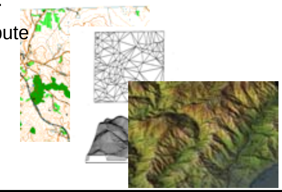
Analytical and Computer Cartography

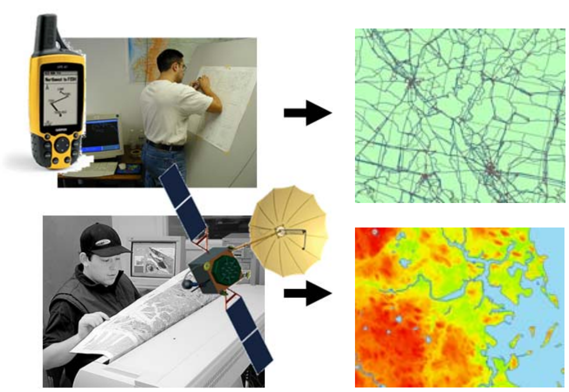
Lecture 7: Spatial Data Structures for Mapping

What is a Map Data Structure?

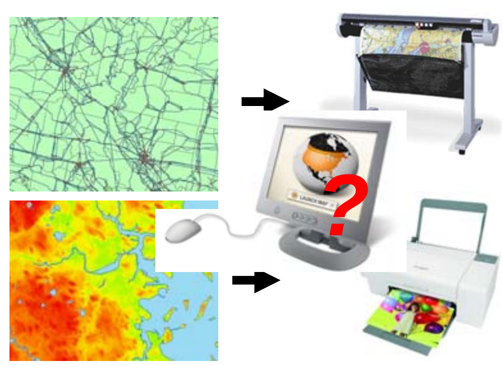
- Map data structures store the information about location, scale, dimension, and other geographic properties, using the primitive spatial data structures (zero-, one-, and two-dimensional objects), or more complex objects such as arrays
- Minimum requirement for computer mapping systems
- The purpose is to support computer cartography, and NOT necessarily analytical cartography.
- A Map data structure plus an attribute data structure is the minimum requirement for the additional analytical functions in Analytical Cartography, and GISystems.



Map Data Structures are largely Input-Determined

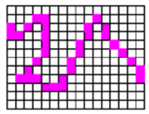


Output constraints on Map Data Structures



Vector or Raster?

OR



- Advantages and Disadvantages (Burrough, 1986)
- Choices determined by Purposes
- Peuquet (1979) showed that "*most algorithms using a vector data structure have an equivalent raster-based algorithm, in many cases more computationally efficient*" (Clarke, 1995)
- Vector I/O devices are being increasingly replaced by raster I/O devices
- Most GIS software packages support both vector and raster data structures

Vectors just seemed more correcter

- Can represent point, line, and area features very accurately.
- Far more efficient than raster data in terms of storage.
- Preferred when topology is concerned
- Support interactive retrieval, which enables map generalization

Vectors are more complex

- Less intuitively understood
- Overlay of multiple vector map is very computationally intensive
- Display and plotting of vectors can be expensive, especially when filling areas

Rasters are faster...

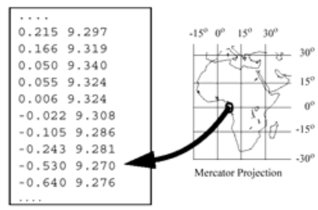
- Easy to understand
- Good to represent surfaces, i.e. continuous fields
- Easy to read and write
  - A grid maps directly onto a programming computer memory structure called an array
- Easy to input and output
  - A natural for scanned or remotely sensed data
  - Easy to draw on a screen or print as an image
- Analytical operations are easier, e.g., autocorrelation statistics, interpolation, filtering

Rasters are bigger

- Inefficient for storage
  - Raster compression techniques might not be efficient when dealing with extremely variable data
  - Using large cells to reduce data volume causes information loss
- Poor at representing points, lines and areas
  - Points and lines in raster format have to move to a cell center. Lines can become fat
- Areas may need separately coded edges
- Each cell can be owned by only one feature
- Good only at very localized topology, and weak otherwise.
- Suffer from the mixed pixel problem.
- Must often include redundant or missing data.

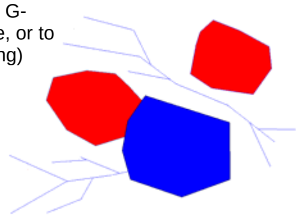
Entity-by-Entity Data Structures

- Cartographic entities are usually classified by dimension into point features, line features, and area features
- The simplest means to digitally representing cartographic entities as objects is to use the feature itself as the lowest common denominator
- Entity-by-Entity data structures are concerned with discrete sets of connected numbers that represent an object in its entirety, not as the combination of features or lesser dimension



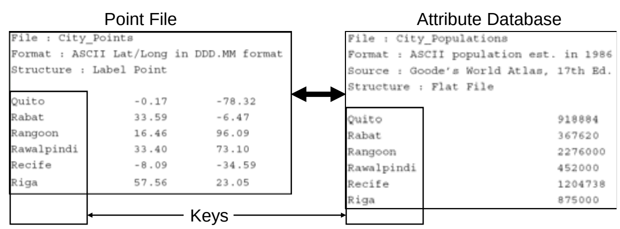
Entity-by-Entity structures do NOT have topology!

- Example: a G-ring representing a lake
- Adequate when computing the length of the boundary, the area, and shading the lake with color
- Extremely computationally intensive if we want to find a county (in G-ring) which intersects the lake, or to determine which river (in String) flows into the lake



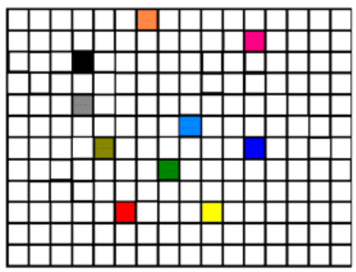
Entity-by-Entity Data Structures - Point Objects (Vector)

- Point list
  - (X, Y) coordinates
  - Feature codes – the keys linked to the attribute database



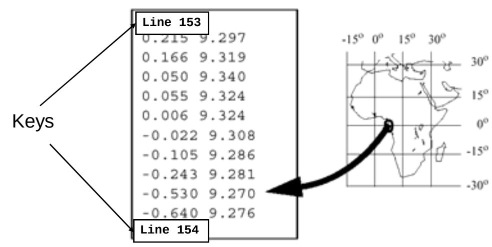
Entity-by-Entity Data Structures - Point Objects (Raster)

- Point Index values (or attributes) assigned to cells; indices as the keys to the attribute database
- One-pixel size



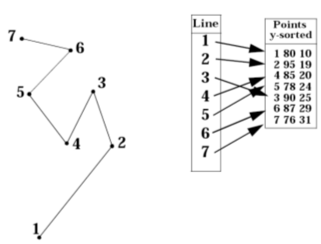
Entity-by-Entity Data Structures - Line Objects (Vector)

- Method I
  - An ordered set of points for a line
  - An identifier for a line as the key to the attribute database



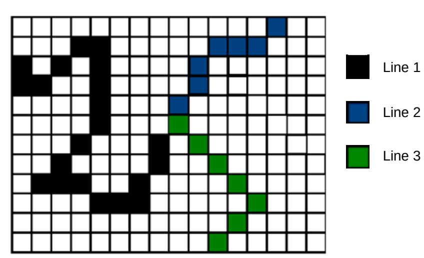
Entity-by-Entity Data Structures - Line Objects (Vector)

- Method II
  - A point file contains all the points (identifiers and coordinates) in the map – Point Dictionary
  - A line file contains all the lines (identifiers and the indices of its vertices)



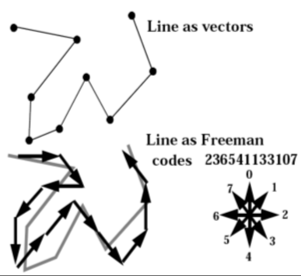
Entity-by-Entity Data Structures - Line Objects (Raster)

- Line Index values (or attributes) assigned to cells; indices as the keys to the attribute database
- Normally thinned to one-pixel width



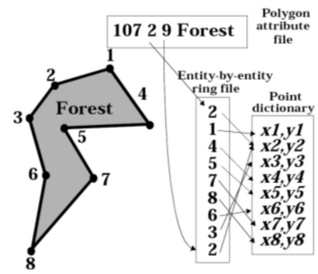
Entity-by-Entity Data Structures - Line Objects (Freeman codes)

- Freeman codes - a line as a sequence of octal (8-based) digits, each digit represents the direction of a step moved along the line
- Vector Freeman codes
- Raster Freeman codes
  - Length = 1 in primary directions
  - Length = $\sqrt{2}$ in diagonal directions
- Run-length for Freeman codes



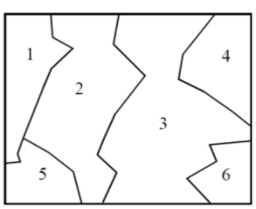
Entity-by-Entity Data Structures - Area Objects (Vector)

- A point dictionary
- A ring file contains all the rings (identifiers and vertex indices); identifiers as the keys to the attribute database



Entity-by-Entity Data Structures - Area Objects (Raster)

- Polygon Index values (or attributes) assigned to cells; indices as keys to the attribute database
- Area calculation by counting cells
- Run-length encoding could be efficient if the data is spatially homogeneous

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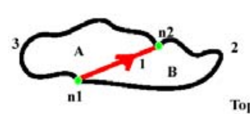
1111122222223333333333344444
1111111222223333333344444444
1111122222222233334444444444
1111222222222223333333344444
1112222222222233333333333344
1122222222222333333333333333
1555222222233333333333336666
5555555222223333333333666666
5555555552223333333333366666
```

Topological Data Structures

- Store the additional characteristics of connectivity and adjacency
- Linkage between Primitive Objects (nodes, links, chains)
- Forward linkage and Reverse linkage
- Finite number of chains can meet at a node

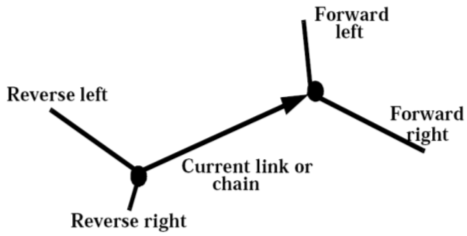


Topological Arcs File

Arc	From	To	PL	PR	n1x	n1y	n2x	n2y
1	n1	n2	A	B	x	y	x	y

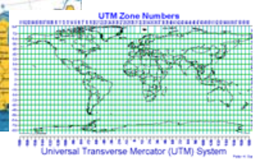
Topological Data Structures (cnt.)

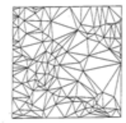
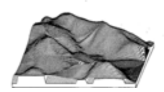
- Right and left turns are needed to traverse a network
- Right- and left-polygon information enabled advanced analytical operations



Tessellations and the TIN

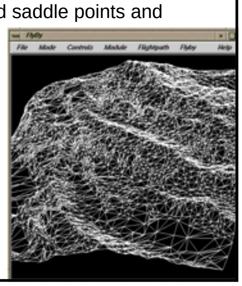
- Tessellations are connected networks that partition space into a set of sub-areas
- Regions of geographic interests
  - Political regions – states, countries
  - Grids
- Triangulated Irregular Networks (TIN)

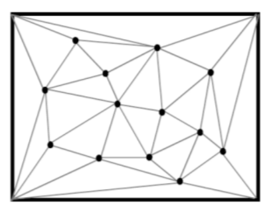
Triangulated Irregular Networks (TIN) - Introduction

- Map data collection often tabulates data at significant points
- Land surface elevation survey - seeks “high information content” points on the landscape, such as mountain peaks, the bottoms of valleys and depressions, and saddle points and break points in slopes
- Assume that between triplets of points the land surface forms a plane
- Triplets of points forming irregular triangles are connected to form a network



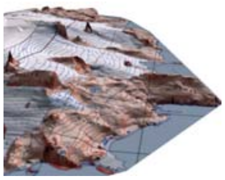
Triangulated Irregular Networks (TIN) - Creation

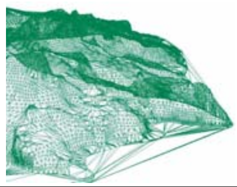
- Delaunay triangulation to create TIN
  - Iterative process
  - Begins by searching for the closest two nodes
  - Then assigns additional nodes to the network if the triangles they create satisfy a criterion, e.g. selecting the next triangle that is closest to a regular equilateral triangle



Triangulated Irregular Networks (TIN) - Advantages

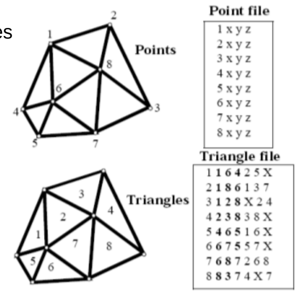
- More accurate and use less space than grids
- Can be generated from point data faster than grids.
- Can describe more complex surfaces than grids, including vertical drops and irregular boundaries
- Single points can be easily added, deleted, or moved





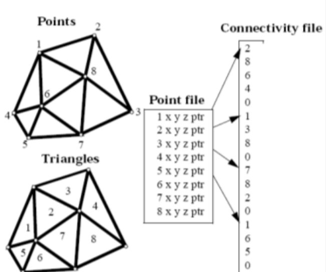
Triangulated Irregular Networks (TIN) - Data Structure I

- Triangle as the basic cartographic object
- The point file contains all the points, stores (X, Y) coordinates and elevations (Z)
- The triangle file contains triangles (three pointers to the point file, plus three additional pointers to adjacent triangles)



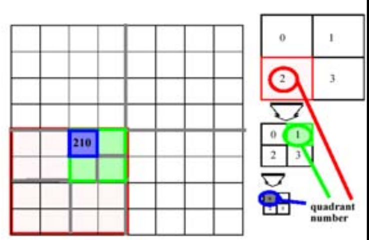
Triangulated Irregular Networks (TIN) - Data Structure II

- Vertices of a triangle as the basic object
- A point file contains (X,Y, Z) values and pointers to the connectivity file
- A connectivity file contains lists of nodes that are connected to the points in the point file; a zero at the end of each list



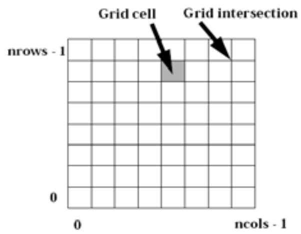
Quad-tree Data Structures

- A type of tessellation data structures
- Partition the space into nested squares -quadrants
- Index methods
  - NE, SW, NE, NW, SE
  - Morton number
- Allow very rapid area searches and relatively fast display

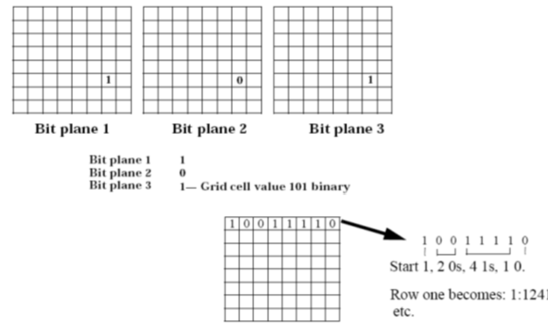


Maps as Matrices

- A grid directly maps into an mathematic expression – matrix
- A matrix can be loaded in a computer memory as an array
- Geographic Information is needed
  - Coordinates of the corners
  - Number of rows and columns
  - Cell size
- Run-length encoding
- Can do indexing and tiling



Maps as Matrices
- Bit planes



Run-length encoding for a bit plane

Ad Hoc versus Standard Data Structures

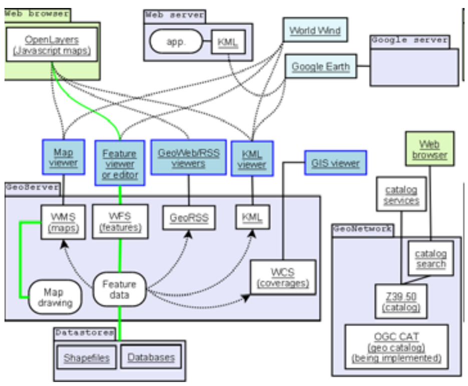
- Each GIS/mapping program uses its own standards
- Wants rapid input/output and transformations
- Wants to avoid computational errors and special cases
- If structures are standards, programs can be reused and made as interchangeable parts
- I/O routines can be written once and shared as libraries
- E.g. ShapeLib: Routines to read and write ESRI .shp files and .dbf atttributes
- Can also map directly onto display routines

Spatial Data Transfer Standard (SDTS)

- SDTS is "*a **robust** way of transferring earth-referenced spatial data between dissimilar computer systems with the potential for no information loss. It is a transfer standard that **embraces** the philosophy of self-contained transfers, i.e. spatial data, attribute, geo-referencing, data quality report, data dictionary, and other supporting metadata all included in the transfer*" (USGS, http://mcmcweb.er.usgs.gov/sdts/)
- Draft standard published in The American Cartographer (1988)
- FIPS (Federal Information Processing Standards) 173 approved 1992
- Standard consists of several parts

SDTS
Spatial Data Transfer Standard

Open Geospatial Consortium

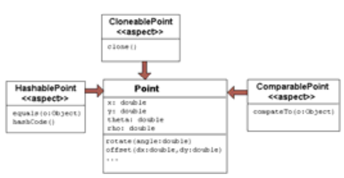


The OGC standards baseline comprises more than 30 standards

- OGC Reference Model - a complete set of reference models
- WMS - Web Map Service: provides map images
- WMTS - Web Map Tile Service: provides map image tiles
- WFS - Web Feature Service: for retrieving or altering feature descriptions
- WCS - Web Coverage Service: provides coverage objects from a specified region
- WPS - Web Processing Service: remote processing service
- CSW - Web Catalog Service: access to catalog information
- SFS - Simple Features - SQL
- GML - Geography Markup Language: XML-format for geographical information
- Styled Layer Descriptor (SLD)
- KML - Keyhole Markup LanguageSensor Observation Service[4] (SOS)
- Sensor Planning Service[5] (SPS)
- SensorML - Sensor Model Language
- Observations and Measurements
- OWS - OGC Web Service Common
- GeoXACML - Geospatial eXtensible Access Control Markup Language (as of 2009 in the process of standardization)

Data Structures and Programming

- Data Model maps onto a data structure
- Data structure eventually implies programming structure
- Unstructured computer programming languages did not support data structures well
- Structured languages (e.g. C, Pascal) allow definition of structures directly (attributes only)
- Object-oriented languages (e.g. C++, Java) allow definition of objects (attributes + behaviors)
- Link between the physical storage of data and the data's use in mapping systems

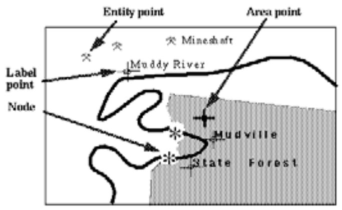


For example

- C programming language
- # Declare a grid
  - Int Grid[100][100];
  - Grid[50][50] = 235;
- # declare a Point Type
  - Typedef struct POINT { int point_id, double x, y;}
  - POINT Point[100];
  - Point[50].x = 123231.0;

Zero Dimensional Objects

- Most primitive object is the POINT
- Can be (x,y) or (x,y,z)
- Consists of geocodes for location in a standard system

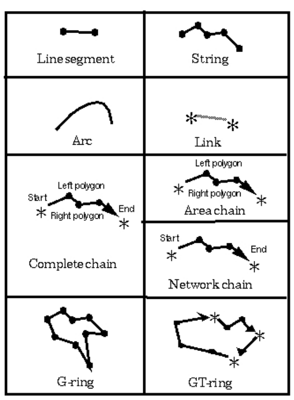


- Should be in world not image geometry
- If significant topologically, is a node.
- Can identify a feature (entity) or a label (label)
- Can be INSIDE an area and carry its identification information

One Dimensional Objects

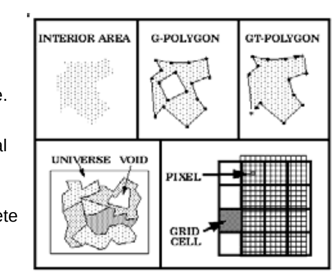
- Divide up by lines with and without topological significance
- Primitive object is the segment
- Segments connect to make a string (line or polyline)
- If defined mathematically, use arc
- If line segment connects nodes, called a link (for a network)
- Topological versions carry end node and or left and right polygon data
- Complete, area and network chain versions
- Area-like objects are G-ring and GT-ring

One Dimensional Objects



Two Dimensional Objects

- Interior area is the space contained by the polygon, i.e. the object not the boundary
- G-polygon contains graphical objects that form a polygon, e.g. a ring
- GT-polygon contains complete topology



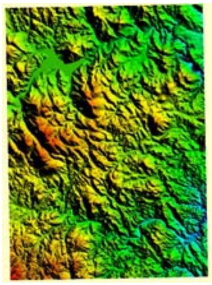
- Toplogical encoding requires **universe** and **void** polygons.
- Special objects
  - pixel (the smallest non-divisible element of a digital image)
  - Grid cell (same as pixel but for a grid)

Aggregate Objects

- **DIGITAL IMAGE**
  - two dimensional array of regular pixels

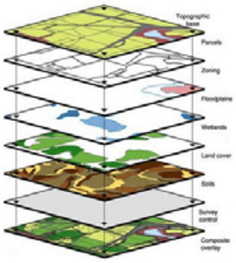
Aggregate Objects (cnt.)

- **GRID**
  - Set of grid cells forming a regular or near regular tesselation



Aggregate Objects (cnt.)

- **LAYER**
  - Distributed set of spatial data representing entity instances within on theme, or with a common attribute.
  - Usually registered with other layers.



Aggregate Objects (cnt.)

- **RASTER**
  - One or more overlapping layers from the same grid or digital image.

Red

Green

Blue

Aggregate Objects (cnt.)

- **GRAPH**
  - **Planar Graph**: Node and link/chain set as applied to a plane surface
  - **Two-dimensional Manifold**: Planar graph with all included objects
- **Network**
  - A graph without two-dimensional objects (links do not have to intersect)
- **Limitations**
  - Three dimensional objects
  - time-sensitive objects
  - Links to other standards
  - Implementation slow via profiles