GIS Functions – Vector

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GIS Functions

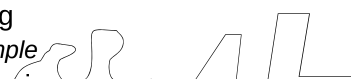
- Data Retrieval
- Map Generalization
- Map Abstraction
- Map Sheet Manipulation
- Buffer Generation
- Polygon Overlay
- Geocoding
- Dynamic Segmentation
- Network Analysis

Data Retrieval

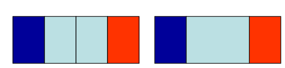
- Examples from ArcGIS
  - Browsing
  - Windowing
    - Zoom & pan
  - Multiple Map Query
    - identify
  - Attribute Query

Map Generalization

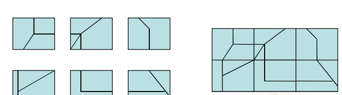
- Line Thinning
  - *Hydro example*

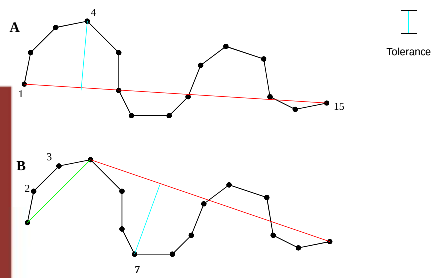


- Polygon Thinning
  - Merging, MMU
- Dissolve

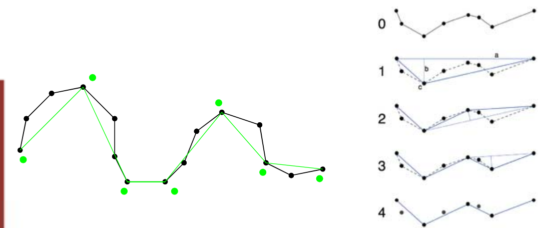


- Edge Matching
  - *MAPJOIN*





The first two steps of the Douglas-Poiker algorithm. The endpoints of the polyline are first connected (A), and the point lying furthest from this line is found. If it lies further than the user-supplied tolerance distance, it is selected as a member of the simplified line, along with the two endpoints, and a new cycle of the algorithm is started. In the next cycle Points 2 and 3 lie within the tolerance of the line 1-4-15, but Point 7 does not.



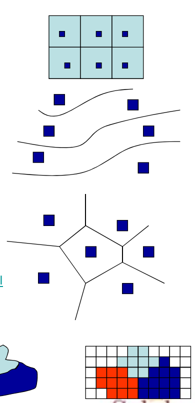
In the final step 7 points remain (identified with green disks), including 1, 4, 7, and 15. No points are beyond the user-defined tolerance distance from the line.

Map Abstraction

- Centroid Calculation
  - Half-moon example
- Automatic Contouring
- Proximal Mapping

http://www.cs.cornell.edu/Info/People/chew/Delaunay.html

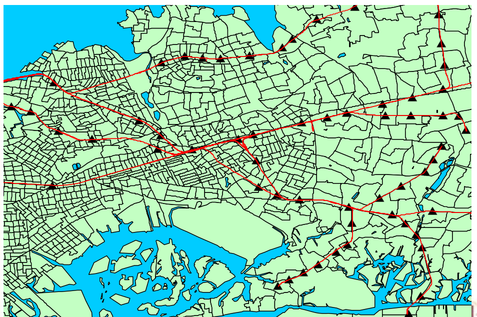
- Reclassification
- Grid Conversion



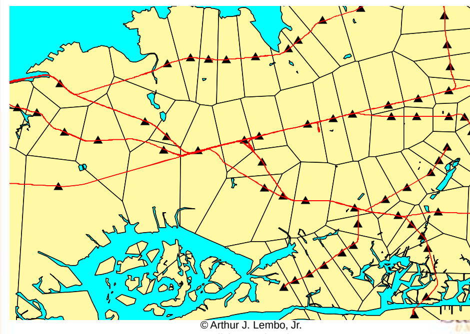
Simple Spatial Analysis – Ticket Vending Machine

Determining the Primary Languages Spoken at Home Around Each Station

Base Data



Thiessen Polygons



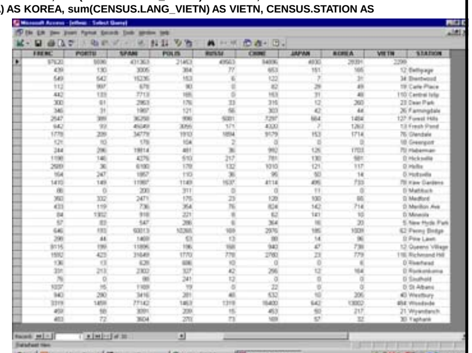
Overlay of Thiessen and Census Data

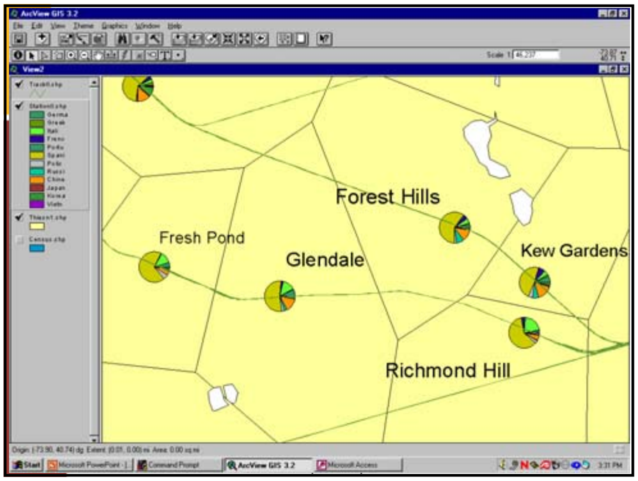
SQL Query of Result

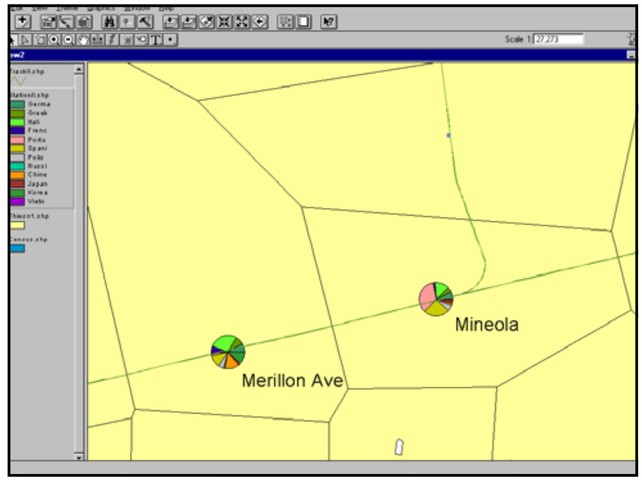
```
SELECT sum(CENSUS.LANG_GERMA) AS GERMA, sum(CENSUS.LANG_GREEK) AS GREEK,
sum(CENSUS.LANG_ITALI) AS ITALI, sum(CENSUS.LANG_FRENC) AS FRENC,
sum(CENSUS.LANG_PORTU) AS PORTU, sum(CENSUS.LANG_SPANI) AS SPANI,
sum(CENSUS.LANG_POLIS) AS POLIS, sum(CENSUS.LANG_RUSSI) AS RUSSI,
sum(CENSUS.LANG_CHINE) AS CHINE, sum(CENSUS.LANG_JAPAN) AS JAPAN,
sum(CENSUS.LANG_KOREA) AS KOREA, sum(CENSUS.LANG_VIETN) AS VIETN, CENSUS.STATION AS
STATION

FROM CENSUS

GROUP BY STATION;
```





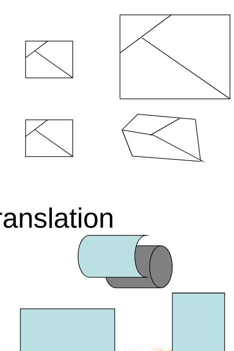


Map Sheet Manipulation

- Scale Change
- Rubbersheeting
- Projection Change

mathcad example

- Coordinate Rotation/Translation



Matrices

- If you are going to understand transformation algorithms, you should understand something about matrix algebra
- **Matrix**: a set of numbers of symbols arranged in a square or rectangular array of “m” rows and “n” columns. The arrangement is such that certain defined mathematical operations can be performed in a systematic and efficient way

Linear equations and matrices

- Given a set of linear equations

$$a_1x_1 + a_1x_2 + a_1x_3 = c_1 \qquad x + y - z = -8$$
$$a_2x_1 + a_2x_2 + a_2x_3 = c_2 \qquad 2x - y + z = -4$$
$$a_3x_1 + a_3x_2 + a_3x_3 = c_3 \qquad -x + 2y + 2z = 21$$

- We can define them in matrix form

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix}$$

- And further define them in matrix notation

$$AX = C$$

- So, if we have a system of linear equations

$$AX = C$$

- We can algebraically reformat the equation by pre-multiplying both sides by the identity matrix

$$AX = C$$
$$(A^T A)^{-1} A^T AX = (A^T A)^{-1} A^T C$$
$$IX = (A^T A)^{-1} A^T C$$
$$X = (A^T A)^{-1} A^T C$$

Solving simultaneous equations

- We can solve the following equation simultaneously through based algebraic manipulation

$$x + 5y = -8$$
$$-x - 2y = -1$$
now add the two equations
$$x + 5y - 8$$
$$\underline{-x - 2y - 1}$$
$$3y = -9$$
$$y = -3$$

Solving simultaneous equations with matrices

- Or, we can use matrices

$$x + 5y = -8$$
$$-x - 2y = -1$$

$$\underbrace{\begin{bmatrix} 1 & 5 \\ -1 & -2 \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} x \\ y \end{bmatrix}}_{X} = \underbrace{\begin{bmatrix} -8 \\ -1 \end{bmatrix}}_{C}$$

More complicated formulas

$$x + 5y = -8$$
$$-x - 2y = -1$$

$$A = \begin{pmatrix} 1 & 5 \\ -1 & -2 \end{pmatrix} \quad C = \begin{pmatrix} -8 \\ -1 \end{pmatrix}$$

$$(A^T A)^{-1} A^T C = \begin{pmatrix} 7 \\ -3 \end{pmatrix}$$

$$x + y - z = -8$$
$$3x - y + z = -4$$
$$-x + 2y + 2z = 21$$

$$A = \begin{pmatrix} 1 & 1 & -1 \\ 3 & -1 & 1 \\ -1 & 2 & 2 \end{pmatrix} \quad C = \begin{pmatrix} -8 \\ -4 \\ 21 \end{pmatrix}$$

$$(A^T A)^{-1} A^T C = \begin{pmatrix} -3 \\ 2 \\ 7 \end{pmatrix}$$

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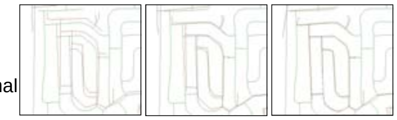
Transformation Methods

- Methods based on polynomials
  - Linear Conformal
  - Affine
  - Second Order Polynomial
- Methods based on finite element analysis
  - Piecewise Linear Homeomorphism



a) Original Map a) 3 Control Points a) 9 Control Points

Improvements in rubbersheeting with the addition of more control points

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Transformation Methods (cont.)

- Methods based on adjustment computations
  - Adjustment of Indirect Observations
  - Adjustment of Indirect Observations and Geometric Constraints

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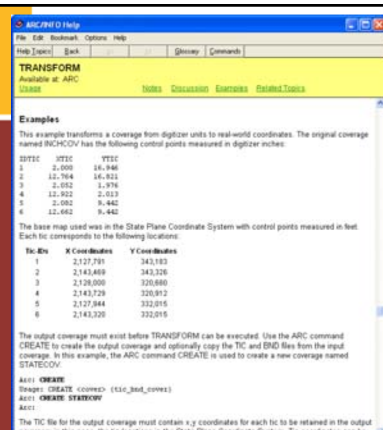

ARC/INFO Help

File Edit Bookmark Options Help

Help Topics Back Glossary Commands

TRANSFORM

Available at: ARC

Usage Notes Discussion Examples Related Topics

Examples

This example transforms a coverage from digitizer units to real-world coordinates. The original coverage named INCHCOV has the following control points measured in digitizer inches:

IDTIC	XTIC	YTIC
1	2.000	16.946
2	12.764	16.821
3	2.052	1.976
4	12.922	2.013
5	2.082	9.442
6	12.662	9.442

The base map used was in the State Plane Coordinate System with control points measured in feet. Each tic corresponds to the following locations:

Tic-IDs	X Coordinates	Y Coordinates
1	2,127,791	343,183
2	2,143,469	343,326
3	2,128,000	320,680
4	2,143,729	320,912
5	2,127,944	332,015
6	2,143,320	332,015

The output coverage must exist before TRANSFORM can be executed. Use the ARC command CREATE to create the output coverage and optionally copy the TIC and BND files from the input coverage. In this example, the ARC command CREATE is used to create a new coverage named STATECOV.

```
Arc: CREATE
Usage: CREATE <cover> {tic_bnd_cover}
Arc: CREATE STATECOV
Arc:
```

The TIC file for the output coverage must contain x,y coordinates for each tic to be retained in the output coverage; in this case, the tic locations in the State Plane Coordinate System. Tic coordinates can be

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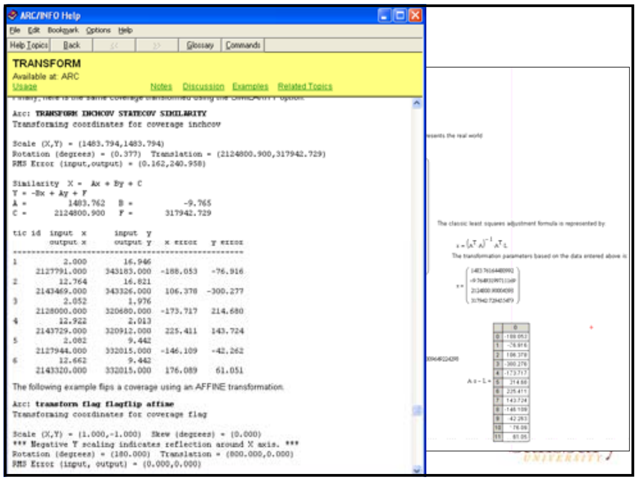
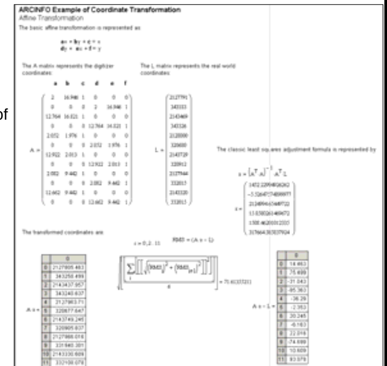


Affine Transformation

- 6 transformation parameters
  - 2 scale changes, one rotation, two translations of the origin, one perpendicularity
  - $a_x + b_y + c = X$ + some residual (v_x)

    $d_y + e_x + f = Y$ + some residual (v_y)
- Additional scale parameter
- Good for accounting for film deformation



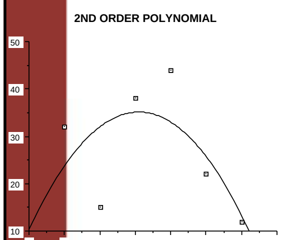
Second Order Polynomial

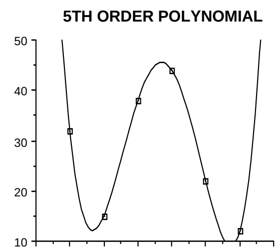
- 12 transformation parameters

  $a + b_x + c_y + d_x^2 + e_{xy} + f_y^2$

  $g + h_x + i_y + j_x^2 + k_{xy} + l_y^2$
- Frequently used as an approximation for more complicated functions
- Polynomials have a tendency to over-model a function

Polynomial Example





Problems with Traditional Methods

- Limited transformation parameters
- Coordinate exchange without true error removal
- Residual error distribution only among control points used

Finite Element Analysis
(Piecewise Linear Homeomorphism)

- Breaks transformation into multiple pieces (triangles)
- Determines transformation parameters for each triangle
- Transforms lines within each triangle using affine transformation

Adjustment Using Indirect Observations

- Determines corrections for lines that produce the highest probability of a simultaneous occurrence
- Errors distributed among all lines
- Adjustment occurs with consideration for the relationship among all lines

$$ {}_{m}A_{n\,n}X_{1} = {}_{m}L_{1} + {}_{m}V_{1} $$

Adjustment Using Indirect Observations and Geometric Constraints

- Determines corrections for lines that produce the highest probability of a simultaneous occurrence, AND, satisfies specific geometric constraints.
- Solves for two sets of equations

$$ {}_{m}A_{n\,n}X_{1} = {}_{m}L_{1} + {}_{m}V_{1} $$

$$ {}_{s}C_{n\,n}X_{1} = {}_{m}g_{1} $$

Transforming Data

Getting a handle on the WTC Damage when no data was available

www.nyu.edu/icis/research/wtc

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Evaluating Water Distribution System Damage

- Data Sources
  - **Digital orthophotography** – not clear but registered with a geographic coordinate system
  - **Aerial photographs** – clear, but unregistered
  - **DEP water main map** – clear, but unregistered
- Issues
  - Maps/photos were not in the correct geographic position, so viewing them simultaneously was impossible
- Solution
  - Register all data to a common basemap and coordinate system within a GIS

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DEP Data

DEP map showing damaged mains after September 11. Obtained from NYC DEP

DEP map showing mains, with size. Obtained from NYC DEP

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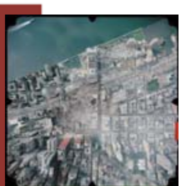
Aerial Photography



High resolution aerial photograph taken by NOAA, downloaded from the Internet

Aerial photograph downloaded from the Internet – Pre September 11th

Aerial photograph taken on September 15. Downloaded from the Internet

Digital Orthophotography

Digital orthophotograph of Manhattan. Downloaded from NYS Digital Ortho Quarter Quad archive

Same photograph from left, zoomed in. Shadows from buildings make seeing the streets more difficult

Registration Process Using ArcInfo

- Obtain digital orthophotograph that is already registered in UTM coordinate system
- Identify common points between higher resolution photographs and digital orthophotograph
- Register photographs to orthophoto coordinate system
- Register DEP map with newly positioned aerial photographs

Results of Registration

Digital Ortho

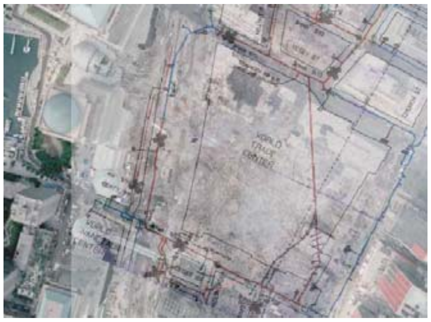
Pre Sept 11

Sept 15

High Res

DEP Map

Damaged Mains



Damaged Mains – Zoomed In

Note: due to the registration process, the absolute position of the main breaks may not be accurate

Damaged Mains – Zoomed In

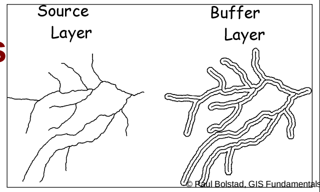
Note: due to the registration process, the absolute position of the main breaks may not be accurate

Conclusion

- Data was not readily available from many organizations.
- The use of registration functions within a GIS enabled disparate data sources to be assembled together into a common basemap
- Further analysis of the relationship between main breaks and debris piles could be explored

Buffer Analysis

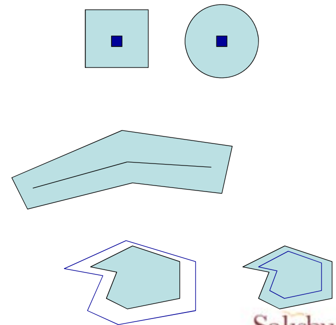
- A type of proximity analysis where a buffer zone is created to perform a search
- Search: specify a distance from a point (radius), line (corridor), area (area)
- Buffer: A zone around a point, line or area
  - Can also create concentric buffers around a point based on distances *example from wells & parcels*



Review Mathcad equations
Review coordinate transform.
http://www.sli.unimelb.edu.au/gisweb/BuffersModule/BuffSelect.htm
Review Conformal
Line generalization animation
Buffer
http://www.sli.unimelb.edu.au/gisweb/menu.html

Buffer Generation

- Point
  - Circle
  - Square
- Line
  - Line Buffer
- Polygon
  - Interior
  - Exterior

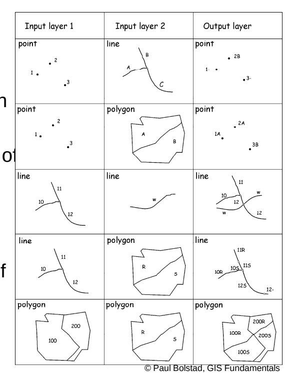


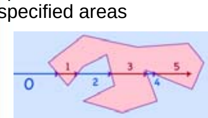
Overlay

- Overlay is an operation in which sets of irregular, non-overlapping regions are merged to form a new set of geographic regions that the two initial sets share
- Relies on boolean operations

Types of Overlay

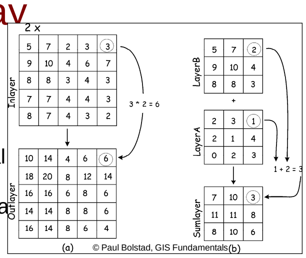
- Polygon on Polygon
  - overlapping two or more polygons to create a new region
- Point in Polygon
  - determine which point features of specified characteristics fall in specified areas
    - Use ray tracing algorithm
- Line in Polygon
  - determine which line features of specified characteristics fall in specified areas





Types of Overlay

- Raster Overlay
  - in raster models this is known as map algebra
  - in map algebra, the retrieval operations are boolean, multiply, recode and algebra
  - overlay operations work on grid cells in a 1:1 relationship



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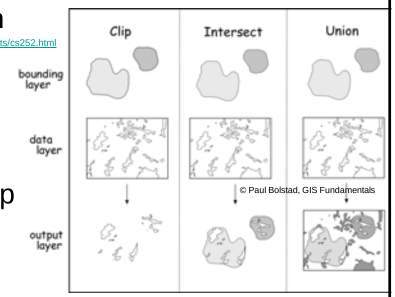
2 2 2 3 3 3 2 2 2
2 2 2 2 2 2 3 3 3
2 2 2 1 1 1 3 3 3

B NOT A

Polygon Overlay

- Intersection
  http://www.lems.brown.edu/~wq/projects/cs252.html
- Clip
- Identity
- Union
- ArcGIS Help



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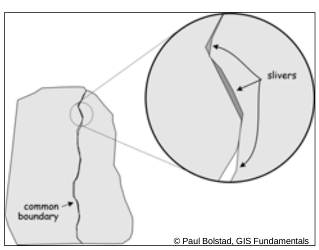
Result of Overlay

- Sliver polygons formed by overlaying two features that are not exactly coincident
- “Fuzzy” tolerance used to remove sliver polygons
- Use ELIMINATE to remove sliver polygons



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Other GIS Overlay Operations

- ArcTools examples
- ARC/INFO Overlay Command Reference
- **CLIP** extracts features from a coverage that overlaps another coverage using the clip coverage as a 'cookie cutter'.
- **IDENTITY** computes the geometric intersection of two coverages. Only those features overlaying the feature extent of the first specified coverage are preserved. Feature attributes from both coverages are joined in the output coverage.
- **INTERSECT** computes the geometric intersection of two coverages. Only those features in the area common to both are preserved. Feature attributes from both coverages are joined in the output coverage.
- **RESELECT** extracts map features from a coverage based on their attribute values.
- **SPLIT** breaks a single coverage into many coverages.
- **UNION** computes the geometric intersection of two polygon coverages. All features and attributes of both coverages are preserved.

Example of Basic Vector GIS Functions in Manifold GIS

- Dissolve
- Polygon Overlay
  - clip, merge, intersect, union
- Data Retrieval
- Point in Polygon
- Overlap (touching, intersection, etc.)

Computational Geometry
(the backbone of GIS operations)

- The use of mathematics to define spatial relationships between points, lines, and polygons
  – Distance
  – Line intersection
  – Distance between point and line
  – Polygon area
  – Determining clockwise rotation
  – Point in Polygon (see line intersection)
  – Thiessen Polygon example

	Line Smoothing	Area calculation	Buffering	Topological Overlay	Point in polygon	Topology creation
Line Distance	X		X			
Area / Perimeter		X		x		X
Distance from point to a line			X			X
Intersection			X	X	X	X