Massachusetts Institute of Technology
Department of Urban Studies and Planning

11.520: A Workshop on Geographic Information Systems

11.188: Urban Planning and Social Science Laboratory

Lecture 3: More GIS Principles & Methods: Projections and Coordinate Systems

September 21, 2005, Joseph Ferreira, Jr.

(including contributions from Visiting Prof. Zhong-Ren Peng who taught the class in Fall of 2003)

Administrative notes:

- Homework set #1 posted online today, due in 2 weeks
- Lab Exercises #1: due today
- Lab Exercise #2: due next Monday (at the start of the Lab)

Today's Topics:

- Elements of the Map
    - Map scale, symbology
    - Classification and thematic shading
- Map projections
- Vector & Raster data models

Elements of the Map

Scale

- Ratio Scale, 1:10,000, or 1:100,000 or 1/100,000

- Verbal Scale:

  - One inch represents 2,000 feet (1:24,000).

  - One centimeter represents 20 kilometers (1:2,000,000)

- Printout vs. onscreen:

  - 10 foot pixel + 72 pixels per inch onscreen ==> One inch represents 720 feet (1:8,600) -

  - But some screens have higher/lower pixel densities; not all screens have square pixels; also, screendump to printer will change scale since printer will have different dot-density than the screen

  - Beware! Good GIS software will try to match screen and printer properties to software settings so screen and printouts will show appropriate scale and show correct scalebars. For the scale to be meaningful, display units and hardware choices must be properly identified.

Large Scale or Small Scale

- In general,

  - Large scale: >= 1:24,000 (good for *small* area representation - city block)

Small scale: <= 1:500,000 (good for *large* area representation - metro area)

But scale is relative, depends on the applications.

Large-scale maps are <u>more</u> detailed than small-scale maps.

Typical Scales Used

In Metric System:

1:10,000 or 1:25,000

1:50,000

1:100,000

In American System:

1:9,600 (one inch represents 800 feet)

1:24,000 (one inch represents 2000 feet)

1:62,500 (one inch represents (slightly less than) one mile)

Six Principal Visual Variables

Visual Variable	Point Symbols	Line Symbols	Area Symbols
Size			
Shape			
Graytone Value			
Texture			
Orientation			
Hue			

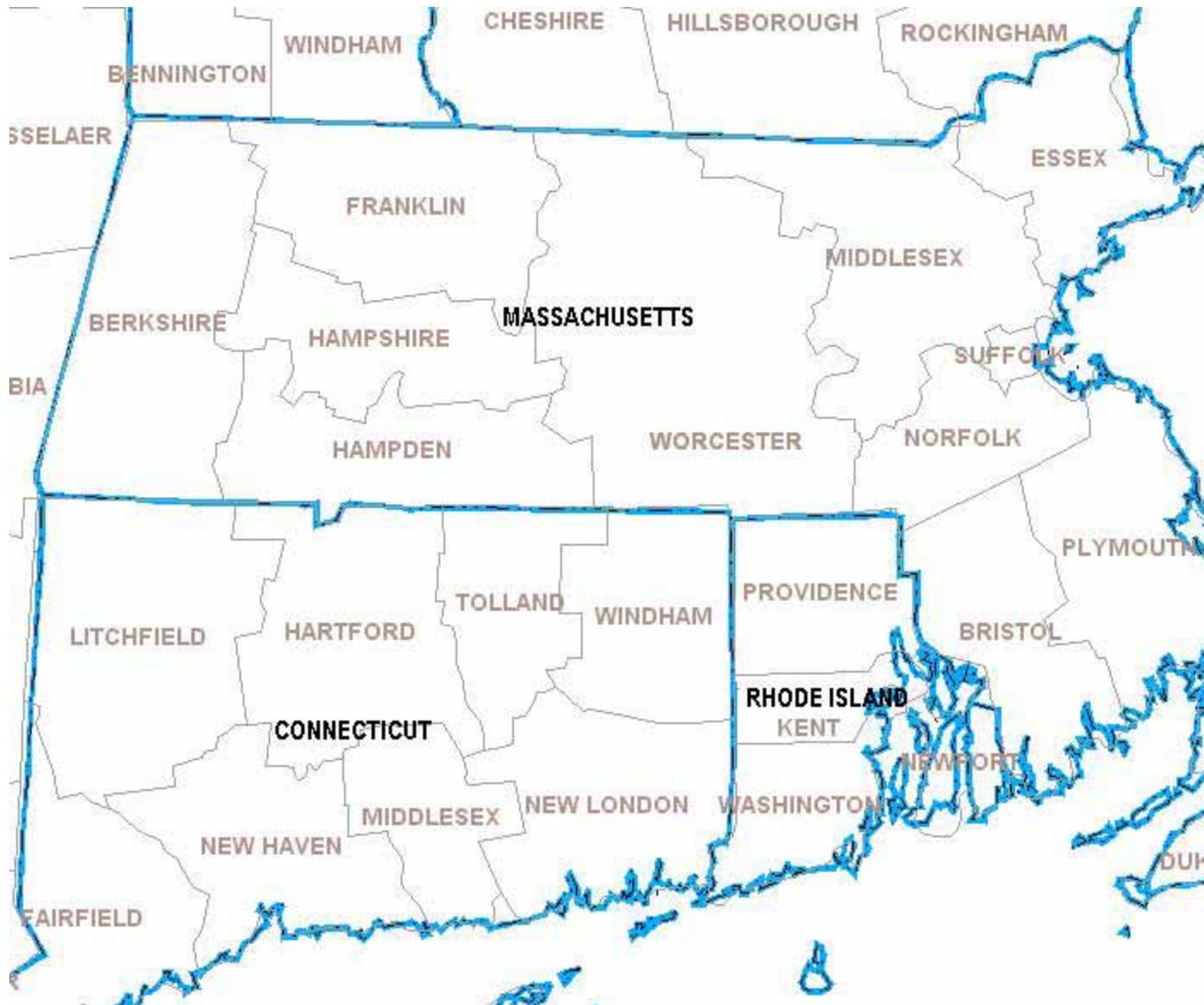## Use contrasting symbols to portray geographic differences

- For qualitative differences

  - Use shape, texture and hue (e.g., land use types).

- For quantitative differences

  - Use size to show variation in amount or count (e.g., population, No. of crime),

Use graytone or hue to show differences in ratio or intensity
(e.g., proportion of household in poverty,
population density).

Southern New England Counties

- Thematic mapping - simplest display of spatially varying phenomena

- Note use of ArcMap 'help files' regarding thematic map types & classification choices
- Different classification schemes:
  - Equal Interval
  - Natural Breaks
  - Quantile
  - Standard Deviation
- Number of classes, color scheme, etc.
- Normalization: Why do we care?
- Exclusion options: no data vs. zero value
- Layouts: Features of a good map (lots more to good cartography - see references)
  - Title, Legend, Scale Bar, North Arrow, Data sources,
  - Your name or organization
  - Other feature labels and annotations

Projections

Geographic Reference System: Latitude and Longitude

Axis: the center of earth rotation.

Equator: The plane through the center of mass perpendicular to the axis.

Longitude: lines slicing the earth parallel to the axis, and perpendicular to the plane of equator.

The line goes through Greenwich has 0 longitude.

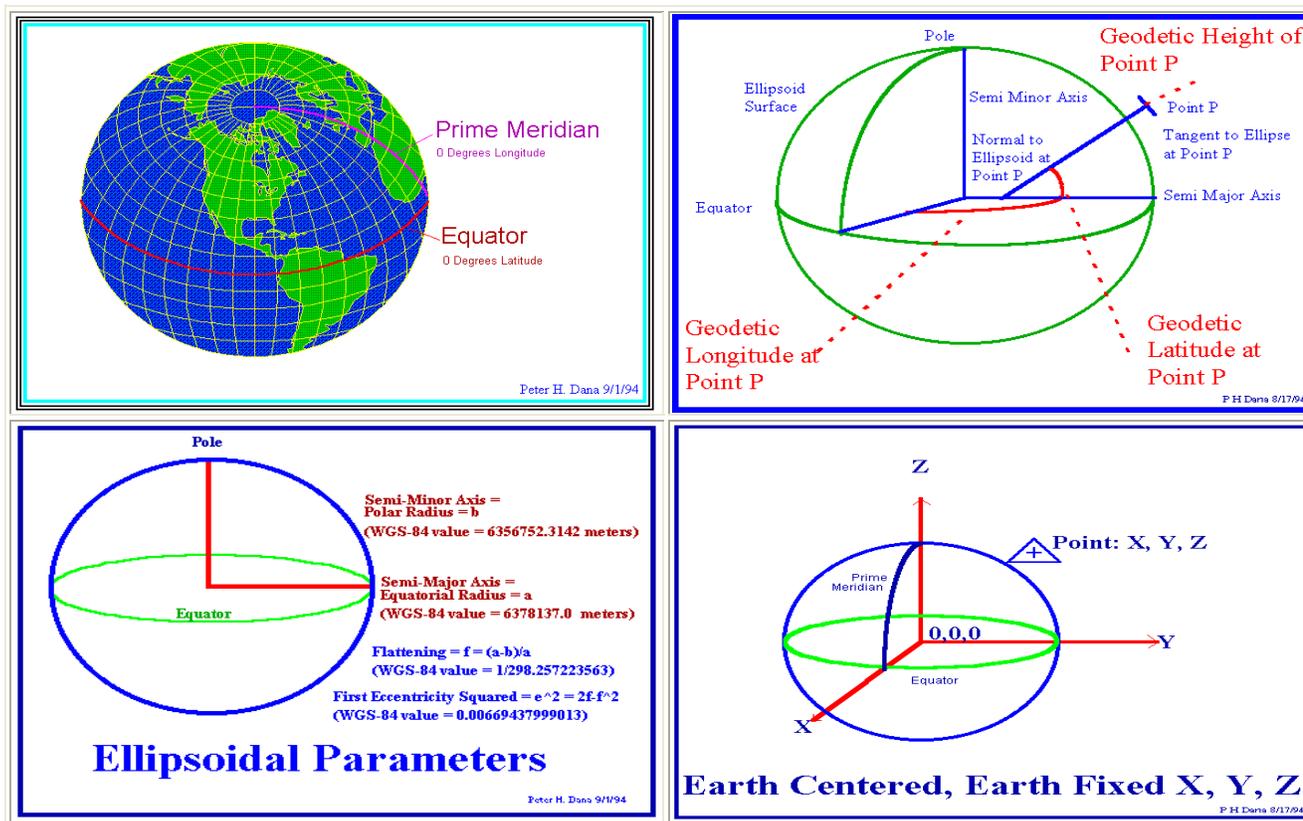Range from 0 to 360 degrees, or 180 degree west (-) to 180 degree east (+).

Latitude

■Latitude is defined based on ellipsoid representing the shape of the earth.

See: Prof. Peter Dana's notes on projections and coordinate systems (U. of Colorado)
http://www.colorado.edu/geography/gcraft/notes/coordsys/coordsys_f.html

<Click the images below to enlarge...>

■WG84 (the World Geodetic System of 1984) is a standard ellipsoid.

■In North America, the most recent ellipsoid data it is called the North American Datum of 1983 (NAD83) (the earlier version is NAD27).

■Latitude definition:

A line drawn through a point of interest perpendicular to the ellipsoid at that location, the angle made by this line with the plane of Equator is the latitude of that point.

Ranges from 90 degree south (-) to 90 degree north (+).

What do Latitude and Longitude mean?

Two points on the same longitude, separated by one degree of latitude are 1/360 of the circumference of earth apart, or about 111 km apart.

One minute latitude is 1.86 km.

One second latitude is 30 m.

For the same latitude, one minute of longitude separation corresponds to <u>different</u> distances depending on the latitude (111 km at equator, nothing at the poles!).

Nowadays, latitude/longitude often expressed in decimal degrees.

Distance calculation using latitude and longitude

- Latitude $-90 \leq \emptyset \leq 90$

- Longitude $-180 \leq \lambda \leq 180$

- Arc distance between two points on the earth surface (spherical):

    - Rcos-1[sinØ1sinØ2+cosØ1cosØ2cos(λ1-λ2)]

    - R is the radius of the spherical earth

Cartesian Coordinate System

- Assign two coordinates to every point on a flat surface.

Map Projections

- Map projections transform the curved, 3-D surface of the planet into a flat, 2-D plane. Note, that Map projections distort map scale in various ways

- Transform a position on the Earth's surface identified by latitude and longitude (Ø, λ) into a position in Cartesian coordinates (x, y).

  - $x = f(Ø, λ)$

  - $Y = g(Ø, λ)$

- Map projections necessarily distort the Earth and the map scale.

Example using Prof. Peter Dana's notes (U. of Colorado)
http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj.html

Example using ArcMap

- ESRI sample data map of 50 US states
- Convert to Mass state plane and compare results

The following contents of today's lecture is derived from Longley, Goodchild, Maguire and Rhind, *Geographic Information Systems and Science*, 2001, as organized by Prof. Zhong-Ren Peng for 11.520 in Fall 2003.

Map Projection Classifications based on preservation properties

- The *conformal* property, preserves the shapes of small features on the Earth's surface (directions). This is useful for navigation. E.g., Mercator projection and Gnomonic projection.

- The *equal area* property, preserves the areas. This is useful for analysis involving areas like the size of the property, e.g., Goode's projection.

- Any projection can have either conformal property or equal area property, but not both.

Map Projection classifications based on physical surface models

- *Cylindrical* projections -- wrapping a cylinder of paper around the Earth, projecting the Earth's features onto it, and then unwrapping the cylinder;

- *Azimuthal* or planar projections -- touching the Earth with a sheet of flat paper;

- *Conic* projection -- wrapping a sheet of paper around the Earth in a cone.

- All three types can have either *conformal* property or *equal area* property, but not both.

Unprojected projection: Plate Carrée or Cylindrical equidistance Projection

- Just maps longitude as x and latitude as y.

- Heavily distorts image of the Earth.

- It does not have either conformal or equal area property.

- But it maintains the correct distance between every point and the Equator.

- Serious problems (distorted area, direction and other properties) can occur when doing analysis using this projection.

The Universal Transverse Mercator (UTM) Projection

- Projected by wrapping a cylinder around the Poles, rather than around the Equator.

- There are 60 zones. Each zone is 6 degree wide and wrapped along a particular line of longitude.

- The project is conformal, the scale is the same in all directions.

- UTM coordinates are in meters, making it easy to make accurate calculations of short distances between points.

- UTM projections have more problems at high latitudes.

State Plane Coordinates and other local systems

- UTM is still not accurate enough for small area surveying.

- During 1930s, each US state adopt its own projection and coordinate system, generally known as State Plane Coordinates (SPC).

- Each state chose its own projection based on its shape to minimize distortion over the area of the state.

- Some states have more than one internal zone.

- The North American Datum 1983 (NAD83) is commonly used for SPC.

Converting Georeferences

- Two datasets can differ in both the projection and the datum, so it is important to know both for every dataset (and the data can be expressed in feet or meters with different origins!)

- Use coordinate conversion to combine datasets that use different systems of georeferencing. Keep in mind, changing projections means the system

must convert projected coordinates **back** to lat/lon (geographic) and then **re-project** into another projection/datum.

- Convert into projections that have desirable properties, e.g., no distortion of area, for analysis.

Representing the Geographic World

Data Models and Data Management

- Vector model - representing *objects* by defining the *location* of their boundaries
- Raster model - representing *space* as 2D or 3D grid cells containing values that measure the presence/absence/strength of some field or phenomena
- Attribute handling - associating/manipulating the properties of objects or cells

Vector data

- Geographic phenomena are represented as points, lines and polygons.

- Lines are captured as points connected by straight lines, hence called polylines.

- An area is captured as a series of points or vertices connected by straight lines.

- Note limitations: e.g., the boundaries of geographic phenomena are usually fuzzy - edge of river/lake/wetlands.
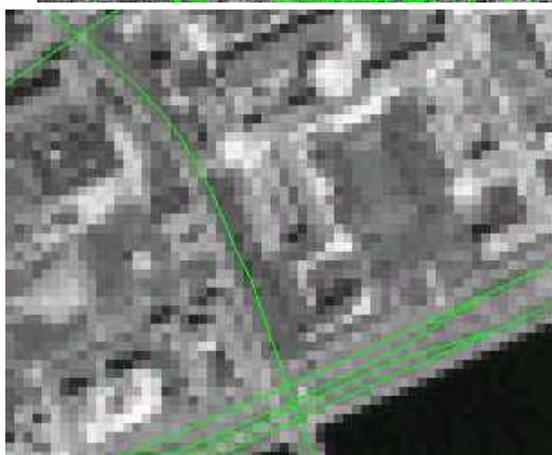
Raster data

- Raster representations divide the world into arrays of cells and assign attributes to the cells.

- The cells may be called pixels (as with orthophoto)

- Examples: satellite images.

- Each cell can only have one value.

- Rules of assigning a value to the cell: largest share, or central point.

Data Models and Data Management

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Examples

- Vector models - the Cambridge block group mapping exercises in Labs 1 & 2
- Raster vs. vector data models
    - regular grid on top of spatial features (instead of encoding boundary)
    - pixel brightness in orthophoto of Boston
    - Vector: points, lines, polygons
        - Coverages: old Arc/Info a directory per layer, plus INFO files
        - Shapefiles: .shp, .shx, .dbf files (and possibly others)
        - Spatial Database Engine (SDE): retrieved dynamically from a database server
    - Raster: orthophotos, scanned maps, grids

Boston/Cambridge Streets superimposed on orthophoto -- plus, zoomed-in view showing raster nature of the ortho.

- Complications
    - islands, lakes, overpasses
    - share edges?, move links when you move points?
    - ambiguity: summer/winter wetland boundaries
    - scale, generalization, conflation, slivers
- More info on Coordinate systems and projections
    - Coordinate Systems
        - Peter Dana's Coordinate Systems Page
    - Datums & Units
        - Peter Dana's Geodetic Datums Page
    - Projections
        - Peter Dana's Projections Page

- [Two Different Projections of North America](#)
- [Three Different Map "Projections" of the Conterminus United States](#)

Last modified 21 September 2005.