Georeferencing & Spatial Adjustment

Aligning Raster and Vector Data to the Real World

- Rotation
- Differential Scaling
- Skew
- Translation
- Distortion
The Problem

- How are geographically unregistered data, either raster or vector, made to align with data that exist in geographical coordinates?

OR

- How are arbitrary coordinates transformed into geographical coordinates?
For Example:

- Align raster image to vector map of state outline

"Source location"

Raster - no geographic coordinates

"Destination location"

Shapefile - stored in geographic coordinates
Nature Of The Problem:

- Data source and final map registration may differ by:
  - Rotation
  - Translation
  - Distortion

- Source location
- Destination location
Texas Example:

- Skewing, e.g. Panhandle
- Translation
- Different x & x’ Scales
- Different y & y’ Scales
General Problem Is Then:

Source \((x, y; \text{unspec.})\) \rightarrow \textbf{Destination} \((x', y'; \text{UTM})\)

("Warp")
How Solved?

- Geometric Transformations
  1. First-order ("Affine") transformation
     ▲ Accomplishes translation, distortion and rotation
     ▲ Straight lines are mapped onto straight lines, parallel lines remain parallel, e.g. square to rectangle
Geometric Transformations

- Affine transformation:

\[ X'_1 = Ax_1 + By_1 + C \]
\[ Y'_1 = Dx_1 + Ey_1 + F \]

Where:

- \( x_1, y_1 \) = coords. of pt. in source layer
- \( X'_1, Y'_1 \) = coords. of same pt. in destination layer
- A, B, C ... F = unknown constants giving best fit of all points
  (minimize Root Mean Square [RMS] error)
Affine Transformation

- Affine transformation constants:
  \[ X_1' = Ax_1 + By_1 + C \]
  \[ Y_1' = Dx_1 + Ey_1 + F \]

- A, E = scale factors
- B, D = rotation terms
- C, F = translation terms

- With six unknowns, need \textit{minimum of three points} (yielding 6 equations).
Affine Transformation

“Goodness of Fit” given by RMS error:

$$\text{RMS error} = \sqrt{\frac{e_1^2 + e_2^2 + e_3^2 + e_4^2}{4}}$$
Geometric Transformations

2. Second- or Third-order Transformations
   - Fit with more constants (12 or 20)
   - *Allow straight lines to map to curves*
   - More displacement links (6 or 10 minimum) required
Transformation Characteristics

Original

1\textsuperscript{st} Order (Affine)  2\textsuperscript{nd} Order  3\textsuperscript{rd} Order

Image from ESRI Help file
Other Transformation Types

- Spline – For local fits only
  - Source control pts. match reference pts. exactly at expense of global fit. 10 pts. required

- Adjust – For global and local fitting
  - Relies on polynomial fitting adjusted to a TIN. 3 pts. required

- Projective – For imagery or scanned maps that differ from source primarily by the map projection
  - Minimum of 4 pts required, RMS given.
Geometric Transformation of Raster Data

- The Problem: Square cells must remain square after transformation. How?
Geometric Transformation of Raster Data – Raster Projection

- Related Problem: Square cells must remain square after projection. How?

![Diagram of unprojected and projected raster data, showing a square remaining square in the unprojected case and becoming quadrilateral in the projected case.]
Geometric Transformation of Raster Data

- **Solution**: “Resampling” – Create and fill a *new matrix* of empty destination cells with values from source raster. Tag remaining cells as “no data”.

![Diagram showing geometric transformation of raster data from unprojected to projected with "no data" cells highlighted.](Image)
Creating New Cells: Resampling Techniques

1. **Nearest Neighbor** – use value of source cell that is nearest transformed destination cell
   - Fastest technique; *use for categorical (nominal or ordinal) or thematic data*

2. **Bilinear interpolation** – combine 4 nearest source cells to compute value for destination cell

3. **Cubic Convolution** – same, but combine 16 nearest cells

Methods 2 and 3 are weighted average techniques – *use for continuous data* (slope, elevation, rainfall, temp. rainfall, etc.)
Implications of Resampling

- Cell size, and number of rows and columns, will change on projection and/or georeferencing.
- Minimize problems by georeferencing with a reference layer that closely matches projection of the layer being georeferenced.
- Raster datasets must be in same projection and coordinate system for analysis.
Where Are New Coordinates Stored?

- “Update Georeferencing” writes transformation parameters to a new, small, separate file of same name as raster but with a different extension (e.g. .jpw, .aux, .xml), depending on original file type.

- “Rectify…” creates a new, georeferenced, raster dataset in GRID, JPEG, TIF or IMAGINE format.
Georeferencing in ArcMap

- Georeferencing Toolbar
  - Link Table Tool
  - Link-creating Tools

Image from ArcGIS georeferencing help file
Procedure

- See Help File on Georeferencing
  - Remember:
    - Align to data that has GCS and PCS of interest.
    - Finish by “Update Georeferencing” or “Rectify...” to ensure coordinates are saved with file
Georeferencing Vector Files

- Take C.A.D. (e.g. .DXF, .AI, .CDR) drawings into a GIS
- Conceptually simpler, in practice more difficult? No.
  - Two equally useful technique:
    - By writing or making reference to a 2 line text ("world" .wld) file
    - By entering transformation coordinates in the drawing Layer Properties
Vector World File format

- World text file format is as follows:

  Line 1:
  <x,y location of pt. 1 in CAD drawing> <space>  
  <x,y location of pt. 1 in geographic space>

  Line 2:
  <x,y location of pt. 2 in CAD drawing> <space>  
  <x,y location of pt. 2 in geographic space>

  E.g. 3.52,4.43 710373,3287333  
  -0.05,4.3 710062,3288033

- See Help on World Files and CAD transformations
Transform by Coordinates

- Enter same information interactively
- Use georeferencing tools to create 2 link points, then “Update Georeferencing”
- See Help file on “Transforming CAD datasets”
“Spatial Adjustment” of Vector Data

Via special editing toolbar permits:

- Transformations ("Warping")
  - Affine
  - Similarity
  - Projective
- "Rubber Sheeting"
- "Edge Matching"
- Attribute transfer
“Georeferencing” vs. “Spatial Adjustment”

- Georeferencing – raster and vector data
  - Best fit of all source control points to all destination control points – transformation (“Warping”) of data for overall best fit
  - Alignment of data to map coordinates
  - R.M.S. error given

- “Spatial Adjustment” – vector data
  - More versatile; can “Warp”, also “Rubbersheet” and “Edgematch”
  - Adjustment by latter two is piece-wise fitting; point by point matching but no overall warping.