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UNIT 19 - GENERATING COMPLEX PRODUCTS

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Compiled with assistance from Doug Banting, Ryerson Polytechnical Institute, Toronto

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This unit seeks to demonstrate the problems of defining GIS products in the real world. Issues with regard to the difficulty of defining procedures for complex sets of operations are explored. An exercise following the Question section can be used to get students thinking seriously about many of the issues raised to this point.

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A. STEPS IN DEFINING A GIS PRODUCT

- what decisions have to be made?
- what information products are needed to make those decisions?
    - e.g. decision is whether student should be allowed to graduate
        - information product is student's transcript, generated from student records database
    - e.g. decision is where to put access road
        - information products may include perspective plots, location of timber stands
- what data must be input or available to the system to make those products?
    - need to know geographical coverage required, thematic data needed and sources of data
- what GIS functions need to be carried out on the data?

B. EXAMPLE GIS PRODUCT DEFINITION

Decisions

- National Forest must manage forest land for multiple uses
    - one use is recreation which may conflict with other uses, e.g. wildlife, timber harvesting
- question is "Where are the most accessible areas which could be considered for the development of recreation facilities?"
    - accessibility is defined in this example in terms of proximity to public roads
        - the best areas are large and close to roads

Information needed

- a map showing forest lands, classified according to accessibility for recreation
    - a scale of 1:24,000, or larger if possible
- the map should show
    - zones and associated accessibility classes for Forest Service land
    - base map information - roads, railroads, cities and towns, Forest Service boundary

Data needed

- roads and railroads - from standard 1:24,000 topographic map
- Forest Service management area - have been drafted on 1:24,000 topographic map from legal descriptions
    - shown as many individual areas, most are contiguous but some are not

- city and town boundaries - have been drafted on 1:24,000 topographic map from legal descriptions

- data will be input as 3 layers overhead - Accessibility analysis data
  - management area boundaries as area objects (layer A1)
  - roads and railroads as line objects (layer B1)
  - city and town boundaries as area objects (layer C1)

Processing steps

overhead - Project flowchart

overhead - Project steps (6 pages)

1. using the forest service areas data (layer A1), assign a new attribute FORESTLAND, value = 1 if area is forest service land, 0 otherwise

2. dissolve boundaries between areas with the same FORESTLAND value, and merge areas to create new area objects with one attribute - FORESTLAND - call the new layer A2

3. using the transportation map B1, select public access roads only - call the new layer B2

4. generate buffers 0.5 miles wide around all objects in layer B2 - call the new layer B3 - assign the attribute INHALF a value of 1 for the buffer area, 0 outside

5. generate buffers 1.0 miles wide around all objects in layer B2 - call the new layer B4 - assign the attribute INONE a value of 1 for the buffer area, 0 outside

6. topologically overlay the objects in layers A2, B3 and B4 (some systems may require two steps to overlay three layers) to obtain layer B5 with area objects with the following attributes: FORESTLAND INHALF

INONE

7. using the city and town boundary layer (C1), assign a new attribute URBAN, value 1 for areas of cities or towns, 0 otherwise

8. topologically overlay the objects in layer C1 with those in layer B5 to obtain layer B6, adding attribute URBAN to the three attributes in B5

9. assign a new attribute ACCESS to the objects in B6 using the following rules:

Value Criteria 0 not forest land (FORESTLAND=0) FU forest land and urban (URBAN=1) 1 forest land, non-urban and within 0.5 miles of rail/public road (INHALF=1) 2 forest land, non-urban, outside 0.5 miles but within 1.0 miles of rail/public road (INONE=1) 3 forest land, non-urban, outside 1 mile of rail/public road (INONE=0)

- note that the criteria are ordered so that in each step only areas that have failed all of the previous tests are considered
- e.g. test for FU assumes that the object has already failed the prior test FORESTLAND=0

10. Dissolve boundaries and merge areas with the same value of ACCESS

- call this new layer B7
- assign unique ID numbers to each new object

11. Measure the areas of objects (in hectares) in B7 and assign this attribute to each object as AREA

12. Modify attribute ACCESS for cases where ACCESS ="1" and area is greater than 2500 to "1A": If ACCESS = "1" and AREA >= 2500 then ACCESS="1A"

13. Create a plot showing: Forest Service ownership boundary (layer A2) All roads and railroads (layer B1) All cities and towns (layer C1) Area objects in layer B7, shaded by value of ACCESS attribute and labelled with ID number assigned in step 10

14. Create a list of all area objects in layer B7, showing the following attributes: ID (number assigned in step 10) ACCESS AREA

Summary of functions needed

- Assign a new attribute (from existing attributes based on mathematical or Boolean operators)
- Dissolve boundaries and merge areas (based on value of specified attribute)
- Select objects (based on attributes satisfying mathematical or Boolean operators)
- Generate buffers (to a specified width around line objects)
- Topologically overlay (two or more layers of area objects to obtain a new layer of area objects)
- Measure area (of area objects, assigning values to a new attribute)
- Modify an attribute (selectively, based on mathematical or Boolean operators)
- Create a plot (of specified classes of objects, showing selected attributes, using various symbol, shade and label options)
- Create a list (of a specified class of objects, showing selected attributes, plus subtotals, totals etc.)
- once this sequence of operations has been worked out, it is very easy to design a macro

which will automatically execute this sequence of steps whenever a layer is updated

C. PRACTICAL PROBLEMS

- practical problems commonly encountered when trying to produce information products include:

Management demands

- to demonstrate the value of the GIS to management, and thus ensure continued support, some useful products will need to be available very early in GIS system implementation
  - but products cannot be generated until all the needed data have been input
  - data input, production need to be coordinated so that some useful products appear quickly

- mandates change, the responsibilities of the agency change from time to time
  - "drop everything you're doing - we need x"
  - difficult to operate a systematically designed approach to GIS when agency's responsibilities are poorly defined or too flexible

Data not available

- information product may require input data which is not currently available as a digital data layer
  - data may have to be collected, compiled and input to support the product

- most agencies do not plan their data acquisition systematically to support their decision-making mandates
  - introduction of GIS into an agency often forces much more systematic data planning

- has led to the development of interagency committees to allow for sharing of data needed by several agencies

Data is available, but there are problems

- scale of data is much too small
  - e.g. a geology coverage is essential, but none is available at a suitably large scale
  - tempting to use the small-scale coverage, but results will be questionable

- geographical coverage is incomplete, or currency varies, or accuracy varies
  - e.g. parts of the city are accurately mapped, other parts are poor quality
  - e.g. topographic maps have widely different update dates
  - how to warn the user when the quality of data changes within a data layer

Data in wrong format

- data may already be digital, but in inappropriate format

e.g. forest management agency has forest inventory maps digitized as raster cells

- 16 by 16 array of cells for each 1 sq km of the area managed
- each cell contains stand number
- stand numbers point to attribute table of stand attributes
- these data had been used for simple tables, measurement of area based on counting cells
- data must now be merged into a vector GIS to support forest management functions
- raster/vector conversion creates area objects, boundaries follow old pixel edges

diagram

Complexity of decision rules

- rules for assigning new attributes can be complex, difficult to specify precisely
- e.g. rules for areas loggable for "Mature Sawlogs":

  overhead - Decision rules - Mature Sawlogs

  - species association: S = spruce SH = spruce/hardwood HS = hardwood/spruce
  - primary species: WS = white spruce
  - texture:
    - requires fine through moderately coarse soils
  - drainage:
    - requires inundated through wet soils as logging occurs when soils are frozen
- objects must satisfy all of conditions 1 through 5 to be acceptable
- assignment of "suitability" attributes can involve as many as 100 attributes

D. SITE SUITABILITY

Spatial search

- spatial search uses attributes to search for most suitable or most profitable or least noxious locations for activities or facilities
  - the activity/facility might require a single point location, a line or an extended area
  - point location examples: wells, observation towers
  - line location examples: power transmission, oil and gas pipelines, highways
  - area location examples: campsites, logging, airports, waste disposal sites
- requires measure of suitability derived from many underlying layers or attributes by assignment rules

Assigning suitability

- the process of combining many data layers into a single layer of suitability has been called cascading
  - many tens of layers may be involved in creating one index of suitability
  - cascading rules can include arithmetic, conditional, logical operations, recoding

- e.g. a study to locate a power transmission corridor through an area about 100 km across
  - used 30,000 cells each 500 m square
  - used over 100 data layers which were cascaded into a single index of suitability ranging from 0 (impossible for route) to 5 (best)
  - some example layers: existing power corridor (yes/no) soil capability for agriculture (score from 1 - best - to 7) urban area (value = population density)

- some types of spatial search are atomistic
  - suitability depends only on the characteristics of the place itself

- other types of search are holistic

  - suitability depends not only on characteristics of the place but also on locations of other facilities
    - e.g. a point is not good for a firetower if there is already a firetower one kilometer away
    - e.g. it makes no sense to consider individual pixels as locations for a highway route - the route as a whole has to make sense

- how to determine rules for assigning weights to contributing factors?
  - different decision-makers will have different preferences - how to find consensus?
  - e.g. committee has to recommend route for new power transmission corridor
    - one member wants to preserve agriculture, suitability gives negative weight to farmland
    - another wants to preserve natural areas, suitability gives negative weight to wetlands, woodlands, positive weight to farmland
    - one wishes simply to minimize construction cost of the power line by using the shortest route

Decision theory

- provides methods which have been used to implement complex choice rules

- a single utility function (SUF) defines the importance given to each value of an attribute by a decision-maker
  - e.g. to the agricultural representative, the attribute CROP_TYPE may be valued as follows: cornland is worth 0.6, pasture 0.2, irrigated tobacco 0.8

- a multiple utility function (MUF) defines the importance given to each attribute (or group of attributes) in the overall measure of suitability
  - e.g. to the agricultural representative, CROP_TYPE gets 0.9, CONSTRUCTION_COST gets 0.1

SUFs and MUFs can be elicited from decision-makers by systematically presenting combinations of options and asking for preferences
    - since different individuals give different weights to factors, there are methods for combining preferences which have been expressed using different MUFs

- decision theory is important to GIS because of the number of applications using spatial search

- see Unit 57 for more on multiple criteria decision making

Sensitivity

- many choices have to be made in defining GIS operations, attribute assignment rules, SUFs and MUFs
    - these choices may be difficult to make
    - how to balance conflicting objectives?

- to assist, it may help to know how sensitive the results are to these choices
    - when the results are sensitive, choices need to be made carefully and accurately
    - when the results are insensitive, choices can be made less carefully
    - e.g. must be very sensitive to the impact on endangered species (cannot use sites with endangered species) while different slope aspects may have little effect on the result

- need to distinguish between sensitivity in principle and in practice
    - in principle, preserving wetlands may be a high priority concern
    - in practice, there may be no wetlands in the study area
    - in practice, wetlands may extend across the study area, so any route will have to cross them and create the same impact
    - Unit 46 discusses sensitivity in more detail

REFERENCES

Massam, B.H., 1980. Spatial Search, Pergamon, London. Excellent discussion of spatial search and applications of decision theory.

French, S., 1986. Decision Theory: An Introduction to the Mathematics of Rationality, Halsted, New York. Good source on decision theory.

EXAM AND DISCUSSION QUESTIONS

1. How much flexibility is there in the sequence of operations in the recreation accessibility example? What changes could be made to the sequence without affecting the result? Can you devise a diagram or flow chart to show this?

2. Describe the relevance of decision theory to spatial search using GIS, with examples.

3. What is the difference between sensitivity in principle and sensitivity in practice in the result of a spatial search?

4. Describe the process you would follow as a consultant working with a resource management agency to determine the information products required from a GIS, and to plan the development of the GIS database.

EXERCISE

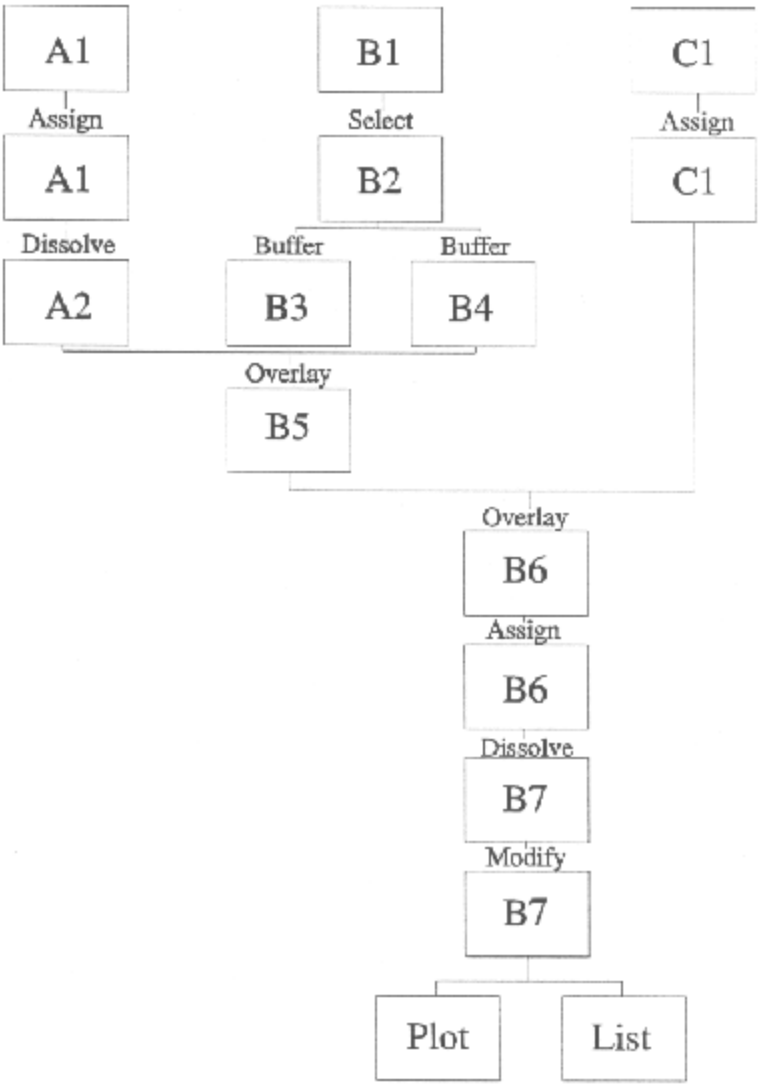
The Milk Marketing Board of Dairyland has been developing a network system for the management of the collection and distribution of milk across Dairyland. What is involved is the routing of 425 trucks varying in capacity from 9 000 to 45 000 liters, to collect approximately 2.3 billion liters of milk per year from 9 800 producers. The milk is carried over several thousands of kilometers of roadways to processing plants, within a very confining time period of two days.

Design a GIS database to include information on the road network, production quantities at farms, processing capacities at dairies, requirements at markets (cities) and amounts shipped and shipping costs from each farm to each processor and from each processor to each market. Define the functions the system will need to (a) produce maps of the producers, processors, markets and shipments, (b) produce tables of quantities produced, processed, marketed and shipped, (c) evaluate changes such as closure of a processor, expansion of a market, change in production levels.

Write a proposal for such a system to be submitted to the Milk Marketing Board.

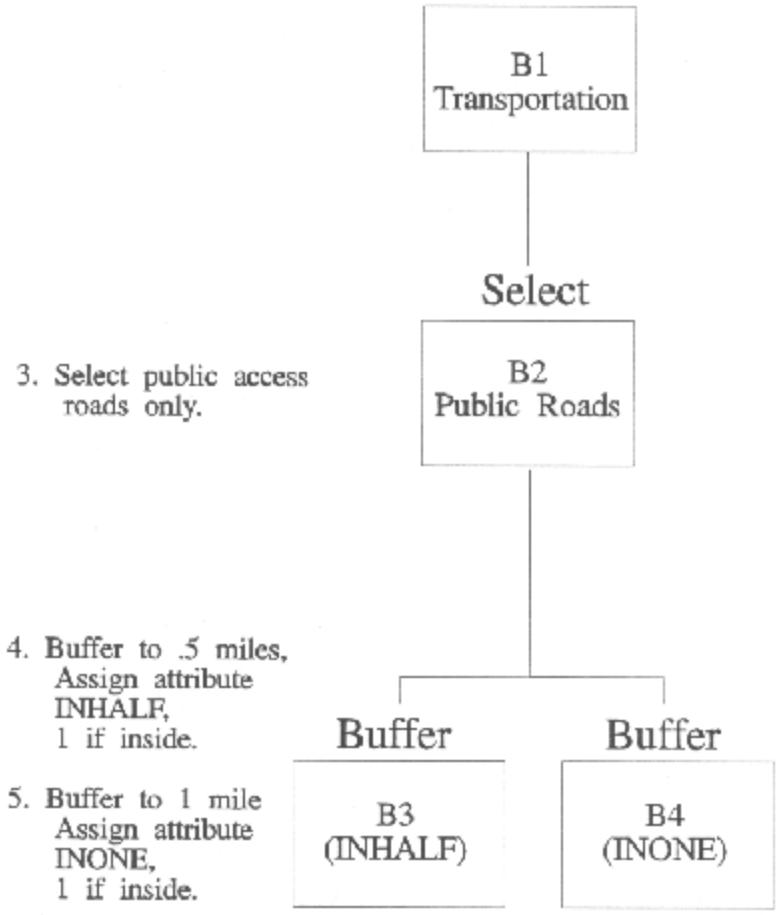
Last Updated: August 30, 1997.

UNIT 19 IMAGES

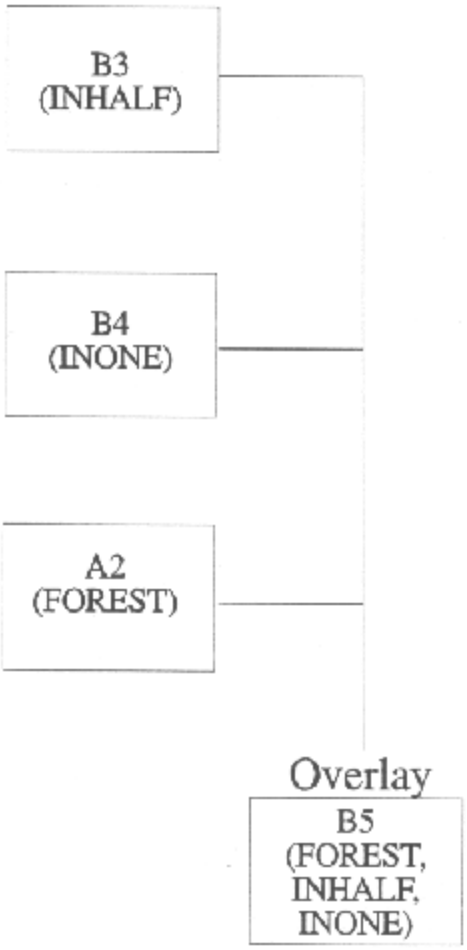


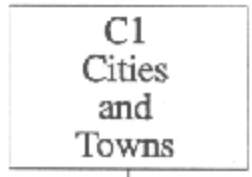
1. Assign new attribute FOREST, 1 if FS land.

2. Dissolve boundaries, create new objects with attribute FOREST.


B1
Transportation
Select
3. Select public access roads only.
B2
Public Roads
4. Buffer to .5 miles, Assign attribute INHALF, 1 if inside.
5. Buffer to 1 mile Assign attribute INONE, 1 if inside.
Buffer
Buffer
B3
(INHALF)
B4
(INONE)

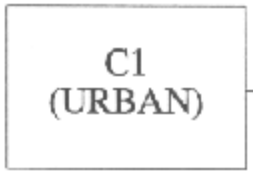
6. Overlay A2, B3 and B4.





Assign

7. Assign new attribute URBAN, 1 if urban.



Overlay

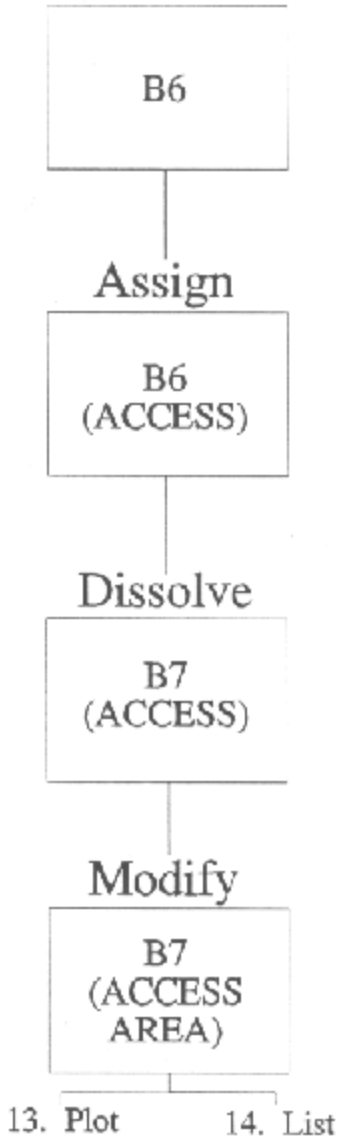
8. Overlay C1 and B5.

9. Assign attribute ACCESS according to this ordered set of criteria:

Value	Criteria
0	FOREST = 0
FU	URBAN = 1
1	INHALF = 1
2	INONE = 1
3	INONE = 0

10. Dissolve boundaries, create new objects with attribute ACCESS.

11. Measure areas, assign attribute AREA.

12. Modify ACCESS as:

    If ACCESS = "1" and AREA ≥ "2500" then ACCESS = "1A"