Notes on cave surveying and GIS

Summary

The idea that reduced cave survey data should be easily readable into a Geographic Information System (GIS) platform such as QGIS is practically a no-brainer, as it can then be integrated with other geographical data such as maps, satellite imagery, digital elevation models, and the like. This is much closer to being achievable than one might think. Here's the contents of a typical survex `.3d` file as exposed by running `dump3d`:

- survey metadata: title, date, and co-ordinate reference system;
- strings of survey legs with metadata: names, flags (normal, duplicate, splay, surface);
- survey stations with metadata: names, flags (exported, entrance, fixed, surface) and passage cross-sections (LRUD data).

Now compare this to a typical ESRI shapefile, or the GeoPackage data format from the Open Geospatial Consortium, which are well known containers for GIS vector data. These formats specify:

- a co-ordinate reference system, and possible other metadata;
- geometries comprising points, lines, polylines (line strings), and polygons, with or without z-dimension (elevation) data;
- geometry attributes consisting of records of various kinds that are user-configurable.

At this point you are supposed to slap yourself on the head and ask why on earth we haven't been using a GIS-compatible format for storing reduced survey data all along! It's certainly flexible enough to contain all the information normally included in a `.3d` file.

Spatial Reference Systems

In order for this to work smoothly, we first have to be on top of our spatial reference system (SRS) in general GIS parlance, or co-ordinate reference system (CRS) in QGIS language. The following notes hopefully contain enough of the truth to be useful. Something closer to the truth can be found in *A guide to coordinate systems in Great Britain* by the Ordnance Survey (OS).

An SRS usually comprises:

- a geodetic datum or Terrestrial Reference System, which is usually an ellipsoid which specifies the overall shape of the earth's surface: WGS84 used in GPS, and OSGB36 used by the Ordnance Survey in the UK are two examples;

- a map projection which is nearly always a Transverse Mercator projection, such as the Universal Transverse Mercator (UTM) system used in GPS: the map projection tries to optimally flatten the curved surface of the earth (there is always some compromise involved here);
- a co-ordinate system (typically metric) defined on top of the map projection, usually specifying a 'false origin' so that co-ordinates are always positive.

Given the geodetic datum one can always work with latitudes and longitudes, but these aren't terribly convenient for cave survey data crunching. Also beware that the same point on the earth's surface may have a different latitude and longitude according to the choice of datum: this is known as a datum shift, and a well-known example is the datum shift between WGS84 and OSGB36 that nowadays only shows up in Magic Map.

WGS84 is pretty much universally used nowadays on the internet, for example Google's Keyhole Markup Language (KML) only supports WGS84 latitude and longitude, to upload to Google Earth. Also most GPS devices report latitude and longitude for WGS84, though more often than not you won't see this directly but rather get metric UTM co-ordinates, or metric British National Grid co-ordinates in the UK.

To further add to the confusion, latitude and longitude can be reported in decimal degrees; or degrees, minutes, and seconds (or even degrees and decimal minutes). For example the entrance to Dow Cave is at NGR SD 98378 74300, which translates to (WGS84) $54^\circ\,9'\,52.2''$ N $2^\circ\,1'\,34.8''$ W where one decimal place in the seconds corresponds to approximately 3 m on the ground, or (WGS84) 54.16450° N 2.02634° W where five decimal places corresponds approximately to 1 m on the ground, or (WGS84) 30U 6 002 262 563 570 for UTM. Online converters between British National Grid references and WGS84 latitudes and logitudes can be found on the internet by searching for 'OSGB36 to WGS84 converter'. To check things, the WGS84 latitude and longitude in decimal degrees can be copied and pasted into Google maps for example, or for that matter directly into the Google search engine.

Note there is a confusing difference between WGS84 Web Mercator often used for online maps, and the standard conformal Mercator projection. For this reason the US DoD has declared the Web Mercator projection 'to be unacceptable for any official use', which is a good enough reason for me to avoid where possible.

In the UK, Ordnance Survey (OS) British National Grid co-ordinates provide a metric SRS which is convenient for cave survey data. Typically one fixes cave entrances using the numeric part of the national grid reference (NGR). The NGR can be specified in two ways. The most convenient way is to use the OS grid letter system in which a pair of letters specifies a 100 km $\times$ 100 km square. Then, within that, a 10-figure national grid reference (NGR) specifies a location to within a square metre. This system (two letters plus 10 figures) is what is usually encountered when using a GPS device set to the British National Grid.

Many datasets in the Cave Registry have entrance fixes specified as 10-fig NGRs, without the grid letters which are assumed known.

Alternatively, and more commonly in GIS, one can use an all-numeric 12-figure NGR in which the leading figures signal the 100 km × 100 km square. For example in the all-numeric scheme the entrance to Dow Cave is at NGR 398378 474300.

In the letter-based system the co-ordinates are often truncated to 8-fig or 6-fig NGRs, to reflect the accuracy of the GPS device for instance (thus 8-fig NGRs are used in the new Northern Caves). In case you forgot your school geography lessons, recall that the correct way to truncate an NGR is to *drop* the least significant figures, not to round to the nearest 10 or 100. This is because an 8-fig (or 6-fig) NGR actually specifies a 10 m × 10 m (or 100 m × 100 m) *square* and not an approximate position as such. Thus the 6-fig NGR for the Dow Cave entrance is NGR SD 983 743.

To check NGRs in the UK, one can use the 'Where am I?' tool in the Magic Map application. Note that unless explicitly set to use WGS84, Magic Map reports OSGB36 latitude and longitude, which as mentioned is offset from WGS84 by a datum shift of up to 50–100 m. Beware copying and pasting these OSGB36 latitudes and longitudes into Google Maps!

Elsewhere in the world, or for that matter in the UK as well, the UTM system offers a convenient metric SRS for embedding cave survey data. Typically one fixes the entrance co-ordinates as the numeric part of the UTM position, making a note of the UTM grid zone. Online converters from WGS84 latitude and longitude to UTM or back are easily found (thus, for example, the Dow Cave entrance above). Perhaps it's restating the obvious but if you accidentally paste OSGB36 latitudes and longitudes into a UTM converter, you will likely be out by 50–100 m.

Georeferencing cave survey data

Back to cave surveying: for most surveys the earth's surface can be regarded as essentially flat, so one is working in a 3d world with eastings, northings, and altitudes, with the origin of the co-ordinate system chosen at one's convenience. Perhaps for synoptic maps of very large karst areas, one might be worried about the curvature of the earth's surface, but for the most part assuming the world is flat should introduce negligible errors, at least in comparison to the errors that typically creep into cave survey projects.

As long as this local cave co-ordinate system can be tied into one of the known geodetic SRS schemes (*i. e. georeferenced*), then any feature in the cave will have a known position in GIS terms, and can thus be tied into any other georeferenced data such as maps, satellite imagery, digital elevation models, *etc.* Given that most cave surveying is done in metres, it is obviously convenient to tie into an SRS which uses metric co-ordinates, such as UTM or British National Grid.

Note that once you've tied the dataset into a recognised SRS, any GIS platform worth its salt will be able to re-project into a different SRS, and will be able to display and combine information from different sources irrespective of the SRS.

The easiest way to georeference cave survey data, with a modern survex distribution, is to `*fix` cave entrances with appropriate co-ordinates and make judicious use of the `*cs` commands (for co-ordinate system): use a plain `*cs` command to specify the input SRS that the entrance co-ordinates are given in, and a `*cs out` command to specify what the output SRS should be. In the UK for instance one can use this to convert between the OS grid letter system and the all-numeric scheme.

The cave survey data used in the examples below is included in the repository under the `DowProv` directory. It is for the Dow Cave - Providence Pot system (Great Whernside, Wharfedale, UK), and is essentially a snapshot of the data held in the Cave Registry Data Archive. Note that the `.svx` files have unix-style line endings so on Windows you might have to use something like Notepad++ to look at them. The processed data is `DowProv.3d`, generated using survex 1.2.32.

Back to georeferencing, the cave-specific file `DowCave.svx` (for example) contains

```
*begin DowCave
*export entrance
...
*entrance entrance
*fix entrance 98378 74300 334
*equate entrance dow1.1
...
```

and the master file `DowProv.svx` contains

```
*cs OSGB:SD
*cs out EPSG:7405
...
*begin DowProv
*include DowCave
...
```

(obviously this is only one of many possible ways to add the metadata into the survex files).

Thus the file `DowCave.svx` contains a `*fix` which specifies the entrance location as a 10-fig NGR SD 98378 74300, without the SD part. The easting and northing here (and elevation ODN) were obtained by field work. Then the file `DowProv.svx` specifies input SRS is the SD square, and asks that the reduced data should be exported using the all-numeric British National Grid scheme, here codified with a European Petroleum Survey Group (EPSG) code, here `EPSG:7405`. Using EPSG numbers avoids potential misunderstanding when importing into a GIS platform, for example in QGIS one can find the exact exported SRS easily enough by searching on the EPSG number.

If you check the processed survey in `aven`, or run `3dtopos` on the `.3d` file, the processed entrance co-ordinates are now indeed

```
(398378.00, 474300.00,   334.00 ) dowprov.dowcave.entrance
```

Whilst this may seem like a crazily over-the-top way to add a '3' and '4' to the entrance co-ordinates, it is actually very simple to implement: one only needs to add two lines (the `*cs` and `*cs out` commands) to the survex file. The benefit is that it is robust, clean, and unambiguous. Moreover, the output SRS is included as metadata in the `.3d` file; thus with `dump3d` one sees

```
CS +init=epsg:7405 +no_defs
```

(this is in fact a PROJ.4 string which species the map projection, and can be directly pushed to a GIS application).

As a slightly less trivial example, one can ask for the reduced survey data to be re-projected as UTM co-ordinates. This can be done almost totally trivially by replacing the previous `*cs out` command with `*cs out EPSG:3042` which specifies the output SRS is (WGS84) UTM zone 30N (this includes zone 30U). If we now reduce the data with `cavern` and check with `3dtopos` we find the Dow Cave entrance has magically moved to

```
(563570.22, 6002262.20,   384.57 ) dowprov.dowcave.entrance
```

and the exported SRS from `dump3d` is

```
CS +init=epsg:3042 +no_defs
```

As expected, the entrance location in UTM is the same as obtained by converting the original NGR first to WGS84 latitude and longitude, then to UTM, using the online converters. Note that in re-projecting to UTM, we also get a vertical datum shift.

For another example, the CUCC Austria data set which comes as sample data with the survex distribution can be georeferenced by adding the following to the top of the `all.svx` file:

```
*cs custom "+proj=tmerc +lat_0=0 +lon_0=13d20 +k=1
    +x_0=0 +y_0=-5200000 +ellps=bessel
    +towgs84=577.326,90.129,463.919,5.137,1.474,5.297,2.4232
    +units=m +no_defs"
*cs out EPSG:31255
```

The first 4 lines are all one line in the real file, and this specifies the custom SRS in which the co-ordinates of the surface fixed points in the Austria data set are specified. The second line determines the output SRS. This doesn't really matter too much as long as the SRS can be recognised by the GIS platform: this example uses the MGI / Austria Gauss-Krüger (GK) Central SRS (`EPSG:31255`), where the *only* difference compared to custom SRS is in the `+y_0` false origin. Another output SRS could be `EPSG:3045` which is (WGS84) UTM zone 33N.

I've gone into these examples in some detail as the survex documentation on the `*cs` command is rather spartan.

As a further benefit, providing the survex data files include correctly formatted `*date` commands (as the Dow-Providence dataset does), the `*cs` commands make survex aware of the geodetic SRS and magnetic declination corrections can be automatically added. This is another reason one might want to 'do things properly' with `*cs` commands. The `DowProv.svx` master file thus also contains the lines (the first two are just comments)

```
; Mag dec calculated for SD 97480 72608 alt 225m
; Dowbergill Bridge, just above Kettlewell
*declination auto 97480 72608 225
```

This correctly applies the magnetic declination using the International Geomagnetic Reference Field (IGRF) model, calculated at the specified location in the input SRS, and applied to *all* the included survey files, in this case taking into account the range of dates which spans some 30 years.

GIS import methods

Quick-and-dirty two dimensional (flat) import

The quickest way to get survey data into a GIS platform (QGIS) once the dataset has been georeferenced as just described is via the DXF file format, using the survex `cad3d` tool, or exporting from `aven`. One can load this DXF file into a GIS platform like QGIS. At present this direct route does not import z-dimension (elevation) data, but nevertheless could be useful as a quick and dirty way to throw for example a centreline onto a map.

Three dimensional import

This import route requires command-line access to the GDAL utilities.

From the DXF file, the centreline can be extracted by running (at the command line)

```
ogr2ogr -f "ESRI Shapefile" DowProv_centreline.shp DowProv.dxf \
  -where "Layer='CentreLine'" -a_srs EPSG:7405
```

We take the opportunity here to add an SRS to match that used in the georeferenced survey data. The resulting shapefile can then be imported in QGIS, and this route *does* preserve z-dimension (elevation) data. Thus, for example, one can run the Qgis2threejs plugin with a suitable digital elevation model (DEM) raster to generate a three dimensional view with the cave features underneath the landscape.

Similarly the stations with labels (and elevations) can be extracted by running

```
ogr2ogr -f "ESRI Shapefile" DowProv_stations.shp DowProv.dxf \
  -where "Layer='Labels'" -a_srs EPSG:7405
```

Import using QGIS plugin

The plugin provides a convenient route to import features (legs and stations) from a `.3d` file, with z-dimension (elevation) and other metadata properly included. Installation instructions can be found in the README.

When installed, a menu item 'Import .3d file' should appear on the 'Vector' drop-down menu in the main QGIS window, and (possibly) a .3d icon in a toolbar (if enabled).

Selecting 'Import .3d file' (or clicking on the .3d icon) brings up a window for the user to select a `.3d` file, and choose whether to import legs or stations, or both. For the former (legs) additional options allow the user to choose whether to include splay, duplicate, and surface legs. For the latter (stations) the user can choose whether to include surface stations. Finally there is an option to import the CRS from the `.3d` file if possible. On clicking OK, vector layers are created to contain the legs and stations as desired. Some attributes are also imported (perhaps most usefully, names).

For the most part importing the CRS from the `.3d` file should work as expected if the survey data has been georeferenced using the survex `*cs` and `*cs out` commands. If it doesn't, one can always uncheck this option and set the CRS by hand. To maximise the likelihood that CRS import works as expected, use an EPSG code in the `*cs out` survex command rather than a PROJ.4 string.

There is one point to bear in mind regarding the elevation data. Because of the (current) limitations in QGIS for creating vector layers in memory, the layer type does not explicitly know that the features include z-dimension (elevation) data. To work around this one can save the layer to a shapefile, for example to an ESRI Shapefile or a GeoPackage file. In QGIS this usually results in the saved shapefile automatically being loaded as a new vector layer, but of course one can also explicitly load the new shapefile. To ensure the z-dimension data is correctly incorporated when saving to a shapefile, in the 'Save as . . . ' dialog make sure that the geometry type is specified (for legs this should be 'LineString', and for stations it should be 'Point') and the 'Include z-dimension' box is checked.

Once the data is in QGIS one can do various things with it. For example, regardless of the above comments about saving with z-dimension data, features (legs or stations) can be coloured by depth to mimic the behaviour of the `aven` viewer in survex (hat tip Julian Todd for figuring this out). The easiest way to do this is to use the `.qml` style files provided in this repository. For example to colour legs by depth, open the properties dialog and under the 'Style' tab, at the bottom select 'Style → Load Style', then choose the `color_legs_by_depth.qml` style file. This will apply a graduated colour scheme with an inverted spectral colour ramp. A small limitation is that the ranges are not automatically updated to match the vertical range of the current data set. Refreshing this is trivial: simply fiddle with the number of 'Classes' (box on right hand side of 'Style' tab) and the ranges will update to match the current dataset.

Another thing one can do is enable 'map tips' using the `NAME` field. Then, hovering the mouse near a station (or leg) will show the name as a pop-up label. Note that the relevant layer (*e. g.* stations) does not have to be displayed for this to work (it has to be the active layer though).

With a digital elevation model (DEM raster layer) one can use the 'Raster Interpolation' plugin to find the surface elevation at all the imported stations (to do this, first create a field to hold the numerical result, then run the plugin). Then, one can use the built-in field calculator to make another field containing the *depth below surface*, as the surface elevation minus the z-dimension of the station, `z($geometry)`. This information can be displayed in the 'map tip', *etc.*

Other import scripts

In the same repository, under the `extra` directory, the script `import3d.py` is a stripped down version of the plugin which could be useful for testing and troubleshooting. It can be added as a user script to the Processing Toolbox.

Also in the `extra` directory, `survex_import_with_tmpfile.py` is a slightly old version of the main plugin script which uses a temporary file to cache the output of `dump3d`.

Georeferencing images, maps, and old surveys

Georeferencing here refers to assigning a co-ordinate system to an image or map, or a scanned hard copy of a survey. The actual steps require identifying so-called Ground Control Points (GCPs), which are identifiable features on the map for which actual co-ordinates are known. One way to do this is to use the GDAL Georeferencer plugin in QGIS. Georeferencing surveys may be easier if there is more than one entrance and the positions are known, or there is already a surface grid. If there is only one entrance then tracing a centerline in Inkscape and using the survex output tool as described here may help.

Copying