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

Raster - no geographic coordinates

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** \((x, y; \text{unspec.})\) \(\rightarrow\) **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

![Diagram showing geometric transformation from square to rectangle]
Geometric Transformations

- **Affine transformation:**

\[
\begin{align*}
X_1' &= Ax_1 + By_1 + C \\
Y_1' &= Dx_1 + Ey_1 + F
\end{align*}
\]

Where:

- \(x_1, y_1\) = coords. of pt. in source layer
- \(X_1', Y_1'\) = coords. of same pt. in destination layer
- \(A, B, C \ldots F\) = 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?

Unprojected  Projected
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. The unprojected (source) grid is shown on the left, and the projected (destination) grid is shown on the right. The transformation involves mapping the source grid to the destination grid, with some cells tagged as "no data".](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.