

GIS Lab #3: Map Projection and Coordinate Systems

Thanks to Mark Helper of Texas University and to Joseph Kerski of USGS

Objectives

- Gain experience in ArcMap using on-the-fly-projection of various common projections
- Learn how to define a projection in ArcCatalog and ArcToolbox
- Learn how to project vector data using ArcToolbox
- Learn how to register imagery and CAD files

Introduction and Summary

Recall from lecture that maps are, in essence, graphs and that creating maps with a computer is analogous to plotting points and lines on graph paper. For software to show the geographic location of features, the features must be stored with x and y coordinates tied to a specific origin (i.e. X=0, Y=0; a "Coordinate System") and a datum. The datum specifies the dimensions of a model of the earth; the length of the minor and major semi-axes of an ellipsoidal earth or the radius of a spheroidal (see lecture notes). Together, the datum and coordinate system comprise the so-called "Spatial Reference" of a data set.

In ESRI lingo, Spatial References are of two types:

1. A Projected Coordinate System ("PCS"), is composed of a datum (e.g. WGS84) and coordinate system parameters (e.g. location of origin and standard parallel(s) in lat. & long., type of developable surface, false easting and northing, etc.; see lecture notes) specific to a map projection. PCS coordinates of features are stored in meters or feet relative to the PCS origin.
2. A Geographic Coordinate System ("GCS"), includes only a datum, location of a Prime Meridian (Y-axis; the X-axis is always the equator), and an angular unit of measure. A GCS has units of decimal degrees - GCS coordinates of features are stored in degrees of latitude and longitude. West longitudes and South latitudes are stored as negative values and the units are decimal degrees (DD), not Degrees, Minutes and Seconds (DMS).

One of the principal, traditional strengths of GIS software is the ability to convert data stored in one Spatial Reference to another Spatial Reference. This map projection process may involve conversion of coordinates from one GCS to another GCS, from a GCS to a PCS, or from one PCS to another PCS. A computer screen or paper map can only have one Spatial Reference; one origin and one set of axes for the graph. Thus, the ability to convert coordinates from one Spatial Reference to

another is a key aspect if one wishes to simultaneously view data sets that have different Spatial References.

Within ArcGIS, ArcToolbox has tools to do these conversions. In so doing, you can create a new, permanent data file containing coordinates in the new Spatial Reference. Alternatively, temporary ("on-the-fly") conversion to a different Spatial Reference is done automatically upon adding data in ArcMap. This on-the-fly conversion permits viewing of data sets that have different Spatial References without first having to create a new file(s) of converted coordinates with ArcToolbox.

For either of these processes to work the software must first know the Spatial Reference of the dataset(s). If this information is missing from a dataset, then ArcToolbox and ArcCatalog have tools for creating it, a necessary first step (called "Defining a Spatial Reference" or "Defining a Projection") before permanent or on-the-fly conversion can be successful. Many older data sets are missing Spatial Reference information and can produce problems if this "defining" step is ignored. Worse still are datasets with the wrong Spatial Reference definition! We will learn to recognize datasets with these shortcomings and to apply appropriate fixes.

Data Management

Create a folder for this exercise and name it *Lab03_projection*. As you know, it is best to name the folder without any spaces in the name.

You now should have 15 files with the following names:

mn.tif
states.dbf
states.prj states.sbn
states.sbx
states.shp
states.shx
states.sbx
stfrancisfire.jpg
toddroads.dbf
toddroads.shp
toddroads.shx
toddhidro.dbf
toddhidro.shp
toddhidro.shx
counties.dwg

Start ArcGIS with a blank map document.

Add the following layers:

states

mn.tif

Rename your data frame as "Minnesota"

1) Based on the main theme of this lesson, why do you suppose that at this point, the Minnesota image does not overlay on top of the boundaries for Minnesota?

2) Where does the Minnesota image lie in relation to the state outlines?

3) What coordinates do you observe for the northwest corner of the Minnesota image?

4) What are the coordinates for the northwest corner of Minnesota on the state outline layer?

5) What does ArcGIS do when no registration information exists for a layer?

You will create header information so you can register the image.

Save your map document as *imageregistration* and give it an appropriate name, placing it into your *Lab03_projection* folder.

Typical images used in GIS and remote sensing analysis are in .bil, .tif, .jpg, and .bip formats. The file extension for a header file is usually the first and last letters of the image file extension, with a "w" at the end for "world" file. For example, the header for mn.tif should be mn.tfw.

* Sometimes, image registration information is embedded inside the image itself. For example, geotiff image files do not have a separate header. Programs do exist that can pull out the header information into a separate file if the user needs it for any reason. However, all GIS software will read geotiffs and correctly place the image.

6) Enter the world file name for the following files under the column "world file name."

image file name **world file name**

sheboygan.jpg

rosebud.tif

southdakota.tif

* Sometimes, image files have header files that are a different format than that discussed here. For example, some tif files will have a .hdr header.

Understanding Registration and World Files

A world (registration) file for an image is just a text file consisting of six lines. Here is a simple example, below. The simplest situation to describe is one using decimal degree (or “geographic projection”) data:

```
0.0107
0.0
0.0
-0.0087
-97.26
49.43
```

If the image is formatted in something like an Albers projection instead of decimal degree, it is still possible to create an effective world file; it just takes a little more tinkering.

Note: Creating a header file for a “projected image” involves basically the same process and header, except that the top left coordinates will be in numbers of meters away from a projection reference. Here is an example of a world file for an image in Albers projection:

```
4100.0
2.51179777165858
-0.08833980138674
-4050.0
-2360630.88315064972267
3182746.43488585297018
```

Each line in a registration file has a special purpose. The lines are not interchangeable, and must always be presented in this order, so writing a correct world file requires understanding the purpose and the data.

LINE1 = how much of a map unit (in this case, degrees) is represented by moving one pixel eastward from any spot (positive number).

LINE2 = how much the image should be skewed from the sides (negative number, but usually zero)

LINE3 = how much the image should be skewed from top and bottom (positive number, but usually zero)

LINE4 = how much of a map unit (in this case, degrees) is represented by moving one pixel southward from any spot (negative number)

LINE5 = X coordinate (in this case, decimal degrees longitude) of the top left (northwest) corner of the image (decimal degrees means negative number for 0-180 west, positive number for 0-180 east).

LINE6 = Y coordinate (in this case, decimal degrees latitude) of the top left (northwest) corner of the image (decimal degrees means negative number for 0-90 south, positive number for 0-90 north).

7) In the example header file above, is the image skewed?

8) In the example header file above, what is the latitude-longitude coordinate of the northwest corner of the image?

9) How many degrees are represented by moving any number of pixels in the E-W direction?

10) How many degrees are represented by moving any number of pixels in the N-S direction?

Creating a World File and Registering an Image

Minimize ArcGIS.

Engage a graphics program such as Photo Editor under "Microsoft Office Tools" or another graphics program. Open the image "mn.tif". This is a Minnesota colorized image file based on a digital elevation model (DEM), with the different colors representing elevation.

Look in the lower right under "W" and "H" for the width and height of the image. If you are using Windows Paint, access "image" and then "attributes" for this information.

11) Enter width in pixels: _____

12) Enter height in pixels: _____

Access ArcGIS again.

Add Data and navigate to the location of your data for this lesson.

Access symbology for the states file. Make the states transparent and symbolize the state boundaries with a 2 or 3 thickness.

Scroll the mouse across the state outlines.

Zoom to the extent of Minnesota's image.

Determine the latitude and longitude coordinates for the top left and bottom right corners of the image, using decimal equivalents for easy fractions ($1/3 = .33$ and so on).

Fill in the following "worksheet," substituting known numbers.

Assume that you do not want any skew.

Line 1 is the longitude of the SE corner minus longitude of NW corner) divided by image width in pixels. Show your work.

13) LINE1 = _____

14) LINE2 = _____

15) LINE3 = _____

Line 4 is the latitude of the SE corner minus latitude of NW corner) divided by the image height in pixels. Show your work.

16) LINE4 = _____

Line 5 is the northwest corner longitude.

17) LINE5 = _____

Line 6 is the northwest corner latitude.

18) LINE6 = _____

Examine the image below. When recording the NW and SE corners, use the locations of the + plus signs shown in this image, so you account for Minnesota's full extent. Don't cut off the Lake of the Woods area or the northeast corner of the state along Lake Superior.

Note that Lines 4 and 5 have to be negative numbers.

19) Why does line 5 have to be negative?

Create the world file with your data above and name it mn.tfw. Create it in WordPad or NotePad. You may use a Word Processor, but make sure you save it **in text file format**.

Note that the header file must have the format (you will substitute your values, above):

```
0.01072  
0.0  
0.0  
-0.0087  
-105.10903  
39.40582
```

Remove the mn.tif layer. Add the layer again after you create the header file. Remember to move your state outlines ABOVE your image and make the fill transparent as a guide in your registration.

20) Does the Minnesota image now overlay on top of your state outlines?

If the two layers are CLOSE, but do not exactly overlay, continue adjusting the header file, removing it and re-adding it to your ArcMap session until you are satisfied with the registration. Images may be offset from the vector data, depending on the accuracy of the image, the vector data used, and the coordinates you decided on. You can create an approximately correct world file through this method, but you may have to refine this file once you see how the image lines up with other known data sets. Each time you change and re-save the world file in your text editor, you must then delete and re-add the image in ArcGIS to test it. To do this in ArcGIS, remove layer. ArcGIS remembers the registration information for an image when it is first brought into a view, so changes to the world file will not re-position the image until the image is added again.

When refining the world file, first ensure the accuracy of Lines 5 and 6. Once this "starting point" is properly set, you can then tweak Lines 1 and 4 to stretch or shrink the image. Add a little bit at a time to the numbers in Lines 1 and 4 to expand an image; subtract from the numbers in Lines 1 and 4 to shrink an image.

21) What coordinate system have you registered your image to?

22) Name a few problems with the method you just used, considering data quality issues and GIS user issues.

23) Create a layout that includes the state outlines and your image, along with any other pertinent information that you consider to be appropriate. Zoom the extent to Minnesota and portions of the adjacent states and provinces. Print this and attach it to these lesson sheets.

Once you've done the best you can do with adjusting the image, do the following:

24) Write the contents of your final header file below:

Save your ArcGIS map document again.

Image Registration Using Georeferencing Tool in ArcMap

In this section, you will use the Georeferencing Tool in ArcMap to register your image.

Start a new ArcMap session.

It is important to start working with an **unregistered** mn.tif image. If you registered your mn.tif above and have a mn.tfw file, the easiest thing to do to “disconnect” the registration information from your image is to rename mn.tif to minnesota.tif.

25) Why does renaming “disconnect” the image registration information from the image itself?

Add minnesota.tif to your data frame.

Add states.shp to the data frame and change the symbology to hollow. Increase the outline width to 2.

Your minnesota image file should once again be sitting down at 0 latitude, 0 longitude.

26) Why is the image at 0 latitude 0 longitude?

View toolbars and access the georeferencing tool.

The general steps for georeferencing a raster using the georeferencing tool are:

1. Add to your map the raster and the vector layers (target data) to which you want to align the raster.
2. Add control points that link known raster positions to known target data positions in map coordinates.
3. When you're satisfied with the registration, save the georeferencing information with the raster.

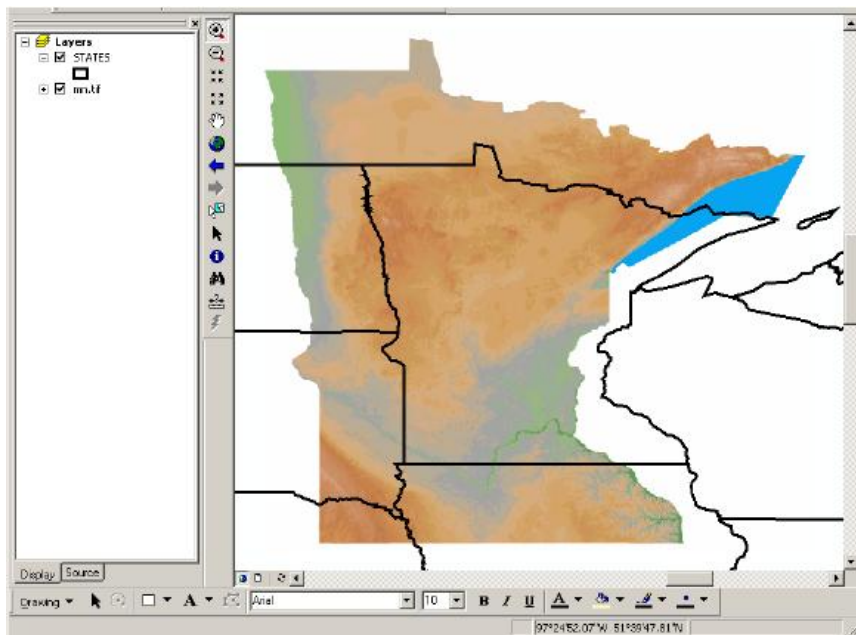
For most rasters, the georeferencing information is stored in a separate file with the same name as the raster but with an .aux file extension. You can permanently

transform the raster by using the Rectify command on the georeferencing toolbar. The coordinate system assigned to the raster is the same as the coordinate system defined on the data frame the raster is part of.

Zoom in on the state of Minnesota **on the states outline map**.

From the Georeferencing toolbar, click the Layer dropdown arrow and click the raster layer you want to georeference.

Click Georeferencing and click Fit to Display. This will display the raster in the same area as the target layers. You can also use the Shift and Rotate tools to move the raster as needed. The view frame should look similar to that below:



Click the Control Points button to add control points. The button looks like 2 crosses with a line joining them:



To add a link, click the mouse pointer over a known location on the raster, then over a known location on the state line (target) data. You may find it useful to zoom in to add your links.

Add enough links for the transformation order. You need a minimum of six links for a second order transformation—that means 12 clicks of the mouse.

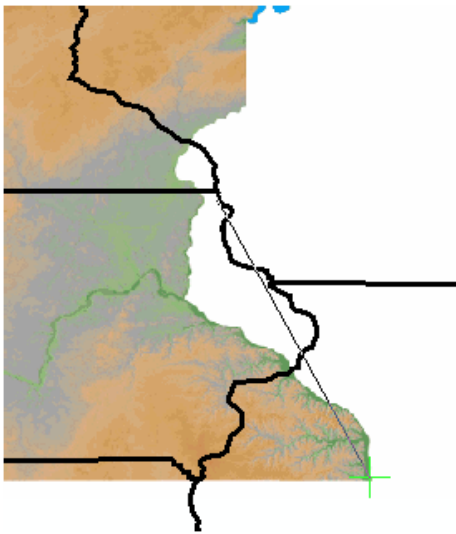
Try to select points that are easily identifiable on each data set, and points that are scattered throughout the data sets for the best registration, such as the corners of

the state. Also, select points that are on all major corners of the state, not just one side. If the image becomes skewed beyond recovery, it is best to delete the data sets from the view frame and start your session over.

Remember that you are drawing links FROM the raster TO the vector (state lines) files.

27) Why is your destination the vector file?

For example, to register the southeast corner of the image to the southeast corner of the state lines file, you would click on the southeast corner of the image FIRST, then the southeast corner of the state lines, as follows:



Click View Link Table to evaluate the transformation. You can examine the residual error for each link and the RMS (Root Mean Square) error. If any of the errors is much higher than the rest, you can delete that row in the table.

28) What is your total residual error?

When you are satisfied with the registration, you can stop entering links.

Click Georeferencing and click Update Georeferencing to save the transformation information with the raster. This creates a new file with the same name as the raster but with an .aux file extension.

29) Using Windows Explorer, browse to your folder and answer the following question: What new file(s) were just created by the georeferencing method?

Save your map document.

Registering CAD file

Activate "Minnesota" data frame

Add counties.dwg to your data frame.

Create (manually) a world file to register the CAD file

The world file structure

A world file is a text file (.wld) containing one or four pairs of x,y coordinates. The first pair of coordinates is the x,y location of any known control point in your drawing file. The second pair of x,y coordinates is a new location in geographic space where you want the CAD drawing control point to be in ArcMap. These coordinates comprise the first point of the two-point transformation. The remaining pairs of coordinates follow the same structure as the first and second pairs. They make up the second point of the two-point transformation.

The world file format is as follows:

x,y location in CAD drawing	space	{x,y location in geographic space}
<From X1,From Y1>		<To X1,To Y1>
<From X2,From Y2>		<To X2,To Y2>

The world file must have the .wld extension and cannot have more than two lines in the above format

Using the Shift tool

1. Click the Shift button on the Georeferencing toolbar.
2. Click the mouse button.
3. While holding down the mouse button, drag the CAD layer to the desired location.
4. Once you've finished positioning the CAD layer, release the mouse button.

The CAD layer will appear at the location you specified.

Using the Rotate tool

1. Click the Rotate button on the Georeferencing toolbar.
2. Click the mouse button.

3. While holding down the mouse button, rotate the CAD layer to the desired orientation.
4. Once you've finished rotating the CAD layer, release the mouse button.

The CAD layer will appear at the orientation you specified.

Using the Scale tool

1. Click the Scale button on the Georeferencing toolbar.
2. Click the mouse button.
3. While holding down the mouse button, scale the CAD layer to the desired size by dragging the pointer up or down.
4. Once you've finished scaling the CAD layer, release the mouse button.

The CAD layer will be the size you specified.

Creating control points

1. Click the Add Control Points button on the Georeferencing toolbar.
2. Click the mouse pointer on the known location in the CAD layer to create the from point.
3. Click the mouse pointer on the known location on the map or reference layer to create the to point.

The control point will appear on the map.

Entering specific x,y map coordinates

1. Click the Add Control Points button on the Georeferencing toolbar.
2. Click the mouse pointer on the known location in the CAD layer to create the from point.
3. Right-click and click Input X and Y.

The Enter Coordinates dialog box appears.

4. Type a x-coordinate value.
5. Type a y-coordinate value.
6. Click OK.

The control point will appear on the map with its destination coordinates defined by the values that were typed on the Enter Coordinates dialog box.

Project a shapefile

You may frequently have datasets representing the same location that are already stored in different projections and coordinate systems. At ArcGIS, there is a Projection Engine that allows you to convert datasets from one projection to another. In this exercise, you will project one dataset to match another.

1. The 6 shapefiles needed for the exercise, **roads_utm27**, **roads_sps83**, **stands_utm83**, and **stands_sps27**. The files will be placed in separate directories (**utm** and **state_plane**) on your removable drive.

Here are the projection parameters for each dataset:

<i>name</i>	<i>data</i>	<i>projection</i>	<i>zone</i>	<i>datum</i>	<i>units</i>
soils_spn27	forest soils	State Plane	WA-North	NAD27	feet
nwi_spn83	National Wetland Inventory	State Plane	WA-North	NAD83	feet
streams_sps83	streams	State Plane	WA-South	NAD83	feet
pls_sec_sps27	PLSS sections	State Plane	WA-South	NAD27	feet
roads_utm27	roads	UTM	10	NAD27	meters
soils_utm83	soils	UTM	10	NAD83	meters

2. Insert a new data frame (**Insert > Data Frame**), and alter its title to **State Plane**.
3. Add all 4 of the State Plane datasets (from the **State Plane** directory) from the file you downloaded and extracted. If you get an error message, click **OK**. This is because none of the shapefiles have projection information stored with them.



Even though these datasets represent features at the same real-world location, the projections they are stored in differ, which is why they do not overlap as expected. Although all 4 of these are stored in the State Plane system, they differ in both the State Plane zone and the datum in which they are stored . These differences are what cause the layers not to line up with each other.

4. Create another data frame (call this one **UTM**) and add both shapefiles from the **UTM** directory to the data frame.

If you zoom in and pan around, you will see clearly where the layers do not line up where they should.

The difference between NAD27 and NAD83 is less profound when using the UTM system than when using State Plane for Washington State, but you should still be able to see how the features do not line up as expected.

We will project the roads dataset so it will overlay the stands correctly.

5. Because neither of these datasets have projections defined, the first step will be to define the projection on each of them. Note that "defining" the projection on a dataset does not alter the dataset in any fundamental way, it just makes a record of what projection the dataset is stored in. However, in order for ArcGIS to project a dataset from one system to another, it must know what the input projection system is. This step, defining the projection, accomplishes the task of letting ArcGIS know about the dataset's current storage parameters. It is absolutely essential that you define a dataset's projection properly. If you make a mistake in defining the projection, errors will ensue any time you use the dataset.
6. Open ArcToolbox. You may want to "dock" it in your application window.
7. Select **Data Management Tools > Projections and Transformations** and double-click the **Define Projection** tool.
 1. Select **roads_utm27** as the **Input Dataset**.
 2. Click the button to select a coordinate system .
 3. Click **Select**. Select **Projected Coordinate Systems > UTM > NAD 1927 > NAD 1927 UTM Zone 10N.prj**. A progress window will display. When the process is complete, **Close** the dialog.
 4. **Don't skip this step!** Do the same for the **stands_utm83** layer, but select the projection **Projected Coordinate Systems > UTM > NAD 1983 > NAD 1983 UTM Zone 10N.prj**
8. From ArcToolbox, now select the tool **Data Management Tools > Projections and Transformations > Feature > Project**.
 1. Select **roads_utm27** as the **Input Dataset**. For the **Output Dataset**, specify that you will be saving the dataset as **roads_utm83**.
 2. For the **Output Coordinate System**, click the button to select a coordinate system . Click **Import**, which will allow you to copy the coordinate system from an existing data source. Navigate to the dataset for **stands_utm83**.
 3. For the **Geographic Transformation**, select **NAD_1927_To_NAD_1983_NADCON**.
9. Click **OK**. A progress dialog will indicate when the process is complete. Click **Close**.

10. The new dataset is added as a layer to the map. Turn off the **roads_utm27** layer and turn on the new **roads_utm83** layer. You will see that it now overlaps with the stands properly.

You have just projected a layer from one projection to another. Use this technique whenever you have datasets that are stored with incompatible projections. In order to be able to project datasets, you will need to know both the input and output projections.