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Georeference in the analysis of the geometric content of early maps

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Summary

The use of geographic information systems (GIS) for the management and the analysis of diachronic geographical and territorial spatial distributed data is the main concern of this paper. This process of obtaining historical information through the reading of spatial changes as depicted in early maps and historical mapping in general is of main importance in cartographic heritage approach. In the study of the development of a territory, historical cartography plays an important role. Maps are offering valuable information related not only to spatial reference but also with respect to the time they are referred. In most cases, due to the scarcity of the geometric referencing and the lack of other relevant information concerning their projective properties, early maps are rather difficult to be inserted into routine GIS at least in a conventional sense. The aim of this research is to show how the metrical content of historical maps (particularly portolan charts, isolarii, and perspective views of towns from the 15th and 16th century) can be recovered using analyses, which lead to definitions of some efficient methodologies for their quantitative analysis.

This implies the use procedures, which are based on the use of transformations known in modern mapping sciences, which are distinguished as *global* (projective, affine, similarity, polynomial) or as *local* (finite element, point based or feature based warping).

Introduction

Historic cartography and early maps has been, for long time, a privileged domain of study almost exclusively for historians and not so much for cartographers and specialists in modern mapping sciences and technologies. Therefore, the early map has been considered as a typical archive document, a testimony of the past, of territories and cities in diverse historical periods. In the last years due to the advancements of new computational technologies the study of the metric properties of early maps, the numerical approach to the issue has gained terrain. Old maps are no longer considered as passive graphic documents offering the grounds for historic, artistic, sociological or literary studies but become representations containing a lot of spatially referenced information affined to geometry, in general, and to geometry-related entities, in particular (Fuse, Shimizu and Morichi, 1998). This modern possibility, thanks to modern technologies, offers new tools in the study of early cartography and maps opening new possibilities in cartographic heritage (Guerra et al, 1999). In this paper the geometric analysis of early maps is based on an approach, which is common in current cartography according to which the extraction of territorial

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information is spatially referenced, or *georeferenced* (see, e.g., Balletti, Guerra and Monti 2000, Balletti 2000a).

But how is it possible to georeference early maps? Especially when this map-family presents, in the vast majority of cases, some common characteristics related to the uncertain metrical map properties, as it is the undefined system of reference, the non-constant or even unknown scale of representation, the unknown units of measure, the veiled, non-existing or approximate projection system, the scarcity of reference surface definition, the semantic content which is difficult to interpret.

These entire shortcomings which are all or partially emerging when one tries to introduce early maps into a GIS environment, lead to the necessity of adopting special strategies which could be diverse in each particular case. An early map presents different levels of point and relational accuracy in planimety and topography. Geometric proportions, conventions and hierarchies are varying from map to map even by the same mapmaker. All these should be identified and distinguished by the modern user who has, in addition, the task to classify them and evaluate according to the early map typology, i.e. in a sea chart, distances, coastlines and bearings are much more accurate than in some other map with different function. Harbours and river mouths are positioned with care and, often, magnified regarding the general map scale of the chart. On the other hand the coasts are represented in a conventional way as well as the topography of the hinterland (such as mountains or representative architectures of a place).

Two types of historic cartographic material are considered here: In the first, maps and plans are of pure cartographic interest made for technical and public purposes as they represent geographic outlines, respecting the proportional relations. In this case, the geographical configuration is in orthogonal projection, while topographical characteristics are depicted in perspective or in front views, according to a schematic conventional look. In the second type belong maps and plans for didactic purposes, mainly for providing illustrations rather than for offering geographical information. But in any case, even such, they are spatial representations of the territory and therefore are contain geoinformation.

In any case, the important issue is that, in general, assigning a proper metric support to all these cartographic documents of the past is very important for the analysis of the geometric content and modern cartographic use. This is important not only to assist the old map as a document for the archives, having a qualitative value, but also to make it useful and valuable for modern cartographic implementations for the extraction of quantitative information.

The idea, which governs the whole concept and supports the research in this direction is that these old map-work has been created in order to serve as an operative and practical tool and that it was used as such. This means that geometry was always present in different ways and in various implementations. Only the *metric* definitions and properties have changed over the periods of mapmaking and, of course, the level of the accuracy threshold, which means the level of the technology of measurements involved in mapping practice and the precision achieved each time.

Georeference

The georeference is applied here as the process, which assigns to non-metrical maps (usually the early maps) a 'metric reference' from the actual geospace or its mappings. When the metric reference is related to the system of earth coordinates or their map-projection counterparts, it is called *georeference.*
This assignment is done with the use of geometric *transformations* applied to points of the non-metrical map with known or given coordinates. These points are called *control points*. The result of the transformation is that all the other points of the non-metrical map are then getting coordinates which are 'predicted' (through proper interpolation functions) from the known or given coordinates of the control points. It is called *global* the transformation due to which the best possible metric reference is assigned to the un-georeferenced map, without keeping unaltered, after the transformation, the coordinates of the control points. On the other hand, it is called *local* the transformation, which keeps unchanged the coordinates of the control points after the transformation. The main characteristics of global transformations can be summarized in the next few steps: The transformation is based on parameters which are calculated before the transformation, with the aid of the known coordinates of the control points; the parameters are valid for any point of the map, in other words they concern the map globally; the larger is the number of the control points used for the computation of the parameters the better statistical solution is achieved; a statistical estimate of the transformation results is among the output of the process in terms of regular statistical quantities.

Global transformation

The global transformations are derived from the well-known full polynomial system of equations

$$X_k = \sum_{i=0}^{m} \sum_{j=0}^{n} a_{ij} x_k^i y_k^j \,, \quad Y_k = \sum_{i=0}^{m} \sum_{j=0}^{n} b_{ij} x_k^i y_k^j$$

where the summation convention in *i,j* is applied up to the order of the polynomial *m,n*. This system relates the coordinates of the control points X_k and Y_k in the geospace (or its mappings) with their coordinates x_k and y_k on the map to be georeferenced, where k ($k=1,2,3,\ldots$) is the control point involved in the transformation. For each point k a set of two equations are taken and the required value of k for the solution of the system, depends on the order of the polynomial used. Today these coordinates x_k and y_k are obtained digitally form the map to be georeferenced. The quantities a_{ij} and b_{ij}, are the unknown parameters which are obtained by the transformation process and are valid all over the area. In a computational process the number of the control points should be always more that the unknown parameters. In the case in which only linear terms are taken into consideration, the above system is providing the linear transformations commonly used in mapping disciplines, known as *conformal*, *affine* and *projective*. The use of non-linear terms provides the higher order *polynomial transformations* with most used that of the second order.

Local transformations

The local transformations are those in which the unknown parameters of the transformation are calculated for a small area close to the control point or for each single control point having thus, a local validity. In the first case belongs the *finite element* transformation in which the whole area to be transformed is divided in a mesh of triangles with the control points as the vertices of the triangles (here the Delaunay triangulation is followed, because of the proper configuration of the resulting triangles). Then, for each triangular area defined by the vertices of the corresponding three control points, an affine transformation is applied, and the parameters obtained are valid within the specific triangular area. The smaller the triangular areas of the mesh the better are the results. This, requires and great enough number of control points.
In the second type of local transformations belong the ones based on conditions, which force the points (or features) on the surface to be transformed to fit exactly to the corresponding control points (or control features). Such transformations are usually known as *point based warping* and *feature based warping*.

Some applications

In order to illustrate the methods mentioned above, three examples are used from the early map-typologies of the Venetian cartographic heritage. The first comes from the isolarii tradition, the second concerns a portolan nautical map and the third the perspective city map of Venice by Jacoppo de' Barbari.

Bordone's Crete

The first example, from the domain of the isolarii, shows how the simplest possible transformation can be applied in studying the rotation of a map without changing at all its shape. In Fig. 1, Bordone's depiction of Crete, from his Isolario from the early 16th century, is georeferenced and transformed to fit optimally to a modern map, keeping unaltered its shape. The transformation used here is a conformal transformation of the global type.
In this case no deformation analysis can be done since the transformation regards only a single orientation issue with respect to the actual North, which here is tilted 6 degrees clockwise. If the interest is focused on the deformational pattern of this Bordone depiction of Crete, then a point wise warping transformation is applied of the local type. In Fig. 2 the original shape of the island is alterated in order to fit in the best possible way the actual coastline.

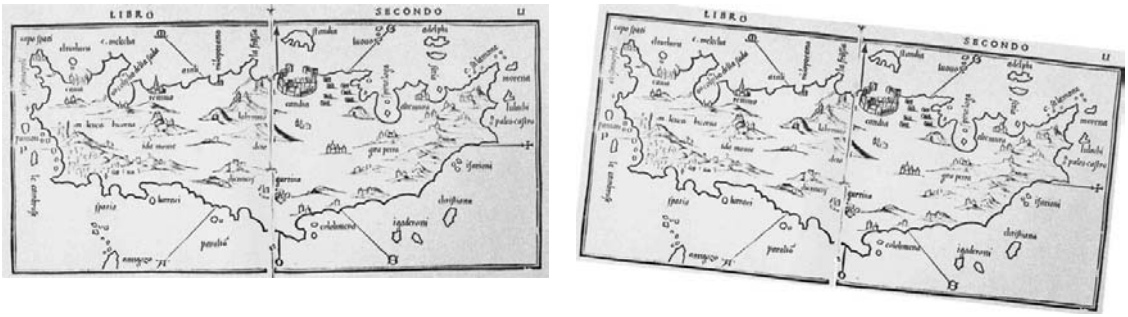

Figure 1. Bordone's Crete is rotated to fit optimally (conformal georeference) the actual orientation of the island, without deforming the shape as depicted in the original map.

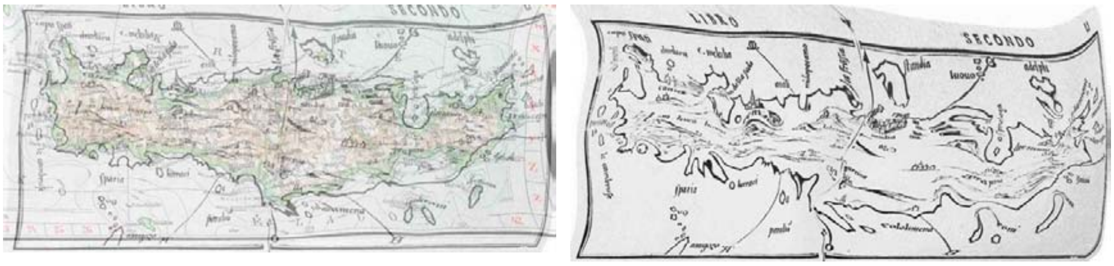

Figure 2. Bordone's Crete is deformed to fit optimally the actual coastline (point-wise exact georeference).

Sideri's East Mediterranean

The second application concerns the study of portolan nautical maps. The 16^{th} century Sideri's representation of East Mediterranean, from the post-Mercator period, has taken as a pilot study to investigate, first (Balletti 2000b) the conformal fitting of the coastline to the actual counterpart (Fig. 3) and second the compliance of the 'rose of the wind' radial pattern, dominant in this type of maps, with the actual alignment of the meridians and parallels (Fig.4). Even if portolan maps were thought as maps without a projection reference, the lack of clear and visible geographic framing in terms of geographic coordinates, do not necessarily imply the lack of, or the non-relation with, a projective system. The results given in a previous research (Boutoura, 2000), on the relation between the 'rays' of the wind roses and the geographic graticule in portolan maps, is confirmed here as it is shown in Fig. 4.

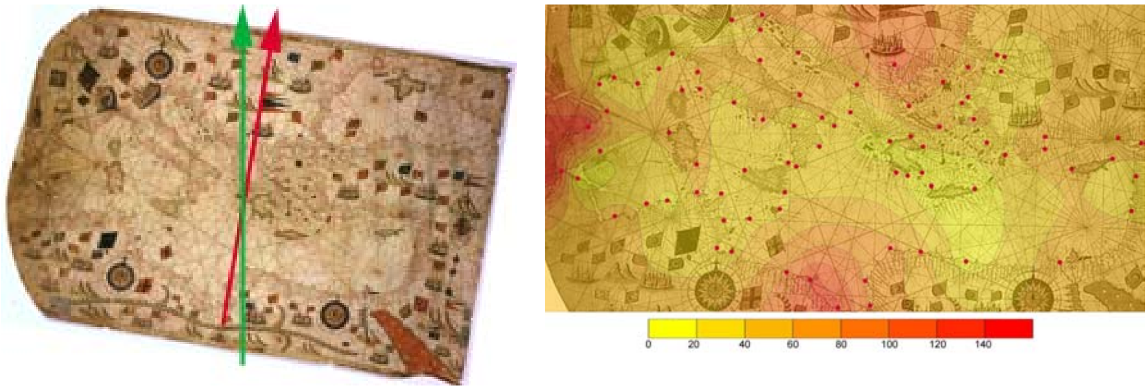

Figure 3. Left: The Sideri's portolan map after the conformal fitting to a modern map in Mercator's projection is rotated 9 degrees clockwise. Right: The residuals of the control points, after the conformal fitting, are illustrated. The areas with best fitting (less residuals) are in the area of the Ionian Islands, Peloponnese and Crete.

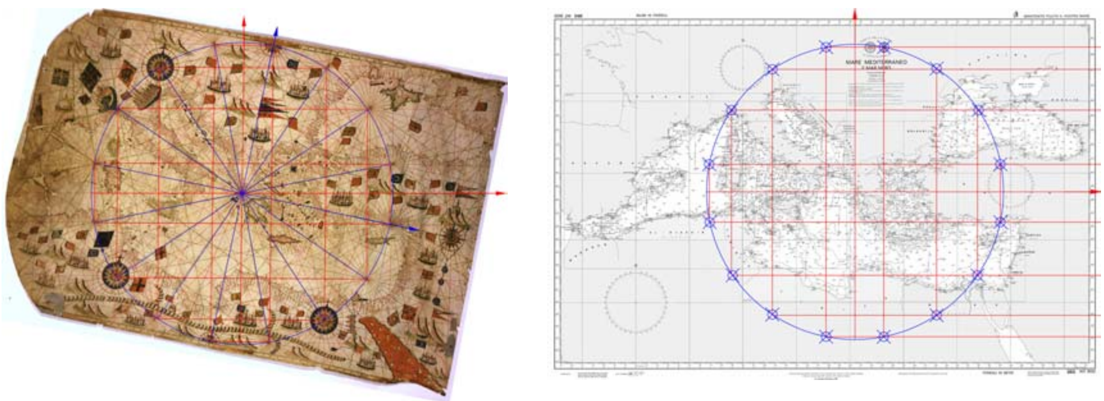

Figure 4. Left: The central 'rose of the winds' dominant in Sideri's portolan map. The map obeys a 9 degrees clockwise rotation after the conformal fitting to a modern map in Mercator's projection. Right: The modern map in Mercator's projection, where the 'rose of the winds' is conformally projected from Sideri's map. The relation between the roses on the perimetre of the central rose and the actual parallels and meridians, is evident.

de' Barbari's Venice

The third example is applied to de' Barbari's perspective map of Venice (1500). This celebrated representation among the first of this type in the map history represents is a most exciting example of the new method of urban representation of the city based on perspective. For the georeference of the perspective map, a modern photomap of Venice is used to test a number of transformations. In Fig. 5 (centre) the photomap of Venice has been auto-transformed according to a perspective projection and this image is compared to the original map, Fig. 5 (top). Fig. 5 (bottom) shows the difference in perspective induced by de' Barbari's representation.

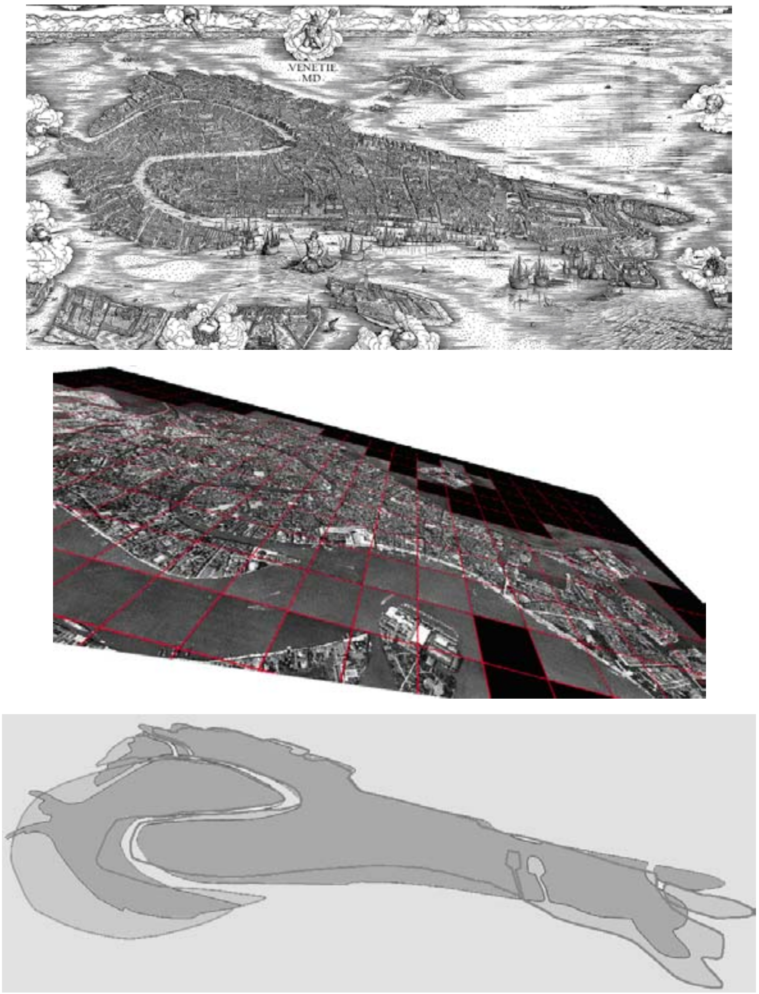

Figure 5. Top: The perspective view of Venice by de' Barbari's. Centre: A modern city photomap in a 'correct' perspective projection. Bottom: The perspective view by de' Barbari's (in grey shaded tone) with respect to the 'correct' perspective photomap.

The perspective alterations in the original city map can be shown also when transforming the perspective photomap into the original following the finite element transformation. In Fig. 6 the alterations in the alignment of the perspective lines are evident. This confirms the theory that the de' Barbari's map does not preserves full projectivity.

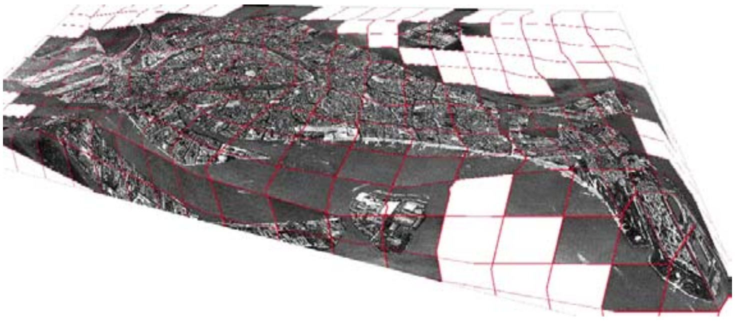

Figure 6. Finite elements transformation: applying this transformation, the new image of the photomap obtained has the same geometry of the de' Barbari one, but the irregular deformation of the grid underlines that the view is not a correct perspective.

References

Balletti C., F. Guerra, C.Monti (2000). Analitical methods and new technologies for geometrical analysis and georeferenced visualisation of historical maps. In *International Archives of Photogrammetry and Remote Sensing,* Vol.XXXII, Part 6W8/1, ISPRS WG VI/3 e WG IV/3, Ljubliana.

Balletti C. (2000a). Analytical and quantitative methods for the analysis of the geometrical content of historical cartography. In *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII, ISPRS WG V/5, Amsterdam.

Balletti C. (2000b). Metodi analitici e quantitative per lo studio del contenuto geometrico delle carte storiche. Tesi di dottorato di ricerca in scienze geodetiche e topografiche, XII ciclo, Politecnico di Milano.

Boutoura C. (2000). Scoperta di un il reticolato geografico in una carta nautica dell'Egeo del XVI secolo. In E. Livieratos (ed.) *Raggi di vento sul mare*. Thessaloniki: Hellenic National Centre for Maps and Cartographic Heritage.

Fuse T., E. Shimizu, S. Morichi (1998). A study on geometric correction of historical maps. In *International Archives of Photogrammetry and Remote Sensing*, Vol XXXII, Part 5, Hakodate.

Guerra, F., C. Balletti, C.Monti, E. Livieratos, C.Boutoura (1999). Studi ed elaborazioni informatiche e 'infografiche' sulla veduta prospettica di de'Barbari. In G. Romanelli, S. Biadene, C. Tonini (eds.) *A volo d'uccello, Jacopo de'Barbari e le rappresentazioni di città nell'Europa del Rinascimento*. Venezia: Arsenale editrice.