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# Introduction to Coordinate Systems and Projections

ArcGIS Desktop 10.1 Instructional Guide



**RICE**

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This guide was created by the staff of the GIS/Data Center in Fondren Library at Rice University and is to be used for individual educational purposes only. The exercises outlined in this guide require access to particular software and datasets which are available at Fondren Library.

# Obtaining the Tutorial Data

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Before beginning the tutorial, you will copy all of the required tutorial data onto your Desktop. Follow the applicable set of instructions below depending on the particular computer you are using.

## Accessing tutorial data from Fondren Library using the *gistrain* profile

If you are completing this tutorial from a public computer in Fondren Library and are logged on using the *gistrain* profile, follow the instructions below:

1. On the Desktop, **double-click** the Computer icon → *gisdata (\\fon-gis04) (O:)* → **Short\_Courses** → **Getting\_Started\_with\_ArcGIS\_Series** → **Introduction\_to\_Coordinate\_Systems\_and\_Projections**.
2. To create a personal copy of the tutorial data, **drag** the *ProjectionsTutorialData* folder onto the Desktop.
3. **Close** all windows.

## Accessing tutorial data online using a personal computer

If you are completing this tutorial from a personal computer, you will need to download the tutorial data online by following the instructions below:

1. Using a web browser, go to the Introduction to Coordinate Systems and Projections short course webpage at: <http://library.rice.edu/gis-projections>
2. At the bottom of the webpage, under the Resources section, **click** the **Introduction to Coordinate Systems and Projections – Tutorial Data** link to download the tutorial data.
3. **Unzip** the *ProjectionsTutorialData* folder.
4. **Copy** the unzipped *ProjectionsTutorialData* folder to your Desktop or another location of your choice. Ensure that you note the file path of the location you have selected.

Any time throughout the tutorial that you see reference to the file path *C:\Users\gistrain\Desktop\ProjectionsTutorialData*, you will need to substitute it with the file path you have just selected.

The following step-by-step instructions and screenshots are based on the Windows 7 operating system with the Windows Classic desktop theme and ArcGIS for Desktop 10.1 software with an Advanced license. If your personal system configuration varies, you may experience minor differences from the instructions and screenshots.

# Exploring GIS Data in ArcCatalog

## Connecting to a folder

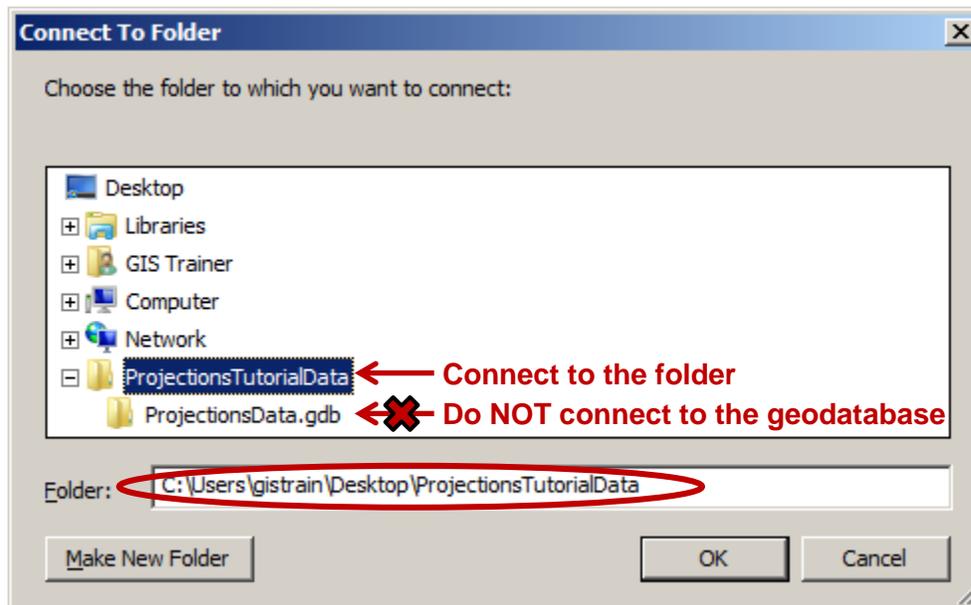
1. On the Desktop, double-click the **ArcCatalog 10.1** icon.
2. On the Standard toolbar, click the **Connect To Folder** button.



3. In the 'Connect To Folder' window, select the **ProjectionsTutorialData** folder located on the Desktop.

Ensure that the *ProjectionsTutorialData* folder is highlighted in blue and not the *ProjectionsData.gdb* geodatabase that appears inside it. You never want to connect directly to a geodatabase, as doing so will prevent you from being able to access any of the data contained inside of it.

4. For 'Folder:', verify that **C:\Users\gistrain\Desktop\ProjectionsTutorialData** is listed as shown below and click **OK**.



In the Catalog Tree, under Folder Connections, you should now see a file path connecting directly to your *ProjectionsTutorialData* folder.

## Previewing GIS data

1. In the Catalog Tree, expand the **ProjectionsTutorialData** folder.
2. In the Catalog Tree, expand the **ProjectionsData** geodatabase.

Inside the *ProjectionsData* geodatabase, you will notice three feature classes.

3. In the Catalog Tree, select the **County** feature class.
4. At the top of the Catalog Display, click the **Preview** tab.

This feature class contains a polygon delineating the boundaries of Harris County. It was obtained from Esri's now outdated Census 2000 TIGER/Line Data website at <http://www.esri.com/data/download/census2000-tigerline>.

5. In the Catalog Tree, select the **MajorRoads** feature class.

This feature class contains centerlines of all of the major roads within the greater Houston and Harris County region. It was obtained from the *COHGIS 2011 route datasets* link on the City of Houston GIS (COHGIS) 2011 Datasets website at <http://mycity.houstontx.gov/home/cohgis.html>.

6. In the Catalog Tree, select the **Schools** feature class.

This feature class contains the point locations of all schools in Texas. It was obtained from the *Download Schools* link on the Texas Education Agency (TEA) Texas School District Locator – Data Download website at <http://ritter.tea.state.tx.us/SDL/sdldownload.html>.

## Defining Data Projections

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All GIS data is created in a particular geographic coordinate system used for mapping locations on a three-dimensional sphere, based on measurements of latitude and longitude. In addition, much GIS data has already been projected onto a two-dimensional plane, based on linear measurements, such as feet or meters. In order for ArcMap to position a data layer in its proper geographic location, it must be told the proper coordinate system and projection in which the data was originally created. Otherwise, the data layer can be displayed as an image of sorts, but the image will not necessarily line up correctly with other data layers in the Map Display.

### Determining if layers are defined

In some cases, the geographic coordinate system and projection of the data has already been defined in ArcGIS, while, in other cases, you will need to define it yourself based on metadata obtained from the source of the data. First, you will need to determine whether or not each feature class has already been defined.

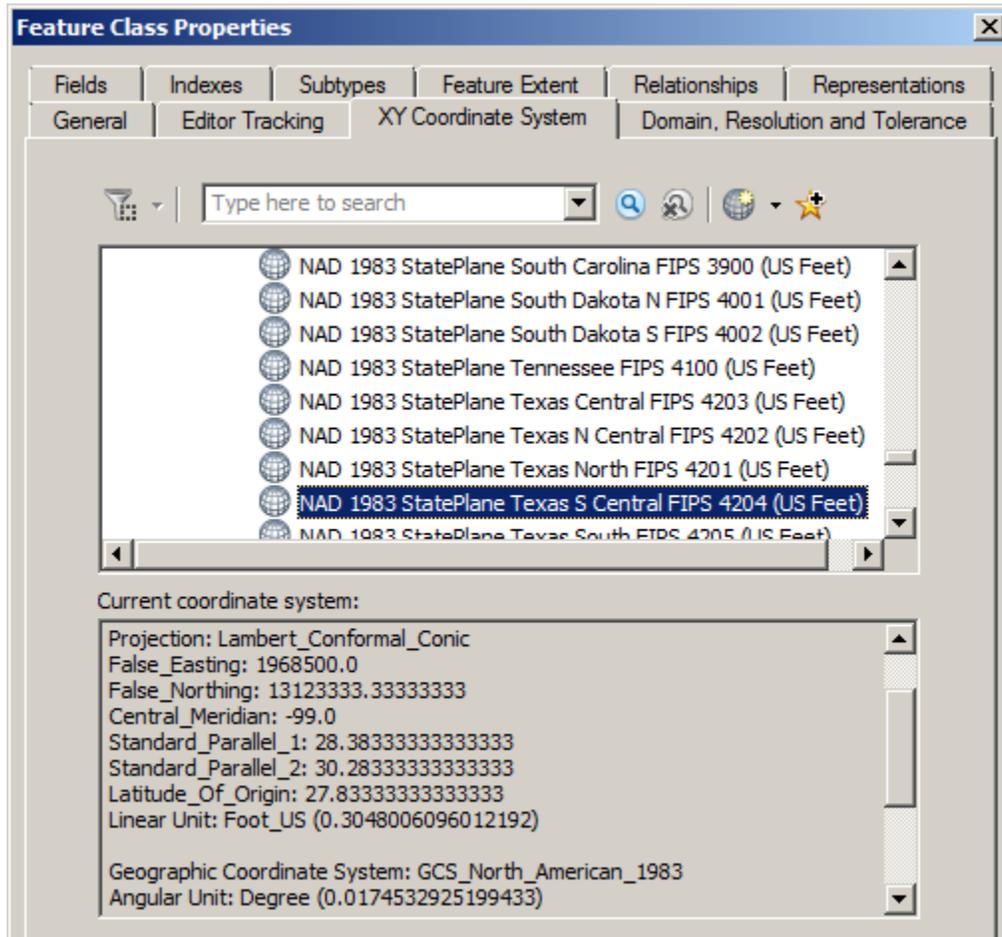
1. In the Catalog Tree, right-click the **MajorRoads** feature class and select Properties....

2. In the 'Feature Class Properties' window, click the **XY Coordinate System** tab.

Under 'Current coordinate system:', scroll down and notice that both a geographic coordinate system and a projection are listed, which indicates that the coordinate system of this feature class has already been defined.

Note that the geographic coordinate system is *GCS\_North\_American\_1983*. "GCS" stands for Geographic Coordinate System. This particular coordinate system is more commonly referred to as the North American Datum 1983 or NAD83.

The general type of projection is *Lambert\_Conformal\_Conic*, but its properties (central meridian, standard parallels, latitude of origin, etc.) have been modified to be optimal for South Central Texas. These modifications are saved under the XY coordinate system name *NAD\_1983\_StatePlane\_Texas\_South\_Central\_FIPS\_4204\_Feet*. The State Plane projection system divides each state into multiple planes that are suitable for mapping local regions within each state. Houston falls within the South Central plane in Texas.



3. In the 'Feature Class Properties' window, click **Cancel**.
4. In the Catalog Tree, right-click the **County** feature class and select **Properties....**

Note that neither a geographic coordinate system nor a projection is listed and the XY coordinate system name is unknown, meaning that the coordinate system of this feature class has not been defined. In other words, ArcGIS does not know which coordinate system the data was created in and, therefore, will probably not be able to accurately line up this data layer with other data layers. Before you can reliably use this feature class, you will need to define its coordinate system and projection.

5. In the 'Feature Class Properties' window, click **Cancel**.
6. In the Catalog Tree, right-click the **Schools** feature class and select **Properties....**

Note that the *Schools* feature class uses the same geographic coordinate system as the *MajorRoads* feature class: *GCS\_North\_American\_1983*. Even the general projection type is the same: *Lambert\_Conformal\_Conic*. However, its properties have been modified to be suitable for all of Texas, rather than just the South Central portion of Texas, so the XY coordinate system name is now *Texas Centric Mapping System/Lambert Conformal*. The Texas Centric Mapping System is an example of a statewide projection that is suitable for mapping the entire state. Statewide projections are commonly developed for large or elongated states, such as Alaska, California, Michigan, and Texas, which would otherwise be divided into numerous small bands using the State Plane system.

7. In the 'Feature Class Properties' window, click **Cancel**.

The geographic coordinate system and projection for each of the three feature classes are summarized in the table below.

<b>Layer</b>	<b>Geographic Coordinate System</b>	<b>Projected Coordinate System</b>
<i>MajorRoads</i>	NAD 1983	State Plane Texas South Central
<i>County</i>	<b>Undefined</b>	<b>Undefined</b>
<i>Schools</i>	NAD 1983	Texas Centric Mapping System

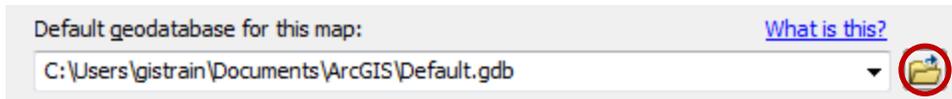
## Setting up a map document

You will begin by opening ArcMap and creating a new map document.

1. On the Desktop, double-click the **ArcMap 10.1** icon.
2. In the 'ArcMap – Getting Started' window, ensure that **My Templates** and the **Blank Map** template are selected.

At the bottom of the window, notice the default geodatabase for this map is currently set to C:\Users\gistrain\Documents\ArcGIS\Default.gdb. The default geodatabase should be set to the geodatabase that will contain most of the data for the particular map document you are working on. In this case, you will want to use the geodatabase in your *ProjectionsTutorialData* folder.

3. Next to the 'Default geodatabase for this map:' box, click the **Browse** button.



4. In the 'Default Geodatabase' window, use the 'Look in:' drop-down box to select **C:\Users\gistrain\Desktop\ProjectionsTutorialData**.
5. Select the ***ProjectionsData.gdb*** geodatabase and click **Add**.
6. Ensure the 'Default geodatabase for this map:' box says "**C:\Users\gistrain\Desktop\ProjectionsTutorialData\ProjectionsData.gdb**" and click **OK**.

At this point, it is a good idea to save your map document and to continue saving regularly.

7. On the Standard toolbar, click the **Save** button.



8. In the 'Save As' window, use the 'Save in:' drop-down box to select the ***ProjectionsTutorialData*** folder.

You will save the map document here, directly inside the *ProjectionsTutorialData* folder, but NOT within the *ProjectionsData* geodatabase.

9. For 'File name:', type "**ProjectionsTutorial**" and click **Save**.

Remember that, in order for your GIS project to open properly on other computers, you must tell the map document to store relative pathnames to its data sources and take your **entire project folder** containing all of your data and your map document with you.

10. Click the **File** menu and select **Map Document Properties....**
11. Towards the bottom of the 'Map Document Properties' window, click the **checkbox** to 'Store relative pathnames to data sources' and click **OK**.
12. On the Standard toolbar, click the **Save** button again to store this setting in your map document.

## Displaying undefined layers

As an experiment, you will now see what happens when you attempt to add an undefined layer into ArcMap.

1. On the right side of the ArcMap window, click the **Catalog** tab.
2. On the Catalog toolbar, click the **Go To Default Geodatabase** button, which will take you to the default geodatabase you specified earlier.



3. Double-click the **ProjectionsData** geodatabase to expand it.
4. Drag the **MajorRoads** feature class into the Map Display.

The data frame, or display, takes on the coordinate system and projection of the first layer added to it. In this case, since the *MajorRoads* layer was the first layer added, the data frame will take on the State Plane Texas South Central projection. To verify this, you will check the coordinate system of the data frame.

5. In the Table of Contents, right-click the **Layers** data frame and select **Properties....**
6. In the 'Data Frame Properties' window, click the **Coordinate System** tab.

Notice that, indeed, the State Plane Texas South Central projection is listed.

7. In the 'Data Frame Properties' window, click **Cancel**.
8. Click the **Catalog** tab again and drag the **Schools** feature class into the Map Display.

Notice that the two layers appear to line up properly, even though they have different projections. This is because ArcMap is able to perform “on-the-fly” projection, as long as the coordinate systems of both layers are defined. On-the-fly projection means that the *Schools* layer is being superficially displayed in the State Plane Texas South Central projection of the data frame, based on calculations performed by ArcMap; however, the projection of the *Schools* feature class itself has not been altered from the Texas Centric Mapping System projection.

Though not recommended, on-the-fly projection may be used whenever a visual display of data is all that is required. On-the-fly projection should never be used when attempting to perform calculations between two layers involving measurements of distance or area, as these measurements are most accurate when all data layers are in the same projection.

Now you will see what happens when you add an undefined layer to the data frame.

9. Click the **Catalog** tab again and drag the **County** feature class into the Map Display.

A warning box pops up saying, “The following data sources you added are missing spatial reference information. This data can be drawn in ArcMap, but cannot be projected.”

**10. Click OK to close the ‘Unknown Spatial Reference’ window.**

Notice that the *County* layer does not appear in the Map Display, even though it is listed in the Table of Contents. This is because ArcMap does not know where to locate the *County* layer relative to the other layers, since it is not defined. Instead, ArcMap does the best it can and treats the coordinates of the *County* layer as if they were in Texas South Central State Plane coordinates, even though they are not.

Notice when you move your cursor around the map display, the coordinates listed in the bottom right of the window are similar to those shown below, indicating units of millions of feet.

3121741.491 13844035.205 Feet

**11. In the Table of Contents, right-click the *County* layer and select Zoom to Layer.**

It is evident that both layers are being drawn in the data frame, but ArcMap simply does not know how to line them up properly. Notice when you move your cursor around the map display now, the coordinates are similar to those shown below, indicating units around -95 and 29 feet.

-95.399 29.834 Feet

Whenever you come across X-coordinates between -180 and 180 and Y-coordinates between -90 and 90, you can be fairly sure that they are actually geographic coordinates of latitude and longitude listed in decimal degrees. The fact that Houston is located at 95° W, 29 N° is further confirmation that the county layer was created in a geographic coordinate system, rather than a projection. In this case, ArcMap is treating these measurements of decimal degrees as if they were measurements of feet in the State Plane Texas South Central System, with the end result of locating Harris County in the middle of the Pacific Ocean.

**12. Right-click the *MajorRoads* layer and select Zoom to Layer.**

Whenever you encounter this type of situation, where two layers show up in the Table of Contents, but do not line up as you expect them to, you know it is most likely a projection problem.

**13. Right-click the *County* layer and select Remove.**

## Determining projections for undefined layers

Of the three feature classes you examined, the *County* feature class was the only one that was undefined. Since the spatial reference information cannot be located using ArcCatalog, you must turn to the source of the data itself. The data was originally downloaded from the following website: <http://www.esri.com/data/download/census2000-tigerline>. A screenshot of the metadata provided on that website appears below.

## Data Information

<b>Name:</b>	Census 2000 TIGER/Line Data
<b>Provider:</b>	<a href="#">U.S. Bureau of the Census</a>
<b>Coverage:</b>	United States
<b>Coordinate System:</b>	Geographic coordinates <b>NAD83</b> for the 48 contiguous states, <b>NAD27</b> for Alaska, and Old Hawaiian Datum for Hawaii
<b>Units:</b>	Decimal degrees
<b>Delivery:</b>	Shapefile
<b>Price:</b>	Free

The metadata indicates that you must define the geographic coordinate system for the layer as NAD83, or North American Datum 1983. Fortunately, this is the same geographic coordinate system used by the other two layers. Since no projection is listed, you can assume that the layer has not been projected and was created in a geographic coordinate system only. The fact that the units are listed as decimal degrees further confirms this assumption.

## Defining undefined layers

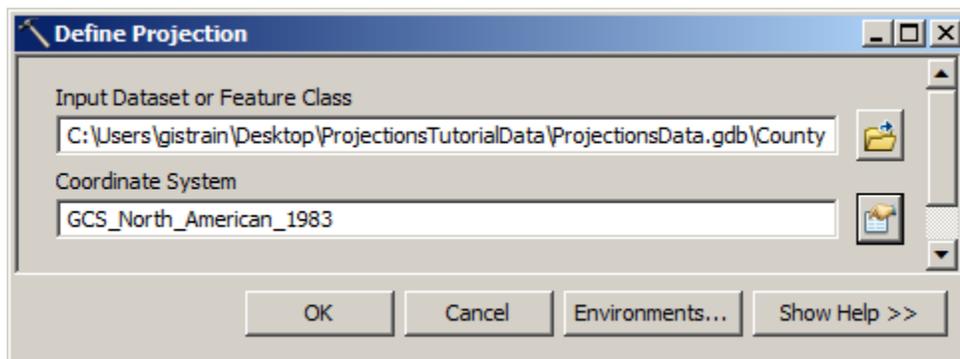
Now that you know the geographic coordinate system of the *County* feature class, you will need to define it so that ArcMap knows, as well. Please note that the geographic coordinate system and projection must be defined based on metadata provided from the data source itself. If you cannot locate such metadata, you should contact the provider of the data for such information. You cannot simply guess or decide which projection to use when defining the data (though, occasionally, you may have to resort to educated guesses and trial-and-error when metadata absolutely cannot be tracked down.)

1. Return to **ArcCatalog**.
2. In the Standard toolbar, click the **ArcToolbox** button.



3. In ArcToolbox, double-click the **Data Management Tools** toolbox.
4. Double-click the **Projections and Transformations** toolset.
5. Double-click the **Define Projection** tool.

6. Drag the **County** feature class from the Catalog Tree into the 'Input Dataset or Feature Class' box in the 'Define Projection' window.
7. Next to the 'Coordinate System' box, click the **Set Coordinate System** button.
8. In the 'Spatial Reference Properties' window, double-click **Geographic Coordinate Systems > North America**.
9. Select **NAD 1983** and click **OK**.
10. Ensure your 'Define Projection' window appears as shown below and click **OK**.



You may have to wait several seconds for the tool to finish running. When it is complete, proceed with the steps below.

11. In the Catalog Tree, right-click the **County** feature class and select **Properties....**

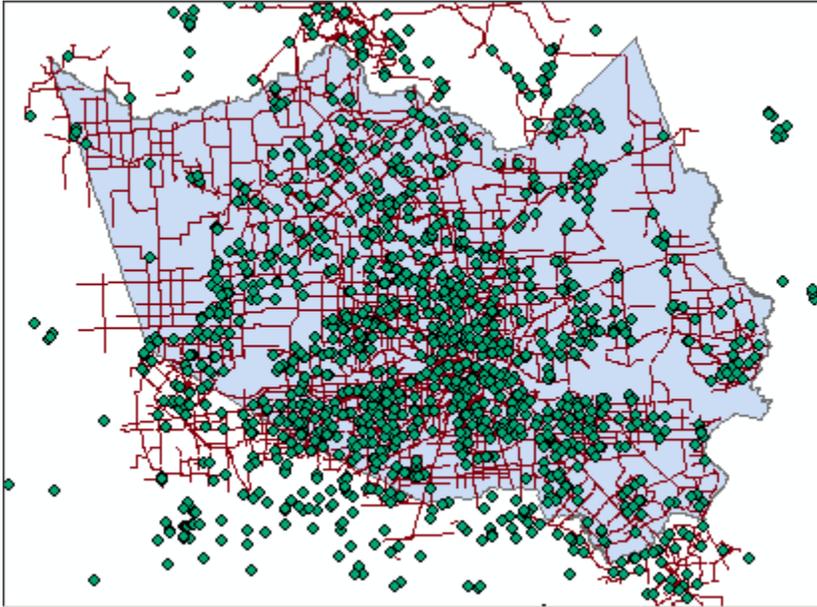
Notice that the XY coordinate system is now listed, since you have defined the feature class.

12. In the 'Feature Class Properties' window, click **Cancel**.

Since the *County* layer is now defined, on-the-fly projection can be used to display it along with the other layers.

13. Return to **ArcMap**.
14. Click the **Catalog** tab again and drag the **County** feature class into the Map Display.

Now all three layers line up as expected.



## Projecting Data

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If you are only interested in creating a visual map, as you have done now, then relying upon on-the-fly projection will suffice. If, on the other hand, you are interested in performing any sort of calculations between the layers that rely upon distance, area, or spatial overlap, then it is recommended that you use the same projection for all layers. In addition, you can only measure linear distances in a projected coordinate system, not in a geographic coordinate system, so the *County* layer would need to be projected anyway, before any sort of measurements could be made.

### Selecting a map projection

Now that all of your data has been defined, you can transform all the feature classes into a common projection. Unlike the process of defining data, where there is only one projection you can use (the one specified in the metadata), when projecting data, you can select whichever projection best suits your particular combination of data and tasks at hand. Since your data focuses on the Harris County region, the State Plane Texas South Central projection would be suitable.

## Determining which layers to project

The State Plane Texas South Central projection has been selected for the final map projection. All layers that are not currently in that projection will need to be re-projected, such as the *County* and *Schools* feature classes. All layers that are already in the final projection can be left as is and do not need to be re-projected, such as the *MajorRoads* feature class.

Layer	Geographic Coordinate System	Projected Coordinate System	Matches Final Projection?
<i>MajorRoads</i>	NAD 1983	State Plane Texas South Central	Yes
<i>County</i>	NAD 1983	None	No
<i>Schools</i>	NAD 1983	Texas Centric Mapping System	No

## Projecting layers

1. Return to **ArcCatalog**.
2. In **ArcToolbox**, under the **Data Management Tools** toolbox and **Projections and Transformations** toolset, double-click the **Feature** toolset.
3. Double-click the **Project** tool.
4. Drag the **County** feature class from the **Catalog Tree** into the 'Input Dataset or Feature Class' box in the 'Project' window.

Note that the input coordinate system is *GCS\_North\_American\_1983*, as you previously defined it. Note that the output dataset is saved to the same geodatabase as the input dataset and the name of the output feature class has the suffix “\_Project” tacked onto the end of the original input feature class name.

5. Next to the 'Output Coordinate System' box, click the **Set Coordinate System** button.

While you could click navigate to or search for the State Plane Texas South Central coordinate system yourself, in this case, you know that the same coordinate system is already used by the *MajorRoads* layer. In such an instance, it is easier to import the coordinate system from another layer, especially if you are not familiar with where the coordinate system of interest is stored.

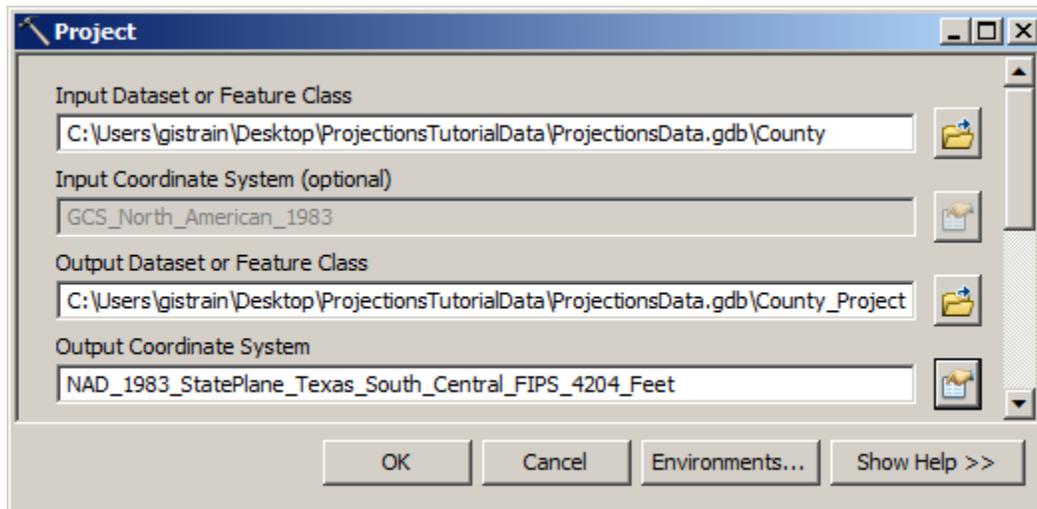
6. On the **XY Coordinate System** toolbar, click the **Add Coordinate System** button and select **Import....**



7. Double-click the *ProjectionsData.gdb* geodatabase.
8. Select the *MajorRoads* feature class and click Add.
9. Verify that *NAD\_1983\_StatePlane\_Texas\_South\_Central\_FIPS\_4204\_Feet* is selected and click OK.

Since both the input and output coordinate system use the same geographic coordinate system, a geographic transformation is not necessary in this case.

10. Ensure that your 'Project' window appears as shown below and click OK.



When previously defining a layer, you simply updated the metadata attached to that layer to include the known coordinate system and projection. When projecting a layer, you have actually created a second copy of the data in the new coordinate system. The original layer stays in the native coordinate system and the new layer is converted to the desired coordinate system.

11. In the Catalog Tree, right-click the *County* feature class and select Properties....

Note that the coordinate system is still *GCS\_North\_American\_1983*.

12. In the 'Feature Class Properties' window, click Cancel.

13. In the Catalog Tree, right-click the *County\_Project* feature class and select Properties....

Note that the new coordinate system is *NAD\_1983\_StatePlane\_Texas\_South\_Central\_FIPS\_4204\_Feet*.

14. In the 'Feature Class Properties' window, click Cancel.

You will now repeat the same process to re-project the *Schools* feature class from the Texas Statewide Mapping System projection into the State Plane Texas South Central projection.

15. Repeat steps 3 - 10 with the **Schools** layer.

16. Close ArcCatalog.

All of your layers have now been projected into the State Plane Texas South Central projection.

17. Return to ArcMap.

18. In the Table of Contents, right-click the **Schools** layer and select Remove.

19. In the Table of Contents, right-click the **County** layer and select Remove.

20. Click the **Catalog** tab.

21. If either or both of the **County\_Project** and **Schools\_Project** layers are not listed under the **ProjectionsData** geodatabase, right-click the **ProjectionsData** geodatabase and select Refresh.

22. Drag the **County\_Project** feature class into the Map Display.

23. Click the **Catalog** tab again and drag the **Schools\_Project** feature class into the Map Display.

24. On the Standard toolbar, click the **Save** button.

Since all layers in your data frame are now in the same projection, you could proceed to make accurate calculations of distance and area between the layers.

Last updated September 10, 2012