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Project 1: Georeferencing Raster Images

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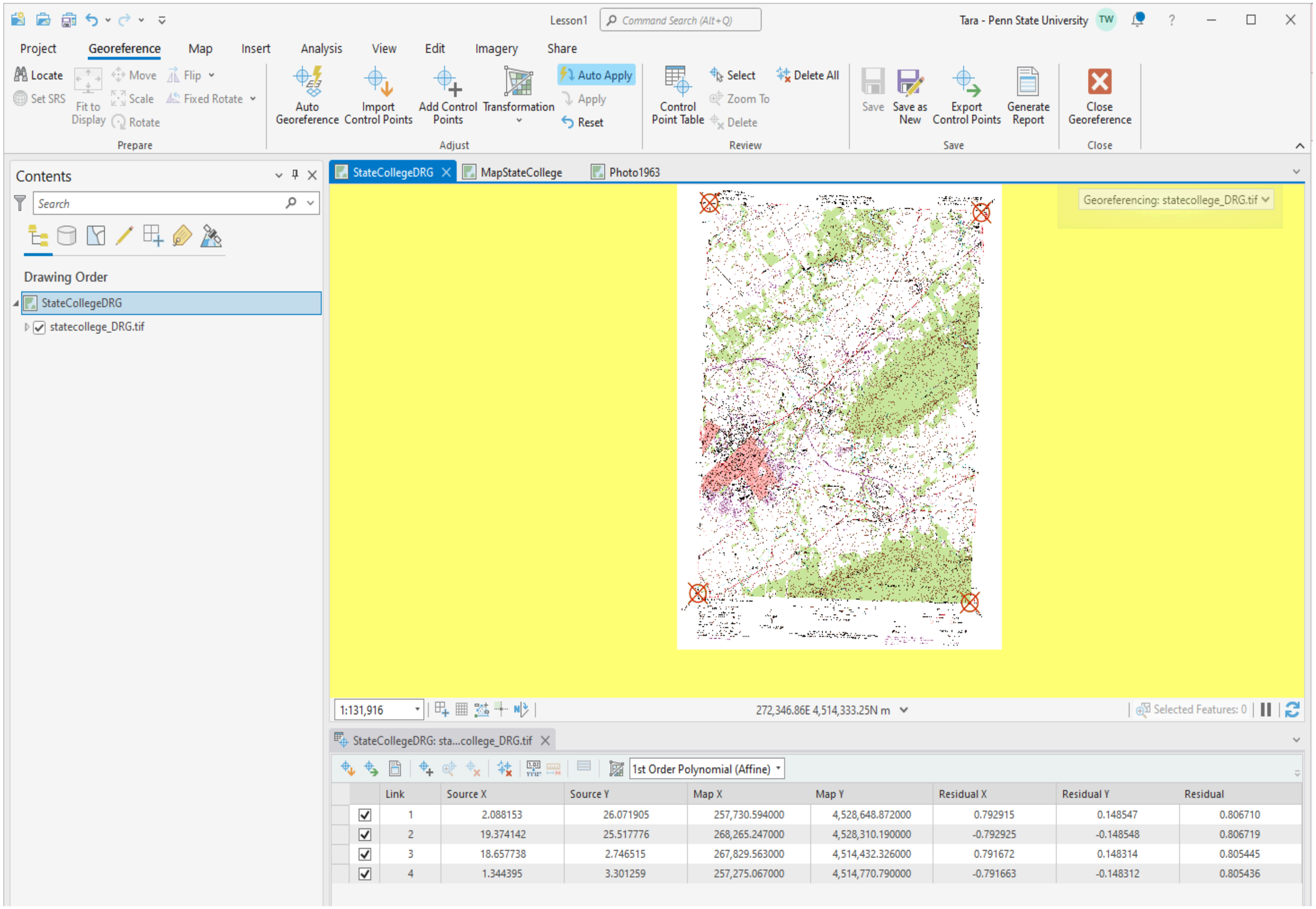
Overview

There are many important skills in the GIS profession, and georeferencing is one of them. Georeferencing can be defined as the “process of converting from the digitizing method-imposed coordinates to georeferenced coordinates” (Sloan & Zeiders, 1999-2023c). There are several transformation methods to perform georeferencing. This project entailed georeferencing the following materials: a modified image of a USGS DRG, a scanned USGS paper topographic quadrangle, and a vertical aerial photo that had not been orthorectified. Affine transformation and explicit XY coordinates were used to georeference the USGS DRG and the USGS paper topographic quadrangle. 2nd Order Polynomial transformation was used to georeference the vertical aerial photo.

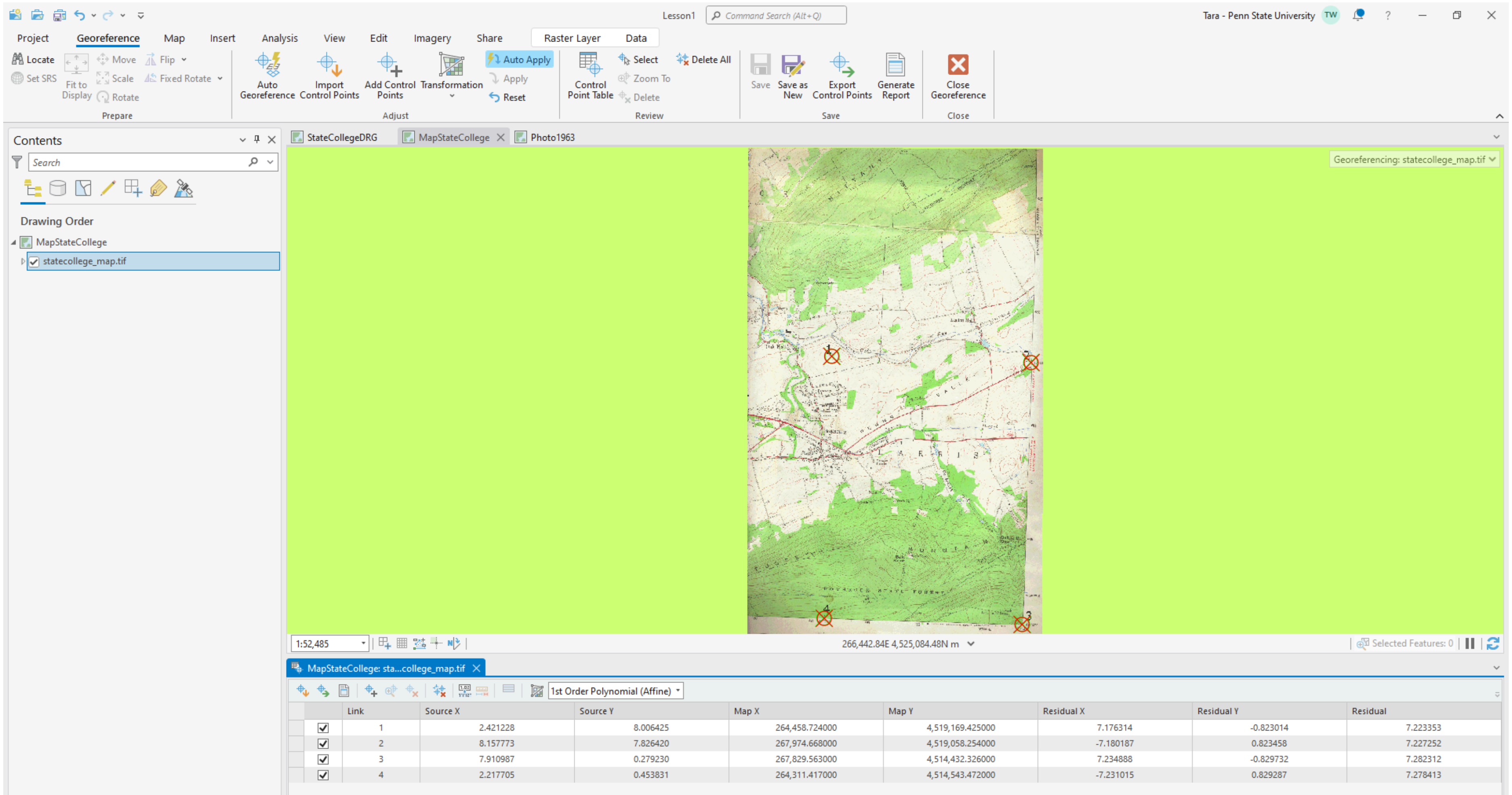
Root mean square (RMS) error acknowledges the fact that all images have some form of geometric distortion and will therefore create an imperfect conversion from one coordinate system to another (Sloan & Zeiders, 1999-2023a). A suitable RMS error should be less than or equal to one half the side dimension, in map projection units, of a cell or pixel (Sloan & Zeiders, 1999-2023a). As such, a suitable RMS error measurement was calculated for the maps in this project, and suitability of the three georeferenced materials were analyzed according to this measurement.

Proof of Georeferencing

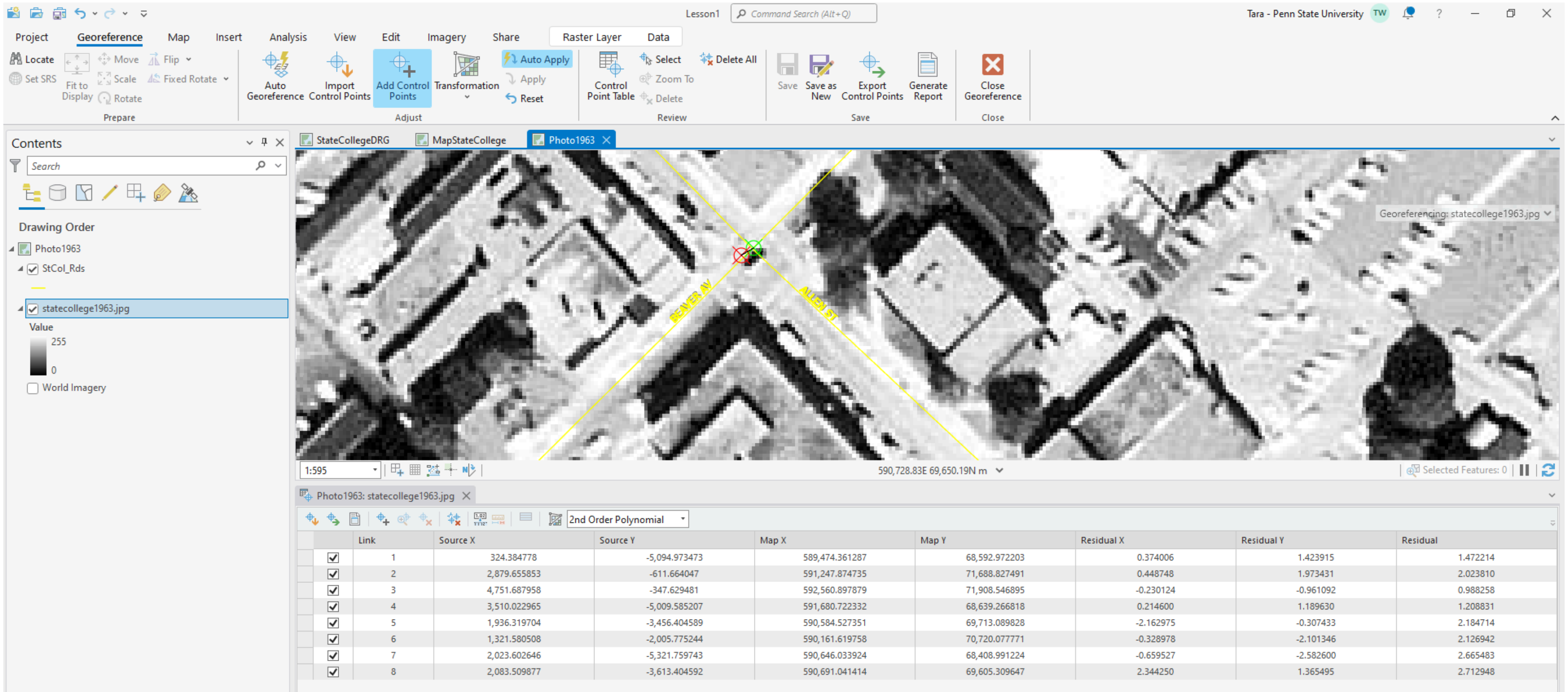
Georeferencing a Modified Image of a USGS DRG (1st Order Polynomial/Affine)



Georeferencing a Scanned USGS Paper Topographic Quadrangle (1st Order Polynomial/Affine)



Georeferencing a Vertical Aerial Photo (2nd Order Polynomial)



	Link	Source X	Source Y	Map X	Map Y	Residual X	Residual Y	Residual
☑	1	324.384778	-5,094.973473	589,474.361287	68,592.972203	0.374006	1.423915	1.472214
☑	2	2,879.655853	-611.664047	591,247.874735	71,688.827491	0.448748	1.973431	2.023810
☑	3	4,751.687958	-347.629481	592,560.897879	71,908.546895	-0.230124	-0.961092	0.988258
☑	4	3,510.022965	-5,009.585207	591,680.722332	68,639.266818	0.214600	1.189630	1.208831
☑	5	1,936.319704	-3,456.404589	590,584.527351	69,713.089828	-2.162975	-0.307433	2.184714
☑	6	1,321.580508	-2,005.775244	590,161.619758	70,720.077771	-0.328978	-2.101346	2.126942
☑	7	2,023.602646	-5,321.759743	590,646.033924	68,408.991224	-0.659527	-2.582600	2.665483
☑	8	2,083.509877	-3,613.404592	590,691.041414	69,605.309647	2.344250	1.365495	2.712948

Root Mean Square Error Calculation

Here is how I calculated the threshold value of acceptable RMS error for this project: First, I took an inventory of known variables. This is an original USGS DRG file and therefore has a cell (pixel) resolution of 250 cells per inch. Scale of the original scanned topographical sheet is 1:24,000. Next, I completed a series of mathematical steps to determine how many meters on the ground the side of one cell represents:

- **Step one: convert pixel into a map inch**
    - 1 pixel = 1/250 of an inch on the map
- **Step two: convert inch on map to inches in real world**
    - 1 inch on map = 24,000 inches in the real world
- **Step three: convert inch on map to meters in real world**
    - There are 39.3701 inches in a meter
    - 1 inch on map = 24,000/39.3701
        - 1 inch on map = 609.599670816 meters in real world
- **Step four: determine how many pixels are in a map inch**
    - There are 250 pixels in an inch
- **Step five: determine how many meters in the real world one pixel represents**
    - 609.59967086 meters / 250 pixels = 2.43839868344

2.43839868344 meters are represented by one pixel. RMS error should be less than or equal to half of this number, which is **1.21919934172 meters**.

Discussion of RMS Error in Three Georeferencing Exercises

In this section, I will discuss RMS error for each of three georeferencing exercises.

In the first exercise, the RMS errors (also known as ‘residual’) for the four control points were as follows: 0.806710, 0.806719, 0.805445, and 0.805436 meters. All of these errors were less than the threshold value of acceptable RMS error (1.21919934172 meters), and therefore fell within acceptable limits. Although this first USGS DRG “lost” its georeferencing information, the Affine transformation performed using explicit XY coordinates resulted in a suitable rate of error. This makes sense, because although the map “lost” its information, the DRG image was originally created meticulously and was virtually free of distortion, and it remained in its original digitized state when being georeferenced in this activity (Sloan & Zeiders, 1999-2023b). Therefore, I can conclude that the modified image of a USGS DRG (statecollege_DRG.tif) was georeferenced successfully.

In the second exercise, the RMS errors for the four control points were as follows: 7.223353, 7.227252. 7.282312 and 7.278413 meters. All four RMS error calculations were significantly higher than the acceptable limit of less than or equal to 1.21919934172 meters. Therefore, the scanned USGS paper topographic quadrangle (statecollege_map.tif) was georeferenced, but with concerning/unacceptable rates of conversion error. Although this second exercise had similarities to the first exercise - it used Affine transformation with explicit XY coordinates and it was basically the same map, only in paper format - the fact that this is a paper version of the first map introduces additional complications to the conversion process. For instance, there was a crease along the top portion of the map that would affect accuracy of the map, especially when choosing control points. Although the first map "lost" its georeferencing information, it did at one point exist in digital form, producing a digital copy that was free from outlandish error. The paper version of this map never had the opportunity to benefit from any initial digital georeferencing processes before this exercise to align it with any future georeferencing tasks placed upon it.

In the third exercise, the RMS errors for the eight control points were as follows: 1.4272214, 2.023810, 0.988258, 1.208831, 2.184714, 2.126942, 2.665483 and 2.712948 meters. Six of these eight points fell above the threshold value of 1.21919934172 meters and two fell within acceptable limits. Ultimately, this means that there are concerning rates of error in this map conversion. In this final exercise, 2nd Order Polynomial transformation was used, and control points were created between a photograph and a layer of streets. It is important to note that this photograph was not orthorectified. The orthorectification process is of profound importance to georeferencing of aerial images - without this process, such images are subject to distortion that makes future georeferencing more error-laden (Esri Insider, 2016). Therefore, it was not surprising that this final photograph did not bear a suitable rate of error overall.

List of Factors Affecting RMS Error Result

1. **Exercise 1**
    a. DRG image was originally created meticulously and was virtually free of distortion (Sloan & Zeiders, 1999-2023b)
    b. At least three control points were set.
    c. Control points were far away from each other, at corners/edges of map.
2. **Exercise 2**
    a. Map was in paper format, which introduces additional complications to the conversion process
        i. Crease along the top portion of the map that would affect accuracy of the map
    b. Although first map "lost" its georeferencing information, it did at one point exist in digital form, producing a digital copy that was free from outlandish error
        i. Paper version of this map never had the opportunity to benefit from any initial digital georeferencing processes before this exercise to align it with any future georeferencing tasks placed upon it.
3. **Exercise 3**
    a. Photograph was not orthorectified.

i. Without this process, images are subject to distortion that makes future georeferencing less accurate (Esri Insider, 2016).
ii. In other words, the image does not contain corrections for distortions from sensors or elevation changes.

General Factors Affecting RMS Error Result

Raster data can be derived from a variety of sources - scanned maps, aerial images, and so forth - and in many instances, can be incorporated into GIS projects with some skill and fortitude (Esri, n.d.-b). This process, however, requires care, and it is not a perfect one. When bringing raster data into a map project within GIS software, it is important to georeference such material to the coordinate system representative of your map. This step is necessary as it will allow you to view, analyze, and query your data alongside the other geographic data in your map project (Esri, n.d.-b). This conversion process will most likely introduce some level of distortion, as source images will always have some amount of inherent geometric distortion, and the process of conversion can introduce even more (Sloan & Zeiders, 1999-2023a).

The process of georeferencing raster data has quite a few variables, depending on the source you are bringing in and the existing coordinate system of your map project. For instance, satellite imagery may already come with its own location information, whereas scanned photographs usually do not. Scanned maps have most likely been made with a coordinate system in mind, but usually do not contain spatial reference information (Esri, n.d.-b). We can liken these qualities to the work of a foreign language translator. When translating one foreign language to another, there are not always direct word and syntax translations. The resulting translated words and sentences often are not a 1:1 match. Some languages are quite similar to others, while others are very different. The same can be said for coordinate systems and converting one system to another. The quality of source material a foreign language translator is working with also matters. Sometimes a foreign language translator is translating a novel of well-written source text - other times, they could be translating a short amount of text, maybe even a muffled audio file. Therefore, in addition to language (coordinate) similarity or dissimilarity, the *quality* of the source material also matters in the conversion process and the ultimate quality of transformation that results.

With these many variables in mind, it is important to understand that there will always be a difference between an image location before versus after its transformation (Sloan & Zeiders, 1999-2023a). This difference is portrayed by RMS error, a number that statistical transformations used in this lesson aim to minimize by designating a threshold of acceptable error in a particular conversion. Despite this goal to minimize RMS error, there are many reasons that might limit one's ability to arrive at a low RMS error when georeferencing raster image data in the real world.

It must be understood that any transformation result depends on the quality of input links, or control points - "the better established the control points, the more accurate the transformed result" (Esri, n.d.-a, par. 7). Different types of conversions would benefit from different transformation methods, which require different numbers of control points. The process of creating such control points can be misleading - more or less control points does not guarantee a more accurately converted map. For instance, 1st Order Polynomial Transformation (Affine) requires three points (Esri, n.d.-b). Having more control points could result in a more accurate map with a lower RMS/residual error, or these additional points could more clearly illustrate an unacceptable conversion error threshold inherent to the conversion. Similarly, 2nd Order Polynomial Transformation requires a minimum of six points. If you have less than six points plotted, the RMS or residual value presents as zero (Sloan & Zeiders, 1999-2023d). An uninformed GIS practitioner could inaccurately assume that ‘zero’ indicates a perfect conversion in this case, which it does not. More points are needed in this instance.

Placement of control points also matters. As a rule of thumb, control points should be placed far away from each other on the map, at corners. They must also be placed in locations of known accuracy (for instance, placing a control point at the precise location of a street intersection would be wiser than placing one within a large park space). Creating control points that are too close together and do not collectively represent the entire span of the map, or placing inaccurate control points, runs the risk of producing error in a transformation and increasing RMS error as a result. Human error when placing seemingly high-quality control points can lead to control points being inaccurately placed. Such errors can be a result of fatigue, vision problems, shaky hands, or simple misjudgment (Sloan & Zeiders, 1999-2023a).

Finally, following the metaphor of a foreign language translator, a novel of intricately written prose in a language similar to the target language of conversion could be easier to translate than a muffled audio file of a dissimilar language. In other words, having a strong starting point is much better than having a weak starting point, or none at all. If satellite imagery has some sort of inherent location system, this may help with a more accurate conversion, as the control points could be mapped between two thorough coordinate systems. This is not a given, as coordinate systems can vary greatly, but it could be a more promising situation when compared to a photograph containing no coordinate system at all. If that photograph were a very clear picture of roadways, there may be hope to place accurate control points. Better yet, if the photograph were orthorectified, this would lend considerably more accuracy stepping into the georeferencing process. Orthorectified images utilize a combination of sensors and reported elevation data to best prepare images for later georeferencing within GIS systems (Esri Insider, 2016). Overall, this activity was a hands-on way of learning about such considerations in the process of georeferencing raster images.

References

Esri (n.d.-a). *Calculate transformation errors (editing)*. ArcGIS Pro. Retrieved January 6, 2023 from https://pro.arcgis.com/en/pro-app/latest/tool-reference/editing/calculate-transformation-errors.htm.

Esri (n.d.-b). *Overview of georeferencing*. ArcGIS Pro. Retrieved January 9, 2023 from https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/overview-of-georeferencing.htm.

Esri Insider (2016, June 29). What is orthorectified imagery?. Esri. Retrieved January 9. 2023 from https://www.esri.com/about/newsroom/insider/what-is-orthorectified-imagery/.

Sloan, J. & Zeiders, M. (1999-2023a). Lesson 1: Concept gallery. In *GEOG483 GIS Database Development*, The Pennsylvania State University World Campus Certificate/MGIS Programs in GIS. Retrieved January 6, 2023 from https://psu.instructure.com/courses/2224681/modules/items/37463373.

Sloan, J. & Zeiders, M. (1999-2023b). Lesson 1: Create the first map. In *GEOG483 GIS Database Development*, The Pennsylvania State University World Campus Certificate/MGIS Programs in GIS. Retrieved January 6, 2023 from https://psu.instructure.com/courses/2224681/modules/items/37463377.

Sloan, J.& Zeiders, M. (1999-2023c). Lesson 1: Introduction and action list. In *GEOG483 GIS Database Development*, The Pennsylvania State University World Campus Certificate/MGIS Programs in GIS. Retrieved January 6, 2023 from https://psu.instructure.com/courses/2224681/modules/items/37463372.

Sloan, J.& Zeiders, M. (1999-2023d). Lesson 1 Part III: Georeference using a target layer. In *GEOG483 GIS Database Development*, The Pennsylvania State University World Campus Certificate/MGIS Programs in GIS. Retrieved January 6, 2023 from https://psu.instructure.com/courses/2224681/modules/items/37463372.