids defined in PROJ

\begin{verbatim}
struct PJ_ELLPS {
    const char *id;
    const char *major;
    const char *ell;
    const char *name;
};
\end{verbatim}

cost char *\textit{id}
Keyword name of the ellipsoid.

cost char *\textit{major}
Semi-major axis of the ellipsoid, or radius in case of a sphere.

cost char *\textit{ell}
Elliptical parameter, e.g. $rf=298.257$ or $b=6356772.2$.

cost char *\textit{name}
Name of the ellipsoid.
type `PJ_UNITS`
Distance units defined in PROJ.

```c
struct PJ_UNITS {
    const char *id;    /* units keyword */
    const char *to_meter; /* multiply by value to get meters */
    const char *name;  /* comments */
    double factor; /* to_meter factor in actual numbers */
};
```

- `const char *id`
  Keyword for the unit.

- `const char *to_meter`
  Text representation of the factor that converts a given unit to meters.

- `const char *name`
  Name of the unit.

- `double factor`
  Conversion factor that converts the unit to meters.

Type `PJ_PRIME_MERIDIANS`
Prime meridians defined in PROJ.

```c
struct PJ_PRIME_MERIDIANS {
    const char *id;
    const char *defn;
};
```

- `const char *id`
  Keyword for the prime meridian.

- `const char *defn`
  Offset from Greenwich in DMS format.

### 10.5.2.9 Info structures

Type `PJ_INFO`
Struct holding information about the current instance of PROJ. Struct is populated by `proj_info()`.

```c
typedef struct {
    int major;
    int minor;
    int patch;
    const char *release;
    const char *version;
    const char *searchpath;
} PJ_INFO;
```

- `const char *PJ_INFO.release`
  Release info. Version number and release date, e.g. "Rel. 4.9.3, 15 August 2016".
const char *PJ_INFO.version
Text representation of the full version number, e.g. "4.9.3".

int PJ_INFO.major
Major version number.

int PJ_INFO.minor
Minor version number.

int PJ_INFO.patch
Patch level of release.

cost char PJ_INFO.searchpath
Search path for PROJ. List of directories separated by semicolons (Windows) or colons (non-Windows), e.g. C:\Users\doctorwho;C:\OSGeo4W64\share\proj. Grids and init files are looked for in directories in the search path.

type PJ_PROJ_INFO
Struct holding information about a PJ object. Populated by proj_pj_info(). The PJ_PROJ_INFO object provides a view into the internals of a PJ, so once the PJ is destroyed or otherwise becomes invalid, so does the PJ_PROJ_INFO

typedef struct {
    const char *id;
    const char *description;
    const char *definition;
    int has_inverse;
    double accuracy;
} PJ_PROJ_INFO;

const char *PJ_PROJ_INFO.id
Short ID of the operation the PJ object is based on, that is, what comes after the +proj= in a proj-string, e.g. "merc".

const char *PJ_PROJ_INFO.description
Long describes of the operation the PJ object is based on, e.g. "Mercator Cyl, Sph&Ell lat_ts=".

const char *PJ_PROJ_INFO.definition
The proj-string that was used to create the PJ object with, e.g. "+proj=merc +lat_0=24 +lon_0=53 +ellps=WGS84".

int PJ_PROJ_INFO.has_inverse
1 if an inverse mapping of the defined operation exists, otherwise 0.

double PJ_PROJ_INFO.accuracy
Expected accuracy of the transformation. -1 if unknown.

type PJ_GRID_INFO
Struct holding information about a specific grid in the search path of PROJ. Populated with the function proj_grid_info().

typedef struct {
    char gridname[32];
    char filename[260];
    char format[8];
    LP lowerleft;
} PJ_GRID_INFO;

(continues on next page)
typedef struct {
    char name[32];
    char filename[260];
    char version[32];
    char origin[32];
    char lastupdate[16];
} PJ_INIT_INFO;

char PJ_INIT_INFO.name[32]  
    Name of init file, e.g. "epsg".
char PJ_INIT_INFO.filename[260]  
    Full path of init file, e.g. "C:\OSGeo4W64\share\proj\epsg"
char PJ_INIT_INFO.version[32]  
    Version number of init file, e.g. "9.0.0"
char PJ_INIT_INFO.origin[32]  
    Originating entity of the init file, e.g. "EPSG"
char PJ_INIT_INFO. lastupdate
Date of last update of the init file.

10.5.2.10 Error codes

New in version 8.0.0.

Three classes of errors are defined below. The belonging of a given error code to a class can bit tested with a binary and test. The error class itself can be used as an error value in some rare cases where the error does not fit into a more precise error value.

Those error codes are still quite generic for a number of them. Details on the actual errors will be typically logged with the PJ_LOG_ERROR level.

Errors in class PROJ_ERR_INVALID_OP

PROJ_ERR_INVALID_OP
Class of error codes typically related to coordinate operation initialization, typically when creating a PJ* object from a PROJ string.

Note: some of them can also be emitted during coordinate transformation, like PROJ_ERR_INVALID_OP_FILE_NOT_FOUND_OR_INVALID in case the resource loading is deferred until it is really needed.

PROJ_ERR_INVALID_OP_WRONG_SYNTAX
Invalid pipeline structure, missing +proj argument, etc.

PROJ_ERR_INVALID_OP_MISSING_ARG
Missing required operation parameter

PROJ_ERR_INVALID_OP_ILLEGAL_ARG_VALUE
One of the operation parameter has an illegal value.

PROJ_ERR_INVALID_OP_MUTUALLY_EXCLUSIVE_ARGS
Mutually exclusive arguments

PROJ_ERR_INVALID_OP_FILE_NOT_FOUND_OR_INVALID
File not found or with invalid content (particular case of PROJ_ERR_INVALID_OP_ILLEGAL_ARG_VALUE)

Errors in class PROJ_ERR_COORD_TRANSFM

PROJ_ERR_COORD_TRANSFM
Class of error codes related to transformation on a specific coordinate.

PROJ_ERR_COORD_TRANSFM_INVALIDCOORD
Invalid input coordinate. e.g. a latitude > 90°.

PROJ_ERR_COORD_TRANSFM_OUTSIDE_PROJECTION_DOMAIN
Coordinate is outside of the projection domain. e.g. approximate mercator with |longitude - lon_0| > 90°, or iterative convergence method failed.
**PROJ coordinate transformation software library, Release 9.3.1**

**PROJ_ERR_COORD_TRANSFM_NO_OPERATION**
No operation found, e.g. if no match the required accuracy, or if ballpark transformations were asked to not be used and they would be only such candidate.

**PROJ_ERR_COORD_TRANSFM_OUTSIDE_GRID**
Point to transform falls outside grid/subgrid/TIN.

**PROJ_ERR_COORD_TRANSFM_GRID_AT_NODATA**
Point to transform falls in a grid cell that evaluates to nodata.

**Errors in class PROJ_ERR_OTHER**

**PROJ_ERR_OTHER**
Class of error codes that do not fit into one of the above class.

**PROJ_ERR_OTHER_API_MISUSE**
Error related to a misuse of PROJ API.

**PROJ_ERR_OTHER_NO_INVERSE_OP**
No inverse method available

**PROJ_ERR_OTHER_NETWORK_ERROR**
Failure when accessing a network resource.

**10.5.2.11 Logging**

**type PJ_LOG_LEVEL**
Enum of logging levels in PROJ. Used to set the logging level in PROJ. Usually using `proj_log_level()`.

enumerator **PJ_LOG_NONE**
Don't log anything.

enumerator **PJ_LOG_ERROR**
Log only errors.

enumerator **PJ_LOG_DEBUG**
Log errors and additional debug information.

enumerator **PJ_LOG_TRACE**
Highest logging level. Log everything including very detailed debug information.

enumerator **PJ_LOG_TELL**
Special logging level that when used in `proj_log_level()` will return the current logging level set in PROJ.

New in version 5.1.0.

**type PJ_LOG_FUNC**
Function prototype for the logging function used by PROJ. Defined as

```c
typedef void (*PJ_LOG_FUNCTION)(void *, int, const char *);
```

where the first argument (void pointer) references a data structure used by the calling application, the second argument (int type) is used to set the logging level and the third argument (const char pointer) is the string that will be logged by the function.

New in version 5.1.0.
### 10.5.2.12 Setting custom I/O functions

New in version 7.0.0.

```c
struct PROJ_FILE_API
    File API callbacks

Public Members

int version
    Version of this structure. Should be set to 1 currently.

PROJ_FILE_HANDLE *(*open_cbk)(PJ_CONTEXT *ctx, const char *filename, PROJ_OPEN_ACCESS
    access, void *user_data)
    Open file. Return NULL if error

size_t (*read_cbk)(PJ_CONTEXT *ctx, PROJ_FILE_HANDLE*, void *buffer, size_t sizeBytes, void
    *user_data)
    Read sizeBytes into buffer from current position and return number of bytes read

size_t (*write_cbk)(PJ_CONTEXT *ctx, PROJ_FILE_HANDLE*, const void *buffer, size_t sizeBytes, void
    *user_data)
    Write sizeBytes into buffer from current position and return number of bytes written

int (*seek_cbk)(PJ_CONTEXT *ctx, PROJ_FILE_HANDLE*, long long offset, int whence, void *user_data)
    Seek to offset using whence=SEEK_SET/SEEK_CUR/SEEK_END. Return TRUE in case of success

unsigned long long (*tell_cbk)(PJ_CONTEXT *ctx, PROJ_FILE_HANDLE*, void *user_data)
    Return current file position

void (*close_cbk)(PJ_CONTEXT *ctx, PROJ_FILE_HANDLE*, void *user_data)
    Close file

int (*exists_cbk)(PJ_CONTEXT *ctx, const char *filename, void *user_data)
    Return TRUE if a file exists

int (*mkdir_cbk)(PJ_CONTEXT *ctx, const char *filename, void *user_data)
    Return TRUE if directory exists or could be created

int (*unlink_cbk)(PJ_CONTEXT *ctx, const char *filename, void *user_data)
    Return TRUE if file could be removed

int (*rename_cbk)(PJ_CONTEXT *ctx, const char *oldPath, const char *newPath, void *user_data)
    Return TRUE if file could be renamed
```
typedef struct PROJ_FILE_HANDLE PROJ_FILE_HANDLE
Opaque structure for PROJ for a file handle. Implementations might cast it to their structure/class of choice.

enum PROJ_OPEN_ACCESS
Open access / mode
Values:

enumerator PROJ_OPEN_ACCESS_READ_ONLY
Read-only access. Equivalent to "rb"

enumerator PROJ_OPEN_ACCESS_READ_UPDATE
Read-update access. File should be created if not existing. Equivalent to "r+b"

enumerator PROJ_OPEN_ACCESS_CREATE
Create access. File should be truncated to 0-byte if already existing. Equivalent to "w+b"

10.5.2.13 Network related functionality
New in version 7.0.0.

typedef struct PROJ_NETWORK_HANDLE PROJ_NETWORK_HANDLE
Opaque structure for PROJ for a network handle. Implementations might cast it to their structure/class of choice.

typedef PROJ_NETWORK_HANDLE *(\*proj_network_open_cbk_type)(PJ_CONTEXT *ctx, const char *url,
unsigned long long offset, size_t size_to_read, void *buffer, size_t *out_size_read, size_t error_string_max_size, char
*out_error_string, void *user_data)
Network access: open callback
Should try to read the size_to_read first bytes at the specified offset of the file given by URL url, and write them
to buffer. *out_size_read should be updated with the actual amount of bytes read (== size_to_read if the file
is larger than size_to_read). During this read, the implementation should make sure to store the HTTP headers
from the server response to be able to respond to proj_network_get_header_value_cbk_type callback.
error_string_max_size should be the maximum size that can be written into the out_error_string buffer (including
terminating nul character).

Return
a non-NULL opaque handle in case of success.

typedef void (*\*proj_network_close_cbk_type)(PJ_CONTEXT *ctx, PROJ_NETWORK_HANDLE *handle, void
*user_data)
Network access: close callback

typedef const char *(\*proj_network_get_header_value_cbk_type)(PJ_CONTEXT *ctx,
PROJ_NETWORK_HANDLE *handle, const char *header_name, void *user_data)
Network access: get HTTP headers

typedef size_t *(\*proj_network_read_range_type)(PJ_CONTEXT *ctx, PROJ_NETWORK_HANDLE *handle,
unsigned long long offset, size_t size_to_read, void *buffer, size_t error_string_max_size, char *out_error_string,
void *user_data)
Network access: read range
Read size_to_read bytes from handle, starting at offset, into buffer. During this read, the implementation should make sure to store the HTTP headers from the server response to be able to respond to proj_network_get_header_value_cbk_type callback.

error_string_max_size should be the maximum size that can be written into the out_error_string buffer (including terminating nul character).

Return
the number of bytes actually read (0 in case of error)

10.5.2.14 C API for ISO-19111 functionality

enum PJ_GUESSED_WKT_DIALECT
Guessed WKT "dialect".

Values:

enumerator PJ_GUESSED_WKT2_2019
WKT2:2019

enumerator PJ_GUESSED_WKT2_2018
Deprecated alias for PJ_GUESSED_WKT2_2019

enumerator PJ_GUESSED_WKT2_2015
WKT2:2015

enumerator PJ_GUESSED_WKT1_GDAL
WKT1 specification

enumerator PJ_GUESSED_WKT1_ESRI
ESRI variant of WKT1

enumerator PJ_GUESSED_NOT_WKT
Not WKT / unrecognized

enum PJ_CATEGORY
Object category.

Values:

enumerator PJ_CATEGORY_ELLIPSOID

enumerator PJ_CATEGORY_PRIME_MERIDIAN

enumerator PJ_CATEGORY_DATUM
enumerator PJCATEGORY_CRS

enumerator PJCATEGORY_COORDINATE_OPERATION

enumerator PJCATEGORY_DATUM_ENSEMBLE

enum PJ_TYPE
Object type.
Values:

enumerator PJ_TYPEUNKNOWN

enumerator PJ_TYPEELLIPSOID

enumerator PJ_TYPEPRIME_MERIDIAN

enumerator PJ_TYPEGEODE蒂IC_REFERENCE_FRAME

enumerator PJ_TYPEDYNAMIC_GEODE蒂IC_REFERENCE_FRAME

enumerator PJ_TYPEVERTICAL_REFERENCE_FRAME

enumerator PJ_TYPEDYNAMIC_VERTICAL_REFERENCE_FRAME

enumerator PJ_TYPEDATUM_ENSEMBLE

enumerator PJ_TYPEDATUM_ENSEMBLE

enumerator PJ_TYPECRS
Abstract type, not returned by proj_get_type()

enumerator PJ_TYPEGEODE蒂IC_CRS

enumerator PJ_TYPEGEOCENTRIC_CRS

enumerator PJ_TYPEGEOGRAPHIC_CRS
proj_get_type() will never return that type, but PJ_TYPE_GEOGRAPHIC_2D_CRS or PJ_TYPE_GEOGRAPHIC_3D_CRS.

enumerator PJ_TYPEGEOGRAPHIC_2D_CRS

enumerator PJ_TYPEGEOGRAPHIC_3D_CRS

enumerator PJ_TYPEVERTICAL_CRS
enumerator PJ_TYPE_PROJECTED_CRS
enumerator PJ_TYPE_COMPOUND_CRS
enumerator PJ_TYPE_TEMPORAL_CRS
enumerator PJ_TYPEENGINEERING_CRS
enumerator PJ_TYPE_BOUND_CRS
enumerator PJ_TYPE_OTHER_CRS
enumerator PJ_TYPE_CONVERSION
enumerator PJ_TYPE_TRANSFORMATION
enumerator PJ_TYPE CONCATENATED_OPERATION
enumerator PJ_TYPE_OTHER_COORDINATE_OPERATION
enumerator PJ_TYPE_TEMPORAL_DATUM
enumerator PJ_TYPEENGINEERING_DATUM
enumerator PJ_TYPE PARAMETRIC_DATUM
enumerator PJ_TYPE_DERIVED_PROJECTED_CRS
enumerator PJ_TYPECOORDINATE_METADATA

enum PJ_COMPARISON_CRITERION

  Comparison criterion.

  Values:

  enumerator PJ_COMP.Strict
      All properties are identical.

  enumerator PJ_COMP.EQUIVALENT
      The objects are equivalent for the purpose of coordinate operations. They can differ by the name of their objects, identifiers, other metadata. Parameters may be expressed in different units, provided that the value is (with some tolerance) the same once expressed in a common unit.
enumerator PJ_COMP_EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS

Same as EQUIVALENT, relaxed with an exception that the axis order of the base CRS of a Derived-CRS/ProjectedCRS or the axis order of a GeographicCRS is ignored. Only to be used with Derived-CRS/ProjectedCRS/GeographicCRS

enum PJ_WKT_TYPE

WKT version.

Values:

enumerator PJ_WKT2_2015

cf osgeo::proj::io::WKTFormatter::Convention::WKT2

enumerator PJ_WKT2_2015_SIMPLIFIED

cf osgeo::proj::io::WKTFormatter::Convention::WKT2_SIMPLIFIED

enumerator PJ_WKT2_2019

cf osgeo::proj::io::WKTFormatter::Convention::WKT2_2019

enumerator PJ_WKT2_2018

Deprecated alias for PJ_WKT2_2019

enumerator PJ_WKT2_2018_SIMPLIFIED

cf osgeo::proj::io::WKTFormatter::Convention::WKT2_2018_SIMPLIFIED

enumerator PJ_WKT1_GDAL

cf osgeo::proj::io::WKTFormatter::Convention::WKT1_GDAL

enumerator PJ_WKT1_ESRI

cf osgeo::proj::io::WKTFormatter::Convention::WKT1_ESRI

enum PROJ_CRS_EXTENT_USE

Specify how source and target CRS extent should be used to restrict candidate operations (only taken into account if no explicit area of interest is specified.

Values:

enumerator PJ_CRS_EXTENT_NONE

Ignore CRS extent

enumerator PJ_CRS_EXTENT_BOTH

Test coordinate operation extent against both CRS extent.
enumerator `PJ_CRS_EXTENT_INTERSECTION`
   Test coordinate operation extent against the intersection of both CRS extent.

enumerator `PJ_CRS_EXTENT_SMALLEST`
   Test coordinate operation against the smallest of both CRS extent.

defined `PROJ_GRID_AVAILABILITY_USE`
   Describe how grid availability is used.

   Values:
   
   enumerator `PROJ_GRID_AVAILABILITY_USED_FOR_SORTING`
      Grid availability is only used for sorting results. Operations where some grids are missing will be sorted last.

   enumerator `PROJ_GRID_AVAILABILITY_DISCARD_OPERATION_IF_MISSING_GRID`
      Completely discard an operation if a required grid is missing.

   enumerator `PROJ_GRID_AVAILABILITY_IGNORED`
      Ignore grid availability at all. Results will be presented as if all grids were available.

   enumerator `PROJ_GRID_AVAILABILITY_KNOWN_AVAILABLE`
      Results will be presented as if grids known to PROJ (that is registered in the grid_alternatives table of its database) were available. Used typically when networking is enabled.

defined `PJ_PROJ_STRING_TYPE`
   PROJ string version.

   Values:
   
   enumerator `PJ_PROJ_5`
      cf `osgeo::proj::io::PROJStringFormatter::Convention::PROJ_5`

   enumerator `PJ_PROJ_4`
      cf `osgeo::proj::io::PROJStringFormatter::Convention::PROJ_4`

defined `PROJ_SPATIAL_CRITERION`
   Spatial criterion to restrict candidate operations.

   Values:
   
   enumerator `PROJ_SPATIAL_CRITERION_STRICT_CONTAINMENT`
      The area of validity of transforms should strictly contain the area of interest.

   enumerator `PROJ_SPATIAL_CRITERION_PARTIAL_INTERSECTION`
      The area of validity of transforms should at least intersect the area of interest.
enum PROJ_INTERMEDIATE_CRS_USE
   Describe if and how intermediate CRS should be used
   Values:

   enumerator PROJ_INTERMEDIATE_CRS_USE_ALWAYS
      Always search for intermediate CRS.

   enumerator PROJ_INTERMEDIATE_CRS_USE_IF_NO_DIRECT_TRANSFORMATION
      Only attempt looking for intermediate CRS if there is no direct transformation available.

   enumerator PROJ_INTERMEDIATE_CRS_USE_NEVER

denum PJ_COORDINATE_SYSTEM_TYPE
   Type of coordinate system.
   Values:

   enumerator PJ_CS_TYPE_UNKNOWN
   enumerator PJ_CS_TYPE_CARTESIAN
   enumerator PJ_CS_TYPE_ELLIPSOIDAL
   enumerator PJ_CS_TYPE_VERTICAL
   enumerator PJ_CS_TYPE_SPHERICAL
   enumerator PJ_CS_TYPE_ORDINAL
   enumerator PJ_CS_TYPE_PARAMETRIC
   enumerator PJ_CS_TYPE_DATETIME_TEMPORAL
   enumerator PJ_CS_TYPE_TEMPORAL_COUNT
   enumerator PJ_CS_TYPE_TEMPORAL_MEASURE

typedef char **PROJ_STRING_LIST
   Type representing a NULL terminated list of NULL-terminate strings.

struct PROJ_CRS_INFO
   #include <proj.h> Structure given overall description of a CRS.
   This structure may grow over time, and should not be directly allocated by client code.
**Public Members**

char *auth_name
   Authority name.

cchar *code
   Object code.

cchar *name
   Object name.

*PJ_TYPE* type
   Object type.

int deprecated
   Whether the object is deprecated

int bbox_valid
   Whereas the west_lon_degree, south_lat_degree, east_lon_degree and north_lat_degree fields are valid.

double west_lon_degree
   Western-most longitude of the area of use, in degrees.

double south_lat_degree
   Southern-most latitude of the area of use, in degrees.

double east_lon_degree
   Eastern-most longitude of the area of use, in degrees.

double north_lat_degree
   Northern-most latitude of the area of use, in degrees.

cchar *area_name
   Name of the area of use.

cchar *projection_method_name
   Name of the projection method for a projected CRS. Might be NULL even for projected CRS in some cases.

char *celestial_body_name
   Name of the celestial body of the CRS (e.g. "Earth").

Since
   8.1

struct PROJ_CRS_LIST_PARAMETERS
   
   *include <proj.h>* Structure describing optional parameters for proj_get_crs_list();.

   This structure may grow over time, and should not be directly allocated by client code.
Public Members

const PJ_TYPE *types
    Array of allowed object types. Should be NULL if all types are allowed

size_t typesCount
    Size of types. Should be 0 if all types are allowed

int crs_area_of_use_contains_bbox
    If TRUE and bbox_valid == TRUE, then only CRS whose area of use entirely contains the specified bounding box will be returned. If FALSE and bbox_valid == TRUE, then only CRS whose area of use intersects the specified bounding box will be returned.

int bbox_valid
    To set to TRUE so that west_lon_degree, south_lat_degree, east_lon_degree and north_lat_degree fields are taken into account.

double west_lon_degree
    Western-most longitude of the area of use, in degrees.

double south_lat_degree
    Southern-most latitude of the area of use, in degrees.

double east_lon_degree
    Eastern-most longitude of the area of use, in degrees.

double north_lat_degree
    Northern-most latitude of the area of use, in degrees.

int allow_deprecated
    Whether deprecated objects are allowed. Default to FALSE.

const char *celestial_body_name
    Celestial body of the CRS (e.g. "Earth"). The default value, NULL, means no restriction

Since
    8.1

struct PROJ_UNIT_INFO

#include <proj.h> Structure given description of a unit.

This structure may grow over time, and should not be directly allocated by client code.

Since
    7.1
Public Members

char *auth_name
Authority name.

char *code
Object code.

char *name
Object name. For example "metre", "US survey foot", etc.

char *category
Category of the unit: one of "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time" or "time"

double conv_factor
Conversion factor to apply to transform from that unit to the corresponding SI unit (metre for "linear", radian for "angular", etc.). It might be 0 in some cases to indicate no known conversion factor.

char *proj_short_name
PROJ short name, like "m", "ft", "us-ft", etc... Might be NULL

int deprecated
Whether the object is deprecated

struct PROJ_CELESTIAL_BODY_INFO
#include <proj.h> Structure given description of a celestial body.
This structure may grow over time, and should not be directly allocated by client code.

Since
8.1

Public Members

char *auth_name
Authority name.

char *name
Object name. For example "Earth"
10.5.3 Functions

10.5.3.1 Threading contexts

PJ_CONTEXT *proj_context_create(void)
Create a new threading-context.

Returns
a new context

PJ_CONTEXT *proj_context_clone(PJ_CONTEXT *ctx)
New in version 7.2.
Create a new threading-context based on an existing context.

Returns
a new context

void proj_context_destroy(PJ_CONTEXT *ctx)
Deallocate a threading-context.

Parameters
• ctx (PJ_CONTEXT *) -- Threading context.

10.5.3.2 Transformation setup

The objects returned by the functions defined in this section have minimal interaction with the functions of the C API for ISO-19111 functionality, and vice versa. See its introduction paragraph for more details.

PJ *proj_create(PJ_CONTEXT *ctx, const char *definition)
Create a transformation object, or a CRS object, from:

• a proj-string,
• a WKT string,
• an object code (like "EPSG:4326", "urn:ogc:def:crs:EPSG::4326", "urn:ogc:def:coordinateOperation:EPSG::1671"),
• an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not guaranteed, heuristics are applied to determine the appropriate best match.
• a OGC URN combining references for compound coordinate reference systems (e.g "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" or custom abbreviated syntax "EPSG:2393+5717"),
• a OGC URN combining references for concatenated operations (e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618")
• a PROJJSON string. The jsonschema is at https://proj.org/schemas/v0.4/projjson.schema.json (added in 6.2)
• a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height" (added in 7.1)

Example call:

PJ *P = proj_create(0, "+proj=etmerc +lat_0=38 +lon_0=125 +ellps=bessel");
If a proj-string contains a +type=crs option, then it is interpreted as a CRS definition. In particular geographic CRS are assumed to have axis in the longitude, latitude order and with degree angular unit. The use of proj-string to describe a CRS is discouraged. It is a legacy means of conveying CRS descriptions: use of object codes (EPSG:XXXX typically) or WKT description is recommended for better expressivity.

If a proj-string does not contain +type=crs, then it is interpreted as a coordination operation / transformation.

If creation of the transformation object fails, the function returns 0 and the PROJ error number is updated. The error number can be read with proj_errno() or proj_context_errno().

The returned PJ-pointer should be deallocated with proj_destroy().

Parameters

- ctx (PJ_CONTEXT *) -- Threading context.
- definition (const char*) -- Proj-string of the desired transformation.

PJ *proj_create_argv(PJ_CONTEXT *ctx, int argc, char **argv)

Create a transformation object, or a CRS object, with argc/argv-style initialization. For this application each parameter in the defining proj-string is an entry in argv.

Example call:

```c
char *args[3] = {"proj=utm", "zone=32", "ellps=GRS80"};
PJ* P = proj_create_argv(0, 3, args);
```

If there is a type=crs argument, then the arguments are interpreted as a CRS definition. In particular geographic CRS are assumed to have axis in the longitude, latitude order and with degree angular unit.

If there is no type=crs argument, then it is interpreted as a coordination operation / transformation.

If creation of the transformation object fails, the function returns 0 and the PROJ error number is updated. The error number can be read with proj_errno() or proj_context_errno().

The returned PJ-pointer should be deallocated with proj_destroy().

Parameters

- ctx (PJ_CONTEXT *) -- Threading context.
- argc (int) -- Count of arguments in argv
- argv (char **) -- Array of strings with proj-string parameters, e.g. +proj=merc

Returns

PJ *

PJ *proj_create_crs_to_crs(PJ_CONTEXT *ctx, const char *source_crs, const char *target_crs, PJ_AREA *area)

Create a transformation object that is a pipeline between two known coordinate reference systems. source_crs and target_crs can be:

- a "AUTHORITY:CODE", like EPSG:25832. When using that syntax for a source CRS, the created pipeline will expect that the values passed to proj_trans() respect the axis order and axis unit of the official definition (so for example, for EPSG:4326, with latitude first and longitude next, in degrees). Similarly, when using that syntax for a target CRS, output values will be emitted according to the official definition of this CRS.

- a PROJ string, like "+proj=longlat +datum=WGS84". When using that syntax, the axis order and unit for geographic CRS will be longitude, latitude, and the unit degrees.

- the name of a CRS as found in the PROJ database, e.g "WGS84", "NAD27", etc.
• more generally any string accepted by `proj_create()` representing a CRS

Starting with PROJ 9.2, `source_crs` or `target_crs` can be a CoordinateMetadata with an associated coordinate epoch (but only one of them, not both).

An "area of use" can be specified in `area`. When it is supplied, the more accurate transformation between two given systems can be chosen.

When no area of use is specific and several coordinate operations are possible depending on the area of use, this function will internally store those candidate coordinate operations in the return PJ object. Each subsequent coordinate transformation done with `proj_trans()` will then select the appropriate coordinate operation by comparing the input coordinates with the area of use of the candidate coordinate operations.

Example call:

```c
PJ *P = proj_create_crs_to_crs(0, "EPSG:25832", "EPSG:25833", 0);
```

If creation of the transformation object fails, the function returns `0` and the PROJ error number is updated. The error number can be read with `proj_errno()` or `proj_context_errno()`.

The returned `PJ`-pointer should be deallocated with `proj_destroy()`.

**Parameters**

- `ctx (PJ_CONTEXT *)` -- Threading context.
- `source_crs (const char*)` -- Source CRS or CoordinateMetadata.
- `target_crs (const char*)` -- Destination SRS or CoordinateMetadata
- `area (PJ_AREA *)` -- Descriptor of the desired area for the transformation.

**Returns**

`PJ *`

`proj_create_crs_to_crs_from_pj(PJ_CONTEXT *ctx, PJ *source_crs, PJ *target_crs, PJ_AREA *area, const char *const *options)`

New in version 6.2.0.

Create a transformation object that is a pipeline between two known coordinate reference systems.

This is the same as `proj_create_crs_to_crs()` except that the source and target CRS are passed as `PJ*` objects which must be of the CRS variety.

Starting with PROJ 9.2, `source_crs` or `target_crs` can be a CoordinateMetadata with an associated coordinate epoch (but only one of them, not both).

**Parameters**

- `options` -- a list of NUL terminated options, or NULL.

The list of supported options is:

- `AUTHORITY=name:` to restrict the authority of coordinate operations looked up in the database. When not specified, coordinate operations from any authority will be searched, with the restrictions set in the `authority_to_authority_preference` database table related to the authority of the source/target CRS themselves. If authority is set to any, then coordinate operations from any authority will be searched. If authority is a non-empty string different of any, then coordinate operations will be searched only in that authority namespace (e.g EPSG).

- `ACCURACY=value:` to set the minimum desired accuracy (in metres) of the candidate coordinate operations.
• ALLOW_BALLPARK=YES/NO: can be set to NO to disallow the use of Ballpark transformation in the candidate coordinate operations.

• ONLY_BEST=YES/NO: (PROJ >= 9.2) Can be set to YES to cause PROJ to error out if the best transformation, known of PROJ, and usable by PROJ if all grids known and usable by PROJ were accessible, cannot be used. Best transformation should be understood as the transformation returned by proj_get_suggested_operation() if all known grids were accessible (either locally or through network). Note that the default value for this option can be also set with the PROJ_ONLY_BEST_DEFAULT environment variable, or with the only_best_default setting of proj.ini (the ONLY_BEST option when specified overrides such default value).

• FORCE_OVER=YES/NO: can be set to YES to force the +over flag on the transformation returned by this function. See Longitude Wrapping

PJ *proj_normalize_for_visualization(PJ_CONTEXT *ctx, const PJ *obj)

Returns a PJ* object whose axis order is the one expected for visualization purposes.

The input object must be either:

• a coordinate operation, that has been created with proj_create_crs_to_crs(). If the axis order of its source or target CRS is northing,easting, then an axis swap operation will be inserted.

• or a CRS. The axis order of geographic CRS will be longitude, latitude [,height], and the one of projected CRS will be easting, northing [, height]

Parameters

• ctx -- PROJ context, or NULL for default context

• obj -- Object of type CRS, or CoordinateOperation created with proj_create_crs_to_crs() (must not be NULL)

Returns

a new PJ* object to free with proj_destroy() in case of success, or nullptr in case of error

PJ *proj_destroy(PJ *P)

Deallocate a PJ transformation object.

Parameters

• P (const PJ *) -- Transformation object

Returns

PJ *

10.5.3.3 Area of interest

New in version 6.0.0.

PJ_AREA *proj_area_create(void)

Create an area of use.

Such an area of use is to be passed to proj_create_crs_to_crs() to specify the area of use for the choice of relevant coordinate operations.

Returns

PJ_AREA * to be deallocated with proj_area_destroy()
void proj_area_set_bbox(PJ_AREA *area, double west_lon_degree, double south_lat_degree, double east_lon_degree, double north_lat_degree)

Set the bounding box of the area of use

Such an area of use is to be passed to proj_create_crs_to_crs() to specify the area of use for the choice of relevant coordinate operations.

In the case of an area of use crossing the antimeridian (longitude +/- 180 degrees), west_lon_degree will be greater than east_lon_degree.

Parameters

• area -- Pointer to an object returned by proj_area_create().
• west_lon_degree -- West longitude, in degrees. In [-180,180] range.
• south_lat_degree -- South latitude, in degrees. In [-90,90] range.
• east_lon_degree -- East longitude, in degrees. In [-180,180] range.
• north_lat_degree -- North latitude, in degrees. In [-90,90] range.

void proj_area_destroy(PJ_AREA *area)

Deallocate a PJ_AREA object.

:param PJ_AREA* area

10.5.3.4 Coordinate transformation

PJ_COORD proj_trans(PJ *P, PJ_DIRECTION direction, PJ_COORD coord)

Transform a single PJ_COORD coordinate.

If the input coordinate contains any NaNs you are guaranteed to get a coordinate with all NaNs as a result.

Changed in version 9.2.0: Define NaN handling. Prior NaN handling behavior was undefined.

Parameters

• P (PJ *) -- Transformation object
• direction (PJ_DIRECTION) -- Transformation direction.
• coord (PJ_COORD) -- Coordinate that will be transformed.

Returns

PJ_COORD

PJ *proj_trans_get_last_used_operation(PJ *P)

New in version 9.1.0.

Return the operation used during the last invocation of proj_trans(). This is especially useful when P has been created with proj_create_crs_to_crs() and has several alternative operations. The returned object must be freed with proj_destroy().

Parameters

• P (PJ *) -- Transformation object

Returns

PJ *
size_t `proj_trans_generic`(`PJ *P, PJ_DIRECTION direction, double *x, size_t sx, size_t nx, double *y, size_t sy, size_t ny, double *z, size_t sz, size_t nz, double *t, size_t st, size_t nt)

Transform a series of coordinates, where the individual coordinate dimension may be represented by an array that is either

1. fully populated
2. a null pointer and/or a length of zero, which will be treated as a fully populated array of zeroes
3. of length one, i.e. a constant, which will be treated as a fully populated array of that constant value

**Note:** Even though the coordinate components are named `x`, `y`, `z` and `t`, axis ordering of the to and from CRS is respected. Transformations exhibit the same behavior as if they were gathered in a `PJCOORD` struct.

The strides, `sx, sy, sz, st`, represent the step length, in bytes, between consecutive elements of the corresponding array. This makes it possible for `proj_trans_generic()` to handle transformation of a large class of application specific data structures, without necessarily understanding the data structure format, as in:

```c
typedef struct {
    double x, y;
    int quality_level;
    char surveyor_name[134];
} XYQS;

XYQS survey[345];
double height = 23.45;
size_t stride = sizeof (XYQS);
...

proj_trans_generic (P, PJ_INV,
    &(survey[0].x), stride, 345, /* We have 345 eastings */
    &(survey[0].y), stride, 345, /* ...and 345 northings. */
    &height, sizeof(double), 1, /* The height is the constant 23.45 m */
    0, 0, 0 /* and the time is the constant 0.00 s */
);
```

This is similar to the inner workings of the deprecated `pj_transform()` function, but the stride functionality has been generalized to work for any size of basic unit, not just a fixed number of doubles.

In most cases, the stride will be identical for `x, y, z,` and `t,` since they will typically be either individual arrays (`stride = sizeof(double)`), or strided views into an array of application specific data structures (`stride = sizeof(...)`).

But in order to support cases where `x, y, z,` and `t` come from heterogeneous sources, individual strides, `sx, sy, sz, st`, are used.

**Note:** Since `proj_trans_generic()` does its work in place, this means that even the supposedly constants (i.e. length 1 arrays) will return from the call in altered state. Hence, remember to reinitialize between repeated calls.

**Parameters**
• **P (PJ*)** -- Transformation object
• **direction (PJ_DIRECTION)** -- Transformation direction.
• **x (double *)** -- Array of x-coordinates
• **sx (size_t)** -- Step length, in bytes, between consecutive elements of the corresponding array
• **nx (size_t)** -- Number of elements in the corresponding array
• **y (double *)** -- Array of y-coordinates
• **sy (size_t)** -- Step length, in bytes, between consecutive elements of the corresponding array
• **ny (size_t)** -- Number of elements in the corresponding array
• **z (double *)** -- Array of z-coordinates
• **sz (size_t)** -- Step length, in bytes, between consecutive elements of the corresponding array
• **nz (size_t)** -- Number of elements in the corresponding array
• **t (double *)** -- Array of t-coordinates
• **st (size_t)** -- Step length, in bytes, between consecutive elements of the corresponding array
• **nt (size_t)** -- Number of elements in the corresponding array

Returns
Number of transformations successfully completed

```c
int proj_trans_array(PJ *P, PJ_DIRECTION direction, size_t n, PJ_COORD *coord)
```
Batch transform an array of PJ_COORD.

Performs transformation on all points, even if errors occur on some points (new to 8.0. Previous versions would exit early in case of failure on a given point)

Individual points that fail to transform will have their components set to HUGE_VAL

Parameters
• **P (PJ*)** -- Transformation object
• **direction (PJ_DIRECTION)** -- Transformation direction.
• **n (size_t)** -- Number of coordinates in coord

Returns
`int 0` if all observations are transformed without error, otherwise returns error number. This error number will be a precise error number if all coordinates that fail to transform for the same reason, or a generic error code if they fail for different reasons.

```c
int proj_trans_bounds(PJ_CONTEXT *context, PJ *P, PJ_DIRECTION direction, double xmin, double ymin, double xmax, double ymax, double *out_xmin, double *out_ymin, double *out_xmax, double *out_ymax, int densify_pts)
```
Transform boundary.

Transform boundary densifying the edges to account for nonlinear transformations along these edges and extracting the outermost bounds.

If the destination CRS is geographic, the first axis is longitude, and xmax < xmin then the bounds crossed the antimeridian. In this scenario there are two polygons, one on each side of the antimeridian. The first polygon should be constructed with (xmin, ymin, 180, ymax) and the second with (-180, ymin, xmax, ymax).
If the destination CRS is geographic, the first axis is latitude, and ymax < ymin then the bounds crossed the antimeridian. In this scenario there are two polygons, one on each side of the antimeridian. The first polygon should be constructed with (ymin, xmin, ymax, 180) and the second with (ymin, -180, ymax, xmax).

Since
8.2

Parameters

- **context** -- The PJ_CONTEXT object.
- **P** -- The PJ object representing the transformation.
- **direction** -- The direction of the transformation.
- **xmin** -- Minimum bounding coordinate of the first axis in source CRS (target CRS if direction is inverse).
- **ymin** -- Minimum bounding coordinate of the second axis in source CRS. (target CRS if direction is inverse).
- **xmax** -- Maximum bounding coordinate of the first axis in source CRS. (target CRS if direction is inverse).
- **ymax** -- Maximum bounding coordinate of the second axis in source CRS. (target CRS if direction is inverse).
- **out_xmin** -- Minimum bounding coordinate of the first axis in target CRS (source CRS if direction is inverse).
- **out_ymin** -- Minimum bounding coordinate of the second axis in target CRS. (source CRS if direction is inverse).
- **out_xmax** -- Maximum bounding coordinate of the first axis in target CRS. (source CRS if direction is inverse).
- **out_ymax** -- Maximum bounding coordinate of the second axis in target CRS. (source CRS if direction is inverse).
- **densify_pts** -- Recommended to use 21. This is the number of points to use to densify the bounding polygon in the transformation.

Returns
an integer. 1 if successful. 0 if failures encountered.

10.5.3.5 Error reporting

**int proj_errno**(PJ *P)

Get a reading of the current error-state of P. An non-zero error codes indicates an error either with the transformation setup or during a transformation. In cases P is 0 the error number of the default context is read. A text representation of the error number can be retrieved with proj_errno_string().

Consult Error codes for the list of error codes (PROJ >= 8.0)

Parameters

- **P** (PJ *) -- Transformation object

Returns
int
int proj_context_errno (PJ_CONTEXT *ctx)

Get a reading of the current error-state of ctx. An non-zero error codes indicates an error either with the transformation setup or during a transformation. A text representation of the error number can be retrieved with proj_errno_string().

Consult Error codes for the list of error codes (PROJ >= 8.0)

Parameters

• ctx (PJ_CONTEXT *) -- threading context.

Returns

int

void proj_errno_set (PJ *P, int err)

Change the error-state of P to err.

Parameters

• P (PJ *) -- Transformation object
• err (int) -- Error number.

int proj_errno_reset (PJ *P)

Clears the error number in P, and bubbles it up to the context.

Example:

```c
void foo (PJ *P) {
    int last_errno = proj_errno_reset (P);
    do_something_with_P (P);

    /* failure - keep latest error status */
    if (proj_errno(P))
        return;

    /* success - restore previous error status */
    proj_errno_restore (P, last_errno);
    return;
}
```

Parameters

• P (PJ *) -- Transformation object

Returns

int Returns the previous value of the errno, for convenient reset/restore operations.

void proj_errno_restore (PJ *P, int err)

Reduce some mental impedance in the canonical reset/restore use case: Basically, proj_errno_restore() is a synonym for proj_errno_set(), but the use cases are very different: set indicate an error to higher level user code, restore passes previously set error indicators in case of no errors at this level.

Hence, although the inner working is identical, we provide both options, to avoid some rather confusing real world code.

See usage example under proj_errno_reset()
• **err** *(int)* -- Error number.

```c
const char *proj_errno_string(int err)
```

New in version 5.1.0.

Get a text representation of an error number.

Deprecated since version This function is potentially thread-unsafe, replaced by `proj_context_errno_string()`.

**Parameters**

• **err** *(int)* -- Error number.

**Returns**

`const char*` String with description of error.

```c
const char *proj_context_errno_string(PJ_CONTEXT *ctx, int err)
```

New in version 8.0.0.

Get a text representation of an error number.

**Parameters**

• **ctx** *(PJ_CONTEXT *)* -- Threading context.

• **err** *(int)* -- Error number.

**Returns**

`const char*` String with description of error.

### 10.5.3.6 Logging

```c
PJ_LOG_LEVEL proj_log_level(PJ_CONTEXT *ctx, PJ_LOG_LEVEL level)
```

Get and set logging level for a given context. Changes the log level to `level` and returns the previous logging level. If called with `level` set to `PJ_LOG_TELL` the function returns the current logging level without changing it.

**Parameters**

• **ctx** *(PJ_CONTEXT *)* -- Threading context.

• **level** *(PJ_LOG_LEVEL)* -- New logging level.

**Returns**

`PJ_LOG_LEVEL`

New in version 5.1.0.

```c
void proj_log_func(PJ_CONTEXT *ctx, void *app_data, PJ_LOG_FUNCTION logf)
```

Override the internal log function of PROJ.

**Parameters**

• **ctx** *(PJ_CONTEXT *)* -- Threading context.

• **app_data** *(void *)* -- Pointer to data structure used by the calling application.

• **logf** *(PJ_LOG_FUNCTION)* -- Log function that overrides the PROJ log function.

New in version 5.1.0.
10.5.3.7 Info functions

`PJ_INFO proj_info(void)`

Get information about the current instance of the PROJ library.

Returns

`PJ_INFO`

`PJ_PROJ_INFO proj_pj_info(const PJ *P)`

Get information about a specific transformation object, `P`.

Parameters

• `P` (const `PJ *`) -- Transformation object

Returns

`PJ_PROJ_INFO`

`PJ_GRID_INFO proj_grid_info(const char *gridname)`

Get information about a specific grid.

Parameters

• `gridname` (const `char *`) -- Gridname in the PROJ searchpath

Returns

`PJ_GRID_INFO`

`PJ_INIT_INFO proj_init_info(const char *initname)`

Get information about a specific init file.

Parameters

• `initname` (const `char *`) -- Init file in the PROJ searchpath

Returns

`PJ_INIT_INFO`

10.5.3.8 Lists

`const PJ_OPERATIONS *proj_list_operations(void)`

Get a pointer to an array of all operations in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Print a list of all operations in PROJ:

```c
PJ_OPERATIONS *ops;
for (ops = proj_list_operations(); ops->id; ++ops)
    printf("%s\n", ops->id);
```

Returns

`const PJ_OPERATIONS *`

`const PJ_ELLPS *proj_list_ellps(void)`

Get a pointer to an array of ellipsoids defined in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Returns

`const PJ_ELLPS *`
const PJ_UNITS *proj_list_units(void)

Get a pointer to an array of distance units defined in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Note: starting with PROJ 7.1, this function is deprecated by proj_get_units_from_database()

Returns
const PJ_UNITS *

const PJ_PRIME_MERIDIANS *proj_list_prime_meridians(void)

Get a pointer to an array of prime meridians defined in PROJ. The last entry of the returned array is a NULL-entry. The array is statically allocated and does not need to be freed after use.

Returns
const PJ_PRIME_MERIDIANS *

10.5.3.9 Distances

double proj_lp_dist(const PJ *P, PJ_COORD a, PJ_COORD b)

Calculate geodesic distance between two points in geodetic coordinates. The calculated distance is between the two points located on the ellipsoid.

The coordinates in a and b needs to be given as longitude and latitude in radians. Note that the axis order of the P object is not taken into account in this function, so even though a CRS object comes with axis ordering latitude/longitude coordinates used in this function should be reordered as longitude/latitude.

Parameters
• P (const PJ *) -- Transformation or CRS object
• a (PJ_COORD) -- Coordinate of first point
• b (PJ_COORD) -- Coordinate of second point

Returns
double Distance between a and b in meters.

double proj_lpz_dist(const PJ *P, PJ_COORD a, PJ_COORD b)

Calculate geodesic distance between two points in geodetic coordinates. Similar to proj_lp_dist() but also takes the height above the ellipsoid into account.

The coordinates in a and b needs to be given as longitude and latitude in radians. Note that the axis order of the P object is not taken into account in this function, so even though a CRS object comes with axis ordering latitude/longitude coordinates used in this function should be reordered as longitude/latitude.

Parameters
• P (const PJ *) -- Transformation or CRS object
• a (PJ_COORD) -- Coordinate of first point
• b (PJ_COORD) -- Coordinate of second point

Returns
double Distance between a and b in meters.

double proj_xy_dist(PJ_COORD a, PJ_COORD b)

Calculate 2-dimensional euclidean between two projected coordinates.

Parameters
• a (PJ_COORD) -- First coordinate
• \textbf{b (PJ_COORD)} -- Second coordinate

Returns
\textit{double} Distance between \textit{a} and \textit{b} in meters.

double 
\textbf{proj_xyz_dist(PJ_COORD a, PJ_COORD b)}

Calculate 3-dimensional euclidean between two projected coordinates.

Parameters
• \textbf{a (PJ_COORD)} -- First coordinate
• \textbf{b (PJ_COORD)} -- Second coordinate

Returns
\textit{double} Distance between \textit{a} and \textit{b} in meters.

\textbf{PJ_COORD proj_geod(const PJ *P, PJ_COORD a, PJ_COORD b)}

Calculate the geodesic distance as well as forward and reverse azimuth between two points on the ellipsoid.

The coordinates in \textit{a} and \textit{b} needs to be given as longitude and latitude in radians. Note that the axis order of the \textit{P} object is not taken into account in this function, so even though a CRS object comes with axis ordering latitude/longitude coordinates used in this function should be reordered as longitude/latitude.

Parameters
• \textbf{P (const PJ *)} -- Transformation or CRS object
• \textbf{a (PJ_COORD)} -- Coordinate of first point
• \textbf{b (PJ_COORD)} -- Coordinate of second point

Returns
\textbf{PJCOORD} where the first value is the distance between \textit{a} and \textit{b} in meters, the second value is the forward azimuth and the third value is the reverse azimuth. The fourth coordinate value is unused.

10.5.3.10 Various

\textbf{PJ_COORD proj_coord(double x, double y, double z, double t)}

Initializer for the \textit{PJ_COORD} union. The function is shorthand for the otherwise convoluted assignment. Equivalent to

\begin{verbatim}
PJ_COORD c = {{10.0, 20.0, 30.0, 40.0}};
\end{verbatim}

or

\begin{verbatim}
PJ_COORD c;
// Assign using the PJ_XYZT struct in the union
c.xyzt.x = 10.0;
c.xyzt.y = 20.0;
c.xyzt.z = 30.0;
c.xyzt.t = 40.0;
\end{verbatim}

Since \textit{PJ_COORD} is a union of structs, the above assignment can also be expressed in terms of the other types in the union, e.g. \textit{PJ_UVWT} or \textit{PJ_LPZT}.

Parameters
• \textbf{x (double)} -- 1st component in a \textit{PJ_COORD}
double proj_roundtrip(PJ *P, PJ_DIRECTION direction, int n, PJCOORD *coord)

Measure internal consistency of a given transformation. The function performs \( n \) round trip transformations starting in either the forward or reverse direction. Returns the euclidean distance of the starting point \( \text{coo} \) and the resulting coordinate after \( n \) iterations back and forth.

If the input coordinate has any NaNs and the expected output of all NaNs is returned then the final distance will be 0.

Changed in version 9.2.0: Define expected NaN distance of 0.

Parameters

- \( P \) (PJ *) -- Transformation object
- \( \text{direction} \) (PJ_DIRECTION) -- Starting direction of transformation
- \( n \) (int) -- Number of roundtrip transformations
- \( \text{coord} \) (PJCOORD *) -- Input coordinate

Returns

double Distance between original coordinate and the resulting coordinate after \( n \) transformation iterations.

PJ_FACTORS proj_factors(PJ *P, PJCOORD lp)

Calculate various cartographic properties, such as scale factors, angular distortion and meridian convergence. Depending on the underlying projection values will be calculated either numerically (default) or analytically.

Starting with PROJ 8.2, the \( P \) object can be a projected CRS, for example instantiated from a EPSG CRS code. The factors computed will be those of the map projection implied by the transformation from the base geographic CRS of the projected CRS to the projected CRS.

The input geodetic coordinate \( \text{lp} \) should be such that \( \text{lp.lam} \) is the longitude in radian, and \( \text{lp.phi} \) the latitude in radian (thus independently of the definition of the base CRS, if \( P \) is a projected CRS).

The function also calculates the partial derivatives of the given coordinate.

Parameters

- \( P \) (PJ *) -- Transformation object
- \( \text{lp} \) (PJCOORD) -- Geodetic coordinate

Returns

PJ_FACTORS

double proj_torad(double angle_in_degrees)

Convert degrees to radians.

Parameters

- \( \text{angle_in_degrees} \) (double) -- Degrees

Returns

double Radians
double `proj_todeg`(double angle_in_radians)

Convert radians to degrees

Parameters

• `angle_in_radians` *(double)* -- Radians

Returns

double Degrees

double `proj_dmstor`(const char *is, char **rs)

Convert string of degrees, minutes and seconds to radians. Works similarly to the C standard library function `strtod()`.

Parameters

• `is` *(const char*)* -- Value to be converted to radians
• `rs` -- Reference to an already allocated char*, whose value is set by the function to the next character in `is` after the numerical value.

char *`proj_rtodms`(char *s, double r, int pos, int neg)

Convert radians to string representation of degrees, minutes and seconds.

Deprecated since version 9.2: Use `proj_rtodms2()` instead.

Parameters

• `s` *(char*)* -- Buffer that holds the output string
• `r` *(double)* -- Value to convert to dms-representation
• `pos` *(int)* -- Character denoting positive direction, typically 'N' or 'E'.
• `neg` *(int)* -- Character denoting negative direction, typically 'S' or 'W'.

Returns

cchar* Pointer to output buffer (same as `s`)

char *`proj_rtodms2`(char *s, size_t sizeof_s, double r, int pos, int neg)

New in version 9.2.0.

Convert radians to string representation of degrees, minutes and seconds.

Parameters

• `s` *(char*)* -- Buffer that holds the output string
• `sizeof_s` *(size_t)* -- Size of s buffer
• `r` *(double)* -- Value to convert to dms-representation
• `pos` *(int)* -- Character denoting positive direction, typically 'N' or 'E'.
• `neg` *(int)* -- Character denoting negative direction, typically 'S' or 'W'.

Returns

cchar* Pointer to output buffer (same as `s`)

int `proj_angular_input`(PJ *P, enum PJ_DIRECTION dir)

Check if an operation expects input in radians or not.

Parameters

• `P` *(PJ*)* -- Transformation object
• `direction` *(PJ_DIRECTION)* -- Starting direction of transformation
Returns

\( \text{int} \ 1 \) if input units is expected in radians, otherwise 0

\textbf{int proj\_angular\_output} (\textit{PJ \*P}, \textit{enum PJ\_DIRECTION dir})

Check if an operation returns output in radians or not.

\textbf{Parameters}

- \( \text{P (PJ \*)} \) -- Transformation object
- \( \text{direction (PJ\_DIRECTION)} \) -- Starting direction of transformation

Returns

\( \text{int} \ 1 \) if output units is expected in radians, otherwise 0

\textbf{int proj\_degree\_input} (\textit{PJ \*P}, \textit{enum PJ\_DIRECTION dir})

New in version 7.1.0.

Check if an operation expects input in degrees or not.

\textbf{Parameters}

- \( \text{P (PJ \*)} \) -- Transformation object
- \( \text{direction (PJ\_DIRECTION)} \) -- Starting direction of transformation

Returns

\( \text{int} \ 1 \) if input units is expected in degrees, otherwise 0

\textbf{int proj\_degree\_output} (\textit{PJ \*P}, \textit{enum PJ\_DIRECTION dir})

New in version 7.1.0.

Check if an operation returns output in degrees or not.

\textbf{Parameters}

- \( \text{P (PJ \*)} \) -- Transformation object
- \( \text{direction (PJ\_DIRECTION)} \) -- Starting direction of transformation

Returns

\( \text{int} \ 1 \) if output units is expected in degrees, otherwise 0

\textbf{10.5.3.11 Setting custom I/O functions}

New in version 7.0.0.

\textbf{int proj\_context\_set\_fileapi} (\textit{PJ\_CONTEXT *ctx}, \textit{const PROJ\_FILE\_API *fileapi}, \textit{void *user\_data})

Set a file API

All callbacks should be provided (non NULL pointers). If read-only usage is intended, then the callbacks might have a dummy implementation.

\textbf{Since}

7.0

\textbf{Note:} Those callbacks will not be used for SQLite3 database access. If custom I/O is desired for that, then \textit{proj\_context\_set\_sqlite3\_vfs\_name()} should be used.
Parameters

• ctx -- PROJ context, or NULL
• fileapi -- Pointer to file API structure (content will be copied).
• user_data -- Arbitrary pointer provided by the user, and passed to the above callbacks. May be NULL.

Returns
TRUE in case of success.

void proj_context_set_sqlite3_vfs_name(PJ_CONTEXT *ctx, const char *name)
Set the name of a custom SQLite3 VFS.
This should be a valid SQLite3 VFS name, such as the one passed to the sqlite3_vfs_register(). See https://www.sqlite.org/vfs.html
It will be used to read proj.db or create&access the cache.db file in the PROJ user writable directory.

Since
7.0

Parameters

• ctx -- PROJ context, or NULL
• name -- SQLite3 VFS name. If NULL is passed, default implementation by SQLite will be used.

void proj_context_set_file_finder(PJ_CONTEXT *ctx, proj_file_finder finder, void *user_data)
Assign a file finder callback to a context.
This callback will be used whenever PROJ must open one of its resource files (proj.db database, grids, etc...)
The callback will be called with the context currently in use at the moment where it is used (not necessarily the one provided during this call), and with the provided user_data (which may be NULL). The user_data must remain valid during the whole lifetime of the context.
A finder set on the default context will be inherited by contexts created later.

Since
PROJ 6.0

Parameters

• ctx -- PROJ context, or NULL for the default context.
• finder -- Finder callback. May be NULL
• user_data -- User data provided to the finder callback. May be NULL.

void proj_context_set_search_paths(PJ_CONTEXT *ctx, int count_paths, const char *const *)
Sets search paths.
Those search paths will be used whenever PROJ must open one of its resource files (proj.db database, grids, etc...)
If set on the default context, they will be inherited by contexts created later.
Starting with PROJ 7.0, the path(s) should be encoded in UTF-8.

Since
PROJ 6.0

Parameters
• ctx -- PROJ context, or NULL for the default context.
• count_paths -- Number of paths. 0 if paths == NULL.
• paths -- Paths. May be NULL.

void proj_context_set_ca_bundle_path(PJ_CONTEXT *ctx, const char *path)
 Sets CA Bundle path.
Those CA Bundle path will be used by PROJ when curl and PROJ_NETWORK are enabled.
If set on the default context, they will be inherited by contexts created later.
The path should be encoded in UTF-8.

Since
PROJ 7.2

Parameters
• ctx -- PROJ context, or NULL for the default context.
• path -- Path. May be NULL.

10.5.3.12 Network related functionality

New in version 7.0.0.

int proj_context_set_network_callbacks(PJ_CONTEXT *ctx, proj_network_open_cbk_type open_cbk,
                                        proj_network_close_cbk_type close_cbk,
                                        proj_network_get_header_value_cbk_type get_header_value_cbk,
                                        proj_network_read_range_type read_range_cbk, void *user_data)

Define a custom set of callbacks for network access.
All callbacks should be provided (non NULL pointers).

Since
7.0

Parameters
• ctx -- PROJ context, or NULL
• open_cbk -- Callback to open a remote file given its URL
• close_cbk -- Callback to close a remote file.
• get_header_value_cbk -- Callback to get HTTP headers
• read_range_cbk -- Callback to read a range of bytes inside a remote file.
• **user_data** -- Arbitrary pointer provided by the user, and passed to the above callbacks. May be NULL.

**Returns**
TRUE in case of success.

```c
int proj_context_set_enable_network(PJ_CONTEXT *ctx, int enabled)
```
Enable or disable network access.
This overrides the default endpoint in the PROJ configuration file or with the PROJ_NETWORK environment variable.

**Since**
7.0

**Parameters**
- **ctx** -- PROJ context, or NULL
- **enable** -- TRUE if network access is allowed.

**Returns**
TRUE if network access is possible. That is either libcurl is available, or an alternate interface has been set.

```c
int proj_context_is_network_enabled(PJ_CONTEXT *ctx)
```
Return if network access is enabled.

**Since**
7.0

**Parameters**
- **ctx** -- PROJ context, or NULL

**Returns**
TRUE if network access has been enabled

```c
void proj_context_set_url_endpoint(PJ_CONTEXT *ctx, const char *url)
```
Define the URL endpoint to query for remote grids.
This overrides the default endpoint in the PROJ configuration file or with the PROJ_NETWORK_ENDPOINT environment variable.

**Since**
7.0

**Parameters**
- **ctx** -- PROJ context, or NULL
- **url** -- Endpoint URL. Must NOT be NULL.
const char *proj_context_get_url_endpoint(PJ_CONTEXT *ctx)
Get the URL endpoint to query for remote grids.

Since
7.1

Parameters
• ctx -- PROJ context, or NULL

Returns
Endpoint URL. The returned pointer would be invalidated by a later call to
proj_context_set_url_endpoint()

const char *proj_context_get_user_writable_directory(PJ_CONTEXT *ctx, int create)
Get the PROJ user writable directory for datumgrid files.

Since
7.1

Parameters
• ctx -- PROJ context, or NULL
• create -- If set to TRUE, create the directory if it does not exist already.

Returns
The path to the PROJ user writable directory.

void proj_grid_cache_set_enable(PJ_CONTEXT *ctx, int enabled)
Enable or disable the local cache of grid chunks
This overrides the setting in the PROJ configuration file.

Since
7.0

Parameters
• ctx -- PROJ context, or NULL
• enabled -- TRUE if the cache is enabled.

void proj_grid_cache_set_filename(PJ_CONTEXT *ctx, const char *fullname)
Override, for the considered context, the path and file of the local cache of grid chunks.

Since
7.0

Parameters
• ctx -- PROJ context, or NULL
• **fullname** -- Full name to the cache (encoded in UTF-8). If set to NULL, caching will be disabled.

void `proj_grid_cache_set_max_size`(`PJ_CONTEXT` *ctx, int max_size_MB)

Override, for the considered context, the maximum size of the local cache of grid chunks.

Since 7.0

Parameters

• ctx -- PROJ context, or NULL
• max_size_MB -- Maximum size, in mega-bytes (1024*1024 bytes), or negative value to set unlimited size.

void `proj_grid_cache_set_ttl`(`PJ_CONTEXT` *ctx, int ttl_seconds)

Override, for the considered context, the time-to-live delay for re-checking if the cached properties of files are still up-to-date.

Since 7.0

Parameters

• ctx -- PROJ context, or NULL
• ttl_seconds -- Delay in seconds. Use negative value for no expiration.

void `proj_grid_cache_clear`(`PJ_CONTEXT` *ctx)

Clear the local cache of grid chunks.

Since 7.0

Parameters

• ctx -- PROJ context, or NULL

int `proj_is_download_needed`(`PJ_CONTEXT` *ctx, const char *url_or_filename, int ignore_ttl_setting)

Return if a file must be downloaded or is already available in the PROJ user-writable directory.

The file will be determined to have to be downloaded if it does not exist yet in the user-writable directory, or if it is determined that a more recent version exists. To determine if a more recent version exists, PROJ will use the "downloaded_file_properties" table of its grid cache database. Consequently files manually placed in the user-writable directory without using this function would be considered as non-existing/obsolete and would be unconditionally downloaded again.

This function can only be used if networking is enabled, and either the default curl network API or a custom one have been installed.

Since 7.0
int proj_download_file(PJ_CONTEXT *ctx, const char *url_or_filename, int ignore_ttl_setting, int (*progress_cbk)(PJ_CONTEXT*, double pct, void *user_data), void *user_data)

Download a file in the PROJ user-writable directory.

The file will only be downloaded if it does not exist yet in the user-writable directory, or if it is determined that a more recent version exists. To determine if a more recent version exists, PROJ will use the "downloaded_file_properties" table of its grid cache database. Consequently files manually placed in the user-writable directory without using this function would be considered as non-existing/obsolete and would be unconditionally downloaded again.

This function can only be used if networking is enabled, and either the default curl network API or a custom one have been installed.

Since

7.0

Parameters

• **ctx** -- PROJ context, or NULL

• **url_or_filename** -- URL or filename (without directory component)

• **ignore_ttl_setting** -- If set to FALSE, PROJ will only check the recentness of an already downloaded file, if the delay between the last time it has been verified and the current time exceeds the TTL setting. This can save network accesses. If set to TRUE, PROJ will unconditionally check from the server the recentness of the file.

Returns

TRUE if the download was successful (or not needed)
10.5.3.13 Cleanup

void proj_cleanup()

    New in version 6.2.0.
    This function frees global resources (grids, cache of +init files). It should be called typically before process termination, and after having freed PJ and PJ_CONTEXT objects.

10.5.3.14 C API for ISO-19111 functionality

New in version 6.0.0.

The PJ* objects returned by proj_create_from_wkt(), proj_create_from_database() and other functions in that section will have generally minimal interaction with the functions declared in the previous sections (calling those functions on those objects will either return an error or default/nonsensical values). The exception is for ISO19111 objects of type CoordinateOperation that can be exported as a valid PROJ pipeline. In this case, objects will work for example with proj_trans_generic(). Conversely, objects returned by proj_create() and proj_create_argv(), which are not of type CRS (can be tested with proj_is_crs()), will return an error when used with functions of this section.

void proj_string_list_destroy(PROJ_STRING_LIST list)

    Free a list of NULL terminated strings.

void proj_context_set_autoclose_database(PJ_CONTEXT *ctx, int autoclose)

    Starting with PROJ 8.1, this function does nothing.
    If you want to take into account changes to the PROJ database, you need to re-create a new context.

Since

    6.2 deprecated Since 8.1

Parameters

    • ctx -- Ignored
    • autoclose -- Ignored

int proj_context_set_database_path(PJ_CONTEXT *ctx, const char *dbPath, const char *const *auxDbPaths, const char *const *options)

    Explicitly point to the main PROJ CRS and coordinate operation definition database ("proj.db"), and potentially auxiliary databases with same structure.
    Starting with PROJ 8.1, if the auxDbPaths parameter is an empty array, the PROJ_AUX_DB environment variable will be used, if set. It must contain one or several paths. If several paths are provided, they must be separated by the colon (:) character on Unix, and on Windows, by the semi-colon (;) character.

Parameters

    • ctx -- PROJ context, or NULL for default context
    • dbPath -- Path to main database, or NULL for default.
    • auxDbPaths -- NULL-terminated list of auxiliary database filenames, or NULL.
    • options -- should be set to NULL for now

Returns

    TRUE in case of success
const char *proj_context_get_database_path(PJ_CONTEXT *ctx)
Returns the path to the database.

The returned pointer remains valid while ctx is valid, and until proj_context_set_database_path() is called.

Parameters
• ctx -- PROJ context, or NULL for default context

Returns
path, or nullptr

const char *proj_context_get_database_metadata(PJ_CONTEXT *ctx, const char *key)
Return a metadata from the database.

The returned pointer remains valid while ctx is valid, and until proj_context_get_database_metadata() is called.

Available keys:

• DATABASE.LAYOUT.VERSION.MAJOR
• DATABASE.LAYOUT.VERSION.MINOR
• EPSG.VERSION
• EPSG.DATE
• ESRI.VERSION
• ESRI.DATE
• IGNF.SOURCE
• IGNF.VERSION
• IGNF.DATE
• NKG.SOURCE
• NKG.VERSION
• NKG.DATE
• PROJ.VERSION
• PROJ_DATA.VERSION : PROJ-data version most compatible with this database.

Parameters
• ctx -- PROJ context, or NULL for default context
• key -- Metadata key. Must not be NULL

Returns
value, or nullptr

PROJ_STRING_LIST proj_context_get_database_structure(PJ_CONTEXT *ctx, const char *const *options)
Return the database structure.

Return SQL statements to run to initiate a new valid auxiliary empty database. It contains definitions of tables, views and triggers, as well as metadata for the version of the layout of the database.
Since 8.1

Parameters
- **ctx** -- PROJ context, or NULL for default context
- **options** -- null-terminated list of options, or NULL. None currently.

Returns
list of SQL statements (to be freed with `proj_string_list_destroy()`), or NULL in case of error.

`PJ_GUESSED_WKT_DIALECT` `proj_context_guess_wkt_dialect(PJ_CONTEXT *ctx, const char *wkt)`
Guess the "dialect" of the WKT string.

Parameters
- **ctx** -- PROJ context, or NULL for default context
- **wkt** -- String (must not be NULL)

`PJ *proj_create_from_wkt(PJ_CONTEXT *ctx, const char *wkt, const char *const *options, PROJ_STRING_LIST *out_warnings, PROJ_STRING_LIST *out_grammar_errors)`
Instantiate an object from a WKT string.

This function calls `osgeo::proj::io::WKTParser::createFromWKT()`
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
- **ctx** -- PROJ context, or NULL for default context
- **wkt** -- WKT string (must not be NULL)
- **options** -- null-terminated list of options, or NULL. Currently supported options are:
  - STRICT=YES/NO. Defaults to NO. When set to YES, strict validation will be enabled.
  - UNSET_IDENTIFIERS_IF_INCOMPATIBLE_DEF=YES/NO. Defaults to YES. When set to YES, object identifiers are unset when there is a contradiction between the definition from WKT and the one from the database./
- **out_warnings** -- Pointer to a PROJ_STRING_LIST object, or NULL. If provided, *out_warnings will contain a list of warnings, typically for non recognized projection method or parameters. It must be freed with `proj_string_list_destroy()`.
- **out_grammar_errors** -- Pointer to a PROJ_STRING_LIST object, or NULL. If provided, *out_grammar_errors will contain a list of errors regarding the WKT grammar. It must be freed with `proj_string_list_destroy()`.

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

`PJ *proj_create_from_database(PJ_CONTEXT *ctx, const char *auth_name, const char *code, PJ_CATEGORY category, int usePROJAlternativeGridNames, const char *const *options)`
Instantiate an object from a database lookup.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.
Parameters

- **ctx** -- Context, or NULL for default context.
- **auth_name** -- Authority name (must not be NULL)
- **code** -- Object code (must not be NULL)
- **category** -- Object category
- **usePROJAlternativeGridNames** -- Whether PROJ alternative grid names should be substituted to the official grid names. Only used on transformations
- **options** -- should be set to NULL for now

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

```c
int proj_uom_get_info_from_database(PJ_CONTEXT *ctx, const char *auth_name, const char *code, const char **out_name, double *out_conv_factor, const char **out_category)
```

Get information for a unit of measure from a database lookup.

Parameters

- **ctx** -- Context, or NULL for default context.
- **auth_name** -- Authority name (must not be NULL)
- **code** -- Unit of measure code (must not be NULL)
- **out_name** -- Pointer to a string value to store the parameter name. or NULL. This value remains valid until the next call to proj_uom_get_info_from_database() or the context destruction.
- **out_conv_factor** -- Pointer to a value to store the conversion factor of the prime meridian longitude unit to radian. or NULL
- **out_category** -- Pointer to a string value to store the parameter name. or NULL. This value might be "unknown", "none", "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time", "time", "parametric" or "parametric_per_time"

Returns

TRUE in case of success

```c
int proj_grid_get_info_from_database(PJ_CONTEXT *ctx, const char *grid_name, const char **out_full_name, const char **out_package_name, const char **out_url, int *out_direct_download, int *out_open_license, int *out_available)
```

Get information for a grid from a database lookup.

Parameters

- **ctx** -- Context, or NULL for default context.
- **grid_name** -- Grid name (must not be NULL)
- **out_full_name** -- Pointer to a string value to store the grid full filename. or NULL
- **out_package_name** -- Pointer to a string value to store the package name where the grid might be found. or NULL
- **out_url** -- Pointer to a string value to store the grid URL or the package URL where the grid might be found. or NULL
- **out_direct_download** -- Pointer to a int (boolean) value to store whether *out_url can be downloaded directly. or NULL
- **out_open_license** -- Pointer to a int (boolean) value to store whether the grid is released with an open license. or NULL
- **out_available** -- Pointer to a int (boolean) value to store whether the grid is available at runtime. or NULL

**Returns**
TRUE in case of success.

```c
PJ *proj_clone(PJ_CONTEXT *ctx, const PJ *obj)
```

"Clone" an object.

The object might be used independently of the original object, provided that the use of context is compatible. In particular if you intend to use a clone in a different thread than the original object, you should pass a context that is different from the one of the original object (or later assign a different context with proj_assign_context()).

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

**Parameters**
- **ctx** -- PROJ context, or NULL for default context
- **obj** -- Object to clone. Must not be NULL.

**Returns**
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

```c
PJ_OBJ_LIST *proj_create_from_name(PJ_CONTEXT *ctx, const char *auth_name, const char *searchedName, const PJ_TYPE *types, size_t typesCount, int approximateMatch, size_t limitResultCount, const char *const *options)
```

Return a list of objects by their name.

**Parameters**
- **ctx** -- Context, or NULL for default context.
- **auth_name** -- Authority name, used to restrict the search. Or NULL for all authorities.
- **searchedName** -- Searched name. Must be at least 2 character long.
- **types** -- List of object types into which to search. If NULL, all object types will be searched.
- **typesCount** -- Number of elements in types, or 0 if types is NULL
- **approximateMatch** -- Whether approximate name identification is allowed.
- **limitResultCount** -- Maximum number of results to return. Or 0 for unlimited.
- **options** -- should be set to NULL for now

**Returns**
a result set that must be unreferenced with proj_list_destroy(), or NULL in case of error.

```c
PJ_TYPE proj_get_type(const PJ *obj)
```

Return the type of an object.

**Parameters**
- **obj** -- Object (must not be NULL)

**Returns**
its type.
int proj_is_deprecated(const PJ *obj)
   Return whether an object is deprecated.

Parameters
   • obj -- Object (must not be NULL)

Returns
   TRUE if it is deprecated, FALSE otherwise

PJ_OBJ_LIST *proj_get_non_deprecated(PJ_CONTEXT *ctx, const PJ *obj)
   Return a list of non-deprecated objects related to the passed one.

Parameters
   • ctx -- Context, or NULL for default context.
   • obj -- Object (of type CRS for now) for which non-deprecated objects must be searched. Must not be NULL.

Returns
   a result set that must be unreferenced with proj_list_destroy(), or NULL in case of error.

int proj_is_equivalent_to(const PJ *obj, const PJ *other, PJ_COMPARISON_CRITERION criterion)
   Return whether two objects are equivalent.

Use proj_is_equivalent_to_with_ctx() to be able to use database information.

Parameters
   • obj -- Object (must not be NULL)
   • other -- Other object (must not be NULL)
   • criterion -- Comparison criterion

Returns
   TRUE if they are equivalent

int proj_is_equivalent_to_with_ctx(PJ_CONTEXT *ctx, const PJ *obj, const PJ *other,
   PJ_COMPARISON_CRITERION criterion)
   Return whether two objects are equivalent.

Possibly using database to check for name aliases.

Since 6.3

Parameters
   • ctx -- PROJ context, or NULL for default context
   • obj -- Object (must not be NULL)
   • other -- Other object (must not be NULL)
   • criterion -- Comparison criterion

Returns
   TRUE if they are equivalent
int proj_is_crs(const PJ *obj)
   Return whether an object is a CRS.
   Parameters
   • obj -- Object (must not be NULL)

const char *proj_get_name(const PJ *obj)
   Get the name of an object.
   The lifetime of the returned string is the same as the input obj parameter.
   Parameters
   • obj -- Object (must not be NULL)
   Returns
   a string, or NULL in case of error or missing name.

const char *proj_get_id_auth_name(const PJ *obj, int index)
   Get the authority name / codespace of an identifier of an object.
   The lifetime of the returned string is the same as the input obj parameter.
   Parameters
   • obj -- Object (must not be NULL)
   • index -- Index of the identifier. 0 = first identifier
   Returns
   a string, or NULL in case of error or missing name.

const char *proj_get_id_code(const PJ *obj, int index)
   Get the code of an identifier of an object.
   The lifetime of the returned string is the same as the input obj parameter.
   Parameters
   • obj -- Object (must not be NULL)
   • index -- Index of the identifier. 0 = first identifier
   Returns
   a string, or NULL in case of error or missing name.

const char *proj_get_remarks(const PJ *obj)
   Get the remarks of an object.
   The lifetime of the returned string is the same as the input obj parameter.
   Parameters
   • obj -- Object (must not be NULL)
   Returns
   a string, or NULL in case of error.

int proj_get_domain_count(const PJ *obj)
   Get the number of domains/usages for a given object.
   Most objects have a single domain/usage, but for some of them, there might be multiple.
Since 9.2

Parameters
- obj -- Object (must not be NULL)

Returns
the number of domains, or 0 in case of error.

const char *proj_get_scope(const PJ *obj)
Get the scope of an object.
In case of multiple usages, this will be the one of first usage.
The lifetime of the returned string is the same as the input obj parameter.

Parameters
- obj -- Object (must not be NULL)

Returns
a string, or NULL in case of error or missing scope.

const char *proj_get_scope_ex(const PJ *obj, int domainIdx)
Get the scope of an object.
The lifetime of the returned string is the same as the input obj parameter.

Since 9.2

Parameters
- obj -- Object (must not be NULL)
- domainIdx -- Index of the domain/usage. In [0,proj_get_domain_count(obj)]

Returns
a string, or NULL in case of error or missing scope.

int proj_get_area_of_use(PJ_CONTEXT *ctx, const PJ *obj, double *out_west_lon_degree, double
 *out_south_lat_degree, double *out_east_lon_degree, double *out_north_lat_degree,
 const char **out_area_name)
Return the area of use of an object.
In case of multiple usages, this will be the one of first usage.

Parameters
- ctx -- PROJ context, or NULL for default context
- obj -- Object (must not be NULL)
- out_west_lon_degree -- Pointer to a double to receive the west longitude (in degrees). Or
  NULL. If the returned value is -1000, the bounding box is unknown.
- out_south_lat_degree -- Pointer to a double to receive the south latitude (in degrees).
  Or NULL. If the returned value is -1000, the bounding box is unknown.
- out_east_lon_degree -- Pointer to a double to receive the east longitude (in degrees). Or
  NULL. If the returned value is -1000, the bounding box is unknown.
• **out_north_lat_degree** -- Pointer to a double to receive the north latitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.

• **out_area_name** -- Pointer to a string to receive the name of the area of use. Or NULL. *p_area_name is valid while obj is valid itself.

**Returns**
TRUE in case of success, FALSE in case of error or if the area of use is unknown.

```c
int proj_get_area_of_use_ex(PJ_CONTEXT *ctx, const PJ *obj, int domainIdx, double *out_west_lon_degree, double *out_south_lat_degree, double *out_east_lon_degree, double *out_north_lat_degree, const char **out_area_name)
```

Return the area of use of an object.

In case of multiple usages, this will be the one of first usage.

**Parameters**
- **ctx** -- PROJ context, or NULL for default context
- **obj** -- Object (must not be NULL)
- **domainIdx** -- Index of the domain/usage. In [0,proj_get_domain_count(obj)]
- **out_west_lon_degree** -- Pointer to a double to receive the west longitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_south_lat_degree** -- Pointer to a double to receive the south latitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_east_lon_degree** -- Pointer to a double to receive the east longitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_north_lat_degree** -- Pointer to a double to receive the north latitude (in degrees). Or NULL. If the returned value is -1000, the bounding box is unknown.
- **out_area_name** -- Pointer to a string to receive the name of the area of use. Or NULL. *p_area_name is valid while obj is valid itself.

**Returns**
TRUE in case of success, FALSE in case of error or if the area of use is unknown.

```c
const char *proj_as_wkt(PJ_CONTEXT *ctx, const PJ *obj, PJ_WKT_TYPE type, const char *const *options)
```

Get a WKT representation of an object.

The returned string is valid while the input obj parameter is valid, and until a next call to `proj_as_wkt()` with the same input object.

This function calls `osgeo::proj::io::IWKTExportable::exportToWKT()`.

This function may return NULL if the object is not compatible with an export to the requested type.

**Parameters**
- **ctx** -- PROJ context, or NULL for default context
- **obj** -- Object (must not be NULL)
- **type** -- WKT version.
- **options** -- null-terminated list of options, or NULL. Currently supported options are:
  - MULTILINE=YES/NO. Defaults to YES, except for WKT1_ESRI
  - INDENTATION_WIDTH=number. Defaults to 4 (when multiline output is on).
– OUTPUT_AXIS=AUTO/YES/NO. In AUTO mode, axis will be output for WKT2 variants, for WKT1_GDAL for ProjectedCRS with easting/northing ordering (otherwise stripped), but not for WKT1_ESRI. Setting to YES will output them unconditionally, and to NO will omit them unconditionally.

– STRICT=YES/NO. Default is YES. If NO, a Geographic 3D CRS can be for example exported as WKT1_GDAL with 3 axes, whereas this is normally not allowed.

– ALLOW_ELLIPSOIDAL_HEIGHT_AS_VERTICAL_CRS=YES/NO. Default is NO. If set to YES and type == PJ_WKT1_GDAL, a Geographic 3D CRS or a Projected 3D CRS will be exported as a compound CRS whose vertical part represents an ellipsoidal height (for example for use with LAS 1.4 WKT1).

– ALLOW_LINUNIT_NODE=YES/NO. Default is YES starting with PROJ 9.1. Only taken into account with type == PJ_WKT1_ESRI on a Geographic 3D CRS.

Returns

a string, or NULL in case of error.

const char *proj_as_proj_string(PJ_CONTEXT *ctx, const PJ *obj, PJ_PROJ_STRING_TYPE type, const char *const *options)

Get a PROJ string representation of an object.

The returned string is valid while the input obj parameter is valid, and until a next call to proj_as_proj_string() with the same input object.

This function calls osgeo::proj::io::IPROJStringExportable::exportToPROJString().

This function may return NULL if the object is not compatible with an export to the requested type.

Warning: If a CRS object was not created from a PROJ string, exporting to a PROJ string will in most cases cause a loss of information. This can potentially lead to erroneous transformations.

Parameters

• ctx -- PROJ context, or NULL for default context
• obj -- Object (must not be NULL)
• type -- PROJ String version.
• options -- NULL-terminated list of strings with "KEY=VALUE" format. or NULL. Currently supported options are:
  – USE_APPROX_TMERC=YES to add the +approx flag to +proj=tmerc or +proj=utm.
  – MULTILINE=YES/NO. Defaults to NO
  – INDENTATION_WIDTH=number. Defaults to 2 (when multiline output is on).
  – MAX_LINE_LENGTH=number. Defaults to 80 (when multiline output is on).

Returns

a string, or NULL in case of error.

const char *proj_as_projjson(PJ_CONTEXT *ctx, const PJ *obj, const char *const *options)

Get a PROJJSON string representation of an object.
The returned string is valid while the input obj parameter is valid, and until a next call to `proj_as_proj_string()` with the same input object.

This function calls `osgeo::proj::io::IJSONExportable::exportToJSON()`.

This function may return NULL if the object is not compatible with an export to the requested type.

Since
6.2

Parameters

- `ctx` -- PROJ context, or NULL for default context
- `obj` -- Object (must not be NULL)
- `options` -- NULL-terminated list of strings with "KEY=VALUE" format. or NULL. Currently supported options are:
  - MULTILINE=YES/NO. Defaults to YES
  - INDENTATION_WIDTH=number. Defaults to 2 (when multiline output is on).
  - SCHEMA=string. URL to PROJJSON schema. Can be set to empty string to disable it.

Returns

a string, or NULL in case of error.

`PJ *proj_get_source_crs(PJ_CONTEXT *ctx, const PJ *obj)`

Return the base CRS of a BoundCRS or a DerivedCRS/ProjectedCRS, or the source CRS of a CoordinateOperation, or the CRS of a CoordinateMetadata.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- `ctx` -- PROJ context, or NULL for default context
- `obj` -- Object of type BoundCRS or CoordinateOperation (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error, or missing source CRS.

`PJ *proj_get_target_crs(PJ_CONTEXT *ctx, const PJ *obj)`

Return the hub CRS of a BoundCRS or the target CRS of a CoordinateOperation.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- `ctx` -- PROJ context, or NULL for default context
- `obj` -- Object of type BoundCRS or CoordinateOperation (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error, or missing target CRS.
PJ_OBJ_LIST *proj_identify(PJ_CONTEXT *ctx, const PJ *obj, const char *auth_name, const char *const *options, int **out_confidence)

Identify the CRS with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when it is available.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference CRS, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

- 100% means that the name of the reference entry perfectly matches the CRS name, and both are equivalent. In which case a single result is returned. Note: in the case of a GeodeticCRS whose axis order is implicit in the input definition (for example ESRI WKT), then axis order is ignored for the purpose of identification. That is the CRS built from GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]] will be identified to EPSG:4326, but will not pass a isEquivalentTo(EPSG_4326,util::IComparable::Criterion::EQUIVALENT) test, but rather isEquivalentTo(EPSG_4326,util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS)
- 90% means that CRS are equivalent, but the names are not exactly the same.
- 70% means that CRS are equivalent, but the names are not equivalent.
- 25% means that the CRS are not equivalent, but there is some similarity in the names.

Other confidence values may be returned by some specialized implementations.

This is implemented for GeodeticCRS, ProjectedCRS, VerticalCRS and CompoundCRS.

Parameters
- ctx -- PROJ context, or NULL for default context
- obj -- Object of type CRS. Must not be NULL
- auth_name -- Authority name, or NULL for all authorities
- options -- Placeholder for future options. Should be set to NULL.
- out_confidence -- Output parameter. Pointer to an array of integers that will be allocated by the function and filled with the confidence values (0-100). There are as many elements in this array as proj_list_get_count() returns on the return value of this function. *confidence should be released with proj_int_list_destroy().

Returns
- a list of matching reference CRS, or nullptr in case of error.

PROJ_STRING_LIST proj_get_geoid_models_from_database(PJ_CONTEXT *ctx, const char *auth_name, const char *code, const char *const *options)

Returns a list of geoid models available for that crs.

The list includes the geoid models connected directly with the crs, or via "Height Depth Reversal" or "Change of Vertical Unit" transformations. The returned list is NULL terminated and must be freed with proj_string_list_destroy().

Since
- 8.1
Parameters

- `ctx` -- Context, or NULL for default context.
- `auth_name` -- Authority name (must not be NULL)
- `code` -- Object code (must not be NULL)
- `options` -- should be set to NULL for now

Returns

list of geoid models names (to be freed with `proj_string_list_destroy()`), or NULL in case of error.

```c
void proj_int_list_destroy(int *list)
```
Free an array of integer.

```c
PROJ_STRING_LIST proj_get_authorities_from_database(PJ_CONTEXT *ctx)
```
Return the list of authorities used in the database.
The returned list is NULL terminated and must be freed with `proj_string_list_destroy()`.

Parameters

- `ctx` -- PROJ context, or NULL for default context

Returns

a NULL terminated list of NUL-terminated strings that must be freed with `proj_string_list_destroy()`, or NULL in case of error.

```c
PROJ_STRING_LIST proj_get_codes_from_database(PJ_CONTEXT *ctx, const char *auth_name, PJ_TYPE type, int allow_deprecated)
```
Returns the set of authority codes of the given object type.
The returned list is NULL terminated and must be freed with `proj_string_list_destroy()`.

See also:

`proj_get_crs_info_list_from_database()`

```c
PROJ_CELESTIAL_BODY_INFO **proj_get_celestial_body_list_from_database(PJ_CONTEXT *ctx, const char *auth_name, int *out_result_count)
```
Enumerate celestial bodies from the database.
The returned object is an array of `PROJ_CELESTIAL_BODY_INFO` pointers, whose last entry is NULL. This array should be freed with `proj_celestial_body_list_destroy()`
Since 8.1

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **auth_name** -- Authority name, used to restrict the search. Or NULL for all authorities.
- **out_result_count** -- Output parameter pointing to an integer to receive the size of the result list. Might be NULL

Returns

an array of PROJ_CELESTIAL_BODY_INFO* pointers to be freed with proj_celestial_body_list_destroy(), or NULL in case of error.

void proj_celestial_body_list_destroy(PROJ_CELESTIAL_BODY_INFO **list)

Destroy the result returned by proj_get_celestial_body_list_from_database().

Since 8.1

PROJ_CRS_LIST_PARAMETERS *proj_get_crs_list_parameters_create(void)

Instantiate a default set of parameters to be used by proj_get_crs_list().

Returns

a new object to free with proj_get_crs_list_parameters_destroy()

void proj_get_crs_list_parameters_destroy(PROJ_CRS_LIST_PARAMETERS *params)

Destroy an object returned by proj_get_crs_list_parameters_create()

PROJ_CRS_INFO **proj_get_crs_info_list_from_database(PJ_CONTEXT *ctx, const char *auth_name, const PROJ_CRS_LIST_PARAMETERS *params, int *out_result_count)

Enumerate CRS objects from the database, taking into account various criteria.

The returned object is an array of PROJ_CRS_INFO* pointers, whose last entry is NULL. This array should be freed with proj_crs_info_list_destroy()

When no filter parameters are set, this is functionally equivalent to proj_get_codes_from_database(), instantiating a PJ* object for each of the codes with proj_create_from_database() and retrieving information with the various getters. However this function will be much faster.

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **auth_name** -- Authority name, used to restrict the search. Or NULL for all authorities.
- **params** -- Additional criteria, or NULL. If not-NULL, params SHOULD have been allocated by proj_get_crs_list_parameters_create(), as the PROJ_CRS_LIST_PARAMETERS structure might grow over time.
- **out_result_count** -- Output parameter pointing to an integer to receive the size of the result list. Might be NULL

Returns

an array of PROJ_CRS_INFO* pointers to be freed with proj_crs_info_list_destroy(), or NULL in case of error.
void proj_crs_info_list_destroy(PROJ_CRS_INFO **list)
    Destroy the result returned by proj_get_crs_info_list_from_database().

PROJ_UNIT_INFO **proj_get_units_from_database(PJ_CONTEXT *ctx, const char *auth_name, const char *category, int allow_deprecated, int *out_result_count)

Enumerate units from the database, taking into account various criteria.
The returned object is an array of PROJ_UNIT_INFO* pointers, whose last entry is NULL. This array should be freed with proj_unit_list_destroy().

Since
    7.1

Parameters
    • ctx -- PROJ context, or NULL for default context
    • auth_name -- Authority name, used to restrict the search. Or NULL for all authorities.
    • category -- Filter by category, if this parameter is not NULL. Category is one of "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time" or "time"
    • allow_deprecated -- whether we should return deprecated objects as well.
    • out_result_count -- Output parameter pointing to an integer to receive the size of the result list. Might be NULL

Returns
    an array of PROJ_UNIT_INFO* pointers to be freed with proj_unit_list_destroy(), or NULL in case of error.

void proj_unit_list_destroy(PROJ_UNIT_INFO **list)
    Destroy the result returned by proj_get_units_from_database().

Since
    7.1

PJ_INSERT_SESSION *proj_insert_object_session_create(PJ_CONTEXT *ctx)
    Starts a session for proj_get_insert_statements()
    Starts a new session for one or several calls to proj_get_insert_statements().
    An insertion session guarantees that the inserted objects will not create conflicting intermediate objects.
    The session must be stopped with proj_insert_object_session_destroy().
    Only one session may be active at a time for a given context.

Since
    8.1

Parameters
    • ctx -- PROJ context, or NULL for default context

Returns
    the session, or NULL in case of error.
void **proj_insert_object_session_destroy** (*ctx*, *PJ_INSERT_SESSION* *session*)

Stops an insertion session started with **proj_insert_object_session_create**()

Since

8.1

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **session** -- The insertion session.

**PROJ_STRING_LIST** **proj_get_insert_statements** (*ctx*, *PJ_INSERT_SESSION* *session*,
const *PJ* *object*, const char *authority*, const char *code*,
int numeric_codes, const char *const *allowed_authorities*,
const char *const *options*)

Returns SQL statements needed to insert the passed object into the database.

**proj_insert_object_session_create**() may have been called previously.

It is strongly recommended that new objects should not be added in common registries, such as "EPSG", "ESRI", "IAU", etc. Users should use a custom authority name instead. If a new object should be added to the official EPSG registry, users are invited to follow the procedure explained at https://epsg.org/dataset-change-requests.html.

Combined with **proj_context_get_database_structure**(), users can create auxiliary databases, instead of directly modifying the main proj.db database. Those auxiliary databases can be specified through **proj_context_set_database_path**() or the PROJ_AUX_DB environment variable.

Since

8.1

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **session** -- The insertion session. May be NULL if a single object must be inserted.
- **object** -- The object to insert into the database. Currently only PrimeMeridian, Ellipsoid, Datum, GeodeticCRS, ProjectedCRS, VerticalCRS, CompoundCRS or BoundCRS are supported.
- **authority** -- Authority name into which the object will be inserted. Must not be NULL.
- **code** -- Code with which the object will be inserted. Must not be NULL.
- **numeric_codes** -- Whether intermediate objects that can be created should use numeric codes (true), or may be alphanumeric (false)
- **allowedAuthorities** -- NULL terminated list of authority names, or NULL. Authorities to which intermediate objects are allowed to refer to. "authority" will be implicitly added to it. Note that unit, coordinate systems, projection methods and parameters will in any case be allowed to refer to EPSG. If NULL, allowedAuthorities defaults to { "EPSG", "PROJ", nullptr }
- **options** -- NULL terminated list of options, or NULL. No options are supported currently.
Returns

a list of insert statements (to be freed with \texttt{proj_string_list_destroy}), or NULL in case of error.

\textbf{char *proj_suggests_code_for} (\texttt{PJ_CONTEXT *ctx, const PJ *object, const char *authority, int numeric_code, const char *const *options})

Suggests a database code for the passed object.

Supported type of objects are PrimeMeridian, Ellipsoid, Datum, DatumEnsemble, GeodeticCRS, ProjectedCRS, VerticalCRS, CompoundCRS, BoundCRS, Conversion.

Since

8.1

Parameters

\begin{itemize}
  \item \texttt{ctx} -- PROJ context, or NULL for default context
  \item \texttt{object} -- Object for which to suggest a code.
  \item \texttt{authority} -- Authority name into which the object will be inserted.
  \item \texttt{numeric_code} -- Whether the code should be numeric, or derived from the object name.
  \item \texttt{options} -- NULL terminated list of options, or NULL. No options are supported currently.
\end{itemize}

Returns

the suggested code, that is guaranteed to not conflict with an existing one (to be freed with \texttt{proj_string_destroy}), or nullptr in case of error.

\textbf{void proj_string_destroy} (char *str)

Free a string.

Only to be used with functions that document using this function.

Since

8.1

Parameters

\begin{itemize}
  \item \texttt{str} -- String to free.
\end{itemize}

\textbf{PJ_OPERATION_FACTORY_CONTEXT *proj_create_operation_factory_context} (\texttt{PJ_CONTEXT *ctx, const char *authority})

Instantiate a context for building coordinate operations between two CRS.

The returned object must be unreferenced with \texttt{proj_operation_factory_context_destroy()} after use.

If authority is NULL or the empty string, then coordinate operations from any authority will be searched, with the restrictions set in the authority_to_authority_preference database table. If authority is set to "any", then coordinate operations from any authority will be searched If authority is a non-empty string different of "any", then coordinate operations will be searched only in that authority namespace.

Parameters

\begin{itemize}
  \item \texttt{ctx} -- Context, or NULL for default context.
  \item \texttt{authority} -- Name of authority to which to restrict the search of candidate operations.
\end{itemize}
Returns
Object that must be unreferenced with `proj_operation_factory_context_destroy()`, or NULL in case of error.

```c
void proj_operation_factory_context_destroy(PJ_OPERATION_FACTORY_CONTEXT *ctx)
```

Drops a reference on an object.

This method should be called one and exactly one for each function returning a `PJ_OPERATION_FACTORY_CONTEXT`.

Parameters
- `ctx` -- Object, or NULL.

```c
void proj_operation_factory_context_set_desired_accuracy(PJ_CONTEXT *ctx,
                                                      PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                                                      double accuracy)
```

Set the desired accuracy of the resulting coordinate transformations.

Parameters
- `ctx` -- PROJ context, or NULL for default context
- `factory_ctx` -- Operation factory context. must not be NULL
- `accuracy` -- Accuracy in meter (or 0 to disable the filter).

```c
void proj_operation_factory_context_set_area_of_interest(PJ_CONTEXT *ctx,
                                                       PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                                                       double west_lon_degree,
                                                       double south_lat_degree,
                                                       double east_lon_degree,
                                                       double north_lat_degree)
```

Set the desired area of interest for the resulting coordinate transformations.

For an area of interest crossing the anti-meridian, `west_lon_degree` will be greater than `east_lon_degree`.

Parameters
- `ctx` -- PROJ context, or NULL for default context
- `factory_ctx` -- Operation factory context. must not be NULL
- `west_lon_degree` -- West longitude (in degrees).
- `south_lat_degree` -- South latitude (in degrees).
- `east_lon_degree` -- East longitude (in degrees).
- `north_lat_degree` -- North latitude (in degrees).

```c
void proj_operation_factory_context_set_area_of_interest_name(PJ_CONTEXT *ctx,
                                                             PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                                                             const char *area_name)
```

Set the name of the desired area of interest for the resulting coordinate transformations.

Parameters
- `ctx` -- PROJ context, or NULL for default context
- `factory_ctx` -- Operation factory context. must not be NULL
- `area_name` -- Area name. Must be known of the database.
void **proj_operation_factory_context_set_crs_extent_use** (*ctx*,
   *factory_ctx*, *PROJ_CRS_EXTENT_USE*
   use)

Set how source and target CRS extent should be used when considering if a transformation can be used (only takes effect if no area of interest is explicitly defined).

The default is PJ_CRS_EXTENT_SMALLEST.

**Parameters**
- *ctx* -- PROJ context, or NULL for default context
- *factory_ctx* -- Operation factory context. must not be NULL
- *use* -- How source and target CRS extent should be used.

void **proj_operation_factory_context_set_spatial_criterion** (*ctx*,
   *factory_ctx*, *PROJ_SPATIAL_CRITERION*
   criterion)

Set the spatial criterion to use when comparing the area of validity of coordinate operations with the area of interest / area of validity of source and target CRS.

The default is PROJ_SPATIAL_CRITERION STRICT_CONTAINMENT.

**Parameters**
- *ctx* -- PROJ context, or NULL for default context
- *factory_ctx* -- Operation factory context. must not be NULL
- *criterion* -- spatial criterion to use

void **proj_operation_factory_context_set_grid_availability_use** (*ctx*,
   *factory_ctx*, *PROJ_GRID_AVAILABILITY_USE*
   use)

Set how grid availability is used.

The default is USE FOR SORTING.

**Parameters**
- *ctx* -- PROJ context, or NULL for default context
- *factory_ctx* -- Operation factory context. must not be NULL
- *use* -- how grid availability is used.

void **proj_operation_factory_context_set_use_proj_alternative_grid_names** (*ctx*,
   *factory_ctx*, int usePROJNames)

Set whether PROJ alternative grid names should be substituted to the official authority names.

The default is true.

**Parameters**
- *ctx* -- PROJ context, or NULL for default context
- *factory_ctx* -- Operation factory context. must not be NULL
• **usePROJNames** -- whether PROJ alternative grid names should be used

```c
void proj_operation_factory_context_set_allow_use_intermediate_crs(PJ_CONTEXT *ctx,
                    PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                    PROJ_INTERMEDIATE_CRS_USE use)
```

Set whether an intermediate pivot CRS can be used for researching coordinate operations between a source and target CRS.

Concretely if in the database there is an operation from A to C (or C to A), and another one from C to B (or B to C), but no direct operation between A and B, setting this parameter to true, allow chaining both operations.

The current implementation is limited to researching one intermediate step.

By default, with the IF_NO_DIRECT_TRANSFORMATION strategy, all potential C candidates will be used if there is no direct transformation.

**Parameters**
- **ctx** -- PROJ context, or NULL for default context
- **factory_ctx** -- Operation factory context. must not be NULL
- **use** -- whether and how intermediate CRS may be used.

```c
void proj_operation_factory_context_set_allowed_intermediate_crs(PJ_CONTEXT *ctx,
                                                              PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                                                              const char *const *list_of_auth_name_codes)
```

Restrict the potential pivot CRSs that can be used when trying to build a coordinate operation between two CRS that have no direct operation.

**Parameters**
- **ctx** -- PROJ context, or NULL for default context
- **factory_ctx** -- Operation factory context. must not be NULL
- **list_of_auth_name_codes** -- an array of strings NLL terminated, with the format { "auth_name1", "code1", "auth_name2", "code2", ... NULL }

```c
void proj_operation_factory_context_set_discard_superseded(PJ_CONTEXT *ctx,
                                                          PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                                                          int discard)
```

Set whether transformations that are superseded (but not deprecated) should be discarded.

**Parameters**
- **ctx** -- PROJ context, or NULL for default context
- **factory_ctx** -- Operation factory context. must not be NULL
- **discard** -- superseded crs or not

```c
void proj_operation_factory_context_set_allow_ballpark_transformations(PJ_CONTEXT *ctx,
                                                                     PJ_OPERATION_FACTORY_CONTEXT *factory_ctx,
                                                                     int allow)
```

Set whether ballpark transformations are allowed.
Since 7.1

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **factory_ctx** -- Operation factory context. must not be NULL
- **allow** -- set to TRUE to allow ballpark transformations.

PJ_OBJ_LIST *proj_create_operations(PJ_CONTEXT *ctx, const PJ *source_crs, const PJ *target_crs, const PJ_OPERATION_FACTORY_CONTEXT *operationContext)

Find a list of CoordinateOperation from source_crs to target_crs.

The operations are sorted with the most relevant ones first: by descending area (intersection of the transformation area with the area of interest, or intersection of the transformation with the area of use of the CRS), and by increasing accuracy. Operations with unknown accuracy are sorted last, whatever their area.

Starting with PROJ 9.1, vertical transformations are only done if both source CRS and target CRS are 3D CRS or Compound CRS with a vertical component. You may need to use proj_crs_promote_to_3D().

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **source_crs** -- source CRS. Must not be NULL.
- **target_crs** -- source CRS. Must not be NULL.
- **operationContext** -- Search context. Must not be NULL.

Returns

a result set that must be unreferenced with proj_list_destroy(), or NULL in case of error.

int proj_list_get_count(const PJ_OBJ_LIST *result)

Return the number of objects in the result set.

Parameters

- **result** -- Object of type PJ_OBJ_LIST (must not be NULL)

PJ *proj_list_get(PJ_CONTEXT *ctx, const PJ_OBJ_LIST *result, int index)

Return an object from the result set.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

- **ctx** -- PROJ context, or NULL for default context
- **result** -- Object of type PJ_OBJ_LIST (must not be NULL)
- **index** -- Index

Returns

a new object that must be unreferenced with proj_destroy(), or nullptr in case of error.

void proj_list_destroy(PJ_OBJ_LIST *result)

Drops a reference on the result set.

This method should be called one and exactly one for each function returning a PJ_OBJ_LIST*

Parameters
**proj_get_suggested_operation** *(PJ_CONTEXT *ctx, PJ_OBJ_LIST *operations, PJ_DIRECTION direction, PJ_COORD coord)*

Return the index of the operation that would be the most appropriate to transform the specified coordinates. This operation may use resources that are not locally available, depending on the search criteria used by *proj_create_operations().*

This could be done by using *proj_create_operations()* with a punctual bounding box, but this function is faster when one needs to evaluate on many points with the same (source_crs, target_crs) tuple.

Since

7.1

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **operations** -- List of operations returned by *proj_create_operations()*
- **direction** -- Direction into which to transform the point.
- **coord** -- Coordinate to transform

**Returns**

The index in operations that would be used to transform coord. Or -1 in case of error, or no match.

**proj_crs_is_derived** *(PJ_CONTEXT *ctx, const PJ *crs)*

Returns whether a CRS is a derived CRS.

Since

8.0

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **crs** -- Object of type CRS (must not be NULL)

**Returns**

TRUE if the CRS is a derived CRS.

**proj_crs_get_geodetic_crs** *(PJ_CONTEXT *ctx, const PJ *crs)*

Get the geodetic CRS / geographic CRS from a CRS.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **crs** -- Object of type CRS (must not be NULL)

**Returns**

Object that must be unreferenced with proj_destroy(), or NULL in case of error.
PJ *proj_crs_get_horizontal_datum*(PJ_CONTEXT *ctx, const PJ *crs)
Get the horizontal datum from a CRS.

This function may return a Datum or DatumEnsemble object.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
- **ctx** -- PROJ context, or NULL for default context
- **crs** -- Object of type CRS (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ *proj_crs_get_sub_crs*(PJ_CONTEXT *ctx, const PJ *crs, int index)
Get a CRS component from a CompoundCRS.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
- **ctx** -- PROJ context, or NULL for default context
- **crs** -- Object of type CRS (must not be NULL)
- **index** -- Index of the CRS component (typically 0 = horizontal, 1 = vertical)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ *proj_crs_get_datum*(PJ_CONTEXT *ctx, const PJ *crs)
Returns the datum of a SingleCRS.

If that function returns NULL,
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

See also:
proj_crs_get_datum_ensemble() to potentially get a DatumEnsemble instead.

Parameters
- **ctx** -- PROJ context, or NULL for default context
- **crs** -- Object of type SingleCRS (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum)

PJ *proj_crs_get_datum_ensemble*(PJ_CONTEXT *ctx, const PJ *crs)
Returns the datum ensemble of a SingleCRS.

If that function returns NULL,
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

See also:

proj_crs_get_datum() to potentially get a Datum instead.

Since

7.2

Parameters

- ctx -- PROJ context, or NULL for default context
- crs -- Object of type SingleCRS (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum ensemble)

PJ *proj_crs_get_datum_forced(PJ_CONTEXT *ctx, const PJ *crs)

Returns a datum for a SingleCRS.

If the SingleCRS has a datum, then this datum is returned. Otherwise, the SingleCRS has a datum ensemble, and this datum ensemble is returned as a regular datum instead of a datum ensemble.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Since

7.2

Parameters

- ctx -- PROJ context, or NULL for default context
- crs -- Object of type SingleCRS (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error (or if there is no datum)

int proj_datum_ensemble_get_member_count(PJ_CONTEXT *ctx, const PJ *datum_ensemble)

Returns the number of members of a datum ensemble.

Since

7.2

Parameters

- ctx -- PROJ context, or NULL for default context
- datum_ensemble -- Object of type DatumEnsemble (must not be NULL)
double `proj_datum_ensemble_get_accuracy`(`PJ_CONTEXT *ctx, const PJ *datum_ensemble`)

Returns the positional accuracy of the datum ensemble.

Since
7.2

Parameters
- `ctx` -- PROJ context, or NULL for default context
- `datum_ensemble` -- Object of type DatumEnsemble (must not be NULL)

Returns
the accuracy, or -1 in case of error.

`PJ *proj_datum_ensemble_get_member`(`PJ_CONTEXT *ctx, const PJ *datum_ensemble, int member_index`)

Returns a member from a datum ensemble.

The returned object must be unreferenced with `proj_destroy()` after use. It should be used by at most one thread at a time.

Since
7.2

Parameters
- `ctx` -- PROJ context, or NULL for default context
- `datum_ensemble` -- Object of type DatumEnsemble (must not be NULL)
- `member_index` -- Index of the datum member to extract (between 0 and `proj_datum_ensemble_get_member_count()`-1)

Returns
Object that must be unreferenced with `proj_destroy()`, or NULL in case of error (or if there is no datum ensemble)

double `proj_dynamic_datum_get_frame_reference_epoch`(`PJ_CONTEXT *ctx, const PJ *datum`)

Returns the frame reference epoch of a dynamic geodetic or vertical reference frame.

Since
7.2

Parameters
- `ctx` -- PROJ context, or NULL for default context
- `datum` -- Object of type DynamicGeodeticReferenceFrame or DynamicVerticalReferenceFrame (must not be NULL)

Returns
the frame reference epoch as decimal year, or -1 in case of error.
PJ *proj_crs_get_coordinate_system(PJ_CONTEXT *ctx, const PJ *crs)

Returns the coordinate system of a SingleCRS.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters

• ctx -- PROJ context, or NULL for default context
• crs -- Object of type SingleCRS (must not be NULL)

Returns

Object that must be unreferenced with proj_destroy(), or NULL in case of error.

PJ_COORDINATE_SYSTEM_TYPE proj_cs_get_type(PJ_CONTEXT *ctx, const PJ *cs)

Returns the type of the coordinate system.

Parameters

• ctx -- PROJ context, or NULL for default context
• cs -- Object of type CoordinateSystem (must not be NULL)

Returns

type, or PJ_CS_TYPE_UNKNOWN in case of error.

int proj_cs_get_axis_count(PJ_CONTEXT *ctx, const PJ *cs)

Returns the number of axis of the coordinate system.

Parameters

• ctx -- PROJ context, or NULL for default context
• cs -- Object of type CoordinateSystem (must not be NULL)

Returns

number of axis, or -1 in case of error.

int proj_cs_get_axis_info(PJ_CONTEXT *ctx, const PJ *cs, int index, const char **out_name, const char **out_abbrev, const char **out_direction, double *out_unit_conv_factor, const char **out_unit_name, const char **out_unit_auth_name, const char **out_unit_code)

Returns information on an axis.

Parameters

• ctx -- PROJ context, or NULL for default context
• cs -- Object of type CoordinateSystem (must not be NULL)
• index -- Index of the coordinate system (between 0 and proj_cs_get_axis_count() - 1)
• out_name -- Pointer to a string value to store the axis name. or NULL
• out_abbrev -- Pointer to a string value to store the axis abbreviation. or NULL
• out_direction -- Pointer to a string value to store the axis direction. or NULL
• out_unit_conv_factor -- Pointer to a double value to store the axis unit conversion factor. or NULL
• out_unit_name -- Pointer to a string value to store the axis unit name. or NULL
• out_unit_auth_name -- Pointer to a string value to store the axis unit authority name. or NULL

out_unit_code -- Pointer to a string value to store the axis unit code. or NULL

Returns
TRUE in case of success

PJ *proj_get_ellipsoid(PJ_CONTEXT *ctx, const PJ *obj)
Get the ellipsoid from a CRS or a GeodeticReferenceFrame.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
• ctx -- PROJ context, or NULL for default context
• obj -- Object of type CRS or GeodeticReferenceFrame (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

int proj_ellipsoid_get_parameters(PJ_CONTEXT *ctx, const PJ *ellipsoid, double *out_semi_major_metre, double *out_semi_minor_metre, int *out_is_semi_minor_computed, double *out_inv_flattening)
Return ellipsoid parameters.

Parameters
• ctx -- PROJ context, or NULL for default context
• ellipsoid -- Object of type Ellipsoid (must not be NULL)
• out_semi_major_metre -- Pointer to a value to store the semi-major axis in metre. or NULL
• out_semi_minor_metre -- Pointer to a value to store the semi-minor axis in metre. or NULL
• out_is_semi_minor_computed -- Pointer to a boolean value to indicate if the semi-minor value was computed. If FALSE, its value comes from the definition. or NULL
• out_inv_flattening -- Pointer to a value to store the inverse flattening. or NULL

Returns
TRUE in case of success.

const char *proj_get_celestial_body_name(PJ_CONTEXT *ctx, const PJ *obj)
Get the name of the celestial body of this object.
Object should be a CRS, Datum or Ellipsoid.

Since
8.1

Parameters
• ctx -- PROJ context, or NULL for default context
• obj -- Object of type CRS, Datum or Ellipsoid. (must not be NULL)

Returns
the name of the celestial body, or NULL.
PJ *proj_get_prime_meridian(PJ_CONTEXT *ctx, const PJ *obj)
Get the prime meridian of a CRS or a GeodeticReferenceFrame.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
- ctx -- PROJ context, or NULL for default context
- obj -- Object of type CRS or GeodeticReferenceFrame (must not be NULL)

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

int proj_prime_meridian_get_parameters(PJ_CONTEXT *ctx, const PJ *prime_meridian, double *out_longitude, double *out_unit_conv_factor, const char **out_unit_name)
Return prime meridian parameters.

Parameters
- ctx -- PROJ context, or NULL for default context
- prime_meridian -- Object of type PrimeMeridian (must not be NULL)
- out_longitude -- Pointer to a value to store the longitude of the prime meridian, in its native unit. or NULL
- out_unit_conv_factor -- Pointer to a value to store the conversion factor of the prime meridian longitude unit to radian. or NULL
- out_unit_name -- Pointer to a string value to store the unit name. or NULL

Returns
TRUE in case of success.

PJ *proj_crs_get_coordoperation(PJ_CONTEXT *ctx, const PJ *crs)
Return the Conversion of a DerivedCRS (such as a ProjectedCRS), or the Transformation from the baseCRS to the hubCRS of a BoundCRS.
The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
- ctx -- PROJ context, or NULL for default context
- crs -- Object of type DerivedCRS or BoundCRSs (must not be NULL)

Returns
Object of type SingleOperation that must be unreferenced with proj_destroy(), or NULL in case of error.

int proj_coordoperation_get_method_info(PJ_CONTEXT *ctx, const PJ *coordoperation, const char **out_method_name, const char **out_method_auth_name, const char **out_method_code)
Return information on the operation method of the SingleOperation.

Parameters
- ctx -- PROJ context, or NULL for default context
- **coordoperation** -- Object of type SingleOperation (typically a Conversion or Transformation) (must not be NULL)
- **out_method_name** -- Pointer to a string value to store the method (projection) name. or NULL
- **out_method_auth_name** -- Pointer to a string value to store the method authority name. or NULL
- **out_method_code** -- Pointer to a string value to store the method code. or NULL

**Returns**

TRUE in case of success.

```c
int proj_coordoperation_is_instantiable(PJ_CONTEXT *ctx, const PJ *coordoperation)
```

Return whether a coordinate operation can be instantiated as a PROJ pipeline, checking in particular that referenced grids are available.

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **coordoperation** -- Object of type CoordinateOperation or derived classes (must not be NULL)

**Returns**

TRUE or FALSE.

```c
int proj_coordoperation_has_ballpark_transformation(PJ_CONTEXT *ctx, const PJ *coordoperation)
```

Return whether a coordinate operation has a "ballpark" transformation, that is a very approximate one, due to lack of more accurate transformations.

Typically a null geographic offset between two horizontal datum, or a null vertical offset (or limited to unit changes) between two vertical datum. Errors of several tens to one hundred meters might be expected, compared to more accurate transformations.

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **coordoperation** -- Object of type CoordinateOperation or derived classes (must not be NULL)

**Returns**

TRUE or FALSE.

```c
int proj_coordoperation_get_param_count(PJ_CONTEXT *ctx, const PJ *coordoperation)
```

Return the number of parameters of a SingleOperation.

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **coordoperation** -- Object of type SingleOperation or derived classes (must not be NULL)

```c
int proj_coordoperation_get_param_index(PJ_CONTEXT *ctx, const PJ *coordoperation, const char *name)
```

Return the index of a parameter of a SingleOperation.

**Parameters**

- **ctx** -- PROJ context, or NULL for default context
- **coordoperation** -- Object of type SingleOperation or derived classes (must not be NULL)
- **name** -- Parameter name. Must not be NULL
Returns
index (>=0), or -1 in case of error.

int proj_coordoperation_get_param(PJ_CONTEXT *ctx, const PJ *coordoperation, int index, const char **out_name, const char **out_auth_name, const char **out_code, double *out_value, const char **out_value_string, double *out_unit_conv_factor, const char **out_unit_name, const char **out_unit_auth_name, const char **out_unit_code, const char **out_unit_category)

Return a parameter of a SingleOperation.

Parameters
- ctx -- PROJ context, or NULL for default context
- coordoperation -- Object of type SingleOperation or derived classes (must not be NULL)
- index -- Parameter index.
- out_name -- Pointer to a string value to store the parameter name. or NULL
- out_auth_name -- Pointer to a string value to store the parameter authority name. or NULL
- out_code -- Pointer to a string value to store the parameter code. or NULL
- out_value -- Pointer to a double value to store the parameter value (if numeric). or NULL
- out_value_string -- Pointer to a string value to store the parameter value (if of type string). or NULL
- out_unit_conv_factor -- Pointer to a double value to store the parameter unit conversion factor. or NULL
- out_unit_name -- Pointer to a string value to store the parameter unit name. or NULL
- out_unit_auth_name -- Pointer to a string value to store the unit authority name. or NULL
- out_unit_code -- Pointer to a string value to store the unit code. or NULL
- out_unit_category -- Pointer to a string value to store the parameter name. or NULL.
  This value might be "unknown", "none", "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time", "time", "parametric" or "parametric_per_time"

Returns
TRUE in case of success.

int proj_coordoperation_get_grid_used_count(PJ_CONTEXT *ctx, const PJ *coordoperation)

Return the number of grids used by a CoordinateOperation.

Parameters
- ctx -- PROJ context, or NULL for default context
- coordoperation -- Object of type CoordinateOperation or derived classes (must not be NULL)

int proj_coordoperation_get_grid_used(PJ_CONTEXT *ctx, const PJ *coordoperation, int index, const char **out_short_name, const char **out_full_name, const char **out_package_name, const char **out_url, int *out_direct_download, int *out_open_license, int *out_available)

Return a parameter of a SingleOperation.

Parameters
- ctx -- PROJ context, or NULL for default context
• **coordoperation** -- Object of type SingleOperation or derived classes (must not be NULL)
• **index** -- Parameter index.
• **out_short_name** -- Pointer to a string value to store the grid short name. or NULL
• **out_full_name** -- Pointer to a string value to store the grid full filename. or NULL
• **out_package_name** -- Pointer to a string value to store the package name where the grid might be found. or NULL
• **out_url** -- Pointer to a string value to store the grid URL or the package URL where the grid might be found. or NULL
• **out_direct_download** -- Pointer to a int (boolean) value to store whether *out_url can be downloaded directly. or NULL
• **out_open_license** -- Pointer to a int (boolean) value to store whether the grid is released with an open license. or NULL
• **out_available** -- Pointer to a int (boolean) value to store whether the grid is available at runtime. or NULL

**Returns**

TRUE in case of success.

double **proj_coordoperation_get_accuracy**(*PJ_CONTEXT* ctx, const *PJ* obj)

Return the accuracy (in metre) of a coordinate operation.

**Parameters**

• **ctx** -- PROJ context, or NULL for default context
• **coordoperation** -- Coordinate operation. Must not be NULL.

**Returns**

the accuracy, or a negative value if unknown or in case of error.

int **proj_coordoperation_get_towgs84_values**(*PJ_CONTEXT* ctx, const *PJ* coordoperation, double *out_values, int value_count, int emit_error_if_incompatible)

Return the parameters of a Helmert transformation as WKT1 TOWGS84 values.

**Parameters**

• **ctx** -- PROJ context, or NULL for default context
• **coordoperation** -- Object of type Transformation, that can be represented as a WKT1 TOWGS84 node (must not be NULL)
• **out_values** -- Pointer to an array of value_count double values.
• **value_count** -- Size of out_values array. The suggested size is 7 to get translation, rotation and scale difference parameters. Rotation and scale difference terms might be zero if the transformation only includes translation parameters. In that case, value_count could be set to 3.
• **emit_error_if_incompatible** -- Boolean to indicate if an error must be logged if coordoperation is not compatible with a WKT1 TOWGS84 representation.

**Returns**

TRUE in case of success, or FALSE if coordoperation is not compatible with a WKT1 TOWGS84 representation.
PJ *proj_coordoperation_create_inverse(PJ_CONTEXT *ctx, const PJ *obj)
Returns a PJ* coordinate operation object which represents the inverse operation of the specified coordinate operation.

Since
6.3

Parameters
• ctx -- PROJ context, or NULL for default context
• obj -- Object of type CoordinateOperation (must not be NULL)

Returns
a new PJ* object to free with proj_destroy() in case of success, or nullptr in case of error

int proj_concatoperation_get_step_count(PJ_CONTEXT *ctx, const PJ *concatoperation)
Returns the number of steps of a concatenated operation.

The input object must be a concatenated operation.

Parameters
• ctx -- PROJ context, or NULL for default context
• concatoperation -- Concatenated operation (must not be NULL)

Returns
the number of steps, or 0 in case of error.

PJ *proj_concatoperation_get_step(PJ_CONTEXT *ctx, const PJ *concatoperation, int i_step)
Returns a step of a concatenated operation.

The input object must be a concatenated operation.

The returned object must be unreferenced with proj_destroy() after use. It should be used by at most one thread at a time.

Parameters
• ctx -- PROJ context, or NULL for default context
• concatoperation -- Concatenated operation (must not be NULL)
• i_step -- Index of the step to extract. Between 0 and proj_concatoperation_get_step_count()-1

Returns
Object that must be unreferenced with proj_destroy(), or NULL in case of error.

double proj_coordinate_metadata_get_epoch(PJ_CONTEXT *ctx, const PJ *obj)
Return the coordinate epoch associated with a CoordinateMetadata.
It may return a NaN value if there is no associated coordinate epoch.

Since
9.2
10.5.4 C++ API

10.5.4.1 General documentation

General API design

The design of the class hierarchy is strongly derived from ISO 19111:2019.

Classes for which the constructors are not directly accessible have their instances constructed with create() methods. The returned object is a non-null shared pointer. Such objects are immutable, and thread-safe.

TODO

General properties

All classes deriving from IdentifiedObject have general properties that can be defined at creation time. Those properties are:

- `osgeo::proj::metadata::Identifier::DESCRIPTION_KEY` ("description"): the natural language description of the meaning of the code value, provided as a string.
- `osgeo::proj::metadata::Identifier::CODE_KEY` ("code"): a numeric or alphanumeric code, provided as an integer or a string. For example 4326, for the EPSG:4326 "WGS84" GeographicalCRS
- `osgeo::proj::metadata::Identifier::CODESPACE_KEY` ("codespaces"): the organization responsible for definition and maintenance of the code, provided as a string. For example "EPSG".
- `osgeo::proj::metadata::Identifier::VERSION_KEY` ("version"): the version identifier for the namespace, provided as a string.
- `osgeo::proj::metadata::Identifier::AUTHORITY_KEY` ("authority"): a citation for the authority, provided as a string or an `osgeo::proj::metadata::Citation` object. Often unused
- `osgeo::proj::metadata::Identifier::URI_KEY` ("uri"): the URI of the identifier, provided as a string. Often unused
- `osgeo::proj::common::IdentifiedObject::NAME_KEY` ("name"): the name of a `osgeo::proj::common::IdentifiedObject`, provided as a string or an `osgeo::proj::metadata::Identifier::NNPtr`.
- `osgeo::proj::common::IdentifiedObject::IDENTIFIERS_KEY` ("identifiers"): the identifier(s) of a `osgeo::proj::common::IdentifiedObject`, provided as a `osgeo::proj::common::Identifier::NNPtr` or an `osgeo::proj::util::ArrayOfBaseObject::NNPtr` of `osgeo::proj::metadata::Identifier::NNPtr`.
- `osgeo::proj::common::IdentifiedObject::ALIAS_KEY` ("alias"): the alias(es) of a `osgeo::proj::common::IdentifiedObject`, provided as a string, a `osgeo::proj::util::GenericName::NNPtr` or an `osgeo::proj::util::ArrayOfBaseObject::NNPtr` of `osgeo::proj::util::GenericName::NNPtr`.
- `osgeo::proj::common::IdentifiedObject::REMARKS_KEY` ("remarks"): the remarks of a `osgeo::proj::common::IdentifiedObject`, provided as a string.
• `osgeo::proj::common::IdentifiedObject::DEPRECATED_KEY` ("deprecated"): the deprecation flag of a `osgeo::proj::common::IdentifiedObject`, provided as a boolean.

• `osgeo::proj::common::ObjectUsage::SCOPE_KEY` ("scope"): the scope of a `osgeo::proj::common::ObjectUsage`, provided as a string.

• `osgeo::proj::common::ObjectUsage::DOMAIN_OF_VALIDITY_KEY` ("domainOfValidity"): the domain of validity of a `osgeo::proj::common::ObjectUsage`, provided as a `osgeo::proj::metadata::ExtentNNPtr`.

• `osgeo::proj::common::ObjectUsage::OBJECT_DOMAIN_KEY` ("objectDomain"): the object domain(s) of a `osgeo::proj::common::ObjectUsage`, provided as a `osgeo::proj::common::ObjectDomainNNPtr` or a `osgeo::proj::util::ArrayOfBaseObjectNNPtr` of `osgeo::proj::common::ObjectDomainNNPtr`.

Applicable standards

ISO:19111 / OGC Topic 2 standard

Topic 2 - Spatial referencing by coordinates.

This is an Abstract Specification describes the data elements, relationships and associated metadata required for spatial referencing by coordinates. It describes Coordinate Reference Systems (CRS), coordinate systems (CS) and coordinate transformation or coordinate conversion between two different coordinate reference systems.

ISO 19111:2019

This is the revision mostly used for PROJ C++ modelling.

OGC 18-005r5, 2021-07-02, ISO 19111:2019

ISO 19111:2007

The precedent version of the specification was: OGC 08-015r2, 2010-04-27, ISO 19111:2007

WKT2 standard

Well-known text representation of coordinate reference systems.

Well-known Text (WKT) offers a compact machine- and human-readable representation of the critical elements of coordinate reference system (CRS) definitions, and coordinate operations. This is an implementation of ISO:19111 / OGC Topic 2 standard

PROJ implements the two following revisions of the standard:
Older specifications of well-known text representation of coordinate reference systems are also supported by PROJ, mostly for compatibility with legacy systems, or older versions of GDAL.

GDAL v2.4 and earlier mostly implements:

OGC 01-009, 2001-01-12, OpenGIS Coordinate Transformation Service Implementation Specification

The GDAL documentation, OGC WKT Coordinate System Issues discusses issues, and GDAL implementation choices.

An older specification of WKT1 is/was used by some software packages:

OGC 99-049, 1999-05-05, OpenGIS Simple Features Specification For SQL v1.1

ISO 19115 (Metadata)

Defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data.

PROJ implements a simplified subset of ISO 19115.

GeoAPI

A set of Java and Python language programming interfaces for geospatial applications.

GeoAPI main page
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10.5.4.2 common namespace

namespace common

Common classes.

osgeo.proj.common namespace
**Typedefs**

typedef std::shared_ptr<UnitOfMeasure> UnitOfMeasurePtr
    Shared pointer of UnitOfMeasure.

typedef util::nn<UnitOfMeasurePtr> UnitOfMeasureNNPtr
    Non-null shared pointer of UnitOfMeasure.

typedef std::shared_ptr<IdentifiedObject> IdentifiedObjectPtr
    Shared pointer of IdentifiedObject.

typedef util::nn<IdentifiedObjectPtr> IdentifiedObjectNNPtr
    Non-null shared pointer of IdentifiedObject.

using ObjectDomainPtr = std::shared_ptr<ObjectDomain>
    Shared pointer of ObjectDomain.

using ObjectDomainNNPtr = util::nn<ObjectDomainPtr>
    Non-null shared pointer of ObjectDomain.

using ObjectUsagePtr = std::shared_ptr<ObjectUsage>
    Shared pointer of ObjectUsage.

using ObjectUsageNNPtr = util::nn<ObjectUsagePtr>
    Non-null shared pointer of ObjectUsage.

class UnitOfMeasure : public osgeo::proj::util::BaseObject
    
    #include <common.hpp> Unit of measure.

    This is a mutable object.

**Public Types**

enum class Type
    
    Type of unit of measure.

    Values:

    enumerator UNKNOWN
        Unknown unit of measure

    enumerator NONE
        No unit of measure

    enumerator ANGULAR
        Angular unit of measure
enumerator **LINEAR**
   Linear unit of measure

enumerator **SCALE**
   Scale unit of measure

enumerator **TIME**
   Time unit of measure

enumerator **PARAMETRIC**
   Parametric unit of measure

**Public Functions**

explicit **UnitOfMeasure** (const std::string &nameIn = std::string(), double toSIIn = 1.0, **Type** typeIn = **Type**::UNKNOWN, const std::string &codeSpaceIn = std::string(), const std::string &codeIn = std::string())

Creates a **UnitOfMeasure**.

cost std::string &**name**()
   Return the name of the unit of measure.

double **conversionToSI**()
   Return the conversion factor to the unit of the International System of Units of the same Type.

   For example, for foot, this would be 0.3048 (metre)
   
   **Returns**
   the conversion factor, or 0 if no conversion exists.

**Type** **type**()
   Return the type of the unit of measure.

cost std::string &**codeSpace**()
   Return the code space of the unit of measure.

   For example "EPSG"
   
   **Returns**
   the code space, or empty string.

const std::string &**code**()
   Return the code of the unit of measure.

   **Returns**
   the code, or empty string.

bool **operator==**(const **UnitOfMeasure** &other)
   Returns whether two units of measures are equal.

   The comparison is based on the name.

bool **operator!==**(const **UnitOfMeasure** &other)
   Returns whether two units of measures are different.

   The comparison is based on the name.
Public Static Attributes

static const UnitOfMeasure NONE
   "Empty"/"None", unit of measure of type NONE.

static const UnitOfMeasure SCALEUNITY
   Scale unity, unit of measure of type SCALE.

static const UnitOfMeasure PARTS_PER_MILLION
   Parts-per-million, unit of measure of type SCALE.

static const UnitOfMeasure PPM_PER_YEAR
   Parts-per-million per year, unit of measure of type SCALE.

static const UnitOfMeasure METRE
   Metre, unit of measure of type LINEAR (SI unit).

static const UnitOfMeasure METRE_PER_YEAR
   Metre per year, unit of measure of type LINEAR.

static const UnitOfMeasure FOOT
   Foot, unit of measure of type LINEAR.

static const UnitOfMeasure US_FOOT
   US survey foot, unit of measure of type LINEAR.

static const UnitOfMeasure Radian
   Radian, unit of measure of type ANGULAR (SI unit).

static const UnitOfMeasure MICRORADIAN
   Microradian, unit of measure of type ANGULAR.

static const UnitOfMeasure DEGREE
   Degree, unit of measure of type ANGULAR.

static const UnitOfMeasure ARC_SECOND
   Arc-second, unit of measure of type ANGULAR.

static const UnitOfMeasure GRAD
   Grad, unit of measure of type ANGULAR.

static const UnitOfMeasure ARC_SECOND_PER_YEAR
   Arc-second per year, unit of measure of type ANGULAR.

static const UnitOfMeasure SECOND
   Second, unit of measure of type TIME (SI unit).
static const UnitOfMeasure YEAR
    Year, unit of measure of type TIME.

class Measure : public osgeo::proj::util::BaseObject
    #include <common.hpp> Numeric value associated with a UnitOfMeasure.
    Subclassed by osgeo::proj::common::Angle, osgeo::proj::common::Length, osgeo::proj::common::Scale

Public Functions

Measure(double valueIn = 0.0, const UnitOfMeasure &unitIn = UnitOfMeasure())
    Instantiate a Measure.

cconst UnitOfMeasure &unit()
    Return the unit of the Measure.

double getSIValue()
    Return the value of the Measure, after conversion to the corresponding unit of the International System.

double value()
    Return the value of the measure, expressed in the unit()

double convertToUnit(const UnitOfMeasure &otherUnit)
    Return the value of this measure expressed into the provided unit.

bool operator==(const Measure &other)
    Return whether two measures are equal.
    The comparison is done both on the value and the unit.

bool _isEquivalentTo(const Measure &other, util::IComparable::Criterion criterion = util::IComparable::Criterion::STRICT, double maxRelativeError = DEFAULT_MAX_REL_ERROR) const
    Returns whether an object is equivalent to another one.
    Parameters
    • other -- other object to compare to
    • criterion -- comparison criterion.
    • maxRelativeError -- Maximum relative error allowed.
    Returns
    true if objects are equivalent.

Public Static Attributes

static constexpr double DEFAULT_MAX_REL_ERROR = 1e-10
    Default maximum resulative error.

class Scale : public osgeo::proj::common::Measure
    #include <common.hpp> Numeric value, without a physical unit of measure.
Public Functions

explicit Scale(double valueIn = 0.0)
  Instantiate a Scale.
  Parameters
  valueIn -- value

explicit Scale(double valueIn, const UnitOfMeasure &unitIn)
  Instantiate a Scale.
  Parameters
  • valueIn -- value
  • unitIn -- unit. Constraint: unit.type() == UnitOfMeasure::Type::SCALE

class Angle : public osgeo::proj::common::Measure
  #include <common.hpp> Numeric value, with a angular unit of measure.

Public Functions

explicit Angle(double valueIn = 0.0)
  Instantiate a Angle.
  Parameters
  valueIn -- value

Angle(double valueIn, const UnitOfMeasure &unitIn)
  Instantiate a Angle.
  Parameters
  • valueIn -- value
  • unitIn -- unit. Constraint: unit.type() == UnitOfMeasure::Type::ANGULAR

class Length : public osgeo::proj::common::Measure
  #include <common.hpp> Numeric value, with a linear unit of measure.

Public Functions

explicit Length(double valueIn = 0.0)
  Instantiate a Length.
  Parameters
  valueIn -- value

Length(double valueIn, const UnitOfMeasure &unitIn)
  Instantiate a Length.
  Parameters
  • valueIn -- value
  • unitIn -- unit. Constraint: unit.type() == UnitOfMeasure::Type::LINEAR

class DateTime
  #include <common.hpp> Date-time value, as a ISO:8601 encoded string, or other string encoding.
**Public Functions**

bool isISO_8601() const

    Return whether the DateTime is ISO:8601 compliant.

**Remark**

The current implementation is really simplistic, and aimed at detecting date-times that are not ISO:8601 compliant.

std::string toString() const

    Return the DateTime as a string.

**Public Static Functions**

static DateTime create(const std::string &str)

    Instantiate a DateTime.

class DataEpoch

    #include <common.hpp> Data epoch.

**Public Functions**

const Measure &coordinateEpoch() const

    Return the coordinate epoch, as a measure in decimal year.

class IdentifiedObject : public osgeo::proj::util::BaseObject, public osgeo::proj::util::IComparable, public osgeo::proj::io::IWKTExportable

    #include <common.hpp> Abstract class representing a CRS-related object that has an identification.

**Remark**

Implements IdentifiedObject from ISO 19111:2019

Subclassed by osgeo::proj::common::ObjectUsage, osgeo::proj::cs::CoordinateSystem, osgeo::proj::cs::CoordinateSystemAxis, osgeo::proj::cs::Meridian, osgeo::proj::datum::Ellipsoid, osgeo::proj::datum::PrimeMeridian, osgeo::proj::operation::GeneralOperationParameter, osgeo::proj::operation::OperationMethod
Public Functions

const metadata::IdentifierNNPtr &name()
    Return the name of the object.
    Generally, the only interesting field of the name will be name()->description().

const std::string &nameStr()
    Return the name of the object.
    Return *(name()->description())

const std::vector<metadata::IdentifierNNPtr> &identifiers()
    Return the identifier(s) of the object.
    Generally, those will have Identifier::code() and Identifier::codeSpace() filled.

const std::vector<util::GenericNameNNPtr> &aliases()
    Return the alias(es) of the object.

const std::string &remarks()
    Return the remarks.

bool isDeprecated()
    Return whether the object is deprecated.

Remark
Extension of ISO 19111:2019

std::string alias()
    Return the (first) alias of the object as a string.
    Shortcut for aliases()[0]->fullyQualifiedName()->toString()

int getEPSGCode()
    Return the EPSG code.
    Returns
    code, or 0 if not found

Public Static Attributes

static const std::string NAME_KEY
    Key to set the name of a common::IdentifiedObject.
    The value is to be provided as a string or metadata::IdentifierNNPtr.

static const std::string IDENTIFIERS_KEY
    Key to set the identifier(s) of a common::IdentifiedObject.
    The value is to be provided as a common::IdentifierNNPtr or a util::ArrayOfBaseObjectNNPtr of common::IdentifierNNPtr.
static const std::string ALIAS_KEY
    Key to set the alias(es) of a common::IdentifiedObject.
The value is to be provided as string, a util::GenericNameNNPtr or a util::ArrayOfBaseObjectNNPtr of util::GenericNameNNPtr.

static const std::string REMARKS_KEY
    Key to set the remarks of a common::IdentifiedObject.
The value is to be provided as a string.

static const std::string DEPRECATED_KEY
    Key to set the deprecation flag of a common::IdentifiedObject.
The value is to be provided as a boolean.

class ObjectDomain : public osgeo::proj::util::BaseObject, public osgeo::proj::IComparable
#include <common.hpp> The scope and validity of a CRS-related object.

Remark
Implements ObjectDomain from ISO 19111:2019

Public Functions

const util::optional<std::string> &scope() 
    Return the scope.
    
    Returns
    the scope, or empty.

class ObjectUsage : public osgeo::proj::common::IdentifiedObject
#include <common.hpp> Abstract class of a CRS-related object that has usages.

Remark
PROJ coordinate transformation software library, Release 9.3.1

Implements *ObjectUsage* from *ISO 19111:2019*

Subclassed by *osgeo::proj::crs::CRS, osgeo::proj::datum::Datum, osgeo::proj::datum::DatumEnsemble, osgeo::proj::operation::CoordinateOperation*

**Public Functions**

```cpp
const std::vector<ObjectDomainNNPtr> &domains()
```

Return the domains of the object.

**Public Static Attributes**

```cpp
static const std::string SCOPE_KEY
```

Key to set the scope of a *common::ObjectUsage*.

The value is to be provided as a string.

```cpp
static const std::string DOMAIN_OF_VALIDITY_KEY
```

Key to set the domain of validity of a *common::ObjectUsage*.

The value is to be provided as a *common::ExtentNNPtr*.

```cpp
static const std::string OBJECT_DOMAIN_KEY
```

Key to set the object domain(s) of a *common::ObjectUsage*.

The value is to be provided as a *common::ObjectDomainNNPtr* or a *util::ArrayOfBaseObjectNNPtr* of *common::ObjectDomainNNPtr*.

**10.5.4.3 util namespace**

```cpp
namespace util
```

A set of base types from ISO 19103, *GeoAPI* and other PROJ specific classes.

*osgeo.proj.util* namespace.

**Typedefs**

```cpp
using BaseObjectPtr = std::shared_ptr<BaseObject>
```

Shared pointer of *BaseObject*.

```cpp
using BoxedValuePtr = std::shared_ptr<BoxedValue>
```

Shared pointer of *BoxedValue*.

```cpp
using BoxedValueNNPtr = util::nn<BoxedValuePtr>
```

Non-null shared pointer of *BoxedValue*.
using `ArrayOfBaseObjectPtr = std::shared_ptr<ArrayOfBaseObject>`

Shared pointer of `ArrayOfBaseObject`.

using `ArrayOfBaseObjectNNPtr = util::nn<ArrayOfBaseObjectPtr>`

Non-null shared pointer of `ArrayOfBaseObject`.

using `LocalNamePtr = std::shared_ptr<LocalName>`

Shared pointer of `LocalName`.

using `LocalNameNNPtr = util::nn<LocalNamePtr>`

Non-null shared pointer of `LocalName`.

using `NameSpacePtr = std::shared_ptr<NameSpace>`

Shared pointer of `NameSpace`.

using `NameSpaceNNPtr = util::nn<NameSpacePtr>`

Non-null shared pointer of `NameSpace`.

using `GenericNamePtr = std::shared_ptr<GenericName>`

Shared pointer of `GenericName`.

using `GenericNameNNPtr = util::nn<GenericNamePtr>`

Non-null shared pointer of `GenericName`.

template<class T>

class `optional`

#include `<util.hpp>` Loose transposition of `std::optional` available from C++17.

**Public Functions**

inline const `T *operator->()` const

Returns a pointer to the contained value.

inline const `T &operator*()` const

Returns a reference to the contained value.

inline explicit `operator bool()` const noexcept

Return whether the optional has a value

inline bool `has_value()` const noexcept

Return whether the optional has a value

struct `BaseObjectNNPtr` : public `util::nn<BaseObjectPtr>`

#include `<util.hpp>` Non-null shared pointer of `BaseObject`. 
class **BaseObject**

```cpp
#include <util.hpp>
```

Class that can be derived from, to emulate Java's Object behavior.

Subclassed by:
- osgeo::proj::common::IdentifiedObject
- osgeo::proj::common::Measure
- osgeo::proj::common::ObjectDomain
- osgeo::proj::coordinates::CoordinateMetadata
- osgeo::proj::metadata::Citation
- osgeo::proj::metadata::GeographicExtent
- osgeo::proj::metadata::Identifier
- osgeo::proj::metadata::PositionalAccuracy
- osgeo::proj::metadata::TemporalExtent
- osgeo::proj::metadata::VerticalExtent
- osgeo::proj::operation::GeneralParameterValue
- osgeo::proj::operation::ParameterValue
- osgeo::proj::util::ArrayOfBaseObject
- osgeo::proj::util::BoxedValue
- osgeo::proj::util::GenericName

class **IComparable**

```cpp
#include <util.hpp>
```

Interface for an object that can be compared to another.

Subclassed by:
- osgeo::proj::common::IdentifiedObject
- osgeo::proj::common::ObjectDomain
- osgeo::proj::metadata::Extent
- osgeo::proj::metadata::GeographicExtent
- osgeo::proj::metadata::PositionalAccuracy
- osgeo::proj::metadata::TemporalExtent
- osgeo::proj::metadata::VerticalExtent
- osgeo::proj::operation::GeneralParameterValue
- osgeo::proj::operation::ParameterValue
- osgeo::proj::util::ArrayOfType<baseObject>
- osgeo::proj::util::BoxedValue
- osgeo::proj::util::GenericName

**Public Types**

enum class **Criterion**

Comparison criterion.

*Values:*

- enumerator **STRICT**
  
  All properties are identical.

- enumerator **EQUIVALENT**
  
  The objects are equivalent for the purpose of coordinate operations. They can differ by the name of their objects, identifiers, other metadata. Parameters may be expressed in different units, provided that the value is (with some tolerance) the same once expressed in a common unit.

- enumerator **EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS**
  
  Same as EQUIVALENT, relaxed with an exception that the axis order of the base CRS of a DerivedCRS/ProjectedCRS or the axis order of a GeographicCRS is ignored. Only to be used with DerivedCRS/ProjectedCRS/GeographicCRS

**Public Functions**

```cpp
bool isEquivalentTo(const IComparable *other, Criterion criterion = Criterion::STRICT, const io::DatabaseContextPtr &dbContext = nullptr) const
```

Returns whether an object is equivalent to another one.

**Parameters**

- **other** -- other object to compare to
- **criterion** -- comparison criterion.
- **dbContext** -- Database context, or nullptr.
Returns
true if objects are equivalent.

class `BoxedValue` : public osgeo::proj::util::BaseObject
#include <util.hpp> Encapsulate standard datatypes in an object.

**Public Functions**

`BoxedValue` (const char *stringValueIn)
Constructs a `BoxedValue` from a string.

`BoxedValue` (const std::string &stringValueIn)
Constructs a `BoxedValue` from a string.

`BoxedValue` (int integerValueIn)
Constructs a `BoxedValue` from an integer.

`BoxedValue` (bool booleanValueIn)
Constructs a `BoxedValue` from a boolean.

class `ArrayOfBaseObject` : public osgeo::proj::util::BaseObject
#include <util.hpp> Array of `BaseObject`.

**Public Functions**

void `add` (const `BaseObject` &obj)
Adds an object to the array.

**Parameters**

- `obj` -- the object to add.

**Public Static Functions**

static `ArrayOfBaseObject` `create` ()
Instantiate a `ArrayOfBaseObject`.

**Returns**

a new `ArrayOfBaseObject`.

class `PropertyMap`
#include <util.hpp> Wrapper of a std::map<std::string, `BaseObject` >

**Public Functions**

`PropertyMap` &`set` (const std::string &key, const `BaseObject` &val)
Set a `BaseObject` as the value of a key.

`PropertyMap` &`set` (const std::string &key, const char *val)
Set a string as the value of a key.

`PropertyMap` &`set` (const std::string &key, const std::string &val)
Set a string as the value of a key.
PropertyMap &set(const std::string &key, int val)
    Set an integer as the value of a key.
PropertyMap &set(const std::string &key, bool val)
    Set a boolean as the value of a key.
PropertyMap &set(const std::string &key, const std::vector<std::string> &array)
    Set a vector of strings as the value of a key.

class GenericName : public osgeo::proj::util::BaseObject
    #include <util.hpp> A sequence of identifiers rooted within the context of a namespace.

    Remark
    Simplified version of GenericName from GeoAPI

    Subclassed by osgeo::proj::util::LocalName

Public Functions

    virtual const NameSpacePtr scope() const = 0
        Return the scope of the object, possibly a global one.
    virtual std::string toString() const = 0
        Return the LocalName as a string.
    virtual GenericNameNNPtr toFullyQualifiedName() const = 0
        Return a fully qualified name corresponding to the local name.
        The namespace of the resulting name is a global one.

class NameSpace
    #include <util.hpp> A domain in which names given by strings are defined.

    Remark
    Simplified version of NameSpace from GeoAPI

Public Functions

    bool isGlobal() const
        Returns whether this is a global namespace.
    const GenericNamePtr &name() const
        Returns the name of this namespace.
class **LocalName** : public osgeo::proj::util::GenericName

```
#include <util.hpp>
```

Identifier within a **NameSpace** for a local object.

Local names are names which are directly accessible to and maintained by a **NameSpace** within which they are local, indicated by the scope.

---

**Remark**

Simplified version of **LocalName** from **GeoAPI**

---

**Public Functions**

virtual const **NamespacePtr** **scope**() const override

Return the scope of the object, possibly a global one.

virtual std::string **toString**() const override

Return the **LocalName** as a string.

virtual **GenericNameNNPtr** **toFullyQualifiedName**() const override

Return a fully qualified name corresponding to the local name.

The namespace of the resulting name is a global one.

---

class **NameFactory**

```
#include <util.hpp>
```

Factory for generic names.

---

**Remark**

Simplified version of **NameFactory** from **GeoAPI**

---

**Public Static Functions**

static **NamespaceNNPtr** **createNameSpace**(const **GenericNameNNPtr**& name, const **PropertyMap**& properties)

Instantiate a **Namespace**.

**Parameters**

- **name** -- name of the namespace.
- **properties** -- Properties. Allowed keys are "separator" and "separator.head".

**Returns**

a new **NameFactory**.

static **LocalNameNNPtr** **createLocalName**(const **NamespacePtr**& scope, const std::string &name)

Instantiate a **LocalName**.

**Parameters**

- **scope** -- scope.
- **name** -- string of the local name.
Returns

a new LocalName.

static GenericNameNNPtr createGenericName(const NameSpacePtr &scope, const std::vector<std::string> &parsedNames)

Instantiate a GenericName.

Parameters

• scope -- scope.
• parsedNames -- the components of the name.

Returns

a new GenericName.

class CodeList

#include <util.hpp> Abstract class to define an enumeration of values.


Public Functions

inline const std::string &toString()

Return the CodeList item as a string.

inline operator std::string()

Return the CodeList item as a string.

class Exception : public std::exception

#include <util.hpp> Root exception class.


Public Functions

virtual const char *what() const noexcept override

Return the exception text.

class InvalidValueTypeException : public osgeo:proj:util:Exception

#include <util.hpp> Exception thrown when an invalid value type is set as the value of a key of a PropertyMap.

class UnsupportedOperationException : public osgeo:proj:util:Exception

#include <util.hpp> Exception Thrown to indicate that the requested operation is not supported.
10.5.4.4 metadata namespace

namespace metadata
    Common classes from ISO 19115 (Metadata) standard.
    
    osgeo.proj.metadata namespace

Typedefs

typedef std::shared_ptr<Extent> ExtentPtr
    Shared pointer of Extent.

typedef util::nn<ExtentPtr> ExtentNNPtr
    Non-null shared pointer of Extent.

using GeographicExtentPtr = std::shared_ptr<GeographicExtent>
    Shared pointer of GeographicExtent.

using GeographicExtentNNPtr = util::nn<GeographicExtentPtr>
    Non-null shared pointer of GeographicExtent.

using GeographicBoundingBoxPtr = std::shared_ptr<GeographicBoundingBox>
    Shared pointer of GeographicBoundingBox.

using GeographicBoundingBoxNNPtr = util::nn<GeographicBoundingBoxPtr>
    Non-null shared pointer of GeographicBoundingBox.

using TemporalExtentPtr = std::shared_ptr<TemporalExtent>
    Shared pointer of TemporalExtent.

using TemporalExtentNNPtr = util::nn<TemporalExtentPtr>
    Non-null shared pointer of TemporalExtent.

using VerticalExtentPtr = std::shared_ptr<VerticalExtent>
    Shared pointer of VerticalExtent.

using VerticalExtentNNPtr = util::nn<VerticalExtentPtr>
    Non-null shared pointer of VerticalExtent.

using IdentifierPtr = std::shared_ptr<Identifier>
    Shared pointer of Identifier.

using IdentifierNNPtr = util::nn<IdentifierPtr>
    Non-null shared pointer of Identifier.
using **PositionalAccuracyPtr** = std::shared_ptr<PositionalAccuracy>
Shared pointer of PositionalAccuracy.

using **PositionalAccuracyNNPtr** = util::nn<PositionalAccuracyPtr>
Non-null shared pointer of PositionalAccuracy.

class **Citation** : public osgeo::proj::util::BaseObject
  
  *#include <metadata.hpp>* Standardized resource reference.
  
  A citation contains a title.

**Remark**
Simplified version of Citation from GeoAPI

**Public Functions**

explicit **Citation**(const std::string &titleIn)
  Constructs a citation by its title.

const **util::optional**<std::string> &**title**()
  Returns the name by which the cited resource is known.

class **GeographicExtent** : public osgeo::proj::util::BaseObject, public osgeo::proj::util::IComparable
  
  *#include <metadata.hpp>* Base interface for geographic area of the dataset.

**Remark**
Simplified version of GeographicExtent from GeoAPI

Subclassed by osgeo::proj::metadata::GeographicBoundingBox

**Public Functions**

virtual bool **contains**(const GeographicExtentNNPtr &other) const = 0
  Returns whether this extent contains the other one.

virtual bool **intersects**(const GeographicExtentNNPtr &other) const = 0
  Returns whether this extent intersects the other one.

virtual GeographicExtentPtr **intersection**(const GeographicExtentNNPtr &other) const = 0
  Returns the intersection of this extent with another one.
class GeographicBoundingBox : public osgeo::proj::metadata::GeographicExtent

#include <metadata.hpp> Geographic position of the dataset.

This is only an approximate so specifying the coordinate reference system is unnecessary.

---

**Remark**

Implements GeographicBoundingBox from GeoAPI

---

**Public Functions**

double westBoundLongitude()

Returns the western-most coordinate of the limit of the dataset extent.

The unit is degrees.

If eastBoundLongitude < westBoundLongitude(), then the bounding box crosses the anti-meridian.

double southBoundLatitude()

Returns the southern-most coordinate of the limit of the dataset extent.

The unit is degrees.

double eastBoundLongitude()

Returns the eastern-most coordinate of the limit of the dataset extent.

The unit is degrees.

If eastBoundLongitude < westBoundLongitude(), then the bounding box crosses the anti-meridian.

double northBoundLatitude()

Returns the northern-most coordinate of the limit of the dataset extent.

The unit is degrees.

virtual bool contains(const GeographicExtentNNPtr &other) const override

Returns whether this extent contains the other one.

virtual bool intersects(const GeographicExtentNNPtr &other) const override

Returns whether this extent intersects the other one.

virtual GeographicExtentPtr intersection(const GeographicExtentNNPtr &other) const override

Returns the intersection of this extent with another one.

---

**Public Static Functions**

static GeographicBoundingBoxNNPtr create(double west, double south, double east, double north)

Instantiate a GeographicBoundingBox.

If east < west, then the bounding box crosses the anti-meridian.

**Parameters**

- **west** -- Western-most coordinate of the limit of the dataset extent (in degrees).
- **south** -- Southern-most coordinate of the limit of the dataset extent (in degrees).
- **east** -- Eastern-most coordinate of the limit of the dataset extent (in degrees).
• **north** -- Northern-most coordinate of the limit of the dataset extent (in degrees).

    **Returns**
    a new `GeographicBoundingBox`.

**class TemporalExtent**: public osgeo::proj::util::BaseObject, public osgeo::proj::util::IComparable

#include <metadata.hpp> Time period covered by the content of the dataset.

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<th><strong>Remark</strong></th>
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<tr>
<td>Simplified version of <code>TemporalExtent</code> from <code>GeoAPI</code></td>
</tr>
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</table>

**Public Functions**

const std::string &**start**()

    Returns the start of the temporal extent.

const std::string &**stop**()

    Returns the end of the temporal extent.

bool **contains**(const `TemporalExtentNNPtr` &other) const

    Returns whether this extent contains the other one.

bool **intersects**(const `TemporalExtentNNPtr` &other) const

    Returns whether this extent intersects the other one.

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<tr>
<td>static <code>TemporalExtentNNPtr</code> <strong>create</strong>(const std::string &amp;start, const std::string &amp;stop)</td>
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<tr>
<td>Instantiate a <code>TemporalExtent</code>.</td>
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    **Parameters**
    • **start** -- start.
    • **stop** -- stop.

    **Returns**
    a new `TemporalExtent`.

**class VerticalExtent**: public osgeo::proj::util::BaseObject, public osgeo::proj::util::IComparable

#include <metadata.hpp> Vertical domain of dataset.

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<tbody>
<tr>
<td>Simplified version of <code>VerticalExtent</code> from <code>GeoAPI</code></td>
</tr>
</tbody>
</table>

10.5. Reference
Public Functions

double minimumValue()  
Returns the minimum of the vertical extent.

double maximumValue()  
Returns the maximum of the vertical extent.

common::UnitOfMeasureNNPtr &unit()  
Returns the unit of the vertical extent.

bool contains(const VerticalExtentNNPtr &other) const  
Returns whether this extent contains the other one.

bool intersects(const VerticalExtentNNPtr &other) const  
Returns whether this extent intersects the other one.

Public Static Functions

static VerticalExtentNNPtr create(double minimumValue, double maximumValue, const common::UnitOfMeasureNNPtr &unitIn)  
Instantiate a VerticalExtent.

Parameters
• minimumIn -- minimum.
• maximumIn -- maximum.
• unitIn -- unit.

Returns  
a new VerticalExtent.

class Extent : public osgeo::proj::util::BaseObject, public osgeo::proj::util::IComparable
#include <metadata.hpp> Information about spatial, vertical, and temporal extent.

Remark
Simplified version of Extent from GeoAPI

Public Functions

const util::optional<std::string> &description()  
Return a textual description of the extent.

Returns  
the description, or empty.

const std::vector<GeographicExtentNNPtr> &geographicElements()  
Return the geographic element(s) of the extent

Returns  
the geographic element(s), or empty.
const std::vector<TemporalExtentNNPtr> &temporalElements()

    Return the temporal element(s) of the extent
    
    Returns
    the temporal element(s), or empty.

cost std::vector<VerticalExtentNNPtr> &verticalElements()

    Return the vertical element(s) of the extent
    
    Returns
    the vertical element(s), or empty.

bool contains(const ExtentNNPtr &other) const

    Returns whether this extent contains the other one.
    
    Behavior only well specified if each sub-extent category as at most one element.

bool intersects(const ExtentNNPtr &other) const

    Returns whether this extent intersects the other one.
    
    Behavior only well specified if each sub-extent category as at most one element.

ExtentPtr intersection(const ExtentNNPtr &other) const

    Returns the intersection of this extent with another one.
    
    Behavior only well specified if there is one single GeographicExtent in each object. Returns nullptr otherwise.

Public Static Functions

static ExtentNNPtr create(const util::optional<std::string> &descriptionIn, const std::vector<GeographicExtentNNPtr> &geographicElementsIn, const std::vector<VerticalExtentNNPtr> &verticalElementsIn, const std::vector<TemporalExtentNNPtr> &temporalElementsIn)

    Instantiate a Extent.
    
    Parameters
    • descriptionIn -- Textual description, or empty.
    • geographicElementsIn -- Geographic element(s), or empty.
    • verticalElementsIn -- Vertical element(s), or empty.
    • temporalElementsIn -- Temporal element(s), or empty.
    
    Returns
    a new Extent.

static ExtentNNPtr createFromBBOX(double west, double south, double east, double north, const util::optional<std::string> &descriptionIn = util::optional<std::string>())

    Instantiate a Extent from a bounding box.
    
    Parameters
    • west -- Western-most coordinate of the limit of the dataset extent (in degrees).
    • south -- Southern-most coordinate of the limit of the dataset extent (in degrees).
    • east -- Eastern-most coordinate of the limit of the dataset extent (in degrees).
    • north -- Northern-most coordinate of the limit of the dataset extent (in degrees).
    • descriptionIn -- Textual description, or empty.
    
    Returns
    a new Extent.
**Public Static Attributes**

static const ExtentNNPtr WORLD
World extent.

class Identifier : public osgeo::proj::util::BaseObject, public osgeo::proj::io::IWKTExportable, public osgeo::proj::io::IJSONExportable

#include <metadata.hpp> Value uniquely identifying an object within a namespace.

**Remark**

Implements Identifier as described in ISO 19111:2019 but which originates from ISO 19115 (Metadata)

**Public Functions**

const util::optional<Citation> &authority()  
Return a citation for the organization responsible for definition and maintenance of the code.

Returns
the citation for the authority, or empty.

cost std::string &code()
Return the alphanumeric value identifying an instance in the codespace.

e.g. "4326" (for EPSG:4326 WGS 84 GeographicCRS)

Returns
the code.

cost util::optional<std::string> &codeSpace()
Return the organization responsible for definition and maintenance of the code.

e.g "EPSG"

Returns
the authority codespace, or empty.

cost util::optional<std::string> &version()
Return the version identifier for the namespace.

When appropriate, the edition is identified by the effective date, coded using ISO 8601 date format.

Returns
the version or empty.

cost util::optional<std::string> &description()
Return the natural language description of the meaning of the code value.

Returns
the description or empty.

cost util::optional<std::string> &uri()
Return the URI of the identifier.

Returns
the URI or empty.
**Public Static Functions**

```cpp
static IdentifierNNPtr create(const std::string &codeIn = std::string(), const util::PropertyMap &properties = util::PropertyMap())
```

Instantiate a `Identifier`.

**Parameters**
- `codeIn` -- Alphanumeric value identifying an instance in the codespace
- `properties` -- See `General properties`. Generally, the `Identifier::CODESPACE_KEY` should be set.

**Returns**
a new `Identifier`.

```cpp
static bool isEquivalentName(const char *a, const char *b) noexcept
```

Returns whether two names are considered equivalent.

Two names are equivalent by removing any space, underscore, dash, slash, { or } character from them, and comparing in a case insensitive way.

**Public Static Attributes**

```cpp
static const std::string AUTHORITY_KEY
```

Key to set the authority citation of a `metadata::Identifier`.

The value is to be provided as a string or a `metadata::Citation`.

```cpp
static const std::string CODE_KEY
```

Key to set the code of a `metadata::Identifier`.

The value is to be provided as an integer or a string.

```cpp
static const std::string CODESPACE_KEY
```

Key to set the organization responsible for definition and maintenance of the code of a `metadata::Identifier`.

The value is to be provided as a string.

```cpp
static const std::string VERSION_KEY
```

Key to set the version identifier for the namespace of a `metadata::Identifier`.

The value is to be provided as a string.

```cpp
static const std::string DESCRIPTION_KEY
```

Key to set the natural language description of the meaning of the code value of a `metadata::Identifier`.

The value is to be provided as a string.

```cpp
static const std::string URI_KEY
```

Key to set the URI of a `metadata::Identifier`.

The value is to be provided as a string.
static const std::string EPSG
   EPSG codespace.

static const std::string OGC
   OGC codespace.

class PositionalAccuracy : public osgeo::proj::util::BaseObject
   #include <metadata.hpp> Accuracy of the position of features.

Remark
Simplified version of PositionalAccuracy from GeoAPI, which originates from ISO 19115 (Metadata)

Public Functions

const std::string &value()
   Return the value of the positional accuracy.

Public Static Functions

static PositionalAccuracyNNPtr create(const std::string &valueIn)
   Instantiate a PositionalAccuracy.
   Parameters
      valueIn -- positional accuracy value.
   Returns
      a new PositionalAccuracy.

10.5.4.5 cs namespace

namespace cs
   Coordinate systems and their axis.
   osgeo.proj.cs namespace

Typesdefs

using MeridianPtr = std::shared_ptr<Meridian>
   Shared pointer of Meridian.

using MeridianNNPtr = util::nn<MeridianPtr>
   Non-null shared pointer of Meridian.
using CoordinateSystemAxisPtr = std::shared_ptr<CoordinateSystemAxis>
    Shared pointer of CoordinateSystemAxis.

using CoordinateSystemAxisNNPtr = util::nn<CoordinateSystemAxisPtr>
    Non-null shared pointer of CoordinateSystemAxis.

typedef std::shared_ptr<CoordinateSystem> CoordinateSystemPtr
    Shared pointer of CoordinateSystem.

typedef util::nn<CoordinateSystemPtr> CoordinateSystemNNPtr
    Non-null shared pointer of CoordinateSystem.

using SphericalCSPtr = std::shared_ptr<SphericalCS>
    Shared pointer of SphericalCS.

using SphericalCSNNPtr = util::nn<SphericalCSPtr>
    Non-null shared pointer of SphericalCS.

using EllipsoidalCSPtr = std::shared_ptr<EllipsoidalCS>
    Shared pointer of EllipsoidalCS.

using EllipsoidalCSNNPtr = util::nn<EllipsoidalCSPtr>
    Non-null shared pointer of EllipsoidalCS.

using VerticalCSPtr = std::shared_ptr<VerticalCS>
    Shared pointer of VerticalCS.

using VerticalCSNNPtr = util::nn<VerticalCSPtr>
    Non-null shared pointer of VerticalCS.

using CartesianCSPtr = std::shared_ptr<CartesianCS>
    Shared pointer of CartesianCS.

using CartesianCSNNPtr = util::nn<CartesianCSPtr>
    Non-null shared pointer of CartesianCS.

using AffineCSPtr = std::shared_ptr<AffineCS>
    Shared pointer of AffineCS.

using AffineCSNNPtr = util::nn<AffineCSPtr>
    Non-null shared pointer of AffineCS.

using OrdinalCSPtr = std::shared_ptr<OrdinalCS>
    Shared pointer of OrdinalCS.
using **OrdinalCSNNPtr** = util::nn<OrdinalCSPtr>
    Non-null shared pointer of **OrdinalCS**.

using **ParametricCSPtr** = std::shared_ptr<ParametricCS>
    Shared pointer of **ParametricCS**.

using **ParametricCSNNPtr** = util::nn<ParametricCSPtr>
    Non-null shared pointer of **ParametricCS**.

using **TemporalCSPtr** = std::shared_ptr<TemporalCS>
    Shared pointer of **TemporalCS**.

using **TemporalCSNNPtr** = util::nn<TemporalCSPtr>
    Non-null shared pointer of **TemporalCS**.

using **DateTimeTemporalCSPtr** = std::shared_ptr<DateTimeTemporalCS>
    Shared pointer of **DateTimeTemporalCS**.

using **DateTimeTemporalCSNNPtr** = util::nn<DateTimeTemporalCSPtr>
    Non-null shared pointer of **DateTimeTemporalCS**.

using **TemporalCountCSPtr** = std::shared_ptr<TemporalCountCS>
    Shared pointer of **TemporalCountCS**.

using **TemporalCountCSNNPtr** = util::nn<TemporalCountCSPtr>
    Non-null shared pointer of **TemporalCountCS**.

using **TemporalMeasureCSPtr** = std::shared_ptr<TemporalMeasureCS>
    Shared pointer of **TemporalMeasureCS**.

using **TemporalMeasureCSNNPtr** = util::nn<TemporalMeasureCSPtr>
    Non-null shared pointer of **TemporalMeasureCS**.

class **AxisDirection** : public osgeo::proj::util::CodeList

    #include <coordinatesystem.hpp> The direction of positive increase in the coordinate value for a coordinate system axis.

---

**Remark**

Implements **AxisDirection** from ISO 19111:2019
Public Static Attributes

static const AxisDirection NORTH
   Axis positive direction is north. In a geodetic or projected CRS, north is defined through the geodetic reference frame. In an engineering CRS, north may be defined with respect to an engineering object rather than a geographical direction.

static const AxisDirection NORTH_NORTH_EAST
   Axis positive direction is approximately north-north-east.

static const AxisDirection NORTH_EAST
   Axis positive direction is approximately north-east.

static const AxisDirection EAST_NORTH_EAST
   Axis positive direction is approximately east-north-east.

static const AxisDirection EAST
   Axis positive direction is 90deg clockwise from north.

static const AxisDirection EAST_SOUTH_EAST
   Axis positive direction is approximately east-south-east.

static const AxisDirection SOUTH_EAST
   Axis positive direction is approximately south-east.

static const AxisDirection SOUTH_SOUTH_EAST
   Axis positive direction is approximately south-south-east.

static const AxisDirection SOUTH
   Axis positive direction is 180deg clockwise from north.

static const AxisDirection SOUTH_SOUTH_WEST
   Axis positive direction is approximately south-south-west.

static const AxisDirection SOUTH_WEST
   Axis positive direction is approximately south-west.

static const AxisDirection WEST_SOUTH_WEST
   Axis positive direction is approximately west-south-west.

static const AxisDirection WEST
   Axis positive direction is 270deg clockwise from north.

static const AxisDirection WEST_NORTH_WEST
   Axis positive direction is approximately west-north-west.
static const AxisDirection NORTH_WEST
    Axis positive direction is approximately north-west.

static const AxisDirection NORTH_NORTH_WEST
    Axis positive direction is approximately north-north-west.

static const AxisDirection UP
    Axis positive direction is up relative to gravity.

static const AxisDirection DOWN
    Axis positive direction is down relative to gravity.

static const AxisDirection GEOCENTRIC_X
    Axis positive direction is in the equatorial plane from the centre of the modelled Earth towards the intersection of the equator with the prime meridian.

static const AxisDirection GEOCENTRIC_Y
    Axis positive direction is in the equatorial plane from the centre of the modelled Earth towards the intersection of the equator and the meridian 90deg eastwards from the prime meridian.

static const AxisDirection GEOCENTRIC_Z
    Axis positive direction is from the centre of the modelled Earth parallel to its rotation axis and towards its north pole.

static const AxisDirection COLUMN_POSITIVE
    Axis positive direction is towards higher pixel column.

static const AxisDirection COLUMN_NEGATIVE
    Axis positive direction is towards lower pixel column.

static const AxisDirection ROW_POSITIVE
    Axis positive direction is towards higher pixel row.

static const AxisDirection ROW_NEGATIVE
    Axis positive direction is towards lower pixel row.

static const AxisDirection DISPLAY_RIGHT
    Axis positive direction is right in display.

static const AxisDirection DISPLAY_LEFT
    Axis positive direction is left in display.

static const AxisDirection DISPLAY_UP
    Axis positive direction is towards top of approximately vertical display surface.
static const AxisDirection DISPLAY_DOWN
    Axis positive direction is towards bottom of approximately vertical display surface.

static const AxisDirection FORWARD
    Axis positive direction is forward; for an observer at the centre of the object this is will be towards its front, bow or nose.

static const AxisDirection AFT
    Axis positive direction is aft; for an observer at the centre of the object this will be towards its back, stern or tail.

static const AxisDirection PORT
    Axis positive direction is port; for an observer at the centre of the object this will be towards its left.

static const AxisDirection STARBOARD
    Axis positive direction is starboard; for an observer at the centre of the object this will be towards its right.

static const AxisDirection CLOCKWISE
    Axis positive direction is clockwise from a specified direction.

static const AxisDirection COUNTER_CLOCKWISE
    Axis positive direction is counter clockwise from a specified direction.

static const AxisDirection TOWARDS
    Axis positive direction is towards the object.

static const AxisDirection AWAY_FROM
    Axis positive direction is away from the object.

static const AxisDirection FUTURE
    Temporal axis positive direction is towards the future.

static const AxisDirection PAST
    Temporal axis positive direction is towards the past.

static const AxisDirection UNSPECIFIED
    Axis positive direction is unspecified.

class RangeMeaning : public osgeo::proj::util::CodeList
#include <coordinatesystem.hpp> Meaning of the axis value range specified through minimumValue and maximumValue.

Remark
PROJ coordinate transformation software library, Release 9.3.1

Implements RangeMeaning from ISO 19111:2019

Since
9.2

Public Static Attributes

static const RangeMeaning EXACT
    any value between and including minimumValue and maximumValue is valid.

static const RangeMeaning WRAPAROUND
    Axis is continuous with values wrapping around at the minimumValue and maximumValue

class Meridian : public osgeo::proj::common::IdentifiedObject, public osgeo::proj::io::IJSONExportable
#include <coordinatesystem.hpp> The meridian that the axis follows from the pole, for a coordinate reference system centered on a pole.

Remark
Implements MERIDIAN from WKT2 standard

Note: There is no modelling for this concept in ISO 19111:2019

Public Functions

const common::Angle &longitude()
    Return the longitude of the meridian that the axis follows from the pole.
    Returns
    the longitude.

Public Static Functions

static MeridianNNPtr create(const common::Angle &longitudeIn)
    Instantiate a Meridian.
    Parameters
    longitudeIn -- longitude of the meridian that the axis follows from the pole.
    Returns
    new Meridian.

class CoordinateSystemAxis : public osgeo::proj::common::IdentifiedObject, public osgeo::proj::io::IJSONExportable
#include <coordinatesystem.hpp> The definition of a coordinate system axis.
Public Functions

const std::string &abbreviation()

Return the axis abbreviation.

The abbreviation used for this coordinate system axis; this abbreviation is also used to identify the
coordinates in the coordinate tuple. Examples are X and Y.

Returns

the abbreviation.

const AxisDirection &direction()

Return the axis direction.

The direction of this coordinate system axis (or in the case of Cartesian projected coordinates, the
direction of this coordinate system axis locally) Examples: north or south, east or west, up or down.
Within any set of coordinate system axes, only one of each pair of terms can be used. For Earth-fixed
CRSs, this direction is often approximate and intended to provide a human interpretable meaning to
the axis. When a geodetic reference frame is used, the precise directions of the axes may therefore
vary slightly from this approximate direction. Note that an EngineeringCRS often requires specific
descriptions of the directions of its coordinate system axes.

Returns

the direction.

const common::UnitOfMeasure &unit()

Return the axis unit.

This is the spatial unit or temporal quantity used for this coordinate system axis. The value of a coor-
dinate in a coordinate tuple shall be recorded using this unit.

Returns

the axis unit.

const util::optional< double > &minimumValue()

Return the minimum value normally allowed for this axis, in the unit for the axis.

Returns

the minimum value, or empty.

const util::optional< double > &maximumValue()

Return the maximum value normally allowed for this axis, in the unit for the axis.

Returns

the maximum value, or empty.

const util::optional< RangeMeaning > &rangeMeaning()

Return the range meaning.

Since

9.2

Returns

the range meaning, or empty.
const MeridianPtr &meridian()

    Return the meridian that the axis follows from the pole, for a coordinate reference system centered on a pole.

Returns
the meridian, or null.

Public Static Functions

static CoordinateSystemAxisNNPtr create(const util::PropertyMap &properties, const std::string &abbreviationIn, const AxisDirection &directionIn, const common::UnitOfMeasure &unitIn, const MeridianPtr &meridianIn = nullptr)

Instantiate a CoordinateSystemAxis.

Parameters
• properties -- See General properties. The name should generally be defined.
• abbreviationIn -- Axis abbreviation (might be empty)
• directionIn -- Axis direction
• unitIn -- Axis unit
• meridianIn -- The meridian that the axis follows from the pole, for a coordinate reference system centered on a pole, or nullptr

Returns
a new CoordinateSystemAxis.

static CoordinateSystemAxisNNPtr create(const util::PropertyMap &properties, const std::string &abbreviationIn, const AxisDirection &directionIn, const common::UnitOfMeasure &unitIn, const util::optional<double> &minimumValueIn, const util::optional<double> &maximumValueIn, const util::optional<RangeMeaning> &rangeMeaningIn, const MeridianPtr &meridianIn = nullptr)

Instantiate a CoordinateSystemAxis.

Since
9.2

Parameters
• properties -- See General properties. The name should generally be defined.
• abbreviationIn -- Axis abbreviation (might be empty)
• directionIn -- Axis direction
• unitIn -- Axis unit
• minimumValueIn -- Minimum value along axis
• maximumValueIn -- Maximum value along axis
• rangeMeaningIn -- Range Meaning
• meridianIn -- The meridian that the axis follows from the pole, for a coordinate reference system centered on a pole, or nullptr

Returns
a new CoordinateSystemAxis.

class CoordinateSystem : public osgeo::proj::common::IdentifiedObject, public osgeo::proj::io::IJSONExportable

#include <coordinatesystem.hpp> Abstract class modelling a coordinate system (CS)
A CS is the non-repeating sequence of coordinate system axes that spans a given coordinate space. A CS is derived from a set of mathematical rules for specifying how coordinates in a given space are to be assigned to points. The coordinate values in a coordinate tuple shall be recorded in the order in which the coordinate system axes associations are recorded.

**Remark**

Implements *CoordinateSystem* from *ISO 19111:2019*

Subclassed by `osgeo::proj::cs::AffineCS`, `osgeo::proj::cs::CartesianCS`, `osgeo::proj::cs::EllipsoidalCS`, `osgeo::proj::cs::OrdinalCS`, `osgeo::proj::cs::ParametricCS`, `osgeo::proj::cs::SphericalCS`, `osgeo::proj::cs::TemporalCS`, `osgeo::proj::cs::VerticalCS`

**Public Functions**

```cpp
const std::vector<CoordinateSystemAxisNNPtr> &axisList()
```

Return the list of axes of this coordinate system.

**Returns**

the axes.

class SphericalCS : public osgeo::proj::cs::CoordinateSystem

#include <coordinatesystem.hpp> A three-dimensional coordinate system in Euclidean space with one distance measured from the origin and two angular coordinates.

Not to be confused with an ellipsoidal coordinate system based on an ellipsoid "degenerated" into a sphere. A *SphericalCS* shall have three axis associations.

**Remark**

Implements *SphericalCS* from *ISO 19111:2019*

**Public Static Functions**

```cpp
static SphericalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)
```

Instantiate a *SphericalCS*.

**Parameters**

- *properties* -- See *General properties*.
- *axis1* -- The first axis.
- *axis2* -- The second axis.
- *axis3* -- The third axis.

**Returns**

a new *SphericalCS*. 
static SphericalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2)

Instantiate a SphericalCS with 2 axis.

This is an extension to ISO19111 to support (planet)-ocentric CS with geocentric latitude.

Parameters
• properties -- See General properties.
• axis1 -- The first axis.
• axis2 -- The second axis.

Returns
a new SphericalCS.

class EllipsoidalCS : public osgeo::proj::cs::CoordinateSystem

#include <coordinatesystem.hpp> A two- or three-dimensional coordinate system in which position is specified by geodetic latitude, geodetic longitude, and (in the three-dimensional case) ellipsoidal height.

An EllipsoidalCS shall have two or three associations.

Remark
Implements EllipsoidalCS from ISO 19111:2019

Public Static Functions

static EllipsoidalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2)

Instantiate a EllipsoidalCS.

Parameters
• properties -- See General properties.
• axis1 -- The first axis.
• axis2 -- The second axis.

Returns
a new EllipsoidalCS.

static EllipsoidalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)

Instantiate a EllipsoidalCS.

Parameters
• properties -- See General properties.
• axis1 -- The first axis.
• axis2 -- The second axis.
• axis3 -- The third axis.

Returns
a new EllipsoidalCS.

static EllipsoidalCSNNPtr createLatitudeLongitude(const common::UnitOfMeasure &unit)

Instantiate a EllipsoidalCS with a Latitude (first) and Longitude (second) axis.
PROJ coordinate transformation software library, Release 9.3.1

Parameters
unit -- Angular unit of the axes.

Returns
a new EllipsoidalCS.

static EllipsoidalCSNNPtr createLatitudeLongitudeEllipsoidalHeight(const common::UnitOfMeasure &angularUnit, const common::UnitOfMeasure &linearUnit)

Instantiate a EllipsoidalCS with a Latitude (first), Longitude (second) axis and ellipsoidal height (third) axis.

Parameters
• angularUnit -- Angular unit of the latitude and longitude axes.
• linearUnit -- Linear unit of the ellipsoidal height axis.

Returns
a new EllipsoidalCS.

static EllipsoidalCSNNPtr createLongitudeLatitudeEllipsoidalHeight(const common::UnitOfMeasure &angularUnit, const common::UnitOfMeasure &linearUnit)

Instantiate a EllipsoidalCS with a Longitude (first), Latitude (second) axis and ellipsoidal height (third) axis.

Parameters
unit -- Angular unit of the axes.

Returns
a new EllipsoidalCS.

Since
7.0

Parameters
• angularUnit -- Angular unit of the latitude and longitude axes.
• linearUnit -- Linear unit of the ellipsoidal height axis.

Returns
a new EllipsoidalCS.

class VerticalCS : public osgeo::proj::cs::CoordinateSystem
#include <coordinatesystem.hpp> A one-dimensional coordinate system used to record the heights or depths of points.

Such a coordinate system is usually dependent on the Earth's gravity field. A VerticalCS shall have one axis association.

Remark
Implements *VerticalCS* from *ISO 19111:2019*

**Public Static Functions**

```cpp
static VerticalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)
```

Instantiate a *VerticalCS*.

**Parameters**

- *properties* -- See *General properties*.
- *axis* -- The axis.

**Returns**

a new *VerticalCS*.

```cpp
static VerticalCSNNPtr createGravityRelatedHeight(const common::UnitOfMeasure &unit)
```

Instantiate a *VerticalCS* with a Gravity-related height axis.

**Parameters**

- *unit* -- linear unit.

**Returns**

a new *VerticalCS*.

**class CartesianCS : public osgeo::proj::cs::CoordinateSystem**

```cpp
#include <coordinatesystem.hpp>
```

A two- or three-dimensional coordinate system in Euclidean space with orthogonal straight axes.

All axes shall have the same length unit. A *CartesianCS* shall have two or three axis associations; the number of associations shall equal the dimension of the CS.

**Remark**

Implements *CartesianCS* from *ISO 19111:2019*

**Public Static Functions**

```cpp
static CartesianCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2)
```

Instantiate a *CartesianCS*.

**Parameters**

- *properties* -- See *General properties*.
- *axis1* -- The first axis.
- *axis2* -- The second axis.

**Returns**

a new *CartesianCS*.

```cpp
static CartesianCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)
```

Instantiate a *CartesianCS*.
Parameters
• properties -- See General properties.
• axis1 -- The first axis.
• axis2 -- The second axis.
• axis3 -- The third axis.
Returns  a new CartesianCS.

static CartesianCSNNPtr createEastingNorthing(const common::UnitOfMeasure &unit)
    Instantiate a CartesianCS with a Easting (first) and Northing (second) axis.
Parameters
    unit -- Linear unit of the axes.
Returns  a new CartesianCS.

static CartesianCSNNPtr createNorthingEasting(const common::UnitOfMeasure &unit)
    Instantiate a CartesianCS with a Northing (first) and Easting (second) axis.
Parameters
    unit -- Linear unit of the axes.
Returns  a new CartesianCS.

static CartesianCSNNPtr createNorthPoleEastingSouthNorthingSouth(const common::UnitOfMeasure &unit)
    Instantiate a CartesianCS, north-pole centered, with a Easting (first) South-Oriented and Northing (second) South-Oriented axis.
Parameters
    unit -- Linear unit of the axes.
Returns  a new CartesianCS.

static CartesianCSNNPtr createSouthPoleEastingNorthNorthingNorth(const common::UnitOfMeasure &unit)
    Instantiate a CartesianCS, south-pole centered, with a Easting (first) North-Oriented and Northing (second) North-Oriented axis.
Parameters
    unit -- Linear unit of the axes.
Returns  a new CartesianCS.

static CartesianCSNNPtr createWestingSouthing(const common::UnitOfMeasure &unit)
    Instantiate a CartesianCS with a Westing (first) and Southing (second) axis.
Parameters
    unit -- Linear unit of the axes.
Returns  a new CartesianCS.

static CartesianCSNNPtr createGeocentric(const common::UnitOfMeasure &unit)
    Instantiate a CartesianCS with the three geocentric axes.
Parameters
    unit -- Linear unit of the axes.
Returns  a new CartesianCS.
class **AffineCS** : public osgeo::proj::cs::CoordinateSystem

#include <coordinatesystem.hpp>  A two- or three-dimensional coordinate system in Euclidean space with straight axes that are not necessarily orthogonal.

---

**Remark**

Implements **AffineCS** from *ISO 19111:2019*

---

**Since**

9.2

---

**Public Static Functions**

static **AffineCSNNPtr create** (const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2)

 Instantiate a **AffineCS**.

**Parameters**

- **properties** -- See *General properties*.
- **axis1** -- The first axis.
- **axis2** -- The second axis.

**Returns**

a new **AffineCS**.

static **AffineCSNNPtr create** (const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis1, const CoordinateSystemAxisNNPtr &axis2, const CoordinateSystemAxisNNPtr &axis3)

 Instantiate a **AffineCS**.

**Parameters**

- **properties** -- See *General properties*.
- **axis1** -- The first axis.
- **axis2** -- The second axis.
- **axis3** -- The third axis.

**Returns**

a new **AffineCS**.

---

class **OrdinalCS** : public osgeo::proj::cs::CoordinateSystem

#include <coordinatesystem.hpp>  n-dimensional coordinate system in which every axis uses integers.

The number of associations shall equal the dimension of the CS.

---

**Remark**

Implements **OrdinalCS** from *ISO 19111:2019*
Public Static Functions

static OrdinalCSNNPtr create(const util::PropertyMap &properties, const std::vector<CoordinateSystemAxisNNPtr> &axisIn)

Instantiate a OrdinalCS.

Parameters
• properties -- See General properties.
• axisIn -- List of axis.

Returns
a new OrdinalCS.

class ParametricCS : public osgeo::proj::cs::CoordinateSystem

#include <coordinatesystem.hpp> one-dimensional coordinate reference system which uses parameter values or functions that may vary monotonically with height.

Remark
Implements ParametricCS from ISO 19111:2019

Public Static Functions

static ParametricCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axisIn)

Instantiate a ParametricCS.

Parameters
• properties -- See General properties.
• axisIn -- Axis.

Returns
a new ParametricCS.

class TemporalCS : public osgeo::proj::cs::CoordinateSystem

#include <coordinatesystem.hpp> (Abstract class) A one-dimensional coordinate system used to record time.

A TemporalCS shall have one axis association.

Remark
Implements TemporalCS from ISO 19111:2019

Subclassed by osgeo::proj::cs::DateTimeTemporalCS, osgeo::proj::cs::TemporalCountCS, osgeo::proj::cs::TemporalMeasureCS

class DateTimeTemporalCS : public osgeo::proj::cs::TemporalCS

#include <coordinatesystem.hpp> A one-dimensional coordinate system used to record time in dateTime representation as defined in ISO 8601.
A *DateTimeTemporalCS* shall have one axis association. It does not use axisUnitID; the temporal quantities are defined through the ISO 8601 representation.

### Remark

Implements *DateTimeTemporalCS* from *ISO 19111:2019*

### Public Static Functions

```cpp
static DateTimeTemporalCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)
```

Instantiate a *DateTimeTemporalCS*.

**Parameters**

- `properties` -- See *General properties*.
- `axisIn` -- The axis.

**Returns**

a new *DateTimeTemporalCS*.

### class TemporalCountCS : public osgeo::proj::cs::TemporalCS

```cpp
#include <coordinatesystem.hpp>
```

A one-dimensional coordinate system used to record time as an integer count.

A *TemporalCountCS* shall have one axis association.

### Remark

Implements *TemporalCountCS* from *ISO 19111:2019*

### Public Static Functions

```cpp
static TemporalCountCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)
```

Instantiate a *TemporalCountCS*.

**Parameters**

- `properties` -- See *General properties*.
- `axisIn` -- The axis.

**Returns**

a new *TemporalCountCS*.

### class TemporalMeasureCS : public osgeo::proj::cs::TemporalCS

```cpp
#include <coordinatesystem.hpp>
```

A one-dimensional coordinate system used to record a time as a real number.

A *TemporalMeasureCS* shall have one axis association.
Remark
Implements TemporalMeasureCS from ISO 19111:2019

Public Static Functions

static TemporalMeasureCSNNPtr create(const util::PropertyMap &properties, const CoordinateSystemAxisNNPtr &axis)

Instantiate a TemporalMeasureCS.

Parameters
• properties -- See General properties.
• axisIn -- The axis.

Returns
a new TemporalMeasureCS.

10.5.4.6 datum namespace

namespace datum

Datum (the relationship of a coordinate system to the body).

osgeo.proj.datum namespace

Typedefs

typedef std::shared_ptr<Datum> DatumPtr

Shared pointer of Datum

typedef util::nn<DatumPtr> DatumNNPtr

Non-null shared pointer of Datum

typedef std::shared_ptr<DatumEnsemble> DatumEnsemblePtr

Shared pointer of DatumEnsemble

typedef util::nn<DatumEnsemblePtr> DatumEnsembleNNPtr

Non-null shared pointer of DatumEnsemble

typedef std::shared_ptr<PrimeMeridian> PrimeMeridianPtr

Shared pointer of PrimeMeridian

typedef util::nn<PrimeMeridianPtr> PrimeMeridianNNPtr

Non-null shared pointer of PrimeMeridian

typedef std::shared_ptr<Ellipsoid> EllipsoidPtr

Shared pointer of Ellipsoid
typedef `util::nn<EllipsoidPtr>` **EllipsoidNNPtr**  
Non-null shared pointer of **Ellipsoid**

typedef `std::shared_ptr<GeodeticReferenceFrame>` **GeodeticReferenceFramePtr**  
Shared pointer of **GeodeticReferenceFrame**

typedef `util::nn<GeodeticReferenceFramePtr>` **GeodeticReferenceFrameNNPtr**  
Non-null shared pointer of **GeodeticReferenceFrame**

using **DynamicGeodeticReferenceFramePtr** = `std::shared_ptr<DynamicGeodeticReferenceFrame>`  
Shared pointer of **DynamicGeodeticReferenceFrame**

using **DynamicGeodeticReferenceFrameNNPtr** = `util::nn<DynamicGeodeticReferenceFramePtr>`  
Non-null shared pointer of **DynamicGeodeticReferenceFrame**

typedef `std::shared_ptr<VerticalReferenceFrame>` **VerticalReferenceFramePtr**  
Shared pointer of **VerticalReferenceFrame**

typedef `util::nn<VerticalReferenceFramePtr>` **VerticalReferenceFrameNNPtr**  
Non-null shared pointer of **VerticalReferenceFrame**

using **DynamicVerticalReferenceFramePtr** = `std::shared_ptr<DynamicVerticalReferenceFrame>`  
Shared pointer of **DynamicVerticalReferenceFrame**

using **DynamicVerticalReferenceFrameNNPtr** = `util::nn<DynamicVerticalReferenceFramePtr>`  
Non-null shared pointer of **DynamicVerticalReferenceFrame**

using **TemporalDatumPtr** = `std::shared_ptr<TemporalDatum>`  
Shared pointer of **TemporalDatum**

using **TemporalDatumNNPtr** = `util::nn<TemporalDatumPtr>`  
Non-null shared pointer of **TemporalDatum**

using **EngineeringDatumPtr** = `std::shared_ptr<EngineeringDatum>`  
Shared pointer of **EngineeringDatum**

using **EngineeringDatumNNPtr** = `util::nn<EngineeringDatumPtr>`  
Non-null shared pointer of **EngineeringDatum**

using **ParametricDatumPtr** = `std::shared_ptr<ParametricDatum>`  
Shared pointer of **ParametricDatum**

using **ParametricDatumNNPtr** = `util::nn<ParametricDatumPtr>`  
Non-null shared pointer of **ParametricDatum**
class Datum : public osgeo::proj::common::ObjectUsage, public osgeo::proj::io::IJSONExportable
#include <datum.hpp>  
Abstract class of the relationship of a coordinate system to an object, thus creating a coordinate reference system.

For geodetic and vertical coordinate reference systems, it relates a coordinate system to the Earth (or the celestial body considered). With other types of coordinate reference systems, the datum may relate the coordinate system to another physical or virtual object. A datum uses a parameter or set of parameters that determine the location of the origin of the coordinate reference system. Each datum subtype can be associated with only specific types of coordinate reference systems.

Remark
Implements Datum from ISO 19111:2019

Subclassed by osgeo::proj::datum::EngineeringDatum, osgeo::proj::datum::GeodeticReferenceFrame, osgeo::proj::datum::ParametricDatum, osgeo::proj::datum::TemporalDatum, osgeo::proj::datum::VerticalReferenceFrame

Public Functions

const util::optional<std::string> &anchorDefinition() const
Return the anchor definition.

A description - possibly including coordinates of an identified point or points - of the relationship used to anchor a coordinate system to the Earth or alternate object.

• For modern geodetic reference frames the anchor may be a set of station coordinates; if the reference frame is dynamic it will also include coordinate velocities. For a traditional geodetic datum, this anchor may be a point known as the fundamental point, which is traditionally the point where the relationship between geoid and ellipsoid is defined, together with a direction from that point.

• For a vertical reference frame the anchor may be the zero level at one or more defined locations or a conventionally defined surface.

• For an engineering datum, the anchor may be an identified physical point with the orientation defined relative to the object.

Returns
the anchor definition, or empty.

const util::optional<common::Measure> &anchorEpoch() const
Return the anchor epoch.

Epoch at which a static reference frame matches a dynamic reference frame from which it has been derived.

Note: Not to be confused with the frame reference epoch of dynamic geodetic and dynamic vertical reference frames. Nor with the epoch at which a reference frame is defined to be aligned with another reference frame; this information should be included in the datum anchor definition.

Since
9.2

Returns
the anchor epoch, or empty.
const util::optional<common::DateTime> &publicationDate() const
Return the date on which the datum definition was published.

Note: Departure from ISO 19111:2019: we return a DateTime instead of a Citation::Date.

Returns
the publication date, or empty.

const common::IdentifiedObjectPtr &conventionalRS() const
Return the conventional reference system.
This is the name, identifier, alias and remarks for the terrestrial reference system or vertical reference system realized by this reference frame, for example "ITRS" for ITRF88 through ITRF2008 and ITRF2014, or "EVRS" for EVRF2000 and EVRF2007.

Returns
the conventional reference system, or nullptr.

class DatumEnsemble : public osgeo::proj::common::ObjectUsage, public osgeo::proj::io::IJSONExportable
#include <datum.hpp> A collection of two or more geodetic or vertical reference frames (or if not geodetic or vertical reference frame, a collection of two or more datums) which for all but the highest accuracy requirements may be considered to be insignificantly different from each other.
Every frame within the datum ensemble must be a realizations of the same Terrestrial Reference System or Vertical Reference System.

Remark
Implements DatumEnsemble from ISO 19111:2019

Public Functions

const std::vector<DatumNNPtr> &datums() const
Return the set of datums which may be considered to be insignificantly different from each other.

Returns
the set of datums of the DatumEnsemble.

const metadata::PositionalAccuracyNNPtr &positionalAccuracy() const
Return the inaccuracy introduced through use of this collection of datums.
It is an indication of the differences in coordinate values at all points between the various realizations that have been grouped into this datum ensemble.

Returns
the accuracy.
Public Static Functions

static DatumEnsembleNNPtr create(const util::PropertyMap &properties, const std::vector<DatumNNPtr> &datumsIn, const metadata::PositionalAccuracyNNPtr &accuracy)

Instantiate a DatumEnsemble.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• datumsIn -- Array of at least 2 datums.
• accuracy -- Accuracy of the datum ensemble

Throws
util::Exception --

Returns
new DatumEnsemble.

class PrimeMeridian : public osgeo::proj::common::IdentifiedObject, public osgeo::proj::io::IPROJStringExportable, public osgeo::proj::io::IJSONExportable
#include <datum.hpp> The origin meridian from which longitude values are determined.

Remark
Implements PrimeMeridian from ISO 19111:2019

Note: The default value for prime meridian name is "Greenwich". When the default applies, the value for the longitude shall be 0 (degrees).

Public Functions

const common::Angle &longitude()

Return the longitude of the prime meridian.

It is measured from the internationally-recognised reference meridian ('Greenwich meridian'), positive eastward. The default value is 0 degrees.

Returns
the longitude of the prime meridian.

Public Static Functions

static PrimeMeridianNNPtr create(const util::PropertyMap &properties, const common::Angle &longitudeIn)

Instantiate a PrimeMeridian.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• longitudeIn -- the longitude of the prime meridian.

Returns
new PrimeMeridian.
**Public Static Attributes**

static const `PrimeMeridianNNPtr` **GREENWICH**
The Greenwich `PrimeMeridian`.

static const `PrimeMeridianNNPtr` **REFERENCE_MERIDIAN**
The "Reference Meridian" `PrimeMeridian`.
This is a meridian of longitude 0 to be used with non-Earth bodies.

static const `PrimeMeridianNNPtr` **PARIS**
The Paris `PrimeMeridian`.

class **Ellipsoid** : public osgeo::proj::common::IdentifiedObject, public osgeo::proj::io::IPROJStringExportable, public osgeo::proj::io::IJSONExportable

#include <datum.hpp>

A geometric figure that can be used to describe the approximate shape of an object.

For the Earth an oblate biaxial ellipsoid is used: in mathematical terms, it is a surface formed by the rotation of an ellipse about its minor axis.

**Remark**

Implements **Ellipsoid** from **ISO 19111:2019**

**Public Functions**

const `common::Length &` **semiMajorAxis()**
Return the length of the semi-major axis of the ellipsoid.

**Returns**
the semi-major axis.

const `util::optional<common::Scale> &` **inverseFlattening()**
Return the inverse flattening value of the ellipsoid, if the ellipsoid has been defined with this value.

**See also:**
computeInverseFlattening() that will always return a valid value of the inverse flattening, whether the ellipsoid has been defined through inverse flattening or semi-minor axis.

**Returns**
the inverse flattening value of the ellipsoid, or empty.

const `util::optional<common::Length> &` **semiMinorAxis()**
Return the length of the semi-minor axis of the ellipsoid, if the ellipsoid has been defined with this value.

**See also:**
computeSemiMinorAxis() that will always return a valid value of the semi-minor axis, whether the ellipsoid has been defined through inverse flattening or semi-minor axis.
Returns
the semi-minor axis of the ellipsoid, or empty.

bool isSphere()
Return whether the ellipsoid is spherical.
That is to say is semiMajorAxis() == computeSemiMinorAxis().

A sphere is completely defined by the semi-major axis, which is the radius of the sphere.

Returns
true if the ellipsoid is spherical.

const util::optional<common::Length> &semiMedianAxis()
Return the length of the semi-median axis of a triaxial ellipsoid.
This parameter is not required for a biaxial ellipsoid.

Returns
the semi-median axis of the ellipsoid, or empty.

double computedInverseFlattening()
Return or compute the inverse flattening value of the ellipsoid.
If computed, the inverse flattening is the result of a / (a - b), where a is the semi-major axis and b the semi-minor axis.

Returns
the inverse flattening value of the ellipsoid, or 0 for a sphere.

double squaredEccentricity()
Return the squared eccentricity of the ellipsoid.
Returns
the squared eccentricity, or a negative value if invalid.

common::Length computeSemiMinorAxis() const
Return or compute the length of the semi-minor axis of the ellipsoid.
If computed, the semi-minor axis is the result of a * (1 - 1 / rf) where a is the semi-major axis and rf the reverse/inverse flattening.

Returns
the semi-minor axis of the ellipsoid.

const std::string &celestialBody()
Return the name of the celestial body on which the ellipsoid refers to.

EllipsoidNNPtr identify() const
Return a Ellipsoid object where some parameters are better identified.

Returns
a new Ellipsoid.

Public Static Functions

static EllipsoidNNPtr createSphere(const util::PropertyMap &properties, const common::Length &radius, const std::string &celestialBody = EARTH)
Instantiate a Ellipsoid as a sphere.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• radius -- the sphere radius (semi-major axis).
• celestialBody -- Name of the celestial body on which the ellipsoid refers to.
Returns
new Ellipsoid.

static EllipsoidNNPtr createFlattenedSphere(const util::PropertyMap &properties, const common::Length &semiMajorAxisIn, const common::Scale &invFlattening, const std::string &celestialBody = EARTH)

Instantiate a Ellipsoid from its inverse/reverse flattening.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• semiMajorAxisIn -- the semi-major axis.
• invFlattening -- the inverse/reverse flattening. If set to 0, this will be considered as a sphere.
• celestialBody -- Name of the celestial body on which the ellipsoid refers to.

Returns
new Ellipsoid.

static EllipsoidNNPtr createTwoAxis(const util::PropertyMap &properties, const common::Length &semiMajorAxisIn, const common::Length &semiMinorAxisIn, const std::string &celestialBody = EARTH)

Instantiate a Ellipsoid from the value of its two semi axis.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• semiMajorAxisIn -- the semi-major axis.
• semiMinorAxisIn -- the semi-minor axis.
• celestialBody -- Name of the celestial body on which the ellipsoid refers to.

Returns
new Ellipsoid.

Public Static Attributes

static const std::string EARTH
Earth celestial body.

static const EllipsoidNNPtr CLARKE_1866
The EPSG:7008 / "Clarke 1866" Ellipsoid.

static const EllipsoidNNPtr WGS84
The EPSG:7030 / "WGS 84" Ellipsoid.

static const EllipsoidNNPtr GRS1980

class GeodeticReferenceFrame : public osgeo::proj::datum::Datum
#include <datum.hpp> The definition of the position, scale and orientation of a geocentric Cartesian 3D coordinate system relative to the Earth.

It may also identify a defined ellipsoid (or sphere) that approximates the shape of the Earth and which is centred on and aligned to this geocentric coordinate system. Older geodetic datums define the location and orientation of a defined ellipsoid (or sphere) that approximates the shape of the earth.
Remark
Implements GeodeticReferenceFrame from ISO 19111:2019

Note: The terminology “Datum” is often used to mean a GeodeticReferenceFrame.

Note: In ISO 19111:2007, this class was called GeodeticDatum.

Subclassed by osgeo::proj::datum::DynamicGeodeticReferenceFrame

Public Functions

const PrimeMeridianNNPtr &primeMeridian()

Return the PrimeMeridian associated with a GeodeticReferenceFrame.

Returns
the PrimeMeridian.

const EllipsoidNNPtr &ellipsoid()

Return the Ellipsoid associated with a GeodeticReferenceFrame.

Note: The ISO 19111:2019 modelling allows (but discourages) a GeodeticReferenceFrame to not be associated with a Ellipsoid in the case where it is used by a geocentric crs::GeodeticCRS. We have made the choice of making the ellipsoid specification compulsory.

Returns
the Ellipsoid.

Public Static Functions

static GeodeticReferenceFrameNNPtr create(const util::PropertyMap &properties, const EllipsoidNNPtr &ellipsoid, const util::optional<std::string> &anchor, const PrimeMeridianNNPtr &primeMeridian)

Instantiate a GeodeticReferenceFrame.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• ellipsoid -- the Ellipsoid.
• anchor -- the anchor definition, or empty.
• primeMeridian -- the PrimeMeridian.

Returns
new GeodeticReferenceFrame.

static GeodeticReferenceFrameNNPtr create(const util::PropertyMap &properties, const EllipsoidNNPtr &ellipsoid, const util::optional<std::string> &anchor, const util::optional<common::Measure> &anchorEpoch, const PrimeMeridianNNPtr &primeMeridian)
Instantiate a \textit{GeodeticReferenceFrame}.

\textbf{Since} 9.2

\textbf{Parameters}

- \textbf{properties} -- See \textit{General properties}. At minimum the name should be defined.
- \textbf{ellipsoid} -- the \textit{Ellipsoid}.
- \textbf{anchor} -- the anchor definition, or empty.
- \textbf{anchorEpoch} -- the anchor epoch, or empty.
- \textbf{primeMeridian} -- the \textit{PrimeMeridian}.

\textbf{Returns}

new \textit{GeodeticReferenceFrame}.

\textbf{Public Static Attributes}

static const \textit{GeodeticReferenceFrame}\textit{NNPtr EPSG\_6267}

The EPSG:6267 / "North\_American\_Datum\_1927" \textit{GeodeticReferenceFrame}.

static const \textit{GeodeticReferenceFrame}\textit{NNPtr EPSG\_6269}

The EPSG:6269 / "North\_American\_Datum\_1983" \textit{GeodeticReferenceFrame}.

static const \textit{GeodeticReferenceFrame}\textit{NNPtr EPSG\_6326}

The EPSG:6326 / "WGS\_1984" \textit{GeodeticReferenceFrame}.

\textbf{class} \textit{DynamicGeodeticReferenceFrame} : public \textit{osgeo::proj\::datum\::GeodeticReferenceFrame}

\textit{#include <datum.hpp>} A geodetic reference frame in which some of the parameters describe time evolution of defining station coordinates.

For example defining station coordinates having linear velocities to account for crustal motion.

\textbf{Remark}

Implements \textit{DynamicGeodeticReferenceFrame} from \textit{ISO 19111:2019}

\textbf{Public Functions}

\textbf{const \textit{common\::Measure &\textbf{\_frameReferenceEpoch}()} const}

Return the epoch to which the coordinates of stations defining the dynamic geodetic reference frame are referenced.

Usually given as a decimal year e.g. 2016.47.

\textbf{Returns}

the frame reference epoch.
const `util::optional<std::string>` &`deformationModelName`() const

   Return the name of the deformation model.

**Note:** This is an extension to the *ISO 19111:2019* modeling, to hold the content of the DYNAMIC.MODEL WKT2 node.

**Returns**

the name of the deformation model.

**Public Static Functions**

```cpp
delete DynamicGeodeticReferenceFrameNNPtr create(const `util::PropertyMap` &properties, const `EllipsoidNNPtr` &ellipsoid, const `util::optional<std::string>` &anchor, const `PrimeMeridianNNPtr` &primeMeridian, const `common::Measure` &frameReferenceEpochIn, const `util::optional<std::string>` &deformationModelNameIn)
```

Instantiate a *DynamicGeodeticReferenceFrame*.

**Parameters**

- `properties` -- See *General properties*. At minimum the name should be defined.
- `ellipsoid` -- the *Ellipsoid*.
- `anchor` -- the anchor definition, or empty.
- `primeMeridian` -- the *PrimeMeridian*.
- `frameReferenceEpochIn` -- the frame reference epoch.
- `deformationModelNameIn` -- deformation model name, or empty

**Returns**

new *DynamicGeodeticReferenceFrame*.

**Class** `RealizationMethod`: public osgeo::proj::util::CodeList

`#include <datum.hpp>` The specification of the method by which the vertical reference frame is realized.

**Remark**

Implements `RealizationMethod` from *ISO 19111:2019*

**Public Static Attributes**

```cpp
deletestatic const `RealizationMethod` LEVELLING
```

The realization is by adjustment of a levelling network fixed to one or more tide gauges.

```cpp
deletestatic const `RealizationMethod` GEOID
```

The realization is through a geoid height model or a height correction model. This is applied to a specified geodetic CRS.
static const RealizationMethod TIDAL
    The realization is through a tidal model or by tidal predictions.

class VerticalReferenceFrame : public osgeo::proj::datum::Datum
#include <datum.hpp> A textual description and/or a set of parameters identifying a particular reference
level surface used as a zero-height or zero-depth surface, including its position with respect to the Earth.

Remark
Implements VerticalReferenceFrame from ISO 19111:2019

Note: In ISO 19111:2007, this class was called VerticalDatum.

Subclassed by osgeo::proj::datum::DynamicVerticalReferenceFrame

Public Functions

const util::optional<RealizationMethod> &realizationMethod() const
    Return the method through which this vertical reference frame is realized.
    
    Returns
    the realization method.

Public Static Functions

static VerticalReferenceFrameNNPtr create(const util::PropertyMap &properties, const
    util::optional<std::string> &anchor =
    util::optional<std::string>(), const
    util::optional<RealizationMethod> &realizationMethodIn
    = util::optional<RealizationMethod>())
    Instantiate a VerticalReferenceFrame.
    
    Parameters
    • properties -- See General properties. At minimum the name should be defined.
    • anchor -- the anchor definition, or empty.
    • realizationMethodIn -- the realization method, or empty.
    
    Returns
    new VerticalReferenceFrame.

static VerticalReferenceFrameNNPtr create(const util::PropertyMap &properties, const
    util::optional<std::string> &anchor, const
    util::optional<common::Measure> &anchorEpoch, const
    util::optional<RealizationMethod> &realizationMethodIn
    = util::optional<RealizationMethod>())
    Instantiate a VerticalReferenceFrame.

Since 9.2
Parameters
- **properties** -- See General properties. At minimum the name should be defined.
- **anchor** -- the anchor definition, or empty.
- **anchorEpoch** -- the anchor epoch, or empty.
- **realizationMethodIn** -- the realization method, or empty.

Returns
new `VerticalReferenceFrame`.

class **DynamicVerticalReferenceFrame** : public osgeo::proj::datum::VerticalReferenceFrame

#include `<datum.hpp>` A vertical reference frame in which some of the defining parameters have time dependency.

For example defining station heights have velocity to account for post-glacial isostatic rebound motion.

Remark
Implements `DynamicVerticalReferenceFrame` from ISO 19111:2019

Public Functions

const `common::Measure & frameReferenceEpoch()` const

Return the epoch to which the coordinates of stations defining the dynamic geodetic reference frame are referenced.

Usually given as a decimal year e.g. 2016.47.

Returns
the frame reference epoch.

const `util::optional<std::string> & deformationModelName()` const

Return the name of the deformation model.

**Note:** This is an extension to the ISO 19111:2019 modeling, to hold the content of the DYNAMIC.MODEL WKT2 node.

Returns
the name of the deformation model.

Public Static Functions

static `DynamicVerticalReferenceFrameNNPtr create(const util::PropertyMap &properties, const util::optional<std::string> &anchor, const util::optional<RealizationMethod> &realizationMethodIn, const common::Measure &frameReferenceEpochIn, const util::optional<std::string> &deformationModelNameIn)`

Instantiate a `DynamicVerticalReferenceFrame`.

Parameters
- **properties** -- See General properties. At minimum the name should be defined.
PROJ coordinate transformation software library, Release 9.3.1

- **anchor** -- the anchor definition, or empty.
- **realizationMethodIn** -- the realization method, or empty.
- **frameReferenceEpochIn** -- the frame reference epoch.
- **deformationModelNameIn** -- deformation model name, or empty

**Returns**
new `DynamicVerticalReferenceFrame`

class **TemporalDatum** : public osgeo::proj::datum::Datum

```
#include <datum.hpp>
```

The definition of the relationship of a temporal coordinate system to an object. The object is normally time on the Earth.

**Remark**

Implements `TemporalDatum` from ISO 19111:2019

**Public Functions**

```
const common::DateTime &temporalOrigin() const
```

Return the date and time to which temporal coordinates are referenced, expressed in conformance with ISO 8601.

**Returns**
the temporal origin.

```
const std::string &calendar() const
```

Return the calendar to which the temporal origin is referenced.

Default value: `TemporalDatum::CALENDAR_PROLEPTIC_GREGORIAN`.

**Returns**
the calendar.

**Public Static Functions**

```
static TemporalDatumNNPtr create(const util::PropertyMap &properties, const common::DateTime &temporalOriginIn, const std::string &calendarIn)
```

Instantiate a `TemporalDatum`.

**Parameters**
- **properties** -- See General properties. At minimum the name should be defined.
- **temporalOriginIn** -- the temporal origin into which temporal coordinates are referenced.
- **calendarIn** -- the calendar (generally `TemporalDatum::CALENDAR_PROLEPTIC_GREGORIAN`)

**Returns**
new `TemporalDatum`. 
Public Static Attributes

static const std::string CALEND\~AR\_\~PROLEPTIC\_GREGORIAN
   The proleptic Gregorian calendar.

class EngineeringDatum : public osgeo::proj::Datum
   #include <datum.hpp> The definition of the origin and orientation of an engineering coordinate reference system.

Remark

Implements EngineeringDatum from ISO 19111:2019

Note: The origin can be fixed with respect to the Earth (such as a defined point at a construction site), or be a defined point on a moving vehicle (such as on a ship or satellite), or a defined point of an image.

Public Static Functions

static EngineeringDatumNNPtr create(const util::PropertyMap &properties, const
   util::optional<std::string> &anchor =
   util::optional<std::string>())

   Instantiate a EngineeringDatum.

   Parameters
     • properties -- See General properties. At minimum the name should be defined.
     • anchor -- the anchor definition, or empty.

   Returns
     new EngineeringDatum.

class ParametricDatum : public osgeo::proj::Datum
   #include <datum.hpp> Textual description and/or a set of parameters identifying a particular reference surface used as the origin of a parametric coordinate system, including its position with respect to the Earth.

Remark

Implements ParametricDatum from ISO 19111:2019
Public Static Functions

static ParametricDatumNNPtr create(const util::PropertyMap &properties, const util::optional<std::string> &anchor = util::optional<std::string>())

Instantiate a ParametricDatum.

Parameters

- properties -- See General properties. At minimum the name should be defined.
- anchor -- the anchor definition, or empty.

Returns

new ParametricDatum.

10.5.4.7 crs namespace

namespace crs

CRS (coordinate reference system = coordinate system with a datum).

osgeo.proj.crs namespace

Typedefs

typedef std::shared_ptr<CRS> CRSPtr
  Shared pointer of CRS

typedef util::nn<CRSPtr> CRSNNPtr
  Non-null shared pointer of CRS

typedef std::shared_ptr<GeographicCRS> GeographicCRSPtr
  Shared pointer of GeographicCRS

typedef util::nn<GeographicCRSPtr> GeographicCRSNNPtr
  Non-null shared pointer of GeographicCRS

typedef std::shared_ptr<VerticalCRS> VerticalCRSPtr
  Shared pointer of VerticalCRS

typedef util::nn<VerticalCRSPtr> VerticalCRSNNPtr
  Non-null shared pointer of VerticalCRS

using BoundCRSPtr = std::shared_ptr<BoundCRS>
  Shared pointer of BoundCRS

using BoundCRSNNPtr = util::nn<BoundCRSPtr>
  Non-null shared pointer of BoundCRS
typedef std::shared_ptr<CompoundCRS> CompoundCRSPtr
    Shared pointer of CompoundCRS

typedef util::nn<CompoundCRSPtr> CompoundCRSNNPtr
    Non-null shared pointer of CompoundCRS

using SingleCRSPtr = std::shared_ptr<SingleCRS>
    Shared pointer of SingleCRS

using SingleCRSNNPtr = util::nn<SingleCRSPtr>
    Non-null shared pointer of SingleCRS

typedef std::shared_ptr<GeodeticCRS> GeodeticCRSPtr
    Shared pointer of GeodeticCRS

typedef util::nn<GeodeticCRSPtr> GeodeticCRSNNPtr
    Non-null shared pointer of GeodeticCRS

using DerivedCRSPtr = std::shared_ptr<DerivedCRS>
    Shared pointer of DerivedCRS

using DerivedCRSNNPtr = util::nn<DerivedCRSPtr>
    Non-null shared pointer of DerivedCRS

typedef std::shared_ptr<ProjectedCRS> ProjectedCRSPtr
    Shared pointer of ProjectedCRS

typedef util::nn<ProjectedCRSPtr> ProjectedCRSNNPtr
    Non-null shared pointer of ProjectedCRS

using TemporalCRSPtr = std::shared_ptr<TemporalCRS>
    Shared pointer of TemporalCRS

using TemporalCRSNNPtr = util::nn<TemporalCRSPtr>
    Non-null shared pointer of TemporalCRS

using EngineeringCRSPtr = std::shared_ptr<EngineeringCRS>
    Shared pointer of EngineeringCRS

using EngineeringCRSNNPtr = util::nn<EngineeringCRSPtr>
    Non-null shared pointer of EngineeringCRS

using ParametricCRSPtr = std::shared_ptr<ParametricCRS>
    Shared pointer of ParametricCRS
using `ParametricCRSNNPtr = util::nn<ParametricCRS>`
Non-null shared pointer of `ParametricCRS`

using `DerivedGeodeticCRSPPtr = std::shared_ptr<DerivedGeodeticCRS>`
Shared pointer of `DerivedGeodeticCRS`

using `DerivedGeodeticCRSNNPtr = util::nn<DerivedGeodeticCRS>`
Non-null shared pointer of `DerivedGeodeticCRS`

using `DerivedGeodeticCRSNNPtr = util::nn<DerivedGeodeticCRS>`
Non-null shared pointer of `DerivedGeodeticCRS`

using `DerivedGeographicCRSPPtr = std::shared_ptr<DerivedGeographicCRS>`
Shared pointer of `DerivedGeographicCRS`

using `DerivedGeographicCRSNNPtr = util::nn<DerivedGeographicCRS>`
Non-null shared pointer of `DerivedGeographicCRS`

using `DerivedGeographicCRSNNPtr = util::nn<DerivedGeographicCRS>`
Non-null shared pointer of `DerivedGeographicCRS`

using `DerivedProjectedCRSPPtr = std::shared_ptr<DerivedProjectedCRS>`
Shared pointer of `DerivedProjectedCRS`

using `DerivedProjectedCRSNNPtr = util::nn<DerivedProjectedCRS>`
Non-null shared pointer of `DerivedProjectedCRS`

using `DerivedProjectedCRSNNPtr = util::nn<DerivedProjectedCRS>`
Non-null shared pointer of `DerivedProjectedCRS`

using `DerivedVerticalCRSPPtr = std::shared_ptr<DerivedVerticalCRS>`
Shared pointer of `DerivedVerticalCRS`

using `DerivedVerticalCRSNNPtr = util::nn<DerivedVerticalCRS>`
Non-null shared pointer of `DerivedVerticalCRS`

using `DerivedVerticalCRSNNPtr = util::nn<DerivedVerticalCRS>`
Non-null shared pointer of `DerivedVerticalCRS`

using `DerivedEngineeringCRSPPtr = std::shared_ptr<DerivedEngineeringCRS>`
Shared pointer of `DerivedEngineeringCRS`

using `DerivedEngineeringCRSNNPtr = util::nn<DerivedEngineeringCRS>`
Non-null shared pointer of `DerivedEngineeringCRS`

using `DerivedParametricCRSPPtr = std::shared_ptr<DerivedParametricCRS>`
Shared pointer of `DerivedParametricCRS`

using `DerivedParametricCRSNNPtr = util::nn<DerivedParametricCRS>`
Non-null shared pointer of `DerivedParametricCRS`

using `DerivedTemporalCRSPPtr = std::shared_ptr<DerivedTemporalCRS>`
Shared pointer of `DerivedTemporalCRS`

using `DerivedTemporalCRSNNPtr = util::nn<DerivedTemporalCRS>`
Non-null shared pointer of `DerivedTemporalCRS`
class CRS : public osgeo::proj::common::ObjectUsage, public osgeo::proj::io::IJSONExportable

#include <crs.hpp> Abstract class modelling a coordinate reference system which is usually single but may be compound.

Remark
Implements CRS from ISO 19111:2019

Subclassed by osgeo::proj::crs::BoundCRS, osgeo::proj::crs::CompoundCRS, osgeo::proj::crs::SingleCRS

Public Functions

bool isDynamic(bool considerWGS84AsDynamic = false) const
Return whether a CRS is a dynamic CRS.
A dynamic CRS is a CRS that contains a geodetic CRS whose geodetic reference frame is dynamic, or a vertical CRS whose vertical reference frame is dynamic.
Since
9.2

Parameters
considerWGS84AsDynamic -- set to true to consider the WGS 84 / EPSG:6326 datum ensemble as dynamic.

GeodeticCRSPtr extractGeodeticCRS() const
Return the GeodeticCRS of the CRS.
Returns the GeodeticCRS contained in a CRS. This works currently with input parameters of type GeodeticCRS or derived, ProjectedCRS, CompoundCRS or BoundCRS.
Returns
a GeodeticCRSPtr, that might be null.

GeographicCRSPtr extractGeographicCRS() const
Return the GeographicCRS of the CRS.
Returns the GeographicCRS contained in a CRS. This works currently with input parameters of type GeographicCRS or derived, ProjectedCRS, CompoundCRS or BoundCRS.
Returns
a GeographicCRSPtr, that might be null.

VerticalCRSPtr extractVerticalCRS() const
Return the VerticalCRS of the CRS.
Returns the VerticalCRS contained in a CRS. This works currently with input parameters of type VerticalCRS or derived, CompoundCRS or BoundCRS.
Returns
a VerticalCRSPtr, that might be null.

CRSNNPtr createBoundCRSToWGS84IfPossible(const io::DatabaseContextPtr &dbContext, operation::CoordinateOperationContext::IntermediateCRSUse allowIntermediateCRSUse) const
Returns potentially a BoundCRS, with a transformation to EPSG:4326, wrapping this CRS.
If no such \textit{BoundCRS} is possible, the object will be returned.

The purpose of this method is to be able to format a PROJ.4 string with a +towgs84 parameter or a WKT1:GDAL string with a TOWGS node.

This method will fetch the \textit{GeographicCRS} of this \textit{CRS} and find a transformation to EPSG:4326 using the domain of the validity of the main \textit{CRS}, and there's only one Helmert transformation.

\begin{verbatim}
Returns
a CRS.
\end{verbatim}

\begin{verbatim}
CRSNNPtr stripVerticalComponent() const

Returns a CRS whose coordinate system does not contain a vertical component.
\end{verbatim}

\begin{verbatim}
const BoundCRSPtr &canonicalBoundCRS()

Return the \textit{BoundCRS} potentially attached to this \textit{CRS}.

In the case this method is called on a object returned by \textit{BoundCRS::baseCRSWithCanonicalBoundCRS()}, this method will return this \textit{BoundCRS}.

\begin{verbatim}
Returns
a BoundCRSPtr, that might be null.
\end{verbatim}

\begin{verbatim}
std::list<CRSNNPtr, int> identify(const io::AuthorityFactoryPtr &authorityFactory) const

Identify the \textit{CRS} with reference \textit{CRS}s.

The candidate \textit{CRS}s are either hard-coded, or looked in the database when \textit{authorityFactory} is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference \textit{CRS}, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

\begin{itemize}
  \item 100\% means that the name of the reference entry perfectly matches the \textit{CRS} name, and both are equivalent. In which case a single result is returned. Note: in the case of a \textit{GeographicCRS} whose axis order is implicit in the input definition (for example ESRI WKT), then axis order is ignored for the purpose of identification. That is the \textit{CRS} built from \textit{OGC[:GCS_WGS_1984, DATUM[D_WGS_1984, SPHEROID[WGS_1984, 6378137.0, 298.257223563]], PRIMEM[Greenwich], 0.0], UNIT[Degree], 0.0174532925199433]} will be identified to EPSG:4326, but will not pass a isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT) test, but rather isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS)
  \item 90\% means that \textit{CRS} are equivalent, but the names are not exactly the same.
  \item 70\% means that \textit{CRS} are equivalent, but the names do not match at all.
  \item 25\% means that the \textit{CRS} are not equivalent, but there is some similarity in the names.
\end{itemize}

Other confidence values may be returned by some specialized implementations.

This is implemented for \textit{GeodeticCRS}, \textit{ProjectedCRS}, \textit{VerticalCRS} and \textit{CompoundCRS}.

\begin{verbatim}
Parameters
  authorityFactory -- Authority factory (or null, but degraded functionality)
\end{verbatim}

\begin{verbatim}
Returns
a list of matching reference \textit{CRS}, and the percentage (0-100) of confidence in the match.
\end{verbatim}

\begin{verbatim}
std::list<CRSNNPtr> getNonDeprecated(const io::DatabaseContextNNPtr &dbContext) const

Return \textit{CRS}s that are non-deprecated substitutes for the current \textit{CRS}.
\end{verbatim}

\begin{verbatim}
CRSNNPtr promoteTo3D(const std::string &newName, const io::DatabaseContextPtr &dbContext) const

Return a variant of this \textit{CRS} "promoted" to a 3D one, if not already the case.
\end{verbatim}
The new axis will be ellipsoidal height, oriented upwards, and with metre units.

**Since**
6.3

**Parameters**
- `newName` -- Name of the new CRS. If empty, `nameStr()` will be used.
- `dbContext` -- Database context to look for potentially already registered 3D CRS. May be nullptr.

**Returns**
a new CRS promoted to 3D, or the current one if already 3D or not applicable.

```cpp
CRSNNPtr demoteTo2D(const std::string &newName, const io::DatabaseContextPtr &dbContext) const
```
Return a variant of this CRS "demoted" to a 2D one, if not already the case.

**Since**
6.3

**Parameters**
- `newName` -- Name of the new CRS. If empty, `nameStr()` will be used.
- `dbContext` -- Database context to look for potentially already registered 2D CRS. May be nullptr.

**Returns**
a new CRS demoted to 2D, or the current one if already 2D or not applicable.

```cpp
class SingleCRS : public osgeo::proj::crs::CRS
```
#include <crs.hpp>
Abstract class modelling a coordinate reference system consisting of one Coordinate System and either one `datum::Datum` or one `datum::DatumEnsemble`.

**Remark**

Implements `SingleCRS` from *ISO 19111:2019*

Subclassed by `osgeo::proj::crs::DerivedCRS`, `osgeo::proj::crs::EngineeringCRS`, `osgeo::proj::crs::GeodeticCRS`, `osgeo::proj::crs::ParametricCRS`, `osgeo::proj::crs::TemporalCRS`, `osgeo::proj::crs::VerticalCRS`

**Public Functions**

```cpp
const datum::DatumPtr &datum() const
```
Return the `datum::Datum` associated with the CRS.
This might be null, in which case `datumEnsemble()` return will not be null.

**Returns**
a Datum that might be null.

```cpp
const datum::DatumEnsemblePtr &datumEnsemble() const
```
Return the `datum::DatumEnsemble` associated with the CRS.
This might be null, in which case `datum()` return will not be null.

**Returns**
a DatumEnsemble that might be null.
const `cs::CoordinateSystemNNPtr &coordinateSystem()`

Return the `cs::CoordinateSystem` associated with the CRS.

Returns

a CoordinateSystem.

class `GeodeticCRS` : public virtual `osgeo::proj::crs::SingleCRS`, public `osgeo::proj::io::IPROJStringExportable`

#include `<crs.hpp>` A coordinate reference system associated with a geodetic reference frame and a three-dimensional Cartesian or spherical coordinate system.

If the geodetic reference frame is dynamic or if the geodetic CRS has an association to a velocity model then the geodetic CRS is dynamic, else it is static.

Remark

Implements `GeodeticCRS` from ISO 19111:2019

Subclassed by osgeo::proj::crs::DerivedGeodeticCRS, osgeo::proj::crs::GeographicCRS

Public Functions

c const `datum::GeodeticReferenceFramePtr &datum()`

Return the `datum::GeodeticReferenceFrame` associated with the CRS.

Returns

a GeodeticReferenceFrame or null (in which case `datumEnsemble()` should return a non-null pointer.)

c const `datum::PrimeMeridianNNPtr &primeMeridian()`

Return the PrimeMeridian associated with the GeodeticReferenceFrame or with one of the GeodeticReferenceFrame of the `datumEnsemble()`.

Returns

the PrimeMeridian.

c const `datum::EllipsoidNNPtr &ellipsoid()`

Return the ellipsoid associated with the GeodeticReferenceFrame or with one of the GeodeticReferenceFrame of the `datumEnsemble()`.

Returns

the PrimeMeridian.

c const `std::vector<operation::PointMotionOperationNNPtr> &velocityModel()`

Return the velocity model associated with the CRS.

Returns

a velocity model. might be null.

c bool `isGeocentric()`

Return whether the CRS is a Cartesian geocentric one.

A geocentric CRS is a geodetic CRS that has a Cartesian coordinate system with three axis, whose direction is respectively `cs::AxisDirection::GEOCENTRIC_X`, `cs::AxisDirection::GEOCENTRIC_Y` and `cs::AxisDirection::GEOCENTRIC_Z`.

Returns

true if the CRS is a geocentric CRS.
bool isSphericalPlanetocentric()
    Return whether the CRS is a Spherical planetocentric one.

    A Spherical planetocentric CRS is a geodetic CRS that has a spherical (angular) coordinate system with 2 axis, which represent geocentric latitude/ longitude or longitude/geocentric latitude.

    Such CRS are typically used in use case that apply to non-Earth bodies.

Since
   8.2

Returns
    true if the CRS is a Spherical planetocentric CRS.

std::list<std::pair<GeodeticCRSNNPtr, int>> identify(const io::AuthorityFactoryPtr &authorityFactory) const

Identify the CRS with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference CRS, and the percentage (0-100) of confidence in the match:

• 100% means that the name of the reference entry perfectly matches the CRS name, and both are equivalent. In which case a single result is returned. Note: in the case of a GeographicCRS whose axis order is implicit in the input definition (for example ESRI WKT), then axis order is ignored for the purpose of identification. That is the CRS built from GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]], PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433]] will be identified to EPSG:4326, but will not pass a isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT) test, but rather isEquivalentTo(EPSG_4326, util::IComparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS)
• 90% means that CRS are equivalent, but the names are not exactly the same.
• 70% means that CRS are equivalent (equivalent datum and coordinate system), but the names are not equivalent.
• 60% means that ellipsoid, prime meridian and coordinate systems are equivalent, but the CRS and datum names do not match.
• 25% means that the CRS are not equivalent, but there is some similarity in the names.

Parameters
    authorityFactory -- Authority factory (or null, but degraded functionality)

Returns
    a list of matching reference CRS, and the percentage (0-100) of confidence in the match.

Public Static Functions

static GeodeticCRSNNPtr create(const util::PropertyMap &properties, const datum::GeodeticReferenceFrameNNPtr &datum, const cs::SphericalCSNNPtr &cs)

Instantiate a GeodeticCRS from a datum::GeodeticReferenceFrame and a cs::SphericalCS.

Parameters
    • properties -- See General properties. At minimum the name should be defined.
    • datum -- The datum of the CRS.
    • cs -- a SphericalCS.
Returns
new GeodeticCRS.

static GeodeticCRSNNPtr create(const util::PropertyMap &properties, const
datum::GeodeticReferenceFrameNNPtr &datum, const
cs::CartesianCSNNPtr &cs)

Instantiate a GeodeticCRS from a datum::GeodeticReferenceFrame and a cs::CartesianCS.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• datum -- The datum of the CRS.
• cs -- a CartesianCS.

Returns
new GeodeticCRS.

static GeodeticCRSNNPtr create(const util::PropertyMap &properties, const
datum::GeodeticReferenceFramePtr &datum, const
datum::DatumEnsemblePtr &datumEnsemble, const
cs::SphericalCSNNPtr &cs)

Instantiate a GeodeticCRS from a datum::GeodeticReferenceFrame or datum::DatumEnsemble and a cs::SphericalCS.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• datum -- The datum of the CRS, or nullptr
• datumEnsemble -- The datum ensemble of the CRS, or nullptr.
• cs -- a SphericalCS.

Returns
new GeodeticCRS.

static GeodeticCRSNNPtr create(const util::PropertyMap &properties, const
datum::GeodeticReferenceFramePtr &datum, const
datum::DatumEnsemblePtr &datumEnsemble, const
cs::CartesianCSNNPtr &cs)

Instantiate a GeodeticCRS from a datum::GeodeticReferenceFrame or datum::DatumEnsemble and a cs::CartesianCS.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• datum -- The datum of the CRS, or nullptr
• datumEnsemble -- The datum ensemble of the CRS, or nullptr.
• cs -- a CartesianCS

Returns
new GeodeticCRS.
**Public Static Attributes**

static const GeodeticCRSNNPtr EPSG_4978  
EPSG:4978 / "WGS 84" Geocentric.

class GeographicCRS : public osgeo::proj::crs::GeodeticCRS

#include <crs.hpp>

A coordinate reference system associated with a geodetic reference frame and a two- or three-dimensional ellipsoidal coordinate system.

If the geodetic reference frame is dynamic or if the geographic CRS has an association to a velocity model then the geodetic CRS is dynamic, else it is static.

---

**Remark**

Implements GeographicCRS from ISO 19111:2019

Subclassed by osgeo::proj::crs::DerivedGeographicCRS

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**Public Functions**

const cs::EllipsoidalCSNNPtr &coordinateSystem()

    Return the cs::EllipsoidalCS associated with the CRS.

    Returns
    a EllipsoidalCS.

GeographicCRSNNPtr demoteTo2D(const std::string &newName, const io::DatabaseContextPtr &dbContext) const

    Return a variant of this CRS "demoted" to a 2D one, if not already the case.

Since 6.3

**Parameters**

- **newName** -- Name of the new CRS. If empty, nameStr() will be used.
- **dbContext** -- Database context to look for potentially already registered 2D CRS. May be nullptr.

**Returns**

a new CRS demoted to 2D, or the current one if already 2D or not applicable.

---

**Public Static Functions**

static GeographicCRSNNPtr create(const util::PropertyMap &properties, const datum::GeodeticReferenceFrameNNPtr &datum, const cs::EllipsoidalCSNNPtr &cs)

    Instantiate a GeographicCRS from a datum::GeodeticReferenceFrameNNPtr and a cs::EllipsoidalCS.

**Parameters**

- **properties** -- See General properties. At minimum the name should be defined.
- **datum** -- The datum of the CRS.
- **cs** -- a EllipsoidalCS.
Returns
new GeographicCRS.

static GeographicCRSNNPtr create(const util::PropertyMap &properties, const
datum::GeodeticReferenceFramePtr &datum, const
datum::DatumEnsemblePtr &datumEnsemble, const
cs::EllipsoidalCSNNPtr &cs)

Instantiate a GeographicCRS from a datum::GeodeticReferenceFramePtr or datum::DatumEnsemble
and a cs::EllipsoidalCS.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• datum -- The datum of the CRS, or nullptr
• datumEnsemble -- The datum ensemble of the CRS, or nullptr.
• cs -- a EllipsoidalCS.

Returns
new GeographicCRS.

Public Static Attributes

static const GeographicCRSNNPtr EPSG_4267
EPSG:4267 / "NAD27" 2D GeographicCRS.

static const GeographicCRSNNPtr EPSG_4269
EPSG:4269 / "NAD83" 2D GeographicCRS.

static const GeographicCRSNNPtr EPSG_4326
EPSG:4326 / "WGS 84" 2D GeographicCRS.

static const GeographicCRSNNPtr EPSG_4807
EPSG:4807 / "NTF (Paris)" 2D GeographicCRS.

static const GeographicCRSNNPtr EPSG_4979
EPSG:4979 / "WGS 84" 3D GeographicCRS.

class VerticalCRS : public virtual osgeo::proj::crs::SingleCRS, public osgeo::proj::io::IPROJStringExportable
#include <crs.hpp> A coordinate reference system having a vertical reference frame and a one-dimensional
vertical coordinate system used for recording gravity-related heights or depths.

Vertical CRSs make use of the direction of gravity to define the concept of height or depth, but the relationship
with gravity may not be straightforward. If the vertical reference frame is dynamic or if the vertical
CRS has an association to a velocity model then the CRS is dynamic, else it is static.
Implements *VerticalCRS* from *ISO 19111:2019*

**Note:** Ellipsoidal heights cannot be captured in a vertical coordinate reference system. They exist only as an inseparable part of a 3D coordinate tuple defined in a geographic 3D coordinate reference system.

Subclassed by *osgeo::proj::crs::DerivedVerticalCRS*

**Public Functions**

const `datum::VerticalReferenceFramePtr datum()` const

Return the `datum::VerticalReferenceFrame` associated with the CRS.

Returns

a VerticalReferenceFrame.

const `cs::VerticalCSNPNPtr coordinateSystem()` const

Return the `cs::VerticalCS` associated with the CRS.

Returns

a VerticalCS.

const `std::vector<operation::TransformationNPNPtr> &geoidModel()`

Return the geoid model associated with the CRS.

Geoid height model or height correction model linked to a geoid-based vertical CRS.

Returns

a geoid model. might be null

const `std::vector<operation::PointMotionOperationNPNPtr> &velocityModel()`

Return the velocity model associated with the CRS.

Returns

a velocity model. might be null

std::list<std::pair<VerticalCRSNNPtr, int>> identify(const `io::AuthorityFactoryPtr &authorityFactory`) const

Identify the CRS with reference CRSs.

The candidate CRSs are looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference CRS, and the percentage (0-100) of confidence in the match. 100% means that the name of the reference entry perfectly matches the CRS name, and both are equivalent. In which case a single result is returned. 90% means that CRS are equivalent, but the names are not exactly the same. 70% means that CRS are equivalent (equivalent datum and coordinate system), but the names are not equivalent. 25% means that the CRS are not equivalent, but there is some similarity in the names.

**Parameters**

authorityFactory -- Authority factory (if null, will return an empty list)

**Returns**

a list of matching reference CRS, and the percentage (0-100) of confidence in the match.


Public Static Functions

static VerticalCRSNNPtr create(const util::PropertyMap &properties, const
datum::VerticalReferenceFrameNNPtr &datumIn, const
cs::VerticalCSNNPtr &csIn)

Instantiate a VerticalCRS from a datum::VerticalReferenceFrame and a cs::VerticalCS.

Parameters

• properties -- See General properties. At minimum the name should be defined. The
  GEOID_MODEL property can be set to a TransformationNNPtr object.
• datumIn -- The datum of the CRS.
• csIn -- a VerticalCS.

Returns

new VerticalCRS.

static VerticalCRSNNPtr create(const util::PropertyMap &properties, const
datum::VerticalReferenceFramePtr &datumIn, const
datum::DatumEnsemblePtr &datumEnsembleIn, const
cs::VerticalCSNNPtr &csIn)

Instantiate a VerticalCRS from a datum::VerticalReferenceFrame or datum::DatumEnsemble and a
cs::VerticalCS.

One and only one of datum or datumEnsemble should be set to a non-null value.

Parameters

• properties -- See General properties. At minimum the name should be defined. The
  GEOID_MODEL property can be set to a TransformationNNPtr object.
• datumIn -- The datum of the CRS, or nullptr.
• datumEnsembleIn -- The datum ensemble of the CRS, or nullptr.
• csIn -- a VerticalCS.

Returns

new VerticalCRS.

class DerivedCRS : public virtual osgeo::proj::crs::SingleCRS

#include <crs.hpp> Abstract class modelling a single coordinate reference system that is defined through
the application of a specified coordinate conversion to the definition of a previously established single
coordinate reference system referred to as the base CRS.

A derived coordinate reference system inherits its datum (or datum ensemble) from its base CRS. The
coordinate conversion between the base and derived coordinate reference system is implemented using the
parameters and formula(s) specified in the definition of the coordinate conversion.

Remark

Implements DerivedCRS from ISO 19111:2019
Public Functions

const SingleCRSNNPtr &baseCRS() const

Return the base CRS of a DerivedCRS.

Returns

the base CRS.

cost operation::ConversionNNPtr derivingConversion() const

Return the deriving conversion from the base CRS to this CRS.

Returns

the deriving conversion.

class ProjectedCRS : public osgeo::proj:: DerivedCRS, public osgeo::proj::IPROJStringExportable

#include <crs.hpp> A derived coordinate reference system which has a geodetic (usually geographic) coordinate reference system as its base CRS, thereby inheriting a geodetic reference frame, and is converted using a map projection.

It has a Cartesian coordinate system, usually two-dimensional but may be three-dimensional; in the 3D case the base geographic CRSs ellipsoidal height is passed through unchanged and forms the vertical axis of the projected CRS's Cartesian coordinate system.

Remark

Implements ProjectedCRS from ISO 19111:2019

Public Functions

const GeodeticCRSNNPtr &baseCRS() const

Return the base CRS (a GeodeticCRS, which is generally a GeographicCRS) of the ProjectedCRS.

Returns

the base CRS.

cost cs::CartesianCSNNPtr &coordinateSystem() const

Return the cs::CartesianCS associated with the CRS.

Returns

a CartesianCS

std::list<std::pair<ProjectedCRSNNPtr, int>> identify(const io::AuthorityFactoryPtr &authorityFactory) const

Identify the CRS with reference CRSs.

The candidate CRSs are either hard-coded, or looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference CRS, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

100% means that the name of the reference entry perfectly matches the CRS name, and both are equivalent. In which case a single result is returned. 90% means that CRS are equivalent, but the names are not exactly the same. 70% means that CRS are equivalent (equivalent base CRS, conversion and coordinate system), but the names are not equivalent. 60% means that CRS have strong similarity.
(equivalent base datum, conversion and coordinate system), but the names are not equivalent. 50% means that CRS have similarity (equivalent base ellipsoid and conversion), but the coordinate system do not match (e.g. different axis ordering or axis unit). 25% means that the CRS are not equivalent, but there is some similarity in the names.

For the purpose of this function, equivalence is tested with the `util::Comparable::Criterion::EQUIVALENT_EXCEPT_AXIS_ORDER_GEOGCRS`, that is to say that the axis order of the base GeographicCRS is ignored.

**Parameters**
- `authorityFactory` -- Authority factory (or null, but degraded functionality)

**Returns**
- a list of matching reference CRS, and the percentage (0-100) of confidence in the match.

```cpp
ProjectedCRSNNPtr demoteTo2D(const std::string &newName, const io::DatabaseContextPtr &dbContext) const
```

Return a variant of this CRS "demoted" to a 2D one, if not already the case.

Since 6.3

**Parameters**
- `newName` -- Name of the new CRS. If empty, nameStr() will be used.
- `dbContext` -- Database context to look for potentially already registered 2D CRS. May be nullptr.

**Returns**
- a new CRS demoted to 2D, or the current one if already 2D or not applicable.

### Public Static Functions

```cpp
static ProjectedCRSNNPtr create(const util::PropertyMap &properties, const GeodeticCRSNNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::CartesianCSNNPtr &csIn)
```

Instantiate a ProjectedCRS from a base CRS, a deriving operation::Conversion and a coordinate system.

**Parameters**
- `properties` -- See General properties. At minimum the name should be defined.
- `baseCRSIn` -- The base CRS, a GeodeticCRS that is generally a GeographicCRS.
- `derivingConversionIn` -- The deriving operation::Conversion (typically using a map projection method)
- `csIn` -- The coordinate system.

**Returns**
- new ProjectedCRS.

class TemporalCRS : public virtual osgeo::proj::crs::SingleCRS

#include <crs.hpp> A coordinate reference system associated with a temporal datum and a one-dimensional temporal coordinate system.

### Remark

Implements TemporalCRS from ISO 19111:2019
**Public Functions**

const `datum::TemporalDatumNNPtr datum()` const  
Return the `datum::TemporalDatum` associated with the `CRS`.  
Returns  
a TemporalDatum

const `cs::TemporalCSNNPtr coordinateSystem()` const  
Return the `cs::TemporalCS` associated with the `CRS`.  
Returns  
a TemporalCS

**Public Static Functions**

static `TemporalCRSNNPtr create(const util::PropertyMap &properties, const `datum::TemporalDatumNNPtr &datumIn, const `cs::TemporalCSNNPtr &csIn)`  
Instantiate a `TemporalCRS` from a datum and a coordinate system.  
Parameters  
• `properties` -- See General properties. At minimum the name should be defined.  
• `datumIn` -- the datum.  
• `csIn` -- the coordinate system.  
Returns  
new `TemporalCRS`.

class `EngineeringCRS` : public virtual osgeo::proj::crs::SingleCRS  
#include `<crs.hpp>` Contextually local coordinate reference system associated with an engineering datum.  
It is applied either to activities on or near the surface of the Earth without geodetic corrections, or on moving platforms such as road vehicles, vessels, aircraft or spacecraft, or as the internal `CRS` of an image.  
In WKT2 standard, it maps to a ENGINEERINGCRS / ENGCRS keyword. In WKT1 specification, it maps to a LOCAL_CS keyword.

**Remark**

Implements `EngineeringCRS` from ISO 19111:2019

**Public Functions**

const `datum::EngineeringDatumNNPtr datum()` const  
Return the `datum::EngineeringDatum` associated with the `CRS`.  
Returns  
a EngineeringDatum
Public Static Functions

static EngineeringCRSNNPtr create(const util::PropertyMap &properties, const datum::EngineeringDatumNNPtr &datumIn, const cs::CoordinateSystemNNPtr &csIn)

Instantiate a EngineeringCRS from a datum and a coordinate system.

Parameters
- properties -- See General properties. At minimum the name should be defined.
- datumIn -- the datum.
- csIn -- the coordinate system.

Returns
new EngineeringCRS.

class ParametricCRS : public virtual osgeo::proj::crs::SingleCRS
#include <crs.hpp>

Contextually local coordinate reference system associated with an engineering datum.
This is applied either to activities on or near the surface of the Earth without geodetic corrections, or on moving platforms such as road vehicles vessels, aircraft or spacecraft, or as the internal CRS of an image.

Remark

Implements ParametricCRS from ISO 19111:2019

Public Functions

const datum::ParametricDatumNNPtr datum() const

Return the datum::ParametricDatum associated with the CRS.

Returns
a ParametricDatum

const cs::ParametricCSNNPtr coordinateSystem() const

Return the cs::TemporalCS associated with the CRS.

Returns
a TemporalCS

Public Static Functions

static ParametricCRSNNPtr create(const util::PropertyMap &properties, const datum::ParametricDatumNNPtr &datumIn, const cs::ParametricCSNNPtr &csIn)

Instantiate a ParametricCRS from a datum and a coordinate system.

Parameters
- properties -- See General properties. At minimum the name should be defined.
- datumIn -- the datum.
- csIn -- the coordinate system.

Returns
new ParametricCRS.
class `InvalidCompoundCRSException`: public osgeo::proj::util::Exception

```
#include <crs.hpp>
```

Exception thrown when attempting to create an invalid compound CRS.

class `CompoundCRS`: public osgeo::proj::crs::CRS, public osgeo::proj::io::IPROJStringExportable

```
#include <crs.hpp>
```

A coordinate reference system describing the position of points through two or more independent single coordinate reference systems.

**Remark**

Implements `CompoundCRS` from *ISO 19111:2019*

**Note:** Two coordinate reference systems are independent of each other if coordinate values in one cannot be converted or transformed into coordinate values in the other.

**Note:** As a departure to *ISO 19111:2019*, we allow to build a `CompoundCRS` from `CRS` objects, whereas *ISO 19111:2019* restricts the components to `SingleCRS`.

**Public Functions**

```cpp
const std::vector<CRSNPtr> &componentReferenceSystems()
```

Return the components of a `CompoundCRS`.

**Returns**

the components.

```cpp
std::list<std::pair<CompoundCRSNNPtr, int>> identify(const io::AuthorityFactoryPtr &authorityFactory) const
```

Identify the CRS with reference CRSs.

The candidate CRSs are looked in the database when authorityFactory is not null.

Note that the implementation uses a set of heuristics to have a good compromise of successful identifications over execution time. It might miss legitimate matches in some circumstances.

The method returns a list of matching reference CRS, and the percentage (0-100) of confidence in the match. The list is sorted by decreasing confidence.

100% means that the name of the reference entry perfectly matches the CRS name, and both are equivalent. In which case a single result is returned. 90% means that CRS are equivalent, but the names are not exactly the same. 70% means that CRS are equivalent (equivalent horizontal and vertical CRS), but the names are not equivalent. 25% means that the CRS are not equivalent, but there is some similarity in the names.

**Parameters**

- **authorityFactory** -- Authority factory (if null, will return an empty list)

**Returns**

a list of matching reference CRS, and the percentage (0-100) of confidence in the match.
Public Static Functions

static CompoundCRSNNPtr create(const util::PropertyMap &properties, const std::vector<CRSNNPtr> &components)

Instantiate a CompoundCRS from a vector of CRS.

Parameters
- properties -- See General properties. At minimum the name should be defined.
- components -- the component CRS of the CompoundCRS.

Throws
InvalidCompoundCRSException --

Returns
new CompoundCRS.

class BoundCRS : public osgeo::proj::crs::CRS, public osgeo::proj::io::IPROJStringExportable
#include <crs.hpp> A coordinate reference system with an associated transformation to a target/hub CRS.

The definition of a CRS is not dependent upon any relationship to an independent CRS. However in an implementation that merges datasets referenced to differing CRSs, it is sometimes useful to associate the definition of the transformation that has been used with the CRS definition. This facilitates the interrelationship of CRS by concatenating transformations via a common or hub CRS. This is sometimes referred to as “early-binding”. WKT2 standard permits the association of an abridged coordinate transformation description with a coordinate reference system description in a single text string. In a BoundCRS, the abridged coordinate transformation is applied to the source CRS with the target CRS being the common or hub system.

Coordinates referring to a BoundCRS are expressed into its source/base CRS.

This abstraction can for example model the concept of TOWGS84 datum shift present in WKT1 specification.

Remark
Implements BoundCRS from WKT2 standard

Note: Contrary to other CRS classes of this package, there is no ISO 19111:2019 modelling of a BoundCRS.

Public Functions

const CRSNNPtr &baseCRS()

Return the base CRS.

This is the CRS into which coordinates of the BoundCRS are expressed.

Returns
the base CRS.

CRSNNPtr baseCRSWithCanonicalBoundCRS() const

Return a shallow clone of the base CRS that points to a shallow clone of this BoundCRS.

The base CRS is the CRS into which coordinates of the BoundCRS are expressed.
The returned CRS will actually be a shallow clone of the actual base CRS, with the extra property that CRS::canonicalBoundCRS() will point to a shallow clone of this BoundCRS. Use this only if you want to work with the base CRS object rather than the BoundCRS, but wanting to be able to retrieve the BoundCRS later.

Returns
the base CRS.

const CRSNNPtr &hubCRS()
Return the target / hub CRS.
Returns
the hub CRS.

const operation::TransformationNNPtr &transformation()
Return the transformation to the hub RS.
Returns
transformation.

Public Static Functions

static BoundCRSNNPtr create(const util::PropertyMap &properties, const CRSNNPtr &baseCRSIn, const CRSNNPtr &hubCRSIn, const operation::TransformationNNPtr &transformationIn)
Instantiate a BoundCRS from a base CRS, a hub CRS and a transformation.

Since
PROJ 8.2

Parameters
• properties -- See General properties.
• baseCRSIn -- base CRS.
• hubCRSIn -- hub CRS.
• transformationIn -- transformation from base CRS to hub CRS.
Returns
new BoundCRS.

static BoundCRSNNPtr create(const CRSNNPtr &baseCRSIn, const CRSNNPtr &hubCRSIn, const operation::TransformationNNPtr &transformationIn)
Instantiate a BoundCRS from a base CRS, a hub CRS and a transformation.

Parameters
• baseCRSIn -- base CRS.
• hubCRSIn -- hub CRS.
• transformationIn -- transformation from base CRS to hub CRS.
Returns
new BoundCRS.

static BoundCRSNNPtrcreateFromTOWGS84(const CRSNNPtr &baseCRSIn, const std::vector<double> &TOWGS84Parameters)
Instantiate a BoundCRS from a base CRS and TOWGS84 parameters.

Parameters
• baseCRSIn -- base CRS.
• TOWGS84Parameters -- a vector of 3 or 7 double values representing WKT1 TOWGS84 parameter.
Returns
new BoundCRS.
static BoundCRSNNPtr createFromNadgrids(const CRSNNPtr &baseCRSIn, const std::string &filename)

Instantiate a BoundCRS from a base CRS and nadgrids parameters.

Parameters
• baseCRSIn -- base CRS.
• filename -- Horizontal grid filename

Returns
new BoundCRS.

class DerivedGeodeticCRS : public osgeo::proj::crs::GeodeticCRS, public osgeo::proj::crs::DerivedCRS

#include <crs.hpp> A derived coordinate reference system which has either a geodetic or a geographic coordinate reference system as its base CRS, thereby inheriting a geodetic reference frame, and associated with a 3D Cartesian or spherical coordinate system.

Remark

Implements DerivedGeodeticCRS from ISO 19111:2019

Public Functions

const GeodeticCRSNNPtr baseCRS() const

Return the base CRS (a GeodeticCRS) of a DerivedGeodeticCRS.

Returns
the base CRS.

Public Static Functions

static DerivedGeodeticCRSNNPtr create(const util::PropertyMap &properties, const GeodeticCRSNNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::CartesianCSNNPtr &csIn)

Instantiate a DerivedGeodeticCRS from a base CRS, a deriving conversion and a cs::CartesianCS.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• baseCRSIn -- base CRS.
• derivingConversionIn -- the deriving conversion from the base CRS to this CRS.
• csIn -- the coordinate system.

Returns
new DerivedGeodeticCRS.

static DerivedGeodeticCRSNNPtr create(const util::PropertyMap &properties, const GeodeticCRSNNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::SphericalCSNNPtr &csIn)

Instantiate a DerivedGeodeticCRS from a base CRS, a deriving conversion and a cs::SphericalCS.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• baseCRSIn -- base CRS.
• derivingConversionIn -- the deriving conversion from the base CRS to this CRS.
class DerivedGeographicCRS : public osgeo::proj::crs::GeographicCRS, public osgeo::proj::crs::DerivedCRS
#include <crs.hpp> A derived coordinate reference system which has either a geodetic or a geographic coordinate reference system as its base CRS, thereby inheriting a geodetic reference frame, and an ellipsoidal coordinate system.

A derived geographic CRS can be based on a geodetic CRS only if that geodetic CRS definition includes an ellipsoid.

Remark
Implements DerivedGeographicCRS from ISO 19111:2019

Public Functions

const GeodeticCRSSNPtr baseCRS() const

Return the base CRS (a GeodeticCRS) of a DerivedGeographicCRS.

Returns
the base CRS.

DerivedGeographicCRSSNPtr demoteTo2D(const std::string &newName, const io::DatabaseContextPtr &dbContext) const

Return a variant of this CRS "demoted" to a 2D one, if not already the case.

Since
8.1.1

Parameters

- newName -- Name of the new CRS. If empty, nameStr() will be used.
- dbContext -- Database context to look for potentially already registered 2D CRS. May be nullptr.

Returns
a new CRS demoted to 2D, or the current one if already 2D or not applicable.

Public Static Functions

static DerivedGeographicCRSSNPtr create(const util::PropertyMap &properties, const GeodeticCRSSNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::EllipsoidalCSNPtr &csIn)

Instantiate a DerivedGeographicCRS from a base CRS, a deriving conversion and a cs::EllipsoidalCS.

Parameters

- properties -- See General properties. At minimum the name should be defined.
- baseCRSIn -- base CRS.
- derivingConversionIn -- the deriving conversion from the base CRS to this CRS.
- csIn -- the coordinate system.
Returns
new DerivedGeographicCRS.

class DerivedProjectedCRS : public osgeo::proj::crs::DerivedCRS

#include <crs.hpp> A derived coordinate reference system which has a projected coordinate reference system as its base CRS, thereby inheriting a geodetic reference frame, but also inheriting the distortion characteristics of the base projected CRS.

A DerivedProjectedCRS is not a ProjectedCRS.

Remark
Implements DerivedProjectedCRS from ISO 19111:2019

Public Functions

const ProjectedCRSNNPtr baseCRS() const

Return the base CRS (a ProjectedCRS) of a DerivedProjectedCRS.

Returns
the base CRS.

DerivedProjectedCRSNNPtr demoteTo2D(const std::string &newName, const io::DatabaseContextPtr &dbContext) const

Return a variant of this CRS "demoted" to a 2D one, if not already the case.

Since
9.1.1

Parameters
• newName -- Name of the new CRS. If empty, nameStr() will be used.
• dbContext -- Database context to look for potentially already registered 2D CRS. May be nullptr.

Returns
a new CRS demoted to 2D, or the current one if already 2D or not applicable.

Public Static Functions

static DerivedProjectedCRSNNPtr create(const util::PropertyMap &properties, const ProjectedCRSNNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::CoordinateSystemNNPtr &csIn)

Instantiate a DerivedProjectedCRS from a base CRS, a deriving conversion and a cs::CS.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• baseCRSIn -- base CRS.
• derivingConversionIn -- the deriving conversion from the base CRS to this CRS.
• csIn -- the coordinate system.

Returns
new DerivedProjectedCRS.
class DerivedVerticalCRS : public osgeo::proj::crs::VerticalCRS, public osgeo::proj::crs::DerivedCRS  
#include <crs.hpp>  A derived coordinate reference system which has a vertical coordinate reference system as its base CRS, thereby inheriting a vertical reference frame, and a vertical coordinate system.

Remark  
Implements DerivedVerticalCRS from ISO 19111:2019

Public Functions

const VerticalCRSNNPtr baseCRS() const  
Return the base CRS (a VerticalCRS) of a DerivedVerticalCRS.

Public Static Functions

static DerivedVerticalCRSNNPtr create(const util::PropertyMap &properties, const VerticalCRSNNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const cs::VerticalCSNNPtr &csIn)  
Instantiate a DerivedVerticalCRS from a base CRS, a deriving conversion and a cs::VerticalCS.

Parameters  
• properties -- See General properties. At minimum the name should be defined.
• baseCRSIn -- base CRS.
• derivingConversionIn -- the deriving conversion from the base CRS to this CRS.
• csIn -- the coordinate system.

Returns  
new DerivedVerticalCRS.

template<class DerivedCRSTraits>  
class DerivedCRSTemplate : public DerivedCRSTraits::BaseType, public osgeo::proj::crs::DerivedCRS  
#include <crs.hpp> Template representing a derived coordinate reference system.

Public Types

typedef util::nn<std::shared_ptr<DerivedCRSTemplate>> NNPtr  
Non-null shared pointer of DerivedCRSTemplate

typedef util::nn<std::shared_ptr<BaseType>> BaseNNPtr  
Non-null shared pointer of BaseType

typedef util::nn<std::shared_ptr<CSType>> CSNNPtr  
Non-null shared pointer of CSType
**Public Functions**

```cpp
const BaseNNPtr baseCRS() const
    Return the base CRS of a DerivedCRSTemplate.
    Returns
    the base CRS.
```

**Public Static Functions**

```cpp
static NNPtr create(const util::PropertyMap &properties, const BaseNNPtr &baseCRSIn, const operation::ConversionNNPtr &derivingConversionIn, const CSNNPtr &csIn)
    Instantiate a DerivedCRSTemplate from a base CRS, a deriving conversion and a cs::CoordinateSystem.
    Parameters
    • properties -- See General properties. At minimum the name should be defined.
    • baseCRSIn -- base CRS.
    • derivingConversionIn -- the deriving conversion from the base CRS to this CRS.
    • csIn -- the coordinate system.
    Returns
    new DerivedCRSTemplate.
```

```cpp
class DerivedEngineeringCRS : public ose geo::proj::crs::DerivedCRSTemplate<DerivedEngineeringCRSTraits>
#include <crs.hpp>
A derived coordinate reference system which has an engineering coordinate reference system as its base CRS, thereby inheriting an engineering datum, and is associated with one of the coordinate system types for an EngineeringCRS.

**Remark**
Implements DerivedEngineeringCRS from ISO 19111:2019
```

```cpp
class DerivedParametricCRS : public ose geo::proj::crs::DerivedCRSTemplate<DerivedParametricCRSTraits>
#include <crs.hpp>
A derived coordinate reference system which has a parametric coordinate reference system as its base CRS, thereby inheriting a parametric datum, and a parametric coordinate system.

**Remark**
Implements DerivedParametricCRS from ISO 19111:2019
```

```cpp
class DerivedTemporalCRS : public ose geo::proj::crs::DerivedCRSTemplate<DerivedTemporalCRSTraits>
#include <crs.hpp>
A derived coordinate reference system which has a temporal coordinate reference system as its base CRS, thereby inheriting a temporal datum, and a temporal coordinate system.

**Remark**
10.5.4.8 operation namespace

namespace operation

Coordinate operations (relationship between any two coordinate reference systems).

osgeo.proj.operation namespace

This covers Conversion, Transformation, PointMotionOperation or ConcatenatedOperation.

Typedefs

typedef std::shared_ptr<CoordinateOperation> CoordinateOperationPtr
    Shared pointer of CoordinateOperation

typedef util::nn<CoordinateOperationPtr> CoordinateOperationNNPtr
    Non-null shared pointer of CoordinateOperation

using CoordinateTransformerPtr = std::unique_ptr<CoordinateTransformer>
    Shared pointer of CoordinateTransformer

using CoordinateTransformerNNPtr = util::nn<CoordinateTransformerPtr>
    Non-null shared pointer of CoordinateTransformer

using TransformationPtr = std::shared_ptr<Transformation>
    Shared pointer of Transformation

using TransformationNNPtr = util::nn<TransformationPtr>
    Non-null shared pointer of Transformation

using GeneralOperationParameterPtr = std::shared_ptr<GeneralOperationParameter>
    Shared pointer of GeneralOperationParameter

using GeneralOperationParameterNNPtr = util::nn<GeneralOperationParameterPtr>
    Non-null shared pointer of GeneralOperationParameter

using OperationParameterPtr = std::shared_ptr<OperationParameter>
    Shared pointer of OperationParameter

using OperationParameterNNPtr = util::nn<OperationParameterPtr>
    Non-null shared pointer of OperationParameter

using GeneralParameterValuePtr = std::shared_ptr<GeneralParameterValue>
    Shared pointer of GeneralParameterValue
using GeneralParameterValueNNPtr = util::nn<GeneralParameterValuePtr>
    Non-null shared pointer of GeneralParameterValue

using ParameterValuePtr = std::shared_ptr<ParameterValue>
    Shared pointer of ParameterValue

using ParameterValueNNPtr = util::nn<ParameterValuePtr>
    Non-null shared pointer of ParameterValue

using OperationParameterValuePtr = std::shared_ptr<OperationParameterValue>
    Shared pointer of OperationParameterValue

using OperationParameterValueNNPtr = util::nn<OperationParameterValuePtr>
    Non-null shared pointer of OperationParameterValue

using OperationMethodPtr = std::shared_ptr<OperationMethod>
    Shared pointer of OperationMethod

using OperationMethodNNPtr = util::nn<OperationMethodPtr>
    Non-null shared pointer of OperationMethod

using SingleOperationPtr = std::shared_ptr<SingleOperation>
    Shared pointer of SingleOperation

using SingleOperationNNPtr = util::nn<SingleOperationPtr>
    Non-null shared pointer of SingleOperation

typedef std::shared_ptr<Conversion> ConversionPtr
    Shared pointer of Conversion

typedef util::nn<ConversionPtr> ConversionNNPtr
    Non-null shared pointer of Conversion

using PointMotionOperationPtr = std::shared_ptr<PointMotionOperation>
    Shared pointer of PointMotionOperation

using PointMotionOperationNNPtr = util::nn<PointMotionOperationPtr>
    Non-null shared pointer of PointMotionOperation

using ConcatenatedOperationPtr = std::shared_ptr<ConcatenatedOperation>
    Shared pointer of ConcatenatedOperation

using ConcatenatedOperationNNPtr = util::nn<ConcatenatedOperationPtr>
    Non-null shared pointer of ConcatenatedOperation
using CoordinateOperationContextPtr = std::unique_ptr<CoordinateOperationContext>
    Unique pointer of CoordinateOperationContext

using CoordinateOperationContextNNPtr = util::nn<CoordinateOperationContextPtr>
    Non-null unique pointer of CoordinateOperationContext

using CoordinateOperationFactoryPtr = std::unique_ptr<CoordinateOperationFactory>
    Unique pointer of CoordinateOperationFactory

using CoordinateOperationFactoryNNPtr = util::nn<CoordinateOperationFactoryPtr>
    Non-null unique pointer of CoordinateOperationFactory

Functions

static std::vector<crs::GeodeticCRSNNPtr> findCandidateGeodCRSForDatum(const
    io::AuthorityFactoryPtr &authFactory, const
    crs::GeodeticCRS *crs,
    const datum::GeodeticReferenceFrame *datum)

static bool isRegularVerticalGridMethod(int methodEPSGCode)

static double negate(double val)

static CoordinateOperationPtr createApproximateInverseIfPossible(const Transformation *op)

struct GridDescription
    #include <coordinateoperation.hpp> Grid description.

Public Members

std::string shortName
    Grid short filename

std::string fullName
    Grid full path name (if found)

std::string packageName
    Package name (or empty)

std::string url
    Grid URL (if packageName is empty), or package URL (or empty)

bool directDownload
    Whether url can be fetched directly.
bool openLicense
    Whether the grid is released with an open license.

bool available
    Whether GRID is available.

class CoordinateTransformer
    #include <coordinateoperation.hpp> Coordinate transformer.
    Performs coordinate transformation of coordinate tuples.

Since
    9.3

Public Functions

PJ_COORD transform(PJ_COORD coord)
    Transforms a coordinate tuple.

    PJ_COORD is a union of many structures. In the context of this method, it is prudent to only use
    the v[] array, with the understanding that the expected input values should be passed in the order and
    the unit of the successive axis of the input CRS. Similarly the values returned in the v[] array of the
    output PJ_COORD are in the order and the unit of the successive axis of the output CRS. For coordinate
    operations involving a time-dependent operation, coord.v[3] is the decimal year of the coordinate epoch
    of the input (or HUGE_VAL to indicate none)

If an error occurs, HUGE_VAL is returned in the .v[0] member of the output coordinate tuple.

Example how to transform coordinates from EPSG:4326 (WGS 84 latitude/longitude) to EPSG:32631
(WGS 84 / UTM zone 31N).

```cpp
auto authFactory = 
    AuthorityFactory::create(DatabaseContext::create(), std::string());
auto coord_op_ctxt = CoordinateOperationContext::create(
    authFactory, nullptr, 0.0);
auto authFactoryEPSG = 
    AuthorityFactory::create(DatabaseContext::create(), "EPSG");
auto list = CoordinateOperationFactory::create()->createOperations(
    authFactoryEPSG->createCoordinateReferenceSystem("4326"),
    authFactoryEPSG->createCoordinateReferenceSystem("32631"),
    coord_op_ctxt);
ASSERT_TRUE(!list.empty());
PJ_CONTEXT* ctx = proj_context_create();
auto transformer = list[0]->coordinateTransformer(ctx);
PJ_COORD c;
c.v[0] = 49; // latitude in degree
c.v[1] = 2; // longitude in degree
c.v[2] = 0;
c.v[3] = HUGE_VAL;
c = transformer->transform(c);
EXPECT_NEAR(c.v[0], 426857.98771728, 1e-8); // easting in metre
```
(continues on next page)
class CoordinateOperation : public osgeo::proj::common::ObjectUsage, public osgeo::proj::io::IPROJStringExportable, public osgeo::proj::io::IJSONExportable
#include <coordinateoperation.hpp> Abstract class for a mathematical operation on coordinates.

A mathematical operation:

- on coordinates that transforms or converts them from one coordinate reference system to another coordinate reference system
- or that describes the change of coordinate values within one coordinate reference system due to the motion of the point between one coordinate epoch and another coordinate epoch.

Many but not all coordinate operations (from CRS A to CRS B) also uniquely define the inverse coordinate operation (from CRS B to CRS A). In some cases, the coordinate operation method algorithm for the inverse coordinate operation is the same as for the forward algorithm, but the signs of some coordinate operation parameter values have to be reversed. In other cases, different algorithms are required for the forward and inverse coordinate operations, but the same coordinate operation parameter values are used. If (some) entirely different parameter values are needed, a different coordinate operation shall be defined.

**Remark**

Implements CoordinateOperation from ISO 19111:2019

Subclassed by osgeo::proj::operation::ConcatenatedOperation, osgeo::proj::operation::SingleOperation

**Public Functions**

const util::optional<std::string> &operationVersion() const

Return the version of the coordinate transformation (i.e. instantiation due to the stochastic nature of the parameters).

Mandatory when describing a coordinate transformation or point motion operation, and should not be supplied for a coordinate conversion.

**Returns**

version or empty.

cost std::vector<metadata::PositionalAccuracyNNPtr> &coordinateOperationAccuracies() const

Return estimate(s) of the impact of this coordinate operation on point accuracy.

Gives position error estimates for target coordinates of this coordinate operation, assuming no errors in source coordinates.

**Returns**

estimate(s) or empty vector.

cost crs::CRSPtr sourceCRS() const

Return the source CRS of this coordinate operation.

This should not be null, expect for of a derivingConversion of a DerivedCRS when the owning DerivedCRS has been destroyed.

### 10.5. Reference


Returns
source CRS, or null.

const crs::CRSPtr targetCRS() const
Return the target CRS of this coordinate operation.

This should not be null, expect for of a deriving Conversion of a Derived CRS when the owning Derived CRS has been destroyed.

Returns
target CRS, or null.

const crs::CRSPtr & interpolationCRS() const
Return the interpolation CRS of this coordinate operation.

Returns
interpolation CRS, or null.

const util::optional<common::DataEpoch> & sourceCoordinateEpoch() const
Return the source epoch of coordinates.

Returns
source epoch of coordinates, or empty.

const util::optional<common::DataEpoch> & targetCoordinateEpoch() const
Return the target epoch of coordinates.

Returns
target epoch of coordinates, or empty.

CoordinateTransformerNNPtr coordinateTransformer(PJ_CONTEXT *ctx) const
Return a coordinate transformer for this operation.

The returned coordinate transformer is tied to the provided context, and should only be called by the thread "owning" the passed context. It should not be used after the context has been destroyed.

Since
9.3

Parameters
cctx -- Execution context to which the transformer will be tied to. If null, the default context will be used (only sfe for single-threaded applications).

Throws
UnsupportedOperationException -- if the transformer cannot be instantiated.

Returns
a new CoordinateTransformer instance.

virtual CoordinateOperationNNPtr inverse() const = 0
Return the inverse of the coordinate operation.

Throws
util::UnsupportedOperationException --

virtual std::set<GridDescription> gridsNeeded(const io::DatabaseContextPtr &databaseContext, bool considerKnownGridsAsAvailable) const = 0
Return grids needed by an operation.

bool isPROJInstantiable(const io::DatabaseContextPtr &databaseContext, bool considerKnownGridsAsAvailable) const
Return whether a coordinate operation can be instantiated as a PROJ pipeline, checking in particular that referenced grids are available.
bool hasBallparkTransformation() const
    
    Return whether a coordinate operation has a "ballpark" transformation, that is a very approximate one, 
    due to lack of more accurate transformations.
    
    Typically a null geographic offset between two horizontal datum, or a null vertical offset (or limited 
    to unit changes) between two vertical datum. Errors of several tens to one hundred meters might be 
    expected, compared to more accurate transformations.

CoordinateOperationNNPtr normalizeForVisualization() const
    
    Return a variation of the current coordinate operation whose axis order is the one expected for visual-
    ization purposes.

Public Static Attributes

static const std::string OPERATION_VERSION_KEY
    
    Key to set the operation version of a operation::CoordinateOperation.
    
    The value is to be provided as a string.

class GeneralOperationParameter : public osgeo::proj::common::IdentifiedObject

#include <coordinateoperation.hpp> Abstract class modelling a parameter value (OperationParameter) or 
    group of parameters.

Remark

Implements GeneralOperationParameter from ISO 19111:2019

Subclassed by osgeo::proj::operation::OperationParameter

class OperationParameter : public osgeo::proj::operation::GeneralOperationParameter

#include <coordinateoperation.hpp> The definition of a parameter used by a coordinate operation method. 
    Most parameter values are numeric, but other types of parameter values are possible.

Remark

Implements OperationParameter from ISO 19111:2019

Public Functions

int getEPSGCode()

    Return the EPSG code, either directly, or through the name.

    Returns
    code, or 0 if not found
**Public Static Functions**

static `OperationParameterNNPtr` `create`(const `util::PropertyMap` &`properties`)

Instantiate a `OperationParameter`.

Parameters

`properties` -- See `General properties`. At minimum the name should be defined.

Returns

a new `OperationParameter`.

static const char * `getNameForEPSGCode`(int `epsg_code`) noexcept

Return the name of a parameter designed by its EPSG code.

Returns

name, or nullptr if not found

class `GeneralParameterValue` : public `osgeo::proj::util::BaseObject`, public

`osgeo::proj::io::IWKTExportable`, public `osgeo::proj::io::IJSONExportable`, public

`osgeo::proj::util::IComparable`

`#include <coordinateoperation.hpp>` Abstract class modelling a parameter value (`OperationParameterValue`) or group of parameter values.

---

**Remark**

Implements `GeneralParameterValue` from `ISO 19111:2019`

---

Subclassed by `osgeo::proj::operation::OperationParameterValue`

class `ParameterValue` : public `osgeo::proj::util::BaseObject`, public

`osgeo::proj::io::IWKTExportable`, public `osgeo::proj::io::IJSONExportable`, public

`osgeo::proj::util::IComparable`

`#include <coordinateoperation.hpp>` The value of the coordinate operation parameter.

Most parameter values are numeric, but other types of parameter values are possible.

---

**Remark**

Implements `ParameterValue` from `ISO 19111:2019`

---

**Public Types**

enum class `Type`

Type of the value.

Values:

enumerator `MEASURE`

Measure (i.e. value with a unit)
enumerator **STRING**
   String

enumerator **INTEGER**
   Integer

enumerator **BOOLEAN**
   Boolean

enumerator **FILENAME**
   Filename

**Public Functions**

```cpp
const Type &type()
   Returns the type of a parameter value.
   
   Returns
       the type.

const common::Measure &value()
   Returns the value as a Measure (assumes type() == Type::MEASURE)
   
   Returns
       the value as a Measure.

const std::string &stringValue()
   Returns the value as a string (assumes type() == Type::STRING)
   
   Returns
       the value as a string.

const std::string &valueFile()
   Returns the value as a filename (assumes type() == Type::FILENAME)
   
   Returns
       the value as a filename.

int integerValue()
   Returns the value as a integer (assumes type() == Type::INTEGER)
   
   Returns
       the value as a integer.

bool booleanValue()
   Returns the value as a boolean (assumes type() == Type::BOOLEAN)
   
   Returns
       the value as a boolean.
```
Public Static Functions

static ParameterValueNNPtr create(const common::Measure &measureIn)
    Instantiate a ParameterValue from a Measure (i.e. a value associated with a unit)
    Returns
    a new ParameterValue.

static ParameterValueNNPtr create(const char *stringValueIn)
    Instantiate a ParameterValue from a string value.
    Returns
    a new ParameterValue.

static ParameterValueNNPtr create(const std::string &stringValueIn)
    Instantiate a ParameterValue from a string value.
    Returns
    a new ParameterValue.

static ParameterValueNNPtr create(int integerValueIn)
    Instantiate a ParameterValue from a integer value.
    Returns
    a new ParameterValue.

static ParameterValueNNPtr create(bool booleanValueIn)
    Instantiate a ParameterValue from a boolean value.
    Returns
    a new ParameterValue.

static ParameterValueNNPtr createFilename(const std::string &stringValueIn)
    Instantiate a ParameterValue from a filename.
    Returns
    a new ParameterValue.

class OperationParameterValue : public osgeo::proj::operation::GeneralParameterValue
    #include <coordinateoperation.hpp> A parameter value, ordered sequence of values, or reference to a file of parameter values.
    This combines a OperationParameter with the corresponding ParameterValue.

Remark

Implements OperationParameterValue from ISO 19111:2019

Public Functions

const OperationParameterNNPtr &parameter()
    Return the parameter (definition)
    Returns
    the parameter (definition).

const ParameterValueNNPtr &parameterValue()
    Return the parameter value.
Returns
the parameter value.

**Public Static Functions**

```cpp
static OperationParameterValueNNPtr create(const OperationParameterNNPtr &parameterIn, const ParameterValueNNPtr &valueIn)
```

Instantiate a `OperationParameterValue`.

Parameters
- `parameterIn` -- Parameter (definition).
- `valueIn` -- Parameter value.

Returns
a new `OperationParameterValue`.

class `OperationMethod` : public osgeo::proj::IdentifiedObject, public osgeo::proj::IJSONExportable

```cpp
#include <coordinateoperation.hpp>
```

The method (algorithm or procedure) used to perform the coordinate operation.

For a projection method, this contains the name of the projection method and the name of the projection parameters.

**Remark**

Implements `OperationMethod` from *ISO 19111:2019*

**Public Functions**

```cpp
const util::optional<std::string> &formula()
```

Return the formula(s) or procedure used by this coordinate operation method.

This may be a reference to a publication (in which case use `formulaCitation()`).

Note that the operation method may not be analytic, in which case this attribute references or contains the procedure, not an analytic formula.

Returns
the formula, or empty.

```cpp
const util::optional<metadata::Citation> &formulaCitation()
```

Return a reference to a publication giving the formula(s) or procedure used by the coordinate operation method.

Returns
the formula citation, or empty.

```cpp
const std::vector<GeneralOperationParameterNNPtr> &parameters()
```

Return the parameters of this operation method.

Returns
the parameters.
int getEPSGCode()
    // Return the EPSG code, either directly, or through the name.
    Returns
code, or 0 if not found

Public Static Functions

static OperationMethodNNPtr create(const util::PropertyMap &properties, const std::vector<GeneralOperationParameterNNPtr> &parameters)
    Instantiate a operation method from a vector of GeneralOperationParameter.

Parameters
    • properties -- See General properties. At minimum the name should be defined.
    • parameters -- Vector of GeneralOperationParameterNNPtr.

Returns
    a new OperationMethod.

static OperationMethodNNPtr create(const util::PropertyMap &properties, const std::vector<OperationParameterNNPtr> &parameters)
    Instantiate a operation method from a vector of OperationParameter.

Parameters
    • properties -- See General properties. At minimum the name should be defined.
    • parameters -- Vector of OperationParameterNNPtr.

Returns
    a new OperationMethod.

class InvalidOperation : public osgeo::proj::util::Exception
    #include <coordinateoperation.hpp> Exception that can be thrown when an invalid operation is attempted to be constructed.

class SingleOperation : public virtual osgeo::proj::operation::CoordinateOperation
    #include <coordinateoperation.hpp> A single (not concatenated) coordinate operation (CoordinateOperation)

Remark
    Implements SingleOperation from ISO 19111:2019

Subclassed by osgeo::proj::operation::Conversion, osgeo::proj::operation::PointMotionOperation, osgeo::proj::operation::Transformation
**Public Functions**

`const std::vector<GeneralParameterValueNNPtr> &parameterValues()`  
Return the parameter values.  
**Returns**  
the parameter values.

`const OperationMethodNNPtr &method()`  
Return the operation method associated to the operation.  
**Returns**  
the operation method.

`const ParameterValuePtr &parameterValue(const std::string &paramName, int epsg_code = 0)`  
const noexcept  
Return the parameter value corresponding to a parameter name or EPSG code.  
**Parameters**  
• **paramName** -- the parameter name (or empty, in which case epsg_code should be non zero)  
• **epsg_code** -- the parameter EPSG code (possibly zero)  
**Returns**  
the value, or nullptr if not found.

`const ParameterValuePtr &parameterValue(int epsg_code)`  
const noexcept  
Return the parameter value corresponding to a EPSG code.  
**Parameters**  
epsg_code -- the parameter EPSG code  
**Returns**  
the value, or nullptr if not found.

`const common::Measure &parameterValueMeasure(const std::string &paramName, int epsg_code = 0)`  
const noexcept  
Return the parameter value, as a measure, corresponding to a parameter name or EPSG code.  
**Parameters**  
• **paramName** -- the parameter name (or empty, in which case epsg_code should be non zero)  
• **epsg_code** -- the parameter EPSG code (possibly zero)  
**Returns**  
the measure, or the empty Measure() object if not found.

`const common::Measure &parameterValueMeasure(int epsg_code)`  
const noexcept  
Return the parameter value, as a measure, corresponding to a EPSG code.  
**Parameters**  
epsg_code -- the parameter EPSG code  
**Returns**  
the measure, or the empty Measure() object if not found.

`virtual std::set<GridDescription> gridsNeeded(const io::DatabaseContextPtr &databaseContext, bool considerKnownGridsAsAvailable)`  
const override  
Return grids needed by an operation.

`std::list<std::string> validateParameters()`  
const  
Validate the parameters used by a coordinate operation.  
Return whether the method is known or not, or a list of missing or extra parameters for the operations recognized by this implementation.
TransformationNNPtr substitutePROJAlternativeGridNames(io::DatabaseContextNNPtr databaseContext) const

Return an equivalent transformation to the current one, but using PROJ alternative grid names.

Public Static Functions

static SingleOperationNNPtr createPROJBased(const util::PropertyMap &properties, const std::string &PROJString, const crs::CRSPtr &sourceCRS, const crs::CRSPtr &targetCRS, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies = std::vector<metadata::PositionalAccuracyNNPtr>())

Instantiate a PROJ-based single operation.

Note: The operation might internally be a pipeline chaining several operations. The use of the SingleOperation modeling here is mostly to be able to get the PROJ string as a parameter.

Parameters

• properties -- Properties
• PROJString -- the PROJ string.
• sourceCRS -- source CRS (might be null).
• targetCRS -- target CRS (might be null).
• accuracies -- Vector of positional accuracy (might be empty).

Returns

the new instance

class Conversion : public osgeo::proj::operation::SingleOperation

#include <coordinateoperation.hpp> A mathematical operation on coordinates in which the parameter values are defined rather than empirically derived.

Application of the coordinate conversion introduces no error into output coordinates. The best-known example of a coordinate conversion is a map projection. For coordinate conversions the output coordinates are referenced to the same datum as are the input coordinates.

Coordinate conversions forming a component of a derived CRS have a source crs::CRS and a target crs::CRS that are NOT specified through the source and target associations, but through associations from crs::DerivedCRS to crs::SingleCRS.

Remark

Implements Conversion from ISO 19111:2019
**Projection parameters**

**Co-latitude of cone axis**

The rotation applied to spherical coordinates for the oblique projection, measured on the conformal sphere in the plane of the meridian of origin.

EPSG:1036

**Latitude of natural origin/Center Latitude**

The latitude of the point from which the values of both the geographical coordinates on the ellipsoid and the grid coordinates on the projection are deemed to increment or decrement for computational purposes. Alternatively it may be considered as the latitude of the point which in the absence of application of false coordinates has grid coordinates of (0,0).

EPSG:8801

**Longitude of natural origin/Central Meridian**

The longitude of the point from which the values of both the geographical coordinates on the ellipsoid and the grid coordinates on the projection are deemed to increment or decrement for computational purposes. Alternatively it may be considered as the longitude of the point which in the absence of application of false coordinates has grid coordinates of (0,0). Sometimes known as "central meridian (CM)".

EPSG:8802

**Scale Factor**

The factor by which the map grid is reduced or enlarged during the projection process, defined by its value at the natural origin.

EPSG:8805

**False Easting**

Since the natural origin may be at or near the centre of the projection and under normal coordinate circumstances would thus give rise to negative coordinates over parts of the mapped area, this origin is usually given false coordinates which are large enough to avoid this inconvenience. The False Easting, FE, is the value assigned to the abscissa (east or west) axis of the projection grid at the natural origin.

EPSG:8806
**False Northing**

Since the natural origin may be at or near the centre of the projection and under normal coordinate circumstances would thus give rise to negative coordinates over parts of the mapped area, this origin is usually given false coordinates which are large enough to avoid this inconvenience. The False Northing, FN, is the value assigned to the ordinate (north or south) axis of the projection grid at the natural origin.

EPSG:8807

**Latitude of projection centre**

For an oblique projection, this is the latitude of the point at which the azimuth of the central line is defined.

EPSG:8811

**Longitude of projection centre**

For an oblique projection, this is the longitude of the point at which the azimuth of the central line is defined.

EPSG:8812

**Azimuth of initial line**

The azimuthal direction (north zero, east of north being positive) of the great circle which is the centre line of an oblique projection. The azimuth is given at the projection centre.

EPSG:8813

**Angle from Rectified to Skew Grid**

The angle at the natural origin of an oblique projection through which the natural coordinate reference system is rotated to make the projection north axis parallel with true north.

EPSG:8814

**Scale factor on initial line**

The factor by which the map grid is reduced or enlarged during the projection process, defined by its value at the projection center.

EPSG:8815
**Easting at projection centre**

The easting value assigned to the projection centre.

EPSG:8816

**Northing at projection centre**

The northing value assigned to the projection centre.

EPSG:8817

**Latitude of pseudo standard parallel**

Latitude of the parallel on which the conic or cylindrical projection is based. This latitude is not geographic, but is defined on the conformal sphere AFTER its rotation to obtain the oblique aspect of the projection.

EPSG:8818

**Scale factor on pseudo standard parallel**

The factor by which the map grid is reduced or enlarged during the projection process, defined by its value at the pseudo-standard parallel.

EPSG:8819

**Latitude of false origin**

The latitude of the point which is not the natural origin and at which grid coordinate values false easting and false northing are defined.

EPSG:8821

**Longitude of false origin**

The longitude of the point which is not the natural origin and at which grid coordinate values false easting and false northing are defined.

EPSG:8822
**Latitude of 1st standard parallel**

For a conic projection with two standard parallels, this is the latitude of one of the parallels of intersection of the cone with the ellipsoid. It is normally but not necessarily that nearest to the pole. Scale is true along this parallel.

EPSG:8823

**Latitude of 2nd standard parallel**

For a conic projection with two standard parallels, this is the latitude of one of the parallels at which the cone intersects with the ellipsoid. It is normally but not necessarily that nearest to the equator. Scale is true along this parallel.

EPSG:8824

**Easting of false origin**

The easting value assigned to the false origin.

EPSG:8826

**Northing of false origin**

The northing value assigned to the false origin.

EPSG:8827

**Latitude of standard parallel**

For polar aspect azimuthal projections, the parallel on which the scale factor is defined to be unity.

EPSG:8832

**Longitude of origin**

For polar aspect azimuthal projections, the meridian along which the northing axis increments and also across which parallels of latitude increment towards the north pole.

EPSG:8833

**Public Functions**

```cpp
class CoordinateOperation
{
public:
  virtual CoordinateOperationNNPtr inverse() const override
  {
    // Return the inverse of the coordinate operation.
  }

  // Throws
  util::UnsupportedOperationException --
};
```
bool isUTM(int &zone, bool &north) const

Return whether a conversion is a Universal Transverse Mercator conversion.

Parameters
• zone -- [out] UTM zone number between 1 and 60.
• north -- [out] true for UTM northern hemisphere, false for UTM southern hemisphere.

Returns
true if it is a UTM conversion.

ConversionNNPtr identify() const

Return a Conversion object where some parameters are better identified.

Returns
a new Conversion.

ConversionPtr convertToOtherMethod(int targetEPSGCode) const

Return an equivalent projection.

Currently implemented:
• EPSG_CODE_METHOD_MERCATOR_VARIANT_A (1SP) to EPSG_CODE_METHOD_MERCATOR_VARIANT_B (2SP)
• EPSG_CODE_METHOD_MERCATOR_VARIANT_B (2SP) to EPSG_CODE_METHOD_MERCATOR_VARIANT_A (1SP)
• EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_1SP to EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_2SP
• EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_2SP to EPSG_CODE_METHOD_LAMBERT_CONIC_CONFORMAL_1SP

Parameters
• targetEPSGCode -- EPSG code of the target method.

Returns
new conversion, or nullptr

Public Static Functions

static ConversionNNPtr create(const util::PropertyMap &properties, const OperationMethodNNPtr &methodIn, const std::vector<GeneralParameterValueNNPtr> &values) const

Instantiate a Conversion from a vector of GeneralParameterValue.

Parameters
• properties -- See General properties. At minimum the name should be defined.
• methodIn -- the operation method.
• values -- the values.

Throws
InvalidOperation --

Returns
a new Conversion.

static ConversionNNPtr create(const util::PropertyMap &propertiesConversion, const util::PropertyMap &propertiesOperationMethod, const std::vector<OperationParameterNNPtr> &parameters, const std::vector<ParameterValueNNPtr> &values) const

Instantiate a Conversion and its OperationMethod.

Parameters
• propertiesConversion -- See General properties of the conversion. At minimum the name should be defined.
• **propertiesOperationMethod** -- See *General properties* of the operation method. At minimum the name should be defined.
• **parameters** -- the operation parameters.
• **values** -- the operation values. Constraint: values.size() == parameters.size()

Throws

*InvalidOperation*  

Returns

a new *Conversion*.

static *ConversionNNPtr* createUTM(const *util::PropertyMap* &properties, int zone, bool north)
Instantiate a Universal Transverse Mercator conversion.

UTM is a family of conversions, of EPSG codes from 16001 to 16060 for the northern hemisphere, and 17001 to 17060 for the southern hemisphere, based on the Transverse Mercator projection method.

Parameters

• **properties** -- See *General properties* of the conversion. If the name is not provided, it is automatically set.
• **zone** -- UTM zone number between 1 and 60.
• **north** -- true for UTM northern hemisphere, false for UTM southern hemisphere.

Returns

a new *Conversion*.

static *ConversionNNPtr* createTransverseMercator(const *util::PropertyMap* &properties, const *common::Angle* &centerLat, const *common::Angle* &centerLong, const *common::Scale* &scale, const *common::Length* &falseEasting, const *common::Length* &falseNorthing)
Instantiate a conversion based on the Transverse Mercator projection method.

This method is defined as *EPSG:9807*.

Parameters

• **properties** -- See *General properties* of the conversion. If the name is not provided, it is automatically set.
• **centerLat** -- See *Latitude of natural origin/Center Latitude*
• **centerLong** -- See *Longitude of natural origin/Central Meridian*
• **scale** -- See *Scale Factor*
• **falseEasting** -- See *False Easting*
• **falseNorthing** -- See *False Northing*

Returns

a new *Conversion*.

static *ConversionNNPtr* createGaussSchreiberTransverseMercator(const *util::PropertyMap* &properties, const *common::Angle* &centerLat, const *common::Angle* &centerLong, const *common::Scale* &scale, const *common::Length* &falseEasting, const *common::Length* &falseNorthing)
Instantiate a conversion based on the Gauss Schreiber Transverse Mercator projection method.

This method is also known as Gauss-Laborde Reunion.

There is no equivalent in EPSG.
Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- centerLat -- See Latitude of natural origin/Center Latitude
- centerLong -- See Longitude of natural origin/Central Meridian
- scale -- See Scale Factor
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createTransverseMercatorSouthOriented(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Transverse Mercator South Orientated projection method.

This method is defined as EPSG:9808.

Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- centerLat -- See Latitude of natural origin/Center Latitude
- centerLong -- See Longitude of natural origin/Central Meridian
- scale -- See Scale Factor
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createTwoPointEquidistant(const util::PropertyMap &properties, const common::Angle &latitudeFirstPoint, const common::Angle &longitudeFirstPoint, const common::Angle &latitudeSecondPoint, const common::Angle &longitudeSecondPoint, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Two Point Equidistant projection method.

There is no equivalent in EPSG.

Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeFirstPoint -- Latitude of first point.
- longitudeFirstPoint -- Longitude of first point.
- latitudeSecondPoint -- Latitude of second point.
- longitudeSecondPoint -- Longitude of second point.
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns
a new Conversion.

```cpp
static ConversionNNPtr createTunisiaMappingGrid(const util::PropertyMap &properties, const
common::Angle &centerLat, const
common::Angle &centerLong, const
common::Length &falseEasting, const
common::Length &falseNorthing)
```

Instantiate a conversion based on the Tunisia Mapping Grid projection method.

This method is defined as EPSG:9816.

_DEPRECATED_

Use `createTunisiaMiningGrid()` instead

**Note:** There is currently no implementation of the method formulas in PROJ.

**Parameters**

- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLat` -- See Latitude of natural origin/Center Latitude
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**

a new Conversion.

```cpp
static ConversionNNPtr createTunisiaMiningGrid(const util::PropertyMap &properties, const
common::Angle &centerLat, const
common::Angle &centerLong, const
common::Length &falseEasting, const
common::Length &falseNorthing)
```

Instantiate a conversion based on the Tunisia Mining Grid projection method.

This method is defined as EPSG:9816.

Since
9.2

**Note:** There is currently no implementation of the method formulas in PROJ.

**Parameters**

- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLat` -- See Latitude of natural origin/Center Latitude
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new Conversion.
static ConversionNNPtr createAlbersEqualArea(const util::PropertyMap &properties, const common::Angle &latitudeFalseOrigin, const common::Angle &longitudeFalseOrigin, const common::Angle &latitudeFirstParallel, const common::Angle &latitudeSecondParallel, const common::Length &eastingFalseOrigin, const common::Length &northingFalseOrigin)

Instantiate a conversion based on the Albers Conic Equal Area projection method.

This method is defined as EPSG:9822.

Note: the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setACEA() of GDAL <= 2.3

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeFalseOrigin -- See Latitude of false origin
- longitudeFalseOrigin -- See Longitude of false origin
- latitudeFirstParallel -- See Latitude of 1st standard parallel
- latitudeSecondParallel -- See Latitude of 2nd standard parallel
- eastingFalseOrigin -- See Easting of false origin
- northingFalseOrigin -- See Northing of false origin

Returns

a new Conversion.

static ConversionNNPtr createLambertConicConformal_1SP(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Lambert Conic Conformal 1SP projection method.

This method is defined as EPSG:9801.

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- centerLat -- See Latitude of natural origin/Center Latitude
- centerLong -- See Longitude of natural origin/Central Meridian
- scale -- See Scale Factor
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns

a new Conversion.
static ConversionNNPtr createLambertConicConformal_1SP_VariantB(const util::PropertyMap &properties, const common::Angle &latitudeNatOrigin, const common::Scale &scale, const common::Angle &latitudeFalseOrigin, const common::Angle &longitudeFalseOrigin, const common::Length &eastingFalseOrigin, const common::Length &northingFalseOrigin)

Instantiate a conversion based on the Lambert Conic Conformal 1SP Variant B projection method. This method is defined as EPSG:1102.

Since 9.2.1

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeNatOrigin -- See Latitude of natural origin/Center Latitude
- scale -- See Scale Factor
- latitudeFalseOrigin -- See Latitude of false origin
- longitudeFalseOrigin -- See Longitude of false origin
- eastingFalseOrigin -- See Easting of false origin
- northingFalseOrigin -- See Northing of false origin

Returns

a new Conversion.

static ConversionNNPtr createLambertConicConformal_2SP(const util::PropertyMap &properties, const common::Angle &latitudeFalseOrigin, const common::Angle &longitudeFalseOrigin, const common::Angle &latitudeFirstParallel, const common::Angle &latitudeSecondParallel, const common::Length &eastingFalseOrigin, const common::Length &northingFalseOrigin)

Instantiate a conversion based on the Lambert Conic Conformal 2SP projection method. This method is defined as EPSG:9802.

Note: the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setLCC() of GDAL <= 2.3

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeFalseOrigin -- See Latitude of false origin
static ConversionNNPtr createLambertConicConformal_2SP_Michigan(const util::PropertyMap &properties, const common::Angle &latitudeFalseOrigin, const common::Angle &longitudeFalseOrigin, const common::Angle &latitudeFirstParallel, const common::Angle &latitudeSecondParallel, const common::Length &eastingFalseOrigin, const common::Length &northingFalseOrigin, const common::Scale &ellipsoidScalingFactor)

Instantiate a conversion based on the Lambert Conic Conformal (2SP Michigan) projection method. This method is defined as EPSG:1051.

Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeFalseOrigin -- See Latitude of false origin
- longitudeFalseOrigin -- See Longitude of false origin
- latitudeFirstParallel -- See Latitude of 1st standard parallel
- latitudeSecondParallel -- See Latitude of 2nd standard parallel
- eastingFalseOrigin -- See Easting of false origin
- northingFalseOrigin -- See Northing of false origin
- ellipsoidScalingFactor -- Ellipsoid scaling factor.

Returns
a new Conversion.

static ConversionNNPtr createLambertConicConformal_2SP_Belgium(const util::PropertyMap &properties, const common::Angle &latitudeFalseOrigin, const common::Angle &longitudeFalseOrigin, const common::Angle &latitudeFirstParallel, const common::Angle &latitudeSecondParallel, const common::Length &eastingFalseOrigin, const common::Length &northingFalseOrigin)

Instantiate a conversion based on the Lambert Conic Conformal (2SP Belgium) projection method.
This method is defined as EPSG:9803.

**Note:** the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::setLCCB() of GDAL <= 2.3

**Warning:** The formulas used currently in PROJ are, incorrectly, the ones of the regular LCC_2SP method.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `latitudeFalseOrigin` -- See Latitude of false origin
- `longitudeFalseOrigin` -- See Longitude of false origin
- `latitudeFirstParallel` -- See Latitude of 1st standard parallel
- `latitudeSecondParallel` -- See Latitude of 2nd standard parallel
- `eastingFalseOrigin` -- See Easting of false origin
- `northingFalseOrigin` -- See Northing of false origin

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createAzimuthalEquidistant(const util::PropertyMap &properties, const common::Angle &latitudeNatOrigin, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Modified Azimuthal Equidistant projection method.

This method is defined as EPSG:9832.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `latitudeNatOrigin` -- See Latitude of natural origin/Center Latitude
- `longitudeNatOrigin` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createGuamProjection(const util::PropertyMap &properties, const common::Angle &latitudeNatOrigin, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Guam Projection method.

This method is defined as EPSG:9831.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `latitudeNatOrigin` -- See Latitude of natural origin/Center Latitude
- `longitudeNatOrigin` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing
Returns
a new Conversion.

static ConversionNNPtr createBonne(const util::PropertyMap &properties, const common::Angle &latitudeNatOrigin, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Bonne projection method.

This method is defined as EPSG:9827.

Parameters
• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• latitudeNatOrigin -- See Latitude of natural origin/Center Latitude. PROJ calls its the standard parallel 1.
• longitudeNatOrigin -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createLambertCylindricalEqualAreaSpherical(const util::PropertyMap &properties, const common::Angle &latitudeFirstParallel, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Lambert Cylindrical Equal Area (Spherical) projection method.

This method is defined as EPSG:9834.

Warning: The PROJ cea computation code would select the ellipsoidal form if a non-spherical ellipsoid is used for the base GeographicCRS.

Parameters
• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• latitudeFirstParallel -- See Latitude of 1st standard parallel.
• longitudeNatOrigin -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createLambertCylindricalEqualArea(const util::PropertyMap &properties, const common::Angle &latitudeFirstParallel, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)
Instantiate a conversion based on the Lambert Cylindrical Equal Area (ellipsoidal form) projection method.

This method is defined as EPSG:9835.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `latitudeFirstParallel` -- See Latitude of 1st standard parallel.
- `longitudeNatOrigin` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createCassiniSoldner(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Cassini-Soldner projection method.

This method is defined as EPSG:9806.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLat` -- See Latitude of natural origin/Center Latitude
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createEquidistantConic(const util::PropertyMap &properties, const common::Angle &latitudeFalseOrigin, const common::Angle &longitudeFalseOrigin, const common::Angle &latitudeFirstParallel, const common::Angle &latitudeSecondParallel, const common::Length &eastingFalseOrigin, const common::Length &northingFalseOrigin)
```

Instantiate a conversion based on the Equidistant Conic projection method.

This method is defined as EPSG:1119.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `latitudeFalseOrigin` -- See Latitude of false origin
- `longitudeFalseOrigin` -- See Longitude of false origin
- `latitudeFirstParallel` -- See Latitude of 1st standard parallel
- `latitudeSecondParallel` -- See Latitude of 2nd standard parallel
- `eastingFalseOrigin` -- See Easting of false origin
- `northingFalseOrigin` -- See Northing of false origin

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createEckertI(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```
Instantiate a conversion based on the Eckert I projection method.

There is no equivalent in EPSG.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

A new Conversion.

```cpp
static ConversionNNPtr createEckertI(
    const util::PropertyMap &properties,
    const common::Angle &centerLong,
    const common::Length &falseEasting,
    const common::Length &falseNorthing)
```

Instantiate a conversion based on the Eckert II projection method.

There is no equivalent in EPSG.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

A new Conversion.

```cpp
static ConversionNNPtr createEckertII(
    const util::PropertyMap &properties,
    const common::Angle &centerLong,
    const common::Length &falseEasting,
    const common::Length &falseNorthing)
```

Instantiate a conversion based on the Eckert III projection method.

There is no equivalent in EPSG.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

A new Conversion.

```cpp
static ConversionNNPtr createEckertIII(
    const util::PropertyMap &properties,
    const common::Angle &centerLong,
    const common::Length &falseEasting,
    const common::Length &falseNorthing)
```

Instantiate a conversion based on the Eckert IV projection method.

There is no equivalent in EPSG.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

A new Conversion.

```cpp
static ConversionNNPtr createEckertIV(
    const util::PropertyMap &properties,
    const common::Angle &centerLong,
    const common::Length &falseEasting,
    const common::Length &falseNorthing)
```
static ConversionNNPtr createEckertV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Eckert V projection method.

There is no equivalent in EPSG.

Parameters

• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• centerLong -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createEckertVI(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Eckert VI projection method.

There is no equivalent in EPSG.

Parameters

• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• centerLong -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createEquidistantCylindrical(const util::PropertyMap &properties, const common::Angle &latitudeFirstParallel, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Equidistant Cylindrical projection method.

This is also known as the Equirectangular method, and in the particular case where the latitude of first parallel is 0.

This method is defined as EPSG:1028.

Note:  This is the equivalent OGRSpatialReference::SetEquirectangular2( 0.0, latitudeFirstParallel, falseEasting, falseNorthing ) of GDAL <= 2.3, where the lat_0 / center_latitude parameter is forced to 0.

Parameters

• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• latitudeFirstParallel -- See Latitude of 1st standard parallel.
• longitudeNatOrigin -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing
static ConversionNNPtr createEquidistantCylindricalSpherical(const util::PropertyMap &properties, const common::Angle &latitudeFirstParallel, const common::Angle &longitudeNatOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Equidistant Cylindrical (Spherical) projection method.
This is also known as the Equirectangular method, and in the particular case where the latitude of first parallel is 0.
This method is defined as EPSG:1029.

Note: This is the equivalent OGRSpatialReference::SetEquirectangular2( 0.0, latitudeFirstParallel, falseEasting, falseNorthing ) of GDAL <= 2.3, where the lat_0 / center_latitude parameter is forced to 0.

Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeFirstParallel -- See Latitude of 1st standard parallel.
- longitudeNatOrigin -- See Longitude of natural origin/Central Meridian
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createGall(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Gall (Stereographic) projection method.
There is no equivalent in EPSG.

Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- centerLong -- See Longitude of natural origin/Central Meridian
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createGoodeHomolosine(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Goode Homolosine projection method.
There is no equivalent in EPSG.
Parameters

- **properties** -- See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See *Longitude of natural origin/Central Meridian*
- **falseEasting** -- See *False Easting*
- **falseNorthing** -- See *False Northing*

Returns

a new *Conversion*.

```cpp
static ConversionNNPtr createInterruptedGoodeHomolosine(const util::PropertyMap &properties,
                                                      const common::Angle &centerLong,
                                                      const common::Length &falseEasting,
                                                      const common::Length &falseNorthing)
```

Instantiate a conversion based on the **Interrupted Goode Homolosine** projection method.

There is no equivalent in EPSG.

**Note:** OGRSpatialReference::SetIGH() of GDAL <= 2.3 assumes the 3 projection parameters to be zero and this is the nominal case.

Parameters

- **properties** -- See *General properties* of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See *Longitude of natural origin/Central Meridian*
- **falseEasting** -- See *False Easting*
- **falseNorthing** -- See *False Northing*

Returns

a new *Conversion*.

```cpp
static ConversionNNPtr createGeostationarySatelliteSweepX(const util::PropertyMap &properties,
                                                          const common::Angle &centerLong,
                                                          const common::Length &height,
                                                          const common::Length &falseEasting,
                                                          const common::Length &falseNorthing)
```

Instantiate a conversion based on the **Geostationary Satellite View** projection method, with the sweep angle axis of the viewing instrument being x.

There is no equivalent in EPSG.
static ConversionNNPtr createGeostationarySatelliteSweepY(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &height, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Geostationary Satellite View projection method, with the sweep angle axis of the viewing instrument being y.

There is no equivalent in EPSG.

Parameters
  - properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
  - centerLong -- See Longitude of natural origin/Central Meridian
  - height -- Height of the viewpoint above the Earth.
  - falseEasting -- See False Easting
  - falseNorthing -- See False Northing

Returns
  a new Conversion.

static ConversionNNPtr createGnomonic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Gnomonic projection method.

There is no equivalent in EPSG.

Parameters
  - properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
  - centerLat -- See Latitude of natural origin/Center Latitude
  - centerLong -- See Longitude of natural origin/Central Meridian
  - falseEasting -- See False Easting
  - falseNorthing -- See False Northing

Returns
  a new Conversion.

static ConversionNNPtr createHotineObliqueMercatorVariantA(const util::PropertyMap &properties, const common::Angle &latitudeProjectionCentre, const common::Angle &longitudeProjectionCentre, const common::Angle &azimuthInitialLine, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Hotine Oblique Mercator (Variant A) projection method.

This is the variant with the no_uoff parameter, which corresponds to GDAL >=2.3 Hotine_Oblique_Mercator projection. In this variant, the false grid coordinates are defined at the inter-
section of the initial line and the aposphere (the equator on one of the intermediate surfaces inherent
in the method), that is at the natural origin of the coordinate system).

This method is defined as EPSG:9812.

Note: In the case where azimuthInitialLine = angleFromRectifiedToSkrewGrid = 90deg, this maps
to the Swiss Oblique Mercator formulas.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it
  is automatically set.
- **latitudeProjectionCentre** -- See Latitude of projection centre
- **longitudeProjectionCentre** -- See Longitude of projection centre
- **azimuthInitialLine** -- See Azimuth of initial line
- **angleFromRectifiedToSkrewGrid** -- See Angle from Rectified to Skew Grid
- **scale** -- See Scale factor on initial line
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new Conversion.

```
static ConversionNNPtr createHotineObliqueMercatorVariantB(const util::PropertyMap
&properties, const
common::Angle
&latitudeProjectionCentre, const
common::Angle
&longitudeProjectionCentre, const
common::Angle
&azimuthInitialLine, const
common::Angle
&angleFromRectifiedToSkrewGrid, const
common::Scale
&scale, const
common::Length
&eastingProjectionCentre, const
common::Length
&northingProjectionCentre)
```

Instantiate a conversion based on the Hotine Oblique Mercator (Variant B) projection method.

This is the variant without the no_uoff parameter, which corresponds to GDAL >=2.3 Ho-
tine_Oblique_Mercator_Azimuth_Center projection. In this variant, the false grid coordinates are
defined at the projection centre.

This method is defined as EPSG:9815.

Note: In the case where azimuthInitialLine = angleFromRectifiedToSkrewGrid = 90deg, this maps
to the Swiss Oblique Mercator formulas.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it
  is automatically set.
- **latitudeProjectionCentre** -- See Latitude of projection centre
- **longitudeProjectionCentre** -- See Longitude of projection centre
- **azimuthInitialLine** -- See Azimuth of initial line
- **angleFromRectifiedToSkrewGrid** -- See Angle from Rectified to Skew Grid
- `scale` -- See *Scale factor on initial line*
- `eastingProjectionCentre` -- See *Easting at projection centre*
- `northingProjectionCentre` -- See *Northing at projection centre*

Returns

a new *Conversion*.

```cpp
static ConversionNNPtr createHotineObliqueMercatorTwoPointNaturalOrigin(
    const util::PropertyMap &properties,
    const common::Angle &latitudeProjectionCentre,
    const common::Angle &latitudePoint1,
    const common::Angle &latitudePoint2,
    const common::Angle &longitudePoint1,
    const common::Angle &longitudePoint2,
    const common::Scale &scale,
    const common::Length &eastingProjectionCentre,
    const common::Length &northingProjectionCentre)
```

Instantiates a conversion based on the Hotine Oblique Mercator Two Point Natural Origin projection method.

There is no equivalent in EPSG.

**Parameters**

- `properties` -- See *General properties* of the conversion. If the name is not provided, it is automatically set.
- `latitudeProjectionCentre` -- See *Latitude of projection centre*
- `latitudePoint1` -- Latitude of point 1.
- `longitudePoint1` -- Longitude of point 1.
- `latitudePoint2` -- Latitude of point 2.
- `longitudePoint2` -- Longitude of point 2.
- `scale` -- See *Scale factor on initial line*
- `eastingProjectionCentre` -- See *Easting at projection centre*
- `northingProjectionCentre` -- See *Northing at projection centre*

Returns

a new *Conversion*. 

static ConversionNNPtr createLabordeObliqueMercator(const util::PropertyMap &properties,
const common::Angle &latitudeProjectionCentre, const
common::Angle &longitudeProjectionCentre, const
common::Angle &azimuthInitialLine,
const common::Scale &scale, const
common::Length &falseEasting, const
common::Length &falseNorthing)

Instantiate a conversion based on the Laborde Oblique Mercator projection method.

This method is defined as EPSG:9813.

Parameters

- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `latitudeProjectionCentre` -- See Latitude of projection centre
- `longitudeProjectionCentre` -- See Longitude of projection centre
- `azimuthInitialLine` -- See Azimuth of initial line
- `scale` -- See Scale factor on initial line
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

Returns

a new `Conversion`.

static ConversionNNPtr createInternationalMapWorldPolyconic(const util::PropertyMap &properties, const
common::Angle &centerLong,
const common::Angle &latitudeFirstParallel, const
common::Angle &latitudeSecondParallel,
const common::Length &falseEasting,
const common::Length &falseNorthing)

Instantiate a conversion based on the International Map of the World Polyconic projection method.

There is no equivalent in EPSG.

**Note:** the order of arguments is conformant with the corresponding EPSG mode and different than OGRSpatialReference::SetIWMPolyconic() of GDAL <= 2.3

Parameters

- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `latitudeFirstParallel` -- See Latitude of 1st standard parallel
- `latitudeSecondParallel` -- See Latitude of 2nd standard parallel
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

Returns

a new `Conversion`.
static ConversionNNPtr createKrovakNorthOriented(const util::PropertyMap &properties, const common::Angle &latitudeProjectionCentre, const common::Angle &longitudeOfOrigin, const common::Angle &colatitudeConeAxis, const common::Angle &latitudePseudoStandardParallel, const common::Scale &scaleFactorPseudoStandardParallel, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Krovak (north oriented) projection method.

This method is defined as EPSG:1041.

The coordinates are returned in the "GIS friendly" order: easting, northing. This method is similar to createKrovak(), except that the later returns projected values as southing, westing, where southing(Krovak) = -northing(Krovak_North) and westing(Krovak) = -easting(Krovak_North).

Note: The current PROJ implementation of Krovak hard-codes colatitudeConeAxis = 30deg17'.17.30311" and latitudePseudoStandardParallel = 78deg30'N, which are the values used for the ProjectedCRS S-JTSK (Ferro) / Krovak East North (EPSG:5221). It also hard-codes the parameters of the Bessel ellipsoid typically used for Krovak.

Parameters
- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeProjectionCentre -- See Latitude of projection centre
- longitudeOfOrigin -- See Longitude of origin
- colatitudeConeAxis -- See Co-latitude of cone axis
- latitudePseudoStandardParallel -- See Latitude of pseudo standard
- scaleFactorPseudoStandardParallel -- See Scale factor on pseudo
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns
a new Conversion.

static ConversionNNPtr createKrovak(const util::PropertyMap &properties, const common::Angle &latitudeProjectionCentre, const common::Angle &longitudeOfOrigin, const common::Angle &colatitudeConeAxis, const common::Scale &latitudePseudoStandardParallel, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Krovak projection method.

This method is defined as EPSG:9819.

The coordinates are returned in the historical order: southing, westing This method is similar to createKrovakNorthOriented(), except that the later returns projected values as easting, northing, where easting(Krovak_North) = -westing(Krovak) and northing(Krovak_North) = -southing(Krovak).

Note: The current PROJ implementation of Krovak hard-codes colatitudeConeAxis = 30deg17'.17.30311" and latitudePseudoStandardParallel = 78deg30'N, which are the values used for
the ProjectedCRS S-JTSK (Ferro) / Krovak East North (EPSG:5221). It also hard-codes the parameters of the Bessel ellipsoid typically used for Krovak.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **latitudeProjectionCentre** -- See Latitude of projection centre
- **longitudeOfOrigin** -- See Longitude of origin
- **colatitudeConeAxis** -- See Co-latitude of cone axis
- **latitudePseudoStandardParallel** -- See Latitude of pseudo standard
- **scaleFactorPseudoStandardParallel** -- See Scale factor on pseudo
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new Conversion.

```cpp
static ConversionNNPtr createLambertAzimuthalEqualArea(
    const util::PropertyMap &properties,
    const common::Angle &latitudeNatOrigin, const common::Angle &longitudeNatOrigin,
    const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Lambert Azimuthal Equal Area projection method.

This method is defined as EPSG:9820.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **latitudeNatOrigin** -- See Latitude of natural origin/Center Latitude
- **longitudeNatOrigin** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new Conversion.

```cpp
static ConversionNNPtr createMillerCylindrical(
    const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Miller Cylindrical projection method.

There is no equivalent in EPSG.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new Conversion.
static ConversionNNPtr createMercatorVariantA(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Mercator (variant A) projection method.

This is the A variant, also known as Mercator (1SP), defined with the scale factor. Note that latitude of natural origin (centerLat) is a parameter, but unused in the transformation formulas.

This method is defined as EPSG:9804.

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- centerLat -- See Latitude of natural origin/Center Latitude. Should be 0.
- centerLong -- See Longitude of natural origin/Central Meridian
- scale -- See Scale Factor
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createMercatorVariantB(const util::PropertyMap &properties, const common::Angle &latitudeFirstParallel, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Mercator (variant B) projection method.

This is the B variant, also known as Mercator (2SP), defined with the latitude of the first standard parallel (the second standard parallel is implicitly the opposite value). The latitude of natural origin is fixed to zero.

This method is defined as EPSG:9805.

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- latitudeFirstParallel -- See Latitude of 1st standard parallel
- centerLong -- See Longitude of natural origin/Central Meridian
- falseEasting -- See False Easting
- falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createPopularVisualisationPseudoMercator(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Popular Visualisation Pseudo Mercator projection method.
Also known as WebMercator. Mostly/only used for Projected CRS EPSG:3857 (WGS 84 / Pseudo-Mercator)

This method is defined as EPSG:1024.

**Parameters**
- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLat** -- See Latitude of natural origin/Center Latitude. Usually 0
- **centerLong** -- See Longitude of natural origin/Central Meridian. Usually 0
- **falseEasting** -- See False Easting. Usually 0
- **falseNorthing** -- See False Northing. Usually 0

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createMercatorSpherical(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Mercator projection method, using its spherical formulation.

When used with an ellipsoid, the radius used is the radius of the conformal sphere at centerLat.

This method is defined as EPSG:1026.

Since 9.3

**Parameters**
- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createMollweide(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Mollweide projection method.

There is no equivalent in EPSG.

**Parameters**
- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

**Returns**
a new Conversion.

```cpp
static ConversionNNPtr createNewZealandMappingGrid(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```
Instantiate a conversion based on the New Zealand Map Grid projection method. This method is defined as EPSG:9811.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLat` -- See Latitude of natural origin/Center Latitude
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new `Conversion`.

```cpp
static ConversionNNPtr createObliqueStereographic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Oblique Stereographic (alternative) projection method. This method is defined as EPSG:9809.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLat` -- See Latitude of natural origin/Center Latitude
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `scale` -- See Scale Factor
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new `Conversion`.

```cpp
static ConversionNNPtr createOrthographic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Orthographic projection method. This method is defined as EPSG:9840.

**Parameters**
- `properties` -- See General properties of the conversion. If the name is not provided, it is automatically set.
- `centerLat` -- See Latitude of natural origin/Center Latitude
- `centerLong` -- See Longitude of natural origin/Central Meridian
- `falseEasting` -- See False Easting
- `falseNorthing` -- See False Northing

**Returns**
a new `Conversion`.

**Note:** Before PROJ 7.2, only the spherical formulation was implemented.
static ConversionNNPtr createAmericanPolyconic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the American Polyconic projection method.

This method is defined as EPSG:9818.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLat** -- See Latitude of natural origin/Center Latitude
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createPolarStereographicVariantA(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Polar Stereographic (Variant A) projection method.

This method is defined as EPSG:9810.

This is the variant of polar stereographic defined with a scale factor.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLat** -- See Latitude of natural origin/Center Latitude. Should be 90 deg ou -90 deg.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **scale** -- See Scale Factor
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createPolarStereographicVariantB(const util::PropertyMap &properties, const common::Angle &latitudeStandardParallel, const common::Angle &longitudeOfOrigin, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Polar Stereographic (Variant B) projection method.

This method is defined as EPSG:9829.

This is the variant of polar stereographic defined with a latitude of standard parallel.

Parameters

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
• latitudeStandardParallel -- See Latitude of standard parallel
• longitudeOfOrigin -- See Longitude of origin
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createRobinson(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Robinson projection method.

There is no equivalent in EPSG.

Parameters

• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• centerLong -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createSinusoidal(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Sinusoidal projection method.

There is no equivalent in EPSG.

Parameters

• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• centerLong -- See Longitude of natural origin/Central Meridian
• falseEasting -- See False Easting
• falseNorthing -- See False Northing

Returns

a new Conversion.

static ConversionNNPtr createStereographic(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Scale &scale, const common::Length &falseEasting, const common::Length &falseNorthing)

Instantiate a conversion based on the Stereographic projection method.

There is no equivalent in EPSG. This method implements the original "Oblique Stereographic" method described in "Snyder's Map Projections - A Working manual", which is different from the "Oblique Stereographic (alternative)" method implemented in createObliqueStereographic().

Parameters

• properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
• centerLat -- See Latitude of natural origin/Center Latitude
• centerLong -- See Longitude of natural origin/Central Meridian
• `scale` -- See `Scale Factor`
• `falseEasting` -- See `False Easting`
• `falseNorthing` -- See `False Northing`

Returns
a new `Conversion`.

static `ConversionNNPtr createVanDerGrinten` (const `util::PropertyMap` &properties, const `common::Angle` &centerLong, const `common::Length` &falseEasting, const `common::Length` &falseNorthing)

Instantiate a conversion based on the Van der Grinten projection method.

There is no equivalent in EPSG.

Parameters
• `properties` -- See `General properties` of the conversion. If the name is not provided, it is automatically set.
• `centerLong` -- See `Longitude of natural origin/Central Meridian`
• `falseEasting` -- See `False Easting`
• `falseNorthing` -- See `False Northing`

Returns
a new `Conversion`.

static `ConversionNNPtr createWagnerI` (const `util::PropertyMap` &properties, const `common::Angle` &centerLong, const `common::Length` &falseEasting, const `common::Length` &falseNorthing)

Instantiate a conversion based on the Wagner I projection method.

There is no equivalent in EPSG.

Parameters
• `properties` -- See `General properties` of the conversion. If the name is not provided, it is automatically set.
• `centerLong` -- See `Longitude of natural origin/Central Meridian`
• `falseEasting` -- See `False Easting`
• `falseNorthing` -- See `False Northing`

Returns
a new `Conversion`.

static `ConversionNNPtr createWagnerII` (const `util::PropertyMap` &properties, const `common::Angle` &centerLong, const `common::Length` &falseEasting, const `common::Length` &falseNorthing)

Instantiate a conversion based on the Wagner II projection method.

There is no equivalent in EPSG.

Parameters
• `properties` -- See `General properties` of the conversion. If the name is not provided, it is automatically set.
• `centerLong` -- See `Longitude of natural origin/Central Meridian`
• `falseEasting` -- See `False Easting`
• `falseNorthing` -- See `False Northing`

Returns
a new `Conversion`.

static `ConversionNNPtr createWagnerIII` (const `util::PropertyMap` &properties, const `common::Angle` &latitudeTrueScale, const `common::Angle` &centerLong, const `common::Length` &falseEasting, const `common::Length` &falseNorthing)
Instantiate a conversion based on the Wagner III projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **latitudeTrueScale** -- Latitude of true scale.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

**Returns**
a new Conversion.

static `ConversionNNPtr createWagnerIV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)`

Instantiate a conversion based on the Wagner IV projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

**Returns**
a new Conversion.

static `ConversionNNPtr createWagnerV(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)`

Instantiate a conversion based on the Wagner V projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

**Returns**
a new Conversion.

static `ConversionNNPtr createWagnerVI(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)`

Instantiate a conversion based on the Wagner VI projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing
Returns

a new *Conversion*.

```cpp
static ConversionNNPtr createWagnerVII(const util::PropertyMap &properties, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Wagner VII projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new *Conversion*.

```cpp
static ConversionNNPtr createQuadrilateralizedSphericalCube(const util::PropertyMap &properties, const common::Angle &centerLat, const common::Angle &centerLong, const common::Length &falseEasting, const common::Length &falseNorthing)
```

Instantiate a conversion based on the Quadrilateralized Spherical Cube projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **centerLat** -- See Latitude of natural origin/Center Latitude
- **centerLong** -- See Longitude of natural origin/Central Meridian
- **falseEasting** -- See False Easting
- **falseNorthing** -- See False Northing

Returns

a new *Conversion*.

```cpp
static ConversionNNPtr createSphericalCrossTrackHeight(const util::PropertyMap &properties, const common::Angle &pegPointLat, const common::Angle &pegPointLong, const common::Angle &pegPointHeading, const common::Length &pegPointHeight)
```

Instantiate a conversion based on the Spherical Cross-Track Height projection method.

There is no equivalent in EPSG.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **pegPointLat** -- Peg point latitude.
- **pegPointLong** -- Peg point longitude.
- **pegPointHeading** -- Peg point heading.
- **pegPointHeight** -- Peg point height.
Returns
a new *Conversion*.

static *ConversionNNPtr* `createEqualEarth` *(const *util::PropertyMap* &properties, const
*common::Angle* &centerLong, const *common::Length* &falseEasting, const *common::Length* &falseNorthing)*

Instantiate a conversion based on the Equal Earth projection method.

This method is defined as EPSG:1078.

**Parameters**
- *properties* -- See General properties of the conversion. If the name is not provided, it is automatically set.
- *centerLong* -- See Longitude of natural origin/Central Meridian
- *falseEasting* -- See False Easting
- *falseNorthing* -- See False Northing

Returns
a new *Conversion*.

static *ConversionNNPtr* `createVerticalPerspective` *(const *util::PropertyMap* &properties, const
*common::Angle* &topoOriginLat, const *common::Angle* &topoOriginLong, const *common::Length* &topoOriginHeight, const *common::Length* &viewPointHeight, const *common::Length* &falseEasting, const *common::Length* &falseNorthing)*

Instantiate a conversion based on the Vertical Perspective projection method.

This method is defined as EPSG:9838.

The PROJ implementation of the EPSG Vertical Perspective has the current limitations with respect to the method described in EPSG:
- it is a 2D-only method, ignoring the ellipsoidal height of the point to project.
- it has only a spherical development.
- the height of the topocentric origin is ignored, and thus assumed to be 0.

For completeness, PROJ adds the falseEasting and falseNorthing parameter, which are not described in EPSG. They should usually be set to 0.

Since
6.3

**Parameters**
- *properties* -- See General properties of the conversion. If the name is not provided, it is automatically set.
- *topoOriginLat* -- Latitude of topocentric origin
- *topoOriginLong* -- Longitude of topocentric origin
- *topoOriginHeight* -- Ellipsoidal height of topocentric origin. Ignored by PROJ (that is assumed to be 0)
- *viewPointHeight* -- Viewpoint height with respect to the topocentric/mapping plane. In the case where topoOriginHeight = 0, this is the height above the ellipsoid surface at topoOriginLat, topoOriginLong.
- *falseEasting* -- See False Easting . (not in EPSG)
- *falseNorthing* -- See False Northing . (not in EPSG)

Returns
a new *Conversion*. 
static ConversionNNPtr createPoleRotationGRIBConvention(const util::PropertyMap &properties, const common::Angle &southPoleLatInUnrotatedCRS, const common::Angle &southPoleLongInUnrotatedCRS, const common::Angle &axisRotation)

Instantiate a conversion based on the Pole Rotation method, using the conventions of the GRIB 1 and GRIB 2 data formats.

Those are mentioned in the Note 2 of https://www.nco.ncep.noaa.gov/pmb/docs/grib2/grib2_doc/grib2_temp3-1.shtml

Several conventions for the pole rotation method exists. The parameters provided in this method are remapped to the PROJ ob_tran operation with:

Another implementation of that convention is also in the netcdf-java library: https://github.com/Unidata/netcdf-java/blob/3ce72c0cd167609ed8c69152bb4a004d1daa9273/cdm/core/src/main/java/ucar/unidata/geoloc/projection/RotatedLatLon.java

The PROJ implementation of this method assumes a spherical ellipsoid.

Since 7.0

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- southPoleLatInUnrotatedCRS -- Latitude of the point from the unrotated CRS, expressed in the unrotated CRS, that will become the south pole of the rotated CRS.
- southPoleLongInUnrotatedCRS -- Longitude of the point from the unrotated CRS, expressed in the unrotated CRS, that will become the south pole of the rotated CRS.
- axisRotation -- The angle of rotation about the new polar axis (measured clockwise when looking from the southern to the northern pole) of the coordinate system, assuming the new axis to have been obtained by first rotating the sphere through southPoleLongInUnrotatedCRS degrees about the geographic polar axis and then rotating through (90 + southPoleLatInUnrotatedCRS) degrees so that the southern pole moved along the (previously rotated) Greenwich meridian.

Returns

a new Conversion.

static ConversionNNPtr createPoleRotationNetCDFCFConvention(const util::PropertyMap &properties, const common::Angle &gridNorthPoleLatitude, const common::Angle &gridNorthPoleLongitude, const common::Angle &northPoleGridLongitude)

Instantiate a conversion based on the Pole Rotation method, using the conventions of the netCDF CF convention for the netCDF format.

Those are mentioned in the Note 2 of https://cfconventions.org/Data/cf-conventions/cf-conventions-1.8/cf-conventions.html#_rotated_pole

Several conventions for the pole rotation method exists. The parameters provided in this method are remapped to the PROJ ob_tran operation with:
Another implementation of that convention is also in the netcdf-java library: https://github.com/Unidata/netcdf-java/blob/3ce72c0cd167609ed8c69152bb4a004d1da9273/cdm/core/src/main/java/ucar/unidata/geoloc/projection/RotatedPole.java

The PROJ implementation of this method assumes a spherical ellipsoid.

Since

8.2

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- gridNorthPoleLatitude -- True latitude of the north pole of the rotated grid
- gridNorthPoleLongitude -- True longitude of the north pole of the rotated grid.
- northPoleGridLongitude -- Longitude of the true north pole in the rotated grid.

Returns

a new Conversion.

static ConversionNNPtr createChangeVerticalUnit(const util::PropertyMap &properties, const common::Scale &factor)

Instantiate a conversion based on the Change of Vertical Unit method.

This method is defined as EPSG:1069 [DEPRECATED].

Parameters

- properties -- See General properties of the conversion. If the name is not provided, it is automatically set.
- factor -- Conversion factor

Returns

a new Conversion.

static ConversionNNPtr createChangeVerticalUnit(const util::PropertyMap &properties)

Instantiate a conversion based on the Change of Vertical Unit method (without explicit conversion factor)

This method is defined as EPSG:1104.

Parameters

properties -- See General properties of the conversion. If the name is not provided, it is automatically set.

Returns

a new Conversion.

static ConversionNNPtr createHeightDepthReversal(const util::PropertyMap &properties)

Instantiate a conversion based on the Height Depth Reversal method.

This method is defined as EPSG:1068.

Since

6.3

Parameters

properties -- See General properties of the conversion. If the name is not provided, it is automatically set.

Returns

a new Conversion.

static ConversionNNPtr createAxisOrderReversal(bool is3D)

Instantiate a conversion based on the Axis order reversal method.
This swaps the longitude, latitude axis.

This method is defined as EPSG:9843 for 2D or EPSG:9844 for Geographic3D horizontal.

**Parameters**

- **is3D** -- Whether this should apply on 3D geographicCRS

**Returns**

a new *Conversion*.

static *ConversionNNPtr* createGeographicGeocentric(const *util::PropertyMap* &properties)

Instantiate a conversion based on the Geographic/Geocentric method.

This method is defined as EPSG:9602.

**Parameters**

- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.

**Returns**

a new *Conversion*.

static *ConversionNNPtr* createGeographic2DOffsets(const *util::PropertyMap* &properties, const *common::Angle* &offsetLat, const *common::Angle* &offsetLong)

Instantiate a conversion with method Geographic 2D offsets.

This method is defined as EPSG:9619.

**Parameters**

- **properties** -- See General properties of the conversion. At minimum the name should be defined.
- **offsetLat** -- Latitude offset to add.
- **offsetLong** -- Longitude offset to add.

**Returns**

new conversion.

static *ConversionNNPtr* createGeographic3DOffsets(const *util::PropertyMap* &properties, const *common::Angle* &offsetLat, const *common::Angle* &offsetLong, const *common::Length* &offsetHeight)

Instantiate a conversion with method Geographic 3D offsets.

This method is defined as EPSG:9660.

**Parameters**

- **properties** -- See General properties of the *Conversion*. At minimum the name should be defined.
- **offsetLat** -- Latitude offset to add.
- **offsetLong** -- Longitude offset to add.
- **offsetHeight** -- Height offset to add.

**Returns**

new *Conversion*.

static *ConversionNNPtr* createGeographic2DWithHeightOffsets(const *util::PropertyMap* &properties, const *common::Angle* &offsetLat, const *common::Angle* &offsetLong, const *common::Length* &offsetHeight)

Instantiate a conversion with method Geographic 2D with height offsets.

This method is defined as EPSG:9618.
Parameters

• properties -- See General properties of the Conversion. At minimum the name should be defined.
• offsetLat -- Latitude offset to add.
• offsetLong -- Longitude offset to add.
• offsetHeight -- Geoid undulation to add.

Returns
new Conversion.

static ConversionNNPtr createVerticalOffset(const util::PropertyMap &properties, const common::Length &offsetHeight)

Instantiate a conversion with method Vertical Offset.

This method is defined as EPSG:9616.

Parameters

• properties -- See General properties of the Conversion. At minimum the name should be defined.
• offsetHeight -- Geoid undulation to add.

Returns
new Conversion.

class Transformation : public osgeo::proj::operation::SingleOperation
#include <coordinateoperation.hpp> A mathematical operation on coordinates in which parameters are empirically derived from data containing the coordinates of a series of points in both coordinate reference systems.

This computational process is usually "over-determined", allowing derivation of error (or accuracy) estimates for the coordinate transformation. Also, the stochastic nature of the parameters may result in multiple (different) versions of the same coordinate transformations between the same source and target CRSs. Any single coordinate operation in which the input and output coordinates are referenced to different datums (reference frames) will be a coordinate transformation.

Remark

Implements Transformation from ISO 19111:2019

Public Functions

const crs::CRSNNPtr &sourceCRS()

Return the source crs::CRS of the transformation.

Returns
the source CRS.

const crs::CRSNNPtr &targetCRS()

Return the target crs::CRS of the transformation.

Returns
the target CRS.

virtual CoordinateOperationNNPtr inverse() const override

Return the inverse of the coordinate operation.

Throws
util::UnsupportedOperationException --
Public Static Functions

static TransformationNNPtr create(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const crs::CRSPtr &interpolationCRSIn, const OperationMethodNNPtr &methodIn, const std::vector<GeneralParameterValueNNPtr> &values, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation from a vector of GeneralParameterValue.

Parameters

- properties -- See General properties. At minimum the name should be defined.
- sourceCRSIn -- Source CRS.
- targetCRSIn -- Target CRS.
- interpolationCRSIn -- Interpolation CRS (might be null)
- methodIn -- Operation method.
- values -- Vector of GeneralOperationParameterNNPtr.
- accuracies -- Vector of positional accuracy (might be empty).

Throws

InvalidOperation --

Returns

new Transformation.

static TransformationNNPtr create(const util::PropertyMap &propertiesTransformation, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const crs::CRSPtr &interpolationCRSIn, const util::PropertyMap &propertiesOperationMethod, const std::vector<OperationParameterNNPtr> &parameters, const std::vector<ParameterValueNNPtr> &values, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation and its OperationMethod.

Parameters

- propertiesTransformation -- The General properties of the Transformation. At minimum the name should be defined.
- sourceCRSIn -- Source CRS.
- targetCRSIn -- Target CRS.
- interpolationCRSIn -- Interpolation CRS (might be null)
- propertiesOperationMethod -- The General properties of the OperationMethod. At minimum the name should be defined.
- parameters -- Vector of parameters of the operation method.
- values -- Vector of ParameterValueNNPtr. Constraint: values.size() == parameters.size()
- accuracies -- Vector of positional accuracy (might be empty).

Throws

InvalidOperation --

Returns

new Transformation.

static TransformationNNPtr createGeocentricTranslations(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Chapter 10. Development
Instantiate a transformation with Geocentric Translations method.

Parameters
- properties -- See General properties of the Transformation. At minimum the name should be defined.
- sourceCRSIn -- Source CRS.
- targetCRSIn -- Target CRS.
- translationXMetre -- Value of the Translation_X parameter (in metre).
- translationYMetre -- Value of the Translation_Y parameter (in metre).
- translationZMetre -- Value of the Translation_Z parameter (in metre).
- accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.

static TransformationNNPtr createPositionVector(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond, double scaleDifferencePPM, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with Position vector transformation method.

This is similar to createCoordinateFrameRotation(), except that the sign of the rotation terms is inverted.

Parameters
- properties -- See General properties of the Transformation. At minimum the name should be defined.
- sourceCRSIn -- Source CRS.
- targetCRSIn -- Target CRS.
- translationXMetre -- Value of the Translation_X parameter (in metre).
- translationYMetre -- Value of the Translation_Y parameter (in metre).
- translationZMetre -- Value of the Translation_Z parameter (in metre).
- rotationXArcSecond -- Value of the Rotation_X parameter (in arc-second).
- rotationYArcSecond -- Value of the Rotation_Y parameter (in arc-second).
- rotationZArcSecond -- Value of the Rotation_Z parameter (in arc-second).
- scaleDifferencePPM -- Value of the Scale_Difference parameter (in parts-per-million).
- accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.
static TransformationNNPtr createCoordinateFrameRotation(
    const util::PropertyMap &properties,
    const crs::CRSNNPtr &sourceCRSIn,
    const crs::CRSNNPtr &targetCRSIn,
    double translationXMetre, double translationYMetre, double translationZMetre,
    double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond,
    double scaleDifferencePPM, const std::vector<
multiformat::PositionalAccuracyNNPtr>&accuracies)

Instantiate a transformation with Coordinate Frame Rotation method.

This is similar to createPositionVector(), except that the sign of the rotation terms is inverted.

Parameters

- properties -- See General properties of the Transformation. At minimum the name should be defined.
- sourceCRSIn -- Source CRS.
- targetCRSIn -- Target CRS.
- translationXMetre -- Value of the Translation_X parameter (in metre).
- translationYMetre -- Value of the Translation_Y parameter (in metre).
- translationZMetre -- Value of the Translation_Z parameter (in metre).
- rotationXArcSecond -- Value of the Rotation_X parameter (in arc-second).
- rotationYArcSecond -- Value of the Rotation_Y parameter (in arc-second).
- rotationZArcSecond -- Value of the Rotation_Z parameter (in arc-second).
- scaleDifferencePPM -- Value of the Scale_Difference parameter (in parts-per-million).
- accuracies -- Vector of positional accuracy (might be empty).

Returns

new Transformation.

static TransformationNNPtr createTimeDependentPositionVector(
    const util::PropertyMap &properties, const
    crs::CRSNNPtr &sourceCRSIn,
    const crs::CRSNNPtr &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre,
    double rotationXArcSecond, double rotationYArcSecond, double rotationZArcSecond,
    double scaleDifferencePPM, double rateTranslationX, double rateTranslationY, double rateTranslationZ,
    double rateRotationX, double rateRotationY, double rateRotationZ, double rateScaleDifference, double referenceEpochYear, const
    std::vector<
multiformat::PositionalAccuracyNNPtr>&accuracies)
Instantiate a transformation with Time Dependent position vector transformation method.

This is similar to `createTimeDependentCoordinateFrameRotation()`, except that the sign of the rotation terms is inverted.

This method is defined as EPSG:1053.

**Parameters**

- `properties` -- See General properties of the Transformation. At minimum the name should be defined.
- `sourceCRSIn` -- Source CRS.
- `targetCRSIn` -- Target CRS.
- `translationXMetre` -- Value of the Translation_X parameter (in metre).
- `translationYMetre` -- Value of the Translation_Y parameter (in metre).
- `translationZMetre` -- Value of the Translation_Z parameter (in metre).
- `rotationXArcSecond` -- Value of the Rotation_X parameter (in arc-second).
- `rotationYArcSecond` -- Value of the Rotation_Y parameter (in arc-second).
- `rotationZArcSecond` -- Value of the Rotation_Z parameter (in arc-second).
- `scaleDifferencePPM` -- Value of the Scale_Difference parameter (in parts-per-million).
- `rateTranslationX` -- Value of the rate of change of X-axis translation (in metre/year)
- `rateTranslationY` -- Value of the rate of change of Y-axis translation (in metre/year)
- `rateTranslationZ` -- Value of the rate of change of Z-axis translation (in metre/year)
- `rateRotationX` -- Value of the rate of change of X-axis rotation (in arc-second/year)
- `rateRotationY` -- Value of the rate of change of Y-axis rotation (in arc-second/year)
- `rateRotationZ` -- Value of the rate of change of Z-axis rotation (in arc-second/year)
- `rateScaleDifference` -- Value of the rate of change of scale difference (in PPM/year)
- `referenceEpochYear` -- Parameter reference epoch (in decimal year)
- `accuracies` -- Vector of positional accuracy (might be empty).

**Returns**

new Transformation.
static TransformationNNPtr createTimeDependentCoordinateFrameRotation(const 
util::PropertyMap &properties, const 
crs::CRSNNPtr &sourceCRSIn, 
const 
crs::CRSNNPtr &targetCRSIn, 
double translationXMetre, 
double translationYMetre, 
double translationZMetre, 
double rotationXArcSecond, 
double rotationYArcSecond, 
double rotationZArcSecond, 
double scaleDifferencePPM, 
double rateTranslationX, 
double rateTranslationY, 
double rateTranslationZ, 
double rateRotationX, 
double rateRotationY, 
double rateRotationZ, 
double rateScaleDifference, 
double referenceEpochYear, 
const 
std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with Time Dependent Position coordinate frame rotation transformation method.

This is similar to createTimeDependentPositionVector(), except that the sign of the rotation terms is inverted.

This method is defined as EPSG:1056.

Parameters
- **properties** -- See General properties of the Transformation. At minimum the name should be defined.
- **sourceCRSIn** -- Source CRS.
- **targetCRSIn** -- Target CRS.
- **translationXMetre** -- Value of the Translation_X parameter (in metre).
- **translationYMetre** -- Value of the Translation_Y parameter (in metre).
- **translationZMetre** -- Value of the Translation_Z parameter (in metre).
• rotationXArcSecond -- Value of the Rotation_X parameter (in arc-second).
• rotationYArcSecond -- Value of the Rotation_Y parameter (in arc-second).
• rotationZArcSecond -- Value of the Rotation_Z parameter (in arc-second).
• scaleDifferencePPM -- Value of the Scale_Difference parameter (in parts-per-million).
• rateTranslationX -- Value of the rate of change of X-axis translation (in metre/year)
• rateTranslationY -- Value of the rate of change of Y-axis translation (in metre/year)
• rateTranslationZ -- Value of the rate of change of Z-axis translation (in metre/year)
• rateRotationX -- Value of the rate of change of X-axis rotation (in arc-second/year)
• rateRotationY -- Value of the rate of change of Y-axis rotation (in arc-second/year)
• rateRotationZ -- Value of the rate of change of Z-axis rotation (in arc-second/year)
• rateScaleDifference -- Value of the rate of change of scale difference (in PPM/year)
• referenceEpochYear -- Parameter reference epoch (in decimal year)
• accuracies -- Vector of positional accuracy (might be empty).

Throws
- InvalidOperation --

Returns
new Transformation.

static TransformationNNPtr createTOWGS84(const crs::CRSNNPtr &sourceCRSIn, const std::vector<double> &TOWGS84Parameters)

Instantiate a transformation from TOWGS84 parameters.

This is a helper of createPositionVector() with the source CRS being the GeographicCRS of sourceCRSIn, and the target CRS being EPSG:4326

Parameters
• sourceCRSIn -- Source CRS.
• TOWGS84Parameters -- The vector of 3 double values (Translation_X, Y, Z) or 7 double values (Translation_X, Y, Z, Rotation_X, Y, Z, Scale_Difference) passed to createPositionVector()

Throws
- InvalidOperation --

Returns
new Transformation.

static TransformationNNPtr createNTv2(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const std::string &filename, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with NTv2 method.

Parameters
• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• filename -- NTv2 filename.
• accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.
static TransformationNNPtr createMolodensky(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double semiMajorAxisDifferenceMetre, double flattingDifference, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with Molodensky method.

This method is defined as EPSG:9604.

See also:
createAbridgedMolodensky() for a related method.

Parameters
• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• translationXMetre -- Value of the Translation_X parameter (in metre).
• translationYMetre -- Value of the Translation_Y parameter (in metre).
• translationZMetre -- Value of the Translation_Z parameter (in metre).
• semiMajorAxisDifferenceMetre -- The difference between the semi-major axis values of the ellipsoids used in the target and source CRS (in metre).
• flattingDifference -- The difference between the flattening values of the ellipsoids used in the target and source CRS.
• accuracies -- Vector of positional accuracy (might be empty).

Throws
InvalidOperation --

Returns
new Transformation.

static TransformationNNPtr createAbridgedMolodensky(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, double translationXMetre, double translationYMetre, double translationZMetre, double semiMajorAxisDifferenceMetre, double flattingDifference, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with Abridged Molodensky method.

This method is defined as EPSG:9605.

See also:
createMolodensky() for a related method.

Parameters
• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• translationXMetre -- Value of the Translation_X parameter (in metre).
• translationYMetre -- Value of the Translation_Y parameter (in metre).
• translationZMetre -- Value of the Translation_Z parameter (in metre).
• semiMajorAxisDifferenceMetre -- The difference between the semi-major axis values of the ellipsoids used in the target and source CRS (in metre).
• flattingDifference -- The difference between the flattening values of the ellipsoids used in the target and source CRS.
• accuracies -- Vector of positional accuracy (might be empty).

Throws

InvalidOperation

Returns

new Transformation.

static TransformationNNPtr createGravityRelatedHeightToGeographic3D(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const std::string &filename, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation from GravityRelatedHeight to Geographic3D.

Parameters

• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• interpolationCRSIn -- Interpolation CRS. (might be null)
• filename -- GRID filename.
• accuracies -- Vector of positional accuracy (might be empty).

Returns

new Transformation.

static TransformationNNPtr createVERTCON(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const std::string &filename, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method VERTCON.

Parameters

• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• filename -- GRID filename.
• accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.

static TransformationNNPtr createLongitudeRotation(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const common::Angle &offset)

Instantiate a transformation with method Longitude rotation.

This method is defined as EPSG:9601.

Parameters

- **properties** -- See General properties of the Transformation. At minimum the name should be defined.
- **sourceCRSIn** -- Source CRS.
- **targetCRSIn** -- Target CRS.
- **offset** -- Longitude offset to add.

Returns

new Transformation.

static TransformationNNPtr createGeographic2DOffsets(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const common::Angle &offsetLat, const common::Angle &offsetLong, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method Geographic 2D offsets.

This method is defined as EPSG:9619.

Parameters

- **properties** -- See General properties of the Transformation. At minimum the name should be defined.
- **sourceCRSIn** -- Source CRS.
- **targetCRSIn** -- Target CRS.
- **offsetLat** -- Latitude offset to add.
- **offsetLong** -- Longitude offset to add.
- **accuracies** -- Vector of positional accuracy (might be empty).

Returns

new Transformation.

static TransformationNNPtr createGeographic3DOffsets(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRSIn, const crs::CRSNNPtr &targetCRSIn, const common::Angle &offsetLat, const common::Angle &offsetLong, const common::Length &offsetHeight, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method Geographic 3D offsets.

This method is defined as EPSG:9660.

Parameters

- **properties** -- See General properties of the Transformation. At minimum the name should be defined.
- **sourceCRSIn** -- Source CRS.
- **targetCRSIn** -- Target CRS.
- **offsetLat** -- Latitude offset to add.
• offsetLong -- Longitude offset to add.
• offsetHeight -- Height offset to add.
• accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.

static TransformationNNPtr createGeographic2DWithHeightOffsets(const PropertyMap &properties, const CRSNNPtr &sourceCRSIn, const CRSNNPtr &targetCRSIn, const Angle &offsetLat, const Angle &offsetLong, const Length &offsetHeight, const std::vector<PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method Geographic 2D with height offsets.

This method is defined as EPSG:9618.

Parameters
• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• offsetLat -- Latitude offset to add.
• offsetLong -- Longitude offset to add.
• offsetHeight -- Geoid undulation to add.
• accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.

static TransformationNNPtr createVerticalOffset(const PropertyMap &properties, const CRSNNPtr &sourceCRSIn, const CRSNNPtr &targetCRSIn, const Length &offsetHeight, const std::vector<PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation with method Vertical Offset.

This method is defined as EPSG:9616.

Parameters
• properties -- See General properties of the Transformation. At minimum the name should be defined.
• sourceCRSIn -- Source CRS.
• targetCRSIn -- Target CRS.
• offsetHeight -- Geoid undulation to add.
• accuracies -- Vector of positional accuracy (might be empty).

Returns
new Transformation.
static TransformationNNPtr createChangeVerticalUnit(const util::PropertyMap &properties, const crs::CRSNNPtr &sourceCRS, const crs::CRSNNPtr &targetCRS, const common::Scale &factor, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a transformation based on the Change of Vertical Unit method.

This method is defined as EPSG:1069 [DEPRECATED].

**Parameters**
- **properties** -- See General properties of the conversion. If the name is not provided, it is automatically set.
- **sourceCRS** -- Source CRS.
- **targetCRS** -- Target CRS.
- **factor** -- Conversion factor
- **accuracies** -- Vector of positional accuracy (might be empty).

**Returns**
- a new Transformation.

class PointMotionOperation : public osgeo::proj::operation::SingleOperation

`#include <coordinateoperation.hpp>` A mathematical operation that describes the change of coordinate values within one coordinate reference system due to the motion of the point between one coordinate epoch and another coordinate epoch.

The motion is due to tectonic plate movement or deformation.

**Remark**

Implements PointMotionOperation from ISO 19111:2019

class ConcatenatedOperation : public osgeo::proj::operation::CoordinateOperation

`#include <coordinateoperation.hpp>` An ordered sequence of two or more single coordinate operations (SingleOperation).

The sequence of coordinate operations is constrained by the requirement that the source coordinate reference system of step n+1 shall be the same as the target coordinate reference system of step n.

**Remark**

Implements ConcatenatedOperation from ISO 19111:2019
Public Functions

const std::vector<CoordinateOperationNNPtr> &operations() const

Return the operation steps of the concatenated operation.

virtual CoordinateOperationNNPtr inverse() const override

Return the inverse of the coordinate operation.

virtual std::set<GridDescription> gridsNeeded(const io::DatabaseContextPtr &databaseContext, bool considerKnownGridsAsAvailable) const override

Return grids needed by an operation.

Public Static Functions

static ConcatenatedOperationNNPtr create(const util::PropertyMap &properties, const std::vector<CoordinateOperationNNPtr> &operationsIn, const std::vector<metadata::PositionalAccuracyNNPtr> &accuracies)

Instantiate a ConcatenatedOperation.

Parameters
- properties -- See General properties. At minimum the name should be defined.
- operationsIn -- Vector of the CoordinateOperation steps.
- accuracies -- Vector of positional accuracy (might be empty).

Throws
InvalidOperation --

Returns
new Transformation.

static CoordinateOperationNNPtr createComputeMetadata(const std::vector<CoordinateOperationNNPtr> &operationsIn, bool checkExtent)

Instantiate a ConcatenatedOperation, or return a single coordinate operation.

This computes its accuracy from the sum of its member operations, its extent

Parameters
- operationsIn -- Vector of the CoordinateOperation steps.
- checkExtent -- Whether we should check the non-emptiness of the intersection of the extents of the operations

Throws
InvalidOperation --

class CoordinateOperationContext

#include <coordinateoperation.hpp> Context in which a coordinate operation is to be used.

Remark
**Public Types**

enum class `SourceTargetCRSExtentUse`

Specify how source and target CRS extent should be used to restrict candidate operations (only taken into account if no explicit area of interest is specified).

*Values:*

- **NONE**: Ignore CRS extent
- **BOTH**: Test coordinate operation extent against both CRS extent.
- **INTERSECTION**: Test coordinate operation extent against the intersection of both CRS extent.
- **SMALLEST**: Test coordinate operation against the smallest of both CRS extent.

enum class `SpatialCriterion`

Spatial criterion to restrict candidate operations.

*Values:*

- **STRICT_CONTAINMENT**: The area of validity of transforms should strictly contain the area of interest.
- **PARTIAL_INTERSECTION**: The area of validity of transforms should at least intersect the area of interest.

enum class `GridAvailabilityUse`

Describe how grid availability is used.

*Values:*

- **USE_FOR_SORTING**: Grid availability is only used for sorting results. Operations where some grids are missing will be sorted last.
- **DISCARD_OPERATION_IF_MISSING_GRID**: Completely discard an operation if a required grid is missing.
enumerator **IGNORE_GRID_AVAILABILITY**

Ignore grid availability at all. Results will be presented as if all grids were available.

enumerator **KNOWN_AVAILABLE**

Results will be presented as if grids known to PROJ (that is registered in the grid_alternatives table of its database) were available. Used typically when networking is enabled.

enum class **IntermediateCRSUse**

Describe if and how intermediate CRS should be used

*Values:*

enumerator **ALWAYS**

Always search for intermediate CRS.

enumerator **IF_NO_DIRECT_TRANSFORMATION**

Only attempt looking for intermediate CRS if there is no direct transformation available.

enumerator **NEVER**

**Public Functions**

const *io::AuthorityFactoryPtr &getAuthorityFactory() const*

Return the authority factory, or null.

const *metadata::ExtentPtr &getAreaOfInterest() const*

Return the desired area of interest, or null.

void **setAreaOfInterest** (const *metadata::ExtentPtr &extent)

Set the desired area of interest, or null.

double **getDesiredAccuracy() const**

Return the desired accuracy (in metre), or 0.

void **setDesiredAccuracy** (double accuracy)

Set the desired accuracy (in metre), or 0.

void **setAllowBallparkTransformations** (bool allow)

Set whether ballpark transformations are allowed.

bool **getAllowBallparkTransformations() const**

Return whether ballpark transformations are allowed.

void **setSourceAndTargetCRSExtentUse** (SourceTargetCRSExtentUse use)

Set how source and target CRS extent should be used when considering if a transformation can be used (only takes effect if no area of interest is explicitly defined).

The default is CoordinateOperationContext::SourceTargetCRSExtentUse::SMALLEST.
SourceTargetCRSExtentUse getSourceAndTargetCRSExtentUse() const
Return how source and target CRS extent should be used when considering if a transformation can be used (only takes effect if no area of interest is explicitly defined).
The default is CoordinateOperationContext::SourceTargetCRSExtentUse::SMALLEST.

void setSpatialCriterion(SpatialCriterion criterion)
Set the spatial criterion to use when comparing the area of validity of coordinate operations with the area of interest / area of validity of source and target CRS.
The default is STRICT_CONTAINMENT.

SpatialCriterion getSpatialCriterion() const
Return the spatial criterion to use when comparing the area of validity of coordinate operations with the area of interest / area of validity of source and target CRS.
The default is STRICT_CONTAINMENT.

void setUsePROJAlternativeGridNames(bool usePROJNames)
Set whether PROJ alternative grid names should be substituted to the official authority names.
This only has effect is an authority factory with a non-null database context has been attached to this context.
If set to false, it is still possible to obtain later the substitution by using io::PROJStringFormatter::create() with a non-null database context.
The default is true.

bool getUsePROJAlternativeGridNames() const
Return whether PROJ alternative grid names should be substituted to the official authority names.
The default is true.

void setDiscardSuperseded(bool discard)
Set whether transformations that are superseded (but not deprecated) should be discarded.
The default is true.

bool getDiscardSuperseded() const
Return whether transformations that are superseded (but not deprecated) should be discarded.
The default is true.

void setGridAvailabilityUse(GridAvailabilityUse use)
Set how grid availability is used.
The default is USE_FOR_SORTING.

GridAvailabilityUse getGridAvailabilityUse() const
Return how grid availability is used.
The default is USE_FOR_SORTING.

void setAllowUseIntermediateCRS(IntermediateCRSUse use)
Set whether an intermediate pivot CRS can be used for researching coordinate operations between a source and target CRS.
Concretely if in the database there is an operation from A to C (or C to A), and another one from C to B (or B to C), but no direct operation between A and B, setting this parameter to ALWAYS/IF_NO_DIRECT_TRANSFORMATION, allow chaining both operations.
The current implementation is limited to researching one intermediate step.
By default, with the IF_NO_DIRECT_TRANSFORMATION strategy, all potential C candidates will be used if there is no direct transformation.

*Intermediate CRS Use* `getAllowUseIntermediateCRS(const)`
Return whether an intermediate pivot CRS can be used for researching coordinate operations between a source and target CRS.

Concretely if in the database there is an operation from A to C (or C to A), and another one from C to B (or B to C), but no direct operation between A and B, setting this parameter to ALWAYS/IF_NO_DIRECT_TRANSFORMATION, allow chaining both operations.

The default is IF_NO_DIRECT_TRANSFORMATION.

```cpp
void setIntermediateCRS(const std::vector<std::pair<std::string, std::string>> &intermediateCRSAuthCodes)
Restrict the potential pivot CRSs that can be used when trying to build a coordinate operation between two CRS that have no direct operation.

Parameters

- `intermediateCRSAuthCodes` -- a vector of (auth_name, code) that can be used as potential pivot RS

```cpp
const std::vector<std::pair<std::string, std::string>> &getIntermediateCRS() const
Return the potential pivot CRSs that can be used when trying to build a coordinate operation between two CRS that have no direct operation.
```

```cpp
void setSourceCoordinateEpoch(const util::optional<common::DataEpoch> &epoch)
Set the source coordinate epoch.
```

```cpp
const util::optional<common::DataEpoch> &getSourceCoordinateEpoch() const
Return the source coordinate epoch.
```

```cpp
void setTargetCoordinateEpoch(const util::optional<common::DataEpoch> &epoch)
Set the target coordinate epoch.
```

```cpp
const util::optional<common::DataEpoch> &getTargetCoordinateEpoch() const
Return the target coordinate epoch.
```

*CoordinateOperationContext NNPtr clone(const)*
Clone a coordinate operation context.

**Since**
9.2

**Returns**
a new context.

**Public Static Functions**

```cpp
static CoordinateOperationContext NNPtr create(const io::AuthorityFactoryPtr &authorityFactory,
const metadata::ExtentPtr &extent, double accuracy)
Creates a context for a coordinate operation.

If a non null authorityFactory is provided, the resulting context should not be used simultaneously by more than one thread.

If authorityFactory->getAuthority() is the empty string, then coordinate operations from any authority will be searched, with the restrictions set in the authority_to_authority_preference database table. If
authorityFactory->getAuthority() is set to "any", then coordinate operations from any authority will be searched. If authorityFactory->getAuthority() is a non-empty string different of "any", then coordinate operations will be searched only in that authority namespace.

**Parameters**

- **authorityFactory** -- Authority factory, or null if no database lookup is allowed. Use
  io::authorityFactory::create(context, std::string()) to allow all authorities to be used.
- **extent** -- Area of interest, or null if none is known.
- **accuracy** -- Maximum allowed accuracy in metre, as specified in or 0 to get best accuracy.

**Returns**
a new context.

class **CoordinateOperationFactory**

```
#include <coordinateoperation.hpp>
```

Creates coordinate operations. This factory is capable to find coordinate transformations or conversions between two coordinate reference systems.

**Remark**

Implements (partially) CoordinateOperationFactory from GeoAPI

**Public Functions**

```
CoordinateOperationPtr createOperation(const crs::CRSNNPtr &sourceCRS, const crs::CRSNNPtr &targetCRS) const
```

Find a CoordinateOperation from sourceCRS to targetCRS.

This is a helper of createOperations(), using a coordinate operation context with no authority factory (so no catalog searching is done), no desired accuracy and no area of interest. This returns the first operation of the result set of createOperations(), or null if none found.

**Parameters**

- **sourceCRS** -- source CRS.
- **targetCRS** -- source CRS.

**Returns**
a CoordinateOperation or nullptr.

```
std::vector<CoordinateOperationNNPtr> createOperations(const crs::CRSNNPtr &sourceCRS, const crs::CRSNNPtr &targetCRS, const CoordinateOperationContextNNPtr &context) const
```

Find a list of CoordinateOperation from sourceCRS to targetCRS.

The operations are sorted with the most relevant ones first: by descending area (intersection of the transformation area with the area of interest, or intersection of the transformation with the area of use of the CRS), and by increasing accuracy. Operations with unknown accuracy are sorted last, whatever their area.

When one of the source or target CRS has a vertical component but not the other one, the one that has no vertical component is automatically promoted to a 3D version, where its vertical axis is the ellipsoidal height in metres, using the ellipsoid of the base geodetic CRS.

**Parameters**

- **sourceCRS** -- source CRS.
- **targetCRS** -- target CRS.
• **context** -- Search context.

**Returns**
a list

std::vector<CoordinateOperationNNPtr> createOperations(const coord::CoordinateMetadataNNPtr &sourceCoordinateMetadata, const crs::CRSNNPtr &targetCRS, const CoordinateOperationContextNNPtr &context) const

Find a list of `CoordinateOperation` from a source coordinate metadata to targetCRS.

Since
9.2

**Parameters**
- **sourceCoordinateMetadata** -- source CoordinateMetadata.
- **targetCRS** -- target CRS.
- **context** -- Search context.

**Returns**
a list

std::vector<CoordinateOperationNNPtr> createOperations(const crs::CRSNNPtr &sourceCRS, const coord::CoordinateMetadataNNPtr &targetCoordinateMetadata, const CoordinateOperationContextNNPtr &context) const

Find a list of `CoordinateOperation` from a source CRS to a target coordinate metadata.

**Since**
9.2

**Parameters**
- **sourceCRS** -- source CRS.
- **targetCoordinateMetadata** -- target CoordinateMetadata.
- **context** -- Search context.

**Returns**
a list
Public Static Functions

static CoordinateOperationFactoryNNPtr create()
   Instantiate a CoordinateOperationFactory.

10.5.4.9 io namespace

namespace io
   I/O classes.
       osgeo.proj.io namespace.

Typedefs

using DatabaseContextPtr = std::shared_ptr<DatabaseContext>
   Shared pointer of DatabaseContext.

using DatabaseContextNNPtr = util::nn<DatabaseContextPtr>
   Non-null shared pointer of DatabaseContext.

using WKTNodePtr = std::unique_ptr<WKTNode>
   Unique pointer of WKTNode.

using WKTNodeNNPtr = util::nn<WKTNodePtr>
   Non-null unique pointer of WKTNode.

using WKTFormatterPtr = std::unique_ptr<WKTFormatter>
   WKTFormatter unique pointer.

using WKTFormatterNNPtr = util::nn<WKTFormatterPtr>
   Non-null WKTFormatter unique pointer.

using PROJStringFormatterPtr = std::unique_ptr<PROJStringFormatter>
   PROJStringFormatter unique pointer.

using PROJStringFormatterNNPtr = util::nn<PROJStringFormatterPtr>
   Non-null PROJStringFormatter unique pointer.

using JSONFormatterPtr = std::unique_ptr<JSONFormatter>
   JSONFormatter unique pointer.

using JSONFormatterNNPtr = util::nn<JSONFormatterPtr>
   Non-null JSONFormatter unique pointer.
using IPROJStringExportablePtr = std::shared_ptr<IPROJStringExportable>
    Shared pointer of IPROJStringExportable.

using IPROJStringExportableNNPtr = util::nn<IPROJStringExportablePtr>
    Non-null shared pointer of IPROJStringExportable.

using AuthorityFactoryPtr = std::shared_ptr<AuthorityFactory>
    Shared pointer of AuthorityFactory.

using AuthorityFactoryNNPtr = util::nn<AuthorityFactoryPtr>
    Non-null shared pointer of AuthorityFactory.

Functions

static crs::GeodeticCRSNNPtr cloneWithProps(const crs::GeodeticCRSNNPtr &geodCRS, const 
util::PropertyMap &props)

BaseObjectNNPtr createFromUserInput(const std::string &text, const DatabaseContextPtr &dbContext, 
bool usePROJ4InitRules)

Instantiate a sub-class of BaseObject from a user specified text.

The text can be a:

- WKT string
- PROJ string
- database code, prefixed by its authority. e.g. "EPSG:4326"
- OGC URN. e.g. "urn:ogc:def:crs:EPSG::4326", "urn:ogc:def:coordinateOperation:EPSG::1671", 
  "urn:ogc:def:ellipsoid:EPSG::7001" or "urn:ogc:def:datum:EPSG::6326"
- OGC URN combining references for compound coordinate reference systems e.g. 
  "urn:ogc:def:crs,crs:EPSG::2393,crs:EPSG::5717" We also accept a custom abbreviated syntax 
  EPSG:2393+5717 or ESRI:103668+EPSG:5703
- OGC URN combining references for references for projected or derived 
  CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)" 
  "urn:ogc:def:crs,crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031"
- OGC URN combining references for concatenated operations e.g. 
  "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618"
- OGC URL for a single CRS. e.g. "http://www.opengis.net/def/crs/EPSG/0/4326"
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N". In that case as uniqueness is not 
  guaranteed, the function may apply heuristics to determine the appropriate best match.
- a CRS name and a coordinate epoch, separated with '@'. For example "ITRF2014@2025.0". (added 
  in PROJ 9.2)
- a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height"
- PROJJSON string
Parameters

- **text** -- One of the above mentioned text format
- **dbContext** -- Database context, or nullptr (in which case database lookups will not work)
- **usePROJ4InitRules** -- When set to true, init=epsg:XXXX syntax will be allowed and will be interpreted according to PROJ.4 and PROJ.5 rules, that is geodetic CRS will have longitude, latitude order and will expect/output coordinates in radians. Projected CRS will have easting, northing axis order (except the ones with Transverse Mercator South Oriented projection). In that mode, the epsg:XXXX syntax will be also interpreted the same way.

Throws

* **ParsingException** --

BaseObjectNNPtr `createFromUserInput` (const std::string &text, PJ_CONTEXT *ctx)

Instantiate a sub-class of BaseObject from a user specified text.

The text can be a:

- WKT string
- PROJ string
- database code, prefixed by its authority. e.g. "EPSG:4326"
- OGC URN combining references for compound coordinate reference systems e.g. "urn:ogc:def:crs:EPSG::2393,crs:EPSG::5717" We also accept a custom abbreviated syntax EPSG:2393+5717
- OGC URN combining references for references for projected or derived CRSs e.g. for Projected 3D CRS "UTM zone 31N / WGS 84 (3D)" "urn:ogc:def:crs:EPSG::4979,cs:PROJ::ENh,coordinateOperation:EPSG::16031"
- OGC URN combining references for concatenated operations e.g. "urn:ogc:def:coordinateOperation,coordinateOperation:EPSG::3895,coordinateOperation:EPSG::1618"
- an Object name. e.g "WGS 84", "WGS 84 / UTM zone 31N”. In that case as uniqueness is not guaranteed, the function may apply heuristics to determine the appropriate best match.
- a compound CRS made from two object names separated with " + ". e.g. "WGS 84 + EGM96 height"
- PROJJSON string

Parameters

- **text** -- One of the above mentioned text format
- **ctx** -- PROJ context

Throws

* **ParsingException** --

#include <io.hpp> Formatter to WKT strings.

An instance of this class can only be used by a single thread at a time.
Public Types

enum class Convention_
    WKT variant.

Values:

enumerator WKT2
    Full WKT2 string, conforming to ISO 19162:2015(E) / OGC 12-063r5 (WKT2:2015) with all possible nodes and new keyword names.

denumerator _WKT2_2015

denumerator WKT2_SIMPLIFIED
    Same as WKT2 with the following exceptions:
    • UNIT keyword used.
    • ID node only on top element.
    • No ORDER element in AXIS element.
    • PRIMEM node omitted if it is Greenwich.
    • ELLIPSOID.UNIT node omitted if it is UnitOfMeasure::METRE.
    • PARAMETER.UNIT / PRIMEM.UNIT omitted if same as AXIS.
    • AXIS.UNIT omitted and replaced by a common GEODCRS.UNIT if they are all the same on all axis.

denumerator _WKT2_2015_SIMPLIFIED

denumerator _WKT2_2019
    Full WKT2 string, conforming to ISO 19162:2019 / OGC 18-010, with (WKT2:2019) all possible nodes and new keyword names. Non-normative list of differences:
    • _WKT2_2019 uses GEOGCRS / BASEGEOGCRS keywords for GeographicCRS.

denumerator _WKT2_2018
    Deprecated alias for _WKT2_2019

denumerator _WKT2_2019_SIMPLIFIED
    _WKT2_2019 with the simplification rule of WKT2_SIMPLIFIED

denumerator _WKT2_2018_SIMPLIFIED
    Deprecated alias for _WKT2_2019_SIMPLIFIED

denumerator _WKT1_GDAL
    WKT1 as traditionally output by GDAL, deriving from OGC 01-009. A notable departure from _WKT1_GDAL with respect to OGC 01-009 is that in _WKT1_GDAL, the unit of the PRIMEM value is always degrees.

denumerator _WKT1_ESRI
    WKT1 as traditionally output by ESRI software, deriving from OGC 99-049.
enum class OutputAxisRule  
Rule for output AXIS nodes  

*Values:*  

enumerator **YES**  
Always include AXIS nodes  

enumerator **NO**  
Never include AXIS nodes  

enumerator **_WKT1_GDAL_EPSG_STYLE**  
Includes them only on PROJCS node if it uses Easting/Northing ordering. Typically used for **_WKT1_GDAL**

### Public Functions

`WKTFormatter &setMultiLine(bool multiLine) noexcept`  
Whether to use multi line output or not.

`WKTFormatter &setIndentationWidth(int width) noexcept`  
Set number of spaces for each indentation level (defaults to 4).

`WKTFormatter &setOutputAxis(OutputAxisRule outputAxis) noexcept`  
Set whether AXIS nodes should be output.

`WKTFormatter &setStrict(bool strict) noexcept`  
Set whether the formatter should operate on strict more or not.  
The default is strict mode, in which case a `FormatException` can be thrown. In non-strict mode, a Geographic 3D CRS can be for example exported as `_WKT1_GDAL` with 3 axes, whereas this is normally not allowed.

`bool isStrict() const noexcept`  
Returns whether the formatter is in strict mode.

`WKTFormatter &setAllowEllipsoidalHeightAsVerticalCRS(bool allow) noexcept`  
Set whether the formatter should export, in WKT1, a Geographic or Projected 3D CRS as a compound CRS whose vertical part represents an ellipsoidal height.

`bool isAllowedEllipsoidalHeightAsVerticalCRS() const noexcept`  
Returns whether the formatter should export, in WKT1, a Geographic or Projected 3D CRS as a compound CRS whose vertical part represents an ellipsoidal height.

`WKTFormatter &setAllowLINUNITNode (bool allow) noexcept`  
Set whether the formatter should export, in _WKT1_ESRI, a Geographic 3D CRS with the relatively new (ArcGIS Pro >= 2.7) LINUNIT node. Defaults to true.

### Since

PROJ 9.1
bool isAllowedLINUNITNode() const noexcept
    Return whether the formatter should export, in _WKT1_ESRI, a Geographic 3D CRS with the relatively new (ArcGIS Pro >= 2.7) LINUNIT node. Defaults to true.

Since
    PROJ 9.1
const std::string &toString() const
    Returns the WKT string from the formatter.

Public Static Functions

static WKTFormatterNNPtr create(Convention convention = Convention::WKT2,
                                DatabaseContextPtr dbContext = nullptr)
    Constructs a new formatter.
    A formatter can be used only once (its internal state is mutated)
    Its default behavior can be adjusted with the different setters.
        Parameters
            • convention -- WKT flavor. Defaults to Convention::WKT2
            • dbContext -- Database context, to allow queries in it if needed. This is used for example for _WKT1_ESRI output to do name substitutions.
        Returns
            new formatter.

static WKTFormatterNNPtr create(const WKTFormatterNNPtr &other)
    Constructs a new formatter from another one.
    A formatter can be used only once (its internal state is mutated)
    Its default behavior can be adjusted with the different setters.
        Parameters
            other -- source formatter.
        Returns
            new formatter.

class PROJStringFormatter

#include <io.hpp> Formatter to PROJ strings.
    An instance of this class can only be used by a single thread at a time.

Public Types

enum class Convention
    PROJ variant.
        Values:

        enumerator PROJ_5
            PROJ v5 (or later versions) string.
enumerator PROJ_4

PROJ v4 string as output by GDAL exportToProj4()

Public Functions

PROJStringFormatter &setMultiLine(bool multiLine) noexcept
Whether to use multi line output or not.

PROJStringFormatter &setIndentationWidth(int width) noexcept
Set number of spaces for each indentation level (defaults to 2).

PROJStringFormatter &setMaxLineLength(int maxLineLength) noexcept
Set the maximum size of a line (when multiline output is enable). Can be set to 0 for unlimited length.

void setUseApproxTMerc(bool flag)
Set whether approximate Transverse Mercator or UTM should be used.

const std::string &toString() const
Returns the PROJ string.

Public Static Functions

static PROJStringFormatterNNPtr create(Convention conventionIn = Convention::PROJ_5,
DatabaseContextPtr dbContext = nullptr)
Constructs a new formatter.
A formatter can be used only once (its internal state is mutated)
Its default behavior can be adjusted with the different setters.

Parameters
• conventionIn -- PROJ string flavor. Defaults to Convention::PROJ_5
• dbContext -- Database context (can help to find alternative grid names). May be nullptr

Returns
new formatter.

class JSONFormatter

#include <io.hpp> Formatter to JSON strings.
An instance of this class can only be used by a single thread at a time.

Public Functions

JSONFormatter &setMultiLine(bool multiLine) noexcept
Whether to use multi line output or not.

JSONFormatter &setIndentationWidth(int width) noexcept
Set number of spaces for each indentation level (defaults to 4).

JSONFormatter &setSchema(const std::string &schema) noexcept
Set the value of the "$schema" key in the top level object.
If set to empty string, it will not be written.
const std::string &toString() const
    Return the serialized JSON.

Public Static Functions

static JSONFormatterNNPtr create(DatabaseContextPtr dbContext = nullptr)
    Constructs a new formatter.
    A formatter can be used only once (its internal state is mutated)
    Returns
    new formatter.

class IJSONExportable
    #include <io.hpp>
    Interface for an object that can be exported to JSON.
    Subclassed by osgeo::proj::coordinates::CoordinateMetadata, osgeo::proj::crs::CRS,
    osgeo::proj::cs::CoordinateSystem, osgeo::proj::cs::CoordinateSystemAxis,
    osgeo::proj::cs::Meridian, osgeo::proj::datum::Datum, osgeo::proj::datum::DatumEnsemble,
    osgeo::proj::datum::Ellipsoid, osgeo::proj::datum::PrimeMeridian, osgeo::proj::metadata::Identifier,
    osgeo::proj::operation::CoordinateOperation, osgeo::proj::operation::GeneralParameterValue,
    osgeo::proj::operation::OperationMethod

Public Functions

std::string exportToJSON(JSONFormatter *formatter) const
    Builds a JSON representation. May throw a FormattingException

class FormattingException : public osgeo::proj::util::Exception
    #include <io.hpp> Exception possibly thrown by IWKTExportable::exportToWKT() or IPROJStringExportable::exportToPROJString().

class ParsingException : public osgeo::proj::util::Exception
    #include <io.hpp> Exception possibly thrown by WKTNode::createFrom() or WKTParser::createFromWKT().

class IWKTExportable
    #include <io.hpp> Interface for an object that can be exported to WKT.
    Subclassed by osgeo::proj::common::IdentifiedObject, osgeo::proj::coordinates::CoordinateMetadata,
    osgeo::proj::metadata::Identifier, osgeo::proj::operation::GeneralParameterValue,
    osgeo::proj::operation::ParameterValue

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**Public Functions**

```cpp
std::string exportToWKT(WKTFormatter *formatter) const

Builds a WKT representation. May throw a FormattingException
```

```cpp
class IPROJStringExportable

#include <io.hpp>

Interface for an object that can be exported to a PROJ string.

Subclassed by osgeo::proj::crs::BoundCRS, osgeo::proj::crs::CompoundCRS, osgeo::proj::crs::GeodeticCRS, osgeo::proj::crs::ProjectedCRS, osgeo::proj::crs::VerticalCRS, osgeo::proj::datum::Ellipsoid, osgeo::proj::datum::PrimeMeridian, osgeo::proj::operation::CoordinateOperation
```

**Public Functions**

```cpp
std::string exportToPROJString(PROJStringFormatter *formatter) const

Builds a PROJ string representation.
```

- For `PROJStringFormatter::Convention::PROJ_5` (the default),
  - For a `crs::CRS`, returns the same as `PROJStringFormatter::Convention::PROJ_4`. It should be noted that the export of a CRS as a PROJ string may cause loss of many important aspects of a CRS definition. Consequently it is discouraged to use it for interoperability in newer projects. The choice of a WKT representation will be a better option.
  - For `operation::CoordinateOperation`, returns a PROJ pipeline.

- For `PROJStringFormatter::Convention::PROJ_4`, format a string compatible with the OGRSpatialReference:exportToProj4() of GDAL <=2.3. It is only compatible of a few CRS objects. The PROJ string will also contain a +type=crs parameter to disambiguate the nature of the string from a CoordinateOperation.
  - For a `crs::GeographicCRS`, returns a proj=longlat string, with ellipsoid / datum / prime meridian information, ignoring axis order and unit information.
  - For a geocentric `crs::GeodeticCRS`, returns the transformation from geographic coordinates into geocentric coordinates.
  - For a `crs::ProjectedCRS`, returns the projection method, ignoring axis order.
  - For a `crs::ProjectedCRS`, returns the PROJ string of its source/base CRS, amended with towgs84 / nadgrids parameter when the deriving conversion can be expressed in that way.

**Parameters**
- **formatter** -- PROJ string formatter.

**Throws**
- FormattingException --

**Returns**
- a PROJ string.

```cpp
class WKTNode

#include <io.hpp>

Node in the tree-splitted WKT representation.
```
**Public Functions**

explicit `WKTNode` (const `std::string &valueIn`)  
Instantiate a `WKTNode`.  
  **Parameters**  
  `valueIn` -- the name of the node.  

const `std::string &value()` const  
Return the value of a node.  

const `std::vector<WKTNode::NNPtr> &children()` const  
Return the children of a node.  

void `addChild(WKTNode::NNPtr &&child)`  
Adds a child to the current node.  
  **Parameters**  
  `child` -- child to add. This should not be a parent of this node.  

const `WKTNode::Ptr &lookForChild(const std::string &childName, int occurrence = 0)` const noexcept  
Return the (occurrence-1)th sub-node of name `childName`.  
  **Parameters**  
  • `childName` -- name of the child.  
  • `occurrence` -- occurrence index (starting at 0)  
  **Returns**  
  the child, or nullptr.  

`int countChildrenOfName(const std::string &childName)` const noexcept  
Return the count of children of given name.  
  **Parameters**  
  `childName` -- name of the children to look for.  
  **Returns**  
  count  

`std::string toString()` const  
Return a WKT representation of the tree structure.  

**Public Static Functions**

static `WKTNode::NNPtrcreateFrom(const std::string &wkt, size_t indexStart = 0)`  
Instantiate a `WKTNode` hierarchy from a WKT string.  
  **Parameters**  
  • `wkt` -- the WKT string to parse.  
  • `indexStart` -- the start index in the wkt string.  
  **Throws**  
  `ParsingException` --  

**Class `WKTParser`**  

# include `<io.hpp>` Parse a WKT string into the appropriate subclass of `util::BaseObject`.
### Public Types

enum class **WKTGuessedDialect**

Guessed WKT "dialect"

*Values:*

enumerator **WKT2_2019**

*WKT2:2019*

enumerator **WKT2_2018**

Deprecated alias for WKT2_2019

enumerator **WKT2_2015**

*WKT2:2015*

enumerator **WKT1_GDAL**

*WKT1 specification*

enumerator **WKT1_ESRI**

ESRI variant of WKT1

enumerator **NOT_WKT**

Not WKT / unrecognized

### Public Functions

**WKTParser &attachDatabaseContext**(const DatabaseContextPtr &dbContext)

Attach a database context, to allow queries in it if needed.

**WKTParser &setStrict**(bool strict)

Set whether parsing should be done in strict mode.

std::list<std::string>**warningList**() const

Return the list of warnings found during parsing.

**Note:** The list might be non-empty only is setStrict(false) has been called.

**WKTParser &unsetIdentifiersIfIncompatibleDef**(bool unset)

Set whether object identifiers should be unset when there is a contradiction between the definition from WKT and the one from the database.

At time of writing, this only applies to the base geographic CRS of a projected CRS, when comparing its coordinate system.

**util::BaseObjectNNPtr createFromWKT**(const std::string &wkt)

Instantiate a sub-class of BaseObject from a WKT string.
By default, validation is strict (to the extent of the checks that are actually implemented. Currently only WKT1 strict grammar is checked), and any issue detected will cause an exception to be thrown, unless setStrict(false) is called priorly.

In non-strict mode, non-fatal issues will be recovered and simply listed in `warningList()`. This does not prevent more severe errors to cause an exception to be thrown.

**Throws**

`ParsingException` --

```cpp
WKTGuessedDialect guessDialect(const std::string &wkt) noexcept
```

Guess the "dialect" of the WKT string.

```cpp
class PROJStringParser
#include <io.hpp>
```

Parse a PROJ string into the appropriate subclass of `util::BaseObject`.

**Public Functions**

```cpp
PROJStringParser &attachDatabaseContext(const DatabaseContextPtr &dbContext)
```

Attach a database context, to allow queries in it if needed.

```cpp
PROJStringParser &setUsePROJ4InitRules(bool enable)
```

Set how init=epsg:XXXX syntax should be interpreted.

**Parameters**

`enable` -- When set to true, init=epsg:XXXX syntax will be allowed and will be interpreted according to PROJ.4 and PROJ.5 rules, that is geodetic CRS will have longitude, latitude order and will expect/output coordinates in radians. Projected CRS will have easting, northing axis order (except the ones with Transverse Mercator South Orientated projection).

```cpp
std::vector<std::string> warningList() const
```

Return the list of warnings found during parsing.

```cpp
util::BaseObjectNNPtrcreateFromPROJString(const std::string &projString)
```

Instantiate a sub-class of BaseObject from a PROJ string.

The projString must contain +type=crs for the object to be detected as a CRS instead of a Coordinate-Operation.

**Throws**

`ParsingException` --

```cpp
class DatabaseContext
#include <io.hpp>
```

Database context.

A database context should be used only by one thread at a time.

**Public Functions**

```cpp
const std::string &getPath() const
```

Return the path to the database.

```cpp
const char *getMetadata(const char *key) const
```

Return a metadata item.

Value remains valid while this is alive and to the next call to `getMetadata`
std::set<std::string> getAuthorities() const

Return the list of authorities used in the database.

std::vector<std::string> getDatabaseStructure() const

Return the list of SQL commands (CREATE TABLE, CREATE TRIGGER, CREATE VIEW) needed to initialize a new database.

void startInsertStatementsSession()

Starts a session for getInsertStatementsFor().

Starts a new session for one or several calls to getInsertStatementsFor(). An insertion session guarantees that the inserted objects will not create conflicting intermediate objects.

The session must be stopped with stopInsertStatementsSession().

Only one session may be active at a time for a given database context.

Since
8.1

Throws
FactoryException --

std::string suggestsCodeFor(const common::IdentifiedObjectNNPtr &object, const std::string &authName, bool numericCode)

Suggests a database code for the passed object.

Supported type of objects are PrimeMeridian, Ellipsoid, Datum, DatumEnsemble, GeodeticCRS, ProjectedCRS, VerticalCRS, CompoundCRS, BoundCRS, Conversion.

Since
8.1

Parameters

• object -- Object for which to suggest a code.
• authName -- Authority name into which the object will be inserted.
• numericCode -- Whether the code should be numeric, or derived from the object name.

Throws
FactoryException --

Returns
the suggested code, that is guaranteed to not conflict with an existing one.

std::vector<std::string> getInsertStatementsFor(const common::IdentifiedObjectNNPtr &object, const std::string &authName, const std::string &code, bool numericCode, const std::vector<std::string> &allowedAuthorities = {"EPSG", "PROJ"})

Returns SQL statements needed to insert the passed object into the database.

startInsertStatementsSession() must have been called previously.

Since
8.1

Parameters
• **object** -- The object to insert into the database. Currently only PrimeMeridian, Ellipsoid, Datum, GeodeticCRS, ProjectedCRS, VerticalCRS, CompoundCRS or BoundCRS are supported.

• **authName** -- Authority name into which the object will be inserted.

• **code** -- Code with which the object will be inserted.

• **numericCode** -- Whether intermediate objects that can be created should use numeric codes (true), or may be alphanumeric (false)

• **allowedAuthorities** -- Authorities to which intermediate objects are allowed to refer to. authName will be implicitly added to it. Note that unit, coordinate systems, projection methods and parameters will in any case be allowed to refer to EPSG.

**Throws**

*FactoryException* --

```cpp
void stopInsertStatementsSession()
```

Stops an insertion session started with `startInsertStatementsSession()`

Since 8.1

### Public Static Functions

```cpp
static DatabaseContextNNPtr create(const std::string &databasePath = std::string(), const std::vector<std::string> &auxiliaryDatabasePaths = std::vector<std::string>(), PJ_CONTEXT *ctx = nullptr)
```

Instantiate a database context.

This database context should be used only by one thread at a time.

**Parameters**

- **databasePath** -- Path and filename of the database. Might be empty string for the default rules to locate the default proj.db

- **auxiliaryDatabasePaths** -- Path and filename of auxiliary databases. Might be empty. Starting with PROJ 8.1, if this parameter is an empty array, the PROJ_AUX_DB environment variable will be used, if set. It must contain one or several paths. If several paths are provided, they must be separated by the colon (:) character on Unix, and on Windows, by the semi-colon (;) character.

- **ctx** -- Context used for file search.

**Throws**

*FactoryException* --

**class AuthorityFactory**

```cpp
#include <io.hpp>
```

Builds object from an authority database.

A `AuthorityFactory` should be used only by one thread at a time.

**Remark**

Implements `AuthorityFactory` from *GeoAPI*
Public Types

enum class ObjectType
    Object type.
    Values:

enumerator PRIME_MERIDIAN
    Object of type `datum::PrimeMeridian`

enumerator ELLIPSOID
    Object of type `datum::Ellipsoid`

enumerator DATUM
    Object of type `datum::Datum` (and derived classes)

enumerator GEODETIC_REFERENCE_FRAME
    Object of type `datum::GeodeticReferenceFrame` (and derived classes)

enumerator VERTICAL_REFERENCE_FRAME
    Object of type `datum::VerticalReferenceFrame` (and derived classes)

enumerator CRS
    Object of type `crs::CRS` (and derived classes)

enumerator GEODETIC_CRS
    Object of type `crs::GeodeticCRS` (and derived classes)

enumerator GEOCENTRIC_CRS
    GEODETIC_CRS of type geocentric

enumerator GEOGRAPHIC_CRS
    Object of type `crs::GeographicCRS` (and derived classes)

enumerator GEOGRAPHIC_2D_CRS
    GEOGRAPHIC_CRS of type Geographic 2D

enumerator GEOGRAPHIC_3D_CRS
    GEOGRAPHIC_CRS of type Geographic 3D

enumerator PROJECTED_CRS
    Object of type `crs::ProjectedCRS` (and derived classes)

enumerator VERTICAL_CRS
    Object of type `crs::VerticalCRS` (and derived classes)
enumerator **COMPOUND_CRS**
   Object of type `crs::CompoundCRS` (and derived classes)

enumerator **COORDINATE_OPERATION**
   Object of type `operation::CoordinateOperation` (and derived classes)

enumerator **CONVERSION**
   Object of type `operation::Conversion` (and derived classes)

enumerator **TRANSFORMATION**
   Object of type `operation::Transformation` (and derived classes)

enumerator **CONCATENATED_OPERATION**
   Object of type `operation::ConcatenatedOperation` (and derived classes)

enumerator **DYNAMIC_GEODETIC_REFERENCE_FRAME**
   Object of type `datum::DynamicGeodeticReferenceFrame`

enumerator **DYNAMIC_VERTICAL_REFERENCE_FRAME**
   Object of type `datum::DynamicVerticalReferenceFrame`

enumerator **DATUM_ENSEMBLE**
   Object of type `datum::DatumEnsemble`

**Public Functions**

`util::BaseObjectNNPtr createObject(const std::string &code) const`
Returns an arbitrary object from a code.

The returned object will typically be an instance of Datum, CoordinateSystem, ReferenceSystem or CoordinateOperation. If the type of the object is known at compile time, it is recommended to invoke the most precise method instead of this one (for example createCoordinateReferenceSystem(code) instead of createObject(code) if the caller know he is asking for a coordinate reference system).

If there are several objects with the same code, a `FactoryException` is thrown.

**Parameters**

- **code** -- Object code allocated by authority. (e.g. "4326")

**Throws**

- `NoSuchAuthorityCodeException`
- `FactoryException`

**Returns**

- object.

`common::UnitOfMeasureNNPtr createUnitOfMeasure(const std::string &code) const`
Returns a `common::UnitOfMeasure` from the specified code.

**Parameters**

- **code** -- Object code allocated by authority.

**Throws**

- `NoSuchAuthorityCodeException`
- `FactoryException`
Returns object.

\texttt{metadata::ExtentNNPtr createExtent(const std::string &code) const}

Returns a \texttt{metadata::Extent} from the specified code.

\textbf{Parameters}
- \texttt{code} -- Object code allocated by authority.

\textbf{Throws}
- \texttt{NoSuchAuthorityCodeException} --
- \texttt{FactoryException} --

\textbf{Returns}
object.

\texttt{datum::PrimeMeridianNNPtr createPrimeMeridian(const std::string &code) const}

Returns a \texttt{datum::PrimeMeridian} from the specified code.

\textbf{Parameters}
- \texttt{code} -- Object code allocated by authority.

\textbf{Throws}
- \texttt{NoSuchAuthorityCodeException} --
- \texttt{FactoryException} --

\textbf{Returns}
object.

\texttt{std::string identifyBodyFromSemiMajorAxis(double a, double tolerance) const}

Identify a celestial body from an approximate radius.

\textbf{Parameters}
- \texttt{semi_major_axis} -- Approximate semi-major axis.
- \texttt{tolerance} -- Relative error allowed.

\textbf{Throws}
- \texttt{FactoryException} --

\textbf{Returns}
celestial body name if one single match found.

\texttt{datum::EllipsoidNNPtr createEllipsoid(const std::string &code) const}

Returns a \texttt{datum::Ellipsoid} from the specified code.

\textbf{Parameters}
- \texttt{code} -- Object code allocated by authority.

\textbf{Throws}
- \texttt{NoSuchAuthorityCodeException} --
- \texttt{FactoryException} --

\textbf{Returns}
object.

\texttt{datum::DatumNNPtr createDatum(const std::string &code) const}

Returns a \texttt{datum::Datum} from the specified code.

\textbf{Parameters}
- \texttt{code} -- Object code allocated by authority.

\textbf{Throws}
- \texttt{NoSuchAuthorityCodeException} --
- \texttt{FactoryException} --

\textbf{Returns}
object.

\texttt{datum::DatumEnsembleNNPtr createDatumEnsemble(const std::string &code, const std::string &type = std::string()) const}

Returns a \texttt{datum::DatumEnsemble} from the specified code.
Parameters

- **code** -- Object code allocated by authority.
- **type** -- "geodetic_datum", "vertical_datum" or empty string if unknown

Throws

- **NoSuchAuthorityCodeException**
- **FactoryException**

Returns

object.

datum::GeodeticReferenceFrameNNPtr createGeodeticDatum(const std::string &code) const

Returns a *datum::GeodeticReferenceFrame* from the specified code.

Parameters

- **code** -- Object code allocated by authority.

Throws

- **NoSuchAuthorityCodeException**
- **FactoryException**

Returns

object.

datum::VerticalReferenceFrameNNPtr createVerticalDatum(const std::string &code) const

Returns a *datum::VerticalReferenceFrame* from the specified code.

Parameters

- **code** -- Object code allocated by authority.

Throws

- **NoSuchAuthorityCodeException**
- **FactoryException**

Returns

object.

c::CoordinateSystemNNPtr createCoordinateSystem(const std::string &code) const

Returns a *c::CoordinateSystem* from the specified code.

Parameters

- **code** -- Object code allocated by authority.

Throws

- **NoSuchAuthorityCodeException**
- **FactoryException**

Returns

object.

crs::GeodeticCRSNNPtr createGeodeticCRS(const std::string &code) const

Returns a *crs::GeodeticCRS* from the specified code.

Parameters

- **code** -- Object code allocated by authority.

Throws

- **NoSuchAuthorityCodeException**
- **FactoryException**

Returns

object.

crs::GeographicCRSNNPtr createGeographicCRS(const std::string &code) const

Returns a *crs::GeographicCRS* from the specified code.

Parameters

- **code** -- Object code allocated by authority.
PROJ coordinate transformation software library, Release 9.3.1

- `FactoryException` -- Returns object.

`crs::VerticalCRS NNPtr createVerticalCRS(const std::string &code) const`  
Returns a `crs::VerticalCRS` from the specified code.  
Parameters  
  `code` -- Object code allocated by authority.  
Throws  
  `NoSuchAuthorityCodeException` --  
  `FactoryException` --  
Returns  
  object.

`operation::Conversion NNPtr createConversion(const std::string &code) const`  
Returns a `operation::Conversion` from the specified code.  
Parameters  
  `code` -- Object code allocated by authority.  
Throws  
  `NoSuchAuthorityCodeException` --  
  `FactoryException` --  
Returns  
  object.

`crs::ProjectedCRS NNPtr createProjectedCRS(const std::string &code) const`  
Returns a `crs::ProjectedCRS` from the specified code.  
Parameters  
  `code` -- Object code allocated by authority.  
Throws  
  `NoSuchAuthorityCodeException` --  
  `FactoryException` --  
Returns  
  object.

`crs::CompoundCRS NNPtr createCompoundCRS(const std::string &code) const`  
Returns a `crs::CompoundCRS` from the specified code.  
Parameters  
  `code` -- Object code allocated by authority.  
Throws  
  `NoSuchAuthorityCodeException` --  
  `FactoryException` --  
Returns  
  object.

`crs::CRS NNPtr createCoordinateReferenceSystem(const std::string &code) const`  
Returns a `crs::CRS` from the specified code.  
Parameters  
  `code` -- Object code allocated by authority.  
Throws  
  `NoSuchAuthorityCodeException` --  
  `FactoryException` --  
Returns  
  object.

`operation::CoordinateOperation NNPtr createCoordinateOperation(const std::string &code, bool usePROJAlternativeGridNames) const`
Returns a `operation::CoordinateOperation` from the specified code.

**Parameters**
- `code` -- Object code allocated by authority.
- `usePROJAlternativeGridNames` -- Whether PROJ alternative grid names should be substituted to the official grid names.

**Throws**
- `NoSuchAuthorityCodeException`
- `FactoryException`

**Returns**

```cpp
std::vector<operation::CoordinateOperationNNPtr> createFromCoordinateReferenceSystemCodes(const std::string &sourceCRSCode, const std::string &targetCRSCode) const
```

Returns a list `operation::CoordinateOperation` between two CRS.

The list is ordered with preferred operations first. No attempt is made at inferring operations that are not explicitly in the database.

Deprecated operations are rejected.

**Parameters**
- `sourceCRSCode` -- Source CRS code allocated by authority.
- `targetCRSCode` -- Source CRS code allocated by authority.

**Throws**
- `NoSuchAuthorityCodeException`
- `FactoryException`

**Returns**

```cpp
std::list<std::string> getGeoidModels(const std::string &code) const
```

Returns a list of geoid models available for that crs.

The list includes the geoid models connected directly with the crs, or via "Height Depth Reversal" or "Change of Vertical Unit" transformations

**Parameters**
- `code` -- crs code allocated by authority.

**Throws**
- `FactoryException`

**Returns**

```cpp
std::list<std::string> getAuthorityCodes(const ObjectType &type, bool allowDeprecated = true) const
```

Returns the set of authority codes of the given object type.
• **type** -- Object type.
• **allowDeprecated** -- whether we should return deprecated objects as well.

**Throws**

*FactoryException*

**Returns**

the set of authority codes for spatial reference objects of the given type

```cpp
std::string getDescriptionText(const std::string &code) const
```

Gets a description of the object corresponding to a code.

**Note:** In case of several objects of different types with the same code, one of them will be arbitrarily selected. But if a CRS object is found, it will be selected.

**Parameters**

- **code** -- Object code allocated by authority. (e.g. "4326")

**Throws**

- *NoSuchAuthorityCodeException*
- *FactoryException*

**Returns**

description.

```cpp
std::list<CRSInfo> getCRSInfoList() const
```

Return a list of information on CRS objects.

This is functionally equivalent of listing the codes from an authority, instantiating a CRS object for each of them and getting the information from this CRS object, but this implementation has much less overhead.

**Throws**

*FactoryException*

```cpp
std::list<UnitInfo> getUnitList() const
```

Return the list of units.

**Since**

7.1

**Throws**

*FactoryException*

```cpp
std::list<CelestialBodyInfo> getCelestialBodyList() const
```

Return the list of celestial bodies.

**Since**

8.1

**Throws**

*FactoryException*

```cpp
const DatabaseContextNNPtr &databaseContext() const
```

Returns the database context.
std::vector<operation::CoordinateOperationNNPtr> createFromCoordinateReferenceSystemCodes(const std::string &sourceCRSAuthName, const std::string &sourceCRSCode, const std::string &targetCRSAuthName, const std::string &targetCRSCode, bool usePROJAlterativeGrids, bool discardIfMissingGrid, bool considerKnownGridsAsAvailable, bool discardSuperseded, bool tryReverseOrder = false, bool reportOnly = false, const meta::ExtentPtr &intersectingExtent1 = nullptr, const meta::ExtentPtr &intersectingExtent2 = nullptr) const
Returns a list of operation::CoordinateOperation between two CRS.

The list is ordered with preferred operations first. No attempt is made at inferring operations that are not explicitly in the database (see createFromCRSCodesWithIntermediates() for that), and only source -> target operations are searched (i.e. if target -> source is present, you need to call this method with the arguments reversed, and apply the reverse transformations).

Deprecated operations are rejected.

If getAuthority() returns empty, then coordinate operations from all authorities are considered.

Parameters
- sourceCRSAuthName -- Authority name of sourceCRSCode
- sourceCRSCode -- Source CRS code allocated by authority sourceCRSAuthName.
- targetCRSAuthName -- Authority name of targetCRSCode
- targetCRSCode -- Source CRS code allocated by authority targetCRSAuthName.
- usePROJAlternativeGridNames -- Whether PROJ alternative grid names should be substituted to the official grid names.
- discardIfMissingGrid -- Whether coordinate operations that reference missing grids should be removed from the result set.
- considerKnownGridsAsAvailable -- Whether known grids should be considered as available (typically when network is enabled).
- discardSuperseded -- Whether coordinate operations that are superseded (but not deprecated) should be removed from the result set.
- tryReverseOrder -- whether to search in the reverse order too (and thus inverse results found that way)
- reportOnlyIntersectingTransformations -- if intersectingExtent1 and intersectingExtent2 should be honored in a strict way.
- intersectingExtent1 -- Optional extent that the resulting operations must intersect.
- intersectingExtent2 -- Optional extent that the resulting operations must intersect.

Throws
- NoSuchAuthorityCodeException
- FactoryException

Returns
- list of coordinate operations
std::vector<operation::CoordinateOperationNNPtr>createFromCRSCodesWithIntermediates(const std::string &source-CR-SAuth-Name, const std::string &source-CRSCode, const std::string &target-CR-SAuth-Name, const std::string &targetCRSCode, bool use-PRO-JAl-ternative-Grid-Names, bool discardIfMissing-Grid, bool consider-Known-GridsAsAvailable, bool discard-Superseded, const std::vector<std::pair<std::string, std::string>> &intermediateCRSAuthCodes, Object-Type allowedIn-termediateObjec-Type = Object-Type::CRS, const std::vector<std::string> &allowedAuthorities = std::vector<std::string>(), const metadata::ExtentPtr &intersectingExtent1 = nullptr, const metadata::ExtentPtr &intersectingExtent2 = nullptr) const
Returns a list `operation::CoordinateOperation` between two CRS, using intermediate codes. The list is ordered with preferred operations first. Deprecated operations are rejected.

The method will take care of considering all potential combinations (i.e. contrary to `createFromCoordinateReferenceSystemCodes()`), you do not need to call it with sourceCRS and targetCRS switched.

If `getAuthority()` returns empty, then coordinate operations from all authorities are considered.

Parameters
- `sourceCRSAuthName` -- Authority name of sourceCRSCode
- `sourceCRSCode` -- Source CRS code allocated by authority sourceCRSAuthName.
- `targetCRSAuthName` -- Authority name of targetCRSCode
- `targetCRSCode` -- Source CRS code allocated by authority targetCRSAuthName.
- `usePROJAlternativeGridNames` -- Whether PROJ alternative grid names should be substituted to the official grid names.
- `discardIfMissingGrid` -- Whether coordinate operations that reference missing grids should be removed from the result set.
- `considerKnownGridsAsAvailable` -- Whether known grids should be considered as available (typically when network is enabled).
- `discardSuperseded` -- Whether coordinate operations that are superseded (but not deprecated) should be removed from the result set.
- `intermediateCRSAuthCodes` -- List of (auth_name, code) of CRS that can be used as potential intermediate CRS. If the list is empty, the database will be used to find common CRS in operations involving both the source and target CRS.
- `allowedIntermediateObjectType` -- Restrict the type of the intermediate object considered. Only `ObjectType::CRS` and `ObjectType::GEOGRAPHIC_CRS` supported currently.
- `allowedAuthorities` -- One or several authority name allowed for the two coordinate operations that are going to be searched. When this vector is not empty, it overrides the authority of this object. This is useful for example when the coordinate operations to chain belong to two different allowed authorities.
- `intersectingExtent1` -- Optional extent that the resulting operations must intersect.
- `intersectingExtent2` -- Optional extent that the resulting operations must intersect.

Throws
- `NoSuchAuthorityCodeException` --
- `FactoryException` --

Returns
- list of coordinate operations

std::string `getOfficialNameFromAlias` (const std::string &aliasedName, const std::string &tableName, const std::string &source, bool tryEquivalentNameSpelling, std::string &outTableName, std::string &outAuthName, std::string &outCode) const

Gets the official name from a possibly alias name.

Parameters
- `aliasedName` -- Alias name.
- `tableName` -- Table name/category. Can help in case of ambiguities. Or empty otherwise.
- `tryEquivalentNameSpelling` -- whether the comparison of aliasedName with the alt_name column of the alias_name table should be done with using `metadata::Identifier::isEquivalentName()` rather than strict string comparison;
- `outTableName` -- Table name in which the official name has been found.
• `outAuthName` -- Authority name of the official name that has been found.
• `outCode` -- Code of the official name that has been found.

Throws

  `FactoryException` --

Returns

  official name (or empty if not found).

```
std::list<

  createObjectsFromName(const std::string &name,
                        const std::vector<ObjectType>& allowedObjectTypes = std::vector<ObjectType>(),
                        bool approximateMatch = true,
                        size_t limitResultCount = 0)
```

Return a list of objects, identified by their name.

Parameters

• `searchedName` -- Searched name. Must be at least 2 character long.
• `allowedObjectTypes` -- List of object types into which to search. If empty, all object types will be searched.
• `approximateMatch` -- Whether approximate name identification is allowed.
• `limitResultCount` -- Maximum number of results to return. Or 0 for unlimited.

Throws

  `FactoryException` --

Returns

  list of matched objects.

```
std::list<std::pair<std::string, std::string>> listAreaOfUseFromName(const std::string &name,
                                                                     bool approximateMatch)
```

Return a list of area of use from their name.

Parameters

• `name` -- Searched name.
• `approximateMatch` -- Whether approximate name identification is allowed.

Throws

  `FactoryException` --

Returns

  list of (auth_name, code) of matched objects.

### Public Static Functions

```
static AuthorityFactoryNNPtr create(const DatabaseContextNNPtr &context,
                                    const std::string &authorityName)
```

Instantiate a `AuthorityFactory`.

The authority name might be set to the empty string in the particular case where createFromCoordinateReferenceSystemCodes(const std::string &, const std::string &, const std::string &) const is called.

Parameters

• `context` -- Context.
• `authorityName` -- Authority name.

Returns

  new `AuthorityFactory`.

```
struct CelestialBodyInfo
```

#include <io.hpp> Celestial Body information
Public Members

std::string authName
   Authority name

std::string name
   Name

struct CRSInfo
   #include <io.hpp> CRS information

Public Members

std::string authName
   Authority name

std::string code
   Code

std::string name
   Name

ObjectType type
   Type

bool deprecated
   Whether the object is deprecated

bool bbox_valid
   Whereas the west_lon_degree, south_lat_degree, east_lon_degree and north_lat_degree fields are valid.

double west_lon_degree
   Western-most longitude of the area of use, in degrees.

double south_lat_degree
   Southern-most latitude of the area of use, in degrees.

double east_lon_degree
   Eastern-most longitude of the area of use, in degrees.

double north_lat_degree
   Northern-most latitude of the area of use, in degrees.
std::string areaName
    Name of the area of use.

std::string projectionMethodName
    Name of the projection method for a projected CRS. Might be empty even for projected CRS in some cases.

std::string celestialBodyName
    Name of the celestial body of the CRS (e.g. "Earth")

struct UnitInfo
    #include <io.hpp> Unit information

Public Members

std::string authName
    Authority name

std::string code
    Code

std::string name
    Name

std::string category
    Category: one of "linear", "linear_per_time", "angular", "angular_per_time", "scale", "scale_per_time" or "time"

double convFactor
    Conversion factor to the SI unit. It might be 0 in some cases to indicate no known conversion factor.

std::string projShortName
    PROJ short name (may be empty)

bool deprecated
    Whether the object is deprecated

class FactoryException : public osgeo::proj::util::Exception
    #include <io.hpp> Exception thrown when a factory can't create an instance of the requested object.
    Subclassed by osgeo::proj::io::NoSuchAuthorityCodeException

class NoSuchAuthorityCodeException : public osgeo::proj::io::FactoryException
    #include <io.hpp> Exception thrown when an authority factory can't find the requested authority code.
Public Functions

const std::string &getAuthority() const
    Returns authority name.
const std::string &getAuthorityCode() const
    Returns authority code.

10.6 Using PROJ in CMake projects

The recommended way to use the PROJ library in a CMake project is to link to the imported library target PROJ::proj provided by the CMake configuration which comes with the library. Typical usage is:

```cmake
find_package(PROJ REQUIRED CONFIG)
target_link_libraries(MyApp PRIVATE PROJ::proj)
```

By adding the imported library target PROJ::proj to the target link libraries, CMake will also pass the include directories to the compiler.

The CMake command find_package will look for the configuration in a number of places. The lookup can be adjusted for all packages by setting the cache variable or environment variable CMAKE_PREFIX_PATH. In particular, CMake will consult (and set) the cache variable PROJ_DIR.

The old CMake name for the PROJ project was "PROJ4" and the switch to the name "PROJ" was made with version 7.0. As of PROJ 9.1, using find_package(PROJ4) will show a CMake Deprecation Warning. The old project name PROJ4 name will be phased out after the PROJ 9.x series.

10.7 Language bindings

PROJ bindings are available for a number of different development platforms.

10.7.1 Python

pyproj: Python interface (wrapper for PROJ)

10.7.2 Java

PROJ-JNI: Java Native Interface for PROJ

10.7.3 Ruby

proj4rb: Bindings for PROJ in ruby
10.7.4 Rust

proj: Rust bindings for the latest stable version of PROJ

10.7.5 Go (Golang)

go-proj: Go bindings for PROJ.

10.7.6 Julia

Proj.jl: Julia bindings and idiomatic wrapper for PROJ.

10.7.7 TCL

proj4tcl: Bindings for PROJ in tcl (critcl source)

10.7.8 MySQL

fProj4: Bindings for PROJ in MySQL

10.7.9 Excel

proj.xll: Excel add-in for PROJ map projections

10.7.10 Visual Basic

PROJ VB Wrappers: By Eric G. Miller.

10.7.11 Fortran

Fortran-Proj: Bindings for PROJ in Fortran (By João Macedo @likeno)

10.8 Version 4 to 6 API Migration

This is a transition guide for developers wanting to migrate their code to use PROJ version 6.

10.8.1 Code example

The difference between the old and new API is shown here with a few examples. Below we implement the same program with the two different API's. The program reads input longitude and latitude from the command line and convert them to projected coordinates with the Mercator projection.

We start by writing the program for PROJ 4:
The same program implemented using PROJ 6:

```c
#include <proj.h>

main(int argc, char **argv) {
    PJ *P;
    PJ_COORD c, c_out;

    /* NOTE: the use of PROJ strings to describe CRS is strongly discouraged */
    /* in PROJ 6, as PROJ strings are a poor way of describing a CRS, and */
    /* more precise its geodetic datum. */
    /* Use of codes provided by authorities (such as "EPSG:4326", etc...) */
    /* or WKT strings will bring the full power of the "transformation */
    /* engine" used by PROJ to determine the best transformation(s) between */
    /* two CRS. */
    P = proj_create_crs_to_crs(PJ_DEFAULT_CTX,
                              "+proj=longlat +ellps=clrs66",
                              "+proj=merc +ellps=clrk66 +lat_ts=33",
                              NULL);

    if (P==0)
        return 1;

    {
        /* For that particular use case, this is not needed. */
        /* proj_normalize_for_visualization() ensures that the coordinate */
        /* order expected and returned by proj_trans() will be longitude, */
        /* latitude for geographic CRS, and easting, northing for projected */
        /* CRS. If instead of using PROJ strings as above, "EPSG:XXXX" codes */
    }

    pj_free(pj_longlat);
    pj_free(pj_merc);

    return 0;
}
```
/* had been used, this might had been necessary. */
PJ* P_for_GIS = proj_normalize_for_visualization(PJ_DEFAULT_CTX, P);
if( 0 == P_for_GIS ) {
    proj_destroy(P);
    return 1;
}
proj_destroy(P);
P = P_for_GIS;

/* For reliable geographic <-> geocentric conversions, z shall not */
/* be some random value. Also t shall be initialized to HUGE_VAL to */
/* allow for proper selection of time-dependent operations if one of */
/* the CRS is dynamic. */
c.lpzt.z = 0.0;
c.lpzt.t = HUGE_VAL;

while (scanf("%lf %lf", &c.lpzt.lam, &c.lpzt.phi) == 2) {
    /* No need to convert to radian */
    c_out = proj_trans(P, PJ_FWD, c);
    printf("%.2f\t%.2f\n", c_out.xy.x, c_out.xy.y);
}
proj_destroy(P);
return 0;
}

Further examples of using the PROJ API are in the quick start document.
### 10.8.2 Function mapping from old to new API

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<th>New API functions</th>
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</tr>
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</tr>
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<td>proj_trans()</td>
</tr>
<tr>
<td>pj_transform</td>
<td>proj_create_crs_to_crs() or proj_create_crs_to_crs_from_pj() + (proj_normalize_for_visualization() +) proj_trans(), proj_trans_array() or proj_trans_generic()</td>
</tr>
<tr>
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<td>No direct equivalent, but can be accomplished by chaining proj_create(), proj_crs_get_horizontal_datum() and proj_create_geographic_crs_from_datum()</td>
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</tr>
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<td>proj_info()</td>
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</table>

### 10.8.3 Backward incompatibilities

Access to the proj_api.h is still possible but requires to define the ACCEPT_USE_OF_DEPRECATED_PROJ_API_H macro.

The emulation of the now deprecated +init=epsg:XXXX syntax in PROJ 6 is not fully compatible with previous versions.

In particular, when used with the pj_transform() function, no datum shift term (towgs84, nadgrids, geoidgrids) will be added during the expansion of the +init=epsg:XXXX string to +proj=YYY .... If you still uses pj_transform() and want datum shift to be applied, then you need to provide a fully expanded string with appropriate towgs84, nadgrids or geoidgrids terms to pj_init().

To use the +init=epsg:XXXX syntax with proj_create() and then proj_create_crs_to_crs(), proj_context_use_proj4_init_rules(ctx, TRUE) or the PROJ_USE_PROJ4_INIT_RULES=YES environment variable must have been previously set. In that context, datum shift will be researched. However they might be different than with PROJ 4 or PROJ 5, since a "late-binding" approach will be used (that is trying to find as much as possible the most direct transformation between the source and target datum), whereas PROJ 4 or PROJ 5 used an "early-binding" approach consisting in always going to EPSG:4326 / WGS 84.
10.8.4 Feedback from downstream projects on the PROJ 6 migration

- PROJ 6 adoption by Spatialite
- On GDA2020, PROJ 6 and QGIS: Lessons learnt and recommendations for handling GDA2020 within geospatial software development

10.9 Version 4 to 5 API Migration

This is a transition guide for developers wanting to migrate their code to use PROJ version 5.

10.9.1 Background

Before we go on, a bit of background is needed. The new API takes a different view of the world than the old because it is needed in order to obtain high accuracy transformations. The old API is constructed in such a way that any transformation between two coordinate reference systems must pass through the ill-defined WGS84 reference frame, using it as a hub. The new API does away with this limitation to transformations in PROJ. It is still possible to do that type of transformations but in many cases there will be a better alternative.

The world view represented by the old API is always sufficient if all you care about is meter level accuracy - and in many cases it will provide much higher accuracy than that. But the view that “WGS84 is the true foundation of the world, and everything else can be transformed natively to and from WGS84” is inherently flawed.

First and foremost because any time WGS84 is mentioned, you should ask yourself “Which of the six WGS84 realizations are we talking about here?”.

Second, because for many (especially legacy) systems, it may not be straightforward to transform to WGS84 (or actually ITRF-something, ETRS-something or NAD-something which appear to be the practical meaning of the term WGS84 in everyday PROJ related work), while centimeter-level accurate transformations may exist between pairs of older systems.

The concept of a hub reference frame (“datum”) is not inherently bad, but in many cases you need to handle and select that datum with more care than the old API allows. The primary aim of the new API is to allow just that. And to do that, you must realize that the world is inherently 4 dimensional. You may in many cases assume one or more of the coordinates to be constant, but basically, to obtain geodetic accuracy transformations, you need to work in 4 dimensions.

Now, having described the background for introducing the new API, let's try to show how to use it. First note that in order to go from system A to system B, the old API starts by doing an inverse transformation from system A to WGS84, then does a forward transformation from WGS84 to system B.

With `cs2cs` being the command line interface to the old API, and `cct` being the same for the new, this example of doing the same thing in both world views will should give an idea of the differences:

```
$ echo 300000 6100000 | cs2cs +proj=utm +zone=33 +ellps=GRS80 +to +proj=utm +zone=32
   +ellps=GRS80
683687.87 6099299.66 0.00

$ echo 300000 6100000 0 0 | cct +proj=pipeline +step +inv +proj=utm +zone=33
   +ellps=GRS80 +step +proj=utm +zone=32 +ellps=GRS80
683687.8667 6099299.6624 0.0000 0.0000
```

Lookout for the `+inv` in the first `+step`, indicating an inverse transform.
10.9.2 Code example

The difference between the old and new API is shown here with a few examples. Below we implement the same program with the two different API's. The program reads input longitude and latitude from the command line and convert them to projected coordinates with the Mercator projection.

We start by writing the program for PROJ v. 4:

```c
#include <proj_api.h>

main(int argc, char **argv) {
    projPJ pj_merc, pj_longlat;
    double x, y;

    if (!(pj_longlat = pj_init_plus("+proj=longlat +ellps=clrk66")))
        return 1;
    if (!(pj_merc = pj_init_plus("+proj=merc +ellps=clrk66 +lat_ts=33")))
        return 1;

    while (scanf("%lf %lf", &x, &y) == 2) {
        x *= DEG_TO_RAD; /* longitude */
        y *= DEG_TO_RAD; /* latitude */
        p = pj_transform(pj_longlat, pj_merc, 1, 1, &x, &y, NULL);
        printf("%.2f	%.2f\n", x, y);
    }

    pj_free(pj_longlat);
    pj_free(pj_merc);
    return 0;
}
```

The same program implemented using PROJ v. 5:

```c
#include <proj.h>

main(int argc, char **argv) {
    PJ *P;
    PJ_COORD c;

    P = proj_create(PJ_DEFAULT_CTX, "+proj=merc +ellps=clrk66 +lat_ts=33");
    if (P==0)
        return 1;

    while (scanf("%lf %lf", &c.lp.lam, &c.lp.phi) == 2) {
        c.lp.lam = proj_torad(c.lp.lam);
        c.lp.phi = proj_torad(c.lp.phi);
        c = proj_trans(P, PJ_FWD, c);
        printf("%.2f\t%.2f\n", c.xy.x, c.xy.y);
    }

    proj_destroy(P);
}
```

Looking at the two different programs, there's a few immediate differences that catches the eye. First off, the included
header file describing the API has changed from proj_api.h to simply proj.h. All functions in proj.h belongs to the proj_ namespace.

With the new API also comes new datatypes. E.g. the transformation object projPJ which has been changed to a pointer of type PJ. This is done to highlight the actual nature of the object, instead of hiding it away behind a typedef. New data types for handling coordinates have also been introduced. In the above example we use the PJ_COORD, which is a union of various types. The benefit of this is that it is possible to use the various structs in the union to communicate what state the data is in at different points in the program. For instance as in the above example where the coordinate is read from STDIN as a geodetic coordinate, communicated to the reader of the code by using the c.lp struct. After it has been projected we print it to STDOUT by accessing the individual elements in c.xy to illustrate that the coordinate is now in projected space. Data types are prefixed with PJ_.

The final, and perhaps biggest, change is that the fundamental concept of transformations in PROJ are now handled in a single transformation object (PJ) and not by stating the source and destination systems as previously. It is of course still possible to do just that, but the transformation object now captures the whole transformation from source to destination in one. In the example with the old API the source system is described as +proj=latlon +ellps=clrk66 and the destination system is described as +proj=merc +ellps=clrk66 +lat_ts=33. Since the Mercator projection accepts geodetic coordinates as its input, the description of the source in this case is superfluous. We use that to our advantage in the new API and simply state the destination. This is simple at a glance, but is actually a big conceptual change. We are now focused on the path between two systems instead of what the source and destination systems are.

10.9.3 Function mapping from old to new API

<table>
<thead>
<tr>
<th>Old API functions</th>
<th>New API functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>pj_fwd</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_inv</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_fwd3</td>
<td>proj_trans()</td>
</tr>
<tr>
<td>pj_inv3</td>
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<tr>
<td>pj_transform</td>
<td>proj_trans_array() or proj_trans_generic()</td>
</tr>
<tr>
<td>pj_init</td>
<td>proj_create()</td>
</tr>
<tr>
<td>pj_init_plus</td>
<td>proj_create()</td>
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<td>pj_free</td>
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</tr>
<tr>
<td>pj_is_latlong</td>
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</tr>
<tr>
<td>pj_is_geocent</td>
<td>proj_angular_output()</td>
</tr>
<tr>
<td>pj_get_def</td>
<td>proj_pj_info()</td>
</tr>
<tr>
<td>pj_latlong_fromProj</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_set_finder</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_set_searchpath</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_deallocate_grids</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_strerror</td>
<td>No equivalent</td>
</tr>
<tr>
<td>pj_strerror</td>
<td>proj_errno()</td>
</tr>
<tr>
<td>pj_get_errno_ref</td>
<td>proj_info()</td>
</tr>
</tbody>
</table>

The source code for PROJ is maintained in a git repository on GitHub. Additionally, a collection of PROJ-compatible transformation grids are maintained in a separate git repository.

Attention: The projects.h header and the functions related to it is considered deprecated from version 5.0.0 and onwards. The header has been removed PROJ in version 6.0.0 released February 1st 2019.
**Attention:** The nmake build system on Windows is on longer supported in version 6.0.0 on onwards. Use CMake instead.

**Attention:** The `proj_api.h` header and the functions related to it is considered deprecated from version 5.0.0 and onwards. The header has been removed in version 8.0.0 released March 1st 2021.

**Attention:** With the introduction of PROJ 5, behavioural changes has been made to existing functionality. Consult *Known differences between versions* for the details.
PROJ implements a number of extensions to standards, that are described below for the sake of broader interoperability.

11.1 PROJJSON

11.1.1 Introduction

PROJJSON is a JSON encoding of WKT2:2019 / ISO-19162:2019: Geographic information - Well-known text representation of coordinate reference systems, which itself implements the model of [ISO19111]. Apart from the difference of encodings, the semantics is intended to be exactly the same as WKT2:2019, and PROJJSON can be morphed losslessly from/into WKT2:2019.

PROJJSON is aimed at encoding definitions of coordinate reference systems (and their composing objects: datums, datum ensembles, coordinate systems, conversion) and coordinate operations.

11.1.2 Normative references

The PROJJSON specification requires prior knowledge of the following normative specifications:

- The JavaScript Object Notation (JSON) Data Interchange Format / IETF RFC 7159

11.1.3 Definitions

- JavaScript Object Notation (JSON), and the terms object, member, name, value, array, number, true, false, and null, are to be interpreted as defined in [RFC7159].
- integer: JSON number whose value has no fractional/exponent part.
- All term and definitions from WKT2:2019 apply.
11.1.4 Schema

A JSON schema of PROJJSON grammar is available at https://proj.org/schemas/v0.6/projjson.schema.json

This schema defines a minimum set of constraints that apply to well-formed PROJJSON. Number of specific CRS and coordinate operation domain constraints are not expressed as JSON schema constraints: unless otherwise stated, the constraints (optional/mandatory/conditional character of information, restricted set of allowed values, etc.) defined in the WKT2:2019 specification also apply, as supplement to the JSON schema constraints.

11.1.5 History of the schema

- v0.7: added "accuracy" property in ConcatenatedOperation. Implemented in PROJ 9.2.1
- v0.6:
  - Implemented in PROJ 9.2
  - Additional optional "source_crs" property in "abridged_transformation".
  - Added CoordinateMetadata
  - Added "datum_epoch" property to GeodeticReferenceFrame and VerticalReferenceFrame
  - Added "minimum_value", "maximum_value" and "range_meaning" properties to Axis
  - Added "affine" in the CoordinateSystem.subtype enumeration.
- v0.5:
  - **Implemented in PROJ 9.1:**
    - add "meridian" member in Axis object type.
    - add "temporal_extent" and "vertical_extent" members in object usage.
    - add "geoid_models" for VerticalCRS if several models are needed.
    - add "deformation_models" members to GeodeticCRS and VerticalCRS (replaces "deformation_model" in DynamicGeodeticReferenceFrame/DynamicVerticalReferenceFrame)
  - **Added in schema, but not implemented in PROJ:**
    - add top-level object PointMotionOperation
- v0.4: additional properties allowed in id object (version, authority_citation, uri). Implemented in PROJ 8.2.
- v0.3: additional properties allowed in BoundCRS object (name, scope, area, bbox, usages, remarks, id, ids). Implemented in PROJ 8.1.
- v0.2: addition of geoid_model in VerticalCRS object.
- v0.1: initial version for PROJ 6.2
11.1.6 Specification

A PROJJSON text is a JSON object which has, at a minimum, a required type member, whose value is a string describing the nature of the encoded geodetic object.

An optional $schema member may be present, with its value being a string with a URL that points to the JSON schema that applies.

Objects may be composed of sub-objects (e.g. a GeographicCRS is made of a Datum or DatumEnsemble and a coordinate system). The type member of the sub-objects can be omitted when there is no ambiguity. For example, in the object which is the value of a coordinate_system member, the type may be omitted. However, the value of the datum object of a GeographicCRS the type should be specified, as it can be either a GeodeticReferenceFrame or a DynamicGeodeticReferenceFrame. More formally, the type should be specified if the JSON schema specifies alternative types for the value of a member using the oneOf construct and those alternative types have a type member. Otherwise it may be omitted.

11.1.6.1 High level objects

Objects described at the first level of a PROJJSON text have the following potential values of the type member:

- Coordinate Reference Systems (CRS):
  - Common ones:
    * GeographicCRS
    * GeodeticCRS
    * ProjectedCRS
    * CompoundCRS
    * BoundCRS
  - More esoteric ones:
    * VerticalCRS
    * EngineeringCRS
    * TemporalCRS
    * ParametricCRS
    * DerivedGeographicCRS
    * DerivedGeodeticCRS
    * DerivedProjectedCRS
    * DerivedVerticalCRS
    * DerivedEngineeringCRS
    * DerivedTemporalCRS
    * DerivedParametricCRS
- Coordinate operations:
  - Transformation
  - Conversion
  - ConcatenatedOperation
11.1.6.2 Identifiers

All objects mentioned above can have an optional id or ids member.

The value of id is a JSON object with the following members:

- **authority**: (required) value of type string. e.g "EPSG", "OGC", "IGNF", etc.
- **code**: (required) value of type string or integer. e.g 4326 or "CRS84"
- **authority_citation**: (optional) value of type string that may be used to give further details of the authority.
- **uri**: (optional) value of type string that may be used to give reference to an online resource.

An object can sometimes be identified in different ways, in which case the ids member can be used to specify a JSON array of objects with the same type of id.

Identifiers are allowed in top-level objects and inner objects. The WKT2:2019 specification recommends that if an object has an identifier, its inner objects should omit their identifiers, with the exceptions mentioned at http://docs.opengeospatial.org/is/18-010r7/18-010r7.html#37.

11.1.6.3 Object usages

CRS and coordinate operation objects are derived classes (in object modeling terminology) of a "object usage" class. An object usage has the following optional members:

- **scope**: (optional) value of type string describing the purpose or purposes of the object. e.g "Geodesy, topographic mapping and cadastre"
- **area**: (optional) value of type string which describes a geographic area over which a CRS or coordinate operation is applicable. e.g. "World"
- **bbox**: (optional) value of type object, with 4 required members: * east_longitude*: (required) number expressing the longitude in degrees of the eastern most part of the extent, within [-180,180] range. * west_longitude*: (required) number expressing the longitude in degrees of the western most part of the extent, within [-180,180] range. For an extent crossing the anti-meridian, west_longitude is lower than east_longitude. * south_latitude*: (required) number expressing the latitude in degrees of the southern most part of the extent, within [-90,90] range. * north_latitude*: (required) number expressing the latitude in degrees of the northern most part of the extent, within [-90,90] range. The coordinates are expressed in an unspecified datum, with the longitudes relative to the international reference meridian.
- **remarks**: (optional) value of type string with an informative text that does not modify the defining parameters of the object. e.g "Use NTv2 file for better accuracy"
- **id** (mutually exclusive with ids): (optional) Identifier of the object, as defined in Identifiers
- **ids** (mutually exclusive with id): (optional) Identifiers of the object, as defined in Identifiers

If several extents and scopes apply to an object, the scope, area and bbox members should not be used. Instead a usages member should be used, whose value is an array of objects, each of them accepting scope and/or area and/or bbox as members. While it is acceptable to use the usages construct for a single usage, it is recommended to avoid it and rather use instead the scope, area and bbox members.
11.1.6.4 Units

A unit may be described either as:

- an object with the following members:
  - type: (required) one of the following types: LinearUnit, AngularUnit, ScaleUnit, TimeUnit, ParametricUnit, Unit
  - name: (required) string.
  - conversion_factor: (required in most cases, except in the temporal quantities of http://docs.opengeospatial.org/is/18-010r7/18-010r7.html#42) number that expresses a multiplicative factor to convert from the specified unit to a reference unit, as specified in http://docs.opengeospatial.org/is/18-010r7/18-010r7.html#41
  - id or ids: (optional, mutually exclusive)

- a string among the following enumeration: metre, degree, unity

Using a string value, when applicable, is recommended for brevity of the object definition.

11.1.6.5 Omitted units in measured parameters

Most numeric parameters should generally be accompanied with the corresponding unit.

For example, for a projection parameter:

```json
{
  "name": "False easting",
  "value": 500000,
  "unit": "metre"
}
```

or:

```json
{
  "name": "False easting",
  "value": 700000,
  "unit": {,
    "type": "LinearUnit",
    "name": "foot",
    "conversion_factor": 0.3048
  }
}
```

For the following cases, the unit may be omitted if it is metre: semi_major_axis, semi_minor_axis and radius members of an ellipsoid

For the following cases, the unit may be omitted if it is degree: longitude of a prime meridian.
11.1.6.6 Coordinate system

In WKT, a ORDER keyword may be present in an axis definition. As the value of that element is equal to the index of axis in the list of axis of the coordinate system (with 1 as the value of the first index), it is absent from the PROJJSON encoding, to avoid any risk of misuse.

11.1.7 Examples

11.1.7.1 GeographicCRS

Using a datum member, implicit prime meridian

The EPSG:6318 / "NAD83(2011)" geographic CRS can be expressed as

```json
{
   "$schema": "https://proj.org/schemas/v0.4/projjson.schema.json",
   "type": "GeographicCRS",
   "name": "NAD83(2011)",
   "datum": {
      "type": "GeodeticReferenceFrame",
      "name": "NAD83 (National Spatial Reference System 2011)",
      "ellipsoid": {
         "name": "GRS 1980",
         "semi_major_axis": 6378137,
         "inverse_flattening": 298.257222101
      }
   },
   "coordinate_system": {
      "subtype": "ellipsoidal",
      "axis": [
      {
         "name": "Geodetic latitude",
         "abbreviation": "Lat",
         "direction": "north",
         "unit": "degree"
      },
      {
         "name": "Geodetic longitude",
         "abbreviation": "Lon",
         "direction": "east",
         "unit": "degree"
      }
      ],
   },
   "scope": "Horizontal component of 3D system."
}
```

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Note the omission of a prime meridian member, which is conformant with the WKT2:2019 conditionality rules, as the prime meridian of the WGS 84 datum is the reference meridian / Greenwich.

**Using a datum member with an explicit prime meridian**

For the EPSG:4806 / "Monte Mario (Rome)" geographic CRS, the prime meridian must be specified:

```json
{
  "$schema": "https://proj.org/schemas/v0.4/projjson.schema.json",
  "type": "GeographicCRS",
  "name": "Monte Mario (Rome)",
  "datum": {
    "type": "GeodeticReferenceFrame",
    "name": "Monte Mario (Rome)",
    "ellipsoid": {
      "name": "International 1924",
      "semi_major_axis": 6378388,
      "inverse_flattening": 297
    },
    "prime_meridian": {
      "name": "Rome",
      "longitude": 12.4523333333333
    }
  },
  "coordinate_system": {
    "subtype": "ellipsoidal",
    "axis": [
      {
        "name": "Geodetic latitude",
        "abbreviation": "Lat",
        "direction": "north",
        "unit": "degree"
      },
      {
        "name": "Geodetic longitude",
        "abbreviation": "Lon",
        "direction": "east",
        "unit": "degree"
      }
    ]
}
```
Using a datum ensemble member

The WGS 84 geographic CRS may also be specified using a datum ensemble representation of the WGS 84 datum:

```json

{  
  "$schema": "https://proj.org/schemas/v0.4/projjson.schema.json",
  "type": "GeographicCRS",
  "name": "WGS 84",
  "datum_ensemble": {  
    "name": "World Geodetic System 1984 ensemble",
    "members": [
      {  
        "name": "World Geodetic System 1984 (Transit)",
        "id": {  
          "authority": "EPSG",
          "code": 1166
        }
      },
      {  
        "name": "World Geodetic System 1984 (G730)",
        "id": {  
          "authority": "EPSG",
          "code": 1152
        }
      },
      {  
        "name": "World Geodetic System 1984 (G873)",
        "id": {  
          "authority": "EPSG",
          "code": 1153
        }
      },
      {  
        "name": "World Geodetic System 1984 (G1150)"
      }
    ]
  }
}
```

(continues on next page)
"id": {
  "authority": "EPSG",
  "code": 1154
}
},
{
  "name": "World Geodetic System 1984 (G1674)",
  "id": {
    "authority": "EPSG",
    "code": 1155
  }
},
{
  "name": "World Geodetic System 1984 (G1762)",
  "id": {
    "authority": "EPSG",
    "code": 1156
  }
},
{
  "name": "World Geodetic System 1984 (G2139)",
  "id": {
    "authority": "EPSG",
    "code": 1309
  }
}
],
"ellipsoid": {
  "name": "WGS 84",
  "semi_major_axis": 6378137,
  "inverse_flattening": 298.257223563
},
"accuracy": "2.0",
"id": {
  "authority": "EPSG",
  "code": 6326
}
},
"coordinate_system": {
  "subtype": "ellipsoidal",
  "axis": [
    {
      "name": "Geodetic latitude",
      "abbreviation": "Lat",
      "direction": "north",
      "unit": "degree"
    },
    {
      "name": "Geodetic longitude",
      "abbreviation": "Lon",
      "direction": "east",
      "unit": "degree"
    }
  ]
}
The above is the output of the following invocation of the projinfo utility of the PROJ software version 9.0.0:

```
projinfo EPSG:4326 -o PROJJSON -q
```

**Note:** PROJ versions prior to PROJ 8.0.0 used versions of the EPSG dataset that did not have the datum ensemble concept. Consequently they used a datum member instead of a `datum_ensemble`. The number of elements in the datum ensemble may also vary over time when new realizations of WGS 84 are added to the ensemble.

### 11.1.7.2 ProjectedCRS

The EPSG:32631 / “WGS 84 / UTM zone 31N” projected CRS can be expressed as:

```json
{
    "$schema": "https://proj.org/schemas/v0.1/projjson.schema.json",
    "type": "ProjectedCRS",
    "name": "WGS 84 / UTM zone 31N",
    "base_crs": {
        "name": "WGS 84",
        "datum": {
            "type": "GeodeticReferenceFrame",
            "name": "World Geodetic System 1984",
            "ellipsoid": {
                "name": "WGS 84",
                "semi_major_axis": 6378137,
                "inverse_flattening": 298.257223563
            }
        }
    },
    "coordinate_system": {
        "subtype": "ellipsoidal",
        "axis": [
            {
                "name": "Geodetic latitude",
                "abbreviation": "Lat",
            }
        ]
    }
}
```
"direction": "north",
"unit": "degree"
},

{  
"name": "Geodetic longitude",
"abbreviation": "Lon",
"direction": "east",
"unit": "degree"
}
]

"id": {
"authority": "EPSG",
"code": 4326
}
},
"conversion": {
"name": "UTM zone 31N",
"method": {
"name": "Transverse Mercator",
"id": {
"authority": "EPSG",
"code": 9807
}
},
"parameters": [
{
"name": "Latitude of natural origin",
"value": 0,
"unit": "degree",
"id": {
"authority": "EPSG",
"code": 8801
}
},
{
"name": "Longitude of natural origin",
"value": 3,
"unit": "degree",
"id": {
"authority": "EPSG",
"code": 8802
}
},
{
"name": "Scale factor at natural origin",
"value": 0.9996,
"unit": "unity",
"id": {
"authority": "EPSG",
"code": 8805
}
}
"coordinate_system": {
  "subtype": "Cartesian",
  "axis": [
    {
      "name": "Easting",
      "abbreviation": "E",
      "direction": "east",
      "unit": "metre"
    },
    {
      "name": "Northing",
      "abbreviation": "N",
      "direction": "north",
      "unit": "metre"
    }
  ]
},
"area": "World – N hemisphere – 0°E to 6°E – by country",
"bbox": {
  "south_latitude": 0,
  "west_longitude": 0,
  "north_latitude": 84,
  "east_longitude": 6
},
"id": {
  "authority": "EPSG",
  "code": 32631
}
11.1.7.3 CompoundCRS

The EPSG:9518 / "WGS 84 + EGM2008 height" compound CRS can be expressed as:

```
{
    "$schema": "https://proj.org/schemas/v0.4/projjson.schema.json",
    "type": "CompoundCRS",
    "name": "WGS 84 + EGM2008 height",
    "components": [
        {
            "type": "GeographicCRS",
            "name": "WGS 84",
            "datum_ensemble": {
                "name": "World Geodetic System 1984 ensemble",
                "members": [
                    {
                        "name": "World Geodetic System 1984 (Transit)",
                        "id": {
                            "authority": "EPSG",
                            "code": 1166
                        }
                    },
                    {
                        "name": "World Geodetic System 1984 (G730)",
                        "id": {
                            "authority": "EPSG",
                            "code": 1152
                        }
                    },
                    {
                        "name": "World Geodetic System 1984 (G873)",
                        "id": {
                            "authority": "EPSG",
                            "code": 1153
                        }
                    },
                    {
                        "name": "World Geodetic System 1984 (G1150)",
                        "id": {
                            "authority": "EPSG",
                            "code": 1154
                        }
                    },
                    {
                        "name": "World Geodetic System 1984 (G1674)",
                        "id": {
                            "authority": "EPSG",
                            "code": 1155
                        }
                    }
                ]
            }
        }
    ]
}
```

(continues on next page)
"authority": "EPSG",
"code": 1156
}
},
{
"name": "World Geodetic System 1984 (G2139)",
"id": {
"authority": "EPSG",
"code": 1309
}
}
],
"ellipsoid": {
"name": "WGS 84",
"semi_major_axis": 6378137,
"inverse_flattening": 298.257223563
},
"accuracy": "2.0",
"id": {
"authority": "EPSG",
"code": 6326
}
},
"coordinate_system": {
"subtype": "ellipsoidal",
"axis": [
{
"name": "Geodetic latitude",
"abbreviation": "Lat",
"direction": "north",
"unit": "degree"
},
{
"name": "Geodetic longitude",
"abbreviation": "Lon",
"direction": "east",
"unit": "degree"
}
]
},
"type": "VerticalCRS",
"name": "EGM2008 height",
"datum": {
"type": "VerticalReferenceFrame",
"name": "EGM2008 geoid"
},
"coordinate_system": {
"subtype": "vertical",
"axis": [
}
11.1.7.4 BoundCRS

The Bound CRS, using as a base EPSG:4258 "ETRS89" geographic CRS, with an explicit transformation to WGS 84 using a null Helmert transformation, can be expressed as

```json
{
    "schema": "https://proj.org/schemas/v0.4/projjson.schema.json",
    "type": "BoundCRS",
    "source_crs": {
        "type": "GeographicCRS",
        "name": "ETRS89",
        "datum_ensemble": {
            "name": "European Terrestrial Reference System 1989 ensemble",
            "members": [
                { "name": "European Terrestrial Reference Frame 1989"
                },
                { "name": "European Terrestrial Reference Frame 1990"
                },
                { "name": "European Terrestrial Reference Frame 1991"
                },
                { "name": "European Terrestrial Reference Frame 1992"
                },
                { "name": "European Terrestrial Reference Frame 1993"
                }
            ]
        }
    }
}
```
"name": "European Terrestrial Reference Frame 1994"
},

{ "name": "European Terrestrial Reference Frame 1996"
},

{ "name": "European Terrestrial Reference Frame 1997"
},

{ "name": "European Terrestrial Reference Frame 2000"
},

{ "name": "European Terrestrial Reference Frame 2005"
},

{ "name": "European Terrestrial Reference Frame 2014"
}
],
"ellipsoid": {
  "name": "GRS 1980",
  "semi_major_axis": 6378137,
  "inverse_flattening": 298.257222101
},

"accuracy": "0.1"
},

"coordinate_system": {
  "subtype": "ellipsoidal",
  "axis": [
    {
      "name": "Geodetic latitude",
      "abbreviation": "Lat",
      "direction": "north",
      "unit": "degree"
    },
    {
      "name": "Geodetic longitude",
      "abbreviation": "Lon",
      "direction": "east",
      "unit": "degree"
    }
  ]
},

"id": {
  "authority": "EPSG",
  "code": 4258
}
},

"target_crs": {
  "type": "GeographicCRS",
  "name": "WGS 84"
"datum": {  
  "type": "GeodeticReferenceFrame",  
  "name": "World Geodetic System 1984",  
  "ellipsoid": {  
    "name": "WGS 84",  
    "semi_major_axis": 6378137,  
    "inverse_flattening": 298.257223563  
  }  
},  
"coordinate_system": {  
  "subtype": "ellipsoidal",  
  "axis": [  
    {  
      "name": "Geodetic latitude",  
      "abbreviation": "Lat",  
      "direction": "north",  
      "unit": "degree"  
    },  
    {  
      "name": "Geodetic longitude",  
      "abbreviation": "Lon",  
      "direction": "east",  
      "unit": "degree"  
    }  
  ]  
},  
"id": {  
  "authority": "EPSG",  
  "code": 4326  
},  
"transformation": {  
  "name": "Transformation from unknown to WGS84",  
  "method": {  
    "name": "Position Vector transformation (geog2D domain)",  
    "id": {  
      "authority": "EPSG",  
      "code": 9606  
    }  
  },  
  "parameters": [  
    {  
      "name": "X-axis translation",  
      "value": 0,  
      "unit": "metre",  
      "id": {  
        "authority": "EPSG",  
        "code": 8605  
      }  
    },  
    {  
      "name": "Y-axis translation",  
      "value": 11.1,  
      "unit": "metre",  
      "id": {  
        "authority": "EPSG",  
        "code": 8605  
      }  
    }  
  ]  
}
"value": 0,
"unit": "metre",
"id": {
   "authority": "EPSG",
   "code": 8606
}
},
{
   "name": "Z-axis translation",
   "value": 0,
   "unit": "metre",
   "id": {
      "authority": "EPSG",
      "code": 8607
   }
},
{
   "name": "X-axis rotation",
   "value": 0,
   "unit": {
      "type": "AngularUnit",
      "name": "arc-second",
      "conversion_factor": 4.84813681109536e-06
   },
   "id": {
      "authority": "EPSG",
      "code": 8608
   }
},
{
   "name": "Y-axis rotation",
   "value": 0,
   "unit": {
      "type": "AngularUnit",
      "name": "arc-second",
      "conversion_factor": 4.84813681109536e-06
   },
   "id": {
      "authority": "EPSG",
      "code": 8609
   }
},
{
   "name": "Z-axis rotation",
   "value": 0,
   "unit": {
      "type": "AngularUnit",
      "name": "arc-second",
      "conversion_factor": 4.84813681109536e-06
   },
   "id": {
      "authority": "EPSG",
      "code": 8610
   }
}
11.1.7.5 Transformation

The EPSG:8549 / "NAD27 to NAD83 (8)" transformation can be expressed as:

```json
{
  "$schema": "https://proj.org/schemas/v0.4/projjson.schema.json",
  "type": "Transformation",
  "name": "NAD27 to NAD83 (8)",
  "source_crs": {
    "type": "GeographicCRS",
    "name": "NAD27",
    "datum": {
      "type": "GeodeticReferenceFrame",
      "name": "North American Datum 1927",
      "ellipsoid": {
        "name": "Clarke 1866",
        "semi_major_axis": 6378206.4,
        "semi_minor_axis": 6356583.8
      }
    }
  },
  "coordinate_system": {
    "subtype": "ellipsoidal",
    "axis": [
      {
        "name": "Geodetic latitude",
        "abbreviation": "Lat",
        "direction": "north",
        "unit": "degree"
      },
      {
        "name": "Geodetic longitude",
        "abbreviation": "Lon",
        "direction": "east",
        "unit": "degree"
      }
    ]
  }
}
```
"abbreviation": "Lon",
"direction": "east",
"unit": "degree"
]}
},
"id": {
  "authority": "EPSG",
  "code": 4267
},
"target_crs": {
  "type": "GeographicCRS",
  "name": "NAD83",
  "datum": {
    "type": "GeodeticReferenceFrame",
    "name": "North American Datum 1983",
    "ellipsoid": {
      "name": "GRS 1980",
      "semi_major_axis": 6378137,
      "inverse_flattening": 298.257222101
    }
  },
  "coordinate_system": {
    "subtype": "ellipsoidal",
    "axis": [
      {
        "name": "Geodetic latitude",
        "abbreviation": "Lat",
        "direction": "north",
        "unit": "degree"
      },
      {
        "name": "Geodetic longitude",
        "abbreviation": "Lon",
        "direction": "east",
        "unit": "degree"
      }
    ]
  },
  "id": {
    "authority": "EPSG",
    "code": 4269
  }
},
"method": {
  "name": "NADCON5 (2D)",
  "id": {
    "authority": "EPSG",
    "code": 1074
  }
},
(continues on next page)
"parameters": [ 
  { 
    "name": "Latitude difference file",
    "value": "nadcon5.nad27.nad83_1986.alaska.lat.trn.20160901.b",
    "id": { 
      "authority": "EPSG",
      "code": 8657
    }
  }, 
  { 
    "name": "Longitude difference file",
    "value": "nadcon5.nad27.nad83_1986.alaska.lon.trn.20160901.b",
    "id": { 
      "authority": "EPSG",
      "code": 8658
    }
  }
],
"accuracy": "0.5",
"scope": "Geodesy.",
"area": "United States (USA) - Alaska.",
"bbox": { 
  "south_latitude": 51.3,
  "west_longitude": 172.42,
  "north_latitude": 71.4,
  "east_longitude": -129.99
},
"id": { 
  "authority": "EPSG",
  "code": 8549
},
"remarks": "Uses NADCON5 method which expects longitudes positive east in range 0-360°; source and target CRSs have longitudes positive east in range -180° to +180°. Accuracy at 67% confidence level is 0.5m onshore, 5m nearshore and undetermined farther offshore."

11.1.8 Deviations with the WKT2:2019 specification

While most of this specification is intended to be interoperable with WKT2:2019, there are a few deviations, reflecting the needs of the PROJ software implementation.
11.1.8.1 PROJJSON extensions

This specification allows a Bound CRS to be used wherever a CRS object is allowed in the OGC Topic 2 abstract specification / ISO-19111:2019. In particular, the members of a compound CRS can be a Bound CRS in this specification, whereas OGC Topic 2 abstract specification restricts it to single CRS. A Bound CRS can also be used as the source or target of a coordinate operation.

11.1.8.2 PROJJSON omissions

This specification does not define an encoding for triaxial ellipsoid (TRIAXIAL WKT keyword)

11.1.9 Reference implementation

PROJJSON is available as input and output of the PROJ software since PROJ 6.2.

11.2 Geodetic TIFF grids (GTG)

New in version 7.0.

11.2.1 Introduction

The Geodetic TIFF grid format has been introduced per PROJ RFC 4: Remote access to grids and GeoTIFF grids. It is a profile of the TIFF and GeoTIFF formats that addresses the specific requirements of geodetic grids: horizontal shifts, vertical shifts, velocity grids, etc... It also follows the Cloud Optimized GeoTIFF principles.

Such grids are available on a CDN of GeoTIFF grids.

11.2.2 General description

The general principles that guide the following requirements and recommendations are such that files will be properly recognized by PROJ, and also by GDAL which is an easy way to inspect such grid files:

- TIFF 6.0 based (could possibly be BigTIFF without code changes, if we ever need some day to handle grids larger than 4GB)
- GeoTIFF 1.1 for the georeferencing. GeoTIFF 1.1 is a recent standard, compared to the original GeoTIFF 1.0 version, but its backward compatibility is excellent, so that should not cause much trouble to readers that are not official GeoTIFF 1.1 compliant.
- Files hosted on the CDN will use a Geographic 2D CRS for the GeoTIFF GeoKeys. That CRS is intended to be the interpolation CRS as defined in [ISO19111], that is the CRS to which grid values are referred to.

Given that they will nominally be related to the EPSG dataset, the GeodeticCRSGeoKey will be used to store the EPSG code of the CRS. If the CRS cannot be reliably encoded through that key or other geokeys, the interpolation_crs_wkt metadata item detailed afterwards should be used.

This CRS will be generally the source CRS (for geographic to geographic horizontal shift grids, or geographic to vertical shift grids), but for vertical to vertical CRS adjustment, this will be the geographic CRS to which the grid is referenced. In some very rare cases of geographic to vertical shift grids, the interpolation CRS might be a geographic CRS that is not the same as the source CRS (into which ellipsoidal height are expressed). The only instance we have in mind is for the EPSG:7001 “ETRS89 to NAP height (1)" transformation using the naptrans2008 VDatum-grid which is referenced to Amersfoort EPSG:4289 instead of ETR589...
On the reading side, PROJ will ignore that information: the CRS is already stored in the source_crs or interpolation_crs column of the grid_transformation table.

For geographic to vertical shift files (geoid models), the GeoTIFF 1.1 convention will be used to store the value of the VerticalGeoKey. So a geoid model that apply to WGS 84 EPSG:4979 will have GeodeticCRSGeoKey = 4326 and VerticalGeoKey = 4979.

- Files hosted on the CDN will use the GeoTIFF defined ModelTiepointTag and ModelPixelScaleTag TIFF tags to store the coordinates of the upper-left pixel and the resolution of the pixels. On the reading side, they will be required and ModelTransformationTag will be ignored.

Note: Regarding anti-meridian handling, a variety of possibilities exist. We do not attempt to standardize this and files hosted on the CDN will use a georeferencing close to the original data producer. For example, NOAA vertical grids that apply to Conterminous USA might even have a top-left longitude beyond 180 (for consistency with Alaska grids, whose origin is < 180) Anti-meridian handling in PROJ has probably issues. This RFC does not attempt to address them in particular, as they are believed to be orthogonal to the topics it covers, and being mostly implementation issues.

- Files hosted on the CDN will use the GTRasterTypeGeoKey = PixelIsPoint convention. This is the convention used by most existing grid formats currently. Note that GDAL typically use a PixelIsArea convention (but can handle both conventions), so the georeferencing it displays when opening a .gsb or .gtx file appears to have a half-pixel shift regarding to the coordinates stored in the original grid file. On the reading side, PROJ will accept both conventions (for equivalent georeferencing, the value of the origin in a PixelIsArea convention is shifted by a half-pixel towards the upper-left direction). Unspecified behavior if this GeoKey is absent.

- Files hosted on the CDN will be tiled, presumably with 256x256 tiles (small grids that are smaller than 256x256 will use a single strip). On the reading side, PROJ will accept TIFF files with any strip or tile organization. Tiling is expressed by specifying the TileWidth, TileHeight, TileOffsets and TileByteCounts tags. Strip organization is expressed by specifying the RowsPerStrip, StripByteCounts and StripOffsets tags.

- Files hosted on the CDN will use Compression = DEFLATE or LZW (to be determined, possibly with Predictor = 2 or 3) On the reading side, PROJ will accept TIFF files with any compression method (appropriate for the data types and PhotometricInterpretation considered) supported by the libtiff build used by PROJ. Of course uncompressed files will be supported.

- Files hosted on the CDN will use little-endian byte ordering. On the reading side, libtiff will transparently handle both little-endian and big-endian ordering.

- Files hosted on the CDN will use PlanarConfiguration=Separate. The tools described in a later section will order blocks so that blocks needed for a given location are close to each other. On the reading side, PROJ will handle also PlanarConfiguration=Contig.

- Files hosted on the CDN will generally use Float32 (BitsPerSample=32 and SampleFormat=IEEEFP) Files may be created using Signed Int 16 (BitsPerSample =16 and SampleFormat = INT), Unsigned Int 16 (BitsPerSample=16 and SampleFormat=UINT), Signed Int 32 or Unsigned Int 32 generally with an associate scale/offset. On the reading side, only those three data types will be supported as well.

- Files hosted on the CDN will have a PhotometricInterpretation = MinIsBlack. It will be assumed, and ignored on the reading side.

- Files hosted on the CDN will nominally have:
  - SamplesPerPixel = 2 for horizontal shift grid, with the first sample being the longitude offset and the second sample being the latitude offset.
  - SamplesPerPixel = 1 for vertical shift grids.
  - SamplesPerPixel = 3 for deformation models combining horizontal and vertical adjustments.
And even for the current identified needs of horizontal or vertical shifts, more samples may be present
(to indicate for example uncertainties), but will be ignored by PROJ.

The ExtraSamples tag should be set to a value of SamplesPerPixel - 1 (given the rules that apply for
PhotometricInterpretation = MinIsBlack)

- The ImageDescription tag may be used to convey extra information about the name, provenance, version and last
  updated date of the grid. Will be set when possible for files hosted on the CDN. Ignored by PROJ.

- The Copyright tag may be used to convey extra information about the copyright and license of the grid. Will be
  set when possible for files hosted on the CDN. Ignored by PROJ.

- The DateTime tag may be used to convey the date at which the file has been created or converted. In case of a
  file conversion, for example from NTv2, this will be the date at which the conversion has been performed. The
  ImageDescription tag however will contain the latest of the CREATED or UPDATED fields from the NTv2
  file. Will be set when possible for files hosted on the CDN. Ignored by PROJ.

- Files hosted on the CDN will use the GDAL_NODATA tag to encode the value of the nodata / missing value,
  when it applies to the grid.

  If offset and/or scaling is used, the nodata value corresponds to the raw value, before applying offset and scaling.
  The value found in this tag, if present, will be honoured (to the extent to which current PROJ code makes use of
  nodata). For floating point data, writers are strongly discouraged to use non-finite values (+/- infinity, NaN) of
  nodata to maxmimize interoperability. The GDAL_NODATA value applies to all samples of a given TIFF IFD.

- Files hosted on the CDN will use the GDAL_METADATA tag to encode extra metadata not supported by baseline
  or extended TIFF.

  - The root XML node should be GDALMetadata
  
  - Zero, one or several child XML nodes Item may be present.

  - A Item should have a name attribute, and a child text node with its value. role and sample attributes may
    be present for attributes that have a special semantics (recognized by GDAL). The value of sample should
    be an integer value between 0 and number_of_samples - 1.

  - Scale and offset to convert integer raw values to floating point values may be expressed with XML Item
    elements whose name attribute is respectively SCALE and OFFSET, and their role attribute is respectively
    scale and offset. The decoded value will be: {offset} + {scale} * raw_value_from_geotiff_file

For a offset value of 1 and scaling of 2, the following payload should be stored:

```
<GDALMetadata>
  <Item name="OFFSET" sample="0" role="offset">1</Item>
  <Item name="SCALE" sample="0" role="scale">2</Item>
</GDALMetadata>
```

- The type of the grid must be specified with a Item whose name is set to TYPE.

Values recognized by PROJ currently are:

* HORIZONTAL_OFFSET: implies the presence of at least two samples. The first sample must contain
  the latitude offset and the second sample must contain the longitude offset. The offset may also be
  expressed as a speed per year for temporal gridshifting. Corresponds to PROJ Horizontal grid shift
  method.

* GEOGRAPHIC_3D_OFFSET: implies the presence of at least 3 samples. The first sample must contain
  the latitude offset, the second sample must contain the longitude offset and the third one the ellipsoidal
  height difference. Typically used for NADCON5 grids. Added in PROJ 9.2 Corresponds to PROJ
  General grid shift method.
∗ ELLIPSOIDAL_HEIGHT_OFFSET: implies the presence of one sample with the ellipsoidal height difference. Generally used in combination with another grid of type HORIZONTAL_OFFSET to perform Geographic 3D offsetting when the horizontal and vertical grids do not have the same resolution, as found in some NADCON5 grids. Added in PROJ 9.2 Corresponds to PROJ General grid shift method.

∗ VERTICAL_OFFSET_GEOGRAPHIC_TO_VERTICAL: implies the presence of at least one sample. The first sample must contain the vertical adjustment. Must be used when the source/interpolation CRS is a Geographic CRS and the target CRS a Vertical CRS. Corresponds to PROJ Vertical grid shift method.

∗ VERTICAL_OFFSET_VERTICAL_TO_VERTICAL: implies the presence of at least one sample. The first sample must contain the vertical adjustment. Must be used when the source and target CRS are Vertical CRS. Corresponds to PROJ Vertical grid shift method.

∗ GEOCENTRIC_TRANSLATION: implies the presence of at least 3 samples. The first 3 samples must be respectively the geocentric adjustments along the X, Y and Z axis. Must be used when the source and target CRS are geocentric CRS. The interpolation CRS must be a geographic CRS. Corresponds to PROJ Geocentric grid shift method.

∗ VELOCITY: implies the presence of at least 3 samples. The first 3 samples must be respectively the velocities along the E(ast), N(orth), U(p) axis in the local topocentric coordinate system. Corresponds to PROJ Kinematic datum shifting utilizing a deformation model method.

∗ DEFORMATION_MODEL: implies the presence of the DISPLACEMENT_TYPE and UNCERTAINTY_TYPE metadata items. Corresponds to PROJ Multi-component time-based deformation model method.

For example:

```html
<Item name="TYPE">HORIZONTAL_OFFSET</Item>
```

The description of each sample must be specified with a Item whose name attribute is set to DESCRIPTION and role attribute to description.

Values recognized by PROJ for this Item are currently:

∗ latitude_offset: valid for TYPE=HORIZONTAL_OFFSET or GEOGRAPHIC_3D_OFFSET . Sample values should be the value to add a latitude expressed in the CRS encoded in the GeoKeys to obtain a latitude value expressed in the target CRS.

∗ longitude_offset: valid for TYPE=HORIZONTAL_OFFSET or GEOGRAPHIC_3D_OFFSET . Sample values should be the value to add a longitude expressed in the CRS encoded in the GeoKeys to obtain a longitude value expressed in the target CRS.

∗ ellipsoidal_height_offset: valid for TYPE=ELLIPSOIDAL_HEIGHT_OFFSET or GEOGRAPHIC_3D_OFFSET . Sample values should be the value to add to the ellipsoidal height of the source CRS to obtain the ellipsoidal height of the target CRS.

∗ geoid_undulation: valid for TYPE=VERTICAL_OFFSET_GEOGRAPHIC_TO_VERTICAL. For a source CRS being a geographic CRS and a target CRS being a vertical CRS, sample values should be the value to add to a geoid-related height (that is expressed in the target CRS) to get an ellipsoidal height (that is expressed in the source CRS), also called the geoid undulation. The value is positive upward from the reference ellipsoid. Note the possible confusion related to what is the source CRS and target CRS and the semantics of the value stored (to convert from the source to the target, one must subtract the value contained in the grid). This is the convention used by the EPSG:9665 operation method.

∗ hydroid_height: valid for TYPE=VERTICAL_OFFSET_GEOGRAPHIC_TO_VERTICAL. For a source CRS being a geographic CRS and a target CRS being a vertical CRS representing a tidal surface (typically Chart Datum, Highest/Lowest Astronomical Tide (HAT/LAT), High/Low Waters, Mean Sea Level), the hydroid height is the value to add to a height related to a tidal surface (that is expressed in

11.2. Geodetic TIFF grids (GTG)
the target CRS) to get an ellipsoidal height (that is expressed in the source CRS). The value is positive upward from the reference ellipsoid. Note the possible confusion related to what is the source CRS and target CRS and the semantics of the value stored (to convert from the source to the target, one must subtract the value contained in the grid). This is the convention used by the EPSG:1115 operation method.

* vertical_offset: valid for TYPE=VERTICAL_OFFSET_VERTICAL_TO_VERTICAL. For a source and target CRS being vertical CRS, sample values should be the value to add to an elevation expressed in the source CRS to obtain a longitude value expressed in the target CRS.

* x_translation / y_translation / z_translation: valid for TYPE=GEOCENTRIC_TRANSLATION. Sample values should be the value to add to the input geocentric coordinates expressed in the source CRS to geocentric coordinates expressed in the target CRS.

* east_velocity / north_velocity / up_velocity: valid for TYPE=VELOCITY. Sample values should be the velocity in a linear/time unit in a ENU local topocentric coordinate system.

* east_offset / north_offset / vertical_offset: valid for TYPE=DEFORMATION_MODEL. For east_offset and north_offset, the unit might be degree or metre. For vertical_offset, the unit must be metre.

For example:

```
<Item name="DESCRIPTION" sample="0" role="description">latitude_offset</Item>
<Item name="DESCRIPTION" sample="1" role="description">longitude_offset</Item>
```

Other values may be used (not used by PROJ):

* latitude_offset_accuracy: valid for TYPE=HORIZONTAL_OFFSET. Sample values should be the accuracy of corresponding latitude_offset samples. Generally in metre (if converted from NTv2)

* longitude_offset_accuracy: valid for TYPE=HORIZONTAL_OFFSET. Sample values should be the accuracy of corresponding longitude_offset samples. Generally in metre (if converted from NTv2)

- The sign convention for the values of the longitude_offset channel should be indicated with an Item named positive_value whose value can be west or east. NTv2 products originally use a west convention, but when converting from them to GeoTIFF, the sign of those samples will be inverted so they use a more natural east convention. If this item is absent, the default value is east.

- The unit of the values stored in the grid must be specified for each sample through an Item of name UNITTYPE and role unittype Valid values should be the name of entries from the EPSG unitofmeasure table. To maximize interoperability, writers are strongly encouraged to limit themselves to the following values:

For linear units:

* metre (default value assumed if absent for vertical shift grid files, and value used for files stored on PROJ CDN)

* US survey foot

For angular units:

* degree

* arc-second (default value assumed if absent for longitude and latitude offset samples of horizontal shift grid files, and value used for files stored on PROJ CDN)

* arc-seconds per year (when used with the Horizontal grid shift method with temporal gridshifting)
For velocity units:

* millimetres per year

The longitude and latitude offset samples should use the same unit. The geocentric translation samples should use the same unit. The velocity samples should use the same unit.

Example:

```xml
<Item name="UNITTYPE" sample="0" role="unittype">arc-second</Item>
<Item name="UNITTYPE" sample="1" role="unittype">arc-second</Item>
```

- For TYPE=DEFORMATION_MODEL, the type of the displacement must be specified with a Item whose name is set to DISPLACEMENT_TYPE.

  The accepted values are: HORIZONTAL, VERTICAL, 3D or NONE

- For TYPE=DEFORMATION_MODEL, the type of the uncertainty must be specified with a Item whose name is set to UNCERTAINTY_TYPE.

  The accepted values are: HORIZONTAL, VERTICAL, 3D or NONE

- The target_crs_epsg_code metadata item should be present. For a horizontal shift grid, this is the EPSG code of the target geographic CRS. For a vertical shift grid, this is the EPSG code of a target vertical CRS. If the target CRS has no associated EPSG code, target_crs_wkt must be used. Ignored by PROJ currently.

- The target_crs_wkt metadata item must be present if the target_crs_epsg_code cannot be used. Its value should be a valid WKT string according to WKT:2015 or WKT:2019 Ignored by PROJ currently.

- The source_crs_epsg_code metadata item must be present if the source and interpolation CRS are not the same (typical use case is vertical CRS to vertical CRS transformation), because the GeoKeys encode the interpolation CRS and not the source CRS. If the source CRS has no associated EPSG code, source_crs_wkt must be used. Ignored by PROJ currently.

- The source_crs_wkt metadata item must be present if the source_crs_epsg_code cannot be used. Its value should be a valid WKT string according to WKT:2015 or WKT:2019. Ignored by PROJ currently.

- The interpolation_crs_wkt metadata item may be present if the GeoKeys cannot be used to express reliably the interpolation CRS. Its value should be a valid WKT string according to WKT:2015 or WKT:2019. Ignored by PROJ currently.

- The recommended_interpolation_method metadata item may be present to describe the method to use to interpolation values at locations not coincident with nodes stored in the grid file. Potential values: bilinear, bicubic. Ignored by PROJ currently.

- The area_of_use metadata item can be used to indicate plain text information about the area of use of the grid (like "USA - Wisconsin"). In case of multiple subgrids, it should be set only on the first one, but applies to the whole set of grids, not just the first one.

- The grid_name metadata item should be present if there are subgrids for this grid (that is grids whose extent is contained in the extent of this grid), or if this is a subgrid. It is intended to be a relatively short identifier Will be ignored by PROJ (this information can be inferred by the grids extent)

- The parent_grid_name metadata item should be present if this is a subgrid and its value should be equal to the parent's grid_name Will be ignored by PROJ (this information can be inferred by the grids extent)

- The number_of_nested_grids metadata item should be present if there are subgrids for this grid (that is grids whose extent is contained in the extent of this grid). Will be ignored by PROJ (this information can be inferred by the grids extent)

- The interpolation_method metadata item may be present to indicate the interpolation method to apply. bilinear or biquadratic are supported. If not specified, defaults to bilinear.
### 11.2.3 Example


```bash
$ tiffinfo ntf_r93.tif
```

```
TIFF Directory at offset 0x4e (78)
Image Width: 156 Image Length: 111
Bits/Sample: 32
Sample Format: IEEE floating point
Compression Scheme: AdobeDeflate
Photometric Interpretation: min-is-black
Extra Samples: 3<unspecified, unspecified, unspecified>
Samples/Pixel: 4
Rows/Strip: 111
Planar Configuration: separate image planes
ImageDescription: NTF (EPSG:4275) to RGF93 (EPSG:4171). Converted from ntf_r93.gsb
  → (version IGN07_01, last updated on 2007-10-31)
DateTime: 2019:12:09 00:00:00
Copyright: Derived from work by IGN France. Open License https://www.etalab.gouv.fr/wp-
  → content/uploads/2014/05/Open_Licence.pdf
Tag 33550: 0.100000,0.100000,0.000000
Tag 33922: 0.000000,0.000000,-5.500000,52.000000,0.000000
Tag 34735: 1,1,1,3,1024,0,1,2,1025,0,1,2,2048,0,1,4275
Tag 42112: <GDALMetadata>
  <Item name="grid_name">FRANCE</Item>
  <Item name="target_crs_epsg_code">4171</Item>
  <Item name="TYPE">HORIZONTAL_OFFSET</Item>
  <Item name="UNITTYPE" sample="0" role="unittype">arc-second</Item>
  <Item name="DESCRIPTION" sample="0" role="description">latitude_offset</Item>
  <Item name="positive_value" sample="1">east</Item>
  <Item name="UNITTYPE" sample="1" role="unittype">arc-second</Item>
  <Item name="DESCRIPTION" sample="1" role="description">longitude_offset</Item>
  <Item name="UNITTYPE" sample="2" role="unittype">arc-second</Item>
  <Item name="DESCRIPTION" sample="2" role="description">latitude_offset_accuracy</Item>
  <Item name="UNITTYPE" sample="3" role="unittype">arc-second</Item>
  <Item name="DESCRIPTION" sample="3" role="description">longitude_offset_accuracy</Item>
</GDALMetadata>
Predictor: floating point predictor 3 (0x3)
```

```bash
$ listgeo ntf_r93.tif
```

```
Geotiff_Information:
  Version: 1
  Key_Revision: 1.1
  Tagged_Information:
    ModelTiepointTag (2,3):
      0 0 0
      -5.5 52 0
    ModelPixelScaleTag (1,3):
```

(continues on next page)
PROJ coordinate transformation software library, Release 9.3.1

11.2. Geodetic TIFF grids (GTG)
11.2.4 Multi-grid storage

Formats like NTv2 can contain multiple subgrids. This can be transposed to TIFF by using several IFD chained together with the last 4 bytes (or 8 bytes for BigTIFF) of an IFD pointing to the offset of the next one.

The first IFD should have a full description according to the General description. Subsequent IFD might have a more compact description, omitting for example, CRS information if it is identical to the main IFD (which should be the case for the currently envisionned use cases), or Copyright / ImageDescription metadata items.

Each IFD will have its NewSubfileType tag set to 0.

If a low-resolution grid is available, it should be put before subgrids of higher-resolution in the chain of IFD linking. On reading, PROJ will use the value from the highest-resolution grid that contains the point of interest.

For efficient reading from the network, files hosted on the CDN will use a layout similar to the one described in the low level paragraph of the Cloud Optimized GeoTIFF GDAL driver page.

The layout for a file converted from NTv2 will for example be:

- TIFF/BigTIFF header/signature and pointer to first IFD (Image File Directory)
- "ghost area" indicating the generated process
- IFD of the first grid, followed by TIFF tags values, excluding the TileOffsets and TileByteCounts arrays
- ...  
- IFD of the last grid, followed by TIFF tags values, excluding the GDAL_METADATA tag, TileOffsets and TileByteCounts arrays
- TileOffsets and TileByteCounts arrays for first IFD
• TileOffsets and TileByteCounts arrays for last IFD
• Value of GDAL_METADATA tag for IFDs following the first IFD
• First IFD: Data corresponding to latitude offset of Block_0_0
• First IFD: Data corresponding to longitude offset of Block_0_0
• First IFD: Data corresponding to latitude offset of Block_0_1
• First IFD: Data corresponding to longitude offset of Block_0_1
• ...
• First IFD: Data corresponding to latitude offset of Block_n_m
• First IFD: Data corresponding to longitude offset of Block_n_m
• ...
• Last IFD: Data corresponding to latitude offset of Block_0_0
• Last IFD: Data corresponding to longitude offset of Block_0_0
• Last IFD: Data corresponding to latitude offset of Block_0_1
• Last IFD: Data corresponding to longitude offset of Block_0_1
• ...
• Last IFD: Data corresponding to latitude offset of Block_n_m
• Last IFD: Data corresponding to longitude offset of Block_n_m

If longitude_offset_accuracy and latitude_offset_accuracy are present, this will be followed by:
• First IFD: Data corresponding to latitude offset accuracy of Block_0_0
• First IFD: Data corresponding to longitude offset accuracy of Block_0_0
• ...
• First IFD: Data corresponding to latitude offset accuracy of Block_n_m
• First IFD: Data corresponding to longitude offset accuracy of Block_n_m
• ...
• Last IFD: Data corresponding to latitude offset accuracy of Block_0_0
• Last IFD: Data corresponding to longitude offset accuracy of Block_0_0
• ...
• Last IFD: Data corresponding to latitude offset accuracy of Block_n_m
• Last IFD: Data corresponding to longitude offset accuracy of Block_n_m

**Note:** TIFF has another mechanism to link IFDs, the SubIFD tag. This potentially enables to define a hierarchy of IFDs (similar to HDF5 groups). There is no support for that in most TIFF-using software, notably GDAL, and no compelling need to have a nested hierarchy, so "flat" organization with the standard IFD chaining mechanism is adopted.
11.2.5 Examples of multi-grid dataset


It contains 5 subgrids. All essential metadata to list the subgrids and their georeferencing is contained within the first 3 KB of the file.

The file size is 4.8 MB using DEFLATE compression and floating-point predictor. It results from a lossless conversion from the 83 MB of the original .gsb file.

https://github.com/OSGeo/PROJ-data/blob/master/ca_nrc/ca_nrc_ntv2_0.tif has been converted from https://github.com/OSGeo/proj-datumgrid/blob/master/north-america/ntv2_0.gsb

It contains 114 subgrids. All essential metadata to list the subgrids and their georeferencing is contained within the first 40 KB of the file.

11.2.6 Revisions

- v0.3: addition of TYPE=GEOGRAPHIC_3D_OFFSET, ELLIPSOIDAL_HEIGHT_OFFSET and interpolation_method (PROJ 9.2)
- v0.2: addition of "arc-seconds per year" as a valid unit (PROJ 9.1.1)
- v0.1: initial version for PROJ 7.0
The PROJ community is what makes the software stand out from its competitors. PROJ is used and developed by a group of very enthusiastic, knowledgeable and friendly people. Whether you are a first time user of PROJ or a long-time contributor the community is always very welcoming.

12.1 Communication channels

12.1.1 Mailing list

Users and developers of the library are using the mailing list to discuss all things related to PROJ. The mailing list is the primary forum for asking for help with use of PROJ. The mailing list is also used for announcements, discussions about the development of the library and from time to time interesting discussions on geodesy appear as well. You are more than welcome to join in on the discussions!

The PROJ mailing list can be found at https://lists.osgeo.org/mailman/listinfo/proj

12.1.2 GitHub

GitHub is the development platform we use for collaborating on the PROJ code. We use GitHub to keep track of the changes in the code and to index bug reports and feature requests. We are happy to take contributions in any form, either as code, bug reports, documentation or feature requests. See Contributing for more info on how you can help improve PROJ.

The PROJ GitHub page can be found at https://github.com/OSGeo/PROJ

Note: The issue tracker on GitHub is only meant to keep track of bugs, feature request and other things related to the development of PROJ. Please ask your questions about the use of PROJ on the mailing list instead.

12.1.3 Gitter

Gitter is the instant messaging alternative to the mailing list. PROJ has a room under the OSGeo organization. Most of the core developers stop by from time to time for an informal chat. You are more than welcome to join the discussion.

The Gitter room can be found at https://gitter.im/OSGeo/proj.4
12.2 Contributing

PROJ has a wide and varied user base. Some are highly skilled geodesists with a deep knowledge of map projections and reference systems, some are GIS software developers and others are GIS users. All users, regardless of the profession or skill level, has the ability to contribute to PROJ. Here’s a few suggestion on how:

- Help PROJ-users that is less experienced than yourself.
- Write a bug report
- Request a new feature
- Write documentation for your favorite map projection
- Fix a bug
- Implement a new feature

In the following sections you can find some guidelines on how to contribute. As PROJ is managed on GitHub most contributions require that you have a GitHub account. Familiarity with issues and the GitHub Flow is an advantage.

12.2.1 Help a fellow PROJ user

The main forum for support for PROJ is the mailing list. You can subscribe to the mailing list here and read the archive here.

If you have questions about the usage of PROJ the mailing list is also the place to go. Please do not use the GitHub issue tracker as a support forum. Your question is much more likely to be answered on the mailing list, as many more people follow that than the issue tracker.

12.2.2 Adding bug reports

Bug reports are handled in the issue tracker on PROJ’s home on GitHub. Writing a good bug report is not easy. But fixing a poorly documented bug is not easy either, so please put in the effort it takes to create a thorough bug report.

A good bug report includes at least:

- A title that quickly explains the problem
- A description of the problem and how it can be reproduced
- Version of PROJ being used
- Version numbers of any other relevant software being used, e.g. operating system
- A description of what already has been done to solve the problem

The more information that is given up front, the more likely it is that a developer will find interest in solving the problem. You will probably get follow-up questions after submitting a bug report. Please answer them in a timely manner if you have an interest in getting the issue solved.

Finally, please only submit bug reports that are actually related to PROJ. If the issue materializes in software that uses PROJ it is likely a problem with that particular software. Make sure that it actually is a PROJ problem before you submit an issue. If you can reproduce the problem only by using tools from PROJ it is definitely a problem with PROJ.
12.2.3 Feature requests

Got an idea for a new feature in PROJ? Submit a thorough description of the new feature in the issue tracker. Please include any technical documents that can help the developer make the new feature a reality. An example of this could be a publicly available academic paper that describes a new projection. Also, including a numerical test case will make it much easier to verify that an implementation of your requested feature actually works as you expect.

Note that not all feature requests are accepted.

12.2.4 Write documentation

PROJ is in dire need of better documentation. Any contributions of documentation are greatly appreciated. The PROJ documentation is available on proj.org. The website is generated with Sphinx. Contributions to the documentation should be made as Pull Requests on GitHub.

If you intend to document one of PROJ’s supported projections please use the Mercator projection as a template.

12.2.5 Code contributions

See Code contributions

12.2.5.1 Legalese

Committers are the front line gatekeepers to keep the code base clear of improperly contributed code. It is important to the PROJ users, developers and the OSGeo foundation to avoid contributing any code to the project without it being clearly licensed under the project license.

Generally speaking the key issues are that those providing code to be included in the repository understand that the code will be released under the MIT/X license, and that the person providing the code has the right to contribute the code. For the committer themselves understanding about the license is hopefully clear. For other contributors, the committer should verify the understanding unless the committer is very comfortable that the contributor understands the license (for instance frequent contributors).

If the contribution was developed on behalf of an employer (on work time, as part of a work project, etc) then it is important that an appropriate representative of the employer understand that the code will be contributed under the MIT/X license. The arrangement should be cleared with an authorized supervisor/manager, etc.

The code should be developed by the contributor, or the code should be from a source which can be rightfully contributed such as from the public domain, or from an open source project under a compatible license.

All unusual situations need to be discussed and/or documented.

Committers should adhere to the following guidelines, and may be personally legally liable for improperly contributing code to the source repository:

- Make sure the contributor (and possibly employer) is aware of the contribution terms.
- Code coming from a source other than the contributor (such as adapted from another project) should be clearly marked as to the original source, copyright holders, license terms and so forth. This information can be in the file headers, but should also be added to the project licensing file if not exactly matching normal project licensing (COPYING).
- Existing copyright headers and license text should never be stripped from a file. If a copyright holder wishes to give up copyright they must do so in writing to the foundation before copyright messages are removed. If license terms are changed it has to be by agreement (written in email is ok) of the copyright holders.
- Code with licenses requiring credit, or disclosure to users should be added to COPYING.
• When substantial contributions are added to a file (such as substantial patches) the author/contributor should be added to the list of copyright holders for the file.

• If there is uncertainty about whether a change is proper to contribute to the code base, please seek more information from the project steering committee, or the foundation legal counsel.

12.2.6 Additional Resources

• General GitHub documentation
• GitHub pull request documentation

12.2.7 Acknowledgements

The code contribution section of this CONTRIBUTING file is inspired by PDAL’s and the legalese section is modified from GDAL committer guidelines.

12.3 Guidelines for PROJ code contributors

This is a guide for PROJ, casual or regular, code contributors.

12.3.1 Code contributions.

Code contributions can be either bug fixes or new features. The process is the same for both, so they will be discussed together in this section.

12.3.1.1 Making Changes

• Create a topic branch from where you want to base your work.
• You usually should base your topic branch off of the master branch.
• To quickly create a topic branch: `git checkout -b my-topic-branch`
• Make commits of logical units.
• Check for unnecessary whitespace with `git diff --check` before committing.
• Make sure your commit messages are in the proper format.
• Make sure you have added the necessary tests for your changes.
• Make sure that all tests pass
12.3.1.2 Submitting Changes

- Push your changes to a topic branch in your fork of the repository.
- Submit a pull request to the PROJ repository in the OSGeo organization.
- If your pull request fixes/references an issue, include that issue number in the pull request. For example:

```
Wiz the bang
Fixes #123.
```

- PROJ developers will look at your patch and take an appropriate action.

12.3.1.3 Coding conventions

**Programming language**

PROJ was originally developed in ANSI C. Today PROJ is mostly developed in C++11, with a few parts of the code base still being C. Most of the older parts of the code base is effectively C with a few modifications so that it compiles better as C++.

**Coding style**

The parts of the code base that has started its life as C++ is formatted with `clang-format` using the script `scripts/reformat_cpp.sh`. This is mostly contained to the code in `src/iso19111/` but a few other `.cpp`-files are covered as well.

For the rest of the code base, which has its origin in C, we don't enforce any particular coding style, but please try to keep it as simple as possible. If improving existing code, please try to conform with the style of the locally surrounding code.

**Whitespace**

Throughout the PROJ code base you will see differing whitespace use. The general rule is to keep whitespace in whatever form it is in the file you are currently editing. If the file has a mix of tabs and space please convert the tabs to space in a separate commit before making any other changes. This makes it a lot easier to see the changes in diffs when evaluating the changed code. New files should use spaces as whitespace.

12.3.2 Tools

12.3.2.1 Reformatting C++ code

The script in `scripts/reformat_cpp.sh` will reformat C++ code in accordance to the project preference.

If you are writing a new `.cpp`-file it should be added to the list in the reformatting script.
12.3.2.2 cppcheck static analyzer

You can run locally scripts/cppcheck.sh that is a wrapper script around the cppcheck utility. This tool is used as part of the quality control of the code.

cppcheck can have false positives. In general, it is preferable to rework the code a bit to make it more 'obvious' and avoid those false positives. When not possible, you can add a comment in the code like

```c
/* cppcheck-suppress duplicateBreak */
```

in the preceding line. Replace duplicateBreak with the actual name of the violated rule emitted by cppcheck.

12.3.2.3 Clang Static Analyzer (CSA)

CSA is run by a GitHub Actions workflow. You may also run it locally.

Preliminary step: install clang tools. For example, on a Debian-like OS:

```bash
sudo apt install clang-tools libfindbin-libs-perl
```

Configure PROJ with the `scan-build` utility of clang:

```
mkdir csa_build
cd csa_build
scan-build cmake ..
```

Build using `scan-build`:

```bash
scan-build make [-j8]
```

If CSA finds errors, they will be emitted during the build. And in which case, at the end of the build process, `scan-build` will emit a warning message indicating errors have been found and how to display the error report. This is with something like

```bash
scan-view /tmp/scan-build-2021-03-15-121416-17476-1
```

This will open a web browser with the interactive report.

CSA may also have false positives. In general, this happens when the code is non-trivial / makes assumptions that hard to check at first sight. You will need to add extra checks or rework it a bit to make it more "obvious" for CSA. This will also help humans reading your code !

12.3.2.4 Typo detection and fixes

Run scripts/fix_typos.sh
12.3.2.5 Include What You Use (IWYU)

Managing C includes is a pain. IWYU makes updating headers a bit easier. IWYU scans the code for functions that are called and makes sure that the headers for all those functions are present and in sorted order. However, you cannot blindly apply IWYU to PROJ. It does not understand ifdefs, other platforms, or the order requirements of PROJ internal headers. So the way to use it is to run it on a copy of the source and merge in only the changes that make sense. Additions of standard headers should always be safe to merge. The rest require careful evaluation. See the IWYU documentation for motivation and details.

IWYU docs

12.4 Code of Conduct

The PROJ project has adopted the Contributor Covenant Code of Conduct. Everyone who participates in the PROJ community is expected to follow the code of conduct as written below.

12.4.1 Our Pledge

In the interest of fostering an open and welcoming environment, we as contributors and maintainers pledge to make participation in our project and our community a harassment-free experience for everyone, regardless of age, body size, disability, ethnicity, sex characteristics, gender identity and expression, level of experience, education, socio-economic status, nationality, personal appearance, race, religion, or sexual identity and orientation.

12.4.2 Our Standards

Examples of behavior that contributes to creating a positive environment include:

- Using welcoming and inclusive language
- Being respectful of differing viewpoints and experiences
- Gracefully accepting constructive criticism
- Focusing on what is best for the community
- Showing empathy towards other community members

Examples of unacceptable behavior by participants include:

- The use of sexualized language or imagery and unwelcome sexual attention or advances
- Trolling, insulting/derogatory comments, and personal or political attacks
- Public or private harassment
- Publishing others’ private information, such as a physical or electronic address, without explicit permission
- Other conduct which could reasonably be considered inappropriate in a professional setting
12.4.3 Our Responsibilities

Project maintainers are responsible for clarifying the standards of acceptable behavior and are expected to take appropriate and fair corrective action in response to any instances of unacceptable behavior.

Project maintainers have the right and responsibility to remove, edit, or reject comments, commits, code, wiki edits, issues, and other contributions that are not aligned to this Code of Conduct, or to ban temporarily or permanently any contributor for other behaviors that they deem inappropriate, threatening, offensive, or harmful.

12.4.4 Scope

This Code of Conduct applies within all project spaces, and it also applies when an individual is representing the project or its community in public spaces. Examples of representing a project or community include using an official project e-mail address, posting via an official social media account, or acting as an appointed representative at an online or offline event. Representation of a project may be further defined and clarified by project maintainers.

12.4.5 Enforcement

Instances of abusive, harassing, or otherwise unacceptable behavior may be reported by contacting the project team at kristianevers@gmail.com. All complaints will be reviewed and investigated and will result in a response that is deemed necessary and appropriate to the circumstances. The project team is obligated to maintain confidentiality with regard to the reporter of an incident. Further details of specific enforcement policies may be posted separately.

Project maintainers who do not follow or enforce the Code of Conduct in good faith may face temporary or permanent repercussions as determined by other members of the project's leadership.

12.4.6 Attribution

This Code of Conduct is adapted from the Contributor Covenant, version 1.4, available at https://www.contributor-covenant.org/version/1/4/code-of-conduct.html

For answers to common questions about this code of conduct, see https://www.contributor-covenant.org/faq

12.5 Request for Comments

A PROJ RFC describes a major change in the technological underpinnings of PROJ, major additions to functionality, or changes in the direction of the project.

12.5.1 PROJ RFC 1: Project Committee Guidelines

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Status
Passed

Last Updated
2018-06-08
12.5.1.1 Summary

This document describes how the PROJ Project Steering Committee (PSC) determines membership, and makes decisions on all aspects of the PROJ project - both technical and non-technical.

Examples of PSC management responsibilities:

- setting the overall development road map
- developing technical standards and policies (e.g. coding standards, file naming conventions, etc...)
- ensuring regular releases (major and maintenance) of PROJ software
- reviewing RFC for technical enhancements to the software
- project infrastructure (e.g. GitHub, continuous integration hosting options, etc...)
- formalization of affiliation with external entities such as OSGeo
- setting project priorities, especially with respect to project sponsorship
- creation and oversight of specialized sub-committees (e.g. project infrastructure, training)

In brief the project team votes on proposals on the proj mailing list. Proposals are available for review for at least two days, and a single veto is sufficient delay progress though ultimately a majority of members can pass a proposal.

12.5.1.2 List of PSC Members

(up-to-date as of 2023-09)

- Kristian Evers @kbevers (DK) Chair
- Howard Butler @hobu (USA)
- Charles Karney @cffk (USA)
- Thomas Knudsen @busstoptaktik (DK)
- Even Rouault @rouault (FR)
- Kurt Schwehr @schwehr (USA)
- Alan Snow @snowman2 (USA)
- Javier Jimenez Shaw @jjimenezshaw (ES)
- Frank Warmerdam @warmerdam (USA) Emeritus

12.5.1.3 Detailed Process

- Proposals are written up and submitted on the proj mailing list for discussion and voting, by any interested party, not just committee members.
- Proposals need to be available for review for at least two business days before a final decision can be made.
- Respondents may vote "+1" to indicate support for the proposal and a willingness to support implementation.
- Respondents may vote "-1" to veto a proposal, but must provide clear reasoning and alternate approaches to resolving the problem within the two days.
- A vote of -0 indicates mild disagreement, but has no effect. A 0 indicates no opinion. A +0 indicate mild support, but has no effect.
• Anyone may comment on proposals on the list, but only members of the Project Steering Committee’s votes will be counted.

• A proposal will be accepted if it receives +2 (including the author) and no vetoes (-1).

• If a proposal is vetoed, and it cannot be revised to satisfy all parties, then it can be resubmitted for an override vote in which a majority of all eligible voters indicating +1 is sufficient to pass it. Note that this is a majority of all committee members, not just those who actively vote.

• Upon completion of discussion and voting the author should announce whether they are proceeding (proposal accepted) or are withdrawing their proposal (vetoed).

• The Chair gets a vote.

• The Chair is responsible for keeping track of who is a member of the Project Steering Committee (perhaps as part of a PSC file in CVS).

• Addition and removal of members from the committee, as well as selection of a Chair should be handled as a proposal to the committee.

• The Chair adjudicates in cases of disputes about voting.

RFC Origin

PROJ RFC and Project Steering Committee is derived from similar governance bodies in both the GDAL and MapServer software projects.

12.5.1.4 When is Vote Required?

• Any change to committee membership (new members, removing inactive members)

• Changes to project infrastructure (e.g. tool, location or substantive configuration)

• Anything that could cause backward compatibility issues.

• Adding substantial amounts of new code.

• Changing inter-subsystem APIs, or objects.

• Issues of procedure.

• When releases should take place.

• Anything dealing with relationships with external entities such as OSGeo

• Anything that might be controversial.

12.5.1.5 Observations

• The Chair is the ultimate adjudicator if things break down.

• The absolute majority rule can be used to override an obstructionist veto, but it is intended that in normal circumstances vetoers need to be convinced to withdraw their veto. We are trying to reach consensus.
12.5.1.6 Committee Membership

The PSC is made up of individuals consisting of technical contributors (e.g. developers) and prominent members of the PROJ user community. There is no set number of members for the PSC although the initial desire is to set the membership at 6.

Adding Members

Any member of the proj mailing list may nominate someone for committee membership at any time. Only existing PSC committee members may vote on new members. Nominees must receive a majority vote from existing members to be added to the PSC.

Stepping Down

If for any reason a PSC member is not able to fully participate then they certainly are free to step down. If a member is not active (e.g. no voting, no IRC or email participation) for a period of two months then the committee reserves the right to seek nominations to fill that position. Should that person become active again (hey, it happens) then they would certainly be welcome, but would require a nomination.

12.5.1.7 Membership Responsibilities

Guiding Development

Members should take an active role guiding the development of new features they feel passionate about. Once a change request has been accepted and given a green light to proceed does not mean the members are free of their obligation. PSC members voting "+1" for a change request are expected to stay engaged and ensure the change is implemented and documented in a way that is most beneficial to users. Note that this applies not only to change requests that affect code, but also those that affect the web site, technical infrastructure, policies and standards.

Mailing List Participation

PSC members are expected to be active on the proj mailing list, subject to Open Source mailing list etiquette. Non-developer members of the PSC are not expected to respond to coding level questions on the developer mailing list, however they are expected to provide their thoughts and opinions on user level requirements and compatibility issues when RFC discussions take place.

12.5.1.8 Updates

June 2018

RFC 1 was ratified by the following members
12.5.2 PROJ RFC 2: Initial integration of "GDAL SRS barn" work

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Status
Adopted, implemented in PROJ 6.0

Initial version
2018-10-09

Last Updated
2018-10-31

12.5.2.1 Summary

This RFC is the result of a first phase of the GDAL Coordinate System Barn Raising efforts. In its current state, this work mostly consists of:

- a C++ implementation of the ISO-19111:2018 / OGC Topic 2 "Referencing by coordinates" classes to represent Datums, Coordinate systems, CRSs (Coordinate Reference Systems) and Coordinate Operations.
- methods to convert between this C++ modeling and WKT1, WKT2 and PROJ string representations of those objects
- management and query of a SQLite3 database of CRS and Coordinate Operation definition
- a C API binding part of those capabilities

12.5.2.2 Related standards

Consult Applicable standards
(They will be linked from the PROJ documentation)

12.5.2.3 Details

Structure in packages / namespaces

The C++ implementation of the (upcoming) ISO-19111:2018 / OGC Topic 2 "Referencing by coordinates" classes follows this abstract modeling as much as possible, using package names as C++ namespaces, abstract classes and method names. A new BoundCRS class has been added to cover the modeling of the WKT2 BoundCRS construct, that is a generalization of the WKT1 TOWGS84 concept. It is strongly recommended to have the ISO-19111 standard open to have an introduction for the concepts when looking at the code. A few classes have also been inspired by the GeoAPI

The classes are organized into several namespaces:

- osgeo::proj::util
  A set of base types from ISO 19103, GeoAPI and other PROJ "technical" specific classes
  
  Template optional<T>, classes BaseObject, IComparable, BoxedValue, ArrayOfBaseObject, PropertyMap, LocalName, NameSpace, GenericName, NameFactory, CodeList, Exception, InvalidValueTypeException, UnsupportedOperationException
• **osgeo::proj::metadata:**  
  Common classes from ISO 19115 (Metadata) standard  
  Classes Citation, GeographicExtent, GeographicBoundingBox, TemporalExtent, VerticalExtent, Extent, Identifier, PositionalAccuracy,

• **osgeo::proj::common:**  
  Common classes: UnitOfMeasure, Measure, Scale, Angle, Length, DateTime, DateEpoch, IdentifiedObject, ObjectDomain, ObjectUsage

• **osgeo::proj::cs:**  
  Coordinate systems and their axis  

• **osgeo::proj::datum:**  
  Datum (the relationship of a coordinate system to the body)  

• **osgeo::proj::crs:**  
  CRS = coordinate reference system = coordinate system with a datum  
  Classes CRS, GeodeticCRS, GeographicCRS, DerivedCRS, ProjectedCRS, VerticalCRS, CompoundCRS, BoundCRS, TemporalCRS, EngineeringCRS, ParametricCRS, DerivedGeodeticCRS, DerivedGeographicCRS, DerivedProjectedCRS, DerivedVerticalCRS

• **osgeo::proj::operation:**  
  Coordinate operations (relationship between any two coordinate reference systems)  

• **osgeo::proj::io:**  
  I/O classes: WKTFormatter, PROJStringFormatter, FormattingException, ParsingException, IWKTFexportable, IPROJStringExportable, WKTFNode, WKTParser, PROJStringParser, DatabaseContext, AuthorityFactory, FactoryException, NoSuchAuthorityCodeException

**What does what?**

The code to parse WKT and PROJ strings and build ISO-19111 objects is contained in `io.cpp`  
The code to format WKT and PROJ strings from ISO-19111 objects is mostly contained in the related `exportToWKT()` and `exportToPROJString()` methods overridden in the applicable classes. `io.cpp` contains the general mechanics to build such strings.

Regarding WKT strings, three variants are handled in import and export:  
- **WKT2_2018**: variant corresponding to the upcoming ISO-19162:2018 standard  
- **WKT2_2015**: variant corresponding to the current ISO-19162:2015 standard  
- **WKT1_GDAL**: variant corresponding to the way GDAL understands the OGC 01-099 and OGC 99-049 standards

Regarding PROJ strings, two variants are handled in import and export:
PROJ coordinate transformation software library, Release 9.3.1

• PROJ5: variant used by PROJ >= 5, possibly using pipeline constructs, and avoiding +towgs84 / +nadgrids legacy constructs. This variant honours axis order and input/output units. That is the pipeline for the conversion of EPSG:4326 to EPSG:32631 will assume that the input coordinates are in latitude, longitude order, with degrees.

• PROJ4: variant used by PROJ 4.x

The raw query of the proj.db database and the upper level construction of ISO-19111 objects from the database contents is done in factory.cpp

A few design principles

Methods generally take and return xxxNNPtr objects, that is non-null shared pointers (pointers with internal reference counting). The advantage of this approach is that the user has not to care about the life-cycle of the instances (and this makes the code leak-free by design). The only point of attention is to make sure no reference cycles are made. This is the case for all classes, except the CoordinateOperation class that point to CRS for sourceCRS and targetCRS members, whereas DerivedCRS point to a Conversion instance (which derives from CoordinateOperation). This issue was detected in the ISO-19111 standard. The solution adopted here is to use std::weak_ptr in the CoordinateOperation class to avoid the cycle. This design artifact is transparent to users.

Another important design point is that all ISO19111 objects are immutable after creation, that is they only have getters that do not modify their states. Consequently they could possibly use in a thread-safe way. There are however classes like PROJStringFormatter, WKTFormatter, DatabaseContext, AuthorityFactory and CoordinateOperationContext whose instances are mutable and thus can not be used by multiple threads at once.

Example how to build the EPSG:4326 / WGS84 Geographic2D definition from scratch:

```cpp
auto greenwich = PrimeMeridian::create(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 8901)
        .set(common::IdentifiedObject::NAME_KEY, "Greenwich"),
    common::Angle(0));
// actually predefined as PrimeMeridian::GREENWICH constant

auto ellipsoid = Ellipsoid::createFlattenedSphere(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 7030)
        .set(common::IdentifiedObject::NAME_KEY, "WGS 84"),
    common::Length(6378137),
    common::Scale(298.257223563));
// actually predefined as Ellipsoid::WGS84 constant

auto datum = GeodeticReferenceFrame::create(
    util::PropertyMap()
        .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
        .set(metadata::Identifier::CODE_KEY, 6326)
        .set(common::IdentifiedObject::NAME_KEY, "World Geodetic System 1984"),
    ellipsoid
    util::optional<std::string>(), // anchor
    greenwich);
// actually predefined as GeodeticReferenceFrame::EPSG_6326 constant
```

(continues on next page)
auto geogCRS = GeographicCRS::create(
    util::PropertyMap()
    .set(metadata::Identifier::CODESPACE_KEY, metadata::Identifier::EPSG)
    .set(metadata::Identifier::CODE_KEY, 4326)
    .set(common::IdentifiedObject::NAME_KEY, "WGS 84"),
    datum,
    cs::EllipsoidalCS::createLatitudeLongitude(scommon::UnitOfMeasure::DEGREE));

// actually predefined as GeographicCRS::EPSG_4326 constant

**Algorithmic focus**

On the algorithmic side, a somewhat involved logic is the CoordinateOperationFactory::createOperations() in coordinateoperation.cpp that takes a pair of source and target CRS and returns a set of possible coordinate operations (either single operations like a Conversion or a Transformation, or concatenated operations). It uses the intrinsic structure of those objects to create the coordinate operation pipeline. That is, if going from a ProjectedCRS to another one, by doing first the inverse conversion from the source ProjectedCRS to its base GeographicCRS, then finding the appropriate transformation(s) from this base GeographicCRS to the base GeographicCRS of the target CRS, and then applying the conversion from this base GeographicCRS to the target ProjectedCRS. At each step, it queries the database to find if one or several transformations are available. The resulting coordinate operations are filtered, and sorted, with user provided hints:

- desired accuracy
- area of use, defined as a bounding box in longitude, latitude space (its actual CRS does not matter for the intended use)
- if no area of use is defined, if and how the area of use of the source and target CRS should be used. By default, the smallest area of use is used. The rationale is for example when transforming between a national ProjectedCRS and a world-scope GeographicCRS to use the area of use of this ProjectedCRS to select the appropriate datum shifts.
- how the area of use of the candidate transformations and the desired area of use (either explicitly or implicitly defined, as explained above) are compared. By default, only transformations whose area of use is fully contained in the desired area of use are selected. It is also possible to relax this test by specifying that only an intersection test must be used.
- whether PROJ transformation grid names should be substituted to the official names, when a match is found in the grid_alternatives table of the database. Defaults to true
- whether the availability of those grids should be used to filter and sort the results. By default, the transformations using grids available in the system will be presented first.

The results are sorted, with the most relevant ones appearing first in the result vector. The criteria used are in that order

- grid actual availability: operations referencing grids not available will be listed after ones with available grids
- grid potential availability: operation referencing grids not known at all in the proj.db will be listed after operations with grids known, but not available.
- known accuracy: operations with unknown accuracies will be listed after operations with known accuracy
- area of use: operations with smaller area of use (the intersection of the operation area of used with the desired area of use) will be listed after the ones with larger area of use
- accuracy: operations with lower accuracy will be listed after operations with higher accuracy (caution: lower accuracy actually means a higher numeric value of the accuracy property, since it is a precision in metre)
All those settings can be specified in the CoordinateOperationContext instance passed to createOperations().

An interesting example to understand how those parameters play together is to use `projinfo -s EPSG:4267 -t EPSG:4326` (NAD27 to WGS84 conversions), and see how specifying desired area of use, spatial criterion, grid availability, etc. affects the results.

The following command currently returns 78 results:

```
projinfo -s EPSG:4267 -t EPSG:4326 --summary --spatial-test intersects
```

The createOperations() algorithm also does a kind of "CRS routing". A typical example is if wanting to transform between CRS A and CRS B, but no direct transformation is referenced in proj.db between those. But if there are transformations between A --> C and B --> C, then it is possible to build a concatenated operation A --> C --> B. The typical example is when C is WGS84, but the implementation is generic and just finds a common pivot from the database. An example of finding a non-WGS84 pivot is when searching a transformation between EPSG:4326 and EPSG:6668 (JGD2011 - Japanese Geodetic Datum 2011), which has no direct transformation registered in the EPSG database. However there are transformations between those two CRS and JGD2000 (and also Tokyo datum, but that one involves less accurate transformations)

```
projinfo -s EPSG:4326 -t EPSG:6668 --grid-check none --bbox 135.42,34.84,142.14,41.58 --summary
```

Candidate operations found: 7
unknown id, Inverse of JGD2000 to WGS 84 (1) + JGD2000 to JGD2011 (1), 1.2 m, Japan - northern Honshu
unknown id, Inverse of JGD2000 to WGS 84 (1) + JGD2000 to JGD2011 (2), 2 m, Japan - excluding northern main province
unknown id, Inverse of Tokyo to WGS 84 (108) + Tokyo to JGD2011 (2), 9.2 m, Japan - onshore excluding northern main province
unknown id, Inverse of Tokyo to WGS 84 (108) + Tokyo to JGD2000 (2) + JGD2000 to JGD2011 (1), 9.4 m, Japan - northern Honshu
unknown id, Inverse of Tokyo to WGS 84 (2) + Tokyo to JGD2011 (2), 13.2 m, Japan - onshore mainland and adjacent islands
unknown id, Inverse of Tokyo to WGS 84 (2) + Tokyo to JGD2000 (2) + JGD2000 to JGD2011 (1), 13.4 m, Japan - northern Honshu
unknown id, Inverse of Tokyo to WGS 84 (1) + Tokyo to JGD2011 (2), 29.2 m, Asia - Japan and South Korea

12.5.2.4 Code repository

The current state of the work can be found in the iso19111 branch of rouault/proj.4 repository, and is also available as a GitHub pull request at https://github.com/OSGeo/proj.4/pull/1040

Here is a not-so-usuable comparison with a fixed snapshot of master branch
12.5.2.5 Database

Content

The database contains CRS and coordinate operation definitions from the EPSG database (IOGP’s EPSG Geodetic Parameter Dataset) v9.5.3, IGNF registry (French National Geographic Institute), ESRI database, as well as a few customizations.

Building (for PROJ developers creating the database)

The building of the database is a several stage process:

Construct SQL scripts for EPSG

The first stage consists in constructing .sql scripts mostly with CREATE TABLE and INSERT statements to create the database structure and populate it. There is one .sql file for each database table, populated with the content of the EPSG database, automatically generated with the build_db.py script, which processes the PostgreSQL dumps issued by IOGP. A number of other scripts are dedicated to manual editing, for example grid_alternatives.sql file that binds official grid names to PROJ grid names.

Concert UTF8 SQL to sqlite3 db

The second stage is done automatically by the make process. It pipes the .sql script, in the right order, to the sqlite3 binary to generate a first version of the proj.db SQLite3 database.

Add extra registries

The third stage consists in creating additional .sql files from the content of other registries. For that process, we need to bind some definitions of those registries to those of the EPSG database, to be able to link to existing objects and detect some boring duplicates. The ignf.sql file has been generated using the build_db_create_ignf.py script from the current data/IGNF file that contains CRS definitions (and implicit transformations to WGS84) as PROJ4 strings. The esri.sql file has been generated using the build_db_from_esri.py script, from the .csv files in https://github.com/Esri/projection-engine-db-doc/tree/master/csv

Finalize proj.db

The last stage runs make again to incorporate the new .sql files generated in the previous stage (so the process of building the database involves a kind of bootstrapping...
Building (for PROJ users)

The make process just runs the second stage mentioned above from the .sql files. The resulting proj.db is currently 5.3 MB large.

Structure

The database is structured into the following tables and views. They generally match a ISO-19111 concept, and is generally close to the general structure of the EPSG database. Regarding identification of objects, where the EPSG database only contains a 'code' numeric column, the PROJ database identifies objects with a (auth_name, code) tuple of string values, allowing several registries to be combined together.

- **Technical:**
  - *authority_list:* view enumerating the authorities present in the database. Currently: EPSG, IGNF, PROJ
  - *metadata:* a few key/value pairs, for example to indicate the version of the registries imported in the database
  - *object_view:* synthetic view listing objects (ellipsoids, datums, CRS, coordinate operations...) code and name, and the table name where they are further described
  - *alias_names:* list possible alias for the *name* field of object table
  - *link_from Deprecated to non Deprecated:* to handle the link between old ESRI to new ESRI/EPSG codes

- **Common:**
  - *unit_of_measure:* table with UnitOfMeasure definitions.
  - *area:* table with area-of-use (bounding boxes) applicable to CRS and coordinate operations.

- **Coordinate systems:**
  - *axis:* table with CoordinateSystemAxis definitions.
  - *coordinate_system:* table with CoordinateSystem definitions.

- **Ellipsoid and datums:**
  - *ellipsoid:* table with ellipsoid definitions.
  - *prime_meridian:* table with PrimeMeridian definitions.
  - *geodetic_datum:* table with GeodeticReferenceFrame definitions.
  - *vertical_datum:* table with VerticalReferenceFrame definitions.

- **CRS:**
  - *geodetic_crs:* table with GeodeticCRS and GeographicCRS definitions.
  - *projected_crs:* table with ProjectedCRS definitions.
  - *vertical_crs:* table with VerticalCRS definitions.
  - *compound_crs:* table with CompoundCRS definitions.

- **Coordinate operations:**
  - *coordinate_operation_view:* view giving a number of common attributes shared by the concrete tables implementing CoordinateOperation
- **conversion**: table with definitions of Conversion (mostly parameter and values of Projection)
- **concatenated_operation**: table with definitions of ConcatenatedOperation.
- **grid_transformation**: table with all grid-based transformations.
- **grid_packages**: table listing packages in which grids can be found. e.g "proj-datumgrid", "proj-datumgrid-europe", ...
- **grid_alternatives**: table binding official grid names to PROJ grid names. e.g "Und_min2.5x2.5_agem2008_isw=82_WGS84_TideFree.gz" --> "egm08_25.gtx"
- **helmert_transformation**: table with all Helmert-based transformations.
- **other_transformation**: table with other type of transformations.

The main departure with the structure of the EPSG database is the split of the various coordinate operations over several tables. This was done mostly for human-readability as the EPSG organization of coordoperation, coordoperationmethod, coordoperationparam, coordoperationparamusage, coordoperationparamvalue tables makes it hard to grasp at once all the parameters and values for a given operation.

### 12.5.2.6 Utilities

A new projinfo utility has been added. It enables the user to enter a CRS or coordinate operation by a AUTHORITY:CODE, PROJ string or WKT string, and see it translated in the different flavors of PROJ and WKT strings. It also enables to build coordinate operations between two CRSs.

#### Usage

```bash
usage: projinfo [-o formats] [-k crs|operation] [--summary] [-q]
[-bbox min_long,min_lat,max_long,max_lat]
[--spatial-test contains|intersects]
[--crs-extent-use none|both|intersection|smallest]
[--grid-check none|discard_missing|sort]
[--boundcrs-to-wgs84]
{object_definition} | (-s {srs_def} -t {srs_def})
```

-o: formats is a comma separated combination of: all,default,PROJ4,PROJ,WKT_ALL,WKT2_2015,WKT2_2018,WKT1_GDAL

Except 'all' and 'default', other format can be preceded by '-' to disable them.

#### Examples

Specify CRS by AUTHORITY:CODE

```
$ projinfo EPSG:4326

PROJ string:
+proj=pipeline +step +proj=longlat +ellps=WGS84 +step +proj=unitconvert +xy_in=rad +xy_out=deg +step +proj=axisswap +order=2,1

WKT2_2015 string:
GEODCRS["WGS 84",
```

(continues on next page)
PROJ coordinate transformation software library, Release 9.3.1

DATUM["World Geodetic System 1984", 
ELLIPSOID["WGS 84",6378137,298.257223563, 
LENGTHUNIT["metre",1]], 
PRIMEM["Greenwich",0, 
ANGLEUNIT["degree",0.0174532925199433]], 
CS[ellipsoidal,2], 
AXIS["geodetic latitude (Lat)",north, 
ORDER[1], 
ANGLEUNIT["degree",0.0174532925199433], 
AXIS["geodetic longitude (Lon)",east, 
ORDER[2], 
ANGLEUNIT["degree",0.0174532925199433]], 
AREA["World"], 
BBOX[-90,-180,90,180], 
ID["EPSG",4326]]

Specify CRS by PROJ string and specify output formats

$ projinfo -o PROJ4,PROJ,WKT1_GDAL,WKT2_2018 "+title=IGN 1972 Nuku Hiva - UTM fuseau 7 Sud +proj=tmerc +towgs84=165.7320,216.7200,180.5050,-0.6434,-0.4512,-0.0791,7.420400 +a=6378388.0000 +rf=297.0000000000000 +lat_0=0.0000000000 +lon_0=-141.000000000 +k_0=0.999660000 +x_0=500000.0000 +y_0=10000000.0000 +units=m +no_defs"

PROJ string:
Error when exporting to PROJ string: BoundCRS cannot be exported as a PROJ.5 string, but its baseCRS might

PROJ.4 string:
+proj=utm +zone=7 +south +ellps=intl +towgs84=165.732,216.72,180.505,-0.6434,-0.4512,-0.0791,7.4204

WKT2_2018 string:
BOUNDCRS[
  SOURCECRS[
    PROJCRS["IGN 1972 Nuku Hiva - UTM fuseau 7 Sud", 
      BASEGEOGCRS["unknown", 
        DATUM["unknown", 
          ELLIPSOID["International 1909 (Hayford)",6378388,297, 
            LENGTHUNIT["metre",1, 
              ID["EPSG",9001]]], 
          PRIMEM["Greenwich",0, 
            ANGLEUNIT["degree",0.0174532925199433], 
              ID["EPSG",8901]]], 
          CONVERSION["unknown", 
            METHOD["Transverse Mercator", 
              ID["EPSG",9807]], 
              PARAMETER["Latitude of natural origin",0, 
                ANGLEUNIT["degree",0.0174532925199433], 
                  ID["EPSG",8801]], 
              PARAMETER["Longitude of natural origin",-141, 
                ANGLEUNIT["degree",0.0174532925199433], 
                  ID["EPSG",8801]]
        ], 
        ID["EPSG",9001]]
      ], 
      ID["EPSG",9001]]
    ]
ANGLEUNIT["degree", 0.0174532925199433],
ID["EPSG", 8802]],
PARAMETER["Scale factor at natural origin", 0.9996,
SCALEUNIT["unity", 1],
ID["EPSG", 8805]],
PARAMETER["False easting", 500000, LENGTHUNIT["metre", 1],
ID["EPSG", 8806]],
PARAMETER["False northing", 10000000, LENGTHUNIT["metre", 1],
ID["EPSG", 8807]],
CS[Cartesian, 2],
AXIS["(E)", east,
ORDER[1],
LENGTHUNIT["metre", 1],
ID["EPSG", 9001]],
AXIS["(N)", north,
ORDER[2],
LENGTHUNIT["metre", 1],
ID["EPSG", 9001]],
TARGETCRS[
GEOGCRS["WGS 84",
DATUM["World Geodetic System 1984",
ELLIPSOID["WGS 84", 6378137, 298.257223563, LENGTHUNIT["metre", 1]],
PRIMEM["Greenwich", 0,
ANGLEUNIT["degree", 0.0174532925199433]],
CS[ellipsoidal, 2],
AXIS["latitude", north,
ORDER[1],
ANGLEUNIT["degree", 0.0174532925199433]],
AXIS["longitude", east,
ORDER[2],
ANGLEUNIT["degree", 0.0174532925199433]],
ID["EPSG", 4326]],
ABRIDGEDTRANSFORMATION["Transformation from unknown to WGS84",
METHOD["Position Vector transformation (geog2D domain)",
ID["EPSG", 9606]],
PARAMETER["X-axis translation", 165.732, ID["EPSG", 8605]],
PARAMETER["Y-axis translation", 216.72,
ID["EPSG", 8606]],
PARAMETER["Z-axis translation", 180.505,
ID["EPSG", 8607]],
PARAMETER["X-axis rotation", -0.6434, ID["EPSG", 8608]],
PARAMETER["Y-axis rotation", -0.4512, ID["EPSG", 8609]],
PARAMETER["Z-axis rotation", -0.0791, ID["EPSG", 8610]],
PARAMETER["Scale difference", 1.0000074204, ID["EPSG", 8611]]]
Find transformations between 2 CRS

Between “Poland zone I” (based on Pulkovo 42 datum) and “UTM WGS84 zone 34N”

Summary view:

```bash
$ projinfo -s EPSG:2171 -t EPSG:32634 --summary
```

Candidate operations found: 1
unknown id, Inverse of Poland zone I + Pulkovo 1942(58) to WGS 84 (1) + UTM zone 34N, 1
→ m, Poland - onshore

Display of pipelines:

```bash
$ PROJ_LIB=data src/projinfo -s EPSG:2171 -t EPSG:32634 -o PROJ
```

PROJ string:

```bash
+proj=pipeline +step +proj=axisswap +order=2,1 +step +inv +proj=sterea +lat_0=50.625 
+lon_0=21.0833333333333 +k=0.9998 +x_0=4637000 +y_0=5647000 +ellps=krass +step 
+proj=cart +ellps=krass +step +proj=helmert +x=33.4 +y=-146.6 +z=-76.3 +rx=0.359 +ry= 
+rz=0.844 +as=0.84 +convention=position_vector +step +inv +proj=cart 
+ellps=WGS84 +step +proj=utm +zone=34 +ellps=WGS84
```
12.5.2.7 Impacted files

New files (excluding makefile.am, CMakeLists.txt and other build infrastructure artifacts):

- **include/proj/: Public installed C++ headers**
  - common.hpp: declarations of osgeo::proj::common namespace.
  - coordinateoperation.hpp: declarations of osgeo::proj::operation namespace.
  - coordinatesystem.hpp: declarations of osgeo::proj::cs namespace.
  - crs.hpp: declarations of osgeo::proj::crs namespace.
  - datum.hpp: declarations of osgeo::proj::datum namespace.
  - io.hpp: declarations of osgeo::proj::io namespace.
  - metadata.hpp: declarations of osgeo::proj::metadata namespace.
  - util.hpp: declarations of osgeo::proj::util namespace.
  - nn.hpp: Code from https://github.com/dropbox/nn to manage Non-nullable pointers for C++

- **include/proj/internal: Private non-installed C++ headers**
  - coordinateoperation_internal.hpp: classes InverseCoordinateOperation, InverseConversion, InverseTransformation, PROJBasedOperation, and functions to get conversion mappings between WKT and PROJ syntax
  - coordinateoperation_constants.hpp: Select subset of conversion/transformation EPSG names and codes for the purpose of translating them to PROJ strings
  - coordinatesystem_internal.hpp: classes AxisDirectionWKT1, AxisName and AxisAbbreviation
  - internal.hpp: a few helper functions, mostly to do string-based operations
  - io_internal.hpp: class WKTCustomes
  - helmert_constants.hpp: Helmert-based transformation & parameters names and codes.
  - lru_cache.hpp: code from https://github.com/mohaps/lrucache11 to have a generic Least-Recently-Used cache of objects

- **src/:**
  - c_api.cpp: C++ API mapped to C functions
  - common.cpp: implementation of common.hpp
  - coordinateoperation.cpp: implementation of coordinateoperation.hpp
  - coordinatesystem.cpp: implementation of coordinatesystem.hpp
  - crs.cpp: implementation of crs.hpp
  - datum.cpp: implementation of datum.hpp
  - factory.cpp: implementation of AuthorityFactory class (from io.hpp)
  - internal.cpp: implementation of internal.hpp
  - io.cpp: implementation of io.hpp
  - metadata.cpp: implementation of metadata.hpp

12.5. Request for Comments
– static.cpp: a number of static constants (like pre-defined well-known ellipsoid, datum and CRS), put in the right order for correct static initializations
– util.cpp: implementation of util.hpp
– projinfo.cpp: new ’projinfo’ binary
– general.dox: generic introduction documentation.

• data/sql/:
  – area.sql: generated by build_db.py
  – axis.sql: generated by build_db.py
  – begin.sql: hand generated (trivial)
  – commit.sql: hand generated (trivial)
  – compound_crs.sql: generated by build_db.py
  – concatenated_operation.sql: generated by build_db.py
  – conversion.sql: generated by build_db.py
  – coordinate_operation.sql: generated by build_db.py
  – coordinate_system.sql: generated by build_db.py
  – crs.sql: generated by build_db.py
  – customizations.sql: hand generated (empty)
  – ellipsoid.sql: generated by build_db.py
  – geodetic_crs.sql: generated by build_db.py
  – geodetic_datum.sql: generated by build_db.py
  – grid_alternatives.sql: hand-generated. Contains links between official registry grid names and PROJ ones
  – grid_transformation.sql: generated by build_db.py
  – grid_transformation_custom.sql: hand-generated
  – helmert_transformation.sql: generated by build_db.py
  – ignf.sql: generated by build_db_create_ignf.py
  – esri.sql: generated by build_db_from_esri.py
  – metadata.sql: hand-generated
  – other_transformation.sql: generated by build_db.py
  – prime_meridian.sql: generated by build_db.py
  – proj_db_table_defs.sql: hand-generated. Database structure: CREATE TABLE / CREATE VIEW / CREATE TRIGGER
  – projected_crs.sql: generated by build_db.py
  – unit_of_measure.sql: generated by build_db.py
  – vertical_crs.sql: generated by build_db.py
  – vertical_datum.sql: generated by build_db.py

• scripts/:
12.5.2.8 C API

`proj.h` has been extended to bind a number of C++ classes/methods to a C API.

The main structure is an opaque `PJ_OBJ*` roughly encapsulating a osgeo::proj::BaseObject, that can represent a CRS or a CoordinateOperation object. A number of the C functions will work only if the right type of underlying C++ object is used with them. Misuse will be properly handled at runtime. If a user passes a `PJ_OBJ*` representing a coordinate operation to a `pj_obj_crs_xxxx()` function, it will properly error out. This design has been chosen over creating a dedicate `PJ_xxx` object for each C++ class, because such an approach would require adding many conversion and free functions for little benefit.

This C API is incomplete. In particular, it does not allow to build ISO19111 objects at hand. However it currently permits a number of actions:

- building CRS and coordinate operations from WKT and PROJ strings, or from the `proj.db` database
- exporting CRS and coordinate operations as WKT and PROJ strings
- querying main attributes of those objects
- finding coordinate operations between two CRS.

`test_c_api.cpp` should demonstrates simple usage of the API (note: for the conveniency of writing the tests in C++, `test_c_api.cpp` wraps the C `PJ_OBJ*` instances in C++ 'keeper' objects that automatically call the `pj_obj_unref()` function at function end. In a pure C use, the caller must use `pj_obj_unref()` to prevent leaks.)

12.5. Request for Comments
12.5.2.9 Documentation

All public C++ classes and methods and C functions are documented with Doxygen.

Current snapshot of Class list

Spaghetti inheritance diagram

A basic integration of the Doxygen XML output into the general PROJ documentation (using reStructuredText format) has been done with the Sphinx extension Breathe, producing:

- One section with the C++ API
- One section with the C API

12.5.2.10 Testing

Nearly all exported methods are tested by a unit test. Global line coverage of the new files is 92%. Those tests represent 16k lines of codes.

12.5.2.11 Build requirements

The new code leverages on a number of C++11 features (auto keyword, constexpr, initializer list, std::shared_ptr, lambda functions, etc.), which means that a C++11-compliant compiler must be used to generate PROJ:

- gcc >= 4.8
- clang >= 3.3
- Visual Studio >= 2015.

Compilers tested by the Travis-CI and AppVeyor continuous integration environments:

- GCC 4.8
- mingw-w64-x86-64 4.8
- clang 5.0
- Apple LLVM version 9.1.0 (clang-902.0.39.2)
- MSVC 2015 32 and 64 bit
- MSVC 2017 32 and 64 bit

The libsqlite3 >= 3.7 development package must also be available. And the sqlite3 binary must be available to build the proj.db files from the .sql files.

12.5.2.12 Runtime requirements

- libc++/libstdc++/MSVC runtime consistent with the compiler used
- libsqlite3 >= 3.7
### 12.5.2.13 Backward compatibility

At this stage, no backward compatibility issue is foreseen, as no existing functional C code has been modified to use the new capabilities.

### 12.5.2.14 Future work

The work described in this RFC will be pursued in a number of directions. Non-exhaustively:

- Support for ESRI WKT1 dialect (PROJ currently ingest the ProjectedCRS in `esri.sql` in that dialect, but there is no mapping between it and EPSG operation and parameter names, so conversion to PROJ strings does not always work.
- Closer integration with the existing code base. In particular, the `+init=dict:code` syntax should now go first to the database (then the `epsg` and `IGNF` files can be removed). Similarly `proj_create_crs_to_crs()` could use the new capabilities to find an appropriate coordinate transformation.
- And whatever else changes are needed to address GDAL and libgeotiff needs.

### 12.5.2.15 Adoption status

The RFC has been adopted with support from PSC members Kurt Schwehr, Kristian Evers, Howard Butler and Even Rouault.

### 12.5.3 PROJ RFC 3: Dependency management

<table>
<thead>
<tr>
<th>Author</th>
<th>Kristian Evers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact</td>
<td><a href="mailto:kreve@sdfe.dk">kreve@sdfe.dk</a></td>
</tr>
<tr>
<td>Status</td>
<td>Adopted</td>
</tr>
<tr>
<td>Last Updated</td>
<td>2019-01-16</td>
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</tbody>
</table>

#### 12.5.3.1 Summary

This document defines a set of guidelines for dependency management in PROJ. With PROJ being a core component in many downstream software packages clearly stating which dependencies the library has is of great value. This document concern both programming language standards as well as minimum required versions of library dependencies and build tools.

It is proposed to adopt a rolling update scheme that ensures that PROJ is sufficiently accessible, even on older systems, as well as keeping up with the technological evolution. The scheme is divided in two parts, one concerning versions of used programming languages within PROJ and the other concerning software packages that PROJ depend on.

With adoption of this RFC, versions used for:

1. programming languages will always be at least two revisions behind the most recent standard
2. software packages will always be at least two years old (patch releases are exempt)
A change in programming language standard can only be introduced with a new major version release of PROJ. Changes for software package dependencies can be introduced with minor version releases of PROJ. Changing the version requirements for a dependency needs to be approved by the PSC.

Following the above rule set will ensure that all but the most conservative users of PROJ will be able to build and use the most recent version of the library.

In the sections below details concerning programming languages and software dependencies are outlined. The RFC is concluded with a bootstrapping section that details the state of dependencies after the accept of the RFC.

### 12.5.3.2 Background

PROJ has traditionally been written in C89. Until recently, no formal requirements of e.g. build systems has been defined and formally accepted by the project. **RFC2** formally introduces dependencies on C++11 and SQLite 3.7.

In this RFC a rolling update of version or standard requirements is described. The reasoning behind a rolling update scheme is that it has become increasingly evident that C89 is becoming outdated and creating a less than optimal development environment for contributors. It has been noted that the most commonly used compilers all now support more recent versions of C, so the strict usage of C89 is no longer as critical as it used to be.

Similarly, rolling updates to other tools and libraries that PROJ depend on will ensure that the code base can be kept modern and in line with the rest of the open source software ecosphere.

### 12.5.3.3 C and C++

Following **RFC2** PROJ is written in both C and C++. At the time of writing the core library is C based and the code described in RFC2 is written in C++. While the core library is mostly written in C it is compiled as C++. Minor sections of PROJ, like the geodesic algorithms are still compiled as C since there is no apparent benefit of compiling with a C++ compiler. This may change in the future.

Both the C and C++ standards are updated with regular intervals. After an update of a standard it takes time for compiler manufacturers to implement the standards fully, which makes adoption of new standards potentially troublesome if done too soon. On the other hand, waiting too long to adopt new standards will eventually make the code base feel old and new contributors are more likely to stay away because they don’t want to work using tools of the past. With a rolling update scheme both concerns can be managed by always staying behind the most recent standard, but not so far away that potential contributors are scared away. Keeping a policy of always lagging behind two iterations of the standard is thought to be the best comprise between the two concerns.

C comes in four ISO standardised varieties: C89, C99, C11, C18. In this document we refer to their informal names for ease of reading. C++ exists in five varieties: C++98, C++03, C++11, C++14, C++17. Before adoption of this RFC PROJ uses C89 and C++11. For C, that means that the used standard is three iterations behind the most recent standard. C++ is two iterations behind. Following the rules in this RFC the required C standard used in PROJ is at allowed to be two iterations behind the most recent standard. That means that a change to C99 is possible, as long as the PROJ PSC acknowledges such a change.

When a new standard for either C or C++ is released PROJ should consider changing its requirement to the next standard in the line. For C++ that means a change in standard roughly every three years, for C the periods between standard updates is expected to be longer. Adaptation of new programming language standards should be coordinated with a major version release of PROJ.
12.5.3.4 Software dependencies

At the time of writing PROJ is dependent on very few external packages. In fact only one runtime dependency is present: SQLite. Building PROJ also requires one of two external dependencies for configuration: Autotools or CMake.

As with programming language standards it is preferable that software dependencies are a bit behind the most recent development. For this reason it is required that the minimum version supported in PROJ dependencies is at least two years old, preferably more. It is not a requirement that the minimum version of dependencies is always kept strictly two years behind current development, but it is allowed in case future development of PROJ warrants an update. Changes in minimum version requirements are allowed to happen with minor version releases of PROJ.

At the time of writing the minimum version required for SQLite it 3.7 which was released in 2010. CMake currently is required to be at least at version 2.8.3 which was also released in 2010.

12.5.3.5 Bootstrapping

This RFC comes with a set of guidelines for handling dependencies for PROJ in the future. Up until now dependencies haven't been handled consistently, with some dependencies not being approved formally by the projects governing body. Therefore minimum versions of PROJ dependencies is proposed so that at the acception of this RFC PROJ will have the following external requirements:

- C99 (was C89)
- C++11 (already approved in RFC2)
- SQLite 3.7 (already approved in RFC2)
- CMake 3.5 (was 2.8.3)

12.5.3.6 Adoption status

The RFC was adopted on 2018-01-19 with +1’s from the following PSC members

- Kristian Evers
- Even Rouault
- Thomas Knudsen
- Howard Butler

12.5.4 PROJ RFC 4: Remote access to grids and GeoTIFF grids

Author
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Status
Adopted

Implementation target
PROJ 7

Last Updated
2020-01-10
12.5.4.1 Motivation

PROJ 6 brings undeniable advances in the management of coordinate transformations between datums by relying and applying information available in the PROJ database. PROJ’s rapid evolution from a cartographic projections library with a little bit of geodetic capability to a full geodetic transformation and description environment has highlighted the importance of the support data. Users desire the convenience of software doing the right thing with the least amount of fuss, and survey organizations wish to deliver their models across as wide a software footprint as possible. To get results with the highest precision, a grid file that defines a model that provides dimension shifts is often needed. The proj-datumgrid project centralizes grids available under an open data license and bundles them in different archives split along major geographical regions of the world.

It is assumed that a PROJ user has downloaded and installed grid files that are referred to in the PROJ database. These files can be quite large in aggregate, and packaging support by major distribution channels is somewhat uneven due to their size, sometimes ambiguous licensing story, and difficult-to-track versioning and lineage. It is not always clear to the user, especially to those who may not be so familiar with geodetic operations, that the highest precision transformation may not always being applied if grid data is not available. Users want both convenience and correctness, and management of the shift files can be challenging to those who may not be aware of their importance to the process.

The computing environment in which PROJ operates is also changing. Because the shift data can be so large (currently more than 700 MB of uncompressed data, and growing), deployment of high accuracy operations can be limited due to deployment size constraints (serverless operations, for example). Changing to a delivery format that supports incremental access over a network along with convenient access and compression will ease the resource burden the shift files present while allowing the project to deliver transformation capability with the highest known precision provided by the survey organizations.

Adjustment grids also tend to be provided in many different formats depending on the organization and country that produced them. In PROJ, we have over time "standardized" on using horizontal shift grids as NTv2 and vertical shift grids using GTX. Both have poor general support as dedicated formats, limited metadata capabilities, and neither are necessarily "cloud optimized" for incremental access across a network.

12.5.4.2 Summary of work planned by this RFC

- Grids will be hosted by one or several Content Delivery Networks (CDN)
- Grid loading mechanism will be reworked to be able to download grids or parts of grids from an online repository. When opted in, users will no longer have to manually fetch grid files and place them in PROJ_LIB. Full and accurate capability of the software will no longer require hundreds of megabytes of grid shift files in advance, even if only a few of them are needed for the transformations done by the user.
- Local caching of grid files, or even part of files, so that users end up mirroring what they actually use.
- A grid shift format, for both horizontal and vertical shift grids (and in potential future steps, for other needs, such as deformation models) will be implemented.

The use of grids locally available will of course still be available, and will be the default behavior.

12.5.4.3 Network access to grids

curl will be an optional build dependency of PROJ, added in autoconf and cmake build systems. It can be disabled at build time, but this must be an explicit setting of configure/cmake as the resulting builds have less functionality. When curl is enabled at build time, download of grids themselves will not be enabled by default at runtime. It will require explicit consent of the user, either through the API (proj_context_set_enable_network()) through the PROJ_NETWORK=ON environment variable, or the network = on setting of proj.ini.

Regarding the minimum version of libcurl required, given GDAL experience that can build with rather ancient libcurl for similar functionality, we can aim for libcurl &ge; 7.29.0 (as being available in RHEL 7).
An alternate pluggable network interface can also be set by the user in case support for libcurl was not built in, or if for the desired context of use, the user wishes to provide the network implementation (a typical use case could be QGIS that would use its QT-based networking facilities to solve issues with SSL, proxy, authentication, etc.)

A text configuration file, installed in ${installation_prefix}/share/proj/proj.ini (or ${PROJ_LIB}/proj.ini) will contain the URL of the CDN that will be used. The user may also override this setting with the `proj_context_set_url_endpoint()` or through the PROJ_NETWORK_ENDPOINT environment variable.

The rationale for putting proj.ini in that location is that it is a well-known place by PROJ users, with the existing PROJ_LIB mechanics for systems like Windows where hardcoded paths at runtime aren’t generally usable.

**C API**

The preliminary C API for the above is:

```c
/** Enable or disable network access. *
 * @param ctx PROJ context, or NULL *
 * @return TRUE if network access is possible. That is either libcurl is available, or an alternate interface has been set. */
int proj_context_set_enable_network(PJ_CONTEXT* ctx, int enable);

/** Define URL endpoint to query for remote grids. *
 * This overrides the default endpoint in the PROJ configuration file or with the PROJ_NETWORK_ENDPOINT environment variable.
 * @param ctx PROJ context, or NULL *
 * @param url Endpoint URL. Must NOT be NULL. */
void proj_context_set_url_endpoint(PJ_CONTEXT* ctx, const char* url);

/** Opaque structure for PROJ. Implementations might cast it to their structure/class of choice. */
typedef struct PROJ_NETWORK_HANDLE
PROJ_NETWORK_HANDLE;

/** Network access: open callback *
 * Should try to read the size_to_read first bytes at the specified offset of the file given by URL url, *
 * and write them to buffer. *out_size_read should be updated with the actual amount of bytes read (== size_to_read if the file is larger than size_to_read). *
 * During this read, the implementation should make sure to store the HTTP headers from the server response to be able to respond to proj_network_get_header_value_cbk_type callback. *
 * error_string_max_size should be the maximum size that can be written into the out_error_string buffer (including terminating null character).
 * @return a non-NULL opaque handle in case of success. */
typedef PROJ_NETWORK_HANDLE* (*proj_network_open_cbk_type)(
```
PJ_CONTEXT* ctx,
const char* url,
unsigned long long offset,
size_t size_to_read,
void* buffer,
size_t* out_size_read,
size_t error_string_max_size,
char* out_error_string,
void* user_data);

/** Network access: close callback */
typedef void (*proj_network_close_cbk_type)(PJ_CONTEXT* ctx,
            PROJ_NETWORK_HANDLE* handle,
            void* user_data);

/** Network access: get HTTP headers */
typedef const char* (*proj_network_get_header_value_cbk_type)(
            PJ_CONTEXT* ctx,
            PROJ_NETWORK_HANDLE* handle,
            const char* header_name,
            void* user_data);

/** Network access: read range */
* Read size_to_read bytes from handle, starting at offset, into
* buffer.
* During this read, the implementation should make sure to store the HTTP
* headers from the server response to be able to respond to
* proj_network_get_header_value_cbk_type callback.
* error_string_max_size should be the maximum size that can be written into
* the out_error_string buffer (including terminating null character).
* @return the number of bytes actually read (0 in case of error)
*/
typedef size_t (*proj_network_read_range_type)(
            PJ_CONTEXT* ctx,
            PROJ_NETWORK_HANDLE* handle,
            unsigned long long offset,
            size_t size_to_read,
            void* buffer,
            size_t error_string_max_size,
            char* out_error_string,
            void* user_data);

/** Define a custom set of callbacks for network access. */
* All callbacks should be provided (non NULL pointers).
* @param ctx PROJ context, or NULL
* @param open_cbk Callback to open a remote file given its URL
* @param close_cbk Callback to close a remote file.

To make network access efficient, PROJ will internally have a in-memory cache of file ranges to only issue network requests by chunks of 16 KB or multiple of them, to limit the number of HTTP GET requests and minimize latency caused by network access. This is very similar to the behavior of the GDAL /vsicurl/ I/O layer. The plan is to mostly copy GDAL's vsicurl implementation inside PROJ, with needed adjustments and proper namespacing of it.

A retry strategy (typically a delay with an exponential back-off and some random jitter) will be added to account for intermittent network or server-side failure.

**URL building**

The PROJ database has a grid_transformation grid whose column grid_name (and possibly grid2_name) contain the name of the grid as indicated by the authority having registered the transformation (typically EPSG). As those grid names are not generally directly usable by PROJ, the PROJ database has also a grid_alternatives table that link original grid names to the ones used by PROJ. When network access will be available and needed due to lack of a local grid, the full URL will be the endpoint from the configuration or set by the user, the basename of the PROJ usable filename, and the "tif" suffix. So if the CDN is at http://example.com and the name from grid_alternatives is egm96_15.gtx, then the URL will be http://example.com/egm96_15.tif

**Grid loading**

The following files will be affected, in one way or another, by the above describes changes: nad_cvt.cpp, nad_intr.cpp, nad_init.cpp, grid_info.cpp, grid_list.cpp, apply_gridshift.cpp, apply_vgridshift.cpp.

In particular the current logic that consists to ingest all the values of a grid/subgrid in the ct->cvs array will be completely modified, to enable access to grid values at a specified (x,y) location.

**proj_create_crs_to_crs() / proj_create_operations() impacts**

Once network access is available, all grids known to the PROJ database (grid_transformation + grid_alternatives table) will be assumed to be available, when computing the potential pipelines between two CRS.

Concretely, this will be equivalent to calling proj_operation_factory_context_set_grid_availability_use() with the use argument set to a new enumeration value

```c
/** Results will be presented as if grids known to PROJ (that is
 * registered in the grid_alternatives table of its database) were
 * available. Used typically when networking is enabled.
 */
```

(continues on next page)
Local on-disk caching of remote grids

As many workflows will tend to use the same grids over and over, a local on-disk caching of remote grids will be added. The cache will be a single SQLite3 database, in a user-writable directory shared by all applications using PROJ.

Its total size will be configurable, with a default maximum size of 100 MB in proj.ini. The cache will also keep the timestamp of the last time it checked various global properties of the file (its size, Last-Modified and ETag headers). A time-to-live parameter, with a default of 1 day in proj.ini, will be used to determine whether the CDN should be hit to verify if the information in the cache is still up-to-date.

```c
/** Enable or disable the local cache of grid chunks
 * This overrides the setting in the PROJ configuration file.
 * @param ctx PROJ context, or NULL
 * @param enabled TRUE if the cache is enabled.
 */
void proj_grid_cache_set_enable(PJ_CONTEXT *ctx, int enabled);

/** Override, for the considered context, the path and file of the local cache of grid chunks.
 * @param ctx PROJ context, or NULL
 * @param fullname Full name to the cache (encoded in UTF-8). If set to NULL, caching will be disabled.
 */
void proj_grid_cache_set_filename(PJ_CONTEXT* ctx, const char* fullname);

/** Override, for the considered context, the maximum size of the local cache of grid chunks.
 * @param ctx PROJ context, or NULL
 * @param max_size_MB Maximum size, in mega-bytes (1024*1024 bytes), or negative value to set unlimited size.
 */
void proj_grid_cache_set_max_size(PJ_CONTEXT* ctx, int max_size_MB);

/** Override, for the considered context, the time-to-live delay for re-checking if the cached properties of files are still up-to-date.
 * @param ctx PROJ context, or NULL
 * @param ttl_seconds Delay in seconds. Use negative value for no expiration.
 */
void proj_grid_cache_set_ttl(PJ_CONTEXT* ctx, int ttl_seconds);

/** Clear the local cache of grid chunks.
 * @param ctx PROJ context, or NULL.
 */
```
/*
void proj_grid_cache_clear(PJ_CONTEXT* ctx);

The planned database structure is:

-- General properties on a file
CREATE TABLE properties(
  url TEXT PRIMARY KEY NOT NULL,
  lastChecked TIMESTAMP NOT NULL,
  fileSize INTEGER NOT NULL,
  lastModified TEXT,
  etag TEXT
); 

-- Store chunks of data. To avoid any potential fragmentation of the
-- cache, the data BLOB is always set to the maximum chunk size of 16 KB
-- (right padded with 0-byte)
-- The actual size is stored in chunks.data_size
CREATE TABLE chunk_data(
  id INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
  data BLOB NOT NULL
); 

-- Record chunks of data by (url, offset)
CREATE TABLE chunks(
  id INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
  url TEXT NOT NULL,
  offset INTEGER NOT NULL,
  data_id INTEGER NOT NULL,
  data_size INTEGER NOT NULL
); 

-- Doubly linked list of chunks. The next link is to go to the least-recently
-- used entries.
CREATE TABLE linked_chunks(
  id INTEGER PRIMARY KEY AUTOINCREMENT CHECK (id > 0),
  chunk_id INTEGER NOT NULL,
  prev INTEGER,
  next INTEGER
); 

CREATE INDEX idx_chunks ON chunks(url, offset);

CREATE INDEX idx_linked_chunks_chunk_id ON linked_chunks(chunk_id);

-- Head and tail pointers of the linked_chunks. The head pointer is for
-- the most-recently used chunk.
-- There should be just one row in this table.
CREATE TABLE linked_chunks_head_tail(
  chunk_id INTEGER NOT NULL
);
The chunks table will store 16 KB chunks (or less for terminating chunks). The linked_chunks and linked_chunks_head_tail table will act as a doubly linked list of chunks, with the least recently used ones at the end of the list, which will be evicted when the cache saturates.

The directory used to locate this database will be `${XDG_DATA_HOME}/proj` (per https://specifications.freedesktop.org/basedir-spec/basedir-spec-latest.html) where `${XDG_DATA_HOME}` defaults to `${HOME}/.local/share` on Unix builds and `${LOCALAPPDATA}` on Windows builds. Exact details to be sorted out, but https://github.com/ActiveState/appdirs/blob/a54ea98feed0a7593475b94de3a359e9e1fe8fdb/appdirs.py#L45-L97 can be a good reference.

As this database might be accessed by several threads or processes at the same time, the code accessing to it will carefully honour SQLite3 errors regarding to locks, to do appropriate retries if another thread/process is currently locking the database. Accesses requiring a modification of the database will start with a BEGIN IMMEDIATE transaction so as to acquire a write lock.

**Note:** This database should be hosted on a local disk, not a network one. Otherwise SQLite3 locking issues are to be expected.

### CDN provider

Amazon Public Datasets has offered to be a storage and CDN provider.

The program covers storage and egress (bandwidth) of the data. They generally don't allow usage of CloudFront (their CDN) as part of the program (we would usually look to have it covered by credits), but in this instance, they would be fine to provide it. They'd only ask that we keep the CloudFront URL "visible" (as appropriate for the use case) so people can see where the data is hosted in case they go looking. Their terms can be seen at https://aws.amazon.com/service-terms/ and CloudFront has its own, small section. Those terms may change a bit from time to time for minor changes. Major changing service terms is assumed to be unfrequent. There are also the Public Dataset Program terms at http://aws.amazon.com/public-datasets/terms/. Those also do not effectively change over time and are renewed on a 2 year basis.

### Criteria for grid hosting

The grids hosted on the CDN will be exactly the ones collected, currently and in the future, by the proj-datumgrid initiative. In particular, new grids are accepted as long as they are released under a license that is compatible with the Open Source Definition and the source of the grid is clearly stated and verifiable. Suitable licenses include:

- Public domain
- X/MIT
- BSD 2/3/4 clause
- CC0
- CC-BY (v3.0 or later)
• CC-BY-SA (v3.0 or later)

For new grids to be transparently used by the proj_create_crs_to_crs() mechanics, they must be registered in the PROJ database (proj.db) in the grid_transformation and grid_alternatives table. The nominal path to have a new record in the grid_transformation is to have a transformation being registered in the EPSG dataset (if there is no existing one), which will be subsequently imported into the PROJ database.

Versioning, historical preservation of grids

The policy regarding this should be similar to the one applied to proj-datumgrid, which even if not formalized, is around the following lines:

• Geodetic agencies release regularly new version of grids. Typically for the USA, NOAA has released GEOID99, GEOID03, GEOID06, GEOID09, GEOID12A, GEOID12B, GEOID18 for the NAVD88 to NAD83/NAD83(2011) vertical adjustments. Each of these grids is considered by EPSG and PROJ has a separate object, with distinct filenames. The release of a new version does not cause the old grid to be automatically removed. That said, due to advertized accuracies and supersession rules of the EPSG dataset, the most recent grid will generally be used for a CRS -> CRS transformation if the user uses proj_create_crs_to_crs() (with the exception that if a VERT_CRS_WKT includes a GEOID_MODEL known to PROJ, an old version of the grid will be used). If the user specifies a whole pipeline with an explicit grid name, it will be of course strictly honoured. As time goes, the size of the datasets managed by proj-datumgrid will be increasing, we will have to explore on we managed that for the distributed .zip / .tar.gz archives. This should not be a concern for CDN hosted content.

• In case software-related conversion errors from the original grid format to the one used by PROJ (be it GTX, NTv2 or GeoTIFF) would happen, the previous erroneous version of the dataset would be replaced by the corrected one. In that situation, this might have an effect with the local on-disk caching of remote grids. We will have to see with the CDN providers used if we can use for example the ETag HTTP header on the client to detect a change, so that old cached content is not erroneously reused (if not possible, we'll have to use some text file listing the grid names and their current md5sum)

12.5.4.4 Grids in GeoTIFF format

Limitations of current formats

Several formats exist depending on the ad-hoc needs and ideas of the original data producer. It would be appropriate to converge on a common format able to address the different use cases.

• Not tiled. Tiling is a nice to have property for cloud-friendly access to large files.

• No support for compression

• The NTv2 structures is roughly: header of main grid, data of main grid, header of subgrid 1, data of subgrid 1, header of subgrid 2, data of subgrid 2, etc. Due to the headers being scattered through the file, it is not possibly to retrieve with a single HTTP GET request all header information.

• GTX format has no provision to store metadata besides the minimum georeferencing of the grid. NTv2 is a bit richer, but no extensible metadata possible.
Discussion on choice of format

We have been made recently aware of other initiatives from the industry to come with a common format to store geodetic adjustment data. Some discussions have happen recently within the OGC CRS Working group. Past efforts include the Esri's proposed Geodetic data Grid eXchange Format, GGXF, briefly mentioned at page 86 of https://iag.dgfi.tum.de/fileadmin/IAG-docs/Travaux2015/01_Travaux_Template_Comm_1_tvd.pdf and page 66 of ftp://ftp.iaspei.org/pub/meetings/2010-2019/2015-Prague/IAG-Geodesy.pdf The current trend of those works would be to use a netCDF / HDF5 container.

So, for the sake of completeness, we list hereafter a few potential candidate formats and their pros and cons.

**TIFF/GeoTIFF**

Strong points:

- TIFF is a well-known and widespread format.
- The GeoTIFF encoding is a widely industry supported scheme to encode georeferencing. It is now a OGC standard
- There are independent initiatives to share grids as GeoTIFF, like that one
- TIFF can contain multiple images (IFD: Image File Directory) chained together. This is the mechanism used for multiple-page scanned TIFF files, or in the geospatial field to store multi-resolution/pyramid rasters. So it can be used with sub-grids as in the NTv2 format.
- Extensive experience with the TIFF format, and its appropriateness for network access, in particular through the Cloud Optimized GeoTIFF initiative whose layout can make use of sub-grids efficient from a network access perspective, because grid headers can be put at the beginning of the file, and so being retrieved in a single HTTP GET request.
- TIFF can be tiled.
- TIFF can be compressed. Commonly found compression formats are DEFLATE, LZW, combined with differential integer or floating point predictors
- A TIFF image can contain a configurable number of channels/bands/samples. In the rest of the document, we will use the sample terminology for this concept.
- TIFF sample organization can be configured: either the values of different samples are packed together (PlanarConfiguration = Contig), or put in separate tiles/strips (PlanarConfiguration = Separate)
- libtiff is a dependency commonly found in binary distributions of the "ecosystem" to which PROJ belongs too
- libtiff benefits from many years of efforts to increase its security, for example being integrated to the oss-fuzz initiative. Given the potential fetching of grids, using security tested components is an important concern.
- Browser-side: there are "ports" of libtiff/libgeotiff in the browser such as https://geotiffjs.github.io/ which could potentially make a port of PROJ easier.

Weak points:

- we cannot use libgeotiff, since it depends itself on PROJ (to resolve CRS or components of CRS from their EPSG codes). That said, for PROJ intended use, we only need to decode the ModelTiepointTag and ModelPixelScaleTag TIFF tags, so this can be done "at hand"
- the metadata capabilities of TIFF baseline are limited. The TIFF format comes with a predefined set of metadata items whose keys have numeric values. That said, GDAL has used for the last 20 years or so a dedicated tag, GDAL_METADATA of code 42112 that holds a XML-formatted string being able to store arbitrary key-pair values.
PROJ coordinate transformation software library, Release 9.3.1

netCDF v3

Strong points:

- The binary format description as given in OGC 10-092r3 is relatively simple, but it would still probably be necessary to use libnetcdf-c to access it
- Metadata can be stored easily in netCDF attributes

Weak points:

- No compression in netCDF v3
- No tiling in netCDF v3
- Multi-samples variables are located in different sections of the files (correspond to TIFF PlanarConfiguration = Separate)
- No natural way of having hierarchical / multigrids. They must be encoded as separate variables
- georeferencing in netCDF is somewhat less standardized than TIFF/GeoTIFF. The generally used model is the conventions for CF (Climate and Forecast) metadata but there is nothing really handy in them for simple georeferencing with the coordinate of the upper-left pixel and the resolution. The practice is to write explicit long and lat variables with all values taken by the grid. GDAL has for many years supported a simpler syntax, using a GeoTransform attribute.
- From the format description, its layout could be relatively cloud friendly, except that libnetcdf has no API to plug an alternate I/O layer.
- Most binary distributions of netCDF nowadays are based on libnetcdf v4, which implies the HDF5 dependency.
- From a few issues we identified a few years ago regarding crashes on corrupted datasets, we contacted libnetcdf upstream, but they did not seem to be interested in addressing those security issues.

netCDF v4 / HDF5

Note: The netCDF v4 format is a profile of the HDF5 file format.

Strong points:

- Compression supported (ZLIB and SZIP predefined)
- Tiling (chunking) supported
- Values of Multi-sample variables can be interleaved together (similarly to TIFF PlanarConfiguration = Contig) by using compound data types.
- Hierarchical organization with groups
- While the netCDF API does not provide an alternate I/O layer, this is possible with the HDF5 API.
- Grids can be indexed by more than 2 dimensions (for current needs, we don't need more than 2D support)

Weak points:

- The HDF 5 File format is more complex than netCDF v3, and likely more than TIFF. We do not have in-depth expertise of it to assess its cloud-friendliness.
- The ones mentioned for netCDF v3 regarding georeferencing and security apply.
GeoPackage

As PROJ has already a SQLite3 dependency, GeoPackage could be examined as a potential solution.

Strong points:

- SQLite3 dependency
- OGC standard
- Multi-grid capabilities
- Tiling
- Compression
- Metadata capabilities

Weak points:

- GeoPackage mostly address the RGB(A) Byte use case, or via the tile gridded data extension, single-sample non-Byte data. No native support for multi-sample non-Byte data: each sample should be put in a separate raster table.
- Experience shows that SQLite3 layout (at least the layout adopted when using the standard libsqlite3) is not cloud friendly. Indices may be scattered in different places of the file.

Conclusions

The 2 major contenders regarding our goals and constraints are GeoTIFF and HDF5. Given past positive experience and its long history, GeoTIFF remains our preferred choice.

Format description

The format description is available in a dedicated Geodetic TIFF grids (GTG) document.

Tooling

A script will be developed to accept a list of individual grids to combine together into a single file.

A ntv2_to_gtiff.py convenience script will be created to convert NTv2 grids, including their subgrids, to the above described GeoTIFF layout.

A validation Python script will be created to check that a file meets the above described requirements and recommendations.

Build requirements

The minimum libtiff version will be 4.0 (RHEL 7 ships with libtiff 4.0.3). To be able to read grids stored on the CDN, libtiff will need to build against zlib to have DEFLATE and LZW support, which is met by all known binary distributions of libtiff.

The libtiff dependency can be disabled at build time, but this must be an explicit setting of configure/cmake as the resulting builds have less functionality.
12.5.4.5 Dropping grid catalog functionality

While digging through existing code, I more or less discovered that the PROJ code base has the concept of a grid catalog. This is a feature apparently triggered by using the +catalog=somefilename.csv in a PROJ string, where the CSV file list grid names, their extent, priority and date. It seems to be an alternative to using +nadgrids with multiple grids, with the extra ability to interpolate shift values between several grids if a +date parameter is provided and the grid catalog mentions a date for each grids. It was added in June 2012 per commit fcb186942ec8532655ff6cf4cc990e5da669a3bc.

This feature is likely unknown to most users as there is no known documentation for it (neither in current documentation, nor in historic one). It is not either tested by PROJ tests, so its working status is unknown. It would likely make implementation of this RFC easier if this was removed. This would result in completely dropping the gridcatalog.cpp and gc_reader.cpp files, their call sites and the catalog_name and datum_date parameter from the PJ structure.

In case similar functionality would be be needed, it might be later reintroduced as an extra mode of Horizontal grid shift, or using a dedicated transformation method, similarly to the Kinematic datum shifting utilizing a deformation model one, and possibly combining the several grids to interpolate among in the same file, with a date metadata item.

12.5.4.6 Backward compatibility issues

None anticipated, except the removal of the (presumably little used) grid catalog functionality.

12.5.4.7 Potential future related work

The foundations set in the definition of the GeoTIFF grid format should hopefully be reused to extend them to support deformation models (was initially discussed per https://github.com/OSGeo/PROJ/issues/1001).

Definition of such an extension is out of scope of this RFC.

12.5.4.8 Documentation

- New API function will be documented.
- A dedicated documentation page will be created to explain the working of network-based access.
- A dedicated documentation page will be created to describe the GeoTIFF based grid format. Mostly reusing above material.

12.5.4.9 Testing

Number of GeoTIFF formulations (tiled vs untiled, PlanarConfiguration Separate vs Contig, data types, scale+offset vs not, etc.) will be tested.

For testing of network capabilities, a mix of real hits to the CDN and use of the alternate pluggable network interface to test edge cases will be used.
12.5.4.10 Proposed implementation

A proposed implementation is available at https://github.com/OSGeo/PROJ/pull/1817

Tooling scripts are currently available at https://github.com/rouault/sample_proj_gtiff_grids/ (will be ultimately stored in PROJ repository)

12.5.4.11 Adoption status

The RFC was adopted on 2020-01-10 with +1’s from the following PSC members

- Kristian Evers
- Even Rouault
- Thomas Knudsen
- Howard Butler
- Kurt Schwehr

12.5.5 PROJ RFC 5: Adopt GeoTIFF-based grids for grids delivered with PROJ

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Status
Adopted

Implementation target
PROJ 7

Last Updated
2020-01-28

12.5.5.1 Motivation

This RFC is a continuation of PROJ RFC 4: Remote access to grids and GeoTIFF grids. With RFC4, PROJ can, upon request of the user, download grids from a CDN in a progressive way. There is also API, such as proj_download_file() to be able to download a GeoTIFF grid in the user writable directory. The content of the CDN at https://cdn.proj.org is https://github.com/OSGeo/PROJ-data, which has the same content as https://github.com/OSGeo/proj-datumgrid converted in GeoTIFF files. In the current state, we could have a somewhat inconsistency between users relying on the proj-datumgrid, proj-datumgrid-[world,northamerica,oceania,eupe] packages of mostly NTv2 and GTX files, and what is shipped through the CDN. Maintaining two repositories is also a maintenance burden in the long term.

It is thus desirable to have a single source of truth, and we propose it to be based on the GeoTIFF grids.
• https://github.com/OSGeo/PROJ-data/ will be used, starting with PROJ 7.0, to create "static" grid packages.

• For now, a single package of, mostly GeoTIFF grids (a few text files for PROJ init style files, as well as a few edge cases for deformation models where grids have not been converted), will be delivered. Its size at the time of writing is 486 MB (compared to 1.5 GB of uncompressed NTv2 + GTX content, compressed to ~ 700 MB currently)

• The content of this archive will be flat, i.e. no subdirectories

• Each file will be named according to the following pattern ${agency_name}_${filename}[.ext]. For example fr_ign_ntf_r93.tif This convention should allow packagers, if the need arise, to be able to split the monolithic package in smaller ones, based on criterion related to the country.

The agency name is the one you can see from the directory names at https://github.com/OSGeo/PROJ-data/. ${agency_name} itself is structure like ${two_letter_country_code_of_agency_nationality}_${some_abbreviation} (with the exception of eur_nkg, for the Nordic Geodetic Commission which isn't affiliated to a single country but to some European countries, and follows the general scheme)

• https://github.com/OSGeo/proj-datumgrid and related packages will only be maintained during the remaining lifetime of PROJ 6.x. After that, the repository will no longer receive any update and will be put in archiving state (see https://help.github.com/en/github/creating-cloning-and-archiving-repositories/about-archiving-repositories)

• PROJ database grid_alternatives table will be updated to point to the new TIFF filenames. It will also maintain the old names as used by current proj-datumgrid packages to be able to provide backward compatibility when a PROJ string refers to a grid by its previous name.

• Upon adoption of this RFC, new grids referenced by PROJ database will only point to GeoTIFF grid names.

• Related to the above point, if a PROJ string refers to a grid name, let's say foo.gsb. This grid will first be looked for in all the relevant locations under this name. If no match is found, then a lookup in the grid_alternatives table will be done to retrieve the potential new name (GeoTIFF file), and if there’s such match, a new look-up in the file system will be done with the name of this GeoTIFF file.

• The package_name column of grid_alternatives will no longer be filled. And url will be filled with the direct URL to the grid in the CDN, for example: https://cdn.proj.org/fr_ign_ntf_r93.tif

• The Python scripts to convert grids (NTv2, GTX) to GeoTIFF currently available at https://github.com/rouault/sample_proj_gtiff_grids/ will be moved to a grid_tools/subdirectories of https://github.com/OSGeo/PROJ-data/ Documentation for those utilities will be added to PROJ documentation.

• Obviously, all the above assumes PROJ builds to have libtiff enabled. Non-libtiff builds are not considered as nominal PROJ builds (if a PROJ master build is attempted and libtiff is not detected, it fails. The user has to explicitly ask to disable TIFF support), and users deciding to go through that route will have to deal with the consequences (that is that grid-based transformations generated by PROJ will likely be non working)
12.5.5.3 Backward compatibility

This change is considered to be mostly backward compatible. There might be impacts for software using proj_coordoperation_get_grid_used() and assuming that the url returned is one of the proj-datumgrid-xxx files at https://download.osgeo.org. As mentioned in https://lists.osgeo.org/pipermail/proj/2020-January/009274.html, this assumption was not completely bullet-proof either. There will be impacts on software checking the value of PROJ pipeline strings resulting proj_create_crs_to_crs(). The new grid names will now be returned (the most impacted software will likely be PROJ’s own test suite)

Although discouraged, people not using the new proj-datumgrid-geotiff-XXX.zip archives, should still be able to use the old archives made of NTv2/GTX files, at least as long as the PROJ database does not only point to a GeoTIFF grid. So this might be a short-term partly working solution, but at time goes, it will become increasingly non-working. The nominal combination will be PROJ 7.0 + proj-datumgrid-geotiff-1.0.zip

12.5.5.4 Testing

PROJ test suite will have to be adapted for the new TIFF based filenames.

Mechanism to auto-promote existing NTv2/GTX names to TIFF ones will be exercised.

12.5.5.5 Proposed implementation

https://github.com/OSGeo/PROJ/pull/1891 and https://github.com/OSGeo/PROJ-data/pull/5

12.5.5.6 Adoption status

The RFC was adopted on 2020-01-28 with +1’s from the following PSC members

- Kristian Evers
- Even Rouault
- Thomas Knudsen
- Howard Butler
- Kurt Schwehr

12.5.6 PROJ RFC 6: Triangulation-based transformations

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Status
Adopted

Implementation target
PROJ 7.2

Last Updated
2020-09-02
12.5.6.1 Summary

This RFC adds a new transformation method, *tinshift* (TIN stands for Triangulated Irregular Network).

The motivation for this work is to be able to handle the official transformations created by National Land Survey of Finland, for:

- horizontal transformation between the KKJ and ETRS89 horizontal datums
- vertical transformations between N43 and N60 heights, and N60 and N2000 heights.

Such transformations are somehow related to traditional grid-based transformations, except that the correction values are hold by the vertices of the triangulation, instead of being at nodes of a grid.

Triangulation are in a number of cases the initial product of a geodesic adjustment, with grids being a derived product. The Swiss grids have for example derived products of an original triangulation.

Grid-based transformations remain very convenient to use because accessing correction values is really easy and efficient, so triangulation-based transformations are not meant as replacing them, but more about it being a complement, that is sometimes necessary to be able to replicate the results of an officially vetted transformation to a millimetric or better precision (speaking here about reproducibility of numeric results, rather than the physical accuracy of the transformation that might rather be centimetric). It is always possible to approach the result of the triangulation with a grid, but that may require to adopt a small grid step, and thus generate a grid that can be much larger than the original triangulation.

12.5.6.2 Details

Transformation

A new transformation method, *tinshift*, is added. It takes one mandatory argument, *file*, that points to a JSON file, which contains the triangulation and associated metadata. Input and output coordinates must be geographic or projected. Depending on the content of the JSON file, horizontal, vertical or both components of the coordinates may be transformed.

The transformation is used like:

```
$ echo 3210000.0000 6700000.0000 0 2020 | cct +proj=tinshift +file=./triangulation_kkj.json
```

```
209948.3217 6697187.0009 0.0000 2020
```

The transformation is invertible, with the same computational complexity than the forward transformation.

Algorithm

Internally, *tinshift* ingest the whole file into memory. It is considered that triangulation should be small enough for that. The above mentioned KKJ to ETRS89 triangulation fits into 65 KB of JSON, for 1449 triangles and 767 vertices.

When a point is transformed, one must find the triangle into which it falls into. Instead of iterating over all triangles, we build a in-memory quadtree to speed-up the identification of candidates triangles. On the above mentioned KKJ -> ETRS89 triangulation, this speeds up the whole transformation by a factor of 10. The quadtree structure is a very good compromise between the performance gain it brings and the simplicity of its implementation (we have ported the implementation coming from GDAL, inherit from the one used for shapefile .spx spatial indices).

To determine if a point falls into a triangle, one computes its 3 barycentric coordinates from its projected coordinates, \( \lambda_i \) for \( i = 1, 2, 3 \). They are real values (in the [0,1] range for a point inside the triangle), giving the weight of each of the 3 vertices of the triangles.
Once those weights are known, interpolating the target horizontal coordinate is a matter of doing the linear combination of those weights with the target horizontal coordinates at the 3 vertices of the triangle ($X_t$ and $Y_t$):

$$
\begin{align*}
X_{\text{target}} &= X_t_1 \ast \lambda_1 + X_t_2 \ast \lambda_2 + X_t_3 \ast \lambda_3 \\
Y_{\text{target}} &= Y_t_1 \ast \lambda_1 + Y_t_2 \ast \lambda_2 + Y_t_3 \ast \lambda_3
\end{align*}
$$

This interpolation is exact at the vertices of the triangulation, and has linear properties inside each triangle. It is completely equivalent to other formulations of triangular interpolation, such as

$$
\begin{align*}
X_{\text{target}} &= A + X_{\text{source}} \ast B + Y_{\text{source}} \ast C \\
Y_{\text{target}} &= D + X_{\text{source}} \ast E + Y_{\text{source}} \ast F
\end{align*}
$$

where the $A$, $B$, $C$, $D$, $E$, $F$ constants (for a given triangle) are found by solving the 2 systems of 3 linear equations, constraint by the source and target coordinate pairs of the 3 vertices of the triangle:

$$
\begin{align*}
X_t_i &= A + X_s_i \ast B + Y_s_i \ast C \\
Y_t_i &= D + X_s_i \ast E + Y_s_i \ast F
\end{align*}
$$

**Note:** From experiments, the interpolation using barycentric coordinates is slightly more numerically robust when interpolating projected coordinates of amplitude of the order of $1e5 / 1e6$, due to computations involving differences of coordinates. Whereas the formulation with the $A$, $B$, $C$, $D$, $E$, $F$ tends to have big values for the $A$ and $D$ constants, and values close to 0 for $C$ and $E$, and close to 1 for $B$ and $F$. However, the difference between the two approaches is negligible for practical purposes (below micrometre precision).

Similarly for a vertical coordinate transformation, where $Z_{\text{off} f_i}$ is the vertical offset at each vertex of the triangle:

$$
Z_{\text{target}} = Z_{\text{source}} + Z_{\text{off} f_1} \ast \lambda_1 + Z_{\text{off} f_2} \ast \lambda_2 + Z_{\text{off} f_3} \ast \lambda_3
$$

**Constraints on the triangulation**

No check is done on the consistence of the triangulation. It is highly recommended that triangles do not overlap each other (when considering the source coordinates or the forward transformation, or the target coordinates for the inverse transformation), otherwise which triangle will be selected is unspecified. Besides that, the triangulation does not need to have particular properties (like being a Delaunay triangulation).

**File format**

To the best of our knowledge, there are no established file formats to convey geodetic transformations as triangulations. Potential similar formats to store TINs are ITF or XMS. Both of them would need to be extended in order to handle datum shift information, since they are both intended for mostly DEM use.

We thus propose a text-based format, using JSON as a serialization. Using a text-based format could potentially be thought as a limitation performance-wise compared to binary formats, but for the size of triangulations considered (a few thousands triangles / vertices), there is no issue. Loading such file is a matter of 20 milliseconds or so. For reference, loading a triangulation of about 115 000 triangles and 71 000 vertices takes 450 ms.

Using JSON provides generic formatting and parsing rules, and convenience to create it from Python script for examples. This could also be easily generated "at hand" by non-JSON aware writers.

For generic metadata, we reuse closely what has been used for the Deformation model master file

Below a minimal example, from the KKJ to ETRS89 transformation, with just a single triangle:
So after the generic metadata, we define the input and output CRS (informative only), and that the transformation affects horizontal components of coordinates. We name the columns of the vertices and triangles arrays. We defined...
the source and target coordinates of each vertex, and define a triangle by referring to the index of its vertices in the vertices array.

More formally, the specific items for the triangulation file are:

**input_crs**
String identifying the CRS of source coordinates in the vertices. Typically EPSG:XXXX. If the transformation is for vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89 transformation, this is EPSG:2393 (KKJ / Finland Uniform Coordinate System). The input coordinates are assumed to be passed in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and easting, northing for projected coordinates.

**output_crs**
String identifying the CRS of target coordinates in the vertices. Typically EPSG:XXXX. If the transformation is for vertical component, this should be the code for a compound CRS (can be EPSG:XXXX+YYYY where XXXX is the code of the horizontal CRS and YYYY the code of the vertical CRS). For example, for the KKJ->ETRS89 transformation, this is EPSG:3067 (ETRS89/TM35FIN(E,N)). The output coordinates will be returned in the "normalized for visualisation" / "GIS friendly" order, that is longitude, latitude for geographic coordinates and easting, northing for projected coordinates.

**transformed_components**
Array which may contain one or two strings: "horizontal" when horizontal components of the coordinates are transformed and/or "vertical" when the vertical component is transformed.

**vertices_columns**
Specify the name of the columns of the rows in the vertices array. There must be exactly as many elements in vertices_columns as in a row of vertices. The following names have a special meaning: source_x, source_y, target_x, target_y, source_z, target_z and offset_z. source_x and source_y are compulsory. source_x is for the source longitude (in degree) or easting. source_y is for the source latitude (in degree) or northing. target_x and target_y are compulsory when horizontal is specified in transformed_components. (source_z and target_z) or offset_z are compulsory when vertical is specified in transformed_components.

**triangles_columns**
Specify the name of the columns of the rows in the triangles array. There must be exactly as many elements in triangles_columns as in a row of triangles. The following names have a special meaning: idx_vertex1, idx_vertex2, idx_vertex3. They are compulsory.

**vertices**
An array whose items are themselves arrays with as many columns as described in vertices_columns.

**triangles**
An array whose items are themselves arrays with as many columns as described in triangles_columns. The value of the idx_vertexN columns must be indices (between 0 and len(vertices)-1) of items of the vertices array.

**Code impacts**

The following new files are added in src/transformations:

- tinshift.cpp: PROJ specific code for defining the new operation. Takes care of the input and output coordinate conversions (between input_crs and triangulation_source_crs, and triangulation_target_crs and output_crs), when needed.
- tinshift.hpp: Header-based implementation. This file contains the API.
- tinshift_exceptions.hpp: Exceptions that can be raised during file parsing
• tinshift_impl.hpp: Implementation of file loading, triangle search and interpolation.

This is the approach that has been followed for the deformation model implementation, and which makes it easier to do unit test.

src/quadtree.hpp contains a quadtree implementation.

Performance indications

Tested on Intel(R) Core(TM) i7-6700HQ CPU @ 2.60GHz, transforming 4 million points

For the KKJ to ETRS89 transformation (1449 triangles and 767 vertices), 4.4 million points / sec can be transformed.

For comparison, the Helmert-based KKJ to ETRS89 transformation operates at 1.6 million points / sec.

A triangulation with about 115 000 triangles and 71 000 vertices operates at 2.2 million points / sec (throughput on more points would be better since the initial loading of the triangulation is non-negligible here)

12.5.6.3 Backward compatibility

New functionality fully backward compatible.

12.5.6.4 Testing

The PROJ test suite will be enhanced to test the new transformation, with a new .gie file, and a C++ unit test to test at a lower level.

12.5.6.5 Documentation

• The tinshift method will be documented.
• The JSON format will be documented under https://proj.org/specifications/
• A JSON schema will also be provided.

12.5.6.6 Proposed implementation

An initial implementation is available at https://github.com/rouault/PROJ/tree/tinshift

12.5.6.7 References

Finnish coordinate transformation (automated translation to English)
12.5.6.8 Adoption status

The RFC was adopted on 2020-09-02 with +1’s from the following PSC members

- Kristian Evers
- Charles Karney
- Thomas Knudsen
- Even Rouault

12.5.6.9 Funding

This work is funded by National Land Survey of Finland

12.5.7 PROJ RFC 7: Drop Autotools, maintain CMake

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Status
Adopted

Implementation target
PROJ 9.0

Last Updated
2021-10-27

12.5.7.1 Summary

This RFC proposes to drop Autotools for PROJ 9.0, and to maintain CMake for build automation, testing and packaging. This will reduce the overall maintenance for PROJ and will enable the library to be integrated into other projects that use CMake.

12.5.7.2 Background

Here is a short timeline of the build tools used for PROJ:

- Throughout the mid-1990s, Gerald Evenden maintained a Unix build system with a few scripts (some derived from Autoconf), and Makefile templates.
- In 2000, Frank Warmerdam wrote Autoconf and Automake configurations for PROJ 4.4.0.
- This was followed by a NMake configuration to build PROJ 4.4.2 for Windows.
- In 2014, a CMake build setup was introduced by Howard Butler for PROJ 4.9.0RC1. The CMake configuration was improved for the 4.9.1 release, but not considered at feature parity with the Autotools builds at the time.
- The NMake build setup was removed for PROJ 6.0.0, as its functionality had been replaced by CMake.
12.5.7.3 Motivation

The primary motivation in removing Autotools is to reduce the burden of maintaining multiple build configurations, which requires developers to be familiar with different tools and configuration files. There are several other benefits in maintaining a single build system:

- Remove extra configuration and m4 macro files from source repository,
- Simplify scripts used for running tests for CI services (GitHub Actions, TravisCI),
- Reduce compilation time (and carbon footprint) used for testing on CI services,
- Ease development effort, particularly with new contributors.

12.5.7.4 Why drop Autotools?

The GNU Build System or Autotools consist of a suite of tools including Autoconf and Automake, which can be used to build software on Unix-like systems. These tools are not cross-platform, and do not naively integrate with development environments on Microsoft Windows. Furthermore, the existing PROJ Autotools builds do not install the CMake configuration files required to find PROJ from other projects that use CMake (#2546).

12.5.7.5 Why use CMake?

CMake is an open source cross-platform tool for build automation, testing and packaging of software. It does not directly compile the software, but manages the build process using generators, including Unix Makefiles and Ninja among other command-based and IDE tools. The CMake software has been under active development since its origins in 2000. The CMake language is carefully developed with backwards-compatible policies that aim to provide consistent behavior across different versions. CMake is currently the preferred build tool for PROJ for the following reasons:

- It has existed in the PROJ code base since 2014, and is familiar to active PROJ contributors,
- It can install configuration files that can be used by other software that use CMake to find PROJ for linking via `find_package()`,
- CMake configurations are used in 3rd-party binary packages of PROJ, including conda-forge and vcpkg,
- It can be used to build PROJ on all major operating systems and compiler combinations (where compatible),
- It has integration with modern IDEs and tools, including Microsoft Visual Studio and Qt Creator.

12.5.7.6 Why not CMake?

Other modern cross-platform build systems exist, including Meson and Bazel, which have many advantages over CMake. However, they are currently not widely used by active PROJ contributors. This RFC should not restrict future build system configurations being introduced to PROJ, if they are proven to have advantages to CMake over time.
12.5.7.7 Potential impacts

Binary packagers that currently rely on Autotools would obviously need to transition building and testing PROJ with CMake. Issues related to multiarch builds of PROJ may become apparent, which can be patched and/or reported to PROJ developers. One feature of Autotools is that both static and dynamic (shared) libraries are built, which packagers may distribute. This feature is currently not set-up for PROJ, as it would need to be configured and built twice.

End-users that use binary packages of PROJ should not be impacted. PROJ should be discoverable via both pkg-config and CMake's find_package(). Other projects that use Autotools will continue to work as expected, linking statically or dynamically to PROJ built by CMake.

12.5.7.8 Transition plan

If this proposal is approved, the following tasks should be completed:

- Rewrite CI tests to only use CMake for packaging, building, testing, installation and post-install tests,
- Remove files only used by Autotools, also update .gitignore,
- Update documentation and HOWTORELEASE notes.

Related issues will be tracked on GitHub with a tag RFC7: Autotools→CMake.

12.5.7.9 Adoption status

The RFC was adopted on 2021-10-26 with +1’s from the following PSC members

- Kristian Evers
- Even Rouault
- Howard Butler
- Thomas Knudsen
- Kurt Schwehr
- Charles Karney
- Thomas Knudsen
13.1 Transformation tutorial

13.1.1 Introduction

This tutorial was developed for the EUREF 2019 Symposium as an introduction to geodetic transformations in PROJ. The intended audience was geodesist in governmental geodetic agencies but the tutorial should be of interest to a broader group of people within GIS, remote sensing and related fields.

The tutorials gives insight into how transformations are set up using the "PROJ language" as well as introduce most of the command line applications packaged with PROJ. In the tutorial properties of several common projections and transformations are investigated.

The tutorial requires a working installation of PROJ. Consult the chapter on installing PROJ.

13.1.2 How to fill out the PROJ tutorial exercises

All the exercises are made as gie tests where one or more inputs are missing. Replace occurrences of <your answer here> with the relevant input. Below is an annotated example of a complete gie test. Your objective is to fill out the exercises from 1 and onwards in a similar fashion.

Below is a simple exercise before the answer has been filled in:

1. Set up an operation that returns the input it is given

```
operation <your answer here>
tolerance 10 mm
accept 12.3 45.6
expect 12.3 45.6
```

An annotated answer could look like this:

```
<gie>
operation +proj=latlon # The latlon "projection" returns the same output as
# given in the input
tolerance 10 mm
accept 12.3 45.6
```

(continues on next page)
The `gie` application can be used to check if the exercise has been answered correctly:

```
gie exercises\<exercise_name>.gie
```

If all answers are correct `gie` will return output similar to:

```
-------------------------------------------------------------------------------
Reading file 'exercises\instructions.md'
-------------------------------------------------------------------------------
total: 1 tests succeeded, 0 tests skipped, 0 tests failed.
-------------------------------------------------------------------------------
```

If incorrect, `gie` will output something like:

```
-------------------------------------------------------------------------------
Reading file 'exercises\instructions.md'
-----
    FAILURE in instructions.md(48):
expected: 12.3 45.6
    got:  1369229.736757265171 5685937.873489554040
    deviation: 999999999.999000 mm, expected: 10.000000 mm
-------------------------------------------------------------------------------
total: 0 tests succeeded, 0 tests skipped, 1 tests FAILED!
-------------------------------------------------------------------------------
```

Where the number of failing exercises (or tests in `gie` terminology) is given, as well as the line number of the failing test (in parenthesis after the file name).

### 13.1.3 Exercises

#### 13.1.3.1 The UTM projection

In this exercise we will learn how to define a simple projection using PROJ. We will investigate a few aspects of the UTM projection, as well as learn how to use a different ellipsoid than the default (GRS80).

Download the `gie` file for the exercise: `projections1.gie`.

**Exercise 1: Setting up a projection**

Set up a UTM projection for use in Estonia.

**Hint:** See *Universal Transverse Mercator (UTM)* for more on the projection
Exercise 2: UTM on the southern hemisphere

Set up a UTM projection for use on the North Island of New Zealand.

Hint: See *Universal Transverse Mercator (UTM)* for more on the projection

| operation  | <your answer here> |
| tolerance  | 1 cm           |

| accept     | 174.740        | -36.841        # Auckland, New Zealand |
| expect     | 298481.34      | 5920382.04     |

Exercise 3: Using a non-standard ellipsoid

Set up a UTM projection based on the Hayford ellipsoid for use in Estonia.

Hint: See *Universal Transverse Mercator (UTM)* for more on the projection

| operation  | <your answer here> |
| tolerance  | 1 cm           |

| accept     | 24.745         | 59.437         # Talinn, Estonia |
| expect     | 372099.99      | 6591034.35     |

13.1.3.2 The Lambert Conic Conformal projection

In this exercise we will introduce the Lambert Conic Conformal (LCC) projection as well as general map projection concepts such as projection center, scale factor, false easting/northing and ellipsoid models.

We will do so by defining various versions of the LCC optimised for use in and around the Gulf of Finland.

In case you are not familiar with the LCC projection, *Wikipedia* describes the Lambert Conic Conformal projection as:

“A Lambert conformal conic projection (LCC) is a conic map projection used for aeronautical charts, portions of the State Plane Coordinate System, and many national and regional mapping systems. It is one of seven projections introduced by Johann Heinrich Lambert in his 1772 publication Anmerkungen und Zusätze zur Entwerfung der Land- und Himmelscharten (Notes and Comments on the Composition of Terrestrial and Celestial Maps).

Conceptually, the projection seats a cone over the sphere of the Earth and projects the surface conformally onto the cone. The cone is unrolled, and the parallel that was touching the sphere is assigned unit scale. That parallel is called the reference parallel or standard parallel.”
By scaling the resulting map, two parallels can be assigned unit scale, with scale decreasing between the two parallels and increasing outside them. This gives the map two standard parallels. In this way, deviation from unit scale can be minimized within a region of interest that lies largely between the two standard parallels. Unlike other conic projections, no true secant form of the projection exists because using a secant cone does not yield the same scale along both standard parallels.

Download the gie file for the exercise: projections2.gie.

**Exercise 1: Standard parallel**

Set up a LCC projection with one standard parallel placed halfway between Helsinki and Tallinn.

**Hint:**
- Approximate location of Helsinki: 60.171N 24.938E
- Approximate location of Tallinn: 59.437N 24.745E
- Approximate mid point between Helsinki and Tallinn: 59.8N 24.8E

**Hint: See Lambert Conformal Conic** for more on the Lambert Conformal Conic projection

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>accept</td>
<td>24.938</td>
</tr>
<tr>
<td>expect</td>
<td>1351962.01</td>
</tr>
<tr>
<td></td>
<td>298663.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>accept</td>
<td>24.745</td>
</tr>
<tr>
<td>expect</td>
<td>1371811.19</td>
</tr>
<tr>
<td></td>
<td>59.437</td>
</tr>
<tr>
<td></td>
<td>218598.22</td>
</tr>
</tbody>
</table>

**Exercise 2: Distance distortion**

Improve the distance distortion of the projection.

The projection defined above is conformal, i.e. has no angular distortions for infinitesimal objects - but there is a minor distortion of distances. This cannot be avoided in general, but locally distortions can be minimized by adjusting the scale factor.

With the default factor of 1, the distance error is 0 for (infinitesimal) line segments at the latitude of the standard parallel.

By reducing the scale factor, the line of zero distance distortion degenerates into two lines, north and south of the standard parallel.

For the abovementioned point in Tallinn, the distance error is around 0.002%, but this can be reduced to zero by varying the scaling factor.

Even by trial and error it is not hard to reduce it to a few millionths of a percent. So try to find a more optimal scaling factor by trial and error using the projection analysis functionality of the proj application.

**Hint:** Modify and use the command below to find a better scaling factor:
echo 24.745 59.437 | proj -V <your projection setup here>

**Hint:** Look for the lines displaying the meridian and parallel scale.

**Hint:** Consult the LCC documentation to find out how to set the scaling factor.

**Hint:** Scaling factors usually deviates from unity by the order of \(1\times10^{-3}\) to \(1\times10^{-5}\)

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 um</td>
</tr>
<tr>
<td>accept</td>
<td>24.745 59.437</td>
</tr>
<tr>
<td>expect</td>
<td>1371783.759883408</td>
</tr>
</tbody>
</table>

**Exercise 3: Using two standard parallels**

Set up a similar LCC projection, this time using two standard parallels. The first passing through Helsinki, the second through Tallinn.

**Hint:**
- Approximate location of Helsinki: 60.171N 24.938E
- Approximate location of Tallinn: 59.437N 24.745E

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 cm</td>
</tr>
<tr>
<td>accept</td>
<td>24.8 59.8</td>
</tr>
<tr>
<td>expect</td>
<td>1359907.80 8024082.260</td>
</tr>
</tbody>
</table>

**Exercise 4: Projection center**

Change the projection center to the midway point between Helsinki and Tallinn.

By changing the projection center we move the origin of the output coordinates to be coinciding with the position where the projection is most accurate.

**Hint:** Start with the projection you designed in exercise 1 above

**Hint:** The mid point between Helsinki and Tallinn is roughly 59.8N 24.8E
**Exercice 5: False easting and northing**

Introduce false eastings and northings.

Oftentimes it is preferable to keep coordinate values positive even when moving west and south of the projection center. This can be achieved by introducing false easting and northing. Add false easting and northing of 1000000.

**13.1.3.3 Specifying ellipsoid models**

In this exercise we will introduce some of the many ways one can specify the ellipsoid model used in projections and transformations.

We will be using the Mercator projection to illustrate the different ellipsoid settings, but note that the same parameter settings can be used for setting the ellipsoid used for most PROJ projections and transformations.

Download the `gie` file for the exercise: `ellipsoids.gie`.

**Exercise 1: Ellipsoid radius**

Use a sphere of radius 1 as the ellipsoid model.

**Hint:** Check the Mercator documentation to find out how to specify an ellipsoid.
Exercise 2. Specifying a ellipsoid

Set up a Mercator projection that uses the Hayford (International) ellipsoid

Hint: Check the Mercator documentation to find out how to specify an ellipsoid

Hint: Running proj -le will return a list of ellipsoids and their parameters.

| operation | +proj=merc | <your answer here> |
| tolerance | 1 cm |
| accept    | 24.745    | 59.437           | # Talinn |
| expect    | 2754709.2020 | 8238786.4803 |

Exercise 3. Semimajor axis and inverse flattening

Specify the Hayford ellipsoid by its semimajor axis radius and inverse flattening

Hint: Find the parameters in the list returned by proj -le

| operation | +proj=merc | <your answer here> |
| tolerance | 1 cm |
| accept    | 24.745    | 59.437           | # Talinn |
| expect    | 2754709.2020 | 8238786.4803 |

Exercise 4. Semimajor and semiminor ellipsoid axes

Set the Clarke 1866 ellipsoid by its semimajor and semiminor axis radii

| operation | +proj=merc | <your answer here> |
| tolerance | 1 cm |
| accept    | 24.745    | 59.437           | # Talinn |
| expect    | 2754630.7723 | 8238298.4968 |

13.1.3.4 Gridshifting

Sometimes it is simpler to define a transformation as a gridded model of displacements rather than a mathematical model. This approach, pioneered by the US National Geodetic Survey in their 1980s era transformation from the old NAD27 datum to the (back then) new NAD83, has become increasingly popular as disk space and CPU cycles have gotten cheaper.

Gridded models of displacements offer the ability to make local adjustments that are not possible with e.g. a Helmert transformation. This fact is especially leveraged in transformations of heights since the geoid is too bumpy to retain enough detail with a simple mathematical definition.
The main problem with grid shifting is availability of the grids needed for a given transformation. The PROJ package requires that the PROJ-data package is installed alongside it.

Download the gie file for the exercise: gridshift.gie.

### Exercises 1. Horizontal gridshifting

In this exercise we will apply a horizontal grid shift as it is done in the transformation from the German DHDN to ETRS89 transformation.

Define the operation that converts from DE_DHDN to ETRS89 using a gridshift.

**Hint:** See [Horizontal grid shift](#)

**Hint:** Find the relevant grid name by inspecting the output of

```
projinfo -s DHDN -t ETRS89 -o WKT2_2019
```

Note that two operations are returned, look for the one which uses the "NTv2" method.

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 mm</td>
</tr>
<tr>
<td>accept</td>
<td>13.0 52.0 0.0</td>
</tr>
<tr>
<td>expect</td>
<td>12.9983317082 51.9986488216 0.0</td>
</tr>
</tbody>
</table>

### 2. Vertical gridshifting

The most common use case for vertical grid shifts is transformation from ellipsoidal heights to physical heights. In most cases this is equivalent to applying an offset from a geoid model, which is exactly what we will do in this exercise.

Set up an operation that transforms ellipsoidal heights to physical heights using the EGM96 model.

**Hint:** See [Vertical grid shift](#)

**Hint:** The relevant grid name is "us_nga_egm96_15.tif"

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 mm</td>
</tr>
<tr>
<td>accept</td>
<td>13.0 52.0 100.0</td>
</tr>
<tr>
<td>expect</td>
<td>13.0 52.0 58.1917</td>
</tr>
</tbody>
</table>
13.1.3.5 The Helmert transformation

In this set of exercises we investigate the Helmert Transformation and some of its properties. The Helmert transformation covers a wide range of configurations, from simple translations of coordinates to the fully-fledged spatiotemporal transformation. Consult Wikipedia and Helmert transform for in-depth technical details on the transformation.

The Helmert transformation works on geocentric, cartesian coordinates. See the Coordinate conversions exercise for more info. In this exercise all coordinates are already given as cartesian coordinates, so you only need to focus on the actual transformation setup.

Download the gie file for the exercise: helmert.gie.

1. Simple coordinate translation

The most basic application of the Helmert transformation is a translation of the x-, y- and z-components of the coordinate. This is rarely a good fit for large areas but locally a 3 parameter Helmert shift can be very effective. Even though the 3 parameter translation doesn’t fit particularly well in large areas of use it is still commonly used between legacy and modern systems. In this exercise we will use a transformation between ED50 in Italy (Sardinia) and WGS84.

**Hint:** You can find the transformations parameters by running the following command:

```bash
projinfo -o WKT2_2019 -k operation EPSG:1142
```

which returns the WKT2 definition of the transformation.

**Hint:** Remember that the input to the Helmert transform is cartesian geocentric coordinates (x, y z).

**Hint:** See Helmert transform to find out how to set up the transformation

| operation | <your answer here> |
| tolerance  | 1 m |
| accept     | 4826177.7574 4049643.9762 991162.2529 # Sardinia (40N, 9E) |
| expect     | 4826080.7574 4049540.9762 991042.2529 |

2. Translation and rotation

For larger areas it is not enough to just rely on translation of coordinates. In that case the solution is to include rotations of the axes and a scale adjustment. The rotational aspect of the transformation is handled by a set of three rotation matrices. Two conventions for the application of the rotations are in common use: Position Vector and Coordinate Frame. In this exercise we will using Position Vector. See the PROJ documentation on the Helmert transformation for further detail.

**Hint:** You can find the transformations parameters by running the following command:

```bash
projinfo -o WKT2_2019 -k operation EPSG:1626
```
3. Position vector/Coordinate frame

Effectively, the difference between the two rotation conventions is the sign of the rotation parameters. In this exercise we will examine this property by looking at a transformation between the German DHDN reference system and ETRS89.

First find the parameters for the EPSG:1309 transformation. In 3a below, enter the parameters as reported by projinfo (using the coordinate frame convention). Adapt the parameters to the position vector convention in 3b.

**Hint:** You can find the transformations parameters by running the following command:

```
projinfo -o WKT2_2019 -k operation EPSG:1309
```

* 3a:

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt; +convention=coordinate_frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>accept</td>
<td>4067886.6403 571704.1839 4862789.0376</td>
</tr>
<tr>
<td>expect</td>
<td>4068519.1921 571728.6671 4863239.3787</td>
</tr>
</tbody>
</table>

* 3b:

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt; +convention=position_vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 m</td>
</tr>
<tr>
<td>accept</td>
<td>4067886.6403 571704.1839 4862789.0376</td>
</tr>
<tr>
<td>expect</td>
<td>4068519.1921 571728.6671 4863239.3787</td>
</tr>
</tbody>
</table>

4. Kinematic transformation between ITRF2008 and ITRF2014

The Helmert transformation also exists in a kinematic, or spatiotemporal, version. This takes the evolution of a coordinate reference system over time into account as well. This is done by pivoting about a reference epoch. The 14-parameter spatiotemporal Helmert is used when super high accuracy transformations are needed. A good example of such a use case is transformations between various realizations of ITRS and ETRS89. In this exercise we look at the transformation from ITRF2008 to ITRF2014.

**Hint:** You can find the transformations parameters by running the following command:

```
projinfo -o WKT2_2019 -s ITRF2008 -t ITRF2014
```
which returns the WKT2 definition of the transformation.

**Hint:** Not all parameters need to be set.

**Hint:** Pay attention to the units of the parameters output by projinfo, you may have to convert them to standard units (e.g. mm -> m).

**Hint:** Note that the coordinates in the test now also includes a time tag in the form of a decimalyear - This is always needed when doing spatiotemporal transformations in PROJ. The time tag is the observation time of the coordinate. Note that the time component of the coordinate is never affected by the transformation.

<table>
<thead>
<tr>
<th>Operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tolerance</td>
<td>1 mm</td>
</tr>
<tr>
<td>Accept</td>
<td>2952736.3768 1360917.6894 5468849.5615 2019.5</td>
</tr>
<tr>
<td>Expect</td>
<td>2952736.3744 1360917.6871 5468849.5586 2019.5</td>
</tr>
</tbody>
</table>

### 13.1.3.6 Coordinate conversions

In ISO19111 terms, a coordinate conversion is an operation that changes coordinates in a source coordinate reference system to coordinates in a target coordinate reference system in which both coordinate reference systems are based on the same datum. Technically this is also true for PROJ although the term is usually narrowed a bit, excluding projections since those are the origin of PROJ they get special treatment.

In this exercise we will be looking at three coordinate conversions that in combination with other operations are very powerful: Unit conversions, axis swapping and geodetic to cartesian conversion. Here we only look at the conversions by themselves which isn't particularly useful, apart from the educational purpose. When used in transformation pipelines they reveal their true power. We will explore that further in the pipelines.gie exercises.

See *Conversions* for a list of all conversions available in PROJ.

Download the `gie` file for the exercise: `conversions.gie`.

#### 1. Unit conversion from meters to feet

Many projected coordinate systems are defined in terms of units other than the meter. In this exercise we will transform the horizontal part of a coordinate from meters to feet.

**Hint:** Consult *Unit conversion* to find out how to set up the transformation

**Hint:** You can use `proj -lu` to learn which units is supported by PROJ.

**Hint:** Note that the horizontal, vertical and temporal parts are treated separately by the unit convert operator.
2. Swapping axes

Many coordinate reference systems are defined such that the axis order is different than the (east, north, up, time) PROJ defaults to. An example of this is the standard representation of a latitude/longitude-pair, where the north component of the coordinate comes first. For this reason we need an operation that can swap the axes around so that a given coordinate reference system can be represented correctly, conforming to the intention of the defining authority.

Set up an operation that puts a longitude/latitude pair on the standard latitude/longitude form.

**Hint:** Consult *Axis swap* to find out how to set up the transformation

**Hint:** Remember that the axisswap operation doesn’t know anything about the nature of the coordinate that is passed to it - it only cares about the the order of the input.

3. Geodetic to cartesian conversion

Some transformations, most notably the Helmert transformation, operate on cartesian geocentric coordinates. Geodetic coordinates (latitude and longitude) is the most commonly used coordinate representation. It is only natural to have a way to convert between the two representations.

Set up a transformation that convert geodetic coordinates to cartesian geocentric coordinates on the Hayford ellipsoid.

**Hint:** Consult *Geodetic to cartesian conversion* to find out how to set up the transformation

**Hint:** Remember that *proj -le* returns a list of available ellipsoid models

**Hint:** Remember that the Hayford ellipsoid is known under a number of other names - most of them including the term "international".
13.1.3.7 Transformation pipelines

In these exercises we will learn how to use Transformation Pipelines. Transformation Pipelines is a powerful construct in PROJ that allow users to combine several operations into one "super operation". Pipelines are used extensively internally in PROJ when a user asks for a transformation between two CRS's (for example when using \textit{cs2cs}). However, users can also write their own custom pipelines for specific purposes.

Before moving on to the exercises below, familiarize yourself with the \textit{pipeline operation in the documentation}. Pay special attention to the rules that govern the use of the pipeline operation.

Download the \textit{gie} file for the exercise: pipelines.gie.

1. Geodetic -> Helmert -> Geodetic

The signature use case for transformation pipelines is the Helmert transformation of geodetic coordinates.

As we have seen in the previous exercises, fundamentally, the Helmert operation works on cartesian coordinates. So when the input coordinates are geodetic, we must convert them to the cartesian space before applying the Helmert transformation.

Similarly, we must convert the transformed cartesian coordinates back to geodetic space to be able to compare the coordinates before and after transformation.

With that in mind, now create a transformation pipeline that take geodetic (longitude/latitude) coordinates, applies a Helmert transform, and returns geodetic coordinates (in a different datum).

To keep it simple we will use the GRS80 ellipsoid for both input and output datum, and a basic 3 parameter transformation, with translations 100,200,300, and using the position vector convention.

\begin{tabular}{ccc}
\textbf{operation} & <your answer here> \\
\textbf{tolerance} & 1 m \\
\textbf{accept} & 12.0 & 53.0 & 75.0 \\
\textbf{expect} & 12.00260406 & 53.00062190 & 398.48468 \\
\end{tabular}

\textbf{Hint}: Remember that in a pipeline step, the inverse of an operation is selected by adding \texttt{+inv} to the parameter list of the operation.
2. Sequential grid shifts

Create a transformation that applies both a horizontal and a vertical grid adjustment. Use the `de_adv_BETA2007.tif` and the `us_nga_egm96_15.tif` grids.

1. Does it matter which grid is applied first?
2. If yes, which goes first? Why?

**Hint:** See *Horizontal grid shift* and *Vertical grid shift*

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 cm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>accept</th>
<th>12.0</th>
<th>53.0</th>
<th>75.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>expect</td>
<td>11.99846399</td>
<td>52.99852627</td>
<td>34.541488647</td>
</tr>
</tbody>
</table>

3. ED50/UTM32 -> ETRS89/UTM33

A transformation from one coordinate reference system to another. A very common use case of transformation pipelines.

In this exercise we have UTM Zone 32 coordinates related to the ED50 datum, which we want to transform to UTM Zone 33 related to ETRS89.

The transformation goes

1. Back-projection
2. Geodetic to cartesian conversion
3. Helmert transformation
4. Cartesian to geodetic conversion
5. Re-projection

which is a very common recipe for transformations between projected coordinate systems.

**Hint:** Find the relevant Helmert parameters by running:

```
projinfo -k operation EPSG:1626 -o WKT2_2019
```

**Hint:** If you can't remember which ellipsoids is used by ED50 and ETRS89 you can look them up with:

```
projinfo <datum>
```

**Hint:** Relevant documentation:

1. *Universal Transverse Mercator (UTM)*
2. *Geodetic to cartesian conversion*
3. Helmert transform

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>1 cm</td>
</tr>
<tr>
<td>accept</td>
<td>687080.63 6210278.55 0</td>
</tr>
<tr>
<td>expect</td>
<td>312871.16 6210214.58 34.08</td>
</tr>
</tbody>
</table>

4. A pipeline from the Real World

The transformation between the German DHDN and ETRS89 is a transformation pipeline consisting of eight steps. Lookup the transformation with projinfo:

```
projinfo -k operation EPSG:1776
```

and copy and paste the pipeline definition as your answer below. Try to decipher the pipeline and answer the following questions:

1. What is the input coordinate type and units?
2. What is the output coordinate type and units?
3. What is the purpose of the +proj=push and +proj=pop steps?

**Hint:** A pipeline definition can span several lines in the gie format. Use this to your advantage and put each step on its own separate line for easier reading

**Hint:** You can use projinfo to get more knowledge about a particular CRS:

```
projinfo <CRS name or code>
```

**Hint:** Look at Push coordinate value to pipeline stack and Pop coordinate value to pipeline stack to find out how to set up the transformation

<table>
<thead>
<tr>
<th>operation</th>
<th>&lt;your answer here&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>3 m</td>
</tr>
<tr>
<td>accept</td>
<td>12.0 53.0 75.0</td>
</tr>
<tr>
<td>expect</td>
<td>12.0032 52.9953 75.0000</td>
</tr>
</tbody>
</table>
13.1.3.8 The Transverse Mercator projection

In this exercise we will introduce the Transverse Mercator projection, the UTM projection and the relationship between the two.

In addition we will investigate the differences between the two Transverse Mercator implementations available in PROJ and when one should be used in favour of the other.

Download the gie file for the exercise: projections3.gie.

Exercise 1. Transverse Mercator with default parameters

Set up a Transverse Mercator projection using the default parameters.

**Hint:** Consult *Transverse Mercator*

| operation | <your answer here> |
| tolerance | 1 mm |
| accept | 24.745 | 56.437 # Talinn, Estonia |
| expect | 1506742.2481 | 6535299.3398 |

Exercise 2: Use the Transverse Mercator to model the UTM projection

The backbone of the UTM projection is a Transverse Mercator projection. In this exercise we will model the behavior of the UTM projection using the Transverse Mercator.

**Hint:** Remember that the UTM projection on the Northern Hemisphere uses a scale factor of 0.9996, a false easting of 500000 and a false northing of 0. UTM on the Southern Hemisphere is similar but with a false northing of 10000000.

**Hint:** The projection center is determined from the UTM zone and can be determined by zone*6 - 183

**Hint:** Tranverse Mercator parameters are documented at *Transverse Mercator*

| operation | <your answer here> |
| tolerance | 1 mm |
| accept | 24.745 | 56.437 # Talinn, Estonia |
| expect | 360965.5942 | 6256998.5609 |
Exercise 3: The less accurate, but faster, version of the Tranverse Mercator

As mentioned in the introduction to this set of exercises, two versions of the Transverse Mercator is implemented in PROJ. The default uses the Engsager/Poder algorithm which is accurate far away from the central meridian of the projection. The downside to this accuracy is that the algorithm is slower. The alternative algorithm, which is toggled by the +approx parameter, is faster but usage is recommended only within a few degrees away from the central meridian.

In this and the following exercises we will explore the accuracy of the two algorithms by checking the roundtrip stability of a number of transformations. A coordinate in Greenland will be used, as it is common practice to store geospatial data covering the whole country in the same UTM zone. This is only possible when using the correct algorithm. For the sake of simplicity, all operations in the following exercises are expressed as UTM projections. The UTM projection also has the +approx parameter which toggles the use of the faster, less accurate transverse mercator algorithm.

We will try to determine the approximate roundtrip accuracy of the +approx algorithm several UTM zones away from the actual zone for the given coordinate. For all the exercises below the aim is to find the lowest tolerance for each roundtrip test. You can of course make all tests pass by setting a tolerance of 1000 km - that's not the point: How low can you go?

After you have answered all exercise 3 questions below, based on your findings consider in which situation use of each of the algorithms is appropriate.

**Hint:** gie accepts most common SI unit prefixes to the meter when specifying the tolerance, e.g. km, m, dm, cm, mm, um, nm.

**Hint:** Look at the output gie produces - the difference between the actual result and the expected result is reported when tests fail.

**Exercise 3a**

As a baseline, determine the roundtrip accuracy of the default algorithm using UTM zone 22.

<table>
<thead>
<tr>
<th>operation</th>
<th>+proj=utm +zone=22</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>&lt;your answer here&gt;</td>
</tr>
<tr>
<td>accept</td>
<td>-20.0 74</td>
</tr>
<tr>
<td>roundtrip</td>
<td>1000</td>
</tr>
</tbody>
</table>

**Exercise 3b**

Determine the roundtrip accuracy of the +approx algorithm using UTM zone 22:

<table>
<thead>
<tr>
<th>operation</th>
<th>+proj=utm +zone=22 +approx</th>
</tr>
</thead>
<tbody>
<tr>
<td>tolerance</td>
<td>&lt;your answer here&gt;</td>
</tr>
<tr>
<td>accept</td>
<td>-20.0 74</td>
</tr>
<tr>
<td>roundtrip</td>
<td>1000</td>
</tr>
</tbody>
</table>
Exercise 3c

Determine the roundtrip accuracy of the \texttt{+approx} algorithm using UTM zone 23:

\begin{verbatim}
operation +proj=utm +zone=23 +approx
tolerance <your answer here>
accept -20.0 74 # Daneborg, Greenland
roundtrip 1000
\end{verbatim}

Exercise 3d

Determine the roundtrip accuracy of the \texttt{+approx} algorithm using UTM zone 24:

\begin{verbatim}
operation +proj=utm +zone=24 +approx
tolerance <your answer here>
accept -20.0 74 # Daneborg, Greenland
roundtrip 1000
\end{verbatim}

Exercise 3e

Determine the roundtrip accuracy of the \texttt{+approx} algorithm using UTM zone 25:

\begin{verbatim}
operation +proj=utm +zone=25 +approx
tolerance <your answer here>
accept -20.0 74 # Daneborg, Greenland
roundtrip 1000
\end{verbatim}

Exercise 3f

Determine the roundtrip accuracy of the \texttt{+approx} algorithm using UTM zone 26:

\begin{verbatim}
operation +proj=utm +zone=26 +approx
tolerance <your answer here>
accept -20.0 74 # Daneborg, Greenland
roundtrip 1000
\end{verbatim}
**Exercise 3g**

Determine the roundtrip accuracy of the +approx algorithm using UTM zone 27:

```
operation  +proj=utm +zone=27 +approx
tolerance   <your answer here>
accept       -20.0  74   # Daneborg, Greenland
roundtrip    1000
```

---

### 13.1.3.9 Answers to the PROJ tutorial exercises

**Projections1: UTM**

1. +proj=utm +zone=35
2. +proj=utm +zone=60 +south
3. +proj=utm +zone=35 +ellps=intl

**Projections2: LCC**

1. +proj=lcc +lat_1=59.8
2. +proj=lcc +lat_1=59.8 +k_0=0.99998
3. +proj=lcc +lat_1=59.437 +lat_2=60.171
4. +proj=lcc +lat_1=59.8 +lat_0=59.8 +lon_0=24.8
5. +proj=lcc +lat_1=59.8 +lat_0=59.8 +lon_0=24.8 +x_0=1000000 +y_0=1000000

**Ellipsoids**

1. +R=1
2. +ellps=intl
3. +a=6378388.0 +rf=297.0
4. +a=6378206.4 +b=6356583.8

**Helmert**

1. +proj=helmert +x=-97 +y=-103 +z=-120
2. +proj=helmert +x=-81.1 +y=-89.4 +z=-115.8 +rx=0.485 +ry=0.024 +rz=0.413 +s=-0.54
   →convention=position_vector
3a. +proj=helmert +x=582 +y=105 +z=414 +rx=-1.04 +ry=-0.35 +rz=3.08 +s=8.3
3b. +proj=helmert +x=582 +y=105 +z=414 +rx=1.04 +ry=0.35 +rz=-3.08 +s=8.3
1. +proj=helmert +convention=position_vector +x=-0.0016 +y=-0.0019 +z=-0.0024
   +s=2e-05 +dz=0.0001 +ds=-3e-05 +t_epoch=2010
Conversions

1. +proj=unitconvert +xy_in=m +xy_out=us-ft
2. +proj=axisswap +order=2,1
3. +proj=cart +ellps=intl

Gridshifts

1. +proj=hgridshift +grids=de_adv_BETA2007.tif
2. +proj=vgridshift +grids=us_nga_egm96_15.tif

Pipelines

1. +proj=pipeline +ellps=GRS80
   +step +proj=cart
   +step +proj=helmert +x=1000 +y=2000 +z=3000 +convention=position_vector
   +step +inv +proj=cart

2. +proj=pipeline
   +step +proj=hgridshift +grids=de_adv_BETA2007.tif
   +step +proj=vgridshift +grids=us_nga_egm96_15.tif

2.1: In principle, yes - practically, no.
2.2: Which grids is applied first depends on how the systems are defined.
    If a geoid model is fitted to a certain datum, you need to make sure that
    the input to the vgridshift operation is in that datum. That is your
    responsibility to check - PROJ can’t figure that out on its own. In this
    case, the EGM96 geoid is fitted to WGS84. The BETA2007 grid results in
    ETRS89 coordinates which for all but the most high accuracy application
    can be regarded as equivalent to WGS84. Hence we do the horizontal grid
    shift first.

3. +proj=pipeline
   +step +inv +proj=utm +zone=32
   +step +proj=cart +ellps=intl
   +step +proj=helmert +x=-81.1 +y=-89.4 +z=-115.8
   +rx=0.485 +ry=0.024 +rz=-0.413 +s=-0.54 +convention=position_vector
   +step +inv +proj=cart +ellps=GRS80
   +step +proj=utm +zone=33

4. +proj=pipeline
   +step +proj=axisswap +order=2,1
   +step +proj=unitconvert +xy_in=deg +xy_out=rad
   +step +proj=push +v_3 +step +proj=cart +ellps=bessel
   +step +proj=helmert +x=598.1 +y=73.7 +z=418.2
   +rx=0.202 +ry=0.045 +rz=-2.455 +s=6.7 +convention=position_vector
   +step +inv +proj=cart +ellps=GRS80
   +step +proj=pop +v_3

(continues on next page)
4.1: Latitude (deg), longitude (deg), height (m)
4.2: Latitude (deg), longitude (deg), height (m)
4.3: Retain the original height of the input coordinate:
Without the push/pop steps the height would be affected by
the Helmert step.

Projections3: Tranverse Mercator

1. +proj=tmerc
2. +proj=tmerc +k_0=0.9996 +lon_0=27 +x_0=500000
3a. 1 cm
3b. 250 km
3c. 100 km
3d. 10 km
3e. 500 m
3f. 2 m
3g. 5 um

13.2 Geodesics and planar approximations using PROJ and geod

The PROJ system supports computations with Geodesic calculations, through API calls or through the geod command line interface. This exercise will proceed mostly by having you copy sample commands from the text onto the command line, and noting the results.

The tutorial is written with the Windows command line in mind but it should be straightforward to use it on Unix-based systems as well.

Hint: Users of Unix-based systems can replace set with export and %VAR% with $VAR to follow the tutorial.
13.2.1 1. Objective

The objective of this exercise is to investigate how well a straight line in a projected plane approximates the geodesic between the same end points.

13.2.2 2. The geodesic

The geodesic we will consider runs from Helsinki to Tallinn, using the following coordinates:

<table>
<thead>
<tr>
<th>City</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helsinki</td>
<td>60.171 N</td>
<td>24.938 E</td>
</tr>
<tr>
<td>Tallinn</td>
<td>59.437 N</td>
<td>24.745 E</td>
</tr>
</tbody>
</table>

So to save some typing, let's define some environment variables. On Windows:

```plaintext
set HEL="60.171 24.938"
set TAL="59.437 24.745"
```

(export HEL="60.171 24.938"
export TAL="59.437 24.745")

(i.e. mark, copy, and paste these lines into the command prompt)

First, we want to solve the "inverse geodetic problem" for the geodesic, i.e. finding the azimuth and distance between the two points:

```plaintext
echo %HEL% %TAL% | geod -I +ellps=GRS80
```

where the `-I` option indicates "the inverse geodetic problem".

`geod` replies with these 3 numbers:

```
-172d22.772" 7d27'46.693" 82488.500
```

The first is the forward azimuth from Helsinki to Tallinn, the second is the return azimuth, while the third is the distance in meters.

We would actually rather have the azimuths in fractional degrees, so we provide an explicit output format, using the `-f` option to geod:

```plaintext
echo %HEL% %TAL% | geod -I -f "%.12f" +ellps=GRS80
```

getting us:

```
-172.370214337896 7.462970382137 82488.500
```

We assert that the planar approximation is worst at the midpoint of the geodesic, i.e. $(82488.5 \text{ m}) / 2 = 41244.25 \text{ m}$, from Helsinki. So now, we want to find the coordinates of this point, by solving the "direct geodetic problem":

```plaintext
echo %HEL% -172.370214337896 41244.25 | geod -f "%.12f" +ellps=GRS80
```

resulting in:

```
59.804045696236 24.840439590098 7.545306054713
```

i.e. the latitude, the longitude, and the return azimuth of the mid point of the geodesic.

Now, for convenience, define this environment variable:
13.2.3 1. The planar approximation

We will be working on ETRS89/UTM35 coordinates, so first define an environment variable, to save some typing:

```bash
set utm35=proj -rs +proj=utm +zone=35 +ellps=GRS80
```

**Note:** The `-rs` option switches the proj coordinate i/o order to latitude/longitude and northing/easting, respectively. We do this to comply with the expected order for the geod program.

Now, find the UTM coordinates of the two end points:

```bash
echo %HEL% | %utm35%
echo %TAL% | %utm35%
```

Note your results and compute the mean of the northings, and the mean of the eastings, to obtain the planar approximation of the mid point.

**Hint:** you can use python as a makeshift command line calculator by saying:

```bash
python -c print((4+8)/2)
```

Now, compute the geographical coordinates corresponding to the UTM mid point:

```bash
echo <your northing your easting> | %utm35% -f "%.12f" -I
```

(note the `-I` option for doing the inverse projection)

For convenience define:

```bash
set MID_APPROX=<your result here>
```

Finally, compute the distance between the geodesic mid point and its planar approximation, by stating it as another case of the inverse geodetic problem:

```bash
echo %MID% %MID_APPROX% | geod -I +ellps=GRS80
```

resulting in:

```
107\textdegree 16.673' -72\textdegree 59.43.193' 2.527
```

i.e. a deviation of 2.5 m over a stretch of about 85 km.
13.2.4 4. Suggested meditations

Consider these aspects:

1. Given that geod is available, fast, and reliable - is it really worth the effort doing approximate calculations in the projected plane?

2. geod includes functionality for computing intermediate points along a geodesic. Check the manual, especially the description of the n_S option, and try to compute the geodesic mid point directly, by setting n_S=2.

3. One should actually expect the result of meditation 2 above to be slightly superior to the result obtained in the exercise. Why?

13.2.5 Answers

| Helsinki, UTM: | 6672241.54 | 385592.95 |
| Tallinn, UTM: | 6590881.40 | 372106.37 |
| Mid point, UTM: | 6631561.47 | 378849.66 |
| Mid point, GEO: | 59.804039062602 | 24.840482644156 |

Meditations:

1. Probably not

2. geod +lat_1=60.171 +lon_1=24.938 +lat_2=59.437 +lon_2=24.745 +n_S=2 +ellps=GRS80 -f "%.12f"

3. Avoids a bit of truncation of the azimuth, and may use a slightly superior algorithm (check the code!)
14.1 Which file formats does PROJ support?

The command line applications that come with PROJ only support text input and output (apart from `proj` which accepts a simple binary data stream as well). `proj`, `cs2cs` and `cct` expects text files with one coordinate per line with each coordinate dimension in a separate column.

Note: If your data is stored in a common geodata file format chances are that you can use GDAL as a frontend to PROJ and transform your data with the `ogr2ogr` application.

14.2 Can I transform from abc to xyz?

Probably. PROJ supports transformations between most coordinate reference systems registered in the EPSG registry, as well as a number of other coordinate reference systems. The best way to find out is to test it with the `projinfo` application. Here's an example checking if there's a transformation between ETRS89/UTM32N (EPSG:25832) and ETRS89/DKTM1 (EPSG:4093):

```
$ ./projinfo -s EPSG:25832 -t EPSG:4093 -o PROJ
Candidate operations found: 1
-------------------------------------
Operation No. 1:
unknown id, Inverse of UTM zone 32N + DKTM1, 0 m, World

PROJ string:
+proj=pipeline
  +step +inv +proj=utm +zone=32 +ellps=GRS80
  +step +proj=tmerc +lat_0=0 +lon_0=9 +k=0.99998 +x_0=200000 +y_0=-5000000
  +ellps=GRS80
```

See the `projinfo` documentation for more info on how to use it.
14.3 Coordinate reference system xyz is not in the EPSG registry, what do I do?

Generally PROJ will accept coordinate reference system descriptions in the form of WKT, WKT2 and PROJ strings. If you are able to describe your desired CRS in either of those formats there's a good chance that PROJ will be able to make sense of it.

If it is important to you that a given CRS is added to the EPSG registry, you should contact your local geodetic authority and ask them to submit the CRS for inclusion in the registry.

14.4 I found a bug in PROJ, how do I get it fixed?

Please report bugs that you find to the issue tracker on GitHub. Here's how.

If you know how to program you can also try to fix it yourself. You are welcome to ask for guidance on one of the communication channels used by the project.

14.5 How do I contribute to PROJ?

Any contributions from the PROJ community is welcome. See Contributing for more details.

14.6 How do I calculate distances/directions on the surface of the earth?

These are called geodesic calculations. There is a page about it here: Geodesic calculations.

14.7 What is the best format for describing coordinate reference systems?

A coordinate reference system (CRS) can in PROJ be described in several ways: As PROJ strings, Well-Known Text (WKT) and as spatial reference ID's (such as EPSG codes). Generally, WKT or SRID's are preferred over PROJ strings as they can contain more information about a given CRS. Conversions between WKT and PROJ strings will in most cases cause a loss of information, potentially leading to erroneous transformations.

For compatibility reasons PROJ supports several WKT dialects (see projinfo -o). If possible WKT2 should be used.

14.8 Which CRS apply to a given location?

You can use the webpage CRS Explorer to view a list of all coordinate reference systems in proj.db, and filter by type, authority, name and location (clicking on the map). It provides WKTs for every coordinate reference system and quick links to epsg.org.
14.9 Why is the axis ordering in PROJ not consistent?

PROJ respects the axis ordering as it was defined by the authority in charge of a given coordinate reference system. This is in accordance to the ISO19111 standard [ISO19111]. Unfortunately most GIS software on the market doesn't follow this standard. Before version 6, PROJ did not respect the standard either. This causes some problems while the rest of the industry conforms to the standard. PROJ intends to spearhead this effort, hopefully setting a good example for the rest of the geospatial industry.

Customarily in GIS the first component in a coordinate tuple has been aligned with the east/west direction and the second component with the north/south direction. For many coordinate reference systems this is also what is defined by the authority. There are however exceptions, especially when dealing with coordinate systems that don't align with the cardinal directions of a compass. For example it is not obvious which coordinate component aligns to which axis in a skewed coordinate system with a 45 degrees angle against the north direction. Similarly, a geocentric cartesian coordinate system usually has the z-component aligned with the rotational axis of the earth and hence the axis points towards north. Both cases are incompatible with the convention of always having the x-component be the east/west axis, the y-component the north/south axis and the z-component the up/down axis.

In most cases coordinate reference systems with geodetic coordinates expect the input ordered as latitude/longitude (typically with the EPSG dataset), however, internally PROJ expects an longitude/latitude ordering for all projections. This is generally hidden for users but in a few cases it is exposed at the surface level of PROJ, most prominently in the proj utility which expects longitude/latitude ordering of input data (unless proj -r is used). (And geod, which on the contrary expects latitude/longitude, and lacks any -r style workarounds.)

In case of doubt about the axis order of a specific CRS projinfo is able to provide an answer. Simply look up the CRS and examine the axis specification of the Well-Known Text output:

```
projinfo EPSG:4326
PROJ.4 string:
+proj=longlat +datum=WGS84 +no_defs +type=crs

WKT2:2019 string:
GEOGCRS["WGS 84",
  DATUM["World Geodetic System 1984",
    ELLIPSOID["WGS 84",6378137,298.257223563,
      LENGTHUNIT["metre",1]],
    PRIMEM["Greenwich",0,
      ANGLEUNIT["degree",0.0174532925199433]],
  CS[ellipsoidal,2],
    AXIS["geodetic latitude (Lat)",north,
      ORDER[1],
      ANGLEUNIT["degree",0.0174532925199433]],
    AXIS["geodetic longitude (Lon)",east,
      ORDER[2],
      ANGLEUNIT["degree",0.0174532925199433]],
  USAGE[
    SCOPE["unknown"],
    AREA["World"],
    BBOX[-90,-180,90,180],
    ID["EPSG",4326]]
```
14.10 Why am I getting the error "Cannot find proj.db"?

The file `proj.db` must be readable for the library to properly function. Like other resource files, it is located using a set of search paths. In most cases, the following paths are checked in order:

- A path provided by the environment variable `PROJ_DATA` (called `PROJ_LIB` before PROJ 9.1)
- A path built into PROJ as its resource installation directory (typically `../share/proj` relative to the PROJ library).
- The current directory.

Note that if you're using conda, activating an environment sets `PROJ_DATA` to a resource directory located in that environment.

14.11 What happened to PROJ.4?

The first incarnation of PROJ saw the light of day in 1983. Back then it was simply known as PROJ. Eventually a new version was released, known as PROJ.2 in order to distinguish between the two versions. Later on both PROJ.3 and PROJ.4 was released. By the time PROJ.4 was released the software had matured enough that a new major version release wasn’t an immediate necessity. PROJ.4 was around for more than 25 years before it again became time for an update. This left the project in a bit of a conundrum regarding the name. For the majority of the life-time of the product it was known as PROJ.4, but with the release of version 5 the name was no longer aligned with the version number. As a consequence, it was decided to decouple the name from the version number and once again simply call the software PROJ.

Use of name PROJ.4 is now strictly reserved for describing legacy behavior of the software, e.g. "PROJ.4 strings" as seen in `projinfo` output.

14.12 Who uses PROJ?

See Software and organizations using or contributing to PROJ

14.12.1 Software and organizations using or contributing to PROJ

14.12.1.1 Free and open source software

- GDAL Translator library for raster and vector geospatial data formats, used by > 100 other software
- GRASS GIS A raster/vector open source GIS
- libgeotiff Library to read/write GeoTIFF keys
- MapServer A popular web mapping application
- PDAL Point Cloud Data Abstraction Library
- PostGIS Spatial database extender for PostgreSQL
- QGIS A cross platform desktop GIS
- QField Mobile data collection app for Android, iOS and Windows.
- R A free software environment for statistical computing and graphics
- mundipy A Python framework for spatial data analysis
14.12.1.2 PROJ bindings in other languages

See Language bindings

14.12.1.3 Proprietary licensed software

- **FME** A GIS translator package. Includes a PROJ based transformer.
- **Avenza Maps** Top mobile mapping app for offline navigation and data collection.
- **Bunting Labs** No-code GIS infrastructure
- **Pix4D Cloud**, desktop and mobile photogrammetry processing and data capture software.

14.12.1.4 Geodetic organizations

- Agency for Data Supply and Infrastructure of Denmark (SDFI)
- Land Information New Zealand (LINZ)
- National Land Survey of Finland (NLS)
- National Land Survey of Iceland (NLS)
- Netherlands Partnership Geodetic Infrastructure (NSGI)
  - Netherlands’ Cadastre, Land Registry and Mapping Agency (Kadaster)
  - Directorate-General for Public Works and Water Management (Rijkswaterstaat)
  - Hydrographic Service of the Royal Netherlands Navy
- Nordic Geodetic commission (NKG)
- Norwegian Mapping Authority (Kartverket)
- Swedish mapping, cadastral and land registration authority (Lantmäteriet)
- **USGS**: PROJ initial author, Gerald E. Evenden, worked at USGS

14.12.1.5 Public organizations

- **Istituto Nazionale di Astrofisica (INAF)**: Planetary Mapping and GIS Laboratory
- **Ecole Nationale des Sciences Géographiques (ENSG-géomatique)**: French geomatic school which depends on the National Institute of Geographic and Forest Information (IGN)

(add yourself here if you are a direct user of PROJ API or utilities)

14.12.1.6 Private organizations

(add yourself here if you are a direct user of PROJ API or utilities)
14.12.1.7 Sponsors

PROJ development, as an upstream dependency of GDAL, benefits from funding brought by its sponsors.
Ballpark transformation

For a transformation between two geographic CRS, a ballpark transformation is a coordinate operation that only takes into account potential difference of axis orders (long-lat vs lat-long), units (degree vs grads) and prime meridian (Greenwich vs Paris/Rome/other historic prime meridians). It does not attempt any datum shift, hence the "ballpark" qualifier in its name. Its accuracy is unknown, and could lead in some cases to errors of a few hundreds of metres.

For a transformation between two vertical CRS or a vertical CRS and a geographic CRS, a ballpark transformation only takes into account potential different in units (e.g. metres vs feet). Its accuracy is unknown, and could lead in some cases to errors of a few tens of metres.

Note: The term "Ballpark transformation" is specific to PROJ.

Pseudocylindrical Projection

Pseudocylindrical projections have the mathematical characteristics of

\[ x = f(\lambda, \phi) \]
\[ y = g(\phi) \]

where the parallels of latitude are straight lines, like cylindrical projections, but the meridians are curved toward the center as they depart from the equator. This is an effort to minimize the distortion of the polar regions inherent in the cylindrical projections.

Pseudocylindrical projections are almost exclusively used for small scale global displays and, except for the Sinusoidal projection, only derived for a spherical Earth. Because of the basic definition none of the pseudocylindrical projections are conformal but many are equal area.

To further reduce distortion, pseudocylindrical are often presented in interrupted form that are made by joining several regions with appropriate central meridians and false easting and clipping boundaries. Interrupted Homolosine constructions are suited for showing respective global land and oceanic regions, for example. To reduce the lateral size of the map, some uses remove an irregular, North-South strip of the mid-Atlantic region so that the western tip of Africa is plotted north of the eastern tip of South America.
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