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Title

Unit 15 - Spatial Relationships in Spatial Analysis

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- NOTES

Having established a basis of the fundamental concepts in GIS data structures, this unit begins a large module looking at how GIS can be used. First we look at how spatial relationships can be analyzed and then present a summary of the range of functions that fall within present GIS capabilities.

UNIT 15 - SPATIAL RELATIONSHIPS IN SPATIAL ANALYSIS

[A. INTRODUCTION](#)

[Review](#)

- the types of spatial objects are points, lines, areas, raster cells (Unit 10)
- these object types are digital representations of phenomena
 - are defined by their dimensionality
 - are sometimes further subdivided
 - e.g. line objects are divided into chains, strings etc. in DCDSTF
- an entity type is a type of phenomenon, e.g. church, city, highway, lake
 - the same entity type may be represented by different types of objects at different scales
 - e.g. a city may be a point at one scale, an area at another
- in the database, several different types of entities may be represented by the same type of object
 - e.g. points may represent both cities and churches
- an object class is a group of objects of the same type, representing the same type of entity
 - e.g. cities and churches are different classes of the same type of object (point)
- the number and meaning of attributes is the same for all objects in a class
 - e.g. church: denomination, capacity, date of construction
 - e.g. city: name, population, date of charter
- object attributes may use various measurement scales (i.e. nominal, ordinal, interval, ratio) - see Unit 6
- we think of a class of objects and its attributes as a table with rows corresponding to objects and columns corresponding to attributes
- classes of objects can be grouped into layers
 - sometimes only one per layer, depending on the system
- the power of a GIS comes from its ability to store relationships among and between

objects - see Unit 12

- relationships can be between objects of the same class
- more often between objects of different classes
- relationships can identify object pairs which have their own attributes
- using this framework of spatial objects and relationships, the range of analysis possible with a GIS is explored

B. ANALYSIS OF ONE CLASS OF OBJECTS

Using attributes

- need only a single attribute table
 - might be any object class
- example using city neighborhoods:
 - attributes include:
 - population count: ratio scale
 - household count: ratio scale
 - average income: \$000s per household, ratio scale
 - name: nominal scale
 - average household expenditure on automobile purchases/year: \$000s, ratio scale
- GIS operations on the attribute table might include:
 - very primitive forms of analysis or enquiry are possible
 - list neighborhoods by average income
 - simple data retrieval, print table
 - list all neighborhoods with average income greater than \$40,000
 - select records satisfying criterion, print table
 - compute the mean expenditure on automobile purchases
 - requires weighting by household count in each area
 - compute and print result
 - look for relationship between average income and average expenditure on automobiles
 - retrieve data and plot a graph
- all of these are capabilities of standard databases, e.g. DBase III
- none use GIS capabilities, no access to spatial data (locations) required

Using locational information

- make a map of average household income, shading each neighborhood accordingly
 - requires locational information to plot outline of neighborhood
- shading might be determined by a function of more than one attribute, e.g. the ratio of household expenditure on automobiles to household income

- this type of capability is offered by automated mapping packages
- compute the area of each neighborhood and store it as a new attribute
 - area computed from locational information (digitized outline of neighborhood)
 - useful in making meaningful maps
 - e.g. map population density as population divided by area rather than simply mapping population over variable sized areas
- other similar measures that can be computed include perimeter, centroid location, distance, e.g. from downtown

C. ANALYSIS OF OBJECT PAIRS

- e.g. pairs formed from each combination of neighborhoods, including neighborhoods paired with themselves
 - with 5 neighborhoods have 15 combinations
 - with n neighborhoods have $n(n+1)/2$ combinations
 - example attributes:
 - distance
 - number of commuters in each direction
 - time to travel by public transit
- draw a map of interactions overhead - Net flows between states
 - map becomes exceedingly complex if all pairs are shown
 - may need to show only most important flows, e.g. to downtown
- analyze commuter trips by time of travel by public transit
 - e.g. how many take over 20 mins, 40 mins, 1 hour
 - produces results in tables

D. ANALYSIS OF MORE THAN ONE CLASS OF OBJECTS

- one of the major strengths of GIS analysis

Shortest path example

- find the shortest path through a street network between two places
 - useful for fire truck dispatching, cabs, delivery vehicles
 - navigation systems are being developed for mounting in vehicles
 - able to display current locations and map of surrounding streets, follow vehicle's path on map
 - able to compute recommended route to given destination

What spatial objects are required?

- links in the network
 - attributes include length
 - also factors such as traffic counts, congestion, number of lanes, average speed are important in finding optimum route

- nodes in the network
 - intersections allow route to move from one link to another using link-node relationships
 - important attributes include presence of traffic light, overpass or underpass
- what about turn restrictions?
 - turn restrictions are not attributes of links or nodes
 - e.g. "no left turn" is an attribute of a pair of links - cannot turn from link A to link B
 - thus a link-link object pair is needed (see Unit 12 for more on object pairs)
 - some systems define a "turn table" which is equivalent to this link-link object pair
- what about stop signs?
 - stop signs are not attributes of nodes but are determined by the direction of entering the node, irrespective of the exit link
 - thus a link-node object pair is needed

Spatial interaction example

- useful for prediction of customer behavior
- handout - Spatial interaction data
- given 3 shopping centers, represented as points
 - attributes: parking spaces, number of stores, quality of signage, age of construction
 - given 5 neighborhoods, represented as areas
 - attributes: population count, average household income, average age
 - given information on # of shopping visits by neighborhood by shopping center (information gathered by street interviews)
 - these are attributes of neither shopping centers or neighborhoods, but of the object pairs
 - produces 15 object pairs plus attributes, including distance
 - commonly used model in this situation is a "Spatial Interaction Model" (SIM) - requires information on:
 - neighborhoods (from attributes of area objects), e.g. average household income
 - shopping centers (from attributes of point objects), e.g. number of parking spaces
 - spatial behavior (from attributes of object pairs)
 - e.g. for each object pair, divide number of trips to appropriate shopping center by population of appropriate neighborhood, plot against distance

handout - Spatial interaction modeling

E. ANALYSIS WHICH DEFINES NEW OBJECTS

- many GIS operations produce new spatial objects from old ones
- may be same or different type, e.g. points producing points or points producing areas
- new objects may have attributes of the old objects which created them

Buffer example

- build a buffer zone (area) around a stream network (a layer of line objects)
 - stream layer has attributes of each stream link, including ID, discharge, length, depth
- buffer operation creates area objects
 - may be: (a) an object for each link (b) one merged object for the entire network
- attributes of the new area object:
 - in case (a) - length, ID, discharge, depth of channel in the buffer object (from link attributes)
 - in case (b) - total length

Street noise example

- street is a line object with attribute "traffic count"
- apply an equation to convert "traffic count" attribute to "noise level"
- build a buffer of 500 m around line
- attach noise level attribute to the new area object
- further development:
 - includes houses as point objects
 - identify all houses lying in buffer ("point in polygon" operation)
 - attach noise level attribute to all houses lying inside area object
 - produce list of all such houses, generate mailing labels from database and mail announcements of meeting to protest noise

Trade area example

- given list of customers of shopping center, with home locations (point objects)
 - create new attribute for each point giving distance to shopping center
 - calculate average distance from all points
- find the "trade area" of the shopping center
 - e.g. draw a circle with radius equal to the average distance to all customers
- produces an area object

attach count of customers within trade area as an attribute of the new object

Polygon overlay example

- perhaps the most important operation in GIS
- given two classes of area objects
 - e.g. two maps for the same area, one showing soil types, the other vegetation zones
- "overlay" the two classes of objects creating a new set of area objects
 - every new area object has two sets of attributes - soil type (copied from the soil map) and vegetation (copied from the vegetation map)

E. GIS ANALYSIS FUNCTIONS

- functions should be defined independently of technical issues, understandable by users with little technical knowledge of GIS, independently of data model
 - e.g. "buffer" - does not depend on choice of raster or vector, or require knowledge of technical detail
- functions are used to translate needs into specific GIS operations
- list of available functions is outgrowth of past GIS user needs
 - emphasis on resource management applications because of strength of that market sector in last 10 years
 - however, is no consensus on the possible domain of GIS, the total set of possible functions
- some GIS claim as many as 1,000 commands
 - since functions and operations are defined at a higher level, each function may require several commands

overhead - GIS Analysis Functions

Measure

- results become attribute of objects
 - measure length of line object
 - measure area or perimeter of area object

Coordinate transformation

- results in new coordinates for points
 - register map to control points, transform coordinates accordingly
 - change projection, scale, coordinate system (e.g. lat/long, State Plane, military grid)

Generate objects

- by user input, e.g. mouse, digitizer tablet
 - area, line, point objects
 - circle around point, e.g. for query
 - grid cell net, lat/long graticule
- from existing objects in the database
 - buffer zones or "corridors" around points, lines, areas
 - areas around points by assigning everywhere to the nearest point, producing polygons (Thiessen, Voronoi or Dirichlet polygons) - e.g. to create "trade areas"
 - representative points in the middle of each area object (centroids)

Select a subset of objects

- based on attributes, or regions, or "window"

Modify attributes of objects

- by user input, e.g. keyboard
- by arithmetic based on existing attributes, e.g. find density
- by rules using relational and Boolean operators
 - e.g. if white spruce and age > 50 years then new attribute is "y"

Dissolve and merge area objects

- generates new, fewer objects

Generalize or smooth lines

- reduce the complexity of a line or area boundary, or smooth it, or reduce the number of digitized points needed to represent it ("weed")
- diagram
- note: generalization is a very complex topic which is covered in detail in Unit 48

Compute statistics for a set of objects

- count them
- total or average a selected attribute
- compute statistical indices, e.g. standard deviation, correlation

Topological overlay

- point in polygon

- line on polygon
- polygon overlay
 - sliver polygon removal

Operations on surfaces

- mostly for topographic surfaces
 - recall there are several methods for digital representation, e.g. digitized contours, grid of heights (DEM), mosaic of triangles (TIN) - Unit 11
- estimate height at a point
- find profile of surface along a line, e.g. a stream profile
- compute contours (line objects) from grid of heights, and vice versa
- compute grid of slopes, aspects
- find area objects of slope or aspect categories, e.g. slope < 5%
- find watershed boundaries from DEM
- find the area visible from a point (viewshed)

Network analysis

- many types of analysis can be carried out on networks, for transportation planning, utility management, airline scheduling, navigation
 - find shortest path through the network between selected points
 - determine whether one point on a stream network is downstream or upstream of another
 - find the parts of the network which can be reached within a given travel time from a selected point

Input and output management

- applications often consist of existing analytical packages running in conjunction with a GIS
 - GIS does the "housekeeping" - handling data input and providing advanced output capabilities
 - analytical package solves the problem

REFERENCES

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Upton, G.J.G. and B. Fingleton, 1985. Spatial Data Analysis by Example, Vol I: Point Pattern and Quantitative Data, Wiley, New York.

EXAM AND DISCUSSION QUESTIONS

1. Compare the classification of map analysis functions in this Unit with that proposed for raster functions by Berry and referenced in Unit 5.
2. Can GIS functions be described and discussed generically, or is the raster/vector distinction unavoidable?
3. Make a list of 6 (10? 15?) functions which should be included in GIS because of their importance in various kinds of analysis of spatial data but which are not listed in this unit.
4. Define "object pairs" and give examples of their use in applications in (a) hydrology, (b) transportation planning.
5. "Spatial data is distinguished by its wealth of possible relationships between objects, and by the need to qualify such relationships in different ways". Discuss.
6. Design a database for an airline reservation system - what types of entities and relationships would be needed, and what attributes of each entity? Would the concept of an object-pair be useful?
7. Describe some of the new objects and associated attributes which can be created by combining a topographic surface (represented by a raster of elevations) with a stream network (represented by line objects).

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UNIT 15 IMAGES

Shopping Centers (points):

	Parking spaces	Stores
1	1,000	45
2	800	25
3	2,000	90

Neighborhoods (areas):

	Population	Average income
1	3,500	45,000
2	4,000	40,000
3	6,000	35,000
4	5,500	30,000
5	5,000	35,000

Trips (point-area object pairs):

Origin	Center	Trips	Distance
1	1	36,000	2
1	2	4,000	5
1	3	7,000	7
2	1	8,000	5
2	2	10,000	3
2	3	75,000	2
3	1	70,000	2
3	2	120,000	1
3	3	30,000	3
4	1	3,000	8
4	2	10,000	4
4	3	35,000	4
5	1	25,000	3
5	2	3,000	6
5	3	5,000	9

Data: information on shopping centers, residential neighborhoods of consumers, and trips made per year from neighborhoods to shopping centers.