Historical GIS (HGIS): An amply mature high-tech tool, to the decisive and effective help in the historical research

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Abstract: The role, developments and the contribution of GIS in historical research reviewed in this paper, mainly oriented to historical researcher, thus several exclusively 'technical' aspects and details (concerning the GIS-experts') are degraded, even omitted. The topics include the main advantages and disadvantages of GIS in historical research (appearing usually with the international term: 'Historical GIS'-HGIS), basic problems which arise due to the "special character and sources" of historical data and finally, the management of historic uncertainty through HGIS. The importance of the "time"-parameter on monitoring and analysing phenomena in the historical research and on the presentation of existing methods of time management available through HGIS, are focal points that also highlighted. Finally, features of electronic mapping through HGIS, which offer innovative depictions and visualisation of historical data, are presented and some thoughts/conclusions on the present and future of HGIS are given, which enhance the attractiveness and effectiveness of this high-tech tool in the historical research.

1. Introduction- Why to select and use Historical GIS (HGIS) for historical research

There is a human need to collect historical records, indisputably. Such a requirement contains also 'connections' to the past (where both, the living and working environments do play a dominant role). For many years the historical research was based on analog historical maps (antique paper maps), usually old and worn, paper documents etc. The co-existence of newer map-versions of the same geographical areas, made the whole case…. exciting (see Fig. 1). Since many of these maps/ documents were only in a limited number of copies, the access to them was not always easy, nor without problems (Bodovsky, Y., 2005).

No need to point out that many times the rarity of such documentary sources (analog maps, documents etc.) dictates the need for their "digital" rescue.

Furthermore, more problems are added and their main source/reason is the 'geographical component' (Duran, Z. et. Al., 2004). Without it, researchers cannot ask

Figure 1: *The generic idea behind HGIS: Comparing and matching, the 'old' with the 'new' map*

territorial questions, either for the data itself or for their relationship to other geographic data in the same area (but at different times) (Gregory, I. N. et al., 2001).
Before about a decade, in most cases of historical research, another wide and intricate problem was that those aforementioned past environments are preserved only and 'simply' as history, carrying the term 'memories' as their only attitude. The 'place/location' (i.e. the geographical component) was missing.

In the "rescue" of these shortcomings and problems, Geographic Information Systems (GIS) come to offer the ideal tool for maintaining, rescuing, analysing, etc. a collective memory of past environments. In simple words, since they are basically data-integration engines, they allow the documentation, visualization and finally, the interpretation of 'place'-related information.

Speaking about 'data', there are two main categories in a GIS: 'Spatial data' (i.e. infos about: 'where') (Geospatial data – Erwin, T. and Sweetkind-Singer, J., 2009) and 'Attribute data' (i.e. infos about: 'what'). Concerning the simultaneous management of data (spatial and attributes, as well), a 'typical' GIS enables two basic ways for it:

- Investigating the spatial component present in a single set of data
- Integrating data from different sources, through their common geographic location (Maguire, D.J. et al., 2005). In plain words, it is precisely the ability to monitor changes over time and to examine in detail the attributes (descriptive data) change to specific locations. This offering of innovative ways, regarding the exploration of data change over time, is this a most useful feature that makes GIS decisive in historical research.

To conclude in simple words, every historical research involving the use of a Geographical Information System (GIS) is defined as «Historical GIS (HGIS)». Such systems were very popular over recent years especially in some historical subdisciplines (p.e. in economic and social history) (Lünen and Travis, C., 2013). HGIS is a powerful emerging field, which only the last 10-15 years was successful in become recognized as a practice (or sub-sector) of historical research[1].

2. Advantages of HGIS

A modern HGIS provides innovative presentation-features of critical historical data on maps, which can finally show previously unknown or unprocessed spatiotemporal relationships (Knowles, A., 2005). These features of digital imaging and representation of the past, are the most exciting elements of a HGIS. However, relatively few historians nowadays have taken full advantage of the possibilities of spatial analysis of a HGIS. So far, the main users are the scholars of the geosciences. Nevertheless, slowly but surely, the tendency of using HGIS is ascendant, thus more and more historians are getting involved with the use of GIS, as they have begun to appreciate the value that is often hidden or ignored in the available geographical information.

In comparison with a 'typical GIS', a HGIS presents a number of additional special features:

1. The geographic questions ('queries') concern a specific part of the historical research.
2. Geographic information contains/provides essential part of the historical data.
3. The bulk of either, the information or the elements that delimit the analytical framework of the study, comprise constructed and analysed spatiotemporal databases.
4. The resultant benefits concern the addition of insight and the rejuvenation of the historical research. All these benefits arise through the strongly improved ability on the identification and exploitation of the geographical characteristics of data.

Three are the most ordinary ways for the historians of using HGIS:

1. As a research tool for the discovery, documentation, rescue and management of research sources.
2. As an innovative and powerful way of presenting complex research results, which visualizes and reveals the development of historical regions.
3. As a strong analytical methodology tool, for the understanding and analysis of spatial relations.

[1] For convenience reasons, from now on, the term HGIS will be used

Besides the capabilities of visualisation of spatial relations, a HGIS also provides functions for more intricate spatial analysis techniques. The spatial resolution (or geographic data analysis) refers to a set of statistical and other methods and techniques that differ from conventional quantitative analysis techniques, to the point where the geographic location is "built" into the system as an integral part of the analysis. This simply means that the results of a spatial analysis will change if you change the position of objects under study.

During the research, HGIS are 'severe' tools! They are not so ...kind to the end-user, especially when inconsistency or incompleteness is present in the project. To deal with a variety of different dates on the same historical event or with deficiencies and omissions on historical data, is a representative example of the expected HGIS-'severe behaviour'. Actually, this severity is pushing the user to perform the research under constant high standards (concerning the quality of both, data and analysis). Thus at the end, this seeming disadvantage fortunately results into a proven asset.

Finally, the use of HGIS gives many conveniences for recording special-data (well known as "metadata" ...or else, " data about data") that characterizes the sources and their quality of the HGIS data.

3. Disadvantages of HGIS

Either the case is about a 'typical' GIS or a HGIS (…or about any kind of GIS-application), the fundamental greatest inevitable disadvantage relates to data-input. As a rule, it comprises the most expensive part of any project, approximating easily the 80-85% of the total cost!. For HGIS-applications, there is another additional burden, which arises from the fact that there are (most probably) doubts about the quality, even the homogeneity of data.

For the users, HGIS means a steep learning curve. By taking as a representative example the historian, when the distance between the historian-GIS-user and disciplines like geodesy, geography, cartography (not to mention statistical analysis and database knowledge and experience) grows, consequently this learning curve becomes steeper, as well. After all, most of the prospective HGIS-users belong to the wider field of literature and history (historians, archaeologists, etc.), so they do not have (or do not get) the desired knowledge concerning the basic disciplines, which build-and-support a HGIS. This situation explains why so far, there is not any satisfactory balance between this steep learning curve in comparison with the derived 'history-benefits' of utilising HGIS.

It has to be remembered that, the time and effort that the data integration, consistency and comprehensiveness, the metadata recording and finally, the iterative analytical mapping, are effort and time consuming works. Nonetheless, at the end, the

spatial history of an area begins to retaliate and the negative balance between learning curve (and effort) is positively reversed, in favour of the user.

Nowadays, when the case is comparison and analysis of data, HGIS offer numerous features and great potential. But when the case is clearly about flexibility, synthesis and generalisation, for the present HGIS are not systems capable to replace the human-brain-analyst.

To use HGIS, spatial data represented in four types of graphical entities: Points, Lines, Polygons, Pixels (Picture Elements). The HGIS is a powerful tool where spatial data are clear and have defined positions in space. However, some historical data can not be displayed sufficiently in space in this way, either because the data does not fall into any of the four types of graphics, or because they are inaccurate, a problem that the HGIS is unable to cope easily (Gregory, I.N., 2003, Demoula, S. 2014). Furthermore, the existing HGIS-tools so far are not adequate to handle spatial and (even worse) temporal ambiguities.

Accuracy of data entry depends on the accuracy of the analog reference map. Most historical data are coming from analog maps, which may not be accurate/precise. Usually, during the map scanning or digitisation procedure, new errors are produced/added, which destroy much of the accuracy-indications of the original source (Forsell, H., 2003). Speaking of maps, the scale is of particular importance in recalling the axiom that 'a map is always accurate within the constraints of its scale'. Of course, in HGIS there is the capability of impressive map-magnifications (either zooming or enlarging), in combination with the integration of data obtained from analog maps drawn on very different scales. As each map is drawn for illustration of specific data, such HGIS-capabilities can bias the extracted from the original map data, so such graphical changes are more likely to lead to inaccuracies, errors and misunderstandings (or any combination of them).

As the origin of HGIS is exclusively based on technological advances in geosciences, consequently their tools and analysis techniques are being oriented largely on the needs of these disciplines. The role of HGIS in the field of historical geography and the humanities has not been yet fully established. Thus, the full 'calibration, modification and adaptation' of HGIS as tools of historical research, in combination with a "specialised" dedicated support, are actions necessary to be dynamically done.

The restrictions on use of HGIS in historical research are mostly pragmatic. Despite that the cost of the required h/w and s/w (including maintenance and support) has significantly decreased in recent years, it can still be high. To buy HGIS-data is often expensive and the use of qualified staff usually means high cost.

As a fact, historians (which come largely from the classic science) are not very familiar (or they are absolutely irrelevant...) with HGIS technology, a fact that complicates the possibility of understanding the structure and requirements of these

complex software tools. The obvious most common result is that the HGIS to be treated simply (and only) as a means of automated (electronic) mapping.

4. The management of historical uncertainty in spatial data

Unlike many areas of research using HGIS and where the data are necessary to be precise and defined, historians are accustomed to dealing with primary sources, which are incomplete and inaccurate and may contain ambiguities, contradictions and prejudices. Numerous historians develop research topics, by omitting data or ambiguities in the primary data sources. There is established that even in Middle Ages (p.e. 12th century), the competent officials were complaining because the maps were inadequate (Gregory, I.N. et al., 2001). Moreover, various historical maps have been lost, and the only information available on geographical locations (e.g. the border of a region) is incomplete and only from fragmentary texts describing their (absent) maps.

The geographical position of an under 'examination' phenomenon, obviously is a key component of historical research (Francaviglia, R.V., 1996), where the ability to provide explicitly the uncertainty in geographic information is needed. It is a scientific research field that is attracting increasing interest and has previously been included in relevant courses and HGIS learning seminars. However, typical commercial GIS software packages have not yet incorporate 'dedicated' functions for easy and generally acceptable management of uncertainty, which encumbers the researchers with additional burdens and responsibility to be aware of how they handle the HGIS corresponding uncertainties, and then, how to adapt courses and HGIS learning seminars on historical topics.

The handling of the uncertainty can be achieved by various means. Researchers in geoinformatics develop data models that allow, for example, various alternative geographical positions of a particular object to coexist, with assessments of the degree of certainty of each alternative. There are standards for digital dictionaries that can connect domain names in more than one specified positions (Demoula, S., 2014). So it is possible information to be entered about:

(a) Different names are used for the same one position.
(b) The changes in the location and extent of the site with time
(c) Historical sources concerning the sites.

To generalise, researchers are striving to develop robust techniques to consider both forms, spatial and temporal uncertainty as well.

5. The need for space-time component (usually known as: spatiotemporal component)

For many years, historians and geographers argue that full understanding of a phenomenon should be well aware of both, the geographical space and the time period during which the phenomenon evolves. This means that the historical data should be addressed by finally taking into account these three components:

(i) Data characteristics, descriptive data (attributes).
(ii) Geographic location
(iii) Time (temporal component).

Unfortunately, the complexity of managing three different types of data simultaneously usually leads the researchers either to the simplification of the space to maintain the temporal dimension, or to simplify the time to maintain the spatial component. If the target is to maintain a consistent historical time series, then the temporal detail should be sacrificed to a large extent. Otherwise, if the target is to maintain the highest percentage of spatial detail, then only a short and discontinuous time series can be available (Cliff, A.D. and Haggett, H.P., 1996).

5.1 The temporal component - Methods of time management in HGIS

As mentioned, due to several significant conceptual issues, the temporal component is a "problem" for most commercial HGIS software packages. Thus, the approach and management of spatiotemporal data are issues left at the discretion of users of HGIS (Griffiths, S., 2013). This is not necessarily a disadvantage, as it provides researchers with the opportunity to develop their own solutions required for the purposes of an investigation. In any case, a full chronological HGIS should be able to answer three types of queries:

1. Changes to an object (for example: "This subject has been moved over the last two years. Yes or No? ", "Where was the subject two years ago?" Or "How that subject has been changed over the last five years?")
2. Changes in the spatial distribution of the phenomenon of study (for example: "What rural areas of date 1/1/1980 have been transformed in urban areas to date 31/12/1989?" Or "Have land uses changes occurred in this basin runoff between 1/1/1980 and 31/12/1989? Or "What was the allocation of commercial land uses on a particular route 25 years ago "?)
3. Changes in temporal relationships between multiple geographic phenomena (for example: "What areas showed a landslide within a week after of a major storm?", "Which of the rural areas located within half a kilometer of the new bypass has changed in urban areas, since the detour completed "?)

Unfortunately, the data models used by HGIS, based on multiple thematic layers data, do not allow for easy handling of the queries of this type. The main problem

is related to the topology of the data. Space-time topology should be developed additionally, which has not yet been sufficiently integrated in HGIS software (Gregory, I.N., 2003).

A simple way to manage time is to deal with it as a feature in a single entry of descriptive data associated with each spatial feature. Multiple sets of records can also be connected to each spatial feature, where each line will have a start-date and an end-date. This allows the handling of complex situations, for example, control of economic statistics in a business (such as production, profits and employment), but where the name and ownership of the enterprise also change over time. Time management in this way permits the spatial features to be created and abolished, as well their characteristics to be altered over time. Limitation to this approach is the fact that the position of the features cannot be amended.

When the temporal nature of the data presents clearer spatial features, then different layers can be used to represent the state at different periods of time. This simple and effective method is called "the key dates approach", and is particularly suitable when the spatial data obtained from reference maps for different time periods (Gregory, I.N., 2003). Its disadvantage resides in the fact that is efficient a limited number of dates, or where the change is recorded in clearly defined intervals between periods of relative stability (Knowles, A. and Hillier, A., 2008). More complicated situations are surely more problematic.

6. Historical maps

Historical maps are the primary data source for most HGIS. They have recorded the geographical information necessary for the "reconstruction" of historical areas, be it city, the region or state. Very often such maps provide information not maintained in any other written source, such as place names, the boundaries of geographical areas and other natural features that have changed or disappeared because of progressive development. However, historical maps reflect the characteristics of their creators and represent the world-view of each era created. This is a fact that must not be overlooked, as well the fact of what was the level of technology and science during the same period (Madry, S., 2006). To consider any historical map as the one absolute truth, is simply unreasonable (Gregory, I.N. et al., 2001).

Also, the use of historical maps actually complicates the research, as cartographers represent the geographic regions in a paper section, by using map projections and scales which primarily serve the purpose of each map (often with significant deviations from ‘reality’). Moreover, the scale of the map compresses the initially considered surface, in order to adjust it and/or to fit it in the available paper sizes.

HGIS obviously gives new perspectives on historical maps as they release them from the static limitations of paper, by allowing new levels of design and presenta-

tion. The digital versions of historical maps are more appropriate for the study of historical sites, for the related maps themselves and finally, for the study of how the involved areas have changed over time. Although the comparison between maps was always possible, the reliability of conclusions was mostly governed from the personal interpretative ability of the researcher (Knowles, A., 2005). The invasion of HGIS guarantees that the interpretation of the spatiotemporal changes is now based on objective criteria. Information that was difficult to be included in traditional historical maps, is now easily accessible. This fact is one of the most important points for the purposes of historical research (Rumsey, D. and Williams, M., 2002). The easy measurement of heights, distances and areas on study areas as well as the representation of the different facets of a region through rotating a map, are ….heavenly tools for historians.

6.1 User techniques, data of historical maps and their errors

Visual overlay capability concerning maps, is an important tool for the needs of historical research. However, to ask queries or to make spatial relationships between measurements of characteristics, spatial characteristics should be transferred from their historical maps and attributed as vector fields in the HGIS layers. This is attainable by digitizing the characteristic features of the maps (as points, lines, and polygons). Digitization is a very time consuming process, but contributes significantly to the amount of data being made available for use in HGIS.

Cities are ideal for geo-visualization, because urban scale maps and mapping of roads provide essential historical information as well as impressive backgrounds for the representation of the past. Urban maps are ideal reporting-backgrounds in a HGIS system, and cover relatively small areas with considerable cartographic analysis. Thus, for the same area it is easy to create map overlays of discrete time periods. Then, with the sequential juxtaposition of digital layers, urban changes over historical periods appear impressively (Gregory, I.N. and Healey, R.G., 2007).

Both the optical scanning and digitization techniques are procedures prone to errors. As error, meant the difference between the ‘real world’ and its digital representation. Usually, the errors arise from simplifications, inaccuracies and deficiencies caused by the limitations of raw data and their entry method, as well. The limitations of primary data mainly concern the scale, the characteristics of the data (either included or excluded), and finally, the accuracy of the original research (Mares, D. and Moschek, W., 2013). The scale determines the degree of detail that can be used for the interpretation of characteristics. Accuracy relates to how effectively the map data of the original investigation have been imprinted on the printout, in relation to their actual position in the geographic system.

The printed (analogue) maps can be deformed over time, especially if exposed to humidity. If such a map has been folded, the placement of a scanner or digitizer

would be impossible, as the resulting deformation will be reflected in the digital copy. If photocopies or other types of map copies as source data, they will also contain additional errors. The technical limitations (resolution, sensitivity etc.) of the scanner or digitizer can also cause errors, or at least to limit the maximum standards of specified accuracy (Gregory, I.N. and Ell P.S., 2007). Historical maps of small scale, are more prone to errors than the large-scale maps (Kallivretakis L., 2003). A large area (e.g. geographical extent of a state) is very difficult to be visualized on a flat surface, in relation to a small area (e.g. geographical area of a city). Large-scale maps are often more precise and easy to be used in a HGIS, because they tend to have less severe geographical errors. They also have more unique features to help identify areas and to supply information, such as information on land use, location of buildings, rivers, torrents and so on.

7. Historical data and HGIS

As 'geographical information', can be considered any information referring to a specific location on the Earth's surface. The most obvious information is displayed on topographical maps (e.g. contours, rivers and landscapes), or it is information related to the areas of thematic maps (e.g. density of population and mortality rates). However, the maps can contain valuable historical information, not necessarily in the Cartesian coordinate system (Madry, S., 2006).

Geographic information can be gleaned outside the conventional maps. The data in a table are geographic information, if the table contains columns or data fields, which give information on the sites. This kind of data is commonly used in history and related disciplines and fields. Typical example: a large proportion of statistical sources, which link their data to the respective locations. However, a large part of geographic information has poorer structure, thus the spatial component of various data sets is ignored. If the location that appears in a photograph can be determined, then the picture itself is a type of geographical information. The images and texts, which are common sources for most historians, often contain a wealth of spatial information, but usually these sources are descriptive, and any interpretation is a prerequisite before the depicted areas can be determined accurately (Lünen and Travis, C., 2013). When a toponym is present in a text-report, then it is geographic information. With some reservations, almost all information with a geographical reference can be considered as 'data' to be inserted in a HGIS. Each data element is linked to its spatial component, called after this association as 'spatial data', which provides information about where exactly is the object on the Earth's surface. Although their widely used names and position-IDs, spatial data can be stored more directly based on their geographical coordinates. Integration of descriptive (attributes) and spatial data, is a feature that differentiates HGIS from conventional methodologies of historical geographical research.

The possibility to include spatial data in historical research, is the strong (….even attractive) motive enabling historians and other researchers to bring new kinds of queries and encourage new perspectives (Gregory, I.N. et al., 2001), because:

- For different data types, the location is a common means of integration.
- Data which defined geographically, exhibit geometrical properties.
- Geographic data collected in a single data set, exhibit spatial dependencies

Apart from providing information and creating databases, HGIS applications for historians should allow access to the historical documents from where the spatial and descriptive information derived, together with the corresponding historical comments. Texts describing parts and images depicted on historical maps may be associated with hyper-links (with geographic data associated with these positions). When there is a recognizable coordinate system for specific historical maps, these maps can be geo-referenced and then be imported into a HGIS. If the coordinate system is not recognizable for other historical maps, then these maps can simply be connected electronically with images, a really better benefit than no connection at all.

7.1 Peculiarities and problems of using historical data

Such problems and peculiarities could be summarized in the following (Alexopoulos, I. 2008):

- Usually, elements of uncertainty and complex interconnections are involved with historical facts and information, while gaps resulting discontinuities in historical knowledge.
- There is not a homogenized classification-categorization system
- 'Old' spatial data do not conform to modern spatial data. A typical generic example is the different definitions for many key geographical terms (such as "limits", the "border", etc.)
- Historical data integrate disparate information and correlations with various data types.
- Older maps usually show the relative rather than absolute positions in space. Therefore, sometimes the scale of historical maps characterizes the accuracy of the geographic representation as ‘approximation’
- A good number of ancient cartographers very often used "special (personal) techniques" and complex artistic decorations, just to conceal the lack of accuracy of their map and diagram drawings.

As expected, piecemeal concentration of historical knowledge reinforces the subjective view and thinking in reports and interpretations of historical events. Accordingly, subjectivity is still transferred most strongly and with more assumptions on maps, if the phenomena mentioned acquire a visual projection in space and not only a description.

Data transferring, from historical sources into HGIS, can be a complex process that often is a research project itself!. Depending on the extent of the study area, long years of developing a HGIS-database may needed, as to produce valuable and useful results. Apart from the tedious data entry process, other problems encountered are (Knowles, A., 2005):

- The desired accuracy concerning the geographical location of data on the map background
- The users' familiarisation with different data formats and the HGIS hardware/software, as well
- Finding or creating the reference maps

Obtaining results from historical sources is a process that cannot easily be automated, since the researcher has to understand the source, attitudes and circumstances that existed at the creation of data as well as to identify the points at which the reliability is not acceptable. All this engagement however can result into very important, even... multidimensional research results.

Innumerable are the factors affecting the use of historical data in a HGIS. The core issue is the access to the original maps and the quality of their scannings. Serious roles do also play the accurate georeferencing techniques, the analytical understanding of cartographic techniques (that have been used by cartographers), and finally, the cultural, political and technological contexts in which the maps were created (Madry, S., 2006). Technically, it should also be taken into consideration the data-format, analysis procedures as well as the visualisation features available in HGIS. All these elements should be treated with extreme caution, without underestimating the potential problems in a HGIS (e.g. using data of different scales, the errors-propagation, spatial autocorrelation, problems of unit conversions etc). Finally, special attention should be given both to queries asked in HGIS, and the conclusions drawn from the analysis, respectively.

7.2 The format of spatial historical data (vector – raster)

There are both conceptual as well as methodological differences between the vector and the raster (mosaic) data systems. The basic difference is that vector systems generate and store information on discrete objects and they give precise/accurate positions with clear boundaries. Raster systems store raster images of the Earth's surface, without precise/accurate positions (because there is no coordinate basis), they require no clear boundaries and they do not reflect vector concepts (e.g. lines) (Bodovsky, Y., 2005).

The question of the type of data to be used depends on the data to be included in the HGIS and the purpose of the whole research scheme. A rule of thumb is that the vector systems are more suitable for studying anthropogenic data (e.g. urban

development, infrastructure networks), while the raster systems are better for studying natural or environmental parameters. Another opinion is that the vector systems are more suitable for precise and known characteristics, while the raster systems are selected when there are relevant uncertainties in the data (Knowles, A., 2005).

Another factor regarding the choice between use raster and vector data is the examination of historical maps to be used as a basis for the creation of a HGIS. Historical maps may include roads, rivers, villages, forests and administrative boundaries, toponyms and shaded areas to emphasize the terrain. They have also clean cartographic information, such as the legend of the map, the scale and the date. A raster data model provides a single image of the map, which will be identical to the original but the electronic version will probably include errors introduced by the digitization process. Essentially, in the raster-version, each pixel has a value that represents the color of the original map. This allows the shaded areas to be encoded as well as the information of toponyms to remain interpretable (Wachowicz, M. and Owens, J.B., 2013). In such cases, there are also problems. For instance, in the raster-model there will exist pixels representing administrative boundaries, but there will be no indication if these limits are related to cover areas (p.e. parishes, districts). This could be even more complicated if on the original map there are intermittent or discontinuous lines, as it is almost impossible for the automated software to detect them as continuous lines.

A vector representation of the map is more abstract than the corresponding raster. Each type of information (roads, rivers, land use, administrative areas etc.) should be kept in a separate data layer. For example, roads should be stored in a lines-layer, and administrative areas in a polygons-layer. A vector system can then determine routes along the roads, the existence of different administrative areas etc. The lengths of the lines and boundaries of administrative areas can be easily calculated. Much of the relevant information, however, is removed, and the hatching/shading cannot be represented directly in the vector system.

Historical maps (and possibly aerial photographs) are understandably the primary source of historical data and reference maps. The digital version of the original sources can be used in ways that go far beyond the purposes for which the data was originally created. Therefore, it is important to create the best possible representation of the original source, as well as data for the documentation of the original source. Models or assumptions made about the accuracy of the data gathered, should be part of this documentation. This procedure guarantees that the digital products produced in the present, could be a resource for prospective researchers.

Considerable effort has been undertaken to develop techniques for the automatic extraction of vector data from a scanned image (raster). This is known as conversion of ‘raster-to-vector’ and can lead to significant savings in time. Conversely, the vector-to-raster conversion is computationally easier, although usually less use-

ful for HGIS. Such a software conversion is often used to convert data from one or more layers of vector data to an output bitmap, but can also be used to make a raster HGIS layer from a vector layer.

7.3 Creating HGIS-layers of spatial data

A layer in HGIS is the equivalent of a table (matrix) in a database, as is the basic unit of information storage that consists of both spatially and descriptive data. Usually, each HGIS-layer is stored in a separate file, and usually has these characteristics: it saves only one type of spatial data, (p.e. points, lines, polygons, grid raster) and it stores information about a topic. For example, if the purpose is to create a points-layer for public buildings, it may be desirable to create a single layer that contains all public buildings, where the type of each building is a feature, or may is desirable to provide a separate layer for each type of building. If the aim is to codify information from a topographic map in a HGIS, then a raster layer can be created that provides: a scanned image of the map itself, a point layer or layers containing public buildings, layer lines containing road and transport networks and rivers, polygon layers containing settlements, administrative areas, lakes and forests etc. More information can be added to all layers, such as the kinds of public buildings, the classification of roads, the names of rivers, the names and types of administrative areas, the names and types of woodland etc.

The most important property of the layers is their ability to integrate data from different sources. Each layer contains a coordinate system. Since this system corresponds to the actual coordinates, data from separate layers can be integrated with high accuracy. In summary, if the locations of a set of characteristics are known, it is then possible to determine how these features relate to a second data set, which is also available as well as its accurate geographical location. For the historians, this feature is invaluable as historical research includes information from various sources and is attempting to combine them to yield as much as a more complete picture of the under study phenomena.

7.4 Attributes (descriptive historical data)

Often, on the occasion of a research paper on a specific area, as many available and different information is being collected, which are mapped/related to the geographical characteristics of the data. By collecting all these potentially disparate data together, it is possible to investigate the relationships between data in order further information to be derived. Examples of descriptive data that can be used in HGIS is information about the presence (or absence) of features, such as roads and buildings, the documents relating to events occurring in one place, the images (photos), video-files and audio-files pertaining to a particular location etc. (Philo, C., 2009). The detailed description of the geographic locations of historical manu-

scripts may also provide descriptive data in a HGIS. Historical maps or drawings can also be part of the descriptive data, especially if they have no immediate reports of the area concerned, even if they cannot be geo-referenced compared with modern maps. Rather than all information about a location to be stored on a single HGIS, the HGIS descriptive data can consist of hyper-links to sites containing information on specific parts or aspects. To convert these data into HGIS-data, all that is needed is to link them to the appropriate geographic coordinate system of the under study sites.

7.5 'Linking' the historical data (spatial and descriptive, as well)

There are three ways in which the descriptive data can be linked to the spatial data:

1. The descriptive data may already contain spatial data in the form of a pair of coordinates for each line of record.
2. There may be a spatial reference (p.e. as a site name) that connects the descriptive data with spatial data.
3. There may be specific geographic designations in descriptive data so that they can be directly linked to spatial data.

An ideal case for linking spatial and descriptive data is when there are attributes comprising a spatial reference (such as a name of a region) and a similar spatial reference (which is also included on a layer of spatial data). This happens often because many data indicate names, so a relational compound can be used to unite the descriptive to the spatial data, assuming that the names of places in two data sets are identical. This often happens with data related to cities or administrative areas, wherein the generated spatial data can be associated with multiple databases. A common problem concerns the spelling of place names (toponyms) in the historical data, since it is usually not standardized and may well change over time (even between different sources). This often requires an ad-hoc solution, i.e. a standard spelling of the toponyms should be included in both sources, so as to provide a perfect match. A more 'scientific' approach is a dictionary to be created, i.e. a database-table that provides a standard spelling of each place name that appears in the descriptive database. Because there may be multiple alternative spellings for the same name, this structure can be used to connect a single HGIS-layer of data across multiple lines of descriptive data.

Another problem is linked with the identification of geographic locations, which may not be identical between the two sources. This often happens when elements (referred to administrative units such as e.g. areas or census areas) are connected with spatial data. As the administrative boundaries change frequently, a layer of spatial data intended to represent descriptive data cannot actually be quite accurate. This may occur due to the use of different languages or because the two data sets have been created without thinking about their integration in a future phase of the

research. This situation requires special handling since it is often necessary the data to be processed manually, by creating a field in both data sets which will have common values and allows to create a relational compound (Gregory, I.N. and Ell, P.S., 2007).

A strategic variation is suggested to be applied, when to the spatial data (been digitized specifically in order to connect to an existing set of descriptive data) it is easy to add unique ID-numbers during their digitization process. In such a case, the addition of a field with unique ID-numbers to the descriptive data (before the digitizing of spatial data), and then in return the use of these same ID-numbers to the spatial data, can lead to significant time savings.

In all these aforementioned cases, it is important descriptive data to be stored on the most appropriate software package, not necessarily into the HGIS itself. Almost all HGIS software packages allow for such an option, which greatly improves the functionality and ease of use of the resulting database.

8. The adaptation of historical data into the real world

Whatever be the method of historical data collection (scanning, digitization), to enable data to be used in a HGIS can take up to three additional stages:

1. The georeference: The procedure to convert the coordinates of digitization into the proper coordinates of the reference system.
2. The selection and application of the appropriate projection
3. The combination of continuous electronic map sheets together, probably based on the rubber-sheeting process, in order to create a single layer, composed of several map sheets.

8.1 Georeference

The process of georeferencing is a fundamental function of HGIS, because it associates a physical map (or a raster image of a map) with spatial locations (see p.e. Fig. 2). It gives to each layer real coordinates of the study area, so it allows the calculation of distances, areas and angles in real units. Thus the layer can be incorporated into any other layers (which also have real coordinates) of the under study area. Georeference is achieved by adding a number of control points onto the layer, (sometimes known as ‘tic points’). In most cases, four points are used and ideally, they are the four corners of the map sheet. Then, the real coordinates are introduced (such as latitude and longitude), a process that requires that the HGIS-software ‘knows’ both the initial coordinates of the control points, and their actual coordinates. The procedure ends with a mathematical transformation, which converts all layers of map-coordinates to the final definite coordinates, respectively.

Figure 2: *Georeferencing of maps of different time periods– The basic concept (Patrick, F., 2008)*

Georeferencing is another important source of potential errors, especially when it comes to old, worn, poorly maintained etc. maps, as many historical maps are. If the map-paper-sheet is deformed in any way, or the map is not located properly on the specific surface of the digitizer or the scanner (or finally, there is any inaccuracy in the digitization of checkpoints or real coordinates), the results will be errors in the georeferencing process, which will remain permanently as a biased-component which will systematically influence the derived layer (Gregory, I.N. and Ell, P.S., 2007).

Most modern maps contain a clearly defined grid that can be used to obtain the control points, in contrast with older maps. One solution is to look for features on the old map, which also exist in a modern map, e.g. the position of the churches, monuments etc. In any case, such features should be selected with care, as they may have moved over time.

Obviously, an ancient map is almost impossible to align perfectly with modern co-ordinate systems. However, for most HGIS applications, the value of historical information contained in printed (analogue) maps, compensate other errors, which

are intruding during the georeferencing procedure. It should be noted that georeferencing does not necessarily improve a historical map, so finally does not make it more accurate. During the process of transforming the original map into its digital form, georeferencing is changing lines and shapes, the distance between objects, the aesthetics of the map and its initial value (as a handmade cultural artifact). Nevertheless, the inability of a perfect alignment between a historical and its contemporal version, it can provide further historical information (Rumsey, D. and Williams, M., 2002). In recent years, the innovation of the 'partially transparent raster' HGIS-layers, can produce complex maps showing the temporal transformation of regions.

8.2 Selecting the projection system

In order to illustrate or highlight points that belong to a reference surface over another, a projection system is required. In this way, the geometric or physical characteristics of the first surface are transferred (through a bijection) on the second. The use of different projection systems can obviously cause deformations on the map. If the original available cartographic material consists of maps of different projection systems, after the selection of the HGIS-projection system, it is necessary transformations of all cartographic data not referenced on it to be carried out, so that the final digital background of HGIS to become uniform and homogeneous. Once a layer is georeferenced, it is appropriate a modern projection system to be adopted for the map. Usually, the initial layer is projected onto the same projection system as the one used in the reference map. No have to be said here that the HGIS software simplifies the use of projection systems, making easy the necessary conversions.

8.3 On the Rubber-Sheeting process

The inaccuracies of geometric elements of historical maps make it difficult to compare their characteristics with the current situation. This drawback is resolved by integrating historical maps in HGIS after rubber-sheeting transformation, i.e. after their geometric correction. This process is used for adjusting the coordinates of all the data points in a dataset. This adjustment results into a more accurate match between known locations and a few data points within the dataset. In this adjusting process, the interconnectivity between points and objects, is preserved by stretching, shrinking, or reorienting their interconnecting lines. The operator (user) selects the lines from the layer (which will undergo the rubber-sheeting), and indicates to which lines from the adjacent layer will unite (Gregory, I.N. and Ell, P.S., 2007). This transformation is provided to compare and overlay multiple map sheets from different time periods. Moreover, it assigns the map scales on historical maps and can make it possible to overlay the current contour lines on the older (historical) maps (Shimizu, E. and Takashi, F., 2000).

If the initial settings were accurate, if digitization was done with accuracy and if georeferencing done correctly, the resultant error eventually introduced in the rubber-sheeting process should theoretically be minimal. However, when the case is about historical maps, it is not always possible to fullfil high precision/accuracy expectations.

9. Visualization of results in HGIS - Map creation

Map production is an integral part of the HGIS. The use of maps for the exploration and presentation of data, based on the results of the analysis of HGIS, is an essential part of the HGIS-toolbox. Exported products mean much more than mere mapping: Graphs, tables, reports, digital files etc. Apart from that fact, all other conventional data-presentation methods are still valid and useful tools. In mapping, the HGIS technology refers to (and propose explanations for) the spatial effects of the under study case. This feature creates a huge field for the investigation and presentation of historical subjects, which are directly related to the geographic reference area, in contrast with the past (Gregory, I.N., 2003).

The map is the best way of presenting spatial information. Cartography is both a science and an art, and has a very long story. From a scientific perspective, the role of cartography is to present the characteristics of the Earth's surface with accuracy and objectivity. From an artistic point of view, its role is to present this information in a manner that is both responsive and visually pleasing. These two roles are sometimes conflicting, and require specialized use of cartographic standards compensating for them (Buckler, J., 1998).

Most HGIS software packages make it easy to produce base maps. This means that almost immediately, after the data are in the 'proper'-for-HGIS-form, the researchers are able to analyze and explore them through maps. The maps can be refined and redesigned again several times as part of the research process, giving the researcher the opportunity to gain a thorough understanding of spatial information contained in the data. At the end of the research process, the production of maps for publication, either on paper or in electronic form, is a relatively straightforward process.

A map can be seen as an abstract presentation of the world. It presents complex information about one or more events in an understandable way, and is also a valid and cogent picture of the underlying data. To do this effectively, a number of general rules must be followed (Gregory, I.N., 2003):

1. There must be a balance. The map should contain as much detail as is needed, but not so many that its theme to be inconspicuous, too "full", or complex.
2. A map should be clear and understandable by itself on its own, without the need to refer to accompanying documents. For this purpose a title, a legend and scale

are needed. The legend should explain all symbols and other information used on the map.

3. The method used for the map symbols should be suitable for the data presented.
4. The symbols used and the hatching/shading should be self-evident, to minimize the need of the map-user's to refer to the legend (a typical example: The waters should be colored blue everywhere).
5. If a shading technique is used to present a thematic hierarchy, the characteristics at the bottom of the hierarchy should be shaded in lighter colors, these on top with darker, and there should be clear and obvious color development in the thematic hierarchy (representative color palette).
6. If a continuous variable (e.g. ethnic migration rate) is subdivided into distinct classes, care must be taken both for the selection of the number of classes and how they are defined. Generally, for maps with a gray-scale (palette), there should be used no more than four or five classes. If in the map a color-scale (palette) is utilized, the classes can be increased if necessary, but never more than ten. Finally, the time-intervals should not be chosen arbitrarily, but must be built on specific characteristics of the data.

9.1 Animation and interactivity

Digital animation is not a luxury. It is a powerful feature that has much to offer to historians. Traditional printed maps are poor 'presenters' of changes over time, in contrast to the movement (animation) of images that can provide this capability. There are many modern file formats that allow the creation of animation, from the simplest animated GIF (where a series of static images are joined successively), to more complex video formats like AVI, MPEG, MOV, SWF, FLV etc. However, although the technical issues associated with the production of animations are very well developed for many scientific disciplines and fields, in relation to the cartographic issues they are still lagging behind.

The animation can present more information than a simple time-line of events. It can also help to show different views of the field, or even to present the study area from above, through 'virtual' landscapes. This technique is particularly applicable to digital terrain models, in which can be inserted both, historical and archaeological evidence as well as contemporary geographical facts. As with animation, this perspective is an exceptional interesting area of research for history, historical geography etc., but must be kept in mind that the end-result aims essentially to the dissemination of information, not only in the presentation of just impressive 'crowd-pleaser' graphics (Gregory, I.N. 2003).

10. Epilogue

The quantitative and social sciences (p.e. fields like urban and environmental history, demography, history, transportation etc.) were the primary targets where historians were focused when they started to use HGIS. It took a good number of years to include 'qualitative interests' in their 'through-HGIS' researches (p.e. concerning fields like: Bible studies, literature and art, culture generally etc.).

From the aspect of applied-HGIS, there is a steady 'deepening'. This means that HGIS is now on an upper level where users/researchers apply it to dedicated scholarships. These new applications produce new knowledge about the past. It is not considered anymore as a hi-tech-"toy", aiming at geosciences and technology 'geeks'. It is a powerful 'tool' that inevitably appeals to a much broader scientific audience.

From the aspect of technical-HGIS, there is a steady 'broadening'. This does mean that technically its scope shows an expanding potential by covering both qualitative and quantitative sources.

The future of HGIS is absolutely linked with the future of the 'basic'-GIS. There is no need to recall and comment here all the new 'tools' are being added to the contemporary GIS-arsenal (p.e. 4D-GIS-x, y, z and time), Web-GIS, Google Earth™ and Maps™, Cloud-GIS etc.), neither their resultant huge and combined benefits …to everyone. No doubt, these major new frontiers do have their decisive expanding impact on the HGIS of course. All the above facts are asking and pushing for the solution of the main problem that underlies: At last, historians need to believe in HGIS! Training, education, changes in ways of thinking, studying and researching, mutual approach from both sides (historians vs HGIS) to the «common purpose», are the most sovereign paths, in order a beneficial and stable-through-time consensus achieved.

Bibliography

Alexopoulos, I., 2008: *Spatio-temporal information in historical research. Apply the Atlas of Hellenism*. 5th National Conference HellasGI, Athens, 4-5/12/2008 (in Greek)

Bodovsky, Y., 2005: *GIS and Historical Research. GIS Resource Document*, 2005.

Buckler, J., 1998: *GIS and historic district management: Annapolis*. CSA Newsletter Vol. X, No. 3, 1998.

Cliff, A.D. and Haggett, P., 1996: *The impact of GIS on epidemiological mapping and modeling*. Cambridge, 1996.

Demoula, S. 2014: *A study of the urban space changes in Thessaloniki for the time period 1430-2000, by using GIS*, PhD Thesis, Dept. Of Civil Engineering, AUTH, 380 pp.

Duran, Z., Garagon, A. and Toz, G., 2004: *Web-based multimedia GIS for historical sites*.

Proceedings of the XX-th ISPRS Congress "Geo-Imagery Bridging Continents. Vol. 35. No. 85.

Erwin, T., and Sweetkind-Singer, J., 2009: *The National Geospatial Digital Archive: A collaborative project to archive geospatial data*. Journal of Map & Geography Libraries 6.1.

Forsell, H., 2003: *Place is not enough - Some considerations concerning theory, context and models when comparing urban political cultures in modern history*. History 30.1

Francaviglia, R. V., 1996: *Main street revisited: time, space, and image building in small-town America*. University of Iowa Press, 1996.

Gregory, I.N., Kemp, K. K. and Mostern, R., 2001: *Geographical information and historical research: Current progress and future directions*. History and Computing, January 13.

Gregory, I.N., 2003: *A place in History: A guide to using GIS in historical research*. Oxford: Oxbow.

Gregory I. N., and Ell P. S., 2007: *Historical GIS: technologies, methodologies, and scholarship*. Cambridge University Press, 2007.

Gregory, I.N. and Healey, R. G., 2007: *Historical GIS: structuring, mapping and analyzing geographies of the past*. Progress in Human Geography, May 31.

Griffiths, S., 2013: *GIS and research into historical "spaces of practice": overcoming the epistemological barriers*. History and GIS. Springer Netherlands.

Kallivretakis, L., 2003: *Historical research of Greek settlements. Research requests and problems of sources*. National Hellenic Research Foundation (in Greek).

Knowles, A., 2005: *Historical Uses of GIS. Future Foundations: Mapping the Past, Building the Philadelphia GeoHistory Network*. PACSCL symposium, Philadelphia 2005.

Knowles, A. and Hillier, A., 2008: *Placing history: how maps, spatial data, and GIS are changing historical scholarship*. ESRI, Inc., 2008.

Lünen, von A. and Travis, C. (Eds), 2013: *History and GIS. Epistemologies, considerations and reflections*, Springer, 2013.

Madry, S., 2006: *The integration of historical cartographic data within the GIS environment. Between Dirt and Discussion*. Springer US.

Mares, D. and Moschek, W., 2013: *Place in Time: GIS and the Spatial Imagination in Teaching History. History and GIS*. Springer Netherlands.

Patrick, F., 2008: *Bringing historic maps into GIS*. Harvard University.

Philo, C., 2009: *International encyclopedia of human geography*. Elsevier.

Rumsey, D. and Williams, M., 2002: *Historical maps in GIS. Past time, past place: GIS for History*. 2002.

Shimizu, E. and Takashi, F. (2000): *Rubber-sheeting of historical maps in GIS and its application to landscape visualization of old-time cities: Focusing on Tokyo of the past.* Proceedings of the 8th International Conference on Computers in Urban Planning.

Wachowicz, M. and Owens, J. B., 2013: *The role of knowledge spaces in geographically-oriented history*. History and GIS. Springer Netherlands.