Watershed Sciences 4930 & 6920
GEOGRAPHIC INFORMATION SYSTEMS

WEEK TWO - Lecture
PROJECTIONS

Joe Wheaton

Some of slides in this lecture adapted from content in Paul Bolstad’s ‘Fundamentals of GIS’

HOUSEKEEPING

- Lab?
- Other Questions, Comments, Concerns...
- Today: Start Projections...
- Thursday: Finish Projections & Learn about data types...

YOUR QUIZ FOR TODAY

- Good Maps & Bad Maps

READING FOR TODAY

- You Read Chapter Three of Bolstad: “Map Projections & Coordinate Systems” (pp. 69-122)
  - Skim 70-72 (History)
  - Read pp. 72-119 in detail

WHAT WE REALLY WANT OUT OF TODAY

- Make you not so dangerous when using coordinate systems
- Make sure you understand what you’re doing when...

IN LAB THIS WEEK...

1. Do I know the difference between a geographic and a projected coordinate system?
2. Do I know the difference between Cartesian, polar and cylindrical coordinate systems?
3. What is an assumed coordinate system?
4. When is it necessary to transform my data from one coordinate system to another?
5. What is the appropriate transformation method to use?
6. When I download data, how do I know what coordinate system it is in?
7. How do I know if my data are in the right place?
WHAT DO YOU NEED TO KNOW?

- What are the choices you have?
  - Select?
  - Import?
  - New?
  - Modify?

TODAY’S PLAN

I. Coordinate Systems
II. Geographic Coordinates (i.e. non-projected)
  I. Establishing coordinates accurately
  II. Datums
III. The Problem
  I. Geoids -> Ellipsoids -> Spheroids
  II. Geoid
IV. Map Projections & Projected Coordinate Systems
  I. The basics + most common CS in GIS
  II. State Plane Coordinate System
  III. Universal Transverse Mercator Coordinate System
V. Public Land Survey System
V. Others
V. Conversions between Coordinate Systems

PLACE DESCRIBED WITH COORDINATES

- A pair or triplet of numbers, that specify location with reference to some origin

2D VS. 3D CARTESIAN COORDINATES

(x, y) (x, y, z)

SPHERICAL COORDINATES

- Two angular measurements (i.e. lat/long) and a radius...

REPORTING ANGLES VS. BEARINGS

- An angle is just a measurement (e.g. 35°)
- A bearing is directional (e.g. N35°W versus S35°E)

Angles can be reported in decimal degrees (DD) or degrees-minutes-seconds (DMS)

DD from DMS:

\[ D = \text{DD} \times 3600 \]

\[ D = \text{DD} + \text{M}/60 + \text{S}/3600 \]

DD from DD:

\[ D = \text{DD} \times 3600 \]

\[ D = D + M/60 + S/3600 \]

\[ M = \text{integer of decimal part} \times 60 \]

\[ S = \text{2nd decimal} \times 60 \]

DMS from DD:

\[ D = \text{DD} \times 3600 \]

\[ D = \text{DD} + M/60 + S/3600 \]

\[ M = \text{integer of DD} \times 60 \]

\[ S = S + 0.5\times \text{DD} \]

\[ \text{DD} = 24 + 9\times 60 \]

\[ \text{DD} = 24 + 9\times 60 \]

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SPHERICAL VS. CARTESIAN

Umm, which are geographic?

SPHERICAL

LATITUDE & LONGITUDE

Longitude:
- defined by planes which pass through earth center and spin axis, which leave a great circle trace, called a meridian, on earth surface
- Prime (Greenwich) meridian is defined as 0° longitude and others are defined 180° east or west from there

Latitude:
- Equator is trace of plane oriented perpendicular to spin axis of earth. Defined as 0° latitude.
- Other lines of latitude defined by intersection of (double) cone whose apex is at earth center and has progressive apical angles of 0-90°.
- Longitude and latitude subdivided into either 60° and 60” or decimal degrees. 1° latitude = 111 km; 1° longitude = 111 km at equator but 0 km at poles.

LATITUDE

LONGITUDE

NOMENCLATURE

- Meridian: Converge at both poles and are evenly spaced along any parallel
- Parallels: Always parallel to each other
Are lines of Latitude great circles?

HOW DO WE GET LAT, LONG ON GROUND?

- Lots & Lots of Triangles
- Different groups using different survey methods in different regions....

AT EVERY TRIANGLE VERTICIE OR NODE

If we measure the initial baseline length $A$, and measure the angles $a$, $b$, and $c$, we are then able to calculate the lengths $B$ and $C$.

by the law of sines, $\frac{A}{\sin(a)} = \frac{B}{\sin(b)}$ and $\frac{C}{\sin(c)}

With the length $C$, known, angles $e$, $f$, and $g$ may then be measured. The law of sines may be used with the new known distance $C$ to calculate lengths $E$ and $F$.

Descriptive datum points may be established to extend the network using primarily angle measurements.

OKAY... BUT, WHAT DOES THAT GIVE US?

- I've got distances between points and angles...
- Are they plan form distances or slope distances?
- How do we turn those into something else?
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DATUM & VERTICAL COORDINATE SYSTEMS

- The datum is a curviplanar surface that wraps around the globe. It is mathematically defined to represent the “average” earth radius. A datum is needed to make the correct projection, and to establish the correct height or depth of a point.

SOME COMMON EXAMPLES

Datum
- Artificial Surface
  - Sphere (Approximate shape)
  - Oblate Ellipsoid (Truer shape)
  - Geoid (Approximate Sea Level)
North American Datum – A geoidal Coordinate System
  - NAD-27(?)
  - NAD-83(?)
  - 10’s of meters difference!
World Geodetic System (GPS)
  - WGS84(?) – A spheroidal coordinate system...

ALL THOSE DIFFERENT CHOICES MATTER

WHAT CHARACTERISTICS WOULD A PERFECT MAP HAVE?

- Distances could be measured accurately
- Directions could be measured accurately
- Areas could be measured accurately
- Shape would not be distorted
- Do we have such a map for earth?
WE DO! BUT, HOW DO WE MAKE IT FLAT?

Globe is only true preserver of: Distance, direction, area, shape and proximity.

THE PROJECTION DILEMMA

• The globe is a 3D surface
• A 2D Surface is a sheet, cylinder or cone

MAP PROJECTIONS

- Earth is a Geoid
  - Transformed mathematically (geodesy) to a simpler shape
- Simpler shape is a reference ellipsoid
  - Further transformed (mathematically) into an actual sphere or spheroid
- Called nominal, reference, or generating globe
  - Further transformed (mathematically) into a flat (plane) surface
  - This is where much of the distortion gets added to the map

MAP PROJECTIONS

From Dr. Krygier (OWU)

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GEOID

Earth’s gravity field... explains geoid shape

GEOID - EQUIPOTENTIAL SURFACE

Level Surfaces = Equipotential Surface
H (Orthometric Height) = Distance along Plumb line (P0 to P)
AN ELLIPSOID DOESN'T WORK GREAT EVERYWHERE

A geoid is the equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level.

ELLIPSOID

- The earth IS NOT a perfect sphere
- So we approximate it with an Ellipsoid
- Ellipsoid is a sphere that is slightly flattened at poles
- A.K.A. Spheroid

WHY SHOULD I CARE ABOUT THE EARTH'S SHAPE?

- Position depends on it!
- GIS is all about mapping positions
- In particular, elevations are adjusted relative to earth’s ‘shape’
- Shape modeled as an ellipsoid

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WHAT IS A PROJECTION?

Why would it be distorted?
• Squeeze or stretch?

CHOICE OF PROJECTION

Will Depend On:
• Extent of your Map
  - The whole globe?
  - Just a hemisphere
  - The poles?
  - A Continent
  - A State
  - A locality
• Location of your Map
  - High vs. Low latitudes?
  - Where longitudinally?

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THE PROJECTION DILEMA

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WHAT CHARACTERISTICS WOULD A PERFECT MAP HAVE?

• Distances could be measured accurately
• Directions could be measured accurately
  – By extension, proximity too
• Areas could be measured accurately
• Shape would not be distorted
Approximately Unprojected
Geographic Coordinates on a Plane

**Mercator Projection**
- Distances accurate?
- Directions accurate?
- Areas accurate?
- Shape not distorted?

**Transverse Mercator Projection**
- Distances accurate?
- Directions accurate?
- Areas accurate?
- Shape not distorted?

### CLASSES OF MAP PROJECTIONS

#### PLANAR PROJECTIONS
- Preserves Shape (true-shape) with meridians parallel.
- Preserves area
- But...

#### CYLINDRICAL PROJECTIONS
- Preserves Shape (true-shape) with meridians parallel.
- Does NOT preserve Area!
- Great circle routes are not the shortest!

#### CONIC PROJECTIONS
- Regular Conic Projection:
  - cone intersects earth at one latitude, called standard parallel

#### MERCATOR PROJECTION
- Vertical cylinder touches globe at equator.
- Projection from earth center outward to cylinder.
- Distorts higher latitudes but keeps directions true throughout map.
- Good for worldwide navigation.
TRANSVERSE MERCATOR
• Horizontal cylinder touches globe
• Projection from earth center outward
• Accurate areas within 15° of intersecting meridian, accurate directions
• Used in many USGS maps

CHOICE OF PROJECTION
Will Depend On:
• Extent of your Map
  - The whole globe?
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STATE PLANE SYSTEMS
• Used 3 conformal projections to minimize distortion to one part in 10,000:
  - Lambert conformal conic
  - Transverse Mercator Projection
  - Oblique Mercator Projection (for Alaska)
• Differs from UTM in origin:
  • Easting origin always arbitrary number of feet west of the western boundary of the zone
  • The northing origin not at the equator as in UTM, instead placed arbitrary number of feet south of the state border

Lambert Conformal Conic
• Cone-ellipsoid intersection
• Standard parallels
• Map from “developed” cone

Cones and ellipsoids
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TRANSVERSE MERCATOR

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UTM KEY: ADJECTIVE IS TRANSVERSE

• The UTM projection is designed to cover the world, excluding the Arctic and Antarctic regions. To keep scale distortions within acceptable limits, 60 narrow, longitudinal zones of six degrees longitude in width are defined and numbered from 1 to 60.
• We are in UTM grid zone 12 N which covers the area 103° - 114° W (zone number 3), and 0° - 8° N (letter N of the latitudinal belt).

UNIVERSAL TRANSVERS MERCATOR (UTM)

• Horizontal cylinder whose diameter is less than earth’s diameter
• Intersects twice so that ring is formed. Ring is 6° wide at equator
• Projection from earth center outward
• Used in many USGS and British Ordnance Survey maps
• Minimal distortion and accurate directions ring
UNITS: Meters

UTM ZONES

• Horizontal cylinder whose diameter is less than earth’s diameter
• Intersects twice so that ring is formed. Ring is 6° wide at equator
• Projection from earth center outward
• Used in many USGS and British Ordnance Survey maps
• Minimal distortion and accurate directions ring
UNITS: Meters
**UTM … EACH ZONE HAS ITS OWN CM**

- Each zone has its own central meridian.
- CM always has Easting value always 500,000 m; to avoid negative coordinates
- For positions north of the equator, the equator is given a Northing value of 0 m.
- For positions south of the equator, the equator is given a (false) Northing value of 10,000,000 m.

**UNIVERSAL TRANSVERSE MERCATOR ZONES**

- A “zone” is created by the UTM projection (above).
- Each zone is 6° wide (longitude) and 8° high (latitude), except near the poles. (Refer to handout).
- There are 60 different zones wrapped around the equator, each created by reorienting the UTM cylinder.
- These zones are labeled from 1 to 60, starting at 180° longitude and proceeding eastward. There are 20 zones north to south excluding the polar regions.
- These are labeled from C (near south pole) to X (near north pole) (excluding I and O for some reason!).
- The polar regions are labeled A, B, and Y, Z. So, any UTM zone can be identified by its number and letter combination: Pocatello is in zone 12T.

**UTM – LOCATION WITHIN ZONE**

To locate within a zone, the distance in meters is measured from a reference point.
- The central meridian of the zone is arbitrarily labeled 500,000 m easting, while the equator is labeled 0 m northing.
- Any point in the zone is measured according to its distance, in meters, from where the central meridian intersects the equator.
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FEDERAL LAND SURVEY - TRS or PLSS

- Initiated in the late 1700s. All but the original 13 states, and a few states derived from them, are covered by this system. Other exceptions occur in the SW United States, where land surveys may be based upon Spanish land grants, and in areas of rugged terrain that were never surveyed.
- State determines a principal meridian (longitude) and a base line (latitude). A grid is created by survey additional lines that are parallel to the principal meridian and base line and are 6 miles apart.
- NOT TRULY A COORDINATE SYSTEM!

FEDERAL LAND SURVEY – TRS or PLSS

- Townships are the north-south 6-mile by 6-mile squares of land and ranges and the east-west 6-mile by 6-mile squares of land.
- The township and ranges are divided into 36 1-mile by 1-mile sections. The sections are numbered from 1-36 beginning in the northeast corner of the township or range.
- Sections are then divided into quarters which can become increasingly quartered and are labeled by direction (NW, NE, SW, SE).

STATE PLANE SYSTEM

- So where are we?

ODDITIES...

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QUIZ 2 DUE BY THURSDAY (ON Canvas)
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**WHAT WE REALLY WANTED OUT OF TODAY**

- Make you not so dangerous when using coordinate systems
- Make sure you understand what you’re doing when...

**WHAT DO YOU NEED TO KNOW?**

- What are the choices you have?
  - Select?
  - Import?
  - New?
  - Modify?

Geographic or Projected? Huh?
A GOOD WAY TO APPRECIATE DIFFERENCES & TRANSFORMATIONS

- Start ArcMap
- Load Bing Imagery Basemap
- Change the Coordinate System of the Data Frame

IN LAB THIS WEEK...

1. Do I know the difference between a geographic and a projected coordinate system?
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3. What is an assumed coordinate system?
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LAB 2 – COORDINATE DATA, PROJECTIONS & TRANSFORMATIONS

Raw TS Data:
Local, Assumed, Cartesian Coordinate System

Transformed TS Data:
Projected in UTM Zone 12N, real world coordinate system

READING FOR THURSDAY
WATS 4931/ 6921 PROJECTS

• Can you stay for an extra 15 minutes?
• Discuss project proposals (Due Feb 1st)