Coordinate System

- A system that represents points in 2- and 3-dimensional space
- Needed to measure distance and area on a map
- Rectangular grid systems were used as early as 270 AD
- Can be divided into global and local systems
Local vs Global systems

- Global coordinate system: Can display the entire world, but may introduce significant error for particular locations.

- Local coordinate system: A coordinate system that works well for a particular part of the world, but not for large areas.
Two types of coordinate systems

1). Geographic Coordinate Systems
   Location on a sphere

2). Projected Coordinate Systems
   Cartesian (two-dimensional) location
Geographic coordinate system

- A global system
  - The Prime Meridian and Equator are the reference planes
  - Latitude: North and South
  - Longitude: East and West

- Measured in degrees
  - Degrees, minutes, seconds: 42° 30' 37" N
  - Decimal degrees: 42.51027778° N
  - Distance between degrees latitude is ~110 km
  - Longitude is more variable
    - 111 km at equator
    - 19 km at 80° N
    - 0 at the North Pole
Geographic Coordinate System in 2d
Two Main Complicating Factors

1. Mapping the surface of a sphere to a flat surface

2. The impacts of local variation
Distortion when shown in two dimensions

Impossible to maintain both scale and shape

Must choose best method for area and size of map

Tissot's Indicatrix
Conformal

Equivalent
Projections

- The earth is “projected” from an imaginary light source in its center onto a surface, typically a cylinder, cone or plane.
Cylindrical Projections

- The Mercator projection is the best-known cylindrical projection.
Mercator Cylindrical Projection
Conic Projections

- Like wrapping a cone of paper around the Earth
  - Line of latitude look like arcs of a circle
  - Lines of longitude are straight lines radiating from the pole
Conformal Conic Projection of Europe
Equal Area Conic Projection of Europe
Equidistant Conic Projection of Europe
Planar projections

• A flat plane
  – Good for a small area
Planar Projection of the South Pole
Planar Projection of the North Pole
Universal Transverse Mercator

- A type of cylindrical projection
- Standard international coordinate system
- More accurately, a series of coordinate systems
  - 60 different zones
  - Each is 6° wide
- Units are meters north or south of the equator and east the western edge of the zone.
Zones are each six degrees of longitude, numbered as shown at the top, from W to E
Transverse Cylindrical Projection for Zone 16 North
UTM Zones in the Central US
Angular and distance measurements

In a Geographic Coordinate System distances are in degrees. Longitudinal degrees vary with latitude.

An unprojected raster is distorted because the resolution is not square. Any calculations of area are inaccurate.
Two Main Factors

1). Mapping the surface of a sphere to a flat surface

2). The impacts of local variation
The earth is not a perfect sphere.

An ellipse is a better, but not perfect measure.

Geoide: The actual geometric surface of the earth (exaggerated).
Definitions: Ellipsoid

• The Earth is not a perfect sphere
  – Bulged at the equator and flattened at the poles
• Flattening is about 21.5 km difference between polar radius and equatorial radius
• A model necessary for accurate range and bearing calculation over long distances
• Best models represent shape of the earth over a smoothed surface to within 100 meters
Definition: Datum

- A mathematical model that describes the shape of the ellipsoid
  - A reference surface for the earth
  - Defines the size and shape of the earth and the origin and orientation of the coordinate system used
  - Different datums for different areas based on different measurements
  - Datums are the basis for coordinate systems
  - Assigning the wrong datum to a coordinate system may result in errors of hundreds of meters
<table>
<thead>
<tr>
<th>Datum</th>
<th>Spheroid</th>
<th>Region of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAD 27</td>
<td>Clark 1866</td>
<td>Canada, US, Atlantic/Pacific Islands, Central America</td>
</tr>
<tr>
<td>NAD 83</td>
<td>GRS 1980</td>
<td>Canada, US, Central America</td>
</tr>
<tr>
<td>WGS 84</td>
<td>WGS 84</td>
<td>Worldwide</td>
</tr>
</tbody>
</table>
Projections and Datums

- Projections and datums are linked
- The datum forms the reference for the projection,
  - Maps in the same projection but different datums will not overlay correctly
  - Maps using the same datum but different projections will not overlay correctly
Georeferencing Maps and Images
Georeferencing / Rectification

• Making an image fit the world
• Changes the geometry of the image
  – Causes of distortion:
    • The angle that the image was taken from
    • The curvature of the earth.
    • The curvature of the lens
    • The rotation of the earth while imagery is being taken.
Registration vs. Georeferencing

• **Registration**: assigning coordinates to pixels; assumes image is already projected

• **Georeferencing**: altering image geometry to conform to a map projection (also called warping)
Ground Control Points

- Physical features with known locations
- These are the points used to georeference an image
- Can be determined
  - Using GPS
  - Finding coordinates for features on a paper map
  - Finding the location on another layer
Georeferencing

- Using Ground Control Points (GCP) to tell the software what area of the selected coordinate system the image represents.
Transformation Methods

• Polynomial transformations create a mathematical relationship between the image and the coordinate system
• Different methods overcome different distortions in the original image
• The Affine (first order polynomial) is the most common
Polynomial transformations

First Order Transformation (Affine)

\[ x_r = (25) + (-8)x_i \]

original image  change of scale in X  change of scale in Y

change of skew in X  change of skew in Y  rotation
Polynomial transformations

Higher order transformations

2\textsuperscript{nd} Order Transformation

3\textsuperscript{rd} Order Transformation
Polynomial transformations

Higher order transformations

original image

some possible results
Error in Polynomial Equations

- Error is measured as the deviation of GCPs from the curve generated.
- ArcGIS uses Root Mean Squares (rms) to evaluate the error in GCP.