Map Projections (Part I)

- One of the most important aspects of mapping is the map projection
- A map projection is any method of representing the surface of a sphere or other shape on a flat surface
- The 3-D earth is transformed to a 2-D flat surface by use of a geometric form, such as a:
  - Plane
  - Cylinder
  - Cone
- It can also be derived mathematically
- There are nearly an infinite number of possible map projections that can be produced, but they generally fall into one of four projection families:
  - Azimuthal (planar)
  - Cylindrical
  - Conic
  - Mathematical
- Each family has its own characteristic grid and potential applications
The Map Projection Process

- The production of a map is a process of representing the earth as a reduced model of reality
- Map projection is the transformation of the spheroid or elliptical surface to a plane surface
- In most GIS and mapping software the cartographer simply selects the map projection that best suits the needs of the mapping project
- Technically, however, there is a three step process that occurs
  - **Step 1:** a spheroid or ellipsoid model is selected that best fits the geoid
  - **Step 2:** transformation of earth coordinates to plane coordinates
  - **Step 3:** Reduction in scale from earth size
- The last two steps are done mathematically by the GIS or mapping software
- When map projections were done manually, cartographers sometimes reduced the scale of the ellipsoid or spheroid model to a reference globe from which the projection was generated.
Developable Surfaces

- The process of transforming and transferring the graticule and its features from a 3-D object on to a 2-D flat surface is the essence of map projection.
- The earth, nor any of its 3-D representations (such as the geoid, ellipsoid, sphere or globe) are developable surfaces.
- It is impossible to take a sphere and make it flat without distortion of some kind.
- Three geometric forms that have developable surfaces are:
  - The plane
  - The cylinder
  - The cone

- Slide #2: Show figure 3.1, Dent

- Some projections are mathematically derived graticules.
• There are four families of map projections based on the developable surfaces and mathematics:
  o Azimuthal (planar)
  o Cylindrical
  o Conic
  o Mathematical
• Each family has many individually named projections, where the name often contains one of more of the following:
  o The name of the geometric figure
  o Some of the projection’s properties
  o The name of the individual identified as the originator of the projection
• Each geometric surface is placed in contact with the sphere:
  o Placed to a point with the plane
  o Placed to a line of contact with the cylinder and cone
• Think of a light bulb shining through the globe’s surface, projecting the graticule and other features onto the developable surface
• All three are developable surfaces but all create distortion of some kind
• The geometric surfaces’ contact with a point or line is called tangency, or the **tangent case**.

• **Slide #3: Show Figure 3.2, Developable projection surfaces, secant case**

• In the **secant case**, each of the surfaces is placed at a line (with the plane) or two lines (with the cylinder and cone) on intersection

• In the secant case, part of the geometric surface intersects and actually goes into the reference globe
Projection Parameters

- Points and lines of tangency or intersection are called **standard points** and **lines**
- If a standard line is also a parallel of latitude then the line is called a **standard parallel**
- If the standard line falls along a meridian of longitude then it is called a **standard meridian**
- **Standard points, lines, parallels** and **meridians** are one of the most important map projection parameters because those corresponding places on the map will have no scale distortion
- That is, the scale of the map along these lines will have the same scale as the reference globe
- The farther away from the standard point or line(s), the greater the distortion (or deformation) that occurs
- **In Slide #4: Figure 3.1**, the **plane** has the least distortion at the North Pole (its standard point)
- The **cylinder** has the least distortion at the equator (its standard parallel)
- The **cone** has the least distortion at 30° N
• The **secant case** helps minimize distortion over a larger area by providing additional control.

• **Slide #5: See Figure 3.4, the secant surface**

• The amount of scale distortion varies with the distance from the standard lines.

• In this example, those lines are standard parallels.

• The positioning of the plane, cylinder and cone shown in **Figures 3.1 and 3.2** are common positions, and are sometimes called their “**normal**” **projection aspect**

• The **projection aspect** is the position of the projected graticule relative to the ordinary position of the geographic grid on the earth.

• This can be visualized as the position of the developable geometric surface to the reference globe.
• In Figures 3.1 and 3.2, the axis of the cylinder and cone run through the North and South Poles and the plane is parallel to the equator
• The normal aspect is the position that produces the simplest graticule
• It is quite common to have other placement positions

• Two other important projection parameters that indicate the projection aspect are the:
  o Central meridian - the meridian that defines the center of the projection
  o Latitude of origin – latitude of the projection’s origin, such as the equator
• Most GIS or mapping software, in addition to the selection of a map projection, allow for these parameters to be adjusted as necessary
Projection Families

Azimuthal Family

- In the **azimuthal** or **planar family**, the spherical grid is projected onto a plane
- The plane can be **tangential** to the sphere at a standard point (**tangent or simple case**)
- Or it can pass through the sphere, making it intersect along its standard line, which is actually a small circle
- Patterns of deformation begin to emerge for the azimuthal class

- Slide #6: See Figure 3.4a

- Deformation increases with distance from either the standard point (tangent case) or the standard line (secant case)
- As with all projection families, scale distortion, and hence deformation, is nonexistent at standard points or lines
• In the example shown in Figure 3.4a, the deformation increases outward in a series of concentric bands
• In the secant case, there is also some distortion that occurs toward the center

• **Slide #7: Show Figure 3.5, Common Projection Aspects For Azimuthal Mapping**

• The plane may be tangent at any point on the spherical grid, depending on the projection aspect
• **Polar aspect** is tangency at the pole
• **Oblique aspect** is tangency at mid-latitude
• **Equatorial aspect** is tangent at the equator
• **Normal aspect** for this family is the polar position when the plane is tangent at one of the poles, since it produces the simplest graticule
• In this case, the meridians are straight lines intersecting the pole and parallels are concentric rings having the pole as their centers
• See Figure 3.4a
• Directions to any point from the point of tangency (pole) are held true
• All lines drawn to the center are great circles

• Normally only one hemisphere is shown at a time
• Azimuthal projections became popular during WWII when there was considerable circumpolar air navigation

Light Source Variations

• Hypothetical light sources can be from positions other the center of the globe
• Adjustments in light sources are most common in azimuthal projections
• Slide #8: See Figure 3.6, Source of Illumination Variations of Azimuthal Mapping
• Changes in the position of the light source result in different graticule and deformation patterns
• **Gnomonic projection** – light is emanating from the center of the globe
• **Stereographic projection** – light source is opposite the point of tangency
• **Orthographic projection** – light source is at theoretical infinity

**Cylindrical Family**

• Cylindrical or rectangular projections are common forms
• They are sometimes seen in atlases and other maps portraying the whole world
• They are developed (graphically or mathematically) by wrapping a flat plane or sheet into a cylinder and making it tangent along a line or intersecting two lines (secant case) on the sphere
• Points on the spherical grid can be transferred to this cylinder which is then “unrolled” into a flat map
• The result is a rectangle-shaped map with parallels and meridians that intersect at 90° angles
• Slide #9: See Figure 3.4b

• The normal aspect for these projections is the equatorial aspect

• See Figure 3.1b

• In the tangent case, the equator is the standard parallel

• This standard parallel is a great circle

• In the secant case, the two standard parallels (small circles) will be located north and south of the equator

• Slide #10: See figure 3.2b

• The areas of least distortion are bands parallel to the standard parallel(s) with increasing exaggeration towards the outer edges of the map plane

• Slide #11: See Figure 3.4b
• Note that in this aspect, the scale preservation is in the east-west direction

• Other common aspects of this projection are:
  o Transverse (polar) case
  o Oblique case

• Slide #12: See Figure 3.7, Common Alternative Projection Aspects for Cylindrical Mapping

• Transverse means that the axis of the cylinder is turned parallel to the equator
• In the Transverse tangent case, the standard parallel has now become the standard meridian (see Figure 3.7a)
• It is preserving the least scale deformation in the north-south direction
• In the secant case of the transverse cylindrical, the small circles produce two standard lines (see Figure 3.7a bottom)
• This aspect is popular for areas with elongated north-south directions

• In the **cylindrical oblique aspect**, the cylinder is placed in any other position on the globe
• It is often placed in such a way that the standard line(s) (a great circle in the tangent case and two small circles in the secant case) are at or near the area that is to be mapped
• Remember that scale distortion increases as you move away from any standard lines
• Political entities that are elongated in a manner other than in a north-south direction, such as **Japan**, which has a **southwest-northeast** alignment, can be successfully mapped
Conic Family

- **Conic projections** are constructed by transferring the graticule from the generating globe to a cone enveloped around the sphere
- The cone is then unrolled into a flat plane

- **Slide #13: See Figure 3.1c**

- The axis of the cone coincides with the axis of the sphere
- This yields either straight or curved meridians that converge on the poles
- Parallels are arcs of circles

- **Slide #14: See Figure 3.4c**
• With few exceptions, most conic projections are presented in their normal aspect

• In the conic projection, tangent case, sometimes called the simple cone projection, the cone is tangent along a chosen parallel, along which there is no distortion

• Slide #15: See Figure 3.1c

• In the secant case, the cone intersects the globe along two parallels

• Slide #16: See Figure 3.2c

• This reduces distortion
The pattern of deformation includes concentric bands parallel to the standard parallels of the projection.

Slide #17: See Figure 3.4c

Conic projections, secant aspect tend to compress scale in areas between the standard lines and to exaggerate scale elsewhere.

Conic projections are best for mapping earth areas having greater east-west extent than north-south.
Map Projection Properties

- In the transformation process from 3-D surface to a plane, some distortion occurs that cannot be completely eliminated.
- **All maps contain errors because of the transformation process**.
- It is impossible to render the spherical surface of the reference globe as a flat map without distortion error caused by:
  - Tearing
  - Shearing
  - Compression

- Slide #18: See Figure 3.9

- The designer’s task is to select the most appropriate projection so that there is a measure of control over the unwanted error.
- These distortions and their consequences for the appearance of the map vary with scale.
- One can think of the globe as being made up of very small quadrilaterals.
• If each quadrilateral was extremely small, it would not differ significantly from a plane surface
• For mapping small earth areas (large-scale mapping), distortion is not a major design problem
• As the mapped area increases to sub-continental or continental proportions, distortion becomes increasingly significant
• In designing maps to portray the whole earth, distortions reach their maximum
• At such scales, cartographers must contend with alterations of projection properties:
  o Area
  o Shape
  o Distance
  o Direction
• No projection of the globe’s graticule can maintain all of these properties simultaneously
• Only on a globe are all four properties maintained
Equal Area Mapping

- Map projections on which area relationships of all parts of the globe are maintained are called **equal area** (or **equivalent**) map projections
- The intersection of meridians and parallels are not at right angles
- Areas of similarly bounded quadrilaterals maintain correct area properties
- Linear or distance distortion often occurs
- On equal area projections, therefore, shape is often quite skewed
- Equivalent projections are very important for general quantitative thematic map work
- Particularly at a global scale
- It is usually desirable to retain area properties, particularly when enumeration units are compared or if area is part of the data being mapped
- Population density, that is, *persons per square mile*, is a prime example
Conformal Mapping

- **Conformal** (or orthomorphic) mapping of the sphere means that angles are preserved around shapes
- Shapes of small areas are preserved
- The quality of **conformality** is applies to small areas
- On conformal projections, meridians intersect parallels at right angles
- Scale is the same in all directions around a point
- Scale may change from point to point, however
- Shapes over large areas will not remain true
- Shapes for small areas are maintained
- Shapes of larger regions, such as continents, may be severely distorted
- Areas are also distorted significantly at smaller scales

- The shaped quality of mapped area is an elusive element
- If we view a continent on a globe so that our eyes are perpendicular to the globe at the point near the center of the continent, we see a shape of that continent
• However, the shape of the continent is distorted because the globe’s surface is falling away from the center point of our vision
• We can view but one point orthographically at a time (view the point at 90° from the tangent)
• If we select another point, our view changes and so does our perception of the continent’s shape
• It becomes difficult to compare the shapes we see on a map to those of the globe.

• For large-scale mapping of small earth surfaces, distortion is not significant
• The choice between an equivalent or a conformal projection becomes somewhat moot, distortion with either projection is minimal in this application
• At smaller scales, the selection of the projection is more critical in the design process
• Even at these scales it is seldom necessary to specify a conformal projection, except in rare circumstances:
  o Mapping phenomena with circular radial patterns may warrant such a choice, for example:
    o Radio broadcast areas
    o Seismic wave patterns
    o Average wind directions

• Most cartographers consider equivalence and conformality the two most important property considerations
• Note that it is impossible for one projection to maintain both equivalency and conformality properties
• Sometimes these properties are referred to as the major properties

• Slide #19: See Figure 3.10a and 3.10b
• a and b illustrate the contrast between conformality and equivalence
• the Mercator Projection (3.10a) is the conformal map and distorts area, especially at higher latitudes
• the distortion is minimal near its standard parallel at the equator but increases greatly towards the poles
• the Hammer Projection (3.10b) is an equal area projection
• the areas are equivalent, but not conformal
• notice the shape distortion around its margin

Equidistance Mapping

• refers to preservation of great circle distances
• there are certain limitations:
  o distance can be held true from one to all other points
  o distance can be held true from a few points to others, but not all points to all others
  o the distance property is never global
  o scale will be uniform along the lines whose distances are true
• these are called **equidistant projections**
• sometimes used in general purpose maps in atlases because such projections are neither conformal nor equal area and often have less distorted-appearing landmasses

**Azimuthal Mapping (direction)**

• on **azimuthal projections**, true directions are shown from one central point to all other points
• directions or azimuths from the central point to other points are accurate, whereas from other non-central points they are not
• **azimuthality** (*maintaining direction*) is not an exclusive projection quality
• it can occur with:
  o **equivalency**
  o **conformality**
  o **equidistance**
Slide #20: Table 3.1 illustrates projection properties that can be combined

Minimum Error Projections

- Some cartographers have stressed the idea that minimum error projections (also called compromise projections) are best suited for general geographic cartography.
- These projections are essentially hybrids that attempt to control or minimize all four:
  - Area
  - Shape
  - Distance
  - Direction
- Map projections properties in varying degrees.
- Often this is done to try to produce a better and more realistic depiction of the globe or parts of it.

Slide #23: see Figure 3.10c Robinson Projection
• the Robinson projection holds no property true
• when compared with the conformal and equal area (major property) figures, it is easy to see why some designers advocate for projections such as these
• for a decade the Robinson projection was the official map projection used by the National Geographic Society for their world maps

Determining Deformation and its Distribution Over the Projection

• two chief methods are available for determining projection distortion and its distribution over a map
• one is to show a geometrical figure (square, triangle or circle) or familiar object (such as a person’s head) and plot it at several locations on the projection graticule

• Slide #24: Shape Distortion on an Equal Area Projection
• distortion on the projection is readily apparent
• this method is very effective and sufficient for most general cartographic analyses
• its weakness is the lack of a general quantitative index of distortion

• Another method is mathematically derived called Tissot’s indicatrix.

Choosing Map Projections

Slide #25/26: Essential Questions

• Projection properties:
  o are the properties of a particular projection suited to the design problem at hand?
  o Are the following needed:
    ▪ Equivalency
    ▪ Conformality
    ▪ Equidistance
    ▪ Azimuthality
• **Deformational patterns:**
  o are the deformational aspects of the projection acceptable for the mapped area?
  o Is linear scale and its variation over the projection within the limits specified in the design goals?
  o Do the characteristics of the linear scale over the projection benefit the *shape* of the mapped area?

• **Projection center:**
  o can the projection be centered easily for the design problem?
  o Can the software accommodate experimentation with the re-centering of the projection, such as an adjustment of the projection’s central meridian?

• **Software support:**
  o is the particular projection supported in your software?
Part of an existing map series or online digital map collection:
  o Does the map belong to a series that already has a projection?
  o Do you want to continue to match that projection?

Slide #27: World Projections

- Many different world projections can be selected for mapping
- The selections can be both debatable and subjective at times
- In some cases the selection can be controversial

Mathematical, Equivalent Projections

- The property of equivalency (equal area) is often the overriding concern in thematic mapping (as opposed to navigation mapping).
The following two, mathematically derived, cylindrical equal area projections are good choices when depicting the entire world on one map:

**Slide #28: Mollweide Projection**

- See Figure 3.8

- Named after Carl B. Mollweide who developed it in 1805
- Slide #29: Has standard parallels (line of tangency or intersection) at 40° 44’ N and S
- The central meridian is half the length of the equator and drawn perpendicular to it
- Parallels are straight lines drawn parallel to the equator but are not drawn with lengths true to scale, except for the standard parallels
- The elliptical shape of the projection gives it a kind of global feel
- Some designers find this pleasing as long as one can accept the distortion along the peripheries
Slide #30: Hammer Projection

- Very similar to the Mollweide projection
- Developed in Germany in 1893
- Sometimes called the **Hammer-Aitoff** projection
- The principal difference between this projection and the Mollweide is the **Hammer has curved parallels**

**Slide #31: See Hammer Projection**

- This curvature results in **less oblique** intersections *(acute angles closer to 90° compared to the Mollweide)* of meridians and parallel at the extremities
- This reduces shape distortion at the extremities

- The **Hammer projection** is also quite acceptable for mapping world distributions
- A comparison with the Mollweide projection shows little difference
Because the parallels are curved, east-west exaggeration at the poles is less on the Hammer than on the Mollweide.
This is most notable when comparing the Antarctic land mass.
Africa is less stretched along the north-south axis on the Hammer.
Overall the Hammer and Mollweide are very similar in appearance and attributes.

**Slide #32: Interrupted Projections**

- One solution to minimize distortion is to make an interrupted projection of the world.
- Many world projections can be turned into an interrupted projection.
- The most well known of the interrupted projections is the Goode’s Homolosine projection.

**Slide #33: See Figure 3.14**
• This is a pseudo-cylindrical (mathematical rather than light-source projected) projection created by J. Paul Goode
• Goode took portions of the Mollweide and Sinusoidal projections and combined them in a manner that created six distinct lobes
• Each lobe has its own central meridian (meridian that defines the center of the projection) and the distortion that would occur in a continuous projection now is directed over water bodies
• There are also versions that keep water bodies intact and pull apart the land areas
• Shape is not as distorted as some of the equal area projections
• The downside to Goode’s and other interrupted projections like this is:
  o As with the Sinusoidal projection, the shape can be distracting
  o The projection requires the map reader to understand the gaps along a line of latitude do not exist
If the thematic phenomena to be mapped are spatially continuous, such as climatic data, then the projection is wrong for the thematic map type.

**Slide #34: Minimum Error Projections**

- A number of cartographers strongly believe that minimum error or compromise projections (projections that do not retain any specific property but try to minimize the worst distortions) are the best way to go.

- **Slide #35: See Robinson projection**

- The **Robinson projection** and Winkel Tripel projections are considered quite acceptable for world thematic mapping.

- The **Robinson projection** was developed by Arthur Robinson for Rand McNally’s world maps in 1961.
• It is more famous, however, as being adopted in 1988 by the National Geographic Society for use as a world projection
• It was replaced in 1998 by another minimum error projection, the Winkel Tripel projection

• **Slide #36**: The Winkel Tripel projection was developed in 1921 by Oswald Winkel

• **Slide #37**: See Winkel Tripel projection

• It has slightly less compression in the polar regions than the Robinson projection
• *Physicists Goldberg and Gott have shown quantitatively that the Winkel Tripel projection may be the best (lowest distortion) compromise projection yet*
Slide #38: Cylindrical Projections

- Used for thematic mapping but not a good choice
- Most famous cylindrical projection is the **Mercator projection**
- Developed by Gerardus Mercator in 1569
- It was developed for navigational use
- All lines of constant compass bearings, called **loxodromes** or **rhumb lines**) are shown as straight lines
- Navigators could therefore follow a compass heading using these maps
- Over time the map became popularized as a general reference map of the world
- The problem with this use is that landmass areas such as Greenland and Russia are extremely distorted at the higher latitudes
- The popularity of the Mercator projection did not wane until the latter half of the 20th century
- Major controversy over its use occurred
Gall-Peters Cylindrical Projection

- Special mention of this projection because of the controversy surrounding it
- Published in 1972 by Arno Peters of Germany as a new map projection
- In fact, the projection had been devised in the mid-1880s by Gall

- **Slide #39:** See Figure 3.16

- **Slide #40:** The purpose behind the invention was to counter the Mercator projection’s areal exaggeration of the high latitudes and its pervasive use as a general purpose map
- Peters believed the Mercator projection accentuated the European dominance over the Third World because the projection’s high latitude exaggeration visually minimizes countries located in the tropics
- The Gall-Peters projection emphasizes many portions of the tropics dominated by less developed countries
• **Slide #41**: Because of the prevalence of the Mercator projection, Peters stressed that his projection be used exclusively

• He also claimed that his projection portrays distances accurately, which is false

• Proponents of the projection argue that the realigning of the perceived areas and shapes shakes up our preconceived notions of Third World areas

• Others argue that the shape distortion is too great to be of much utility (especially with other available mapping options)

• The Gall-Peters projection especially distorts shape in the very undeveloped areas that Peters is trying to portray more fairly

• The real objection to Peters, however, is with the misconceptions he renders about the projection (the claim that Peters is the only projection that should be used, and that all distances on the projection can be measured correctly)

• **Slide #42**: Nonetheless, the Gall-Peters projection has been adopted by:
One good thing has come from the controversy, namely, that the inadequacies of using the Mercator projection for world thematic mapping have finally been noted to the general population.

**Slide #43: American Cartographic Association Ban of Rectangular Maps**

http://geography.about.com/library/weekly/aa030201b.htm
Slide #44: Projections for Mapping Continents

Lambert Azimuthal (planar) Equal Area Projection

- Slide #45: See Figure 3.17

- Is a versatile projection
- In its equatorial aspect, this may be one of the best choices for mapping a hemisphere and certainly a continent
- The standard point (point of tangency) can be placed anywhere
- Most GIS software support oblique positioning for this projection
- Since the distortion is radial outward from the center of the projection, it is critical that the latitude and longitude of the standard point be placed at the center of the continent or other area of interest
Slide #46: Bonne Projection

- Named after Rigobert Bonne (1727-1795)
- It’s an equal area conical projection, with a central meridian and the cone assumes tangent to a standard parallel

Slide #47: See Figure 3.18

- All parallels are concentric circles, with the center of the standard parallel at the apex of the cone
- Scale is true at the central meridian and also for each parallel
- Map designers select the Bonne projection for a variety of continental mapping cases

Slide #48: It is commonly used to map:
  - Asia
  - North America
  - South America
  - Australia and other large areas
• although **equivalency** (*equal area*) is maintained throughout, shape distortion is particularly evident at the northeast and northwest corners

• because of this, the Bonne projection is really best suited for mapping compact regions lying on only one side of the equator

• **Slide #49:** because shape is best along the central meridian, the distortion becoming objectionable at greater distances from it, the selection of the central meridian relative to the important mapped area (and zooming to that area) is critical

• **Slide #50:** some projections that are suitable for world maps are sometimes not the best for mapping continental areas

• others, such as the:
  o **Sinusoidal**
  o **Mollweide**
  o **Goode’s Homolosine**
  o **Compromise projections**
Can be used effectively for a continent such as Africa or South America, as long as the central meridian is adjusted properly.

**Slide #51: Mapping Multiple Size Countries at Mid-Latitudes**

- Mapping larger countries at mid-latitudes can be handled in a variety of ways.
- The *Lambert Azimuthal (planar) Equal Area* or the *Albers Equal Area Conic projection* may be used.
- If **conformality** (*angles are preserved around points and shapes of small areas are preserved*) is desired, the *Lambert Conformal Conic projection* can be used.
- In general, a **conic projection** is usually adequate for mapping large countries or political units that have an east-west extent.
• Slide #52: While the Mercator projection is not recommended for world thematic mapping, the Transverse Mercator projection is often used for countries and other political entities that have a pronounced north-south orientation.

• Slide #53: The cylinder is rotated so that the standard parallel becomes a standard meridian, meaning there is no scale distortion in the north-south direction at the standard meridian.

• If the secant is employed case is employed, then two standard lines (small circles) straddle the projection’s central meridian, increasing the amount of relatively low distortion areas.

• The Transverse Mercator projection would be an appropriate choice for mapping a country such as Chile.

• Slide #54: It is important to note that as mapped areas become smaller in extent, the selection of the projection becomes less critical, potential scale errors begin to drop off considerably.
Projected Coordinate Systems

- **Slide #55:** All projections involve coordinate systems such as latitude and longitude
- Another option for mapping is to use a related but yet distinct concept of the projected coordinate system
- Combines the projection process with the parameters of a particular grid
- There are a number of national, state and county level projected coordinate systems

**Slide #56: State Plane Coordinate (SPC) System**

- Was originally developed in the early 1930s
- It was devised so local engineers, surveyors and others could tie their work into the reference then used, the **Clarke ellipsoid of 1866**, which was used in the **NAD of 1927** but has since migrated to **NAD 1983**
- They desired a simple rectangular coordinate system on which easy plane geometry and trigonometry
could be applied for surveying because working with spherical coordinated was cumbersome

- If the area of the earth being mapped is small enough, virtually no distortion exists
- This is the principal behind the **State Plane Coordinate System**
- Accuracies must be less than one part in 10,000
- States are partitioned into a series of zones

- **Slide #57**: see Figure 3.20, **The Zones of the State Plane Coordinate System**

- in the continental US these zones are elongated either in the north-south direction or east-west direction
- many states have more than one zone
- each zone is referred to as north, central or south, as appropriate
- each zone is assigned its coordinate systems with its own origin and its own projection
• **Slide #58:** there are three conformal projections used to map the states:
  - o **secant case** of the **Lambert Conformal Conic** for zones with elongated east-west dimension
  - o the **secant case** of the **Transverse Mercator** for zones with elongated north-south dimensions
  - o the **secant case** of the **Oblique Mercator** for one section of Alaska
• in each case, over small areas these projections essentially project as rectangular grids, with little or no areal or distance distortion
• because they are conformal, no angular distortion between the meridians and parallels is present

• a particular zone’s coordinate system is designed so that surveyors work only with positive coordinates
Slide #59: Universal Transverse Mercator (UTM) System

- the UTM System along with the Universal Polar Stereographic System (for polar regions) was created after WWII by several allied nations in order to produce a unified and consistent coordinate system after years of trying to trade information in different coordinate systems
- Slide #60: the UTM system is not as accurate as the State Plane Coordinate system, with accuracies of one part in 2500.
- Many US states distribute much of their public domain spatial data in UTM format which can easily loaded into GIS and mapping software

- See Slide #61: Figure 3.22

- The UTM system is a projected coordinate system that covers the entire world from 80° south to 84° North
• It is subdivided into **60 six-degree zones** that are elongated in the north-south direction
• The continental US has 10 zones (zones 10-19) that extend from 126°W to 66°W

• **Slide #62**: See Figure 3.23

• **Slide #63**: The projection for this system is the **secant case of the Transverse Mercator**
• The transverse cylinder is positioned such that the central meridian runs north-south through the zone’s center
• The central meridian for zone one is 177°W
• The two standard lines (small circles) will straddle the central meridian at 180 km (111.85 miles) to the meridian’s east and west
• Relatively low scale distortion is thus maintained in the north-south direction
• The cylinder is repositioned 60 times, once for each zone
• **Slide #64:** Coordinates are based on the equator, which serves as the *x-axis*
• The *y-axis* is positioned at 500,000 meters west of a particular zone’s central meridian
• By generating this false origin, all coordinates are positive
• In the northern hemisphere, a point is measured as so many meters east (of the *y*-axis that intersects the false origin) and so many meters north of the equator

• **Slide #65:** See Figure 3.24

• **Slide #66:** In the southern hemisphere, the origin is moved south by 10,000,000 meters, which is not too far from the South Pole
• Again, this keeps coordinates positive

• As with *State Plane Coordinates*, **UTM** is often used to map entire states since there is relative accuracy
of coordinates and so much data is readily available in this format