Temporal & 3-D Representations

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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
  - Oceanographic and meteorological models need to consider variations both in the vertical and temporal dimensions
- This presentation will look at how these additional dimensions can be incorporated into GISs.

Vertical Dimension ~ “3D”

- There are 2 ways of looking at representations of the vertical dimension (normally called third dimension) in GIS
- Most commonly recognized: data structure where a z value (normal 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 of 3-D representation and is often referred to as “2 1/2 Dimensions”

Elevation Represented as Points

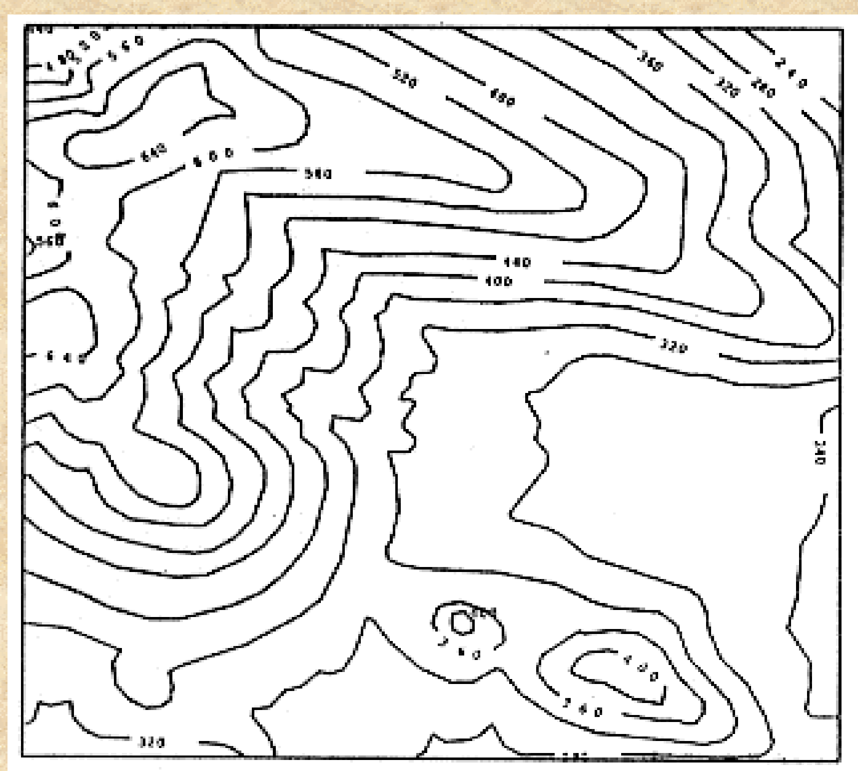
Tiefort Mountains, California

Lattice description for smlat22
Lattice size and origin
  Points X/Y = 21 21
  Origin (x,y) = 540000.00
3911940.000
Lattice distance between points:
  Distance in X = 30.000
  Distance in Y = 30.000
Surface value in range:
  Min z=235.000
  Max z=631.00
Lattice boundary:
  Xmin=540000.000
  Xmax= 540600.000
  Ymin= 3911940.000
  Ymax = 3912540.000

456	485	521	555	574	571	550	526	505	484	462	442	423	403	382	357	327	296	268	248	235
501	529	565	596	610	590	578	558	538	518	496	474	454	434	413	389	361	330	298	269	246
552	577	608	626	624	614	598	581	565	548	530	509	489	467	445	422	397	368	336	301	269
580	606	623	625	615	601	589	579	571	563	553	536	521	501	478	455	430	401	366	329	292
579	606	615	609	592	573	559	550	548	546	544	538	531	518	500	479	451	417	380	342	304
570	596	602	592	575	551	528	514	506	505	509	507	506	503	494	477	453	420	383	346	309
578	597	599	586	564	538	509	484	467	458	458	458	459	461	459	453	441	420	392	359	322
605	616	607	584	556	525	495	464	434	414	406	406	405	406	407	409	410	407	395	373	342
631	629	611	580	545	511	480	448	415	386	367	361	356	353	352	355	362	370	373	366	349
630	624	603	570	529	491	459	430	398	367	343	331	323	316	312	312	317	324	331	332	324
609	603	587	556	518	479	442	411	383	354	330	317	305	296	290	288	288	290	293	292	285
572	574	572	555	525	486	446	409	376	347	324	310	298	288	281	276	274	272	271	268	260
530	542	556	556	537	504	462	418	377	345	321	306	294	284	277	272	267	263	260	256	250
491	510	531	543	534	507	466	420	377	342	319	304	291	282	274	269	264	260	256	252	245
457	475	495	509	507	486	452	411	371	339	318	307	295	286	278	271	265	261	257	250	242
424	439	455	466	466	452	427	395	364	342	328	319	312	303	293	284	276	268	260	250	240
394	405	418	427	427	417	398	375	355	343	344	344	340	328	319	311	299	284	266	251	240
370	377	388	395	395	385	371	355	340	336	345	353	347	347	351	350	333	303	275	255	242
351	355	365	372	370	360	349	337	327	324	335	334	338	350	367	375	359	328	293	265	246
336	338	346	352	349	342	333	323	316	314	313	312	317	331	348	360	358	336	306	276	254
322	323	327	330	330	327	321	315	308	302	297	294	296	304	313	320	321	313	295	275	258

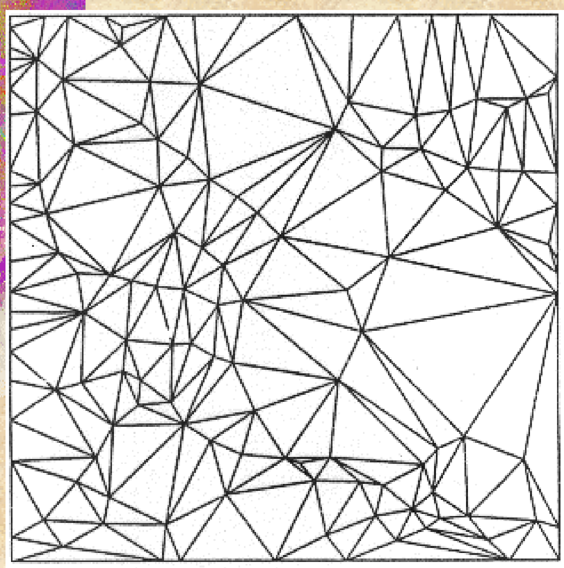
Elevation Represented as Lines

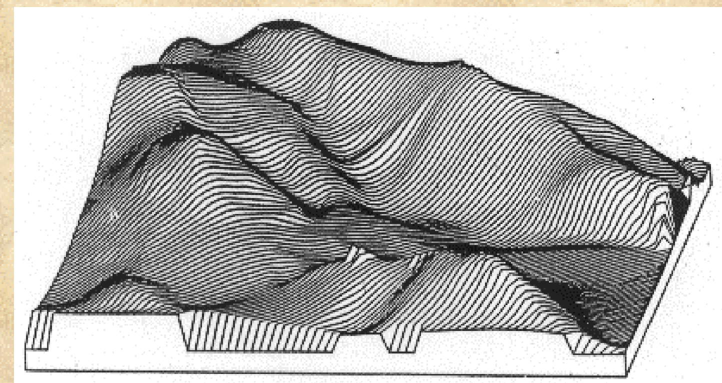
Tiefort Mountains, California



Elevation Represented as Areas

Tiefort Mountains, California

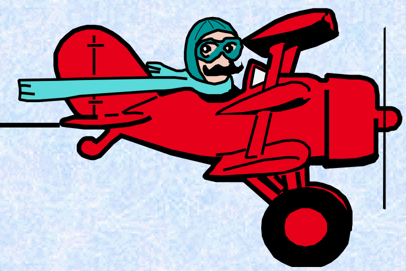




Vertical Dimension ~ Continued

- These 2/12D 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 (i.e., land cover) to simulated tress, etc.
  - With powerful computers, it is possible to animate 2 1/2D plots to create simulations of flying over topography

Interesting Fact

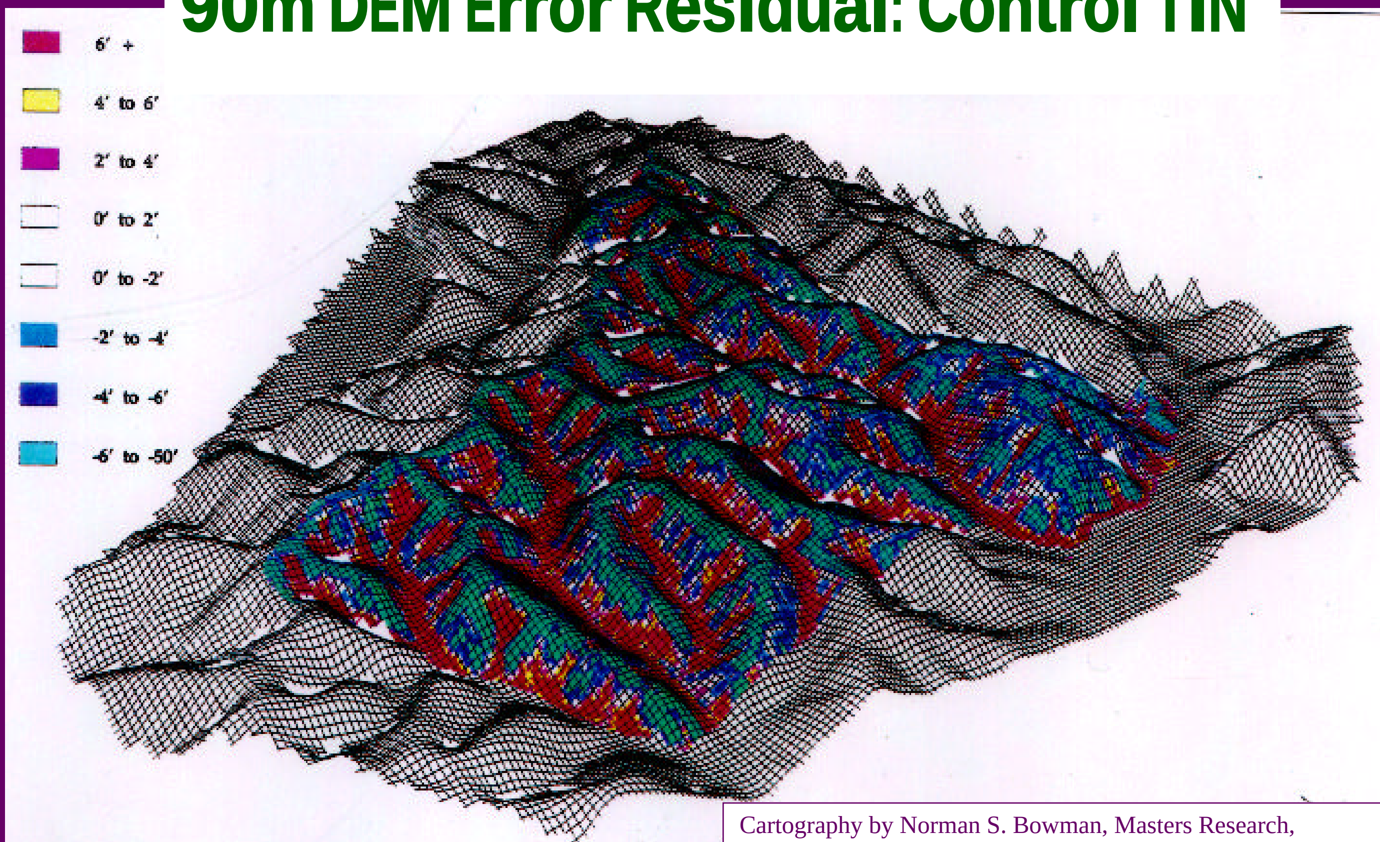


"LA the Movie" was created by Jet Propulsion Lab, Pasadena, CA, by draping a Landsat scene over a DEM of LA, then simulating the view from a moving aircraft.

Vertical Dimension ~ Continued

- True 3D 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, I.e, soundings in the ocean or atmosphere, geologic logs of wells
- True 3D representation allows:
  - Visualization of volumes
    - 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

90m DEM Error Residual: Control TIN



Cartography by Norman S. Bowman, Masters Research, Geographic Resources Center, Department of Geography, University of Missouri-Columbia, May 1995

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 dimension 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.

Character of Phenomenon

- A major determinant of the type of representation used is the ‘phenomenon-structure’ itself
- Three-dimensional phenomena have several characteristics:
  – Distribution
  – Topological complexity
  – Geometric complexity

Distribution

- Continuous
  - Present in some quantity in all places
    - *Examples:* land, stratigraphic of piezometric surface
    - Similar to 2D raster representations
- Discrete
  - Distinct objects which occupy specific locations
    - *Examples:* lithology, ore bodies, tunnels, caves
    - Similar to 2D vector objects.

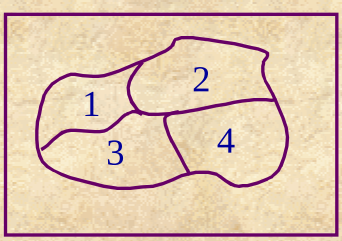
Topological Complexity

How the object is composed

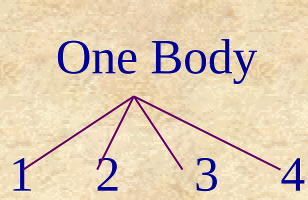
- *this has a major effect on the data structure used*

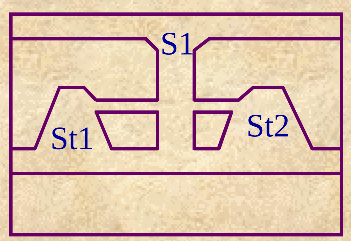
- Compound (One class)
  - Composed of identical smaller objects
    - Well casing or well log
    - One body composed of smaller bodies
- Mixed (Multiple classes)
  - Composed of smaller, dissimilar objects
    - Mine composed of shafts, adits, etc., which are hierarchically-arranged either adjacent of, or wholly within each other
- Interpenetrating (multiple phenomena)
  - Mixed, but objects may share subsets of each other's volumes
    - Large-scale structural geology
    - Karst features intersecting with water table & geologic structures

Topological Complexity

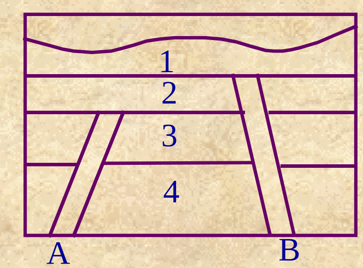


Ore Body
Composed of
Smaller Bodies

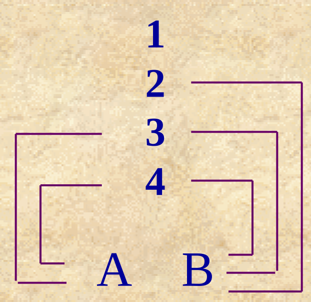




Mine with
Shaft and
Two Stations



Layers of
Sedimentary Rock
With Volcanic Dikes



Geometric Complexity

Degree to which the representation is irregular or convoluted

Involves questions of:

- Accuracy: How much is required?
  - Design applications (i.e., 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

Methods of Representation

- Specific approach taken is a function of:
  - User needs and capabilities
  - Character, distribution and complexity of phenomenon
  - Characteristics of the data available, or the means to collect it

2 1/2 Dimesions

vs.

True 3D Represenations

2 1/2 Dimesions vs. True 3D Represenations

2 1/2 Dimensions

- 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

Transitional ~ 2 1/2 D to 3D

2 1/2 Dimesions
vs.
True 3D Represenations

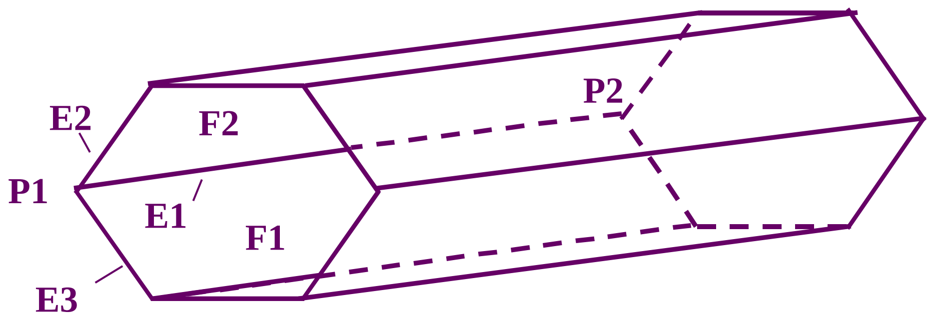
- Multi-valued surfaces and volumes
  - More than one z-value for each x,y pair
    - Usually continuous distributions
    - Topological complexity is low
    - Geometric complexity can be high
  - Can be displayed by isolines
    - May become difficult to comprehend
  - Often subjected to geostatistical analysis in prospecting and scientific research
  - Not as widely available in turnkey systems

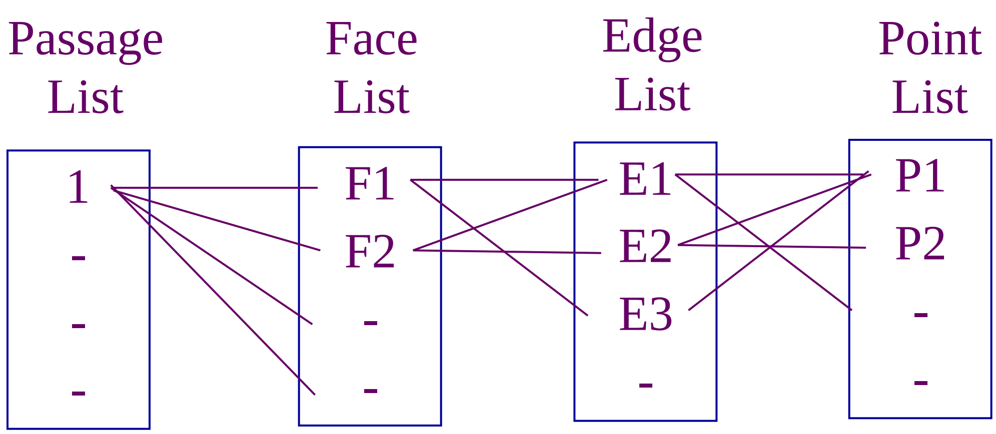
2 1/2 Dimesions
vs.
True 3D Represenations

True 3-D Representations

- Boundary Representations (B-reps)
  - 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)

B-Rep of a Cave Passage





2 1/2 Dimesions vs. True 3D Representations

True 3-D Rep. ~ Continued

- Boundary Representations ~ Continued
  - 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)

2 1/2 Dimesions
vs.
True 3D Represenations

True 3-D Rep. ~ Continued

- Boundary Representations ~ Continued
  - 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

True 3-D Rep. ~ Continued

2 1/2 Dimesions
vs.
True 3D Represenations

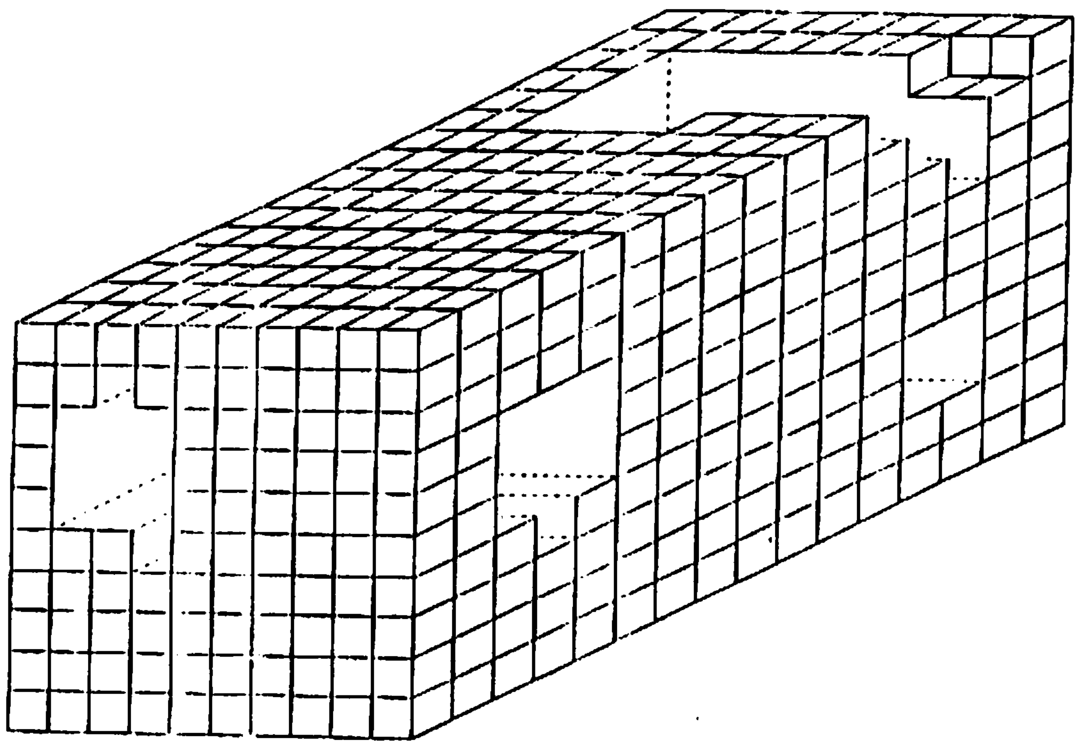
- Spatial Occupancy Enumeration (SOE)
  - Volume is divided into cubes of voxels
    - Can have on (full) or off (empty) status
    - Or, can have attribute values
  - Vertical resolution is often different (higher) from horizontal resolution (I.e., modeling the atmosphere
  - Objects can be displayed as positive (casts) or negative (molds)

SOE of a Mine/Quarry

2 1/2 Dimesions

vs.

True 3D Represenations



2 1/2 Dimesions
vs.
True 3D Represenations

True 3-D Rep. ~ Continued

- Spatial Occupancy Enumeration ~ Continued
  - 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

2 1/2 Dimesions
vs.
True 3D Represenations

True 3-D Rep. ~ Continued

- Spatial Occupancy Enumeration ~ Continued
  - Usually produced by converting from B-reps (similar to converting vectors to rasters in 2-D)
  - Properties like mass, volume, and surface area are quickly computed as Boolean operations or voxel counts
  - These can be indexed using octtrees

Octtrees

- 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

2 1/2 Dimesions vs. True 3D Represenations

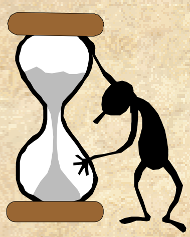
- These 3D representations are relatively new, so there’s little collective experience on how to implement them in the earth sciences & engineering
- It may be easiest to utilize technology developed in other fields (mechanical, engineering, medicine) and adapt to needs.
- However, the needs of medical imaging are different from earth science
    - Medical imaging technology is NOT designed for modeling, it does NOT need analytical tools for abstraction & interpretation that earth science applications do
    - Medical imaging is time dependent (it is usually necessary to track moving objects b/w one 3-D image and the next) while many earth science applications do NOT require this

Time Dependence

- Adds a third dimension to spatial data, just as the vertical dimension does
  - Hagerstand (1970) has used the vertical dimension to visualize movement in human systems - movements in the play become trajectories in three dimensions
  - 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 model for time dependent data has not been fully developed

Possible Models *for Time Dependence*

- Boundaries of reporting zones change through time
  - – Since the boundaries turn on & off rather than move, the solution is to store all boundary lines which ever existed, then to reconstruct objects from boundaries at any given time
    - i.e., Great American History Project stored boundaries for all definitions of US counties since the early 19th Century, reconstructed counties as any Census year from selected boundary pieces

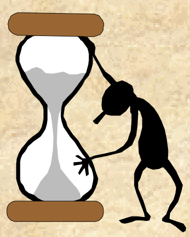


Possible Models *for Time Dependence*

- 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

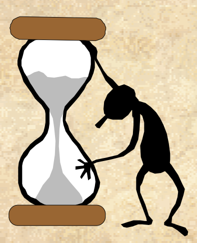
Possible Models *for Time Dependence*

- 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 - i.e., 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



Possible Models *for Time Dependence*

- Shapes of objects change through time (continued)
  - Alternatively, use a 3D space with the vertical dimension as time, populated by 3D objects, i.e., 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 *(i.e., remotely sense images)*
  - Objects at each time slice, but unrelated from one time to another - layers *(i.e., GAHP US counties)*
  - Objects at each time slice, related or tracked from one time to another - related layers *(i.e., migration data)*
  - Objects defined continuously in time dimension - 3D objects *(i.e., individual space-time travel behavior)*