Overview of the exercise
This is an exercise designed to be done in the Tufts GIS Lab (or at home if you have copied the exercise data folder). It will familiarize students who have been introduced to coordinate system concepts with the issues they may face in real-world situations using ArcGIS.

A solid understanding of coordinate systems is critical for GIS users. Selecting an appropriate coordinate system is necessary for good visualization. The accuracy of spatial queries, overlays, and calculations (e.g., area and perimeter) can be affected by coordinate system choices. The issues may manifest themselves as errors that preclude completion of a certain query or calculation, or errors in the results of a query. For example, you cannot calculate the area of polygons for a data set that is not projected (e.g., that is in the Geographic Coordinate System - GCS). In addition, spatial queries with a GCS coordinate system may not perform properly. If you are using an inappropriate Projected Coordinate System, your selections based on spatial relationships (“show me all the buildings within 2 miles of a geologic fault line”) and your area/perimeter/length calculations can be completed but they could have significant errors.

The bottom line is:

- You need to be aware of what the coordinate system is for each of your data sets
- You should generally work within an appropriate projected coordinate system for your area of interest (NOT a Geographic Coordinate System!)
When performing spatial analysis (where spatial relationships matter – e.g., spatial overlays, proximity functions, and area/length/perimeter calculations), all the data sets involved should be in the SAME projected coordinate system.

Many, if not most, of the most common problems encountered by GIS users turn out to be related to coordinate system issues. This tip sheet takes you through several common issues you’ll encounter in GIS that have to do with coordinate systems. If you need guidance for mapping network drives to these servers, please see Accessing GIS lab drives from outside the lab (first tip sheet on the Tufts GIS Center’s ArcGIS 10 Tips and Tutorials web site - https://wikis.uit.tufts.edu/confluence/x/nwDUAg)

After completing this exercise, you should:

- Know where to look in ArcGIS to get information about a data set’s coordinate system
- Know how to change the coordinate system of a data frame in ArcMap
- Understand how to select an appropriate coordinate system for a given area
- Understand some of the problems that might occur in GIS due to map projection and coordinate system issues

More information about coordinate systems is available through ArcGIS 10.1 Online Help in their Guidebook for Map Projections

**Copying the Map Projection Exercise Folder to your H: drive or Desktop**

Before you begin, you need to have your own, write-able copy of the exercise data

1. Copy the Map Projection Exercise folder from S:\Tutorials\Tufts\Tutorial Data to your H: drive or Desktop. Copy and paste the entire folder.
2. Once you have it on your H: drive, navigate to it and right-click on the Map Projection Exercise folder and choose Properties – General tab
3. Uncheck the Read-Only box

![Uncheck this box and click OK below]

4. Navigate to your copy of the Map Projection Exercise folder and double-click the following map file: map_projection_exercise_01.mxd – that will start ArcMap

What’s the coordinate system of this data set?
It’s critical that you know the coordinate system of each of the data sets you are using.

Each data set is in a particular coordinate system. It has to be – it can’t be created without being in a coordinate system. However, ArcGIS software does not require a person to explicitly define what coordinate system the data is in when they create it. Most professionally produced GIS data sets will have a defined coordinate system. You can find out what a data set’s coordinate system is in the properties window for each individual layer.

1. Right-click on the Towns_Poly layer in the Table of Contents and choosing Properties, then the Source tab. You should see information about where the data set is located, and then about its coordinate system, including whether it is a Projected Coordinate System or a Geographic Coordinate System (not projected, uses latitude and longitude):

![Projection name, type, parameters, and unit of the coordinate system (meters)]
What's the coordinate system of my data frame?

It’s also critical for you to know the coordinate system of the data frame you are working with in ArcMap. The data frame always takes on the coordinate system of the first data set you add. You can then change it to a more appropriate one if you need to.

You can view the coordinate system of your data frame in one of two ways in ArcMap:

1. Click on View – Data Frame Properties and then click on the Coordinate System tab
2. Or, right-click on Layers in the Table of Contents column (or whatever your Data Frame is called), then click on Properties, and then the Coordinate System tab

If the first data set you add is missing a spatial reference, then your Data Frame’s coordinate system will also be undefined. This is bad!

Your turn – find the coordinate system

1. In ArcMap, find the coordinate system of the data frame. What is it?

2. For 4 of the data layers within the red box below, write down the coordinate system, including if given, the NAME, TYPE of PROJECTION and the UNIT (linear or angular):

So for Cities, you would write down the highlighted information below:
For **Towns_Poly**, you would write down the information highlighted in yellow on the next page:

<table>
<thead>
<tr>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Coordinate System: NAD_1983_StatePlane_Massachusetts_Mainland_FIPS_Conic</td>
</tr>
<tr>
<td>Projection: Lambert_Conformal_Conic</td>
</tr>
<tr>
<td>False_Easting: 200000.00000000</td>
</tr>
<tr>
<td>False_Northing: 750000.00000000</td>
</tr>
<tr>
<td>Central Meridian: -71.50000000</td>
</tr>
<tr>
<td>Standard_Parallel_1: 41.71666667</td>
</tr>
<tr>
<td>Standard_Parallel_2: 42.68333333</td>
</tr>
<tr>
<td>Latitude_Of_Origin: 41.00000000</td>
</tr>
<tr>
<td>Linear Unit: Meter</td>
</tr>
</tbody>
</table>

3. Are the **World Countries**, **admin**, and **Maine County Boundaries** data sets projected?

4. Why do you think the Maine Counties data set isn’t using a State Plane coordinate system? (Hint: in ArcMap, turn on the **State Plane Zones NAD83** layer and zoom in to Maine. And remember that State Plane zones are for **local** mapping.)

**Setting an appropriate coordinate system for mapping**

We’ve discussed in class the different types of coordinate systems, and when one is more appropriate than another. You can also review the ArcGIS 10.1 web help section for Supported Map Projections for advice.

Note that on the ArcGIS map for this session, we have three coordinate system grids – one for latitude and longitude (in 10 degree blocks), one for the UTM zones of the world (zone labels are at the top), and one for the State Plane Zones (NAD 83) of the US (zone names will appear if you zoom in below 1:20,000,000 scale). Take a look at the UTM and State Plane Zones (zoom in to a state or group of states to see the State Plane zones more clearly)

The various **State Plane Coordinate Systems** were developed primarily to facilitate **local** mapping (at the city or metropolitan scale).

The **UTM Coordinate System** was developed to facilitate accurate mapping for both **local and regional mapping**. They are especially useful for regions that **extend north/south**.

The **Geographic Coordinate System** is **not** a projected coordinate system – it is a useful way to distribute data for large areas (e.g., the US or the World) but you should always choose a **projected** coordinate system when using this data in a map or for spatial analysis.

To create a good map with an appropriate projection, you can change the Data Frame’s coordinate system by going to the **Data Frame’s Properties – Coordinate System tab** (remember how to get there?). You can then navigate to a **projected** coordinate system of your choice.
We have talked about the State Plane and UTM coordinate systems in class. Note there are other coordinate systems and map projections that ArcGIS makes available – for example to make a map of the continent of Africa you might want to choose a map projection specifically designed for that – recall that Conformal means the map projection retains angular relationships and the accurate shapes of features as much as possible, and that Equal Area means that the projection retains accurate area and relative sizes and of features as much as possible:

Select a coordinate system:

![Image showing coordinate system selection]

**Your Turn – Set an Appropriate Coordinate System**

Based on what you have learned in class, and using the UTM Zones and State Plane Zones data sets to guide you where appropriate, choose *four* of the following areas and set an appropriate coordinate system for the data frame for each in turn. (Click on View – Dataframe Properties, then the Coordinate System tab. You should choose either from the Projected Coordinate Systems folder or if one of the layers on the map has what you want, you can choose from the Layers folder). When you see choices, look for NAD 1983 and WGS 1984 as the best options North American locations (NAD 1983) or the rest of the world (WGS 1984) respectively.

Write down your choices and be prepared to tell the class what you chose and why, and any problems you had deciding.

1. Massachusetts
2. Somerville
3. Nantucket
4. Maine
5. The New England coast from Cape Cod to the northernmost part of Maine
6. The northeast Maine coast
7. The Florida Panhandle
8. The US Gulf Coast between Tallahassee, FL, and New Orleans
9. Chicago
10. Washington, DC
11. The Aleutian Island chain (off Alaska)
12. San Francisco metropolitan region
13. All of California
14. The Northeast US (DC to Maine)
15. Port au Prince, Haiti
16. All of Chile
17. The area around Conception, Chile, where the earthquake and tsunami occurred
18. All of Brazil
19. A continent of your choice, for purposes of showing the most accurate shape of features
20. A continent of your choice, for purposes of showing the most accurate area of features

Hey, where’s my data layer? – Fixing missing/incorrect spatial references
In this section you will learn how to handle data sets that are missing a spatial reference or that have the wrong spatial reference.

In ArcMap, choose File – Open and open the map_projection_exercise_02.mxd map file from where you copied the exercise data folder (you don’t need to save the old one)

We are zoomed into Boston, with the MassGIS Towns poly layer and the Boston Redevelopment Authority’s Planning District layer.

- Write down the coordinate system and linear units of each of these layers
- Write down the coordinate system and linear units of the data frame

It’s fairly common that cities use the “feet” version of their area’s State Plane coordinate system, while MassGIS uses the “meter” version.

The major point here is that both data sets appear together in the correct location even though they are in different coordinate systems (one based on feet and the other on meters), because ArcGIS knows what those coordinate systems are.

Occasionally, data set’s coordinate system has NOT been defined explicitly by its creator. Every GIS data set is in some coordinate system, and the ArcGIS software sees these coordinates, but
unless the data creator has explicitly recorded the coordinate system of the data, the software has no way of knowing what system these coordinates represent, so no way of knowing where in the world they may be.

When you try to add a data layer that has no defined coordinate system to your ArcMap session, you’ll get an error message like this:

The data layer might draw, but it may or may not draw in the right place. And you never want to use data that has a missing spatial reference. BAD!

**Adding data from the City of Newton**

1. Add the **building footprint** layer from the City of Newton (H: \Map Projection Exercise\Newton_Data\bldgfoot.shp) – what happens?

2. Write down the coordinate system and linear unit of this data layer.

3. Why do you think the building footprints are not displaying correctly?

**Finding the lost data**

1. Right-click on **building footprints** and choose **Zoom to Layer** – what happens?

2. Click on the **Go Back to Previous Extent** button

Newton is somewhere but not where it is supposed to be....

3. Click on the **full extent** button

4. Can you find the Newton building footprint data layer?

**Correcting the problem**

I happen to know based on information from the City of Newton that the coordinate system for the Newton GIS data is the Massachusetts State Plane Mainland, NAD 83, with linear units of **FEET**. The reason it is showing up many miles to the northeast is that ArcGIS is reading the coordinates of the City of Newton data (which are really in **feet**) as if they were **meters**!

Remember, the MassGIS **town poly** is in the Mass State Plane NAD83 meters system (which is also what the **Data Frame’s** coordinate system is in). On that layer, the area of Newton is
something like 223,500 meters east and nearly 900,000 meters north of the State Plane zone’s origin point.

But Newton data set coordinates show up as something like 737,000 meters east, and nearly 3,000,000 meters north of the State Plane’s origin point. That’s a lot farther east and north – way up north of Maine somewhere. Because ArcGIS didn’t know the coordinates were in feet, it treated them like they were in meters and placed them further north and east accordingly. If the software knew the coordinates were in feet it would have put them in the right place.

So we have a problem here:

- The building footprint data set’s coordinate system is missing a spatial reference and needs to be defined

The correct coordinate system (known through my investigation) is Massachusetts State Plane Mainland, NAD 83, with linear units of FEET

Let’s first define the projection for the data set missing a spatial reference. This process will create a small projection file (.prj) that will then reside with the data set.

1. In ArcMap, click on the red Arc Toolbox icon
2. Navigate as shown here and double click on the **Define Projection** tool

3. Click on *Show Help*. Note that this tool is **ONLY** for use with datasets that have *unknown* or *incorrect* coordinate systems. Most data already have defined coordinate systems, so this tool will not be used frequently, but is important in the rare instance that a data set comes without a defined coordinate system.

4. For the *Input Dataset* click on the black arrow to select **BLDGFOOT**

5. Follow the graphic below to select a new coordinate system:
6. Choose State Plane - NAD 1983 (US Feet) and the Massachusetts choice as you see below (don’t choose Massachusetts ISL – that’s for the Islands!):
7. Click **OK**, and **OK** again to complete the task. The process will take a minute or so then you will get a pop-up message that it has completed.

Do the Newton building footprints eventually show up in the right place? Click on the redraw icon at the bottom of the map if necessary.

Is the data layer for Newton now in the correct location?

You have now learned to define coordinate systems. The most important points here are:

- You should never work with data sets that are missing a spatial reference
- You need to know what the spatial reference is for the data set before you can use the DEFINE PROJECTION tool
- You need to investigate the accompanying documentation or make phone calls to find out what the data set's coordinate system really is – it has one, you just don’t know what it is.
- **Never, ever, ever, ever, ever** use the DEFINE PROJECTION tool to define the coordinate system you would like the data set to be in if you DO NOT KNOW what it really is! What you want does not matter! You need to know what coordinate system the data set IS in. If you start guessing you can make matters much, much worse! **BAD and CONFUSING!!!!**

### Setting up for Spatial Analysis

The last important thing you need to know is that for performing spatial analysis, it is good practice to put all the data sets that are part of the analysis into the SAME projected coordinate system. By spatial analysis, we mean doing queries and analysis that involve spatial relationships, like calculating area, creating buffers, select by location, and various overlay tools. If you are only mapping things, then the data sets can remain in their own coordinate systems, as long as these are all defined. But if you start doing spatial analysis, then it is best to make copies of these data sets that are in a shared projected coordinate system.

Let’s say that we want the Newton building footprints data layer to be part of a spatial analysis involving 3 data sets from MassGIS. The Newton building footprints layer is in the Mass State Plane Mainland NAD 83 (**feet**) coordinate system, and the MassGIS data is all in Mass State Plane Mainland NAD 83 (**meters**). We are going to create a new copy of the Newton footprints in the same coordinate system and linear units as the MassGIS data sets.

This will only work if your data set’s coordinate system is currently correctly defined. This process does not convert the original coordinate system to a new one the way that DEFINE PROJECTION does – rather it makes a COPY of the original data set in a NEW projection.

To convert the Newton building footprints to Mass Mainland State Plane NAD 83 Meters:
1. In ArcToolbox, go to Data Management Tools – Projections and Transformations – Feature and double-click on the Project tool as shown below:

![Image of ArcToolbox with Project tool highlighted]

2. Fill out the Project dialog box as you see below – note this will create a new output data set that is a copy of the bldgfoot, but in the new coordinate system you define here:

![Image of Project dialog box]

Give the new data set a descriptive name, with the projection info:

Projected - State Plane NAD 1983 (Meters) - Massachusetts

3. Complete the process by clicking OK and OK – the process will take a minute. If the data set is not added automatically, use the Add Data button to find and add the new layer yourself.

4. You can now remove the older buildings data set.
You can do this with other data layers as well, as long as they have a correctly defined coordinate system.

**READ THE FOLLOWING!!!!!**

**Warning**: if you incorrectly define a data layer’s coordinate system using the DEFINE PROJECTION tool, and then convert it into a different coordinate system using PROJECT, you are going to be really, really sorry, not to mention EXTREMELY confused and frustrated.

DEFINE PROJECTION is for defining the coordinate system of an existing data set when that data set’s coordinate system is missing or known by you to be wrong. Usually it’s the former case. The DEFINE PROJECTION tool does NOT make a copy of the data set – it changes the original data set! You want to avoid this unless you know for certain it is absolutely necessary.

PROJECT is to give a new projection to a data set in a correctly defined coordinate system. The PROJECT tool creates a new copy of the data set in the desired projection.

So be careful and always...

*Practice safe mapping – define your projection!*