# Fundamentals of GIS

## Emphasizing GIS Use for Natural Resource Management

BSRSI

Produced for:

Basic Science and Remote Sensing Initiative

Department of Geography

Michigan State University

# FUNDAMENTALS OF GIS

## EMPHASIZING GIS USE FOR NATURAL RESOURCE MANAGEMENT

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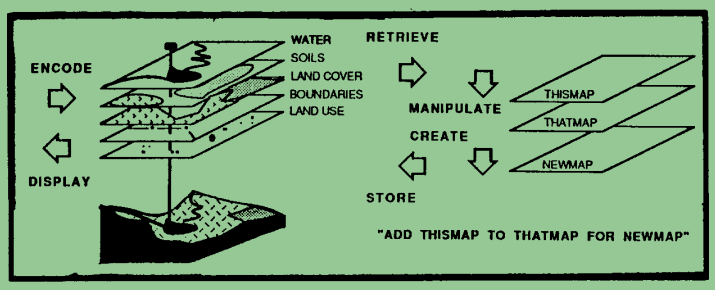
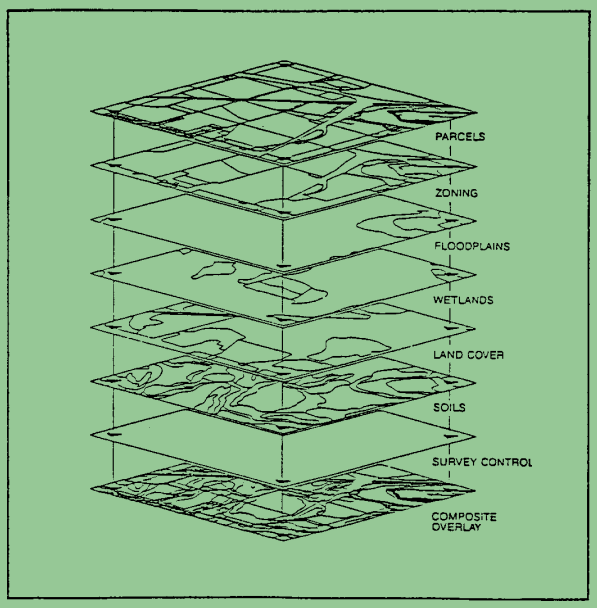


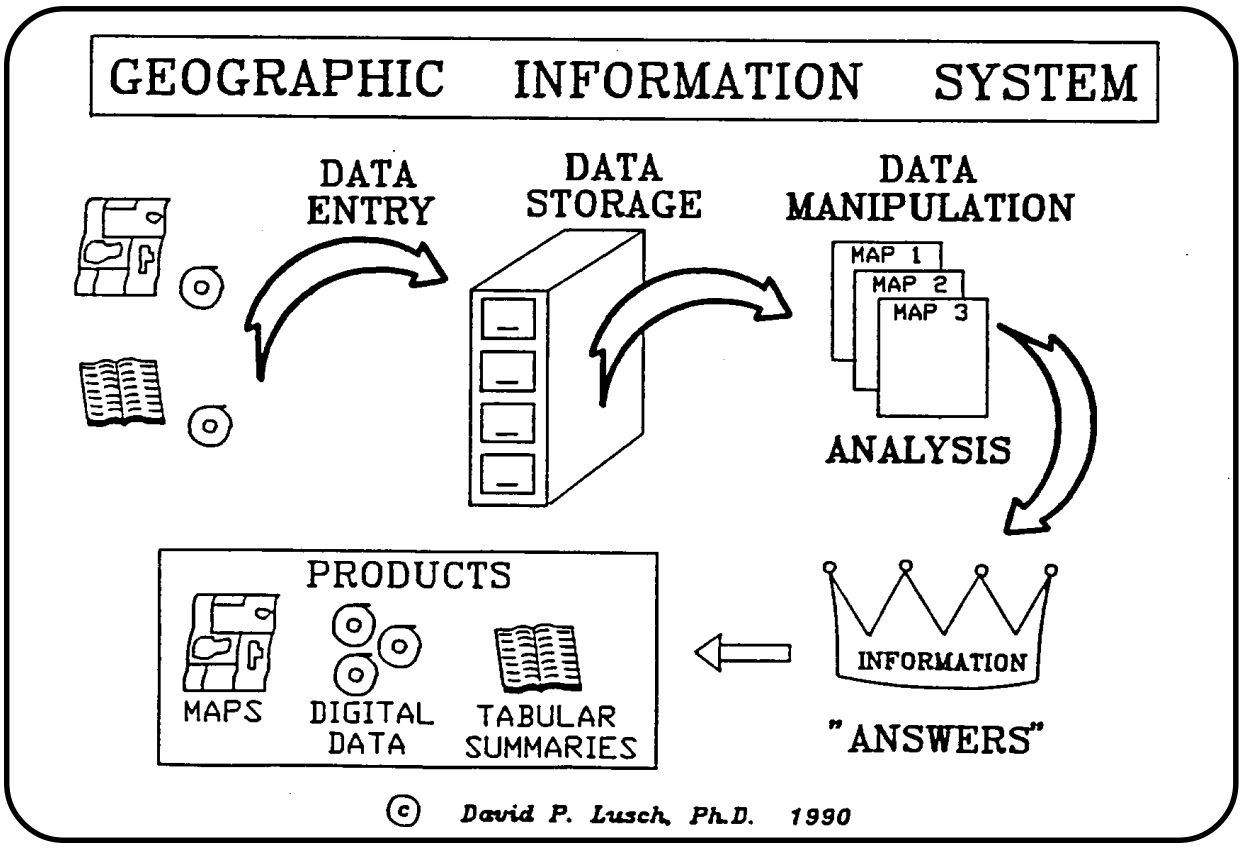

**November, 1999**

OVERVIEW OF GIS

# G I S

## Geographic Information Systems

An INTEGRATED SYSTEM of COMPUTER HARDWARE and SOFTWARE coupled with ***PROCEDURES*** and a ***HUMAN ANALYST*** which together support the CAPTURE, MANAGEMENT, MANIPULATION, **ANALYSIS**, **MODELLING**, and DISPLAY of SPATIALLY REFERENCED DATA



# G I S Capabilities:

## ❑ QUERY FOR LOCATION

**"Show me all the countries of South America that have a population greater than 20,000,000. "**

## ❑ QUERY FOR CONDITION

**"Display the population of each country I point to on the map."**

## ❑ TREND ANALYSIS

**"Show me where the census blocks are that have experienced more than a 50% population change between 1980 and 1990."**

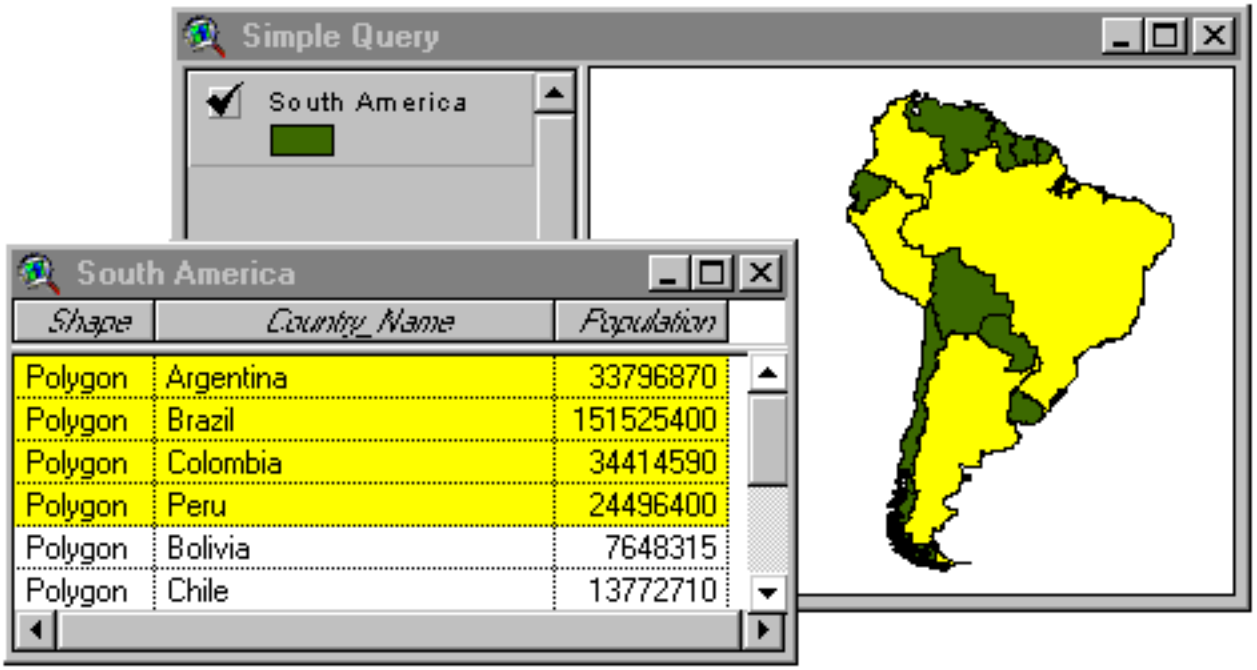
## ❑ PATTERNS ANALYSIS

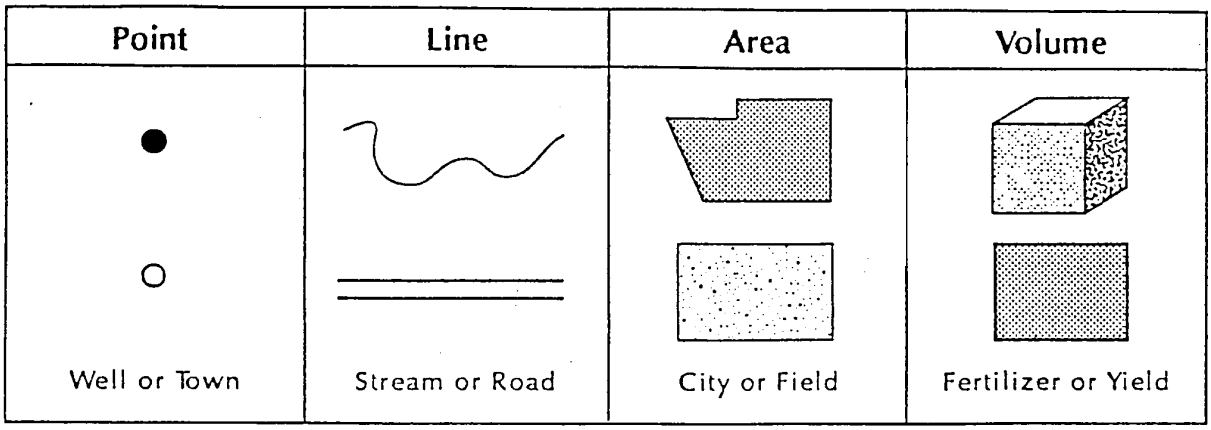
**"Calculate the fragmentation index for all the forest patches in the municipio."**

## ❑ MODELLING

**"Which route for the new highway has the lowest cost in terms of losses of housing, prime farmland, and wetlands, while minimizing the needs for cutting and filling."**

## Query: Population > 20,000,000

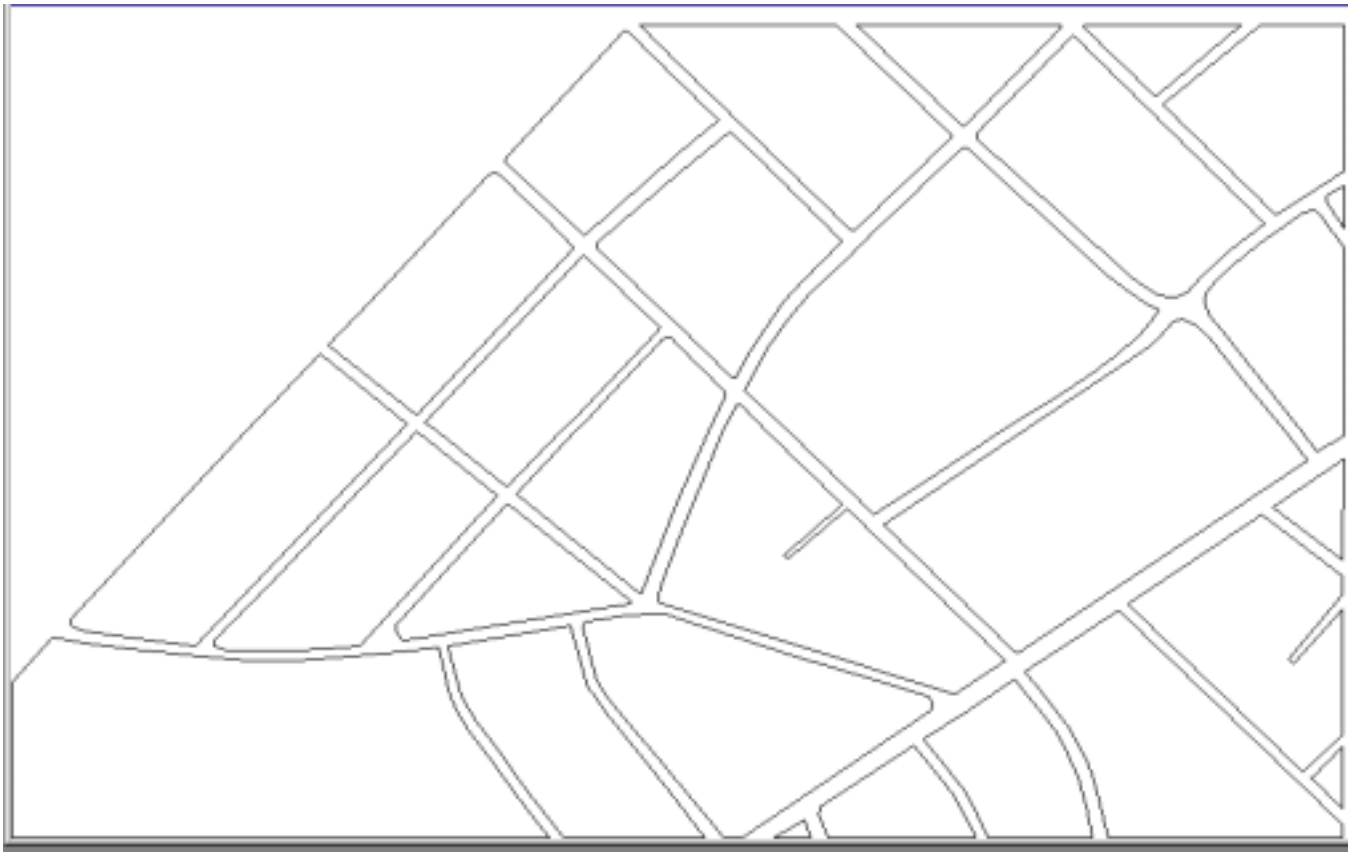


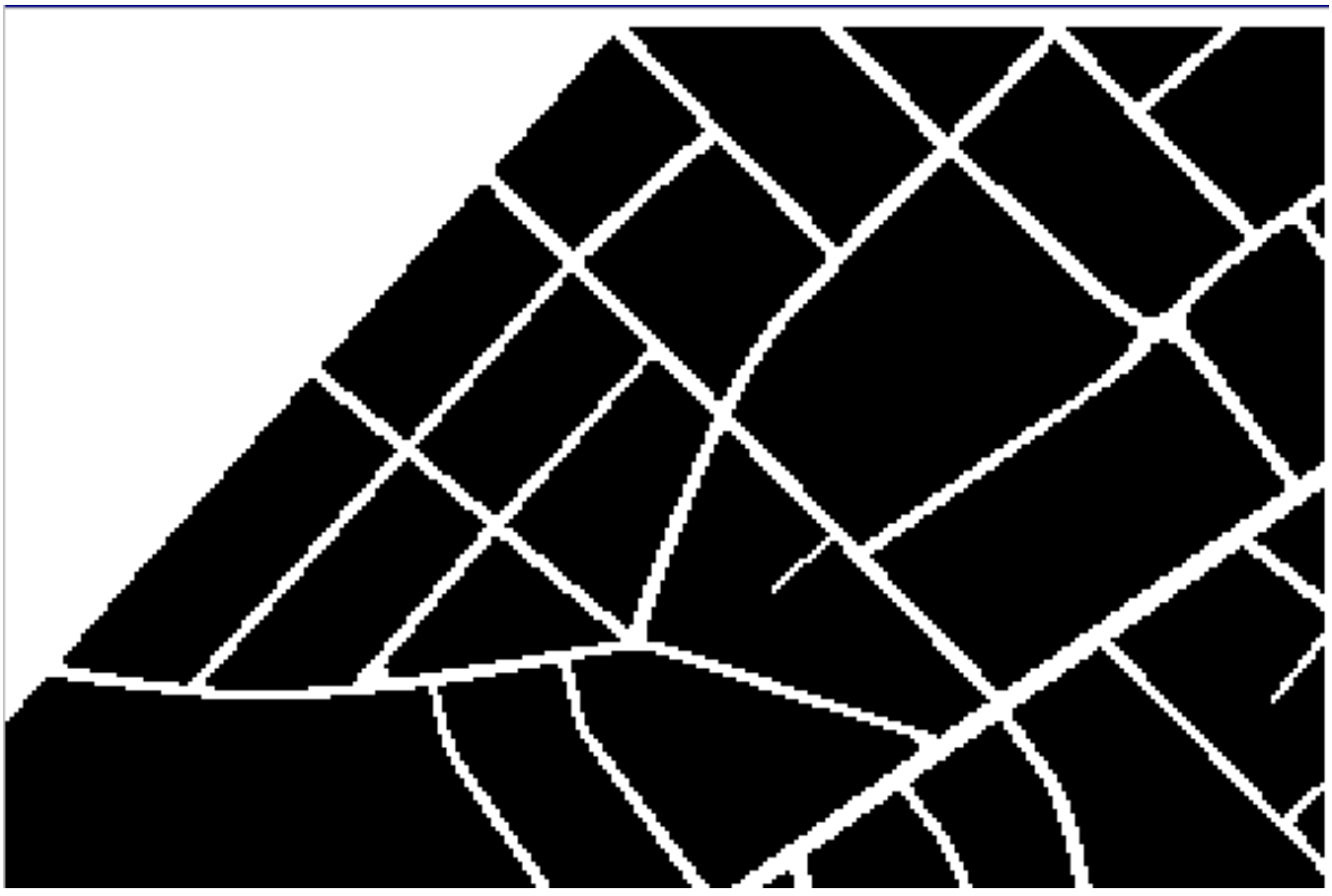




**Geometric Classes of Data**

## DATA TYPES

| VECTOR | RASTER |
|---|---|
| Point = Position, no area | Point = 1 cell |
| Line = Length, no width | Line = Multiple cells joined at edges or corners, usually with only 1 or 2 neighbors |
| Polygon = Area and perimeter | Polygon = Group of contiguous cells joined at edges or corners |





# VECTOR STRUCTURE

## Advantages

- ❑ Good representation of the landscape being mapped
- ❑ Topology can be completely described, including network linkages
- ❑ Great looking graphics ("Looks like a map is supposed to")
- ❑ Generalization of the graphics is possible while still maintaining the great look ("What the map reader doesn't know won't hurt them")

# RASTER STRUCTURE

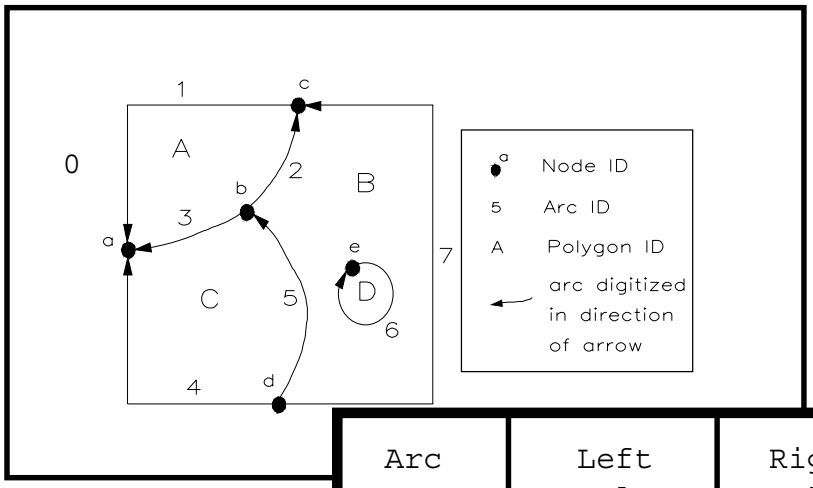
## Advantages

- ❑ Overlaying maps is easy and "perfect" (i.e. no possibility of sliver polygons developing since all raster cell borders are coincident
- ❑ Integration of remotely sensed imagery (satellite images or scanned airphotos) is straight-forward
- ❑ A huge variety of complex spatial analyses are supported
- ❑ Software is generally cheaper and easier to learn compared to vector GISs

# TOPOLOGY

**Geometrical relationships between spatial objects (Points, Lines, and Areas), such as adjacency, that are not altered by distortion, as long as the surface is not torn**

## Example of "Built" Topology (from Arc/Info)




| Arc ID | Left Poly | Right Poly | From Node | To Node |
|---|---|---|---|---|
| 1 | A | 0 | c | a |
| 2 | A | 0 | b | c |
| 3 | C | A | b | a |
| 4 | 0 | C | d | a |
| 5 | C | B | d | b |
| 6 | B | D | e | e |
| 7 | B | 0 | d | c |

| Polygon ID | Number of arcs | List of arcs |
|---|---|---|
| A | 3 | -1,-2,3 |
| B | 4 | 2,-7,5,0,-6 |
| C | 3 | -3,-5,4 |
| D | 1 | 6 |

# Vector GIS ATTRIBUTE DATABASE

| ID | Name | Quality | ... |
|---|---|---|---|
| 0 | N/A | | |
| 1 | Fir Lake | High | |

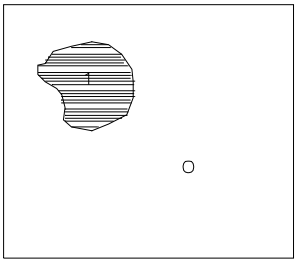
| ID | Species | Size | ... |
|---|---|---|---|
| 0 | N/A | | |
| 1 | Jack Pine | Pole | |
| 2 | Spruce | Sapling | |
| 3 | Jack Pine | Sapling | |

| ID | Type | Depth | ... |
|---|---|---|---|
| 0 | N/A | | |
| 1 | B | | |
| 2 | A | | |
| 3 | B | | |
| 4 | C | | |
| 5 | C | | |
| 6 | A | | |
| 7 | R | | |

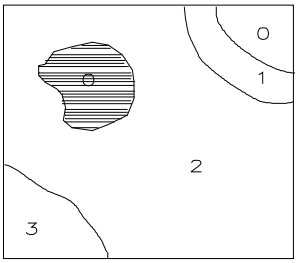
| Type | Drainage | ... |
|---|---|---|
| A | Fair | |
| B | Poor | |
| C | Good | |
| R | Rock | |

Related Table "Type" is KEY FIELD

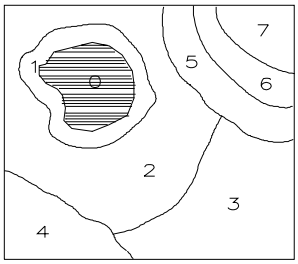
**Lakes**




**Forest Types**




**Soils**



# ENTITY RELATIONSHIPS

| | |
|---|---|
| **Point - Point** | **Is nearest to ...** |
| | **Interacts with ...** |
| **Point - Line** | **Is on ...** |
| | **Is nearest to ...** |
| **Point - Area** | **Is within ...** |
| | **Is adjacent to ...** |
| **Line - Line** | **Intersects ...** |
| | **Is upstream of ...** |
| **Line - Area** | **Crosses ...** |
| | **Is contained within ...** |
| | **Is nearest to ...** |
| **Area - Area** | **Is adjacent to ...** |
| | **Overlaps ...** |
| | **Is enclosed by ...** |

# A Classification of GIS Functions

❑ **Analysis of Spatial and Attribute Data**

- **Non-spatial analyses**

  **Attribute query and display**
  **Map retrieval and display**
  **Attribute classification**
  **Map measurements (distance, direction, area, etc.)**

- **Spatial analyses**

  **Overlay operations**

  **Neighborhood functions**

  **Distance and Connectivity functions**
  - **Contiguity measures**
  - **Proximity analysis**
  - **Network analysis**
  - **Spread functions**
  - **Seek operands**
  - **Intervisibility analysis**
  - **Solar illumination calculation**
  - **Perspective view**

  **Search operations**
  - **Line-in-polygon; Point-in-polygon**
  - **Topographic functions**
  - **Thiessen polygons**
  - **Interpolation**
  - **Contour generation**

*This classification has been adapted from:*

*Aronoff, Stan. 1989. Geographic Information Systems: A Management Approach. Ottawa, Ontario, Canada: WDL Publications. 294p.*

# A Classification of GIS Functions

- **Maintenance of Attribute Data**

  **Format conversions**
  **Database error checking**
  **Database editing**

- **Maintenance of Spatial Data**

  **Format conversions**
  **Geometric transformations**
  **Projection conversions**
  **Conflation**
  **Edge matching**
  **Editing of graphic elements**
  **Line coordinate thinning**

- **Output functions**

  **Map annotation**
  **Text labels**
  **Texture patterns and line styles**
  **Graphic symbols**
  **Plotting**
  **Printing (laser printers, color inkjet printers, etc.)**

*This classification has been adapted from:*

*Aronoff, Stan. 1989. Geographic Information Systems: A Management Approach. Ottawa, Ontario, Canada: WDL Publications. 294p.*

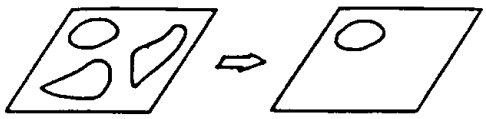
# Spatial Analyses

## Basic Functional Classes

- ❑ **Reclassifying Maps** — *Vector and Raster*
- ❑ **Overlaying Maps**
- ❑ **Measuring Distance and Connectivity**
- ❑ **Characterizing Neighborhoods**

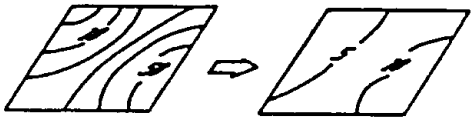
Position — *Vector and Raster*

"only those in the NW"

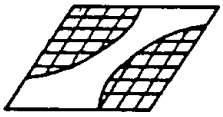


Value — *Vector and Raster*

"change feet to meters"



"elevations between 20 & 40 feet"

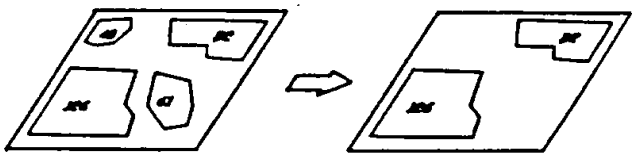


# RECLASSIFYING MAPS

## Size

**Vector and Raster**

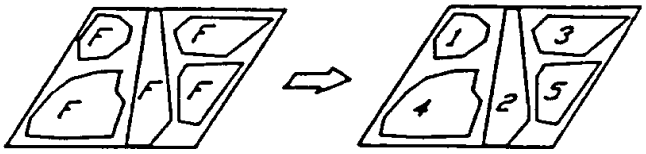
"larger than 80 acres"



## Contiguity

**Raster Only**

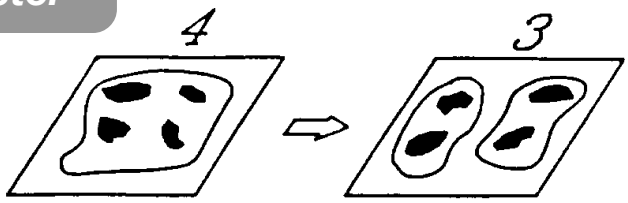
"work with individual members rathers than the class as a whole"




## Shape

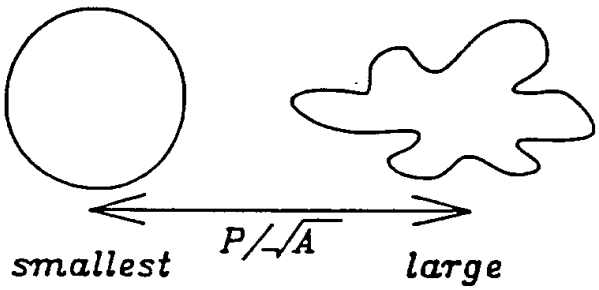
**Vector and Raster**

- Spatial Integrity




[# Holes – (# Fragments – 1)]

- Boundary Configuration



# SPATIAL ANALYSES

## Basic Functional Classes

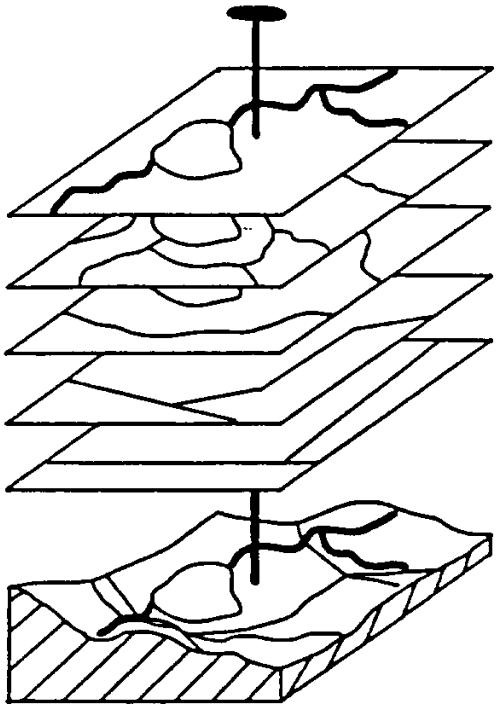
- ❑ Reclassifying Maps
- ❑ Overlaying Maps — *Vector and Raster*
- ❑ Measuring Distance and Connectivity
- ❑ Characterizing Neighborhoods

## Point by Point

*Vector and Raster*

*"piercing – needle" approach*

**All locations in the coverage or grid are evaluated. The results extend to the spatial limits of the input maps.**

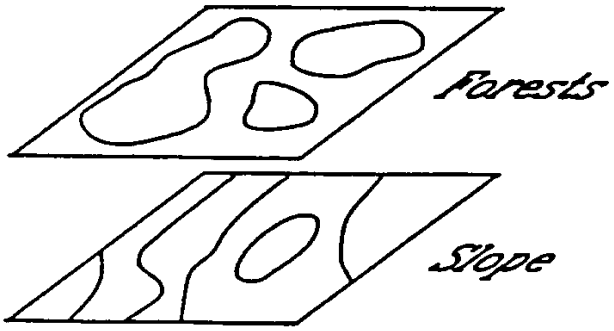


# OVERLAYING MAPS

## Region-wide

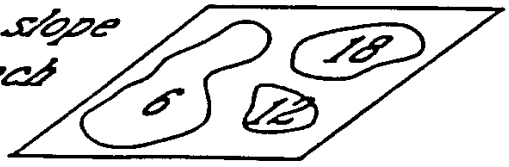
Vector and Raster

"cookie-cutter" approach




**All locations in the coverage or grid are not necessarily evaluated. The results are constrained to the spatial nature of the reference map.**

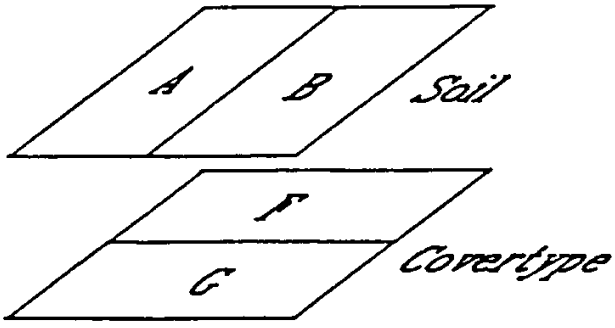
Average slope within each forest patch



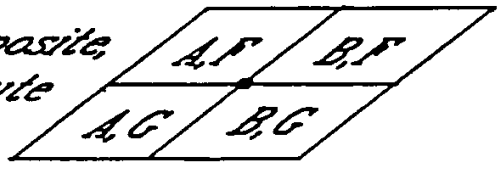

Vector Only

## Topologic Overlay

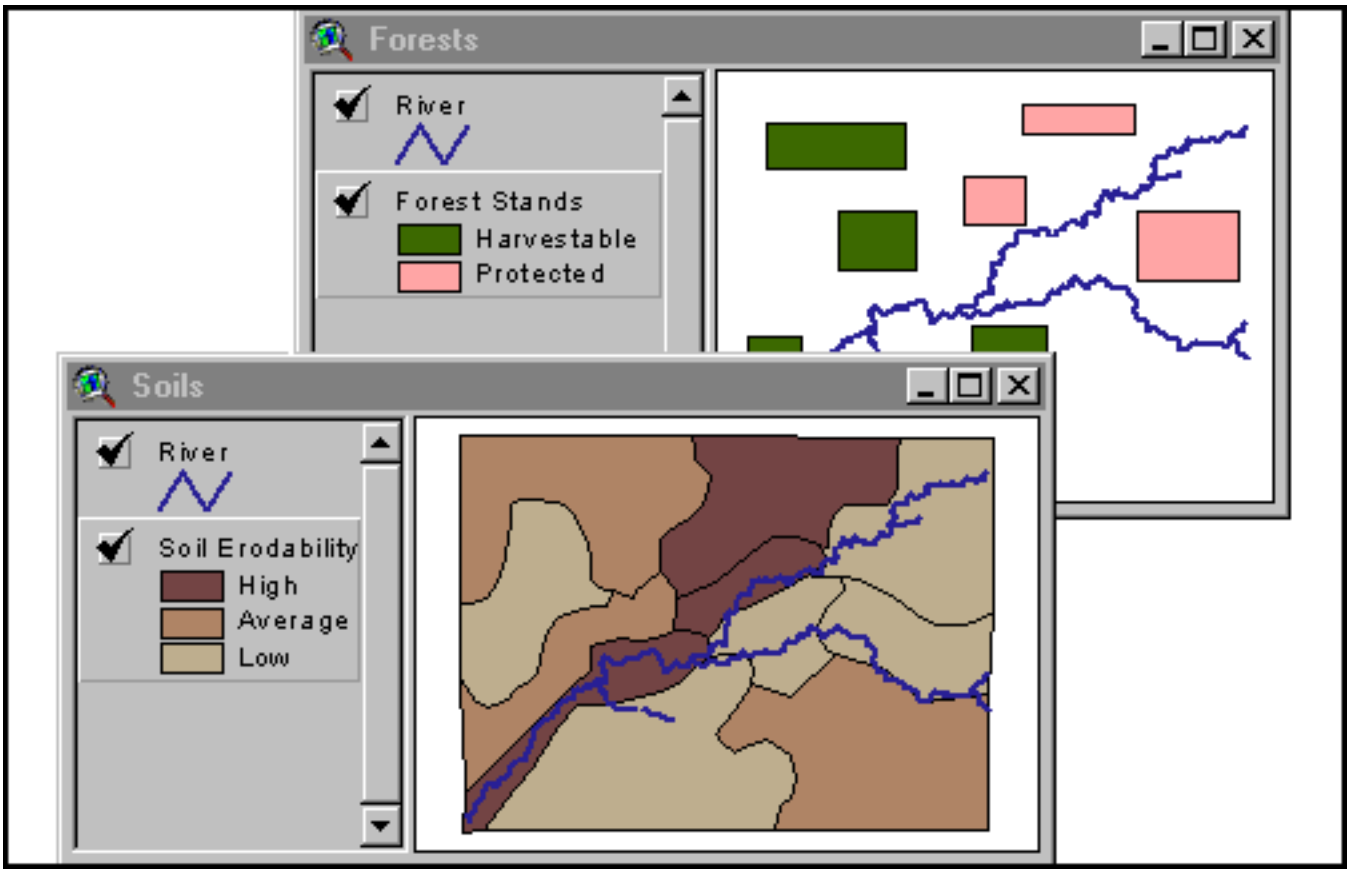
"co-occurrence" mapping

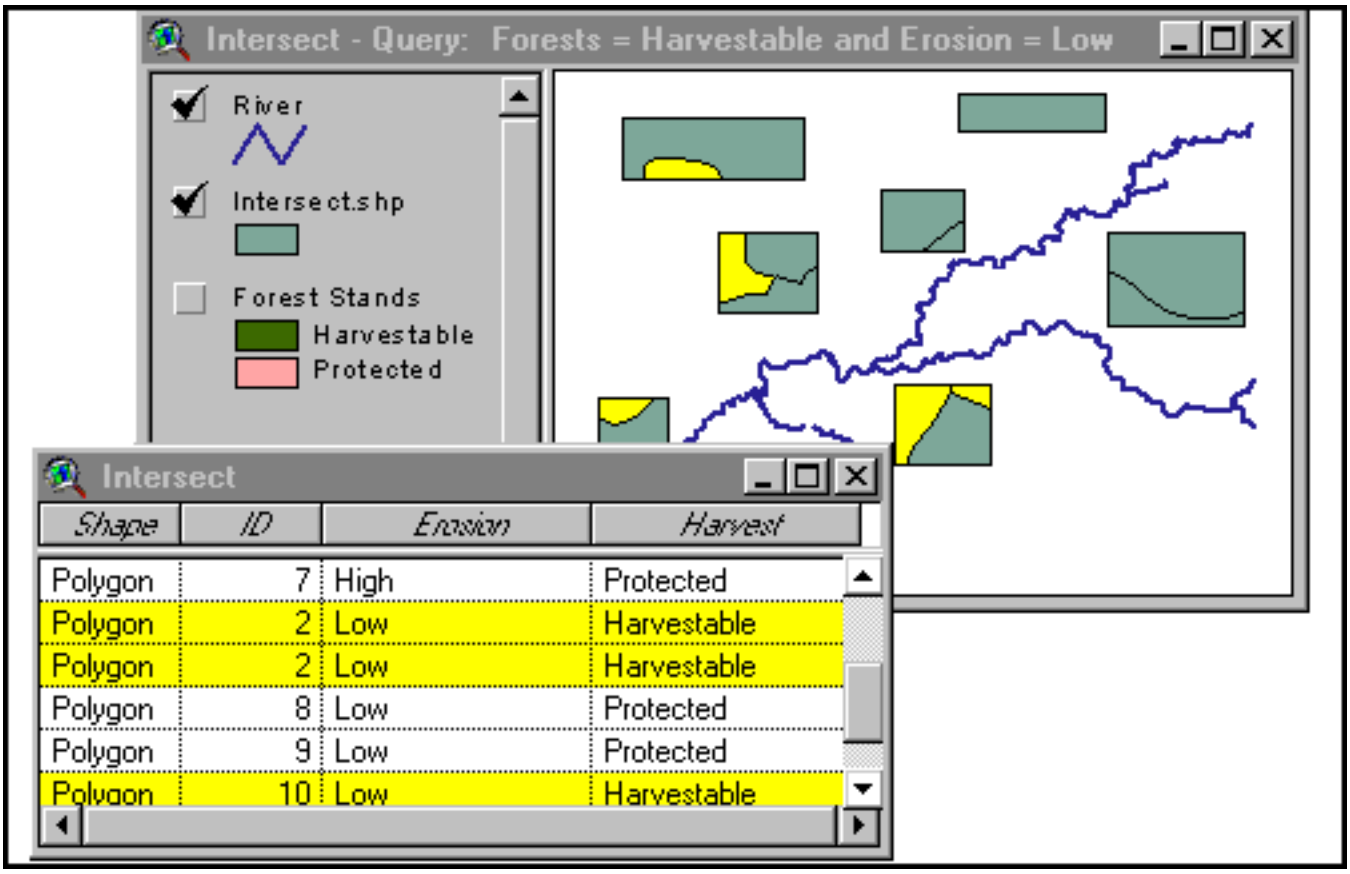



Composite, multi-attribute map




Note the new NODE - topologically correct areas were created

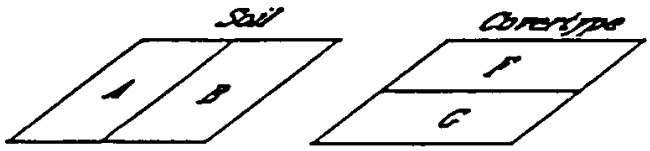

Forests
River
Forest Stands
Harvestable
Protected
Soils
River
Soil Erodability
High
Average
Low


Intersect - Query: Forests = Harvestable and Erosion = Low
River
Intersect.shp
Forest Stands
Harvestable
Protected
Intersect
Shape | ID | Erosion | Harvest
Polygon | 7 | High | Protected
Polygon | 2 | Low | Harvestable
Polygon | 2 | Low | Harvestable
Polygon | 8 | Low | Protected
Polygon | 9 | Low | Protected
Polygon | 10 | Low | Harvestable

# OVERLAYING MAPS

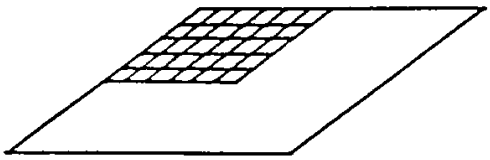
## Boolean Overlay

**Vector and Raster**



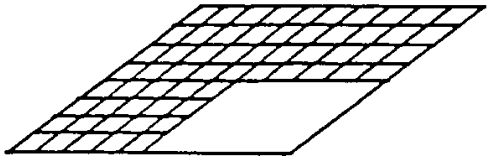

- Intersection

  *"Forest AND Soil A"*



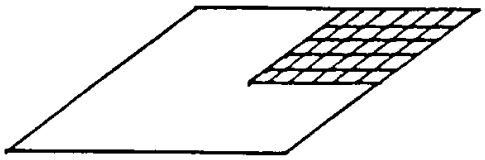
- Union

  *"Forest OR Soil A"*



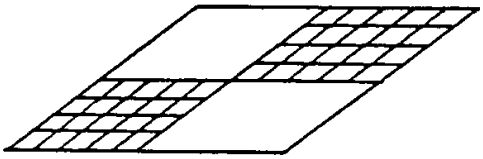
- Negate

  *"Forest, but NOT on Soil A"*

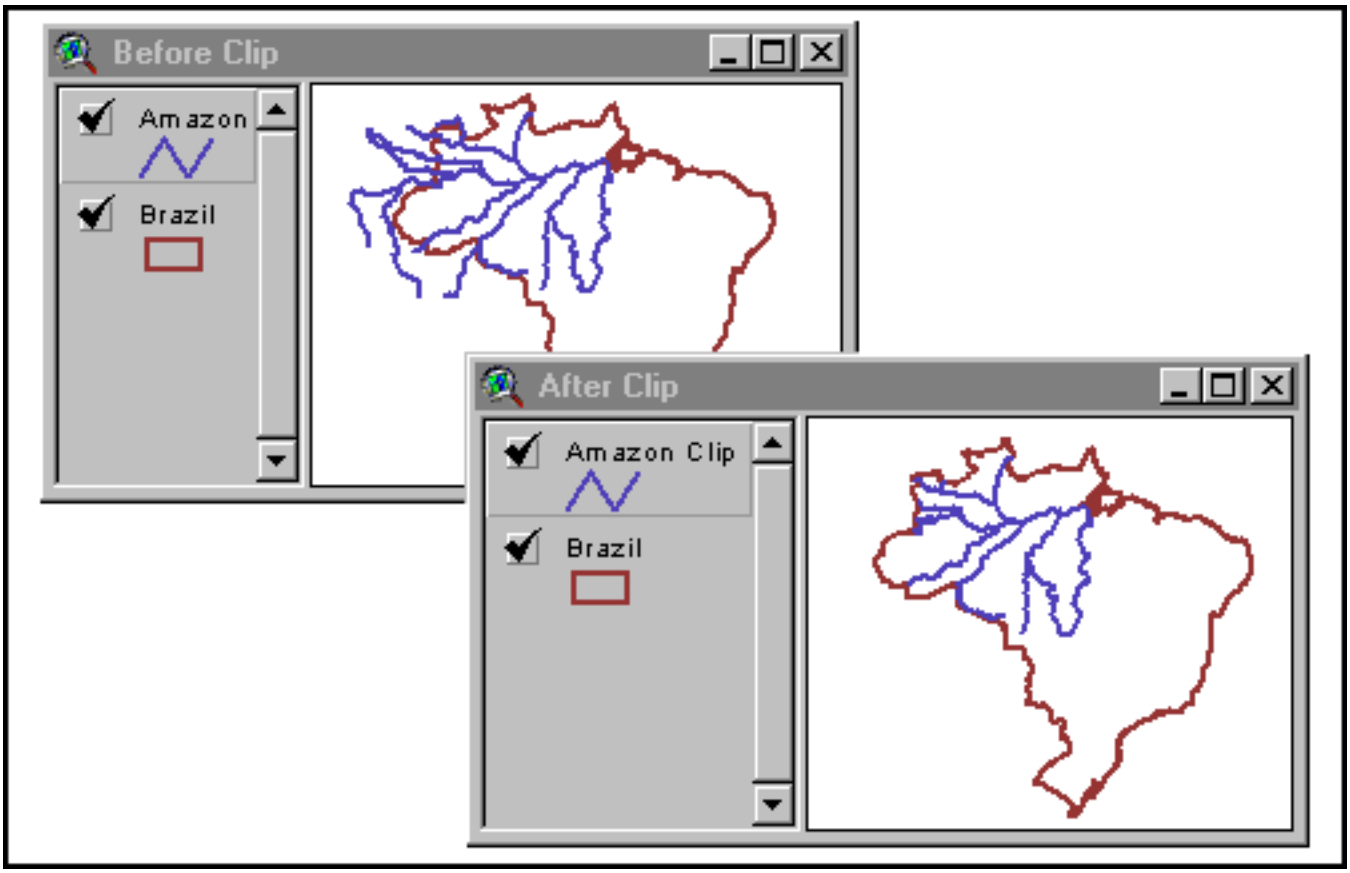


- Exclusive Or

  *"Forest XOR Soil A"*



**Note: Most relational database management systems support a "SWAP" function which selects the *currently unselected* items in the database. In the example above, the "SWAP" function would return the white areas after the hatched areas had initially been selected.**


Before Clip
Amazon
Brazil
After Clip
Amazon Clip
Brazil

# SPATIAL ANALYSES

## Basic Functional Classes

- ❑ **Reclassifying Maps**
- ❑ **Overlaying Maps**
- ❑ **Measuring Distance and Connectivity**
- ❑ **Characterizing Neighborhoods**

## DISTANCE MEASURES

### Point to Point

*Vector and Raster*

*"How far is it from A to B?"*

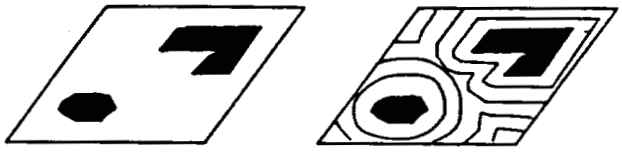
USEFUL, BUT LIMITED

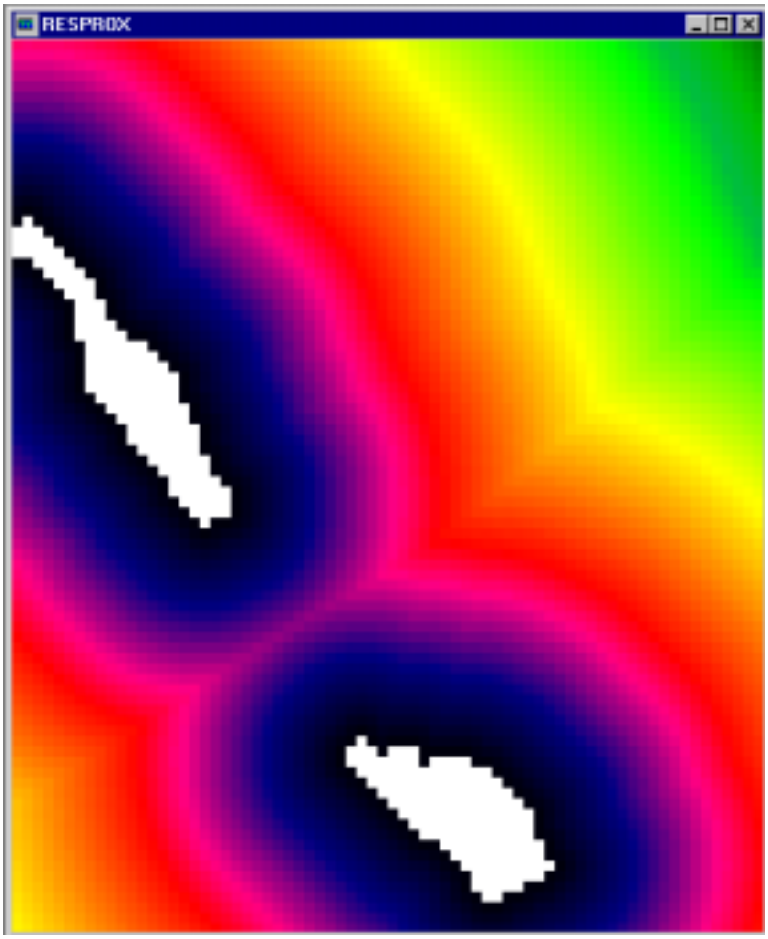
### Proximity

*Raster Only*

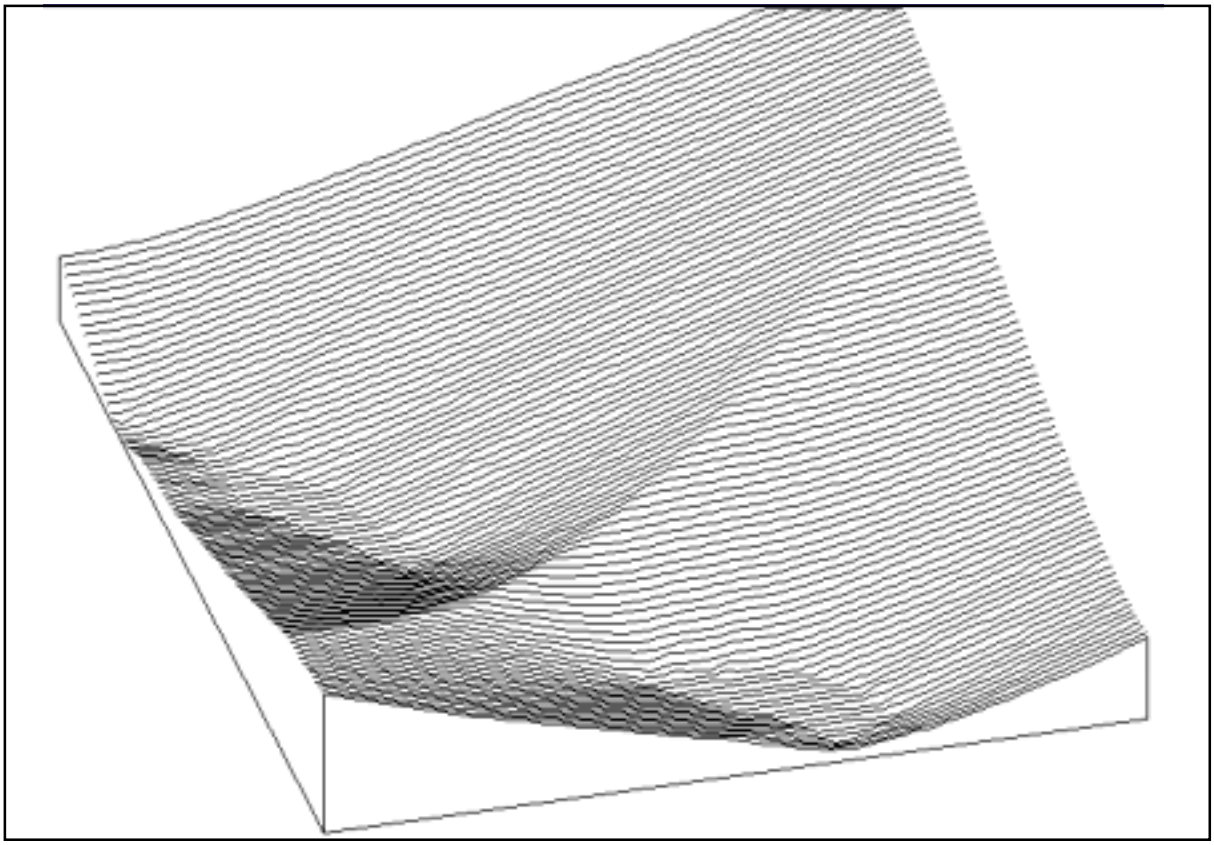
*"How far from the forest is every location on the map?"*

POWERFUL AND VERY DIFFICULT TO DO BY HAND





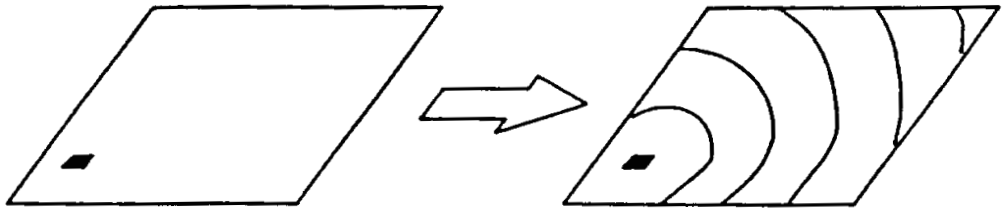

Simple (i.e. unweighted)
PROXIMITY SURFACE



# DISTANCE MEASURES

## I Movement

Raster Only

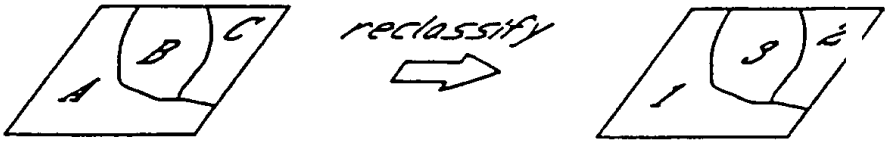


Start Location

Travel Time
(Impedance = 0)

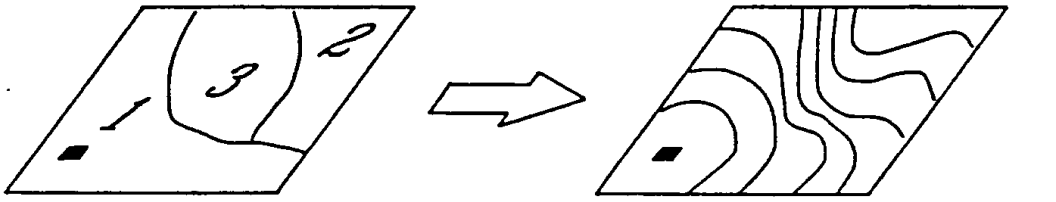
## II Movement

Raster Only




A = gently sloping grassland
B = steeply sloping forest
C = gently sloping forest

1 = easy hiking
2 = harder hiking
3 = difficult hiking

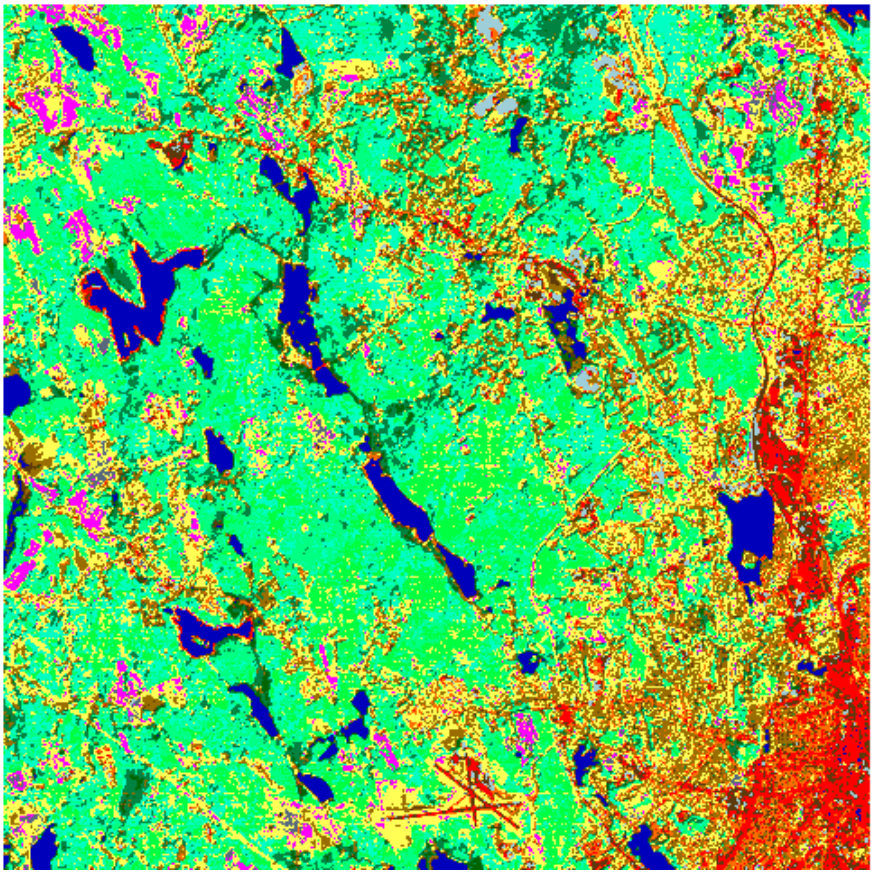



Start Location

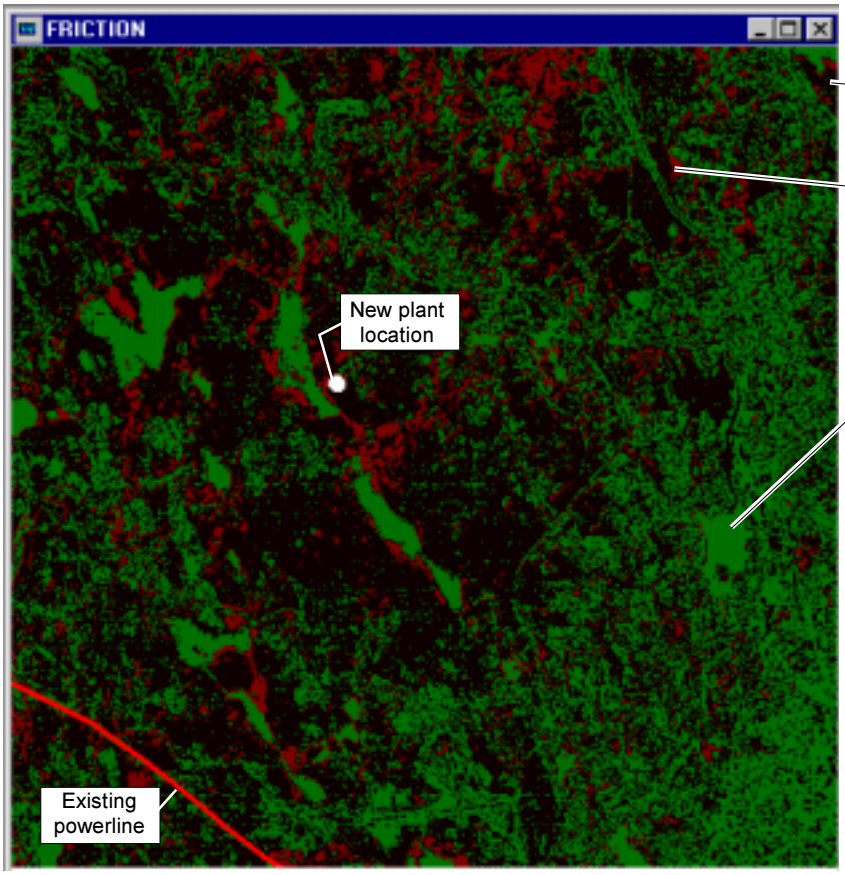
Travel Time
(with variable impedances)

# Least-Cost Pathway Analyses

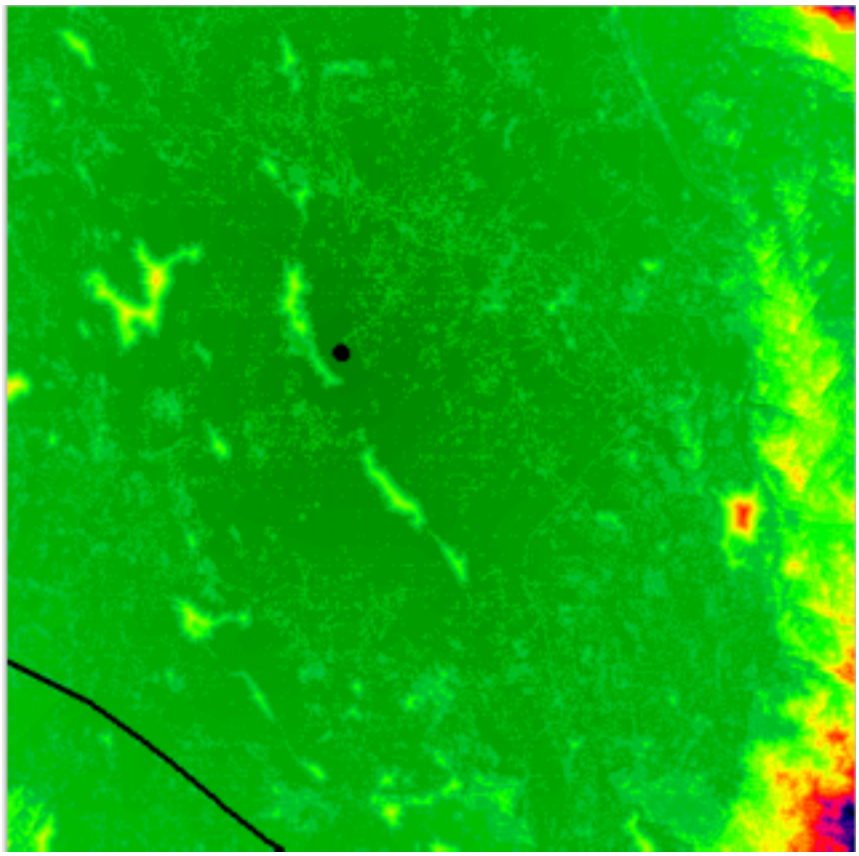
- Create a FRICTION map from one or more existing coverages
- Create a COST SURFACE map by executing the PROXIMITY analysis *WEIGHTED BY* the FRICTION map
- Execute the LEAST-COST PATHWAY module from one or more starter entities (points, lines or areas) to a destination. It will FIND the one (or more) routes that ACCUMULATE the least cost.




**Land Use**
(classified from Landsat TM imagery)

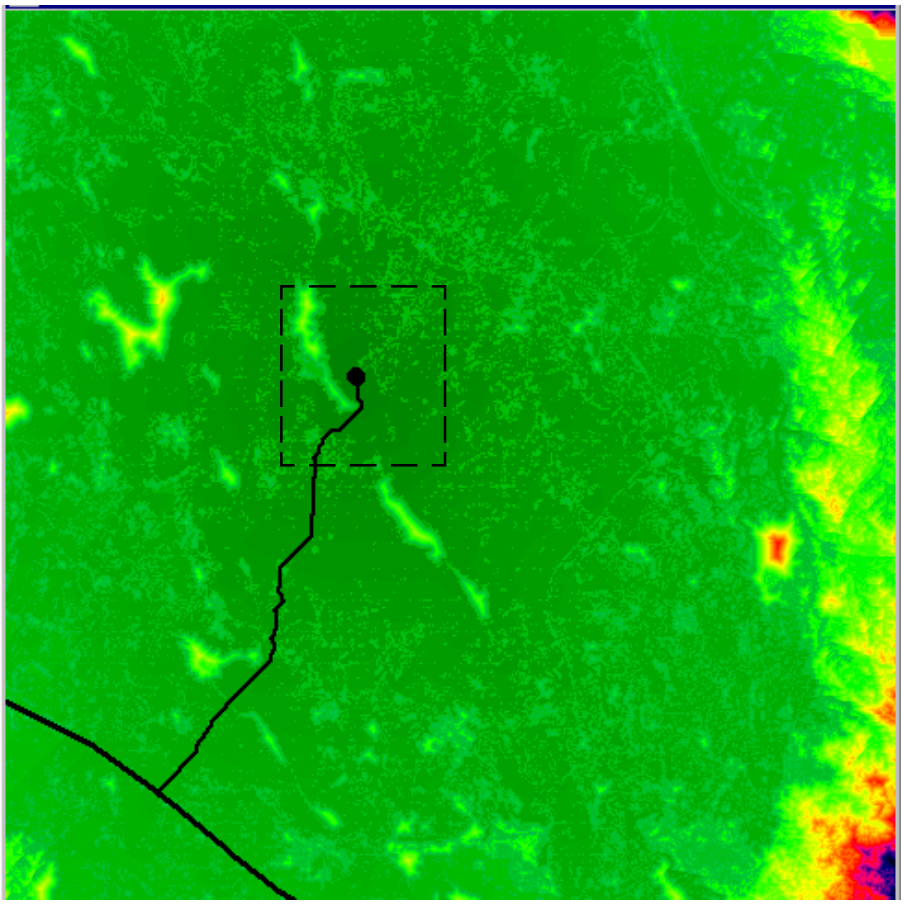



**Friction Surface**
(reclassed from the Land Use map)

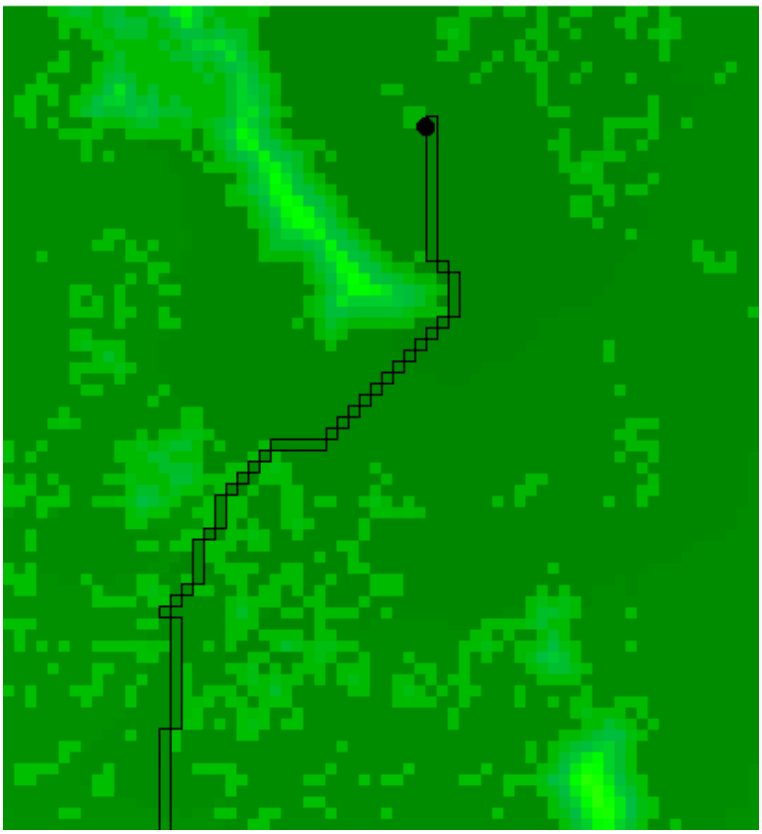


**Cost Surface (Proximity x Friction)**

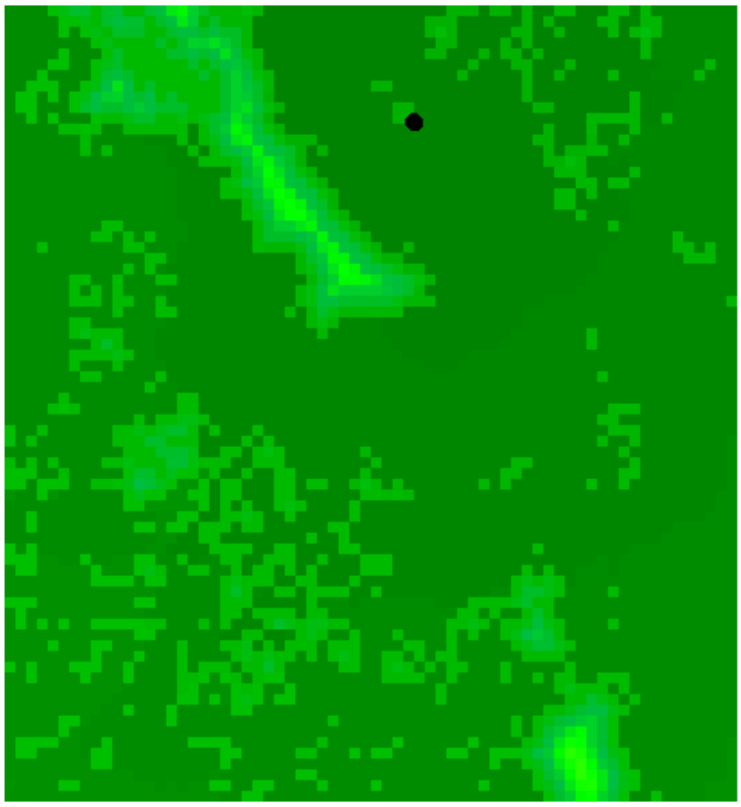
**Least-Cost Pathway**



## Least-Cost Pathway



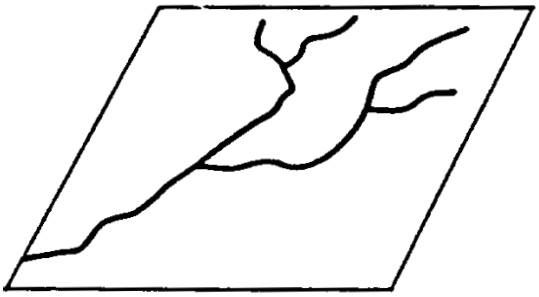
## Least-Cost Pathway

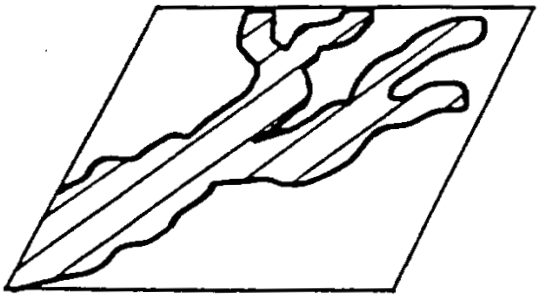


# CONNECTIVITY

## Buffering

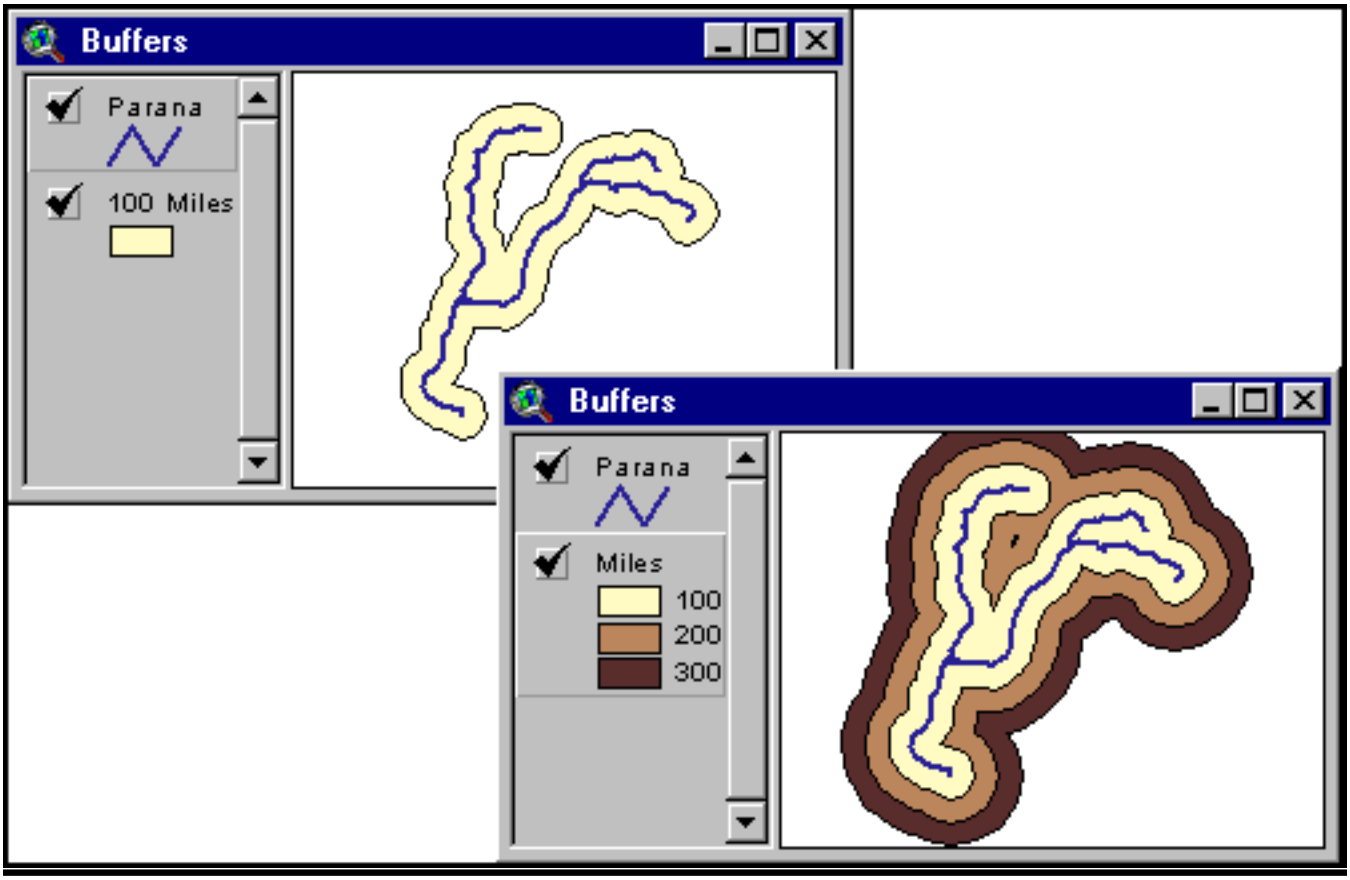
Vector and Raster

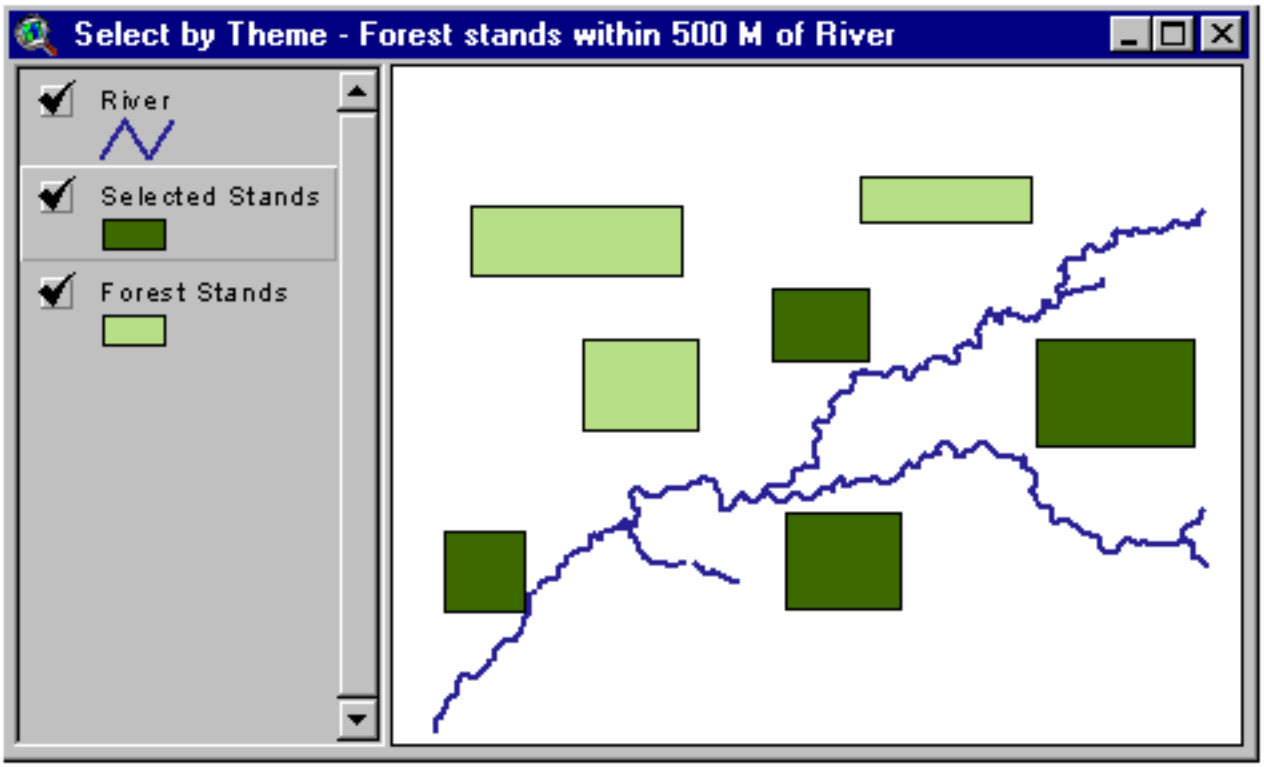


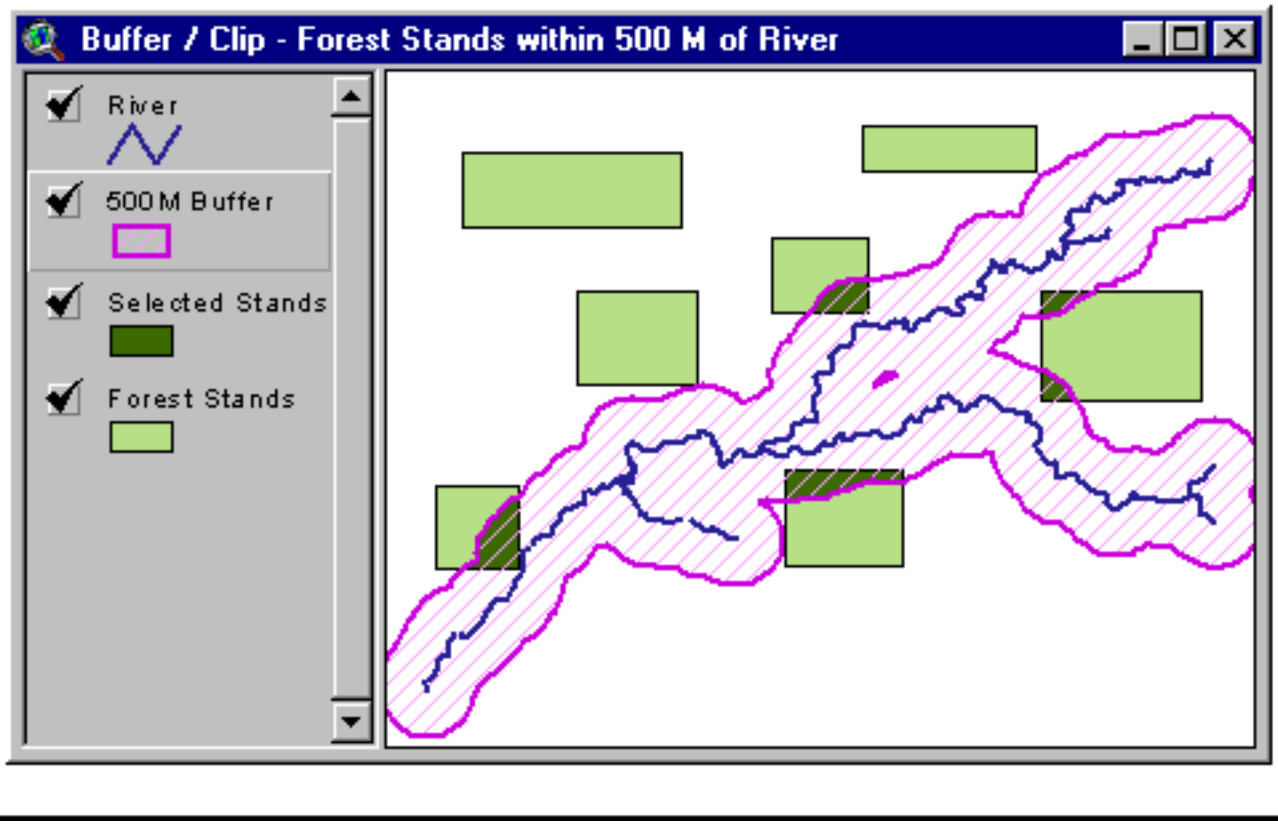


establish limited use zones

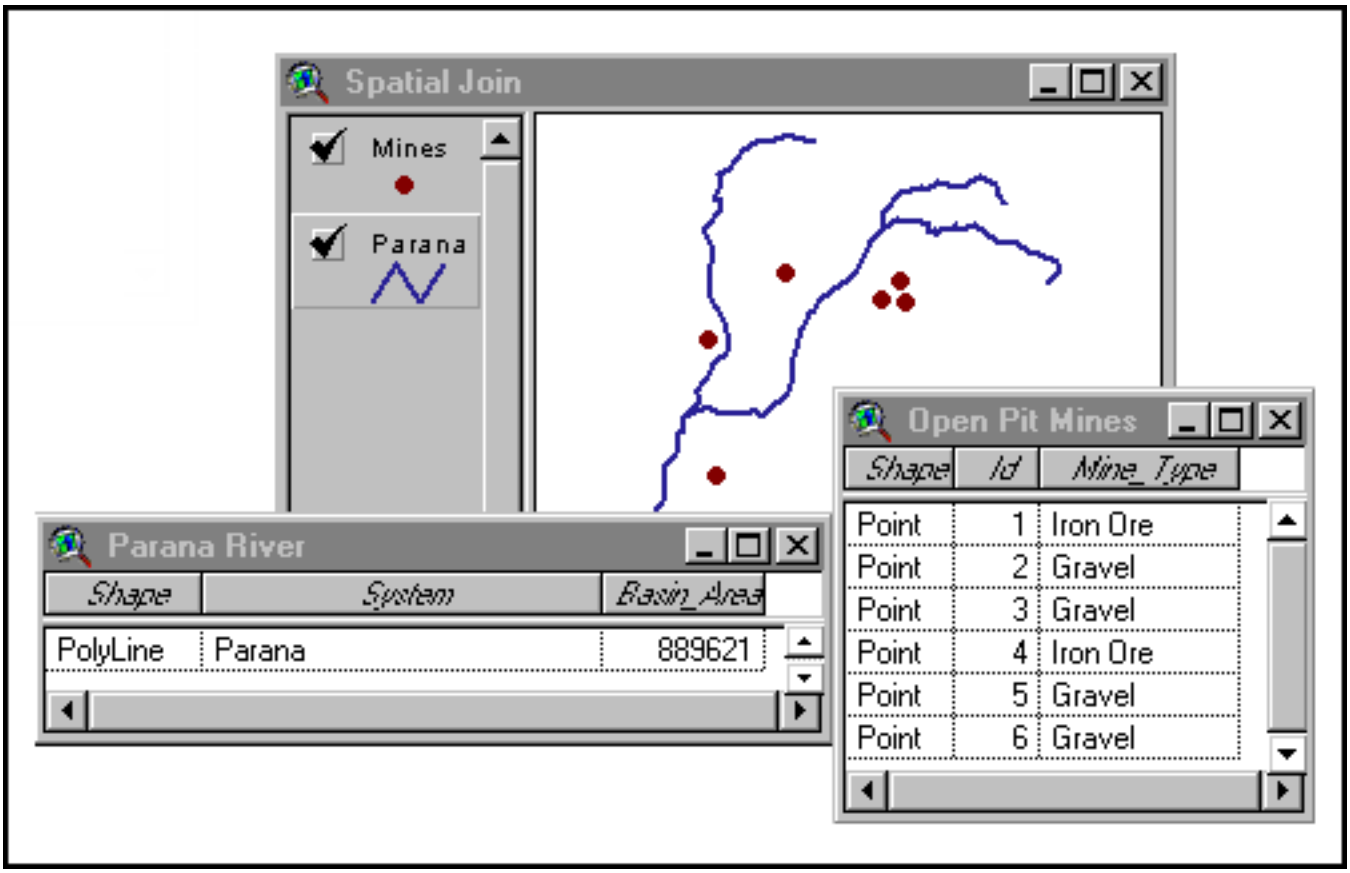
| | |
|---|---|
| 100 m | 1st-order streams |
| 200 m | 2nd-order streams |
| 500 m | 3rd-order streams |

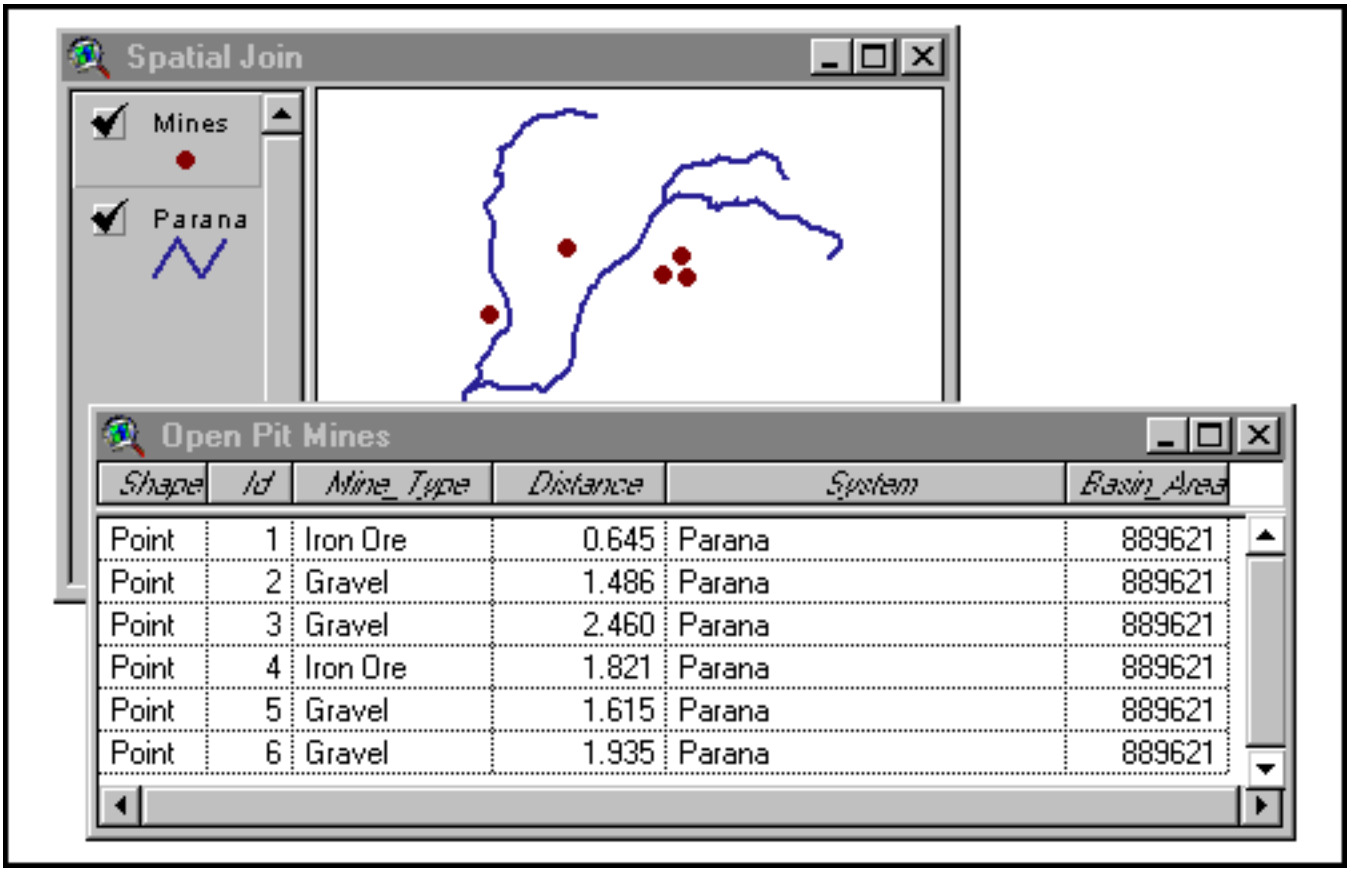





Spatial Join
Mines
Parana
Parana River
Shape
System
Basin_Area
PolyLine
Parana
889621
Open Pit Mines
Shape
Id
Mine_Type
Point 1 Iron Ore
Point 2 Gravel
Point 3 Gravel
Point 4 Iron Ore
Point 5 Gravel
Point 6 Gravel

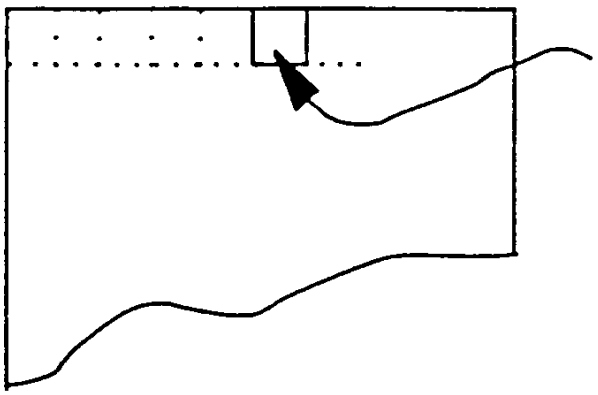

Spatial Join
Mines
Parana
Open Pit Mines
Shape Id Mine_Type Distance System Basin_Area
Point 1 Iron Ore 0.645 Parana 889621
Point 2 Gravel 1.486 Parana 889621
Point 3 Gravel 2.460 Parana 889621
Point 4 Iron Ore 1.821 Parana 889621
Point 5 Gravel 1.615 Parana 889621
Point 6 Gravel 1.935 Parana 889621

# SPATIAL ANALYSES

## Basic Functional Classes

- ❑ Reclassifying Maps
- ❑ Overlaying Maps
- ❑ Measuring Distance and Connectivity
- ❑ Characterizing Neighborhoods — *Raster Only*

## CHARACTERIZING NEIGHBORHOODS



Neighborhood = User-Defined Area of Scrutiny

"Roving Window"

(e.g. ... per square mile; ... per hectare)

# WINDOW OPERATIONS

*Raster Only*

**Slope**

**Slope Aspect**

**Maximum, Minimum**

**Mean, Median, Mode**

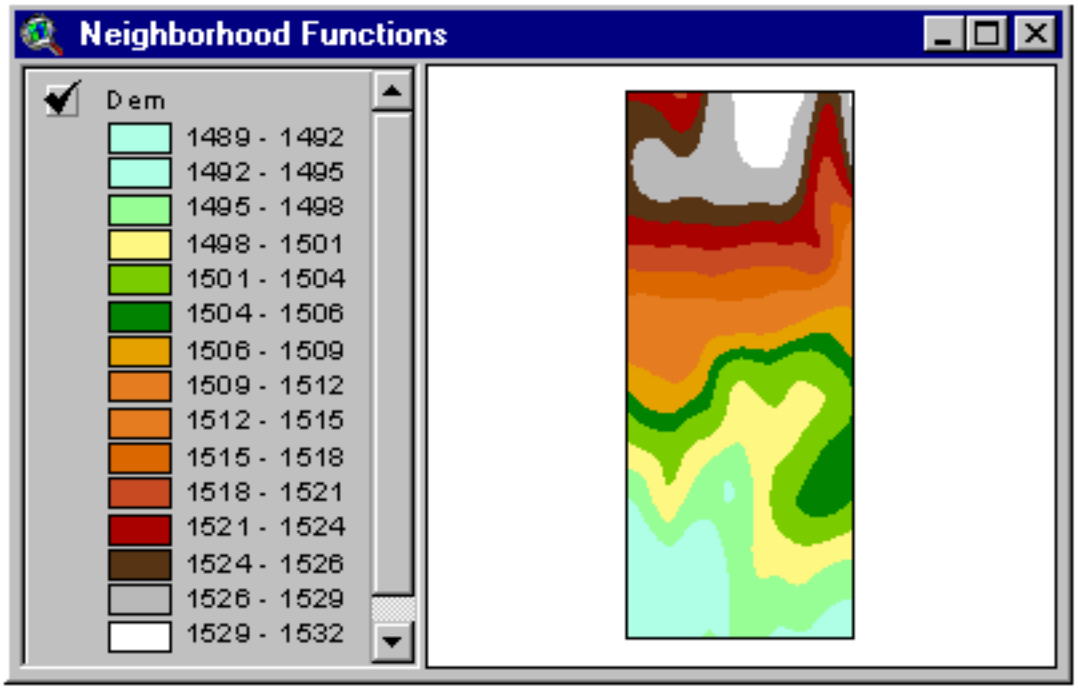
**Standard Deviation**

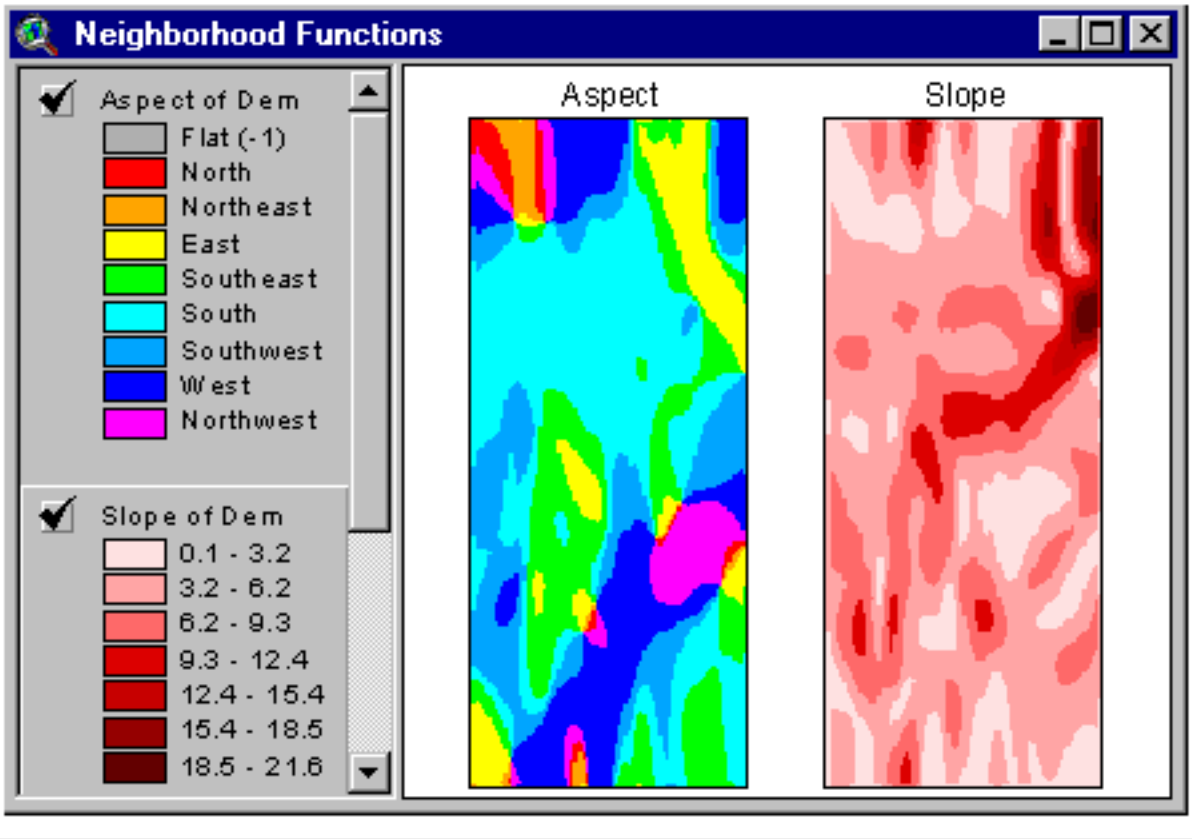
**Majority, Minority**

**Total Count**

**Diversity**

**Large number of Spatial Pattern or Texture Indexes**
**(e.g. Dominance Index, Relative Richness, etc.)**


Neighborhood Functions
Dem
1489 - 1492
1492 - 1495
1495 - 1498
1498 - 1501
1501 - 1504
1504 - 1506
1506 - 1509
1509 - 1512
1512 - 1515
1515 - 1518
1518 - 1521
1521 - 1524
1524 - 1526
1526 - 1529
1529 - 1532


Neighborhood Functions
Aspect of Dem
Flat (-1)
North
Northeast
East
Southeast
South
Southwest
West
Northwest
Slope of Dem
0.1 - 3.2
3.2 - 6.2
6.2 - 9.3
9.3 - 12.4
12.4 - 15.4
15.4 - 18.5
18.5 - 21.6
Aspect
Slope

# Examples of Neighborhood Operations to Determine Spatial Pattern

Each of the following measures are calculated within a **3 x 3 pixel window** which systematically roves throught the data set. The outcome calculation is assigned to the center cell in the window (in the output file), then the window moves over one pixel along a row and recalculates a new value for that center-pixel location, etc.

**Relative Richness** = n / (nmax) x 100

*where* n = number of different classes present

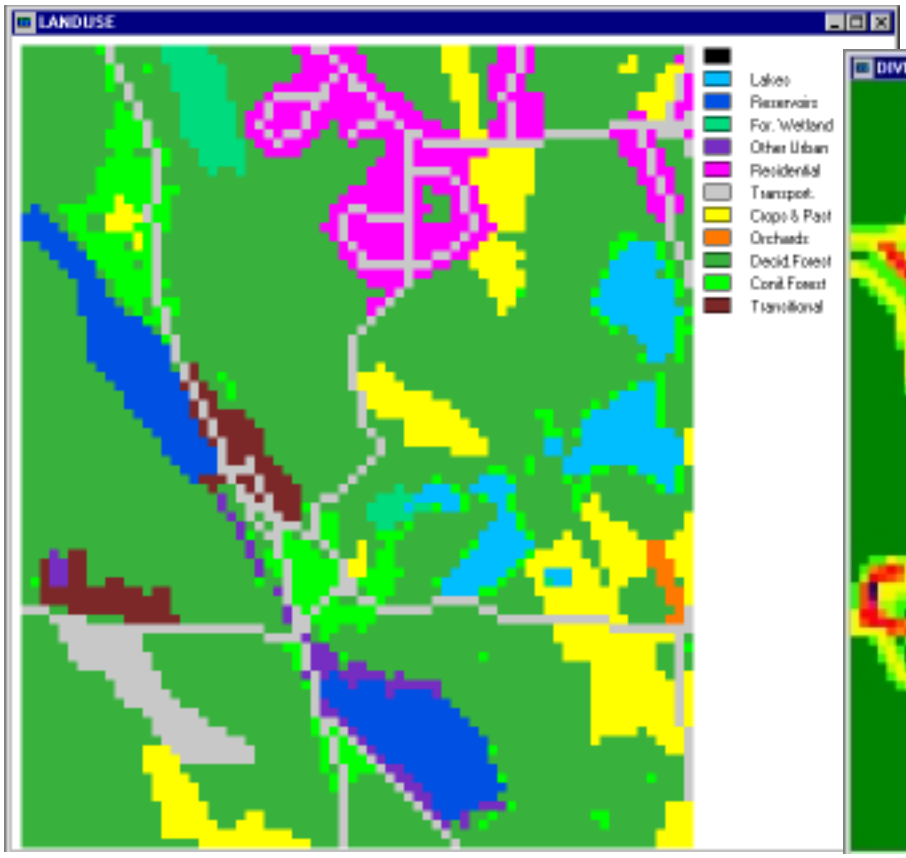
**Diversity** = -sum[(p) x ln(p)]

*where* sum = the sum over all classes; p = proportion of the footprint in each class; ln = natural logarithm

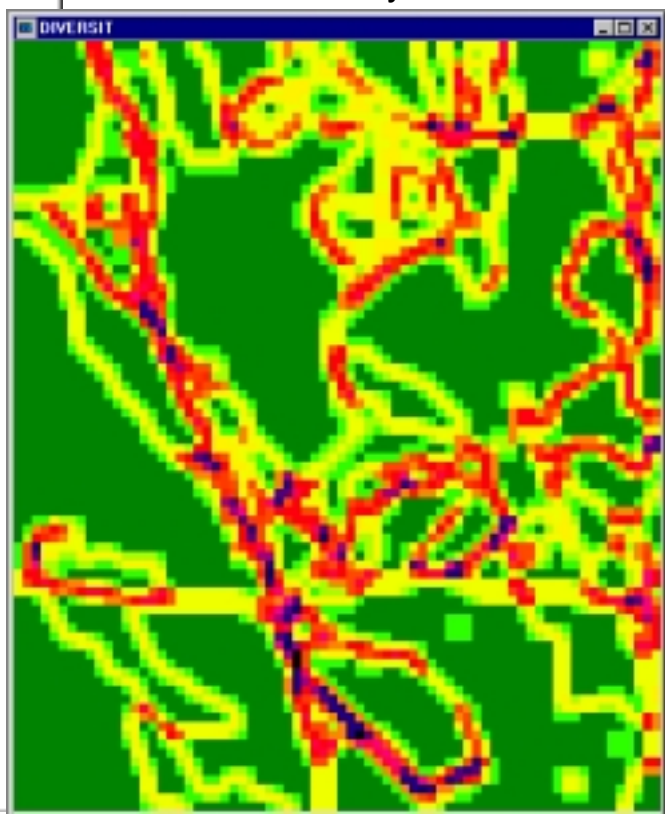
**Dominance** = Hmax - H

*where* H = Diversity; Hmax = maximum diversity = ln(n); n = number of different classes present; ln = natural logarithm

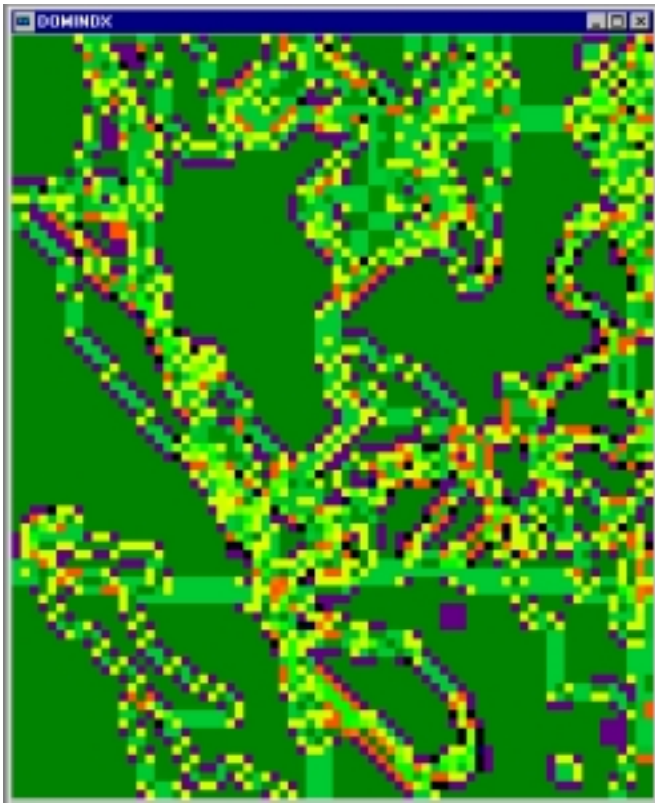
from: Turner, M.G. 1989. Landscape Ecology: The Effect of Pattern on Process, *Annu. Rev. Ecol. Syst.*, 20, 171-197.




Diversity




Dominance Index




Relative Richness