Lab 2: Georeferencing

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GEOG 329 B01

February 27th, 2019

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1.1 Zero-order Polynomial

A zero-order polynomial shift requires a minimum of one control point in order to georeference an image (ESRI, 2016). A zero-order polynomial shift is typically only used on data that is already georeferenced and only requires an adjustment (ESRI,2016). Zero-order polynomials can only shift an image in the x and y directions and cannot warp or stretch the image.

1.2 First-order or Affine Transformation

A first-order polynomial transformation requires a minimum of six control points to georeference an image (ESRI, 2016). A first-order polynomial transformation is able to shift, stretch, scale and rotate an image in the x and y directions (ESRI, 2016). This transformation is commonly used to georeference images and preserves straight lines as it does not warp the image in the x,y or z directions.

1.3 Third or Higher order Polynomial

A third-order polynomial transformation requires a minimum of 10 control points to georeference an image, and higher-order polynomials such as fourth and fifth degree will require more respectively (ESRI, 2016). A third-order or higher polynomial transformation is able to shift, stretch, scale, rotate and warp images in the x, y and z directions. These transformations are rarely used however they can be effective when a three dimensional representation is required.

1.4 Spline Transformation

A spline transformation requires a minimum of 10 control points in order to georeference an image (ESRI, 2016). A spline transformation aims at maximizing local accuracy at the cost of global accuracy. A spline transformation turns source control points into exact control points, however the distances and areas between the points are not guaranteed to be accurate (ESRI, 2016). This transformation is useful when the accuracy of certain points of interest needs to be high and the surrounding areas are not as important.

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The first-order or affine transformations were used to georeference the two historical maps (Figure 1 and Figure 2) in this study. The first-order was chosen because it was able to adequately georeference the image without drastically warping the surface and without making the map difficult to interpret as the higher-order transformations would. Both maps used ten control points in order for all transformations to be compared and the first-order transformation was deemed the most suitable. Ten points is not necessary for a first-order polynomial transformation as most of the changes occur within the first six control points (Sonntag, 2017). The highest RMSE's in theory should occur within the first six control points and the additional points will introduce little change. This is not conclusive from Tables 1 and 2 and the additional points were added so all transformations could be compared.

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Increasing the number of control points on a first-order polynomial transformation past six points should minimally change the alignment of an image. Table 1 and Table 2 do not conclusively show this as the residuals for 7, 8 , 9 and 10 are similar yet slight smaller on average then the first 6. The transformation that benefits most from more control points is the spline transformation as the more points that are placed, the greater the accuracy as source control points are turned into exact locations when georeferencing (Sonntag, 2017).

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Table 1 and Table 2 show the RMSE's and positions of the control points for the 1860 and 1903 maps of Victoria respectively. The 1860 small-scale map had an overall RMS error forward of 32.3342 meters and the 1903 large-scale map had an overall RMS error forward of 12.7838 meters.

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Large-scale and small-scale maps can have a large effect an overall RMSE. In a small-scale map such as the 1860 map shown in Figure 1, a one centimeter residual on the computer screen may be upwards of 50 meters, where as alternatively in a large-scale map such as the 1903 map shown in Figure 2 the same apparent residual may only be 5 meters. In addition, upon the final rectify the system will attempt to minimize all residuals to align the image and this is much easier to do without drastic warping or stretching if the control points cover a smaller area. Another factor that greatly affects overall RMSE is the survey quality of the map. Since these maps are historical the survey standards certainly would not have been as high which introduces uncertainty into the analysis.

6 Figures and Tables

Table 1: Control points and RMSE of Georeferenced 1860 Map of Victoria, BC, Canada

Link	X Source	Y Source	X Map	Y Map	Residual_x	Residual_y	Residual
1	3379.405556	-4274.809935	472406.065581	5363934.374557	0.0630737	-8.94931	8.94953
2	2875.534783	-4458.925603	471315.426611	5363440.044230	-9.72926	7.15144	12.0748
3	4311.821164	-5666.207957	474170.603066	5361164.500066	12.1833	23.4334	26.4113
4	3600.920814	-4527.198909	472812.652275	5363433.522338	-20.8525	-13.1536	24.6545
5	3678.495448	-4412.390586	473002.721569	5363751.229406	-9.55191	38.9373	40.0918
6	3946.547617	-4763.003480	473505.400872	5362958.527832	-17.7226	-55.0017	57.7865
7	3027.344461	-4663.076380	471632.637145	5363046.419271	18.963	21.3439	28.551
8	3463.616118	-4675.033790	472522.819662	5363053.180151	-2.18852	-43.1423	43.1978
9	4092.999602	-4443.057336	473874.893622	5363754.410451	-0.482612	16.1878	16.195
10	3668.301266	-4058.665420	473070.840448	5364488.378619	29.3181	13.1932	32.1498

Total RMSE Forward: 32.3342 meters
Transformation: First-order Polynomial (Affine)

Table 2: Control points and RMSE of georeferenced 1903 Fire Insurance Map of Victoria, BC, Canada

Link	X Source	Y Source	X Map	Y Map	Residual_x	Residual_y	Residual
1	4.554762	18.596541	472842.287317	5364097.505745	-8.17819	4.06007	9.13055
2	17.542016	18.754497	473051.000546	5364069.999267	4.49075	-18.4587	18.9971
3	4.446555	10.756650	472859.001062	5363980.000560	7.61991	13.1079	15.1618
4	17.173731	8.380394	473033.394243	5363937.891428	-10.9284	16.7636	20.0112
5	3.320192	4.643016	472841.999532	5363853.000617	5.63733	-15.8094	16.7845
6	15.508737	2.560418	473027.002330	5363824.998430	5.92702	-3.10213	6.68975
7	17.400046	12.502686	473052.000278	5363990.002636	5.60107	2.43031	6.1056
8	9.443074	3.503687	472920.997966	5363841.996571	-8.18465	-4.85892	9.51828
9	10.774978	9.656260	472940.339711	5363951.127633	-6.95267	5.67997	8.97785
10	11.348678	12.463998	472960.009457	5363990.647516	4.96778	0.187342	4.97132

Total RMSE Forward: 12.7838 meters
Transformation: First-order Polynomial (Affine)

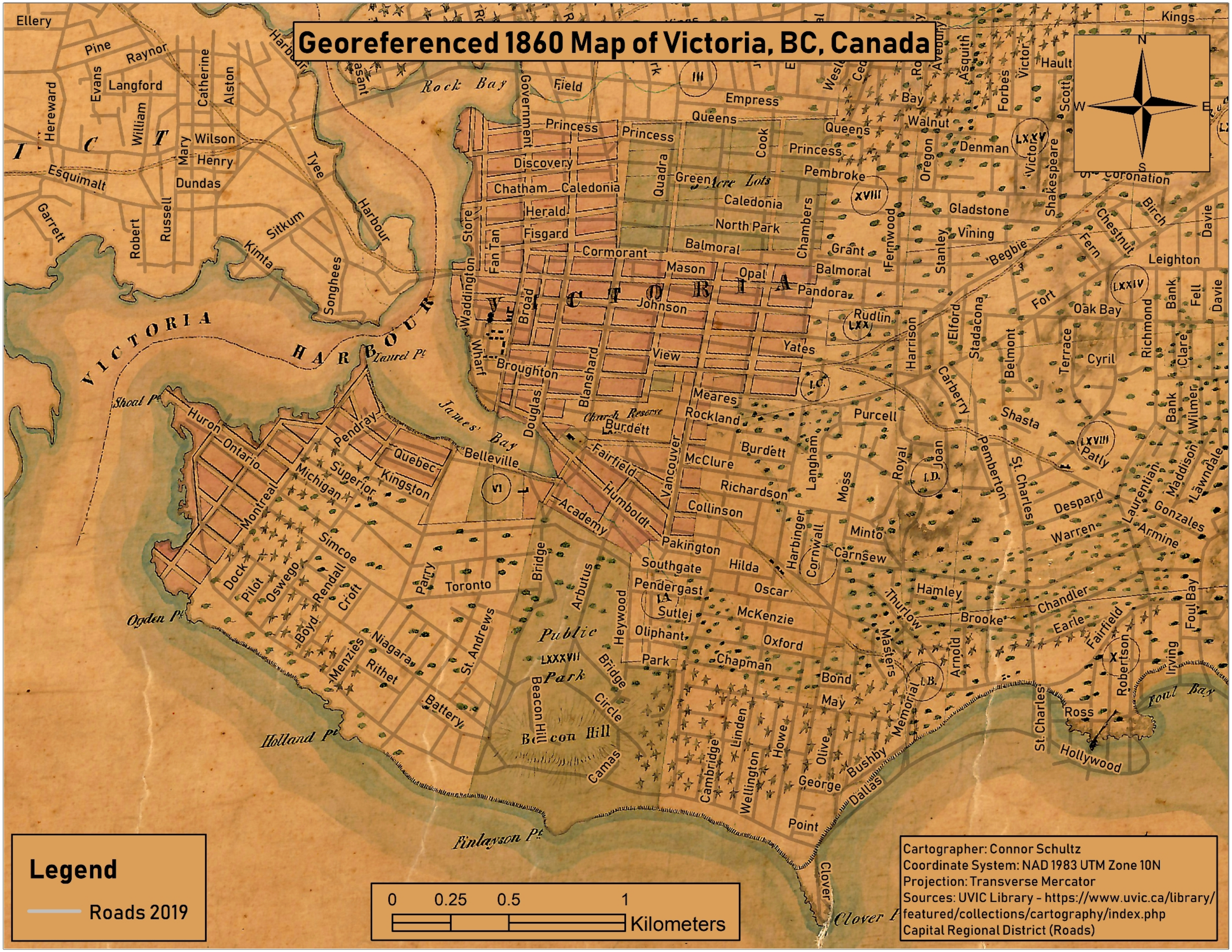

Figure 1: Georeferenced historical map of Downtown Victoria Area in 1860

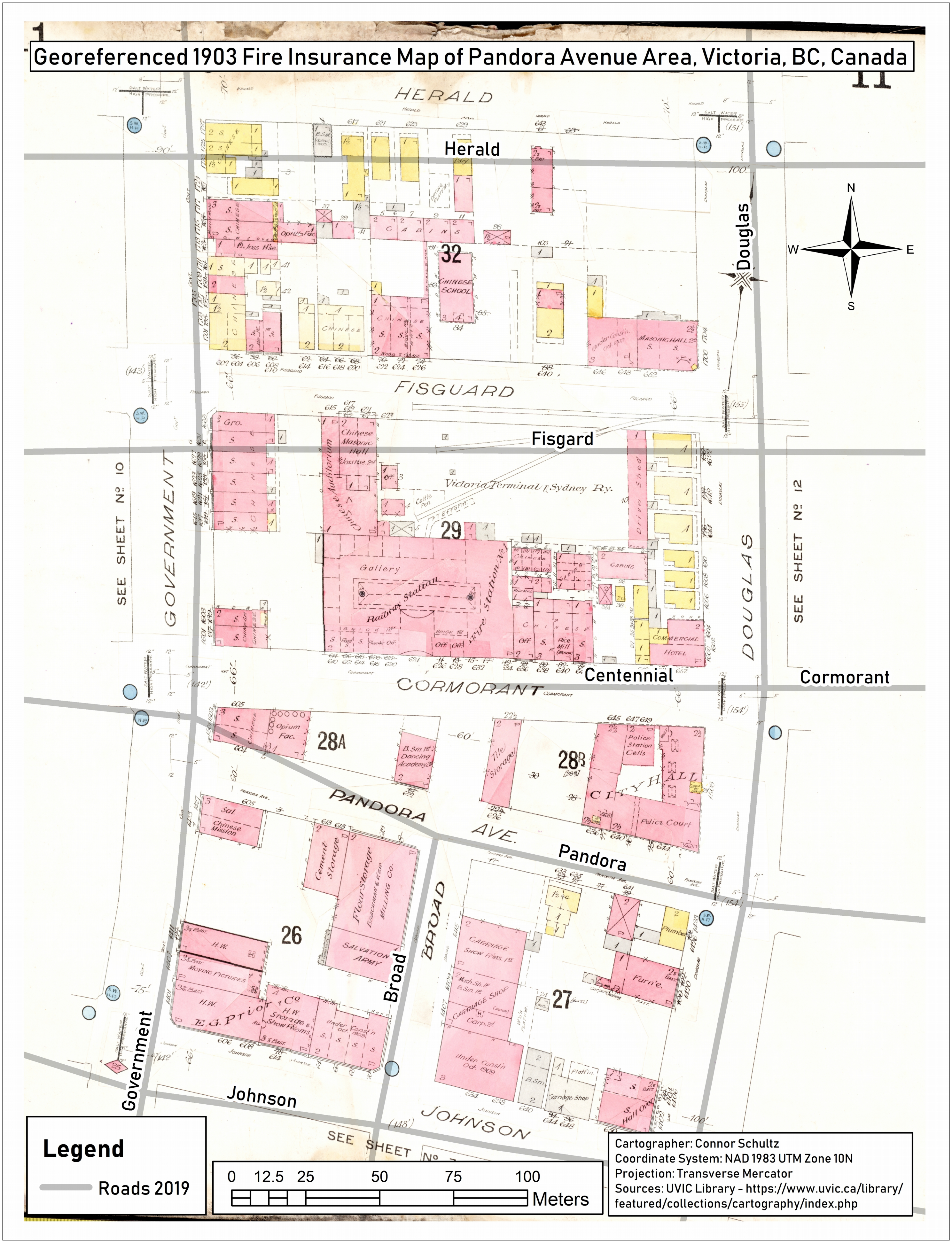

Figure 2: Georeferenced historical fire insurance map in Downtown area of Victoria in 1903

7 References

ESRI, (2016). Fundamentals of georeferencing a raster dataset.. Retrieved February 25, 2019, from http://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/fundamentals-for-georeferencing-a-raster-dataset.htm

Sonntag, J. (2017, March 13). Understanding Transformations within Geo-referencing: 1st Order and Spline. Retrieved February 25, 2019, from https://sites.temple.edu/psmgis/2017/03/13/understanding-transformations-within-geo-referencing-1st-order-and-spline/