Example Applications of Historical Maps in GIS and Databases

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Abstract. Historical maps are a vital and often used source in a variety of disciplines and applications. Since a decade or two, they have moved into the GIS-community. A large scanning project by Lantmäteriverket will make most of the maps in Sweden available as raster images. Two major projects have modelled the maps for storage in databases, but they have several drawbacks. In our project we model the maps as close to the original structure as possible with a very data oriented view. In this article some different applications are presented, which goes beyond the traditional use of historical maps are used in GIS. These brief examples involve data mining, statistics, retrogressive analysis and hypothesis testing.

1 Introduction

This article is the last in a series of three, which describes a database and GIS-project around a series of historical maps made over the island of Gotland in the Baltic Sea. In this article we will give some examples of how these, and other historical maps, can be used, once they reside in the database- and GIS-system.

The domestic map making in Sweden dates back to the late 16th and early 17th century. Maps in both small- and large-scales have been quite extensively produced in various time-periods. The small-scale maps are called geographical maps and the large-scale maps are called geometrical maps. The latter depict the landscape at land parcel level, normally in scales between 1:4 000 and 1:8 000. There are text descriptions of the mapped features linked to the map via a code marking system. These first generations of large-scale maps are called Äldre geometriska jordeböcker (Older geometrical cadastres). The results of the next phase in the geometrical mapping are called Yngre geometriska jordeböcker (Younger geometrical cadastres). This mapping started in the 1670-80’s for several reasons. Fiscal reasons were prominent, with the mapping as a basis for setting taxes. Gotland and other incorporated parts became in large extent mapped in this period [17] [19].
The results of all the mapping conducted during several centuries are kept in various archives today and can probably be counted in the range of millions (including duplicates). Sweden is rightfully famous for its large collection of large-scale historical maps. In other countries maps of this kind do exist, and if so only sporadically, based on private initiatives by single land owners, and not by the state, as in Sweden.

For several years Lantmäteriverket (The Swedish National Land Survey Agency) has conducted a major scanning project. The goal is to digitise all historical maps (and the accompanying texts) in their archives. The project is planned to be finished in 2008 and the maps are gradually made available via the Internet as a pay service for the public [27]. This will even further boost the use of historical maps in GIS- and database applications.

1.1 Previous research

There are a multitude of smaller projects dealing with digitalisation of historical maps that are very narrow in their scope. They are set up for a restricted purpose and do not go beyond to handle a few maps. The database modelling process is normally very limited and also poorly documented. Two projects have been dealing with historical maps in a more all-embracing fashion. They are Nationalutgåva av de äldre geometriska kartorna project at The National Archives of Sweden [16] and the Digitala Historiska Kartor (DHK) at The National Board of Antiquities of Sweden [1]. The former project only deals with the maps from the first phase of Swedish large-scale mapping between 1633 and 1655. The focus of the project is the text descriptions. The text descriptions of these first Swedish large-scale maps were very brief and short.

The other major project, Digitala Historiska Kartor (DHK) at The National Board of Antiquities of Sweden, is well documented with a series of preliminary reports and one final publication with a conceptual model [1]. The focus of the DHK-project was the general information, which can be found in any Swedish large scale historical map. The analyses also focused on how the maps are used in the cultural heritage sector and mainly treat the information used in this sector.

1.2 The GM1700 map project

GIS-applications and analysis using historical maps has mainly been focused on overall landscape or land use studies over a small area. In these studies a limited amount of the information in the historical maps has been handled. Mostly it is the land parcels, building sites, etc. Not much of the text descriptions are handled, and when they are, it is done in a very simple database manner. Our project has a wider scope and attempts to deal more with the maps and the text descriptions and to model how these maps are organized. We analyse the concepts contained, the meaning of these concepts and how they relate to each other. To do this there is a need for a broader perspective and a more data oriented view of the maps and the text descriptions. An ontology was developed over the Universe of Discourse, since the
concepts are in focus and we wanted to be able to map the concepts from different kinds of maps, with their own ontologies to each other [21]. The ontology is presented in [23]. The ontology is also a domain model/conceptual schema which is used as a basis for a database model to enable the storage of these maps and all the information in the databases; as close to the original structure as possible. The logical database schema and mapping between the frame-based ontology and E/R-based logical schema is described in [24]. We see the GM1700 maps as archive artefacts and documents. For most researchers in the humanities the access to the unadulterated source is vital. This project is an attempt to make these maps available and manageable in a way that can be trusted by researchers in the humanities and reducing, or even eliminating, the need to go to the source itself, for most of the problems formulated. In analogy with the thoughts of Bittner and Smith [22] that a map in itself is an ontology, we can say that the document is an ontology and the focus of this work is to elucidate, clarify and repack the ontology, to make it more explicit and easily understood.

Figure 1 Part of a map and text description from the GM1700 map series. The arrows show the linking of the map and text descriptions via the code marking system.

The maps where made by seven surveyors between 1693 and 1705, henceforth referred too as GM1700 (Gotlandic Maps of 1700). These are the first maps produced over the island of Gotland. They are unique in many senses, both regarding the type of information they contain and the fact that they cover the entire island. The purpose of the mapping was taxation and to gain knowledge about Gotland. The maps are made in the scale of 1:8 000 in the manner described in the instructions for the surveyors of the time. Jointly with the maps are text descriptions of the mapped features and additional information (fig 1). The mapped features and the texts are linked by a system of code markings. Not all features are code marked and not all text
is linked to the map. There can be some variations in the contents and manner, depending on which surveyor who made the map [20]. An amateur researcher, Jakob Ronsten, have made transcripts of all the text descriptions which are much richer than the older geometrical cadastres.

2 Usage of historical maps in GIS

Historical maps are in most cases used in GIS in the same fashion and for the same purposes as in the pre-GIS days. That is to produce map overlays that can be compared with other maps over the same area (other historical or modern maps) and also other types of spatial data, for visual interpretation. In the pre-GIS days this was done with manual rectification and geocoding on plastic film of the historical maps into a modern coordinate system. This process has, with the help of GIS-tools, now moved into the computer. There are numerous examples of this kind of analysis development of the historical maps and interpretation of areas over time, using this approach. As an example the landscape analysis of Holm parish in Uppland, Sweden can be mentioned. In this study historical maps and archaeological sites are used as the main sources for landscape analysis and used in a GIS system, together with other sources [3]. In The DHK publication, Digitala historiska kartor – Tillämpningar i GIS för kulturmiljövård [2] a series of example applications are presented which gives a fairly good overview of how historical maps are used in different kinds of landscape analysis in GIS-system. They are mostly dealing with analysis concerning land use, and the overall development of the landscape from different perspectives and how you can visualize these changes. Examples are also given on how to use data from historical maps to visualize the impact of different activities, e.g. building a new road, to the historical continuity of the landscape. These types of studies are of great value and are often used in the pilot study phase of major building and planning processes, but do not go much beyond the traditional usage of historical maps. In the examples given in [2] the maps are often visualised in 2-D where the map or reconstructed land use is draped over a digital elevation model (DEM) or in 3-D as a fly-through etc. Also the capability of the modern GIS-system to distribute the maps and the results to a larger audience over the Internet is shown. The examples in [2] cover much on how historical maps are used in the cultural resource management and also point to some extended use. It is for these kinds of application the conceptual model of DHK is designed and for these purposes it is also a good model. If you have other questions and need the map specific- or generation specific information from different historical maps, then the DHK model must be extended or new ones created.

In the remaining part of the paper we will give some brief examples of extended use of the historical maps in GIS using more of the statistical and calculative powers, together with visualisation, of GIS. We have a firm belief usage of GIS by researcher in the humanities in all kinds of problem solving and reasoning around spatial dimensions will increase. Historical maps can be used as sources for all kinds of problems and theories and also hypothesis testing of a more academic and research fashion. These examples presented here do of course not cover all possible uses of GIS and historical maps. Some of these examples could only be performed with a
2.1 Locating abandoned farmsteads

The geometrical cadastres from the 17th and 18th century depict the situation and features in Swedish villages or farms, which had bearing on the contemporary society and administration. The state of affairs showed in the maps was the result of a long development that goes far back in time. With proper analysis of the maps, together with other data, the situation in the area can be extrapolated back in time to the medieval/Viking age or even further back. This kind of analysis is called retrogressive analysis, which is a firmly rooted tradition in Swedish and European historical geography. The organization of the cultural landscape that can be seen in the geometrical cadastres was created long before the creation of the maps and could be traced back in time, maybe as far back as two thousand years [10]. Dan Carlsson uses the GM1700-maps as the main source in a retrogressive analysis concerning the agricultural- and settlement development on Gotland during the Iron Age. In his thesis he argues that the organisation and structure of the Gotlandic farms we see today, was established during the older Iron Age [13].

The older and younger cadastres are the most suited maps for these kinds of studies. This is of course because they are the oldest depiction of the cultural landscape, but also because later maps are made with the purpose of redistributing land and thus shows two time horizons; the state of affairs before the redistribution of the land and the state after it. These two can sometimes be hard to separate in the maps [10]. The cadastres are on the other hand created primarily to depict the current state of affairs. In a retrogressive analysis both the map itself and the text part are important ingredients. As examples the study conducted in GIS by Charlotte Fabech & Jytte Ringtved [9] can be mentioned. They used historical maps and other methods to recreate the prehistoric landscape and land use in the Bjerringbro/Hvorslev area in Denmark. Sven-Olof Lindquist has shown in [15], that also the later maps like, a Lagaskifte map from 1878, can be useful in retrogressive analysis. Due to the purpose of the map, redistribution of land, the mapping was very careful and accurate in soil quality assessment. Without knowing it, the land surveyor mapped fossilised field systems with a dating from 500 B.C. The fields are depicted in the maps as regular patterns of different soil quality, which is the result of the farming techniques of the time. With the proper retrogressive analysis, historical maps can be used for studies of phenomenon and processes with a much wider time frame than just the creation date of the map.
How a farmstead’s land parcels is scattered and placed in space can also be important clues to the history and age of a farmstead [13]. The patterns of scattered land parcels can reveal the places of ancient farmsteads. Together with other factors like; site quality class, (e.g. high amount of mould indicate intensive farming during a long period); land parcel names (names can indicate disappeared farmsteads); and ancient remains, areas of interest can be located. This is a well known fact and parameters like the ones listed are often used in retrogressive studies, like [13] [10].

To graphically display the location of each farm’s land parcel, standard techniques based on SQL and GIS-functions can be used. The result is very easy to interpret and
the visual power is vast, as shown in fig 2. The parameters of interest in this example are: ancient remains of iron age settlements, fields with mould, names of land parcels indicating old farmstead names and “remote” areas where many different farmsteads own land, which the arrows from each farm to its own land parcels indicates. In the marked areas we can see areas, with he names “Fylleqwie” and “Huusarfwa” which can be old farm names, and are interesting for further investigation concerning abandoned farmsteads. These abandoned farms’ infields have been requisitioned by the neighbouring farmsteads, probably due to desertion for some reason.

2.2 The Christianisation of Gotland

Sven-Olof Lindquist [4] has conducted reasoning around the formation of parishes and the introduction of Christianity on Gotland. This is made from a chorological point of view, which is very well suited for performing in GIS-systems. At the time for the paper (1981) he had no access to GIS-systems, so all calculations had to be mad by hand in paper maps. This took very long time, even when only a sample of parishes were selected (31 of 92). In 2001 [5] Sven-Olof Lindquist, together with one of the authors, made some of the calculations in GIS. This time it was made for the entire island, 92 parishes, since data now were available in digital format for the entire island. This time the calculations and creation of the resulting maps only took a few hours to produce.

The main research question was to try to answer the debated question whether the formation of the parishes was a prolonged process, which some scholars advocate, or if it was a quite rapid process which Lindquist believes. A secondary question was the question of who took the initiative to erect the parish churches and decide where it should be placed. Was it a single man (great man) or a joint decision of farmers that were all peers? The GIS analysis focused on the second question. The data used in the analysis was the positions of the farmsteads in 1700 and the parish borders of that time. The usage of the farm sites from 1700 for a process that took place 700 years earlier is was motivated in a retrogressive analysis. The hypothesis was that the physical location of the church was a joint decision by the farmers and it was placed as “fair” as possible, which means that it should have a central location, in relation to all of the farmsteads. The first analysis was to compare the extension of the parishes around the churches, to the “optimal” one. The optimal extension was defined as the thiessen polygon around the church. The location of the farmsteads was then compared to the optimal parish and the actual parish it belonged to. Only around 8 % of the farmsteads lay closer to another church then the church to which it belonged, which point towards strengthening the hypothesis (fig 3a). If natural obstructions like bogs etc, where to be taken into account the number would probably decrease. As a further test of the hypothesis, the distance between the church and the minimum transport distance from the farmsteads was compared. The rationale for this is as follows: If the distance is short, it points to the fact that the positioning of the church is “fair”, and all farmers had a say in the decision. If the distance is long, it is interpreted as the decision around the placing of the church is not made in consensus. In the GIS-system the transport minimum was calculated as the centre of gravity, by
taking the mean position along the X- and Y axis of all the farmsteads in each parish. The distance between this point and the church was calculated. This distance was then visualised with a circle, with the distance as radius, around each parish, as shown in Fig 3b.

Figure 3a: The reddish areas are the difference between the optimal parishes, represented by thiessen polygons around the churches and the existing parishes.

Figure 3b: The distance between the centre of gravity of the farmsteads and the church, in each parish

The results strengthen the hypothesis further. The parishes that have long distances are all known to be anomalous and there were known explanations for these anomalies.

2.3 Statistics and calculations

Statistical calculations and other quantitative methods have a long tradition in studies of past times with historical maps as source material, often combined with other sources. These calculations have, in the past been very tedious. With a system like ours, they will be rapid and precise. Calculations can easily be made, both from tabular data from the text part and from the geometrical properties of the mapped features in the map itself. A good example of a classical study of this kind is Svenskt agrarsamhälle under 1200 år [12] in which data from historical maps are used in calculations of yield, consumption etc in the agricultural societies of the past to depict the development over a longer period. There are numerous examples of these kinds of studies.

Calculations and statistics will maybe not give the answers to most problems formulated in the humanities, but it makes often very a good starting point or help in the interpretation of many problems. It helps in describing and giving a good overview of a situation or state of affairs, which can be useful in reasoning about a problem. In a GIS system it can also be presented in a graphically powerful way and
displayed in the map. Here we will show some examples of how calculations and statistics can be used in the presented system.

2.3.1 Ways of acquisition
In the GM1700 maps, there are in many cases notations of the owner and how s/he acquired the farm. There is also often information about ownership and ways of acquisitions that goes back some generations, at the most 4 generations back. This is very unusual in other historical maps and can be an important source in many kinds of studies. For example in studies concerning the mobility of the peasant population and also ownership matters. To illustrate this we can show some figures and maps concerning the ways in which the present owners (in 1702) had acquired their farms. Of the 39 different farms (23 registration units, which is divided in 39 farms) 23 are freeholder farms. Of these 10 (43.5 %) are purchased by the present farmer. The legislation of the time, gave a freeholder the right to freely sell his farms, not parts of it, but kin had purchase option. The maps, together with other sources, like church records in a parish, can be of great value in studies around questions concerning purchases and other forms of transfer of property or lease.

This example uses the map-specific information in the GM 1700. These basic statistical calculations could have been performed for any of the unique information found in these maps, like the tax commodities, wood supplies.

Figure 4 Map and statistics showing the ways of acquisitions of farms in Fröjel parish
2.4 Location of iron-age settlements

The need and demand for the ways to predict and understand the reasons for the location of various archaeological sites is of great importance, both for Cultural Resource Management (CRM) and for Academic research in Archaeology. A predictive model attempts to predict where archaeological sites or features are located, by looking for tendencies and patterns observed in a region or by theory and notions of the distribution of sites or features [14]. An example is a large Danish project called “Foranderlige landskaber” [11] in which different techniques for predictive modelling where tested, to identify archaeological sensitive areas, base on the methods developed and tested in an other project [8].

The information used in the models is of two parts, the dependent and the independent variables. The dependent variables are the archaeological sites or features whose distribution is sought. The independent variable is the characteristics that are recorded at each land parcel. These characteristics can be divided in four major themes, according to Kvamme [14]: Environmental variables, cultural and social factors, positional characteristic and radiometric characteristics. With the basis in retrogressive analysis, historical maps can be used in Predictive modelling. The information from historical maps is a social factor, used the same way as other ancient remains.

In the agricultural district areas around Roma in the centre of Gotland there are relatively few ancient remains recorded in the national database of ancient remains.
The general belief is that there have been many ancient remains, but the modern farming has wiped out most of the visible traces in the landscape of past times. With predictive modelling it can be possible to find the areas where it is most likely that some of these ancient remains once lay.

In Gotland there are several researchers who have noticed that there is a correlation between “Kämpegravar”, which are Iron Age house foundations with dating around 200-600 AD and the land use found in GM1700 maps. The meadows and farmstead sites from the GM1700, and other variables where used in a predictive model to verify this theory and also try to predict areas, where these house foundations had been located [7]. The model preformed very well and had high significance. Even if the areas picked by the model are to large to be really useful in field archaeology, predictive modelling techniques can be very useful in finding patterns in data and also in finding archaeological “sensitive” areas, with a higher likelihood to inhabit different types of ancient remains, than others. Historical maps can here be a very good source for variables, according to the methods in retrogressive analysis.

2.5 Distances

Distances were probably of great importance for many reasons in the old agricultural society [13]. The farmstead lot was generally placed near the fields, which were of highest economic value and also most vulnerable. Distances were also costly for transportation and time reasons; the greater distances between the land parcels, the more time had to be spent on transportation. Distances are not only important in studies concerning the contemporary society at the time of the creation of the maps. Distances also play a vital role in many other analyses. As an example of a study that would have been much helped by our system (too our belief), is Östergrens thesis [25] concerning Viking Age silver hoards. In this study distances between different features found in the GM1700 and the find places of silver hoards is of paramount importance for the analyses. In a GIS these distances are very easy to calculate, with standard techniques.

As mentioned above the scattered-ness of a farmsteads land parcels can reveal something of the age and older phases in the farmsteads history. It also effects the farming itself, as discussed above concerning distances. It is hard to pinpoint exactly how this works, but generally a more scattered farm has been subjected to more changes in its history, thus indicating a longer history. For example inheritance of other farms, strategic marriage, moved building site or the requisitioning of abandoned farms land, as in the examples showed above. As a tool to visualize this scattered-ness in statistical terms we have created an index, which shows how far a farm has to different percentages of its land. The index is defined by summing, for each farm, the land parcel acreage and finding the median (i.e. the distance that separates the 50 % remotest areas of the farm's land). The median of these values is set at 100; thus values above or below 100 indicate a higher or lower degree of scattered-ness. These calculations can of course also be done at other breakpoints,
like quartiles (25%, 50%, and 75%) and others. The resulting numbers can then be visualized in different ways.

Figure 6. Map over Fröjel parish showing each of the parish scatter-ness indexes as a circle

3 Discussions and future work

Swedish large-scale historical maps are a unique source for many types of historical analyses. It is not only used in historical research, but also in ecology, archaeology, geography, linguistics etc. They are also used in a very high degree in none-research, for example in cultural heritage management, social- and physical planning at all levels, etc. Prior projects concerning the digitalisation of historical maps have drawbacks in various ways, affecting the usefulness of the digitised maps, for other purposes then the original scope of the project. The project Digitala Historiska Kartor (DHK) [1] at Riksantikvarieämbetet had a too general approach, not addressing all the map- or generation specific information found in different maps. It only handled the general information, found in any historical map. The project Nationalutgåva av de äldre geometriska kartorna at Riksarkivet [16] mostly addressed the text part of the maps, leaving the map itself, more or less unprocessed.
With our work we have showed a novel approach more suited when dealing with such a diverse- and semantically rich domain like historical maps. Instead of a traditional database modelling process, with models created in meta-models like the OO meta-model or E/R meta-model, we have created a domain model as an ontology, which is more suited for modelling semantic/conceptual analyses. The semantic analysis is made with the aim of capturing all concepts in each map series. To model all information in all types of maps a very data oriented view is needed. This approach leads to a model that is very map-dependent, not like the DHK-model, which is very general. The idea behind our approach is that each map series or map-generation needs an ontology of its own, if all information is to be modelled. These different ontologies, can then be mapped or aligned to each other, or even merged into one Swedish Historical Map Ontology. Ontologies are more suited for this than traditional database modelling techniques. With this approach we do not lose any (or at least very little) information from the maps in the modelling process. Of course both the modelling of a domain model of this kind and populating the resulting database, takes longer time then when a more general model is used. We believe that in the long-run, it will save time since different scholars and agencies do not have to redo the process, due to the lack of data, for their specific problem.

The usage of historical maps in GIS has, in most cases, been focused on the use of the GIS-tools as merely a display tool. The focus has mainly been concerned with displaying the maps as “they are”, not trying to reveal and display, any nested or hidden information in the maps. The analytic and statistical capabilities of modern GIS-packages have seldom been used. In this paper we have showed some examples of usage of historical maps, in which we use more of these capabilities of GIS. The graphical and display capabilities of GIS, is also an essential part of our examples, but we have focused on using them to highlight and display the more deeply nested knowledge only visible after the information has been processed and analysed.

Some of these analyses are only possible to carry out if you have a domain model like ours that picks up the map specific information and handles both the map and the text part. As an example of this we used the notations around the owners and how they acquired the farm. Due to the lack of scanned maps, we could not fully demonstrate the analyses that can be performed. We only had access to scanned maps from one parish, Fröjel. A lot of the map-specific information, present in other parts of the island, was not present here. Among these are the very interesting notations around disputes of land and co-ownership. With the full database, these questions could be analysed. Interesting questions would be, are there any special distributions of the farms and land disputed or co-owned? Can any characteristics of the farms involved be spotted? One working hypothesis could be that the disputed or co-owned land is land once belonging to now (around the year 1700) abandoned farms. Also the notations of what commodities the farmers used to pay taxes would be interesting to analyse, to see the spatial distribution.

With our model will, for the first time, essentially every piece of information from historical maps be digitised and stored in a database. This enables to search for novel, and yet unknown patterns and correlations with advanced data mining techniques to gain new knowledge from the maps. One example was given around predictive modelling for Iron Age settlements in which information from the GM1700 was used.
In our example logistic regression analysis was used, but other data mining techniques can probably be used for a great variety of problems and theories. This is, however, a largely undiscovered field of research and further research is needed to explore all the possibilities.

Historical maps are often used in retrogressive studies. In these analyses you extrapolate the depicted state of affairs found in the maps, back in time to reveal the situation several hundreds, or even thousands, of years prior the creation data of the maps. As an example we did a fairly elementary, but very powerful, graphical analysis that can reveal the location of abandoned farmsteads. In some areas the maps reveals very unusual situations, like in the parish of När. Farms from many surrounding parishes own land by the coast at a place called Hammaren. We believe that with a method like the one presented here, could help clarifying and revealing the true nature of these states of affairs. This could probably be a good starting point for a deeper analysis. There are probably several more locations, not so obvious, that can be located with this method.

We hope that we, with this paper, have given some relevant examples on how properly modelled historical maps can be used in a variety of different applications and problems. The examples we have given, of course, not correspond to a comprehensive set of analyses. This field is largely an undiscovered area of research and we hope many others will follow in our steps and try to reveal more knowledge from historical maps using advanced data processing.

In these examples we have only worked with one time horizon of historical maps. Our argumentation around the benefits of creating an ontology, rather than a traditional conceptual model, focuses on the ability to map concepts from different maps to each other. However, we made a greater priority to get a working system, a demo application, with only one map series so we could show all the capabilities of such a system. The next phase in this work is to create more ontologies over different map generations/series from Gotland and map these ontologies to each other and enable temporal studies. This is a non-trivial problem since these later maps had a completely different focus; land redistribution among neighbouring farmers. The orderer of the map is not the Crown, but the farmers themselves. This means that the main concept is no longer the fiscal unit, but the operating unit, e.g. the land each farmer owned, not which fiscal farm it belonged to. This leads to, at least, for the later lagaskiftes maps (1827-1972) that it can be hard to identify, which fiscal unit a land parcel belongs to, since farmers could have an operating unit consisting of different parts of many fiscal units.
References


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