UNIT 42 - TEMPORAL AND THREE-DIMENSIONAL REPRESENTATIONS

Compiled with assistance from John H. Ganter, University of Pennsylvania

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A. INTRODUCTION

- although the vast majority of GISs currently work only in two dimensions, across the plane, certain applications require the addition of other dimensions, namely time or elevation/depth
  - most geological applications require a consideration of attributes in the vertical dimension as well as the horizontal ones
  - temporal variations are important in many economic and social studies
  - oceanographic and meteorological models need to consider variations both in the

vertical and the temporal dimensions

- this unit will look briefly at how these additional dimensions can be incorporated into GISs

B. VERTICAL DIMENSION ("3D")

- there are two very different ways of looking at representations of the vertical dimension (normally called the third dimension) in GIS

- the most commonly recognized is a data structure where a z value (normally elevation) is recorded as an attribute for each data point (x,y)
  - these z values can be used in a perspective plot to create the appearance of 3 dimensions
  - this is not true three dimensional representation and is often referred to as "2 1/2 dimensions"

  overhead - Perspective plot - Tiefort Mountains, CA, same data used for graphics in Unit 11

- these 2 1/2D plots are an attractive way of displaying topography and other continuous surfaces from DEMs or TINs
  - perspective plots can be computed from any viewpoint
  - additional layers can be "draped" over the surface using color
  - "artist's impressions" can be created by converting classes (e.g. of land cover) to simulated trees, etc.

  - with powerful computers, it is possible to animate 2 1/2D plots to create simulations of flying over topography
    - "LA the Movie" was created by Jet Propulsion Lab, Pasadena CA, by draping a Landsat scene over a DEM of LA, then simulating the view from a moving aircraft

- true three dimensional representations store data in structures that reference locations in 3D space (x,y,z)
  - here z is not an attribute but an element of the location of the point
  - this permits data to be recorded at several points with equal x and y coordinates, e.g., soundings in the ocean or atmosphere, geologic logs of wells

- true 3D representations allow:
  - visualization of volumes
    - is difficult to understand volumes when they are represented by several orthographic projections
  - modeling of volumes
    - algorithms for spatial analysis of volumes are simpler if the data is in a volumetric form

Uses of 3D representations

- 3D representations of spatial information have several important applications:
  - designing major developments such as mines, quarries, dams and reservoirs
  - geologic exploration
  - scientific explanation of three dimensional processes such as ocean currents
    - here don't necessarily know what is being sought
    - therefore, the structure of the representation can constrain the types of analyses that are performed and what is found

C. CHARACTER OF THE PHENOMENON

- a major determinant of the type of representation used is the 'phenomenon-structure' itself

- three dimensional phenomena have several characteristics:

Distribution

1. Continuous
   - present in some quantity in all places
     - e.g. land, stratigraphic or piezometric surface
     - similar to 2D raster representations

2. Discrete
   - distinct objects which occupy specific locations
     - e.g. lithology, ore bodies, tunnels, caves
     - similar to 2D vector objects

Topological complexity

- how the object is composed
  - this has a major effect on the data structure used

overhead - Topological complexity

1. Compound (One class)

   - composed of identical smaller objects
     - well casing or well log

     - ore body composed of smaller bodies

2. Mixed (Multiple classes)
   - composed of smaller, dissimilar objects
     - mine composed of shafts, adits, etc. which are hierarchically-arranged either adjacent to, or wholly within each other

3. Interpenetrating (Multiple phenomena)
   - mixed, but objects may share subsets of each other's volumes
     - large-scale structural geology

        - karst features intersecting with the water table and geologic structures

Geometric complexity

- degree to which the representation is irregular or convoluted
- involves questions of:

Accuracy

- how much is required?
    - design applications (e.g. tunneling) - must be highly accurate
    - prospecting or science applications - general relations may be more important

Precision

- resolution of measurement and detail of analysis
    - often depends on scale of examination and nature of phenomenon
    - may have to filter and generalize to reduce storage and computation burden

D. METHODS OF REPRESENTATION

- specific approach taken is a function of:
    - user's needs and capabilities
    - character, distribution and complexity of phenomenon
    - characteristics of the data available, or the means to collect it

2 1/2 dimensions

1. Single-valued surfaces
    - single z (elevation) value for each coordinate pair
        - usually continuous distributions
        - topologic complexity is low
        - geometric complexity can be high
    - defines a surface with no thickness
        - usually displayed with isolines
    - geometrically 3-D, but topologically 2-D
    - suited to visualization and some modeling
    - available in many mapping and statistical packages

2. Multi-valued surfaces and volumes
    - more than one z-value for each x,y pair
        - usually continuous distributions
        - topological complexity is low
        - geometric complexity can be high
    - can be displayed with isolines
        - may become difficult to comprehend

- often subjected to geostatistical analysis in prospecting and scientific research
- not as widely available in turnkey systems

True three dimensional representations

1. Boundary representations (B-reps) overhead - B-Rep of a Cave Passage
   - objects are defined as polyhedra bounded by planes or faces
     - can be displayed with hidden line removal for easier comprehension
   - each object can be represented by a number of: faces - flat planes, usually triangular (a mixture of rectangles and hexagons on the overhead) edges - define the edges of the faces (3 per triangular face) points - define the ends of the edges (2 per edge)
   - suited to discrete objects
     - topological complexity can be high
     - geometric complexity can be high
   - well suited to design, some exploration and explanation applications
   - widely available in CAD systems
     - the TIN is a type of B-rep, constrained to be single-valued (i.e. one value of z for every x,y)
   - requires a powerful user-interface to construct combinatorially-complex objects
     - each part of the B-rep (planes, edges, points) must be carefully and consistently defined for each application in order to maintain validity
   - performance degrades rapidly with high geometric complexity

2. Spatial occupancy enumeration (SOE) overhead - SOE of a Mine/Quarry
   - volume is divided into cubes or voxels
     - can have on (full) or off (empty) status
     - or, can have attribute values
   - vertical resolution is often different (higher) from horizontal resolution, e.g. modeling the atmosphere
   - objects can be displayed as positive (casts) or negative (molds)
   - suited to discrete objects or continuous distributions
     - combinatorial complexity can be very high
     - geometric complexity can be high, within limits of voxel resolution
   - suited to exploration and explanation applications, also analytical operations in design
     - some systems exist for mine modeling, also medical applications
   - usually produced by converting from B-reps (similar to converting vectors to rasters in 2D)
   - properties like mass, volume and surface area are quickly computed as Boolean operations or voxel counts
   - these can be indexed using octtrees (also octrees) overhead - Octree
     - is an extension of the quadtree concept to 3 dimensions
     - cells are numbered by starting on one level and using the same pattern as a quadtree, then moving up a level and continuing with the same pattern but numbering from 4 to 7

Summary

- these 3D representations are relatively new, so there is little collective experience on how to implement them in the earth sciences and engineering

- it may be easiest to utilize technology developed in other fields (mechanical engineering, medicine) and adapt to needs
    - however, the needs of medical imaging are different from earth science
        - medical imaging technology is not designed for modelling, it does not need analytical tools for abstraction and interpretation that earth science applications do
        - medical imaging is time dependent (it is usually necessary to track moving objects between one 3D image and the next) while many earth science applications do not require this

E. TIME DEPENDENCE

- time dependence adds a third dimension to spatial data, just as the vertical dimension does
    - Hagerstrand (1970) has used the vertical dimension to visualize movement in human systems - movements in the plane become trajectories in three dimensions

suggested overhead - Time dependence as a third dimension based on Hagerstrand model (not supplied, see for example Haggett, P., A.D. Cliff, A. Frey, 1977, Locational Models, Edward Arnold, London, p. 16)

- computer science deals with time dependence of records in databases
    - records may be valid only for limited times

- the geographical cases are more complex - objects may have limited existence, but may also move, change shape, and change attributes

- similarly to the 3D case, the set of database models for time dependent data has not been fully developed

Possible models

1. boundaries of reporting zones change through time
    - since the boundaries turn on and off rather than move, the solution is to store all boundary lines which ever existed, then to reconstruct objects from the

      boundaries at any given time

        - e.g. Great American History Project stored boundaries for all definitions of US counties since the early 19th Century, reconstructed counties at any Census year from selected boundary pieces (see Unit 30)

2. attributes of objects change through time - define a limited number of time "slices", and store the attributes as separate tables for each time slice

- if attributes are needed between time slices, interpolate

3. shapes of objects change through time
   - define time slices, and store the objects at each slice
     - may be difficult to identify objects from one time slice to the next because objects may coalesce or split - e.g. kelp beds in the ocean off the coast of California
     - may be easier to avoid identifying objects, and store classified but unrelated rasters at each time - equivalent to the SOE or voxel solution to 3D data
   - alternatively, use a 3D space with the vertical dimension as time, populated by 3D objects, e.g. the lines in Hagerstrand's diagrams - equivalent to B- reps
     - attach attributes to these objects
     - if the attributes change through time, we have a problem similar to that of continuously varying attributes on transportation networks

Summary

- the main issue is the extent to which objects should be identified - either in 2 or 3D

- solutions vary from one extreme of no objects to the other of fully 3D objects:
  - no objects at all - voxels
    - e.g. remotely sensed images
  - objects at each time slice, but unrelated from one time to another - layers
    - e.g. GAHP US counties
  - objects at each time slice, related or tracked from one time to another - related layers
    - e.g. migration data
  - objects defined continuously in the time dimension - 3D objects
    - e.g. individual space-time travel behavior

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DISCUSSION AND EXAM QUESTIONS

1. You are directed to build a 3-D representation for (a) a civil engineer; (b) a petroleum geologist; (c) a hydrogeologist; (d) a meteorologist. What kinds of questions might you ask each specialist about their job and what they want from the representation?

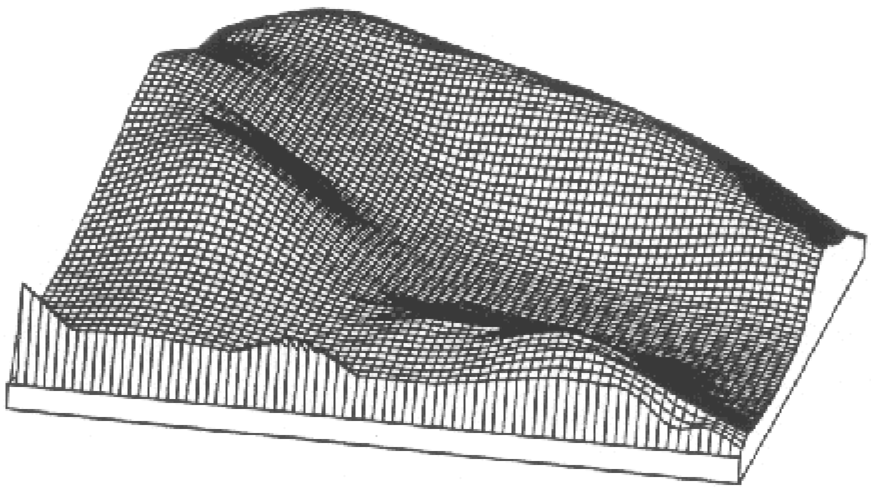
2. How do the distributions considered by each of the individuals (above) compare?

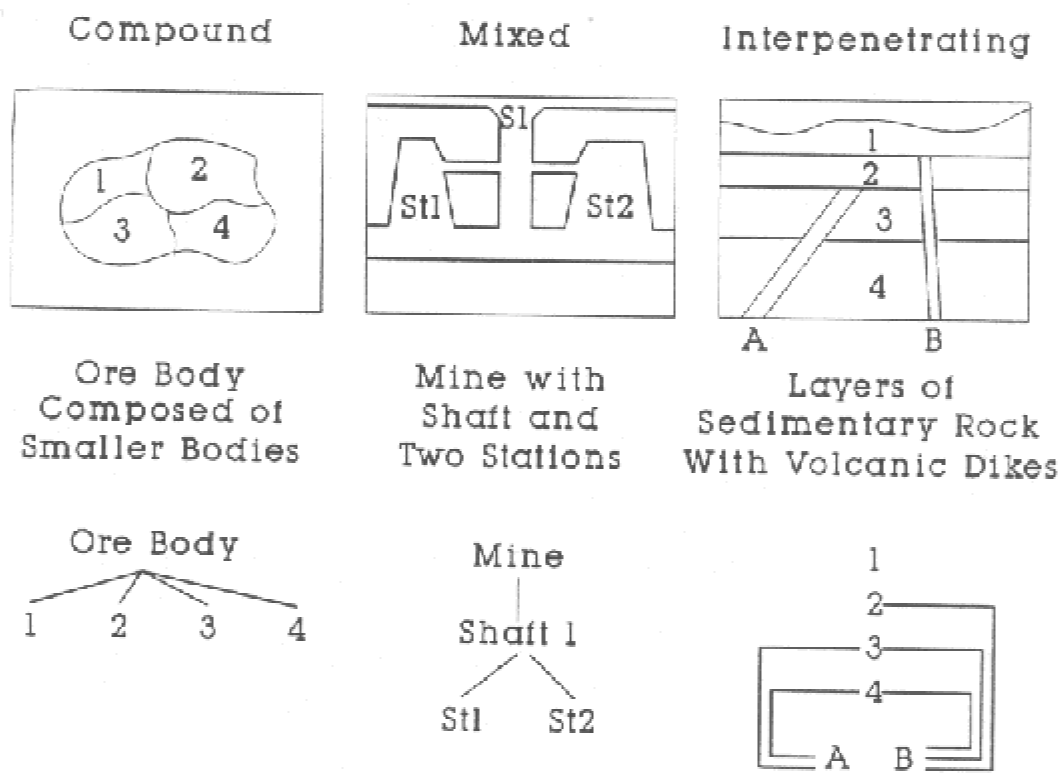
3. What would be the advantages and limitations of surface representations, B-reps and SOE in different disciplines and applications?

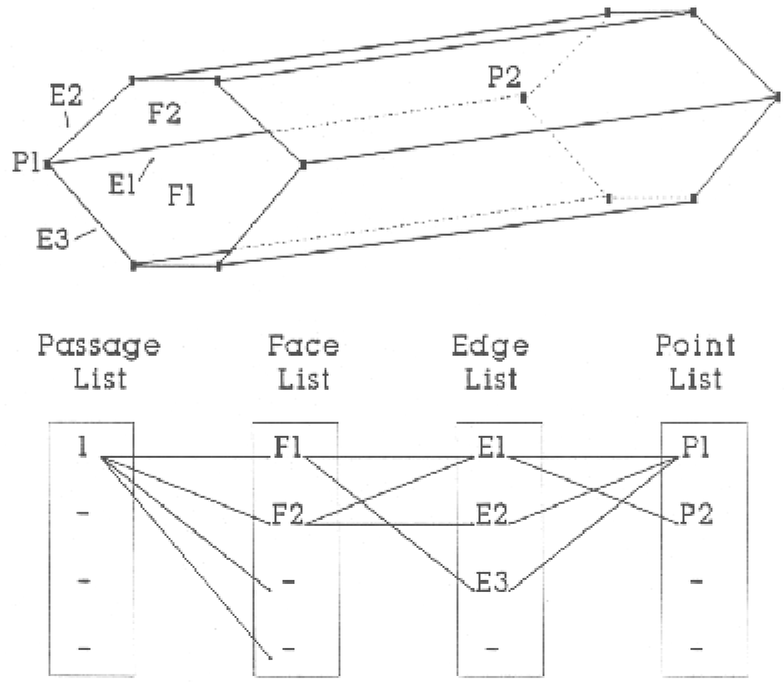
4. Many people have assumed that the problems of moving from 2D to 3D in GIS are comparable to those of moving from 2D to time-dependent 2D. Do you agree?

Last Updated: August 30, 1997.

UNIT 42 IMAGES



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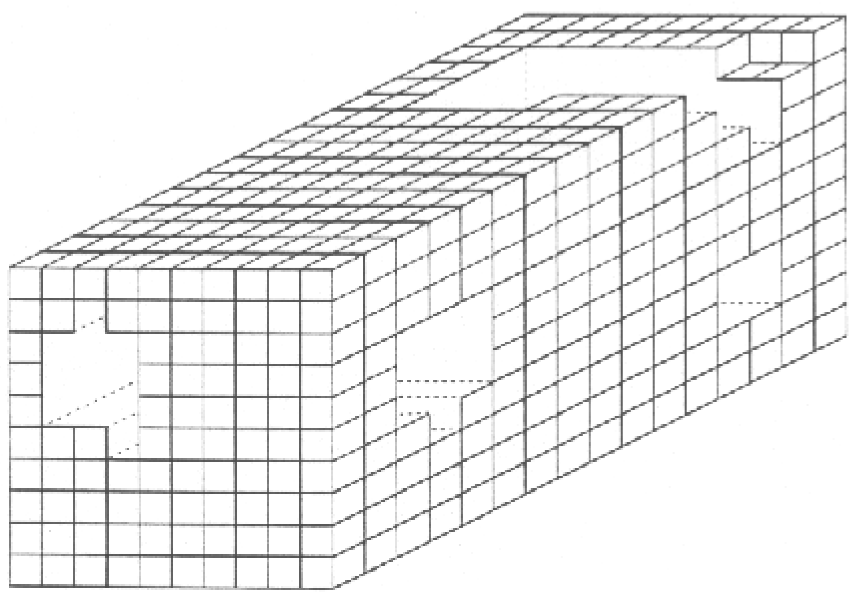

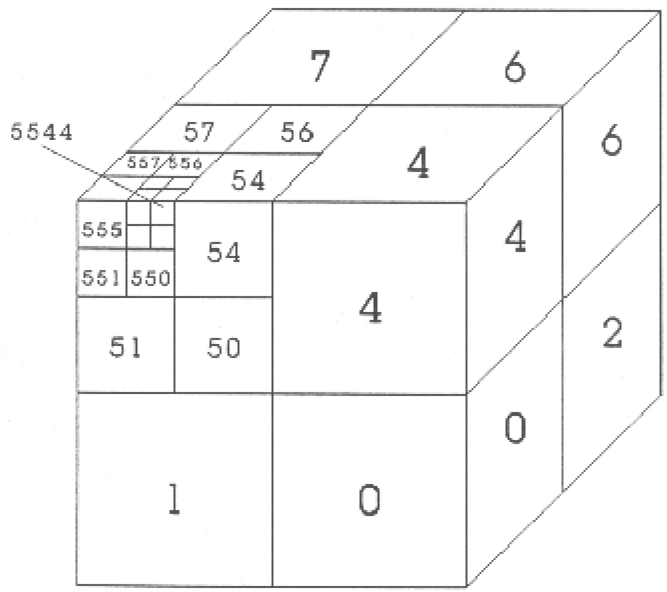
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