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Transformation pipelines for PROJ.4

Thomas Knudsen and Kristian Evers

Agency for Data Supply and Efficiency, Geodetic Dept, Copenhagen, Denmark

For more than 2 decades, PROJ.4 has been the globally leading map projection library for open source (and probably also closed source) geospatial software.

While focusing on mathematically well defined 2D projections from geographical to planar coordinates, PROJ.4 has nevertheless, since its introduction in the 1980s, provided limited support for more general geodetic datum transformations, and has gradually introduced a higher degree of support for 3D coordinate data and reference systems.

The support has, however, been implemented over a long period of time, as need became evident and opportunity was found, by a number of different people, with different needs and at different times.

Hence, the PROJ.4 3D support has not been the result of neither deep geodetic, nor careful code architectural considerations.

This has resulted in a library that supports only a subset of commonly occurring geodetic transformations. To be more specific: It supports any datum shift that can be completed by a combination of two Helmert shifts (to and from a pivot datum) and, potentially, also a non-linear planar correction derived from interpolation in a correction grid.

While this is sufficient for most small scale mapping activities, it is not at all sufficient for operational geodetic use, nor for many of the rapidly emerging high accuracy geospatial applications in agriculture, construction, transportation and utilities.

To improve this situation, we have introduced a new framework for implementation of geodetic transformations, which will appear in the next release of the PROJ.4 library.

Before describing the details, 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.

The homology between these steps and a Unix shell style pipeline is evident. With this as its main architectural inspiration, the primary feature of our implementation is a *pipeline driver*, that takes as its user supplied arguments, a series of *elementary operations*, which it strings together in order to implement the full transformation needed.

Also, we have added a number of elementary geodetic operations, including Helmert transformations, general high order polynomial shifts (2D Horner's scheme) and the abridged Molodensky transformation.

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.

With these improvements in place, we assert that PROJ.4 is now well on its way from being a mostly-map-projection library, to becoming an almost-generic-geodetic-transformation library.