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 – projected, stored in State Plane coordinates
Nature Of The Problem:

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

- Source location
- Destination location

Rotation
Translation
Differential Scaling
Skew
Distortion
Texas Example:

- Skewing, e.g. Panhandle
- Translation
- Different $x$ & $x'$ Scales
- Different $y$ & $y'$ Scales

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General Problem Is Then:

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

("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 minimum of three points (yielding 6 equations).
Affine Transformation

“Goodness of Fit” given by RMS error:

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

- Source C.P.
- Destination C.P.
- Residual Error (vector length)
Geometric Transformations

- 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 data

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.

Image from ESRI Help file
The Problem: Square cells must remain square after transformation. How?
Related Problem: Square cells must remain square after projection. How?
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” (null).
*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 the 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

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.
- Three equally useful techniques:
  - By writing or making reference to a 2 line text ("world" .wld) file
  - By entering transformation coordinates in the drawing Layer Properties
  - By importing vector layers into a Geodatabase and using the Spatial Adjustment (see below) toolbar!
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.
Georeferencing Demo

- Practice georeferencing scanned geologic map for Lab 4 & 5
- Download:
  Geo-327g_386g>Georeferencing_Demo>2019WMA
  to begin