World Academy of Science, Engineering and Technology
International Journal of Civil and Architectural Engineering
Vol:4, No:6, 2010

Application of Geographic Information Systems (GIS) in the History of Cartography

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***Abstract*—** This paper discusses applications of a revolutionary information technology, Geographic Information Systems (GIS), in the field of the history of cartography by examples, including assessing accuracy of early maps, establishing a database of places and historical administrative units in history, integrating early maps in GIS or digital images, and analyzing social, political, and economic information related to production of early maps. GIS provides a new mean to evaluate the accuracy of early maps. Four basic steps using GIS for this type of study are discussed. In addition, several historical geographical information systems are introduced. These include China Historical Geographic Information Systems (CHGIS), the United States National Historical Geographic Information System (NHGIS), and the Great Britain Historical Geographical Information System. GIS also provides digital means to display and analyze the spatial information on the early maps or to layer them with modern spatial data. How GIS relational data structure may be used to analyze social, political, and economic information related to production of early maps is also discussed in this paper. Through discussion on these examples, this paper reveals value of GIS applications in this field.

***Keywords*—C**artography, GIS, history, maps.

I. Introduction

GEOGRAPHIC Information Systems (GIS) is a revolutionary information technology for managing, analyzing, and displaying spatially reference data and the attribute data. They are applied in many disciplines and decision making processes. This paper discusses GIS applications in the field of the history of cartography by examples, including assessing accuracy of early maps, establishing a database of places and historical administrative units in history, integrating early maps in GIS or digital images, and analyzing social, political, and economic information related to production of early maps. Through discussion on these examples, this paper reveals value of GIS applications in this field.

II. Assessing Accuracy of Early Maps

The analysis of the accuracy of early maps is an important aspect in the study of the history of cartography. "The accuracy of early maps has been a popular theme in the cartographic literature" since the 1960s [1]. The method called distortion grids "is at least as old as the 1840s" [2] and has subsequently been used in several studies on the accuracy of early maps. Since the 1960s, with the rapid growth of computer technology, various experiments using computer-aided methods, such as the coordinate method and the circle method, have been conducted [3] [4] [5] [6] [7] [8] [9] [10]. Application of GIS in assessing accuracy of early maps can be divided into four steps. The first step is to identify locations of the points and features of an early map on a modern base map, i.e., to find strictly comparable points and features between the early map and the modern base map. This modern base map with the identified points and features is used as the reference map to evaluate the accuracy of the early map. To identify locations of the points and features of an early map on a modern base map can be very difficult for several reasons. First, some points or features on an early map may have disappeared over time. Even though some of them still exist today, their names may be different from those indicated on the early map. Further difficulties are caused by place names which are the same as the old ones, but represent different features at the present time. Therefore, one must be very careful when conducting study on this step. The second step is to digitize the original early paper map into GIS. Thirdly, the digitized early map is overlaid with the modern base map. At the stage of overlay, three conditions have to be met. First, the two maps must be in the same scale. Secondly, the two maps must be in the same orientation. Finally, two identical points on the two maps need to be selected as common control points for an overlay. Because the scale of an early map might vary in different sections and its orientation might also be different from that of the modern base map, carefully choosing the common control points which can most accurately overlay and produce the maximum attainable degree of coincidence of these two maps is critical for this analysis. The principle to select the first common control point should be based on which point will provide the best possible overall average fit of the two maps. Geometrically the point in the center of the maps is deemed best for this purpose. The principle to choose the second common control point is determined by which point will most accurately show the scale and orientation of the maps when it is connected with the first common control point. The most distant point from the center is best served for this purpose because it has the smallest percentage of error in the overlay process when connecting to the first control point. This principle is similar to one of the standard principles in selecting control points for GIS data conversion through digitizing. The control points for digitizing are used by GIS to calculate a digitizing tablet-to-map transformation--an equation that makes it possible for GIS to translate positions on the tablet to coordinates in a GIS file. Therefore, selection of these control points has direct

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impact on accuracy of GIS data conversion. Control points must be carefully selected around the edge of a map so that they are distant from each other and have a smaller percentage of error in the data conversion process. In addition to the distance from the center, a point in an area of denser features and identified points should carry more weight than those in areas of fewer features and identified points. The last step is to examine distortion of the early map based on the overlaid early map and the modern base map. The absolute distortion can be analyzed by the linear distance between the point on the early map and the identical point on the modern base map. The relative distortion of the early map can be examined by measuring the ground distances and angles between two points on the early map and comparing with those on the modern base map. In addition, distribution patterns and buffer regions around certain points on these two maps can also be analyzed using GIS [11].

III. Establishing a Database of Places and Historical Administrative Units in History

In any studies on history, including the history of cartography, a database of places and historical administrative units in history is a valuable resource. The China Historical Geographic Information Systems (CHGIS), project co-edited by Bol and Ge and launched in 2001 has made great contribution in this respect. CHGIS establishes a digital database of populated places and historical administrative units for the period of Chinese history between 222 BCE and 1911. It provides a base GIS platform for researchers to use in spatial analysis, temporal statistical modeling, and representation of selected historical units as digital maps. "Having downloaded the CHGIS datasets, the user can search the database for administrative units and capitals for any given time in Chinese history, can create customized digital maps for particular times and places, or can join their own datasets for spatial analysis, thematic mapping, or other specialized statistical modeling according to their own interests. Also included in the datasets are layers for historical coastlines, major rivers, and generalized elevations" [12]. Other similar contributions are the United States National Historical Geographic Information System (NHGIS) and the Great Britain Historical Geographical Information System. NHGIS provides, free of charge, aggregate census data and GIS-compatible boundary files for the United States between 1790 and 2000 [13]. The Great Britain Historical Geographical Information System is a digital collection of information about Britain's localities as they have changed over time. Information comes from census reports, historical gazetteers, travelers'' tales and historic maps [14]. Apparently, the efforts of establishing similar database in other areas and/or time periods would be valuable contribution to the field.

IV. Integrating Early Maps in GIS or Digital Images

As Rumsey and Williams point out, early "maps record the geographical information that is fundamental to reconstructing past places, whether town, region, or nation. Historical maps often hold information retained by no other written source, such as place-names, boundaries, and physical features that have been modified or erased by modern development" [15]. GIS provides digital means to display and analyze the spatial information on these maps or to layer them with other modern spatial data. Rumsey and Williams discussed value and process of including nineteenth and early twentieth century paper maps in GIS through scanning, georeferencing, and digitizing features on original early maps to create vector GIS layers.

At the stage of georeferencing, the selected control points on the scanned original early map are aligned with their actual geographic location by either assigning geographic coordinates to each point or by linking each point to its equivalent on modern digital map. The further adjustment may be done manually by trying to find the best fit of all parts of the original early map. It needs to be pointed out here that purpose of the georeferencing is to align the original early map with modern coordinate system in order to display and analyze the spatial information of the original early map more precisely. For this purpose, theoretically more control points are selected, the better fit the original early map would be to the modern coordinate system. However, georeferencing does not improve the accuracy of the original early maps. The representation of features from these maps in the GIS at best will only be as accurate as the original source. The purpose and process of georeferencing here are different from one discussed in section 2 in this paper: Assessing Accuracy of Early Maps, in which only two identical points on the two maps need to be selected as common control points for an overlay. If more than two common control points are aligned, the original accuracy of the early maps will be changed and the result of measuring absolute and relative accuracy of the early maps would be faulty.

Because features on the scanned original early maps are just images, these features need to be digitized as points, lines, or polygons to create vector GIS layers in order to perform spatial analysis using GIS. Once vectors layers are created from the original early maps, the attribute data, such population of administrative divisions, can be added and linked with these spatial features.

Integrating early maps into GIS or digital images creates valuable resource and techniques to study spatial information in past and the early maps themselves. Nevertheless, this is time-consuming, labor intensive, and expensive process. It is encouraging that more and more institutions and scholars have made contributions in this aspect, including the Library of Congress Geography and Map Division [16], United States Digital Map Library [17], David Rumsey Historical Map Collection [18], the University of Wisconsin at Milwaukee American Geographic Society Library Digital Map Collection [19], Washington State University [20], Library of University of Illinois at Urbana-Champaign [21], and National Library of Scotland [22].

V. Analyzing Social, Political, and Economic Information Related to Production of Early Maps

The relationship between maps and culture and society is recent research interest in the field of the history of cartography. As Rundstrom comments: "The study of maps in their cultural milieu has interested researchers in several disciplines, including geography, but this approach was not widely accepted by cultural geographers until the 1970s, and historians of cartography began to see maps explicitly as cultural artifacts only recently" [23]. Lewis has also pointed out that the examination of the roles of maps within societies and the values placed on them by societies is a recent growth of research interest [24]. The study of maps cannot be divorced from the cultural context in which they were produced. According to Harley's theory, "...the scientific rules of mapping are, in any case, influenced by a quite different set of rules, those governing the cultural production of the map... They are related to values, such as those of ethnicity, politics, religion, or social class, and they are also embedded in the map-producing society at large... Such an interplay of social and technical rules is a universal feature of cartographic knowledge" [25].

In my study on the maps in Chinese administrative gazetteers of the Song dynasty (960-1279 AD), I found out that there was close relation between production of these gazetteers and political importance and economic development of the areas covered by these gazetteers. In both the history of cartography and Chinese study fields, the maps in the gazetteers of the Song dynasty have rarely been explored. However, as Joseph Needham, a world-renowned scholar in the history of Chinese science, commented, "Anyone at all acquainted with Chinese literature is familiar with the host of 'gazetteers',... In other literatures there is little comparable to this forest of monuments which the industry of provincial scholars erected over the centuries" [26]. The Song Age has particular importance for the development of the gazetteers for two reasons. First, as Zhang Guogan, a noted scholar in the studies of gazetteers, pointed out, "The style of the gazetteers was not completed and standardized until the Song dynasty." [27] Only in Song time, did the gazetteers assume their final style, *fangzhi*, as comprehensive records of administrative units or local regions. The social, political, economic, cultural, geographical, and technical changes in this period were contributed to the development of this new form [28] [29]. The style of gazetteers formed during the Song Age continued without significant change for almost a thousand years of subsequent Chinese history. The second reason for the importance of the Song time is that a significant number of gazetteers were produced during this period. In addition, the progress of printing technology during the Song time made it possible to produce many copies of the gazetteers and provided a better chance for these gazetteers to survive. Since very few earlier gazetteers have survived, the existing Song gazetteers have become highly valued objects for both research and collecting. Because techniques for making maps were much more complicated than those for writing and printing text, the chances of maps surviving are much less than those for texts.

After carefully examining the areas covered by these gazetteers, I found out that these gazetteers are all located in the southern part of China along the lower course of the Yangzi River or along the southeast coast. During the period when these gazetteers were compiled, these areas were either political centers or economically developed regions. For example, Linan, the area covered by *The Gazetteer of Linan Prefecture (Linan zhi)*, was the capital of the Southern Song dynasty. In addition, it was also heavily populated and a very large commercial center. Near the end of the dynasty, the number of households living in Linan prefecture reached around 390,000 and its population reached 1,240,000. The city was crowded by merchants' shops, craftsmen's workshops, and inns. Businesses and places of entertainment remained active until midnight. Jiankang, the region described by *The Gazetteer of Jiankang Prefecture (Jiankang zhi)*, was another important place on the frontier of the Southern Song. It was a commercial center and an important place for military defense with about 250,000 residents [30]. In general, the area of the southern part of the Lower Yangzi basin, which was the major region described by these gazetteers, was an economically developed area and the richest land for agricultural production in the Song age, especially for rice-growing. During the Song time, rice growing increased rapidly because of the adoption of transplanting seedlings and the appearance of new tools and technology. Among all the great cultivation systems, the paddy is the one with the greatest yield per acre. This upsurge of rice production played a very important role in the growing economy and made it possible to release a large number of people from working on the soil.

GIS uses relational data structure. The spatial features on the earth surface, such as townships, rivers, and provinces, are represented by points, lines, or polygons and are displayed into layers in GIS. Each layer represents different type of spatial feature. In addition, each layer has its own attribute table which stores attribute information related to the spatial feature in the layer. The spatial and attribute information are linked to each other and can be edited and analyzed together. Thus, the above mentioned data on political significance, population, economy and other information related to the places can be input into the attribute table of the GIS and linked to points, lines, or polygons of the spatial features. Once the database containing both spatial and attribute data is established, these data can be queried and analyzed using GIS. For example, population, population density, crop yield, distribution of merchants' shops, craftsmen's workshops, and inns of the areas where theses gazetteers and maps were produced can be analyzed spatially and quantitatively using GIS. Thus GIS may become a powerful tool to explore relationship between maps, gazetteers, and society in which they were produced and to be applied in other studies in history.

VI. Conclusions

Through discussion on the above GIS applications in the field of the history of cartography, it reveals that GIS brings new techniques to study early maps and historical geography. Evaluation of the accuracy of early maps is an important aspect in the field of the history of cartography and GIS provides a new mean to perform this type of research.

Meanwhile, caution is needed when assessing accuracy of early maps. The interpretation of the accuracy of early maps should not be separated from their specific cultural context. As Harley and Woodward point out, "Maps are graphic representations that facilitate a spatial understanding of things, concepts, conditions, processes or events in the human world" [31]. A map not only shows the spatial information, such as cities, rivers, and provinces, but also gives specific insight into cultural beliefs and concepts. Thus maps, especially early maps, may have multiple functions in their specific cultural context. The value of some early maps should not be judged solely in terms of their accuracy because geodetic precision might not be the original intent of the map makers. In such cases, analysis concerning their accuracy only provides a reference about how the map makers dealt with "position" when they were making the maps. The value of these maps cannot be underestimated because of their positional inaccuracy. Establishing a database of places and historical administrative units in history, integrating early maps in GIS or digital images, and analyzing social, political, and economic information of the past using GIS provide valuable source for any studies in history, including the history of cartography. Applications of GIS in the history of cartography are certainly beyond the above discussed examples and can only be limited by one's imagination.

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