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MapAnalyst - A digital tool for the analysis of the planimetric accuracy of historical maps

Keywords: Planimetric accuracy; geometric distortion; cartometry; MapAnalyst; distortion grid; history of cartography.

Summary

Modern digital techniques have the potential to greatly simplify the analysis and visualization of geometric properties of historical maps. This paper first outlines the purpose and goals of an analysis of a historical map's planimetric accuracy, and identifies possible sources for geometrical imprecision. It then treats important considerations that the map historian should keep in mind, when transforming two sets of control points into a common coordinate system, which is a prerequisite to the generation of most accuracy visualizations. Important aspects for publishing accuracy analysis results are listed in order to guarantee the comparability of the results. MapAnalyst is then presented, a new user-friendly software application for the automatic generation of accuracy visualizations. Using the freely available MapAnalyst software, the map historian identifies complementary sets of control points on the historical map and a modern reference map. MapAnalyst then automatically generates a variety of visualizations illustrating the map's planimetric accuracy. The paper concludes with ideas for new visualization techniques that could assist the map historian to more easily grasp the geometric characteristics of historical maps.

Analysis of the planimetric accuracy of historical maps

The purpose of a cartometric analysis of an historical map is to investigate its planimetric accuracy – the extent to which distances and bearings between identifiable objects coincide with their true value. For graphically visualizing a map's geometric accuracy, map historians have developed various techniques that illustrate the results of cartometric analyses, for example error vectors or distortion grids. When interpreting an accuracy visualization, one must keep in mind that the visualization reflects geometric imprecision induced by two sources: First, the cartographer may have committed errors at the different stages of map production (e.g. surveying and data compilation, map drawing, and reproduction); second, it is well known that paper or other media which store maps are not inert materials, i.e. shrinking and stretching distort the map's geometry. In some special cases, the distortions can be determined and software tools may even allow for rectifying digital scans of these maps. Most often, however, the differentiation between these two error sources is not possible. Hence, it is appropriate to question the usefulness of accuracy visualizations for historical maps. Why should we analyze a historical map's accuracy and produce visualizations thereof? Blakemore and Harley (1980) answer this question by identifying three possible applications.

? First, a map historian may accomplish a series of comparative analysis to demonstrate the technical virtuosity of the cartographer(s), or to determine how accuracy changed over time for a given area.

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? Second, a cartometric study may yield information about geodetic bases, techniques of surveying, the projection, or source maps used to compile the map.
? Third, an accuracy analysis can assist a historical geographer when extracting, interpreting, and evaluating the information quality of a historical map.

Transformation of the old and the new map to a common coordinate system

Most accuracy visualizations are derived from two sets of control points. One set identifies locations in the old map, and the other set localizes the corresponding positions in a new reference map. Before accuracy visualizations can be generated, the two point sets must share a common coordinate system. This implies a geometrical transformation of one point set to the coordinate space of the other one. Engineers and researches in surveying, geographical information science or computer graphics usually accomplish this by using affine transformations. Map historians can use algorithms and techniques developed by these engineering areas, for example the least-square method. The least-square method determines the transformation by globally minimizing the (squared) distances between the two point sets.
An important aspect of affine transformations is the direction of transformation. Should we transform the old map to the new reference map – or should we transform the reference map to the old map? The numerical and graphical results (e.g. distortion grids) vary considerably depending on this choice (see figure 1 for an example). While applications in geodesy often use the general Gauss-Helmert model that treats both coordinate systems as imperfect, the computationally simpler Gauss-Markov model that only alters the coordinate system of one map is entirely sufficient for our purposes (Beineke 2005). With this model, however, the transformation must convert the new reference map to the coordinate system of the old map to be correct in a mathematically sense. Thus, the recommended way is to generate accuracy graphics in the coordinate system of the old map.
For further analysis it is sometimes desirable to deviate from this rule and generate the graphics in the coordinate system of the new map. This facilitates comparison with modern geo-referenced data; for example, a geo-referenced digital elevation model could be used to detect correlations between the historical map's accuracy with terrain elevation. The same approach can be chosen to compare multiple historical maps: The map historian could generate a distortion grid for each historical map and visually overlay and compare them in the coordinate system of the reference map. Hence, whether the visualizations are generated for the coordinate system of the old map or of the new reference map is not the crucial factor. What is important, though, is that the scale factor and the rotation angle of a historical map are determined by an affine transformation, and that this transformation follows the mathematically correct way, i.e. it must transform the new reference map to the old map. The correct scale factor is then the inverse of the scale factor of the affine transformation.
The results of two analyses are only comparable when the same visualizations and statistical indicators, as well as the same methods and algorithms for their computation are used. Thus, in order to be able to compare the scale factors and the rotation angles of historical maps, the map historian should bear the following points in mind:
? Compute scale factors and rotation angles using affine transformations with the least-square methods.
? The affine transformation must convert coordinates from the modern reference map to the historical map.

? Use as much control points as there can be possibly identified in the historical map.
? Together with the scale factor and the rotation angle, also report on the type of affine transformation used, the number of control points, the standard deviation and the mean positional error of the control points.

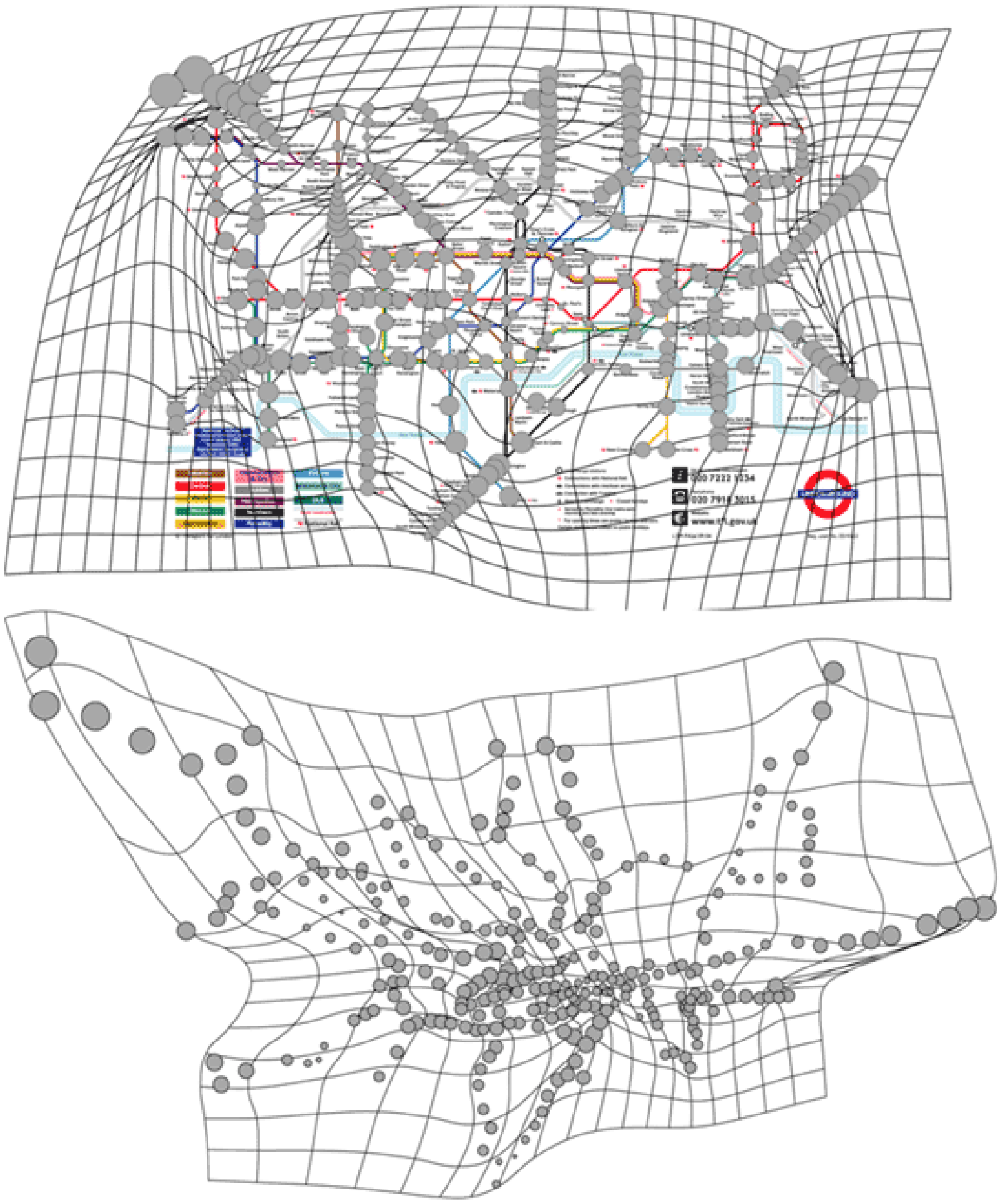

Figure 1. Distortion grids for the London Underground Map in the coordinate system of the analyzed map (top), and in the coordinate system of the reference map (bottom) (Jenny 2006).
Circular diagrams represent the differences between the two sets of control points.
Visualizations generated with MapAnalyst.

MapAnalyst

The cartometric analysis of historical maps is undoubtedly faster and more reliable with computer software than with traditional manual methods. Despite the fact that a variety of visualizations and statistical values can be computed in short time, no user-friendly software has been widely available up to the present. Most of the existing applications generally were not easily available, required a particular operating system, were partially based on expensive GIS, could not be easily extended, or did not provide an easy-to-use interface. In short, to successfully analyze a map, the map historian needed knowledge in the fields of programming, mathematics, computer graphics, and error theory. This need for such a software package inspired the Institute of Cartography of ETH Zurich to develop MapAnalyst, a user-friendly software that is freely available for interested map historians at http://mapanalyst.cartography.ch (Jenny and Weber 2005, Jenny et. al. 2007). MapAnalyst is a Java application and runs on all major computer platforms; for example, figure 2 shows a screenshot of MapAnalyst running on Mac OS X. The software allows for the efficient identification and management of control points in a historical map and in a reference map, and computes error vectors, distortion grids and other accuracy visualisations. There exists a wide palette of parameters to fine-tune the generated graphics, which can be exported to standard graphics file formats. MapAnalyst also computes the historical map's scale, rotation angle and other statistical indicators that are required to compare the accuracy of historical maps.

Possible extensions and directions of future research

While MapAnalyst offers many interesting options and tools for the accuracy analysis of historical maps, map historians may imagine alternative techniques for the analysis of old maps. Indeed, the open-source architecture of MapAnalyst allows interested map historians to easily customize and expand its functionality. Determining the projection of historical maps is an old problem that has been bothering map historians since the beginning of historical map research. A user friendly software that automatically compares a series of map projections with varying parameters and finally presents the best fits, would greatly simplify the investigation of historical maps, and possibly even shed new light on old unsolved problems in the history of cartography (e.g. the projection of the Portolan maps, see Tobler 1965, Balletti and Boutoura 2001, Boutoura 2006).

Most visualization techniques used by map historians were developed before personal computers became widely available. Modern computer technology offers interesting options for the creation of alternative visualizations of the accuracy of historical maps. Possible areas of future research by map historians could be the visualization of accuracy using the third dimension. For example, figure 3 shows how scale varies in a historical map: elevations show compressed areas (smaller scale) and depressions show dilated areas (larger scale). The thick black lines are the isolines of the mean scale of the map, and the red dots locate the control points used to compute the variation of scale. The map historian could possibly gain new insights into the characteristics of a map if specialized tools would allow for the automatic production of similar navigable views in three-dimensions that could be explored interactively.

An additional area where one can identify the necessity for further research is the problem of determining and visualizing the local reliability of accuracy visualization. For example, when control points are unequally distributed, the derived distortion grid will show more undulations in areas where the density of control points is high – whereas in areas with a lower density of points, the distortion grid will appear smoother and imply a higher accuracy. Though, the contrary might be the case: Mountainous areas are usually only loosely populated and hence fewer anthropogenic objects with clearly identifiable locations are found in these areas. Additionally, the planimetric quality in mountainous areas is often much lower than in flat areas due to topographical obstacles. Hence, the distortion grid shows regularly shaped meshes in a mountainous area, although the geometric accuracy in this area is most probably worse than in flatter areas. This problem is of course not limited to distortion grids, but affects any type of accuracy visualization. Methods for computing and visualizing the local variability of the reliability of an accuracy analysis itself should therefore be developed.

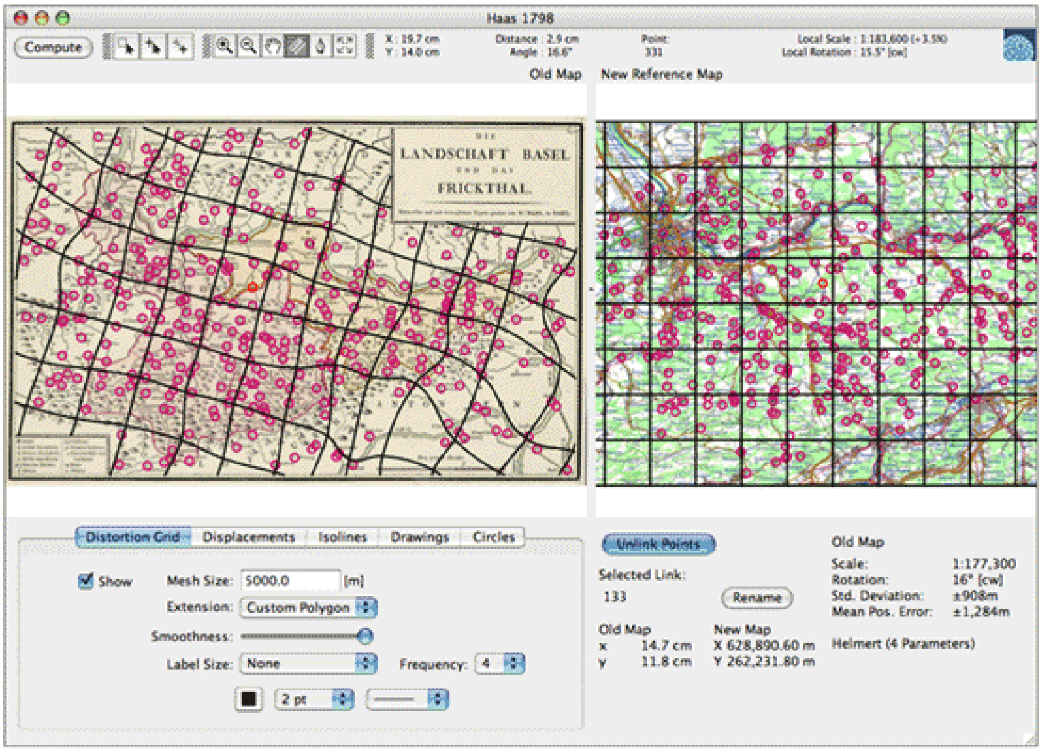

Figure 2. Screenshot of MapAnalyst's user interface.

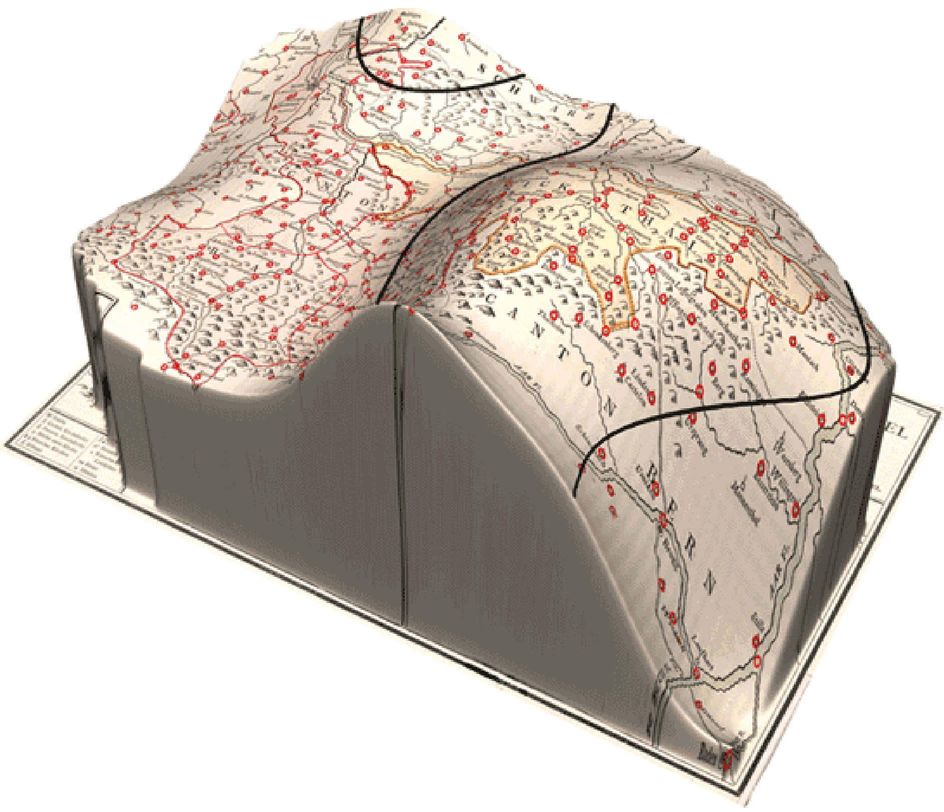

Figure 3. Elevations: compressed areas (smaller scale); depressions: dilated areas (larger scale); black lines: isolines of mean scale; red dots: control points. Map: W. Haas, Die Landschaft Basel und das Frickthal (1798). Size 21 x 34 cm, mean scale: 1:177,300, mapped area: northwestern Switzerland. Rendering with a customized version of MapAnalyst and Bryce 5.5.

Distortion grids are not only used by map historians, but also in other areas, for example where geometrical changes in time are visualized. One example is the visualization of the palaeontological evolution of skeletons (Fig. 4); another example is the visualization of changes in travel time, as in figure 5. Various fields of research could therefore benefit of a mutual exchange of techniques for the computation of distortion grids.

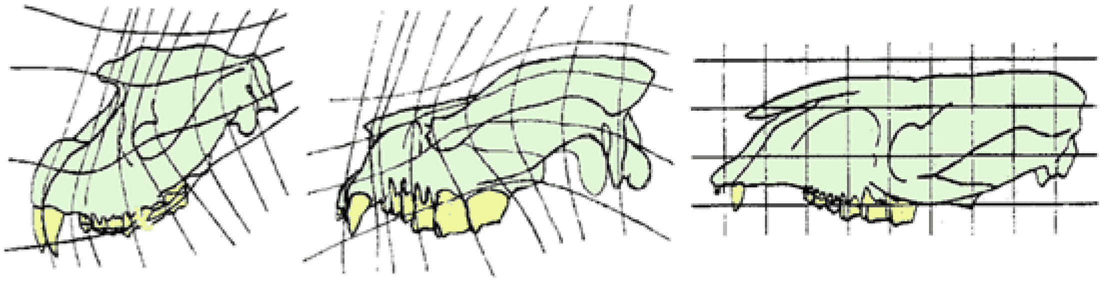

Figure 4. Distortion grid showing cranial evolution (Wall and Heinbaugh 1999).

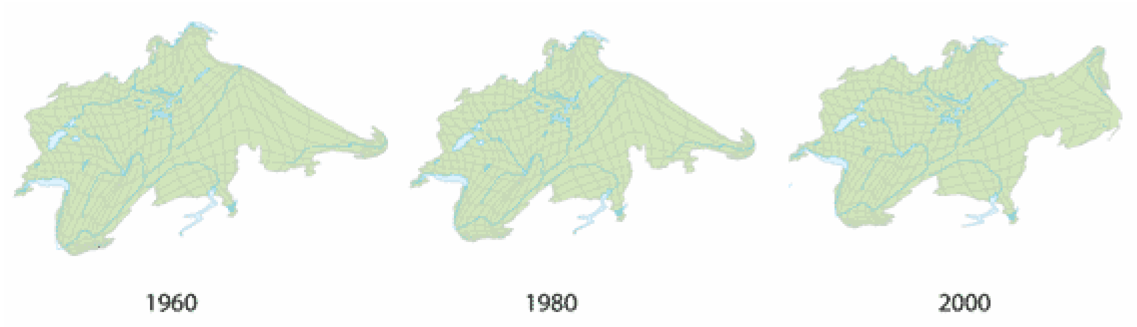

Figure 5. The development of the traveling time in Switzerland by public transport (Axhausen and Hurni 2005).

Conclusion

MapAnalyst offers the map historian exciting new tools for the planimetric analysis of historical maps. Compared to manual techniques, MapAnalyst greatly simplifies and accelerates the analysis, and increases the reliability of the results. With MapAnalyst, a variety of complementary visualizations can be generated within very short time. Its user interface is easy to learn, and the generated graphics can be exported to widely used graphics formats.

While MapAnalyst offers interesting options for the analysis and visualization of the accuracy of historical maps, there are still many areas where one can imagine improvements to the underlying methods. The chapter describing directions of future research mentioned the need for improved tools to automatically determine the projection of a map. Another important issue is the need for metadata describing the accuracy of visualization itself, i.e. we need methods to illustrate the local reliability of our visualizations. Interactive three-dimensional representations also offer exciting new perspectives for the exploration of the geometrical characteristics of historical maps. An intensive exchange of ideas with experts of other scientific areas, who visualize spatial and non-spatial phenomena with similar techniques as described here, could provide additional ideas and valuable tools for the benefit of map historians.

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