

## **APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS (GIS): MAPS, SCALES, AND PROJECTIONS**

*Note: See accompanying scales.ppt file.*

Maps are an important source of data and an important form of output for GIS. Creating a map requires several types of abstraction, including:

- (1) selection of features to show,
- (2) simplification of complex features (e.g., jagged coastlines),
- (3) exaggeration of small features (so they appear on the map),
- (4) classification of features into groups (e.g., roads, soil types) and
- (5) symbolization to represent different classes of features.

*Topographic* maps show surface features (topography) while *thematic* maps show distributions of data for various features (e.g., number of threatened vertebrate species of countries). Note that maps are static (they show one instant of time) and are usually out of date!

Historically, maps have been very important for navigation. Other uses include display of data, storage of data and analysis. However, manual analysis using paper maps is very time consuming (e.g., to measure areas) and imprecise. GIS uses spatial databases that greatly facilitate spatial analysis, as well as production of custom maps. The types of analysis that can be performed depend on the types of data available and the capabilities of the GIS.

A spatial database is a particular digital view of the real world. It may contain features that do not exist in the real world (e.g., contour lines). It also represents continuous features of the world at discrete points. Real world data have spatial, temporal and thematic characteristics. Spatial data are stored as locations. Temporal data for a fixed location can be stored for several discrete time instants or as a rate of change. Thematic data are stored as attributes of features (e.g., population).

Data may be collected by direct measurement in the field, by remote sensing, or from secondary sources (e.g., maps, tables or other databases). The resolution of the data is determined by the sampling procedure. The sampling strategy should be designed to capture appropriate spatial and temporal variation. However, data collected or developed by one part of an organization for its own purposes are often used by other parts of the organization (or other organizations) for purposes other than that for which the data were collected. Thus, it is important to know how data were collected or created. Poor decisions may result from using data for purposes other than those for which they were intended.

## Scale

The *scale* of a map is the ratio between distances on the map and the corresponding distance in the real world. In a map with a scale of 1:24000 (e.g., a USGS topographic map), one inch on the map equals 2000 feet on the earth (24000 inches = 2000 feet). Because scales are expressed as ratios, large scale maps show small areas. A map with a large scale (ratio) such as 1:2 (i.e., 1/2) is half life-size; a map with a small scale such as 1:2,000,000 (i.e., 1 cm on the map equals 2,000,000 cm or 20 km in the real world) can show a large area. For example, a map 1 meter wide could show a geographic region 2000 km across if the scale is 1:2,000,000. The scale on a map may not be consistent in all parts of the map due to the *projection*.

## Coordinate Systems

Coordinate systems identify locations. They are based on measurements from a given location (origin). For a two dimensional surface, Cartesian coordinates are usually used with a location denoted by (x,y) where x and y are the horizontal and vertical displacements, respectively, from the origin. The straight line distance between two points  $(x_1, y_1)$  and  $(x_2, y_2)$  can be calculated as

$$distance = [(x_1 - x_2)^2 + (y_1 - y_2)^2]^{1/2}.$$

For locations on the earth, latitude and longitude are used in a *Geographic Coordinate System*. This system uses a 3-dimensional spherical surface to display real world locations. The origin is the intersection of the equator and the central or prime meridian (through Greenwich, England). A *meridian* is a line of constant longitude and a *parallel* is a line of constant latitude (e.g., the tropic of Capricorn). Latitude measures the angle from the earth's center to a point on the surface and ranges from -90 at the South Pole to +90 at the North Pole. Longitude measures the angle along the equator between the meridian through a point and the central meridian and ranges from -180 (westerly) to +180 (easterly).

The equator is the only parallel as long as the meridian. With increasing latitude, the distance covered by one degree change in latitude becomes increasingly smaller until the distance becomes zero at the poles. For example, using the Clarke 1866 spheroid, at the equator, one degree longitude = 111.321 km; at 60 degrees latitude, one degree longitude = 55.802 km!

The shortest distance between two points on a sphere is the *great circle distance* and is given by

$$distance = 3959 \cdot \arccos [\sin(lat_1) \cdot \sin(lat_2) + \cos(lat_1) \cdot \cos(lat_2) \cdot \cos | long_2 - long_1 | ].$$

Latitude and longitude are measured in degrees, minutes and seconds but are often used as decimal degrees (e.g., in the equation above). For example, the location of St. Louis is 90 degrees 12 minutes (or 90.20 degrees) west longitude and 38 degrees 35 minutes (or 38.583 degrees) north latitude. This location could also be describes as a longitude of -90.20 (it is west

longitude). Similarly, locations in the southern hemisphere could be described with a negative latitude.

## Map Projections

A map projection is a system for converting locations on the surface of the earth (a three dimensional object) to a planar (two dimensional) surface, such as a piece of paper or a video monitor. Projections are given by mathematical relationships that convert coordinates on the earth to coordinates on a plane. Many different projections exist, but each generally involves projecting a three dimensional surface (the earth) onto a flattenable surface such as a cylinder, cone or plane. This gives rise to cylindrical, conic and azimuthal (or planar) projections. Projections cause distortions in angle, area, direction, shape and distance. Each projection has specific properties and characteristic distortions that make it useful for specific applications -- and not useful for other applications.

An excellent overview of map projections, including many illustrations is at [http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj\\_f.html](http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj_f.html)

### Properties of map projections:

There are three major properties of map projections:

1. Conformality - preserves local angles (i.e., the angle between two intersecting lines is the same on the earth and on a conformal map), and thus shapes. Meridians and parallels intersect at 90 degree angles. In conformal maps, area may be greatly distorted.
2. Equal area - preserves relative areas of features. Consequently, shape may be distorted; this is most obvious in small-scale maps and may be hard to see in large-scale maps. Meridians and parallels may not intersect at right angles.
3. Equidistant - preserves distance from specific points (the center of the map) or along specific lines. However, no projection is equidistant to and from all points on a map. In sinusoidal, equator and all parallels are of true length.

No flat map can be both conformal and equal area. Thus, a flat map can not accurately represent both the area and the relative positions of features on the earth. However, this may not be a significant problem for small areas.

Another problem for projections is that the earth is not a perfect sphere. It is flattened somewhat at the poles and has an irregular shape. The polar axis is ~ 23 km shorter than the equatorial axis, and thus the earth is best represented by an ellipsoid; in fact an ellipsoid that has been rotated on its minor axis. Different ellipsoids have been developed to fit the earth's surface – the best ellipsoid depends on where you are in the world. Approximately 30 ellipsoids are being used today. Recently satellites have been used to determine the earth's size and shape and are more precise. These ellipsoids are used to develop datum models. Such datum models, given set features of the earth (origin, orientation, parameters, reference ellipsoid, define a network of known control points through triangulation and trilateration. In the U.S., the USGS has adopted the Geodetic Reference System of 1980 (GRS 80) as the best ellipsoid. WGS 84 is the standard

ellipsoid model (or datum) of the Earth for GPS (e.g., check your GPS unit). Prior to the 1970's the U.S. used primarily the North American Datum 1927 (NAD 27), which references the Clarke 1866 ellipsoid. However, with satellites and advanced technology, during the 1970's and 1980's, locations were readjusted and transformed from NAD 27 to NAD 83, which caused control points to shift by as much as 200 m (primarily horizontal shifts); NAD 83 is a more accurate datum and uses the GRS 80 ellipsoid as the reference surface. Some differences between NAD27 and NAD83 are the length of the semi-major axis; datum origin (Meades Ranch, Kansas vs. center of the mass of the earth), number of control points (25,000 vs. 250,000), etc.

There are a great number of different map projections. (ArcGIS provide tools to change projections.) Note that although the same data may *look* different in two projections, it is the same data and should have the same attributes (area, perimeter, etc.). Some common projections are listed below.

## 1. CYLINDRICAL PROJECTIONS:

### **Mercator:**

Equator is tangent to cylinder.

*Area:* increasingly distorted near the poles (Greenland is really only 1/8<sup>th</sup> size of South America; looks larger).

*Shape:* conformal; i.e., local shapes accurate.

*Distance:* scale true along equator, or secant latitudes.

*Direction:* any straight line drawn represents true direction.

Commonly used for (older) world maps.

Originally created to display true bearings in sea travel; sea navigation.

Meridians parallel and equally spaced.

Best for regions near equator.

### **Robinson:**

Pseudocylindrical.

*Shape:* distortion low within 45 degrees of origin and along equator.

*Area:* distortion low within 45 degrees of origin and along equator

*Direction:* distorted

*Distance:* usually scale is true along 38 degrees N and S, and constant along any latitude.

Neither conformal nor equal area.

Designed to make the world "look right"

Adopted by *Rand McNally* and *National Geographic* for world maps, may replace Mercator in school use.

### **Sinusoidal:**

*Shape:* distorted away from central meridian and equator; less so in interrupted sinusoidal

*Area:* equal area

*Direction:* local angles correct along central meridian and equator; distorted elsewhere

*Distance:* scale along all parallels and central meridian is accurate

Interrupted sinusoidal maps use several central meridians.

Useful for continental maps.

## 2. CONIC PROJECTIONS: (can not show the whole world)

### Albers Equal-Area:

*Shape:* accurate along standard parallels and minimum distortion between them; 90 degree angles preserved, but scale changes and thus projection is not conformal

*Area:* equal area

*Direction:* true along standard parallels

*Distance:* increasingly inaccurate away from middle latitudes

Used for maps of the conterminous U.S. (USGS)

Best for middle latitudes and for regions predominately east-west

Total range in latitude should not exceed 30-35 degrees.

Not useful for continents

### Equidistant conic:

*Shape:* true along standard parallels, increasing with distance away from standard parallels

*Area:* distortion constant along any parallel but increasing with distance away from standard parallels

*Direction:* locally true along standard parallels

*Distance:* true along meridians and standard parallels

Regional maps only; should be limited to range of 30 degrees latitude.

Common for atlas maps of small countries.

### Lambert conformal conic:

*Shape:* conformal

*Area:* minimal distortion near standard parallels but increasing with distance away from standard parallels

*Direction:* true because of conformality

*Distance:* locally true along standard parallels; reduced between and increasing beyond standard parallels

Used for many USGS 15 minute and 7.5 minute topographic maps.

One of the most widely used projections in the U.S.

Good for areas east-west in extent.

State Plane Coordinates for all east-west zones in U.S.

## 3. AZIMUTHAL PROJECTIONS:

**Gnomonic:**

*Shape:* increasingly distorted away from center

*Area:* increasingly distorted away from center

*Direction:* accurate from center

*Distance:* no line has accurate scale, amount of distortion increases with distance from center

Uses center of earth as its perspective point.

Used for navigation and seismic work since all great circles are straight lines.

**Orthographic:**

*Shape:* increasingly distorted away from center

*Area:* increasingly distorted away from center; areal scale is zero at edge of hemisphere

*Direction:* true from central point

*Distance:* scale perpendicular to the radii, along parallels of polar aspect is accurate

Used for perspective views (e.g., from space).

**Stereographic:**

*Shape:* conformal

*Area:* true at center, distortion increasing with distance

*Direction:* accurate from center; local angles accurate everywhere

*Distance:* scale increases with distance from center

Used for mapping circular regions on moon, Mars and Mercury.

Used for polar maps.

**4. OTHER COORDINATE SYSTEMS**

Coordinate systems are constructed on the basis of map projections but are not projections themselves.

**Universal Transverse Mercator (UTM):**

Special adaptation of Transverse Mercator (cylindrical)

Adopted by International Union of Geodesy and Geophysics, NATO, U.S. Army, etc.

World divided into 60 UTM zones (each 6 degrees wide).

Used from 84 degrees north to 80 degrees south.

(Polar stereographic projection used for polar regions.)

Typically false easting of 500,000 meters

In south zones, false northing of 10,000,000 meters

*Shape:* conformal

*Area:* minimal within UTM zone

*Direction:* local angles true

*Distance:* scale factor of 0.9996 to reduce lateral distortion within each zone; lines 180 km east and west of central meridian have scale factor of one.

Used for U.S. topo quads, 1:100,000 scale.  
Most popular worldwide.  
Not designed for areas that span more than a few zones.

**State Plane Coordinates (SPC):**

Not a projection. Coordinate system that divides 50 states of U.S., Puerto Rico and Virgin Islands into > 120 sections or zones.  
Projection is cylindrical or conic depending on shape of different states  
North-south states use Transverse Mercator.  
East-west states use Lambert Conformal Conic.  
Projections selected to minimize distortion over the state.  
Developed in 1930's by U.S. Coast and Geodetic Survey and adopted by U.S. state agencies for state level mapping.

**ArcGIS Exercise:**

**Defining a map projection.**

Frequently, shapefiles do not have their projection defined, and in order to take full advantage of the data and its information, you will want to define its projection in ArcCatalog. The shapefile, *moecosec.shp*, provides data on the ecological sections of Missouri. The data are available on-line from the Missouri Spatial Data Information Service web page (<http://msdis.missouri.edu/>) or in the j:\arcstuff\arcdata\gisclass\missouri folder. The projection information for these data are:

Projection	ALBERS		
Datum	NAD27		
Units	METERS	Spheroid	CLARKE1866
Parameters:			
1st standard parallel		29 30	0.000
2nd standard parallel		45 30	0.000
central meridian		-96 0	0.000
latitude of projection's origin		23 0	0.000
false easting (meters)			0.00000
false northing (meters)			0.00000

You can define a shapefile's coordinate system in several ways within ArcCatalog: (a) select one of the predefined coordinate systems, (b) import parameters used by another data source, or (c) define a new, custom coordinate system. You can modify the parameters afterwards as needed. The shapefile's coordinate system, once defined, is stored in a projection file (.prj) with the same name as the shapefile.

? Define the coordinate system for *moecosec.shp*.

**To define a coordinate system in ArcCatalog:**

1. Open ArcCatalog.

2. Highlight the data source that you want to define the coordinate system.
3. Select Properties from the File menu.
4. Click the Fields tab, and click the Shape column in the column list.
5. Click (...) next to Spatial Reference in the Field Properties box.

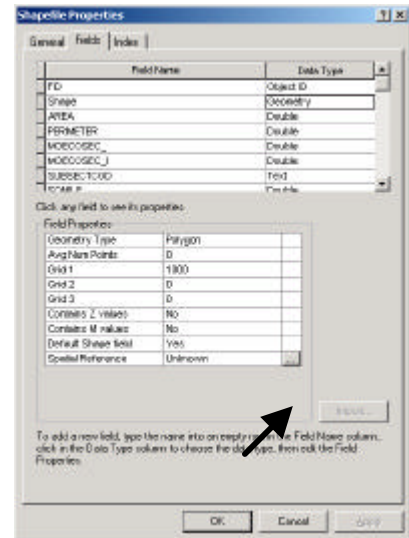
A new window, Spatial Reference Properties, pops open. Click *Select* to choose a predefined coordinate system, *Import* to choose a data source that has the same coordinate system as you want to define, or select *New* to define a new, custom coordinate system.



Click on Select to choose predefined system.

Navigate to “Projected Coordinate System”, and “Continental” folder.

Select “North America” folder, and *USA Contiguous Albers Equal Area Conic USGS.prj* as the projection file. Click Add.



Scroll through the Details of the coordinate system. How does it compare to the spatial information described above? If it does not completely match, then you can modify certain parameters. (The parameters are given in decimal degrees and thus match the spatial information provided above; e.g., 30 minutes equals 0.500 degrees.) You should notice that the Datum information does not match.

9. Select Modify to change the coordinate system’s Datum from NAD83 to NAD27. The Projected Coordinate System Properties window opens.
10. Click Modify next to Geographic Coordinate System. Select *D\_North\_American\_1927* as the new datum. Note that the spheroid is automatically updated to *Clarke\_1866*. Click OK to close the Projected Coordinate System Properties window.

If you have more shapefiles to define, you could save this projection file and use it again for other data sources. After checking that the shapefile is defined correctly, click OK and close all windows.

### Transforming a Map Projection.

ArcMap does “transformations on the fly”, which allows one to easily see two data sources that have different coordinate systems on the same map. These transformations do not change the original data source. To change the original data source, you would use ARC/INFO portion of ArcGIS.

You can also modify the coordinate system by changing the data frame properties. Again the original data source remains unchanged.

### To transform data on the fly:

- ? Start ArcMap and open a new document.
- ? Add *mostategeo*.

What is the coordinate system for this coverage of the state of Missouri?

- ? Insert a new data frame and add *moecosec.shp*.

What is the coordinate system for this data layer?

You can view the coordinate system in ArcMap by checking either the properties of the layer (use RMB and click in title, then select Properties, and Source), or check the properties of the data frame (right click data frame title, select Properties, and Coordinate System).

- ? Copy the *mostategeo* and paste in New Data Frame (i.e., with *moecosec.shp*).

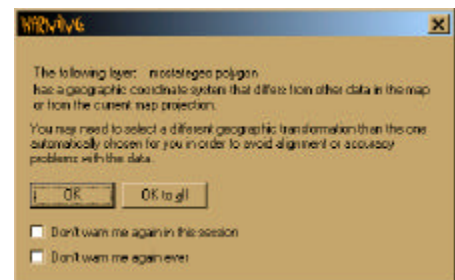
To copy a layer:

- a. Using RMB, click on title of layer and select ‘Copy’.
- b. Highlight the title of the data frame you want to paste the layer, using the RMB click on the title and select ‘Paste Layer’.

Can you see the polygon representing the state of Missouri? No. This is because the state is in a different coordinate system (Geographic, i.e., degrees-minutes-seconds, with Clarke 1866 ellipsoid).

- ? Remove the *mostategeo* layer from the New Data Frame.
- ? Add *mostategeo* layer using ‘Add Data’ button from the Standard Tool bar.

A Warning window pops open that warns you the data you are trying to add is in a different coordinate system. ArcGIS will automatically adjust the layer in order to match the two different coordinate systems and do a “transformation on the fly”. Click OK. You should now be able to see the Missouri state polygon with the Ecological Sections data layer even



though the two are in different coordinate systems.

**To transform a coordinate system in ArcMap:**

This transformation will not modify the original data source, but will change its appearance in the ArcMap document for display and analysis purposes.

1. Open Properties window for the Data Frame, and go to Coordinate System tab.
2. In the Select a coordinate system window, click on the Predefined folder.
3. Navigate to the desired coordinate system (e.g., Projected Coordinate System, Continental, North America, USA Contiguous Albers Equal Area).
4. Click OK. The warning window will re-appear. Click OK. Note how the appearance of the map has changed.
5. Reexamine the Data Frame Properties to see the adjusted changes to the coordinate system.

