Ontology as Conceptual Schema when Modelling Historical Maps for Database Storage

by

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Abstract: Sweden has an enormous treasure in its vast number of large-scale historical maps from a period of 400 years made for different purposes, that we call map series. The maps are also very time and regional dependent with respect to their concepts. A large scanning project by Lantmäteriverket will make most of these maps available as raster images. In many disciplines in the humanities and social sciences, like history, human geography and archaeology, historical maps are of great importance as a source of information. They are used frequently in different studies for a variety of problems. A full and systematic analyse of this material from a database perspective has so far not been conducted. During the last decade or two, it has been more and more common to use data from historical maps in GIS-analysis. In this thesis a novel approach to model these maps is tested. The method is based on the modelling of each map series as its own ontology, thus focusing on the unique concepts of each map series. The scope of this work is a map series covering the province of Gotland produced during the period 1693-1705. These maps have extensive text descriptions concerned with different aspects of the mapped features. Via a code marking system they are attached to the maps. In this thesis a semantic analysis and an ontology over all the concepts found in the maps and text descriptions are presented. In our project we model the maps as close to the original structure as possible with a very data oriented view. Furthermore; we demonstrate how this ontology can be used as a conceptual schema for a logical E/R database schema. The Ontology is described in terms of the Protégé meta-model and the E/R schema in UML. The mapping between the two is a set of elementary rules, which are easy for a human to comprehend, but hard to automate. The E/R schema is implemented in a demonstration system. Examples of some different applications which are feasibly to perform by the system are presented. These examples go beyond the traditional use of historical maps in GIS today.
Acknowledgements

A work like this can not be accomplished without the assistance and support from many people. First I would like to thank LARS-MAGNUS LAHNE, who made it possible in the first place to start this endeavour, by arranging the financing. My wife BERIT and daughter SARA need thanks for accepting my absence from home from time to time. HÅKAN MATTSON and BO-GÖRAN JOHANSSON need extra thanks for help concerning database and mathematical issues. TRYGGVE SILTBERG, SVEN-OLOF LINDQUIST and also DAN CARLSSON have been of great help with remarks and discussions around the historical maps of Gotland and other historical and archaeological issues. My supervisor ERLAND JUNGERT and also many others: Thanks!

Gustaf Svedjemo
Visby, April 2007
# Table of Contents

1. **INTRODUCTION** .............................................................................................................................................. 1  
   1.1. **PROBLEMATISATION** .............................................................................................................................. 2  
   1.2. **THE SCOPE** ............................................................................................................................................. 2  
   1.3. **PRIOR RESEARCH ON DIGITISING HISTORICAL MAPS** ......................................................................... 3  

2. **SWEDISH LARGE-SCALE MAPPING** .................................................................................................................. 6  
   2.1. **GOTLANDIC LARGE-SCALE MAPS** ......................................................................................................... 9  

3. **KNOWLEDGE MODELLING** ............................................................................................................................. 11  
   3.1. **MODELLING CONSIDERATIONS** ............................................................................................................. 12  
       3.1.1. **Modelling Objectives** .................................................................................................................... 13  
       3.1.2. **Real Estate and Land Parcels** ........................................................................................................... 13  
       3.1.3. **Space and Time** ............................................................................................................................ 14  
       3.1.4. **Uncertainty** ...................................................................................................................................... 15  
       3.1.5. **Completeness and Coherence** ......................................................................................................... 16  
   3.2. **THE ONTOLOGY OF THE GM1700 MAPS** ............................................................................................. 18  
       3.2.1. **Value Partitions** ............................................................................................................................. 20  
       3.2.2. **Remaining classes** .......................................................................................................................... 21  

4. **ONTOLOGY AS CONCEPTUAL MODEL** ............................................................................................................. 21  
   4.1. **MAPPING THE ONTOLOGY TO AN E/R SCHEMA** .................................................................................... 22  
       4.1.1. **Mapping principles** .......................................................................................................................... 24  
       4.1.2. **Mapping decisions** .......................................................................................................................... 26  

5. **THE DEMONSTRATION SYSTEM** ................................................................................................................... 27  
   5.1. **GIS TABLES AND GEOMETRICAL ASPECTS** ......................................................................................... 27  

6. **APPLICATIONS** ............................................................................................................................................... 31  
   6.1. **EXTENDED USE OF HISTORICAL MAPS IN GIS** .................................................................................... 31  
       6.1.1. **Retrogressive studies - Scattered-ness of land parcels** ................................................................. 32  
       6.1.2. **Hypothesis testing - The Christianisation of Gotland** ..................................................................... 35  
       6.1.3. **Statistics and calculations** ............................................................................................................... 36  
       6.1.3.1. **Ways of acquisition** ..................................................................................................................... 37  
       6.1.4. **Data mining - Predictive modelling** ................................................................................................. 38  
       6.1.5. **Distances** ........................................................................................................................................ 40  

7. **CONCLUSIONS AND FUTURE WORK** .......................................................................................................... 41  

REFERENCES .......................................................................................................................................................... 46  

APPENDIX A **PAPER 1** ........................................................................................................................................ 53  

APPENDIX B **PAPER 2** ........................................................................................................................................ 68  

APPENDIX C **PAPER 3** ........................................................................................................................................ 81
1. Introduction

Sweden has an enormous treasure in its vast number of large-scale historical maps archived over a period of 400 years. These maps are regularly used for temporal studies in many disciplines and different types of historical and archaeological research problems. A full and systematic analysis of the maps, for the purpose of database storage, has not been conducted. In this work, an implementation of a database and a GIS system for the Gotlandic maps made between 1693 and 1705, henceforth referred to as GM1700, is presented. The system is based on an ontology and the ontology corresponds to a conceptual model in the database modelling process. The approach is data oriented, since the views and exact research questions the system is designed for were not known at modelling time. The assumed users are researchers in history, archaeology, human geography, and adjacent disciplines while the purpose is to be able to create views and queries based on their research questions at hand. For most researchers in the humanities and social sciences 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 these disciplines, thus reducing, or even eliminating, the need to go to the source itself for most of the problems formulated. This makes it vital to keep the original structure of the information.

When dealing with a knowledge domain like historical maps, where a semantic and conceptual analysis is needed in depth, it is a better method to create an ontology rather than an ordinary conceptual model, based on the OO-paradigm or E/R-paradigm, for the understanding of the domain. An ontology is richer in semantics and the tools developed are more suited for the semantic analysis. This is something also recognised by Aests et al [81] in their work with topographical maps from different mapping agencies across Europe. In their paper they discuss the benefits of using ontologies when dealing with a semantically heterogenic Universe of Discourse. We also believe that visualization and understanding of the ontology is simpler for non-computer experts, like domain experts, when ontology-engineering tools are used.

We use the term ontology in the meaning of an ontological static model of a domain (much like a conceptual model). The model describes the concepts, slots (relations and attributes), axioms, etc., of the domain. Individuals are only used to express values of slots. Our ontology, previously presented in [67] is, however, possible to populate with individuals, if required.

The use of frame-based modelling tools creates a need to map the ontology to a conventional logical database schema –expressed in the E/R paradigm– if a relational DBMS is to be used. We do this by means of a set of elementary mapping rules that bridge the gap between the two meta-models’ –the frame paradigm and the E/R paradigm- most fundamental primitives.

Use of information from historical maps is a long time a standard procedure in many domains in Sweden. Since so many populated areas have at least one historical map they are consequently of great importance as sources for historical knowledge of that area. The maps are frequently used in different studies of a variety of problems and also in different planning activities, such as the archaeological phase of preliminary investigations in
construction planning and cultural management in both public- and private sectors. They are also used extensively in academic research in archaeology, geography, history, linguistics, and other disciplines. Examples of research areas are; naming customs, agricultural development, ownership, spatial distribution of historical phenomena, etc.

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, which probably can be counted in the range of millions. 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 [39]. This will even further boost the use of historical maps in GIS- and database applications.

The small system described in this paper can be seen as a test project to gain knowledge and experience of the methods developed. This will later be implemented in a larger, more general, system capable of handling all classifications of Swedish large-scale historical maps.

1.1. Problematisation

The majority of agencies and researchers that have dealt with the digitalisation of historical maps, at least in Sweden, have done it to solve some specific problems and for use in special areas of interest, mostly concerning landscape analysis, archaeology or cultural management. This is of course very essential and important parts of using historical maps in modern research and cultural management. These function oriented views, however, do not use the full potential and all of the information found in the maps and text descriptions. Efforts made in most of the digitalisation projects are of low value for problems and analyses that have other focus. If new questions are asked and new approaches found, there is, with the present systems, a need to redo all or parts of the work for collection of new information.

1.2. The Scope

The scope of this work is to model a GIS and a database system that can handle as much as possible of the information contained in the maps and text descriptions. There is a need for a broader perspective and a more data oriented view of the maps and text descriptions. The aim is to provide a database from which data and information can be extracted for many different analyses and problems so that the need to go back to the source is consequently minimized. The objective is to build a GIS data warehouse from which information can be retrieved and processed, with or without a map, for many different applications and analyses in mind.

The information in the maps and text descriptions is of large interest in many disciplines in the humanities, and the social sciences. The system planned will also have capabilities for handling data and entity classes in a more traditional database fashion, where the geometrical property is not in focus. An example can be to join tables with information at a more abstract spatial level like farms, villages or parishes.
1.3. Prior research on digitising historical maps

A method developed by the Department of Human Geography at Stockholm University in the 80’s was concerned with rectifying and transforming historical maps into transparent plastic films. This method has long been used in comparative studies with contemporary maps [16] [28]. It can be seen as an analogue overlay analysis, which is a standard technique in GIS analysis today. The introduction of GIS and other digital means has not fostered the development of new analysis and approaches. The maps have continued to be used more or less in the same manner. The full potential of the maps has never been used and all the text information has, so far, not been digitalised.

In Sweden, some projects have been set up in order to digitise or establish routines for digitising historical maps. One of the first digitalisations of historical maps in Sweden was with the GM1700. This was done in the 1980’s in the project Markdatabas Gotland (MDG). The project is described in several articles, for example Widegren [75]. The method used was very fast and imprecise and the geometrical quality was not very good. The only information extracted was the geometry for the fields, meadows, building sites, and bogs. None of the remaining attributes were extracted. This resulted in GIS layers of the different land uses mentioned above in both raster- and vector formats. Unskilled students made the digitalisation and the layers have very poor topology, with a lot of slivers and double features.

In the early 1990’s Riksantikvarieämbetet (The National Board of Antiquities of Sweden) initiated a series of projects together with other government bodies in order to work out a method to digitalise and georeference the historical maps in a GIS environment. These are the KartGIS and LiM projects. The projects mainly looked at small-scale maps; particularly a series of maps often called Häradskartan, and came up with a series of publications and an application within the LiM project [28]. These projects were function oriented with the goal to digitise data to be used in predefined tasks and analyses and much information was left untreated.

Two larger projects in recent years have been dealing with historical maps in a more all-embracing fashion. These are the project Nationalutgåva av de äldre geometriska kartorna at Riksarkivet (The National Archives of Sweden) [56] and the project Digitala Historiska Kartor (DHK) at Riksantikvarieämbetet. The former project only deals with the maps from the first phase of Swedish large-scale mapping between 1633 and 1655. The project is still running, but the database application and conceptual analysis is, so far, very poorly documented. The only documentation is the logical database schema, which can be hard to interpret without being part of the database modelling process. The focus of the project is the text descriptions. The geometrical aspects of the maps are not handled. The only link between the database and the maps are the coordinates for each settlement unit, (bebyggelseenhet, normally a village) and some other features like mills etc. Most features like the land use and fencing-systems, roads, etc. are not georeferenced at all. The text descriptions of these first Swedish large-scale maps are also very short and brief, as seen in table 1.
<table>
<thead>
<tr>
<th>Code marking</th>
<th>Original text in Old Swedish</th>
<th>Translated into modern English by the authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nye Berqwara j Kinnewaldz Häredt J Skatelöfz Sochn vthi Smålandh</td>
<td>New Bergwaro in Kinnewaldz hundred in Skatelötz parish in Småland (province)</td>
</tr>
<tr>
<td>2</td>
<td>Vthsäde ... 18 t(unno)r</td>
<td>Sowing 18 (barrels)</td>
</tr>
<tr>
<td>3</td>
<td>Vthsäde ... 18 t(unno)r</td>
<td>Sowing 18 (barrels)</td>
</tr>
<tr>
<td>4</td>
<td>Vthsäde till haßle ... 5 ¼ t(unn)a J alla gerden bepins leer jord medh sandh beblendetat</td>
<td>Sowing for hassle 5 ¼ barrel In all fields is there clay soil mixed with sand</td>
</tr>
<tr>
<td>5</td>
<td>Engh tillsammans recknis på begge sider om åån, fåås när medelmåtigh gräßwext ähr... 166 laß</td>
<td>Meadow together counted on both sides of the river, on average growth it yields 166 (wagon) loads</td>
</tr>
<tr>
<td>6</td>
<td>Äälafiske.</td>
<td>Eel fishing</td>
</tr>
<tr>
<td>7</td>
<td>Betishagar.</td>
<td>Enclosed pasture-land</td>
</tr>
<tr>
<td>8</td>
<td>Platzen som Hans Nåd will låta bygga sätisgården.</td>
<td>The place where His Grace wants to build the manor</td>
</tr>
<tr>
<td>9</td>
<td>Quarn.</td>
<td>Mill</td>
</tr>
<tr>
<td>10</td>
<td>Holmar, huilka säges tillförne hafwer werea een kongzgård byghd och skulle wara nedsunkin.</td>
<td>Islet, of which it is said have been built with a State demesne which is sunken down</td>
</tr>
<tr>
<td>11</td>
<td>Engh huilkwen hafwer een tidh werea bergat vthha brukzfolket wid Huseby. Godh Lägenheet med bööke ekeskogh och annor nödtortgh skogh såsom och med vthmark. Ähr och lägenheet att göra meer åker.</td>
<td>Meadow, which has been for some time harvested by the workers from Huseby Good place with beech, oak and other scanty wood and outlying land. There is room for more fields.</td>
</tr>
<tr>
<td>12</td>
<td>Engh hagar.</td>
<td>Meadow enclosed pasture.</td>
</tr>
<tr>
<td>13</td>
<td>Vthmark.</td>
<td>Outlying land</td>
</tr>
</tbody>
</table>

**Karttext:**

<table>
<thead>
<tr>
<th>Karttext:</th>
<th>Text in the map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacus Salen, Jgla siön</td>
<td>Lake Salen, Iglia lake</td>
</tr>
</tbody>
</table>

**Figure 1.** Detail from the map over Bergquara (Bergkvara). The numbers in the map are the code-markings linking the text descriptions (transcript in the table above) to the map.
The other major project, DHK at The National Board of Antiquities of Sweden, is well documented with a series of preliminary reports and one final publication [28]. The work also includes a conceptual model. The project identified three levels of information in historical maps; *map specific*, *generation specific* and *general information*. The map specific information is found in one or a few maps. A map generation is a series of maps created with the same objective during a shorter period of time, e.g., *Storskifte*, *Laga skifte* (these examples are two different land reforms in Sweden). The general information can be found in any historical map. They made a user survey to analyse how the maps are used in the cultural heritage sector and mainly treat the information used in this sector. The focus of the DHK-project was the general information in the maps. The approach was to analyse the concepts found in many of the historical maps to find the lowest common denominator behind these concepts. This means that a lot of map- or generation specific information is hard or impossible to handle in their model. They [28] divide the general information into the following themes: *Types of land, land use, topography, hydrology, constructions, administrative divisions (at mapping time) and soil assessment*.

On the international scene, the author has not found any examples of work of this kind except the work by Pearson and Collier [50], with the British maps made between 1836 and 1850 in the Tithe Survey. These maps also depict the land at land parcel level. Also Pearson’s and Collier’s work seems very function oriented and not all the information is extracted into databases and GIS-layers.
2. Swedish Large-Scale mapping

In Sweden, the domestic mapmaking dates back to the late 16th and early 17th centuries. Both small- and large-scale map productions have been quite extensive in various time-periods. The large-scale mapping is often called geometrical mapping and the small scale is called geographical mapping. The real start of domestic small-scale map production can be traced to the Royal instruction from Karl IX in 1603 to the general mathematicus Andreas Bureus to make a map to describe the Nordic kingdoms, *Tabula cosmographica regnorum septentrionalium*, [8]. On April the 4th 1628, King Gustaf II Adolphus in a new instruction gives Andreas Bureus the order to make large-scale maps over all farms and villages showing all their “...fields, meadows, woods and land”. In addition, the mapping of all the cities, mines and other resources was included in the instruction. This can be seen as the starting date for the Swedish National Ordnance survey, *Lantmäteriverket*. It was a very ambitious program, but there were no skilled surveyors in Sweden. The first thing Bureus had to do was to train six young men in the art of surveying. In 1630 the first maps were delivered.

The main purpose of the mapping was to gain insight of the resources of the country. Sweden was expanding and rapidly developing in economical, political, scientific and cultural senses, but there was a lack of knowledge about the realm and there were no good maps available. The instructions demonstrate an ambition to reform farming to produce higher yields, through notes to the surveyor, to help the peasants in different matters [79] [71].

Common to most Swedish-Large scale maps are the text descriptions of the mapped features which are joined with the maps and also the additional information as seen in fig 1 and fig 3. The map features and the texts are linked by a system of code markings. The extent of these text descriptions vary between different maps and map series, from fairly limited to very informative, like in the GM1700.

What we now identify as the first phase of the geometrical mapping of Sweden’s villages was between the 1630’s and 1650’s. Several thousand villages and solitary farms

![Figure 2. Areas in Sweden with a geometrical cadastre prior to 1700. From [71]](image-url)
were mapped [79]. These maps together with the text descriptions were bound in large books, or cadastres. They are called Äldre geometriska jordeböcker (Older geometrical cadastres). No mapping was conducted by Lantmäteriverket in the provinces, or on the eastern and southern shores of the Baltic Sea, during this time-period. Until the 1680’s the number of land-surveyors was constant at around 20 in present day Sweden. Some additional surveyors worked in Finland, which until 1809 was a part of Sweden.

From the 1650’s and for some decades to come, the efforts of mapping Sweden were concentrated on small-scale geographical map production. The idea from the beginning was to use the geometrical maps as concept maps in the geographical map production. Since the scope of this work is large-scale maps only, the geographic mapping will not be described here. For an overview of Swedish geographical mapping, see [8].

The next phase in the geometrical mapping of villages and farms started in the 1670’s and had several goals. Sweden had been successful in the wars of the 1640’s and 50’s and large areas were incorporated into the realm. King Karl XI’s reduction of the nobles’ land entailed that many villages and farms came under the Crown. Fiscal reasons were also prominent with the mapping as the basis for setting taxes. Another reason could be the controversies on landowning and right of usufruct of land where the land surveyors were called in to settle the disputes. From 1688 the instructions gave the surveyor the right to help settle disputes on his free time [25]. These maps are often bound into books, but they also exist as loose maps. The number of land surveyors increased to 70-80. Skåne, Blekinge, Gotland and other incorporated parts became to a large extent mapped during this period. Later in this paper, the mapping of Gotland will be addressed.

Not all of Sweden was mapped during these first two phases. The maps are sporadically spread over the country and not all villages and farms in the mapped parishes have geometrical maps from these first periods, but most of Sweden was covered, as seen in fig 2. The mapping by Lantmäteriverket was mainly conducted on freeholder’s farms and on the tenant farmers of crown-land. Some maps only cover vicarages, etc. The nobility land was normally not mapped. In the cases where a village had mixed forms of ownership, the nobility’s farms were most often missing in the maps. In some cases, the nobility had their estates mapped themselves, but not in conjunction with the mapping by Lantmäteriverket. [71] [64].

Lagging behind England, Holland and other European countries, Sweden in 1749 got its first modern act of redistribution of land, Storskiftesförordningen, which was revised in 1757, 1762 and 1783. This was the start of a series of land reforms. They were initiated by the fact that the land of each farm had during the centuries been scattered in many small pieces of land in the infields, thus making farming very inefficient. Together with bytvånget –an act stating that all the farmers in a village had to synchronise and agree on how to work the land- the situation became untenable. There was no room for new techniques and improvements of the agricultural sector [17]. The reforms aimed at aggregating the number of land parcels each farm had into fewer and larger parcels. This had to be made a fair division with respect to the quality of the soil, so less fertile land had to be compensated with a larger area. From now on, the main purpose for Lantmäteriverket was to be officiator in redistributions done under the act. The number of surveyors increased with 60 to keep up with the increased workload, and the geographical mapping had to be placed on hold. Later
on, other bodies were set up to conduct the geographical, mapping. In 1807 a new act of redistribution of land was established, *Enskiftesförordningen*. This was inspired by the successful redistribution by Baron Rutger MacLean of his estate Svaneholm in Skåne 1783-86. This had been very successful, in economical terms, with dramatically increased yield. Each farmer got one piece of land on which he built his house. The reform thus split up the villages and the farmer was no longer dependent on the other farmers in the village for making decisions, thus he became “king in his with his own realm” and could improve the farming after his own ideas. In 1803 an act was passed for Skåne and in 1809 for the rest of the country. On the flat fertile plains of Skåne, and some other areas, this most often worked well. For the rest of the country it was too strict and could not be conducted in many parts since it was impossible to gather each farmer’s land in just one piece in an equitable way. The act was modified in 1827 with the establishment of *Laga skiftesförordningen*. Under this act the farmers’ land would be gathered in two or three land parcels [79]. This was, with amendments, in force until 1972. Most of Sweden’s farms were affected by these acts and thus mapped, but some regions were unaffected and thus lacked maps. The act of Laga skifte had a huge effect, not only on farming, but on the whole Swedish countryside and also social effects. The old medieval villages were split up and replaced by solitary farms [29]. The modern rectilinear landscape, with straight roads and square fields we see today, started to take form. This is because the real-estate boundaries were drawn like straight-lines instead of following natural boundaries, like before. Later, the introduction of large agricultural machinery strengthened this process.

Parallel to the redistribution of farmland, mapping was conducted in the vast forests in the northern Sweden. There was a need to establish the boundaries between the Crown’s forests and the privately owned forests. This process was called *Avvittring* (separation). In these *Avvittringskartor* (separation maps), the forests are mapped and described well, but the infields are just briefly mapped. There are also many maps of mines, towns and other things.

The results of these mappings conducted during several centuries are kept in various archives today. The most important sources of geometrical maps are *Lantmäteriverket’s* central archive in Gävle and the archives in the local offices throughout the country. For most of the period, the surveyors had to make copies and renovations of the maps and send them to the central body in Stockholm (*Lantmäteriverket* moved to Gävle in the 1970’s). The original field map was kept at the local office. The central archive today contains more than 200 000-300 000 maps and the local archives probably more. Other major archives are Riksarkivet (The National Archives) and Krigsarkivet (The Military Archives). There are also many Swedish maps abroad covering lost territories. Those maps were often surrendered in peace treaties. In Russia there are about 20 000 Swedish maps and many in Germany as well.
2.1. Gotlandic Large-Scale maps

In the peace treaty of Brömsebro in 1645, Gotland definitively became Swedish. Under the Danish rule, many of the old medieval Gotlandic taxes and laws were kept in force. The Danes had not mapped the island, and the foreign geographical maps of the island were deficient.

The Swedish crown reformed and made Gotland Swedish. In 1654, a survey of all the farms was conducted for tax purposes. No maps were produced and the text descriptions were gathered in a cadastre, *Jordeboken 1654*, that is still available in the original version. Bratt [8] mentions a series of maps in the scale of 1:30 000 over the island made in those years. He has probably confused a much later reproduction in that scale of the taxation maps from 1747 made in the 1930’s by the geographer Ivar Moberg [48] and the establishment of the map-less cadastre of 1654. During most of the latter part of the 17th century, Gotland had been assigned for Queen Christina’s alimony and before that it was a part of the duchy of her chosen hereditary prince, later King Karl X Gustav. Gotland did not come under full control of the Crown until 1689. The first mapping of the island was made by seven land surveyors between 1693 and 1705 (approximately), i.e., the GM1700. The official instruction and order to start the mapping is issued on 22nd of May 1693 by the King, but it had already started in 1692. These maps are unique in the sense of the nature of the information they contain. Many of the information types found in them are very rare and most often not present in other historical map series. Also, the total coverage of an
entire region makes them unique. All farms on the entire island were mapped, as well as the island’s only town, Visby. Gotland had no land owned by the nobility with exemption of land dues. All the land belonged to the Crown, freeholders or town-dwellers.

The maps are made in the scale of 1:8 000 in the manner described in the instructions for the surveyors of the time. Not all features are code marked and not all text is linked to the maps. There can be some variations in the contents and manner, depending on which surveyor made the map [58]. A private researcher, Jakob Ronsten, made transcripts of all the text descriptions, as seen in fig 3.

The maps are produced, as said above, to gain knowledge of Gotlandic conditions and to establish a basis for taxation. This is reflected in what is mapped. No map is a true depiction of a piece of the earth. It is always a selection of information. Depending on the purpose of the mapping, the information presented in the map differs. For the GM1700 this means that the predominant features and information is about, for the 18th century, important economic matters. Since the taxes were mostly based on farming, the infields are best mapped. In addition, other resources closely connected to a rural economy like woods, fishing, mills, etc. are described, but not as precise as the infields. Roads, hydrology, etc. are also mapped because the large-scale maps were also intended as a base for the production of small-scale maps in which these features were vital.

The information is mostly grouped by the fiscal estate and not the operating unit. This means that abandoned farms are also listed as fiscal estates, even when the land is no longer worked by some other farm. There are a lot of anomalies and exceptions from the common practice, like Frijord (Free land), Flytande jord (Floating soils), etc. In the instruction for the taxation (and mapping) of Gotland there is a paragraph with instructions to the surveyors to sort out all the local practices of this kind and to introduce the standard practices from the Swedish mainland.

The GM1700 was never established as a foundation for taxes, except for the most northern parish of Fårö and Slotssladugården [76], which were first mapped in 1693. This is due to many reasons, but probably mainly because the mapping took longer than expected and also because of the outbreak of the Great Nordic War, which lasted between 1700 and 1721. In this war Sweden was engaged in acts of war with most of its neighbouring and other countries to and fro. The war drained a lot of Sweden’s resources and ended in a vast loss of territory for Sweden, among others all the Baltic provinces. The maps of the GM1700 were nearly completed, but it seems like most of the renovated maps were never sent to Stockholm since the only copies left are the ones kept in Visby. Some parishes were finally completed in the 1720’s.

There was, however, still no taxation based on the maps. This process was resumed in the 1730’s and finalised with the establishment of new taxes in 1747. For this the old maps of the GM1700 were used as a starting point. Most of the information in the taxation maps established in 1747 was copied from the GM1700 maps. The taxation maps of 1747 can be seen as an updated version of the GM1700 where only the changes since the last mapping is new information [76].
3. Knowledge modelling

With the GM1700 we could make many models for different purposes. Maybe the most natural thing would be to try to model how the land- and real estate situation on Gotland was organized and try to reach new and better knowledge about 1700’s society. This is, however, a task for historians and if this was tried here this would be a thesis in history and not in Informatics. The result of this work will hopefully become a tool for such research. Another view could be to focus on the geographical objects in the maps. Within the GIS community there has been discussions about the use of ontologies in GIS. This work is very much focused on the use of ontologies in software development and data integration [22] [74], specifying “Ontological Foundations for Geographic Information” [83]. There are many articles written about ontologies for geographical objects; their attributes and relationships and ontologies of geography, such as [24] [82]. This research is mainly focused on the nature of geo-objects and their representation and meaning. It is aimed at the geographic objects as such and to reach a common understanding about the specifics in the GIS-community. We do not have our focus on the geographical objects in this work. The main purpose is to learn more about the maps themselves and to model how these maps are organized, what concepts they contain, what these concepts mean and how they relate to each other. Our focus is the GM1700 maps as archive artefacts and documents. The geometrical and geographical representations of the geographic objects we find in the maps are merely attributes of the document, even if it is an important one. The ontology will also be a domain model which will be used as a basis for a database model to enable the storing of these maps and all the information in databases as close to the original structure as possible. In analogy with the thoughts of Bittner and Smith [7] 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. For most researchers in humanities the access to the unadulterated source is vital. We want to make these maps available and manageable in databases and GIS-systems, in a way that can be trusted by researchers in the humanities, and thus reducing or even eliminating, the need to go to the source itself for most of the problems formulated.

As a modelling technique, the ontological approach was chosen. It has advantages over more traditional ones. It can facilitate the interaction between the domain experts and modellers and create a semantically clearer and richer model, less prone to misinterpretations, and more. The latter is very well described by Bishr & Kuhn [6]:

“A computer model can only be said to be a correct representation of reality within the environment where it is created and used. Once this model is exposed to the outside world the notion of correctness becomes meaningless, as there is no specification to which it can refer. Ontologies fill this need: they provide the specification to be followed by individual computational models.”

In our case we will use this ontology to build one possible database schema in E/R and implement this in a GIS and database system. This is however only one possible database solution and implementation. The ontology is meant to be a knowledge model and foundation also for other uses and applications.
The basic building block in an ontology is a taxonomy, with classes, attributes, relations etc. based on the Frame paradigm and/or OO and Logics (first-order or Descriptive Logics). These different paradigms are based on the same foundation and basic thoughts, but denote their modelling primitives differently. This can lead to a sometimes confusing terminology. Table 2 describes what the different paradigms’ vocabularies approximately denote [40].

Table 2. What different paradigms’ vocabularies approximately denote, from [40]

<table>
<thead>
<tr>
<th>OOP Systems</th>
<th>Frame Systems</th>
<th>Description Logics</th>
</tr>
</thead>
<tbody>
<tr>
<td>instance</td>
<td>frame, instance, individual</td>
<td>instance, individual</td>
</tr>
<tr>
<td>attribute, instance variable</td>
<td>slot</td>
<td>role</td>
</tr>
<tr>
<td>value</td>
<td>filler</td>
<td>filler</td>
</tr>
<tr>
<td>class, type</td>
<td>frame, schema</td>
<td>class, concept</td>
</tr>
</tbody>
</table>

3.1. Modelling considerations

Around 95% of the surveying was done by seven land surveyors during a period of roughly 12 years. During this time new instructions were issued from the central office in Stockholm [76]. However, the maps indicate that the surveyors had a large degree of freedom to organize and make their own decisions about the maps, since the manners and information in the maps differ quite a lot. It seems like the surveyors’ manners changed over time. If this is due to the change in instructions or if it is based on their experience is hard to tell without further analyses. Most of the parishes are mapped by one surveyor in one season, but some parishes are mapped over several years by up to 3 surveyors. The mapping season was from spring to autumn and in the winter they made the fair copying of the field map, and compiled and calculated all the material collected in the field maps and notations. This process together with difficulties in the field with geographically scattered estates, and to our belief, unclear conditions of the state of affairs on the countryside of Gotland, lead to a series of maps that are very inconsequent and incoherent.

The maps are organized in parishes (administrative and geographical areas) and list a series of units, that we call registration units (RUs). Under these RUs are lists of features (land parcels and other resources) belonging to an estate or situated within an area. In the absolute majority of cases these RUs coincide with farms and other clearly defined estates, but in many cases the RUs are listings of land parcels belonging to farms situated in other parishes, church land or other concepts hard to exactly identify. Sometimes it is also clear that the surveyor is not sure of what it is he is mapping, as seen in the table below.

Table 3. An example of a piece of land (land parcel) that the surveyor probably did not know who owned or what legal status it had. It is listed as a RU with its own registration number (17) in Barlingbo parish. Most likely it belongs to a farm Röstade in Ekeby parish, but there are two farms Röstade in Ekeby parish, Stora Röstade and Lilla Röstade (translated by the author)

<table>
<thead>
<tr>
<th>17 Röstäde in Ekeby Parish</th>
<th>True field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sq.ell</td>
<td>Tdl (acre)</td>
</tr>
<tr>
<td>A</td>
<td>41,394</td>
</tr>
</tbody>
</table>
### 3.1.1. Modelling Objectives

There are some developed methodologies for building ontologies, like Uschold and King’s (extended in 1996 by Uschold and Grüninger). The basis for their methodology is three different strategies: Top-down, bottom-up, and middle out. They advocate the middle-out strategy, which balances the level of detail. It starts with defining the most fundamental concepts, and goes to the more abstract and specific terms as needed [73]. Another example is Grüninger and Fox’s methodology which is very formal and based on first order logic. Methontology, is developed at Universidad Politécnica de Madrid and has it roots in software development processes [31]. In this work no specified methodology will be used, but we will try to achieve some generally accepted criteria for what makes a good ontology [5]:

- **Clarity and Objectivity**: which means that the ontology should provide the meaning of defined terms by providing objective definitions and natural language documentation.
- **Completeness**: which means that a definition expressed in terms of necessary and sufficient conditions is preferred over a partial definition (defined only through necessary or sufficient condition).
- **Coherence**: for permitting inferences consistent with the definitions.
- **Maximum monotonic extendibility**: It means that new general or specialized terms should be included in the ontology in such a way that it does not require the revision of existing definitions.
- **Minimal ontological commitments**: which mean to make as few claims as possible about the world being modelled, giving the parties committed to the ontology freedom to specialize and instantiate the ontology as required.
- **Ontological Distinction Principle**: which means that classes in an ontology should be disjoint.
- **Diversification of hierarchies**: to increase the power provided by multiple inheritance mechanisms.
- **Modularity**: to minimize the coupling between the modules.
- **Minimization of the semantic distance between sibling concepts**: which means that similar concepts are grouped together and represented using the same primitives.
- **Standardization of names whenever possible**

(From: [5]):

Fulfilling all these criteria will probably be hard with regard to the nature of the universe of discourse. Before we start presenting the ontology, there are some general discussions we have to undertake about the nature of the maps, some of the central concepts, and what we are trying to model.

### 3.1.2. Real Estate and Land Parcels

The main concepts in the maps are the real estates and their resources. Of the resources the land each estate possessed is the most important, especially the infield. The infield consists of the fields and the meadows. Real estate in the Swedish Encyclopaedia (NE) is defined as “a unit of immovable property (land) established by a set of rules of law”. In the Swedish
law there is no explicit definition of what a real estate is, but it is normally said that “Every legal real estate must be entered in the national cadastre (real-estate register)” [9]. The definition shows that research around real estate is to a very high degree multi disciplinary and involves law, economics and political science. Stubkjaer [65] lists these areas to be the ones which have to be involved when trying to establish an ontology of real estates. In our case, when dealing with a situation 300 years ago, we have to add the discipline of history as the main subject when trying to establish what constituted a real estate on Gotland around the year 1700. Basically the same definitions could probably be used for this time period, but there are no explicit definitions made by Swedish historians about the concept of real estates 300 years ago in Sweden. However, among historians by trade there seems to be a generally accepted fact, that a real estate is a piece of land registered in a Cadastre or other historical documents with equivalent status. Different types of real estate are surrounded by different kinds of laws, practices, tax rules, etc.

This ontology cannot have the scope of a real estate ontology for Gotland, since the objective is to keep it as close to the original source, the maps, as possible. Smith & Zaibert [62] distinguish three different aspects when studying landed property; the geographical, the ontological, and the cognitive aspects. In this work, it is the geographical aspect which deals with how the real estate is related to the land itself that is in focus and not the ontological aspect of what a real estate really is or the cognitive aspect which is closely related to cultural issues. The concept of real estate must, however, play an important role, since the surveyors used it as a central concept. The real estate concepts we use in this ontology do not cover all aspects of a real estate, since not all aspects of the real estate occur in the maps or are known.

A modern digital Cadastre for Sweden is developed, but this has a very different focus, with the administrative and transaction parts as core classes [66]. Modern cadastres have many functions for handling processes and administrative work. This makes it more of a SPAN-ontology [7], which models processes, as explained below. This ontology can probably be aligned, in some parts, with our ontology for temporal studies.

3.1.3. Space and Time

The land belonging to the estates is mapped in land parcels. The land parcels as we see them in the maps are no natural phenomenon. They are man made artefacts, so called fiat objects of a social nature. This means that the limits of the objects, their boundaries, are not natural, but rather determined by humans and based on social criteria. The opposite of fiat objects is bona fide objects or boundaries, that are natural, like rivers, shorelines, etc. [61]. In our case fiat objects can be made up of both fiat- and bona fide boundaries, e.g., when a meadow goes down to the shore.

These land parcels which are fiat objects form another fiat object, the real estate itself. A real estate is the mereological sum of the outer boundaries of all the land parcels belonging to that estate. They can be scattered land parcels and thus, form a fiat object of a “higher-order” [61].

A real estate does not only have an extension in space but also in time. Most of the estates we meet in the maps still exist today and were formed long before the creation of the maps. This is also true for some of the land parcels. The temporal nature of an estate,
and a land parcel, is that it has a beginning and an end, and can during its life cycle change its nature and boundaries, but it is at any given time wholly present. The last property makes it an endurant, as opposed to a perdurant, which is never wholly present in any given time (e.g., your life). The ontology we are making can be regarded as an SNAP–ontology, since the maps are just a snapshot in time of enduring objects. This is in contrast to SPAN–ontologies which are dealing with perduring objects. SPAN-ontologies are used more to model processes etc. [7]. To analyse how these enduring objects, real estates and other features, behave over time is not necessary for this work since we only work with one time-index. This is however something that has to be addressed when several time indices along the same spatial region are involved, e.g. if we introduce another map series of a later date. This is something that will be done in future work.

3.1.4. Uncertainty

Every universe of discourse (UoD) has some amount of uncertainty in different aspects. When dealing with a UoD created more than 300 years ago, the uncertainty is, more or less, everywhere. You can group the uncertainty into two major groups. The first one deals with uncertainties you can expect in any material of maps and descriptions, also modern ones. This we call normal uncertainty. The other group of uncertainties is related to the historical dimension of the UoD, which we call historical uncertainty. To the latter–type is, for example, the discussion above about what constitutes a real estate in the 17th century or what the measurement unit “Manslätt” was, which is used for measuring meadows, and other measurement units which today are not fully understood. Uncertainties of these kinds require the methodology and toolboxes of history to analyse. But a full understanding will most likely not be reached. The source material is mostly too scarce. For this work, these uncertainties are something we have to accept. For those cases where there have been a need to dig deeper in a concept, we rely on research already done by scholars of history and adjacent disciplines. Historians, ethnologists, and archivists have done much research about the Gotland society and administration of the 18th century, for example [48] [45] [60]. In many cases information from the GM1700 has been a vital resource in these research efforts.

Among the general uncertainties are the semantic problems with unclear or multiple meanings of concepts or terms present. In contemporary material this can, in many cases, be handled by communicating with the creators of the material. In historical material this can be a two fold problem of both the general uncertainty type and the historical uncertainty type. In the uncertainty, around the concept of “deserted” used for farms or land parcels, it can have many meanings and not all are fully understood [72]. Also, many of the quantifications are expressed in a qualitative manner, i.e., some, few, many, big or small, and some are expressed in numbers in descriptions of the same type of features, etc.

Figure 4 Land parcels of different kinds in one of the maps over the Fröjel parish
Some of these normal uncertainties can be dealt with by using various methods. This is a huge research area and numerous theories and methods are developed, for example probabilistic or logical reasoning methods [13]. However, this is a problem hard to tackle and something, which we believe, is a non trivial problem to solve in any trustworthy way that can be accepted by scholars of the humanities. This is essential, since they are the assumed users of the system and, at least in Europe, quantitative methods are not always accepted among scholars of history and adjacent disciplines. This goes probably also in an even higher degree for “letting the computer do the interpretations”. Since the handling of uncertainty is such a problematic topic and requires much research in the field of historical maps, this will not be addressed further in this work, but we hope to address this field of research in future projects.

### 3.1.5. Completeness and Coherence

One of the requirements of an ontology is to make it complete and coherent as mentioned above. For this, OWL which is based on descriptive logic (DL), was tried in the modelling process [4]. It was, however, not possible to use formal logic due to the nature of the UoD. We will exemplify why it is not possible to use DL on these maps. We will use two of the concepts found in the maps, field and farm, to show how we hoped to find necessary and sufficient conditions to define these concepts.

#### Table 4

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>true field</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>yield</td>
<td>Sq.ell</td>
<td>acres</td>
<td>kappland</td>
</tr>
<tr>
<td>10 Guffrede a Crown farm with the hide 1</td>
<td></td>
<td>2</td>
<td>5,279</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>a Hemåker is of gravel and mould with flat rock underneath. Fraudulent, is harmed by dryness during dry (years), sowed with 1 lop (1/4 of a barrel)</td>
<td></td>
<td>2</td>
<td>5,279</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The field of this farm is annually sowed in two field rotation with rye, easy to plough and 1 acre can, with a good pair of draught-animal, be ploughed in a day</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 shows a very good description of one of the fields belonging to a farm. It contains nearly all the information ever noted for a field, but this is unusual. Normally only parts of this information are present for a field. There is a great variation in what information the field descriptions contain and different combinations of the information above are noted. In the worst cases the information is only a name and acreage, as in table 5.

#### Table 5

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>field</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Hessle Crown farm, ½ hide and all deserted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Stufåker</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>B Lilla åker</td>
<td></td>
<td>40.25</td>
</tr>
</tbody>
</table>
There are two properties which are found in every instance of a field. They include acreage specified in the units Tunnland and Kannland/Kappland and a name. These can then be set as necessary and sufficient conditions for that concept, and thus defining it. We believed it was only fields that had acreage measured in the specified units. This was an approach that we hoped to follow for most of the concepts. The problem is that the maps are so full of exceptions and anomalies that it could not be accomplished. In the case of the fields, it turned out that one of the surveyors calculated all land parcels in these units and thus acreage in Tunnland or Kappland/Kannland did not define a field. Another example is the farm concept, which we believed could be defined with the necessary and sufficient condition of all having a hide (mantal), which is what defines a farm [60]. Other agricultural estates are not supposed to have hides at this time (in the 1740’s all Vicarages and Crown estates are measured in hide). However, it turned out that some farms lacked a hide and some vicarages had a hide.

Features of different concepts found in the maps are defined by the fact that someone states that this is a feature of this kind. A field is always a field no matter what it is used for or even if it has not be ploughed for 40 years (such examples exist). This is probably because many of the features, mostly the infields, are noted in older cadastres which the surveyor had access to. The infields where also tax objects and their status could not easily be changed. The surveyor then described it in a manner that he uses for fields. The problem is that this manner is not consistent among the different surveyors or even the same surveyor. It seems like every time there is something unusual to tell about a feature, they tend to note the anomalies and forget the regular descriptions.

No properties or combinations of them were found which could be used for any necessary and sufficient conditions for any concept. This fact leads us to abandon OWL and descriptive logic. The main point with using logic is to be able to reason about the ontology [63]. This was not possible in our case, at least not in any significant degree. Trying to impose some kind of logic to the ontology would undermine the most fundamental goal of the ontology; the ambition of keeping it as close to the original maps as possible.
3.2. The Ontology of the GM1700 maps

The ontology consists, at present, of 256 classes (concepts), 90 slots, 2 facets and 221 instances. Slots are used to describe attributes and some types of relationships. Later, in section 4.1., we will describe the main differences between the frame- and OO- and E/R paradigm in more detail. In this section the notions of class and concept can be used more or less indiscernible. There are nine root classes, of which two are core classes, modelling all the central concepts. The remaining seven classes’ model smaller concepts found in descriptions of the core features or are created for design purposes and clarity of the ontology [34].

The concept of RU has partly already been described. It has two subclasses; RealEstates and NonRealEstates. Siltberg [60] identifies the following real estate types to be present on Gotland, according to the cadastres of 1654 and 1747: farms, sites, free soils, floating soils, outland soils, hospitals soils, other lands (= common lands, grazing lands, woods, meadows), islands, fisheries, lime works, mills.

For this work, we use Siltberg’s categorization of real estates, but with some additions and alterations. The real estate types of grazing lands, woods and meadows are grouped under the superclass OTHERESTATE, but not common lands. This is because common lands is not so unusual and may correspond to any type of land, but the other ones are of land types that exist as classes under LANDPARCELS and are very rare (ten instances altogether in 1654). Furthermore, two estate types are added; CROWNESTATE and PARISHESTATE. This is because the two biggest agricultural estates on the island are owned by the Crown and the estates owned by the Church are, for practical reasons, all regarded as farms by Siltberg. Furthermore, there are Ru's of free soils, floating soils, outland soils, hospitals soils, common lands, where it is not absolutely clear if they are one or more estates, but to clarify this is a research endeavour in itself. For this ontology we regard them as one estate if they are noted under one RU.
The class **NONREALESTATES** is created for all the RU's where features are listed under it for other reasons than forming an estate. They can, for example, belong to an estate in another parish or their status is unknown.

The other core root class is the one covering all features found in the maps, the class **FEATURES**. It is subdivided into the three classes **MAPPEDFEATURES**, **UNMAPPEDFEATURES** and **NAMEDPLACES**. The class **UNMAPPEDFEATURES** is created for concepts found in the descriptions of real estates and land parcels and are linked to them. These are the concepts (classes) of **TAXES** and **DOCUMENTS**. The class **NAMEDPLACES** holds all the instances of places mentioned in the texts. These named places can in many cases be found in the maps. For those found in the maps, a geometry can be assigned, or if the named place is a RU or **MAPPEDFEATURES** that already exists as an instance that instance can be selected.

The **MAPPEDFEATURES** class is subdivided into the **DESCRIBEDFEATURES**, which contains all the features described in the text part and are mainly linked to the maps via the code marking system. Here, the inconsistency of the maps is also notable, since not all features supposed to have code marking, have one. This is due to various reasons. It seems like it mostly depends on which surveyor carried out the mapping. Some are more careful than others in this respect. Examples of mapped features are the classes **LANDPARCEL** and **OTHERESTATERESOURCES**. The latter is often linked to the map via the **NAMEDPLACES** class. The subclasses of the class **UNDISCRIBEDFEATURES** hold all map features not described in the text part. These can be roads, fences, other buildings, text written in the map itself, etc.

**Figure 6.** The class hierarchy of **FEATURES**
### 3.2.1. Value Partitions

Value partitions are classes or instances used to describe the values of the qualities that other concepts can take. Classes will typically be used representing a continuous space which is partitioned values in the collection of values. This is used because the classes can be subdivided and thus refining the values in a continuous way. Instances are used when an enumerated list is primarily wanted since instances cannot be refined [51].

It is normally advised against using both types of value partitions in the same ontology, yet this is done here. The class `VALUEPARTITIONS` and its subclasses are enumerated lists of all the values the different concepts can take. The classes `PRODUCTSANDLIVESTOCK` and `DESCRIPTIVEWORDS` are maybe not genuine value partitions, but act as such. The difference between these classes and commonly used value partitions is that they have slots, which can hold quantitative values or values from the class `VALUEPARTITIONS`. This can be explained with an example.

`BEAMS` is a subclass of `WOODPRODUCTS` under the class `PRODUCTSANDLIVESTOCK`. Beams hold all the varieties of the concept beams we can find in the descriptions of taxes (as a tax commodity) or woods (as a product) and also meadows (as a product). A description can be something like “Tax is paid with some beams…” or “Stoor forest…small beams, saw logs…”. The class `Beams` has the slots `QUALITATIVEAMOUNT` and `QUALITATIVESIZE`, which can take instances of the classes `QUALITATIVEAMOUNTS` and `QUALITATIVEsizes` respectively, which are subclasses of `VALUEPARTITIONS`. The class `Beams` also has the slot `QUANTATIVEAMOUNTINTEGER`, because sometimes the value can be the number of beams produced. In this fashion we can create all the values needed to describe all the variations in the concept of beams. The number of values is not known, but judging from the sample descriptions, there are not so many variations of the different concepts modelled in this way.
3.2.2. Remaining classes

The remaining root classes are PERSONS, MEASUREMENTS, GEOMETRIES and FARMSPECIFICS. The class PERSONS is very straightforward and contains all the persons mentioned in the maps (subclass NATURALPERSON) and also the legal persons (subclass LEGALPERSON) existing at that time (the Crown, the Church and the Hospital). The natural persons are mostly owners and lesaers of the farms. MEASUREMENTS holds all the ACREAGES, PLOUGINGTIMES and LENGTHS found in the maps, in respective subclasses. The class GEOMETRIES is not meant for instantiations, since creating geometries in an ontology would be very complex and without meaning. Every node would need an instance of its own with its coordinates. The class is only made for modelling purposes to show which concepts can have geometries and of what type. Class FARMSPECIFICS is created for design purposes, since a FARMESTATE can be divided into many shares, which have different owners and lesaers, hide, soil nature etc. One FARMESTATE can have relations to many FARMSPECIFICS. Some VICARAGEESTATE also has one relation to FARMSPECIFICS, since they have a hide as explained above.

4. Ontology as Conceptual Model

Applying ontologies to model a domain and/or to develop knowledge bases results in a generic domain model and it can be used in many applications. We believe an ontology to have many similarities with a conceptual model used in database modelling, even if differences exist. Most of these differences are concerned with the objectives and usage of the two, but also differences in modelling primitives exist when a Frame based meta-model -from the KR-tradition of Artificial Intelligence (AI)- is used to build the ontology [32] [40]. Traditionally, conceptual models for databases are expressed in other meta-models, like Object Oriented (OO), Extended Entity Relationship (EE/R) or the Entity Relationship (E/R).

In this work, the ontology corresponds to a conceptual schema. Ontologies based on the Frame paradigm make the conceptual model semantically richer, since the Frame paradigm has more expressiveness than the traditional meta-models and can be used both as a conceptual model and as meta-data. Since we aim to store the maps in an ordinary relational database, some kind of mapping must be conducted between the ontology and the E/R based logical database schema. The differences between the two meta-models and the logical database schema can be eliminated by some elementary mapping rules, which are discussed below. There is no need to map an ontology to a conceptual schema expressed in another meta-model, which in turn will be mapped to a logical schema. This is actually what is done when applying the automated tools, described below, of model transformation between different meta-models, since they have no or very limited support for the generalisation/specialisation of classes that is needed. This process is more of an art than an engineering task. This will be explained more in detail further on.

The ontology made for the GM1700, is modelled in Protégé from Stanford University, which uses an implementation of the Frame paradigm. In Protégé, the meta-data is easily generated as a class tree in HTML or XML, RDF or other formats. The Frame paradigm can support logic, axioms, etc. The full powers of Protégé’s implementation of the Frame
paradigm was not possible to use because of the illogical nature of the UoD of the GM1700 maps, as explained above.

### 4.1. Mapping the ontology to an E/R schema

According to Milton and Kazmierczak [47], data modelling languages (meta-models) constitute an ontological meta-model giving the terms that support a description of the world including what it consists of and how it can be structured. Such an ontology can be implicit or explicit. To map different modelling languages to each other a meta-meta-model (can also be seen as a meta-ontology) is needed which specifies how these meta-models relate to each other. The modelling primitives of the different meta-models have to be mapped to each other, specifying how they relate to each other. Research based on Bunge's or/and Chisholm's Ontologies has been conducted by, among others, Milton & Kazmierczak [47] [46] to investigate whether they can serve as an ontological foundation for such a meta-meta-model. This can be seen as a novel field of research, at least with respect to the mapping of ontologies based on the KR tradition and database models in the data modelling traditions as Baclawski et al [2] points out. Fonseca et al [23] present a formal framework for mapping ontologies into conceptual schemas based on the OMT-G model, which is an object oriented data model for geographic applications and meant for modelling the geometry and the topology of spatial data and spatial relationships, etc.

The Logical database schema in this work is developed in E/R –with UML notation– which is based on a different meta-model then the one used in Protégé. It uses an adoption of OKBC based on the Frame paradigm [12]. The differences between the E/R-model and the Frame paradigm affect the mapping of the ontology to the logical database schema to some degree. There are several ways of conducting this transformation between the different meta-models. Most efforts made on mappings between ontologies and E/R schemas are made in the reverse order, i.e., from an E/R schema to an ontology to be used in the Semantic Web. An example of this approach is given in [78], which is a formal and automated approach mapping E/R schema into OWL-ontologies. Astrova [1] presents a methodology based on an analysis of key-, data- and attribute correlations, as well as combinations between them. The main drive for these efforts is to be able to migrate data intensive web pages based on relational databases into XML-based pages, like RDF or OWL, which can be indexed and aligned on the web.

When mapping the ontology between different meta-models three main approaches exist; manual or automatic or a combination of the two, where the latter corresponds to a semi-automatic approach. Most research has focused on finding algorithms for automated mapping. The basic mapping principles behind these efforts are, however very similar, and to our belief, they produce similar results. The automated mapping is a very complex task, which Baclawski et al [2] show in their paper on mapping between the ontology languages DAML and UML, which are based on different meta-models.

There are several papers describing algorithms and automated methods for mapping between different models described in different languages and meta-models. In [32] an automated process for mapping ontologies to conceptual schemas is described. It sets up a set of mapping rules very similar to those presented here, but without the
generalisation/specialisation mappings needed for mapping to an E/R schema. Another example of an algorithm for automated mapping is given by Gail et al [30] which is based on mapping OWL ontologies to E/R schemata. In their work, the automatic specialisation of deeply nested subclasses are also implemented, but at a predefined depth for all subclasses. As stated above, we believe there is no need to develop a conceptual schema, since the ontology itself already is a conceptual schema, which can be mapped directly to the logical database schema.

An environment used in this project, besides Protégé is Rational Rose. Rational Rose was used to model the E/R-based logical database model in UML notation. Both Rational Rose and Protégé have support for XMI via two plug-ins (either with MOF or UML as meta-meta-model), which enables the transformation and the migrating of data between Protégé (OKBC) and UML [36] [37]. Both these extensions have been explored. These techniques for transforming and migrating meta-models are new and still immature. The result is very rough and needs manual work to get a usable E/R logical database model. Baclawski et al [2] also argue that an extension of the UML is needed to support a full and complete mapping between most KR languages and UML. These two tools are mainly developed for code generation for software projects, etc. All the generalizations and specializations need to be carried out manually since no support for database modelling in the E/R model is implemented in them. There are other tools based on the MOF transformation model, like QVT for the eclipse environment which was not tested in this work, but judging from the description, it would produce a result with similar drawbacks [14].

The result of an automated transformation is merely the ontology expressed in a different language, based on a different meta-model; it is not a logical database schema. After these experiences, we choose to do the transformation and the mapping manually, and not use the automated approach. The ultimate solution to the mapping problem is a semi-automated process, since we believe the mapping of an ontology to an E/R logical database schema is more of an art than an engineering task. There are so many decisions to make and numerous alternatives to choose from in the process, so even if the automatic transformation can transform the model from one meta-model to another, it would still need so much manual post processing that little would be gained. Most of the 256 classes (concepts) in the ontology are subclasses that will be generalised in the E/R model at different levels according to the different mapping principles based on the different decision criteria. Below in fig 8 & 9 is a graphical illustration of the two mapping principles, automated mapping and our manual mapping with mapping rules.
4.1.1. Mapping principles

The Frame paradigm is, in all its essential parts, very similar to the object paradigm and is based on the same data model [35] [40]. This makes the process of mapping the ontology to an E/R-based logical database schema very much like mapping from an EE/R-schema to an E/R-schema. There are some differences which have to be considered. In the Frame paradigm there are no such things as relations and associations used to connect classes (relationships) in the E/R-model. In the Frame paradigm relationships are created either in the hierarchical structure using subclasses or using slots. Slots describe both properties
(attributes) of a class and binary relationships between instances [27]. The former are in Protégé called Primitive slot and the latter Instance slots.

There are basically four different ways to map the class hierarchy of EE/R to E/R, these are: 1. Multiple relations – superclass and subclasses, 2. Multiple relations – subclasses only. 3. Single relations with a single type attribute. 4. Single relation with multiple type-attributes [15] [19]. All of these options have been used in this project, to yield the most appropriate logical schema.

Handling the binary relationships created using instance slots is quite straightforward. If the cardinality is set to single, it models a 1:1 relationship in the E/R model and if it is set to multiple, it is a 1:N relationship. A property (facet) of slots implemented in the Protégé meta-model is inverse slots for creating reciprocal relationships between two classes. This feature can be used to model N:M relationships if the inverse relationship is multiple at both ends. Multi valued attributes work the same way as it would in an ordinary E/R model, where the multi valued attribute gets a relation of its own.

These simple mapping rules were enough for the mapping of our ontology to an E/R based logical database schema since our UoD could not use the full expressiveness of Protégé. We believe the mapping rules to be sound, but are aware that they are not complete.
4.1.2. Mapping decisions

The 256 classes in the ontology were mapped to 28 entity types in the E/R schema. Most mappings were quite straightforward and do not need any further explanation.

There are two “core” entity types in the schema, TblRegEnhet\(^1\), (concept: REGISTRATIONUNIT) which holds registration units (mainly real estates, e.g., farms) and TblBeskrivetObjekt (concept: DESCRIBEDFEATURE) which holds all the resources described under an estate. The resources can be land parcels, mills, fishing, hunting, etc. Between these two entity types there are five different relationships. These are the relationships of list, uses (1:M), paysTo, partOf and litigation (N:M). The relationships of list, uses and partOf models the fact that a resource is always listed under a registration unit, but can be used or owned by some other registration units. The relationship partOf is in the ontology modelled with a reciprocal instance slot, multiple at both ends, since co-ownership can exist. This makes it an N:M relationship in the schema. The same goes for the relationship of litigation, which models the fact that a resource, mainly land parcels held by one estate, can be claimed by other estates (not persons). Instead of modelling these two N:M relationships separately, they are joined in one relationship with one intermediate entity, TblDelav and a role attribute is used to separate the two relationships, called roll. This attribute can take the values of “owner” or “litigator”. This makes also sense, since all ownership matters now are gathered in one relationship, as shown in fig 10.

Some concepts and properties in the ontology can be found in both the descriptions of the two core concepts REGISTRATIONUNIT and DESCRIBEDFEATURE, thus having relationships to both. These are the concepts of TAXES, DOCUMENTS, NOTABLEEVENTSORANNOTATIONS and PERSONS and also the multi valued property of featureName. They are all separate entity types with relationships to both TBLBESKRIVETOBJEKT and TBLREGENHET.

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\(^1\) The ontology is available in both English and Swedish, since it is possible to have multiple languages in Protégé. The logical database schema and the database itself are both made in Swedish, since we assume the usage to be mainly in Sweden.
5. The demonstration system

The demonstration system is divided into two parts, the database system and the GIS system. These are connected through a standard ODBC-interface. The Intrasis system made by RAÄ/UV (Swedish National Heritage Board/Department for Archaeological Excavations) [55] has the same approach, and it is believed to be very common. For this small test system MapInfo was chosen for the GIS part and Access for the DBMS part. This division was chosen in order to get the best from the two worlds. A GIS DBMS-system normally lacks a lot of features found in a full-fledged DBMS system, like proper referential integrity control.

5.1. GIS tables and geometrical aspects

The maps were scanned and georeferenced into the Swedish National reference system RT 90 and then vectorised and stored in the GIS-tables with the code markings as primary key attributes (TBLBESKRIVETOBJPOLYGON). The concepts which can be represented as geometries are all MAPPEDFEATURES with subclasses LANDPARCELS, which all are represented as polygons, OTHERESTATERESOURCES which is represented with points and NAMEDPLACES which are also represented by points.

The separation of the database tables and the GIS tables leads to the necessity of some denormalisation by duplicating some attributes. The maps can be damaged or faded so sometimes the code markings can be hard to read. They are the connection between the TBLBESKRIVETOBJEKT in the DBMS-system and the GIS table TBLBESKRIVETOBJPOLYGON. This table stores the polygons defining the land parcels. The type of land parcel can still be seen by the manner and colour in which it is depicted. To avoid loss of this information the discriminate attribute markslagFlag from the DBMS table TBLBESKRIVETOBJEKT is duplicated in the GIS table TBLBESKRIVETOBJPOLYGON. This attribute discriminates what subclass of land parcel it is.

The rest of the GIS-tables are represented by appropriate geometrical types and needs no further presentation. The mapped features that lack text descriptions have no relationships to the DBMS tables. They are only represented by appropriate geometries.

One well known problem with old historical maps is the uneven distribution of errors. This has its roots in the relatively primitive instruments used in the field mapping and also the simple methods without error checking. The methods where either angle measurements with truncation from two or more station points or polar measurement with angle- and distance measurements from one station point. Both have been used at various times in Sweden. At the time of creation of the GM1700, the polar measurement was the standard method used by Lantmäteriverket. This is the one with the lowest precision of the two [77]. For the geometrical cadastres, the method used was a purely graphical method, invented in 1590 by Nürnberg professor Johann Prætorius. It was conducted with a measuring table, alidad-rule and measuring chain (or string) as key instruments.
Figure 11. The mapping method used by Lantmäteriverket was invented by Johann Prætorius. The figure shows the method used with angle measurements with truncation from two station points.

Not all features were of equal importance and some things are not properly measured, but merely sketched [70]. The precision also deteriorates rapidly with increased distance. Since the areas of main interest (the infields) were parted by large areas of woodland, and other not so important areas, the resulting map contains areas with relatively high precision within (the infields), but the true relations between these areas are not accurate [11]. Both distance and angle errors occur between them.

There are several projects in Sweden and internationally, that have worked with different methodologies for transforming and warping historical maps to correct these errors and make the historical maps fit to modern maps. Projects Digitala Historiska Kartor (DHK) [54] and Stadsmiljöns förändring [11] can be mentioned as examples. They have all identified it as a non-trivial problem to solve and it cannot be done with any high accuracy without time consuming manual elements. Also internationally there are many papers published around these issues, even if this most often concerns other types of maps, like small-scale maps. For example, in Balletti’s paper [3] concerning the georeferencing of portolan charts, Isolarii, and perspective views of towns, or Shimizu & Fuse’s [59] about applying different algorithms when rubber-sheeting historical maps over Tokyo. All methods are based on picking ground control points (GPC) in both the historical maps and the modern ones. This implies that you must find features in the historical map that are unchanged in the modern map. With a large amount of GPC’s evenly spread over the map some algorithms tested in [3] and [59] might produce a fairly good result. However, the numbers of identifiable GPC’s in GM1700 vary greatly, but normally the number is very limited and not evenly spread. Some areas of Gotland have undergone much change in the past 300 years and some less. These changes can also be very hard to detect. What seems to
be a change might just be a geometrical error or vice versa. As an example, one of the GPCs used in georeferencing the GM1700 over Fröjel parish was the site of the farm Depps which seemed to lie in its original place in a curve of a road. After the transformation the road in the GM1700 did not properly line-up with the modern one. Later we received information that the road had been moved around 30 meters to the west in the 1950’s with exactly the same curvature. Most of these methods tested in these projects and papers can also be summarised by the fact; whatever method you choose, you will always have a number of undesired effects. If you correct one type of error, you will almost certainly introduce some new ones, maybe even worse. Based on our previous experiences and after literature studies, we did not address the problem at any depth. We believe it to be better to interfere with the maps’ geometry as little as possible. We used a standard resample algorithm which had as little impact on the maps internal geometry as possible, as described below.

A fairly simple and quick methodology was developed, designed especially for this map series, based on a hypothesis about how the renovation maps originally were produced. The hypothesis is that all the land and registration units (RU) in each parish was mapped in small areas and concatenated into one big concept (field) map over the parish, (some copies of these maps have survived). For the fair copying a number of adjacent Registration units where copied directly from the field map to a separate renovation map. Each parish was in this way divided into 3-5 renovation maps, all copied from the same concept map. Since a real estate can be dispersed in one parish, or even over many parishes, all the renovation maps of a parish overlay, as shown in fig 4. When the GCP’s were picked in each map separately a large mismatch between the different maps appeared, since different formulas were used for each map. The geocoding and warping process developed is based on reversing the map production process we described above, and produce one map of all the renovation maps for each parish. This was done by adding all renovation maps as separate layers into one single image. Then rotate and move each map until they all fitted together. The fit was very good, and confirmed the hypothesis about how the maps where produced. Each layer was then exported as a separate map with exactly the same geometrical properties and extent. GCPs, common for all maps, could then be picked in any of the maps. The same formula, with the same variables, could then be applied to all the maps for the transformation.
Figure 12. The five renovation maps over Fröjel concatenated as separate layers into one big map.

The transformation and resampling was done using a standard 1st order polynomial resample algorithm in a GIS. This could of course be succeeded by a manual rectification process, as described in [54], for highest possible result. This was not necessary since the result from the resampling was considered sufficient for our purpose.
6. Applications

Historical maps have been the subject of studies and the information they contain have also been used in many different kinds of studies and analysis for a long time. The Oldest Gotlandic map series, the GM1700 and the ratified taxation maps of 1747, have been used by many scholars, like [48] [20]. Historians, ethnologists and archivist have done much research about the Gotland society and administration of the 18th century, for examples, see [48] [45] [60].

Historical maps are in most cases used in GIS-systems in the same fashion and for the same purposes as in the analogue pre-GIS days. This is to produce map overlays that can be compared with other maps over the same area (other historical or modern maps) and with other types of spatial data, mostly 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 computers. There are numerous examples of this kind of analysis of the temporal and historical development of an area, 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 [41]. In The DHK publication, *Digitala historiska kartor – Tillämpningar i GIS för kulturmiljövården* [52] a series of example applications are presented which gives a fairly good overview of how historical maps are used in different kinds of landscape analyses in a GIS-system. They are mostly concerned with analyses that concern land use, and the overall development of the landscape from different perspectives and how you can visualise these changes. Examples are also given on how to use data from historical maps to visualize the impact of different activities, e.g. by 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 don’t go much beyond the traditional usage of historical maps. In the examples given in [52] the maps are often visualised in 2-D where the map or reconstructed land use are draped over a Digital Elevation model (DEM) or in 3-D as a fly-through etc. Also, the capability of modern GIS-systems to distribute the maps and results to a larger audience over the Internet is shown. The examples in [52] 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, the DHK model must be extended or new ones created.

6.1. Extended use of historical maps in GIS

In the remaining part of the work we will give some brief examples of extended use of historical maps in GIS using more of the statistical and calculative capabilities together with the visual power of GIS. We have a firm belief that with the increased skills and
knowledge in GIS by researchers in the humanities that have taken place during the past years, the usage of GIS 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. The examples presented here do of course not cover all possible uses of historical maps in GIS, but serve merely as some examples. Some of these examples could only be performed with a database model that also models the map-specific information, which our model does. Due to the lack of access to scanned maps, the pilot system only contains data from one parish, Fröjel. This limits what we can do to demonstrate the possible analyses you can do with our map-specific model. For many studies, a sample larger then just one parish is needed. One of the unique features of the GM1700 is its coverage of a whole region, the island of Gotland, developed during a short time period.

The Lantmäteriverket (The Swedish National Land Survey Agency) has a national project for scanning all historical maps in their archives. The Gotland archive is due to be scanned in 2008. Some information from the GM1700 map series is already digitised in GIS-layers in a prior, smaller project, by the Department of Human Geography at the Stockholm University in the 1980’s [75]. We will also use these layers together with our own layers and database to demonstrate the feasibility of the approach taken in this work.

6.1.1. Retrogressive studies -Scattered-ness of land parcels

The geometrical cadastres from the 17th and 18th century depicts the situation and features in Swedish villages or farms, which had bearing on contemporary society and administration. The state of affairs shown 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. One of the leading names in this field was Hannerberg [53], who made many studies based on metrology, since he had a firm belief that the size and placement of village sites and field parcels were formally organized and based on measurements. He meant that 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. [53]. Dan Carlsson [10] 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.

The older and younger cadastres are the most suited maps for these kinds of studies. This is of course because they are the oldest depictions of the cultural landscape, but also because later maps are made with the purpose of redistributing land and thus show 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 [53]. The cadastres are on the other hand created primarily to depict the current state of affairs. Sven-Olof Lindquist has however shown in [42], 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 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. In a retrogressive analysis both the map itself and the text part are
important ingredients. As an example the study conducted in GIS by Charlotte Fabech &
Jytte Ringtved [21] 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.

With the proper retrogressive analysis, historical maps can be used for studies of
phenomenon and processes with a much wider time frame then just the creation date of the
maps. How a farmstead’s land parcels are scattered and placed in space can also be
important clues to the history and age of a farmstead [10]. 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 abandoned farmsteads), and ancient
remains, the patterns of scattered land parcels can reveal the places of ancient farmsteads.
This is a well known fact and parameters like the ones listed are often used in retrogressive
studies, like in [10] and [53]. With the demonstration system presented here it is easy to
graphically display this with the method we have developed.

To graphically display the location of each farm’s individual land parcels, a technique,
based on join operations in SQL, together with other basic GIS-functions, was developed.
The result is very easy to interpret and the visual power is vast. fig 13 shows the result of
such a visualisation. 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
names such as “Fylleqwie” and “Huusarfwa” which can be old farm names, and are
interesting for further investigation concerning abandoned farmsteads. These abandoned
farm’s infields have been requisitioned by the neighbouring farmsteads, probably due to
desertion for some reason.
Figure 13. Maps showing areas which may contain sites of ancient, abandoned farms. 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 indicate. In the marked areas we can see areas with the place names “Fylleqwie” and “Huusarwa” which can be old farm names, and are interesting for further investigation concerning abandoned farmsteads.
6.1.2. Hypothesis testing - The Christianisation of Gotland

Sven-Olof Lindquist [43] 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 of the paper (1981) he had no access to GIS-systems, so all calculations had to be made by hand based on paper maps. This took a very long time, even when only a sample of parishes was selected (31 of 92). In 2001 [44] Sven-Olof Lindquist together with the author, made some of the calculations in GIS. This time we made it 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 digital 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 is a quite rapid process which Lindquist believes. A secondary question was the question of who took the initiative to erect the parish church and decide where it should be placed. Was it a single farmer (a 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 were the positions of the farmsteads in 1700 and the parish borders of the time. The usage of the farm sites from 1700 for a process that took place 700 years earlier 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 meant that it should have a central location, in relation to all the farmsteads. The first analysis was to compare the extensions 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 to which it belonged. Only around 8% of the farmsteads lay closer to another church than the church to which it belonged, which points towards strengthening the hypothesis (fig 14a). If natural obstructions like bogs etc, were to be taken into account this figure would probably decrease even further. As a further test of the hypothesis, the distances between the churches and the minimum transport distances from the farmsteads were compared. The rationale for this is as follows: If the distance is short, it points to the fact that the positioning of the churches is “fair”, and all farmers had a say in the decision. If the distance is long, it is interpreted as the decision around the location 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 where then visualised with a circle, with the distance as radius, around each parish church, as shown in fig 14b.
The results strengthen the hypothesis further. The parishes that have long distances are all known to be anomalous and there are known explanations for these anomalies.

6.1.3. 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 feature itself. A good example of a classical study of this kind is *Svenskt agrarsamhälle under 1200 år* [33] in which data from historical maps are used in calculations of yields, food consumption and other factors 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 not give the answers to most problems formulated in the humanities, but they will make a good starting point or help in the interpretation of many problems. They help in describing and giving a good overview of a situation or state of affairs, which can be useful in reasoning around many problems. In a GIS system they can also be made graphically powerful and displayed in the map.
6.1.3.1. 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 several generations. This is very unusual in other historical maps and can be an important source in many types of studies.

Figure 15. Map and statistics showing the ways of acquisitions of farms in Fröjel parish
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 farm parts (23 registration units, which are divided into 39 farm parts) 23 are freeholder farm parts. Of these 10 (43.5%) are purchased by the present farmer. Even if the sample is very small and maybe not statistically significant, the numbers of purchase are very high. The legislation of the time gave a freeholder the right to freely sell his farms, not parts of it, but kin had first 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 GM1700. These basic statistical calculations could have been performed for any of the unique information found in these maps, like the tax commodities, wood supplies, etc.

6.1.4. Data mining - Predictive modelling

The need and demand for 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 [38]. The method was first developed in the US and is also used in Europe. An example is a large Danish project called “Foranderlige landskaber” [57] in which different techniques for predictive modelling were tested, to identify archaeological sensitive areas, based on the methods developed and tested in another project [18].
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 recorded at each land parcel. These characteristics can be divided in four major themes according to Kvamme [38]: 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 Gotland there are several researchers who have noticed that there is a correlation between “Kämpegravar”, which are Iron Age house foundations with a dating approximately between 200 and 600 AD, and the land use found in GM1700 maps. The
meadows and farmstead sites from the GM1700, and other variables were used in a predictive model to verify this theory and also tried to predict areas, where these house foundations had been located [68]. The model performed very well and had high significance. Even if the areas picked by the model are too large to be really useful in field archaeology, predictive modelling techniques can be very useful in finding patterns in data and also in finding archaeologically “sensitive” areas, with likelihood to inhabit ancient remains. Historical maps can be a very good source for variables, according to the retrogressive analysis.

6.1.5. Distances
Distances were probably of great importance for many reasons in the old agricultural society [10]. The farmstead lots were 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 (to our belief), is Majvor Östergren’s thesis [80] concerning Viking Age silver hoards. In this study distances between different features found in the GM1700 and the find places of silver hoards are of paramount importance for the analyses. In a GIS system these distances are very easy to calculate with standard methods.

As mentioned above the scattered-ness of a farmstead’s land parcels can reveal something of the age and older phases in its 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. Examples include inheritance of other farms, strategic marriage, moved building site or the requisitioning of abandoned farm land, as illustrated above. As a tool to visualise this scattered-ness in statistical terms we have created an index that shows how far a farm has to 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 visualised in different ways.
7. Conclusions and future work

The Swedish treasure of large-scale historical maps has been in focus as a vital source of knowledge about past times in many applications and research problems. At least two major projects have addressed the issue of modelling them for use in databases and GIS-system. They are the Nationalutgåva av de äldre geometriska kartorna project at Riksarkivet (The National Archives of Sweden) [56] and the Digitala Historiska Kartor (DHK) at Riksantikvarieämbetet [28]. These two projects are very well suited for their intended use, but for a deeper understanding and knowledge base for historical maps they are not sufficient.

With our work we have showed a novel approach that is very well suited for 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 the domain model as a Frame-based ontology, which is more suited for modelling semantic/conceptual analyses. Frame based ontologies are richer in semantics and the tools developed are more suited for semantic
analysis. We also believe that visualisation and understanding is simpler for non-computer experts, like domain experts, when ontology tools are used. The semantic analysis is made with the aim of capturing all concepts in each map series. A very data oriented view is needed if all information in all types of historical maps is to be modelled. This approach leads to a model that is very map-dependent. 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.

The difference between different Swedish historical map series can be quite extensive, because the different maps are created in great distance in space and time and they are also developed for different purposes. With the diversity and heterogeneity of Sweden's provinces and regions, the semantics is very rich and regional dependent. The semantics of the concepts has also changed over time. In order to model all the variations in the different historical map series there is a need for several ontologies, which can in a much easier way be semantically aligned and mapped to each other than normally modelled database schemata can. One of the fundamental ideas behind ontologies is their ability to map semantics of concepts in different knowledge domains to each other, as pointed out by [49]. By the use of ontologies as a modelling tool for different historical map series, each map series can be modelled as a knowledge domain of its own and all the map-specific information can be captured. The different ontologies can be aligned, mapped to each other or merged for creation of a top level ontology for Swedish historical maps or creation of different database implementations. This is a great improvement as to how the modelling of different databases for Swedish historical maps has been conducted in the past. In the DHK project a single conceptual model was created for all Swedish historical maps based on the lowest common denominator [28]. This approach leads to a loss of information and also to a loss of understanding and knowledge of the different map series. With our 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 and populating the resulting database take longer time than 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 basic idea behind the design of the ontology is to have a structure which shows and describes all the different concepts found in the maps and how they relate to each other. This ontology will be a fast and easy way of finding answers to questions like: “What measurements are found in the maps?”; “What kind of descriptive words are used?”; or “What types of real estate are there in the maps?”; etc, etc. We believe that the main purpose is achieved with the presented ontology. These are the objectives of presenting how the maps are organized and what concepts they contain and how these concepts are related to each other.

The ontology created for the GM1700 maps does however not meet all the requirements for an ontology presented in section 3.1.1, but this seldom is the case.
a)  *Clarity and objectivity* is for this ontology the most vital requirement and it is covered as far as possible, when dealing with historical material in which the scarce source material and diversity of interpretation is always a problem.

b)  *Completeness and coherence* is not possible to meet as explained above. The structure of the maps is far too inconsistent and incoherent to allow any formal logic and inference.

c)  *Maximum monotonic extendibility.* We believe that the ontology can be extended in a way which will not need the revision of existing definitions. If new concepts are found in the maps, they can simply be added in the existing hierarchy.

d)  *Minimal ontological commitments and modularity* is irrelevant in this case since the ontology is about one single world and one module.

e)  *Ontological distinction principles are* met since the basic assumption in the environment used is that all classes are disjointed.

f)  *Minimization of the semantic distances between sibling concepts* are met as far as can be expected with this kind of UoD, where there is a large heterogeneity among the concepts.

g)  *Standardization of names* has, when possible, been done but the readability and easiness to understand the names of the concepts have been in focus.

We believe that the important items are met, except the coherence and completeness, which are impossible to fulfil in this UoD without compromising the objectives of the ontology or without extensive research within the field of history, as explained earlier.

The ontology serves many purposes. It is first a knowledge model of the domain of the GM1700 map series and secondly a conceptual schema and meta-data for the E/R logical database schema from which the implemented database is developed.

The mapping of ontologies to database models is quite a new research area. Most of it is at present focused on finding algorithms for automating the process and map into the conceptual model. Eventually this research will bridge the two traditions of ontologies and database modelling, and to our belief ontologies or at least the ideas behind ontologies, with their rich semantics and focus on the meaning of concepts, will be a standard procedure in database modelling as well.

We argue, that by setting up some elementary manual mapping rules, this mapping is no more of a problem than mapping from OO or EE/R and an ontology can be mapped directly into a logical E/R-schema thus utilising all the benefits of using an ontology in the domain modelling process. Our elementary mapping rules are sound but not complete, since they only cover some of all primitives that need to be mapped for a complete mapping between the two meta-models. Such mapping rules do not, to our knowledge, yet exist. We have here demonstrated that it is easy to define your own mapping rules in an informal way. There is no need for mapping an ontology to a conceptual schema, since mapping from a conceptual schema, modelled according to an OO-based meta model, to an E/R-schema, is always more of an art than an engineering task and includes many decisions and tasks that can hardly be automated. At best, the process can be semi-automated, with a human making most of the mapping decisions.
Swedish large-scale historical maps are a unique source for many types of historical analysis. They are not only used in historical research, but also in ecology, archaeology, geography, linguistics, etc. They are also used to a very high degree in non-research, for example in cultural heritage management, social planning at all levels, etc. Prior projects concerning the digitalisation of historical maps have drawbacks in various ways, which affects the usefulness of the digitised maps for other purposes then the original scope of the project.

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 have mainly been about displaying the maps as “they are” together with other GIS-layers, 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 shown some examples of usage of historical maps, in which we use more of the analytic and statistical capabilities of GIS. The graphical and display capabilities of GIS are also essential parts of our examples, but we have focused on using them to highlight and display the more deeply nested knowledge that is only visible after the information has been processed and analysed.

Some of these analyses are only possible for 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 in Fröjel. 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 if there is any special distribution 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 (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. Furthermore, all the places where they had fishing and hunting rights could be visualised and analysed.

With our model essentially every piece of information from historical maps will be digitised and stored in a database for the first time. 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 possibilities.

Historical maps are often used in retrogressive studies. In such 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 to the creation data of the maps. As an example we did a fairly simple, but very powerful, graphical analysis that can reveal the location of abandoned farmsteads. In some areas the maps reveal 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 a method like the one presented here could help in clarifying and revealing the true nature of this state 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 this work has given some good examples of how properly modelled historical maps can be used in a variety of different applications and problems. The examples we have given are, of course, not a comprehensive set of analyses you can perform. This is a largely undiscovered area of research and we hope many others will follow in our steps and try to reveal more knowledge in historical maps with advanced data processing.

In the given 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. Maybe the most natural solution would have been to create two ontologies over two different map generations/series to show this capability. 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. The aim is to enable a variety of temporal studies, both spatial and non-spatial. This is a non-trivial problem as the later maps have a completely different focus of land redistribution among neighbouring farmers since the procurer 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 working unit, e.g., the land each farmer owned, not which farm it belonged to. This leads to, at least for the later lagaskiftes maps (1827-1972), a situation where it can be hard to identify which fiscal unit a land parcel belongs to since farmers could have a working unit consisting of different parts of many fiscal units.
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Appendix A

Paper 1

Ontology over the Historical Maps of Gotland 1693-1705

Gustaf Svedjemo, Erland Jungert 2005
Ontology over the Historical Maps of Gotland 1693-1705

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Abstract. In many disciplines in the humanities and social sciences, like history, human geography and archeology, historical maps are of great importance as a source of information. They are used frequently in different studies for a variety of problems. Since the last decade or two, it has been more and more common to use data from historical maps in GIS-analysis. On Gotland, the large-scale map production has a more then 300-year history. There are several different map generations that are produced for different purposes. The scope of this work is a map series produced over the province of Gotland in 1693-1705. These maps have extensive text descriptions of different aspects of the mapped features. Via a code marking system they are attached to the maps. In this work a semantic analysis and an ontology over all the concepts found in the maps and text descriptions will be presented.

1 Introduction

Using Swedish large scale historical maps, which depicts the landscape at a land parcel level with extensive text descriptions, in a GIS environment is being more and more common in many academic disciplines and other fields, e.g. field archaeology, cultural heritage management and forestry.

Several projects have been conducted to find ways for digitizing these maps and store the information in various databases for example the Mark Databas Gotland project at Stockholm University, dept. of Human Geography [30], KartGIS, LiM project Landskapsprojektet and Digitala Historiska Kartor by Riksantikvarieämbetet [11] [8]. Most efforts of this kind are performed in an intuitive way and are very function oriented and do not retrieve all the data in the text descriptions.

On the international scene, the authors have not found any examples of work of this kind, except the work by Pearson and Collier [17] with the British maps made between 1836-50 in the Tithe Survey, which also depicts the land at land parcel level. Their work seams also function oriented and not all the information is extracted into databases and GIS-layers.

The aim of this work is to find methods and models for retrieving all of the information in large-scale historical maps so they can be stored in a Data warehouse. The Universe of Discourse (UoD) is the Gotlandic maps from 1693-1705, hence forth referred to as GM 1700. The first step is to model and analyze the UoD. The method chosen for this is an Ontological approach and tools.
Two words often used in this paper, concepts and features, are sometimes hard to separate. With feature means the form a concept takes in the maps, either in the text descriptions or as a geometrical shape or symbol in the maps themselves. The features can be regarded as instances of concepts.

2 Universe of Discourse and Scope

In Sweden, the domestic map making 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 large-scale maps are often called geometrical maps and depicts the landscape at land parcel level, normally in scales between 1:4 000 and 1:8 000. The small scales are called geographical maps.

These first generations of large scale maps are called *Äldre geometriska jordeböcker* (Older geometrical cadastres) and was created for about 25 years from 1630. The next phase of the geometrical mapping started in the 1680’s for several reasons and the results are stored in *Yngre geometriska jordeböcker* (Younger geometrical cadastres). Among the reasons where fiscal reasons a prominent one, with the mapping as the basis for setting taxes. Gotland and other incorporated parts became in large extent mapped in this period [26] [29].

The results of all Swedish mapping conducted during several centuries are kept in various archives today and can be counted in millions. Sweden is rightfully famous for its large collection of large scale historical maps. In other countries maps of this kind do exist, but only sporadically based on private initiatives by single land owners, and not with a national extent by the Crown, as in Sweden.

**Illustration 1.** Part of a map and text description from the GM 1700 map series
The majority of agencies and researchers who have dealt with digitalization of historic maps, at least in Sweden, have done so from a need to solve some specific problems and for the use in special areas of interest, mostly concerning landscape analysis, archaeology or cultural management and by only using the geometrical and land use aspect of the maps. This is of course a very essential and important part of using the historical maps in modern research and cultural management. These function oriented views does not use the full potential and all of the information found in the maps and text descriptions. These efforts made in DHK and other digitalization projects are of low value for problems and analysis that have other focuses. If new questions where asked and new approaches found, there is, with the present systems, a need to redo all or parts of the work to collect new information.

2.1 Scope

The scope of this work is to learn more about the maps and text descriptions themselves and to model how these maps are organized, what concepts they contain and what they mean 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 text descriptions. The ontology will be a domain model which will be used as basis for a database model to enable the storing of these maps and all the information in databases as close to the original structure as possible. In accordance with Bittner’s and Smith’s [4] thoughts that a map itself is an ontology, we could say that the focus of this work is to elucidate, clarify and repack that ontology and thus making it more explicit and easily understood. 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.

The information in the GM 1700 is quite complex and reflects a society and administrative way that had bearing and was better understood by the contemporary surveyors, then by us today. Historians, ethnologists and archivist have done much research about the Gotland society and administration of the 18th century, for examples; see [15] [16] [20].

2.2 Universe of Discourse, UoD

The first large scale mapping of the Gotland was between 1693 and 1705. These maps are unique in the sense of completeness. All farms (with few exceptions) on the entire island were mapped, and also the islands only town, Visby. 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 (ill 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
made the map [19]. An amateur researcher, Jakob Ronsten, have made transcripts of all the text descriptions, as seen in illustration 1.

The reasons for the mapping are reflected in what is mapped. No map is a true depiction of a piece of the Earth. It is always a selection of information. Depending on the purpose of the mapping, the information presented in the map differs. For the GM 1700 this means that the predominant features and information is about, for the 18th century, important economic matters. Since the taxes were mostly based on farming, the infields are best mapped. In addition, other resources closely connected to a rural economy like woods, fishing, mills etc are described, but not as precise as the infields. Roads, hydrology etc are also mapped, because the large-scale maps were also intended as a base for the small-scale map production, where these features were important. In addition much information on land disputes, co-ownership, crops, field rotation, owners and how they acquired their estates and much more, is noted.

95% of the surveying was done by 7 land surveyors during a period of 12 years. During this time there were new instructions issued from the central office in Stockholm [31]. But over all the maps indicates that the surveyors had a large degree of freedom to organize and make their own decisions about the maps, since the manners and information in the maps can differ quite a lot between them. It also looks like the surveyors manners changed over time. If this is due to the change in instructions or if it is based on their experience is hard to tell. Most of the parishes are mapped by one surveyor in one season, but some parishes are mapped over several years by up to 3 surveyors. The mapping season was from spring to autumn and in the winter they made the fair coping of the field map and compiled and calculated all the material collected in field maps and notations. This process together with difficulties in the field with geographically scattered estates, and to our belief, unclear conditions of the state of affairs in the Gotland countryside, has lead to a series of maps that is very inconsequent and incoherent.

<table>
<thead>
<tr>
<th>17 Röstade in Ekeby Parish</th>
<th>True field</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>field Röstade in Ekeby parish of clay</td>
</tr>
<tr>
<td>41,394</td>
<td>2.85</td>
</tr>
</tbody>
</table>

Table 1 An example of a piece of land (land parcel) that the surveyor probably did not know who owned or what status it had. It is listed as a Ru, with its own registration number (17) in Barlingbo parish. Most likely it belongs to a farm Röstede in Ekeby parish, but there are two farms Röstede in Ekeby parish, Stora Röstede and Lilla Röstede (translated)

The maps are organized in parishes (administrative and geographical areas) and lists a series of units, what we call Registration Units (Ru). Under these Ru:s are lists of features (land parcels and other resources) belonging to an estate or situated within an area. In the absolute majority of cases these Ru:s coincide with farms and other clearly defined estates, but in many cases the Ru:s are listings of land parcels belonging to farms situated in other parishes, church land and other concepts hard to exactly identify. Sometimes it’s also clear that the surveyor is not sure of what it is he is mapping, as seen in table 1.

### 2.2.1 Modeling

As modeling technique, the ontological approach was chosen. We belive it has advantages to more traditional ones. It can facilitate the interaction between the domain experts and modelers and create a semantically clearer and richer model, less prone to
misinterpretation, and more [3]. In this work no specified methodology will be used, as e.g [12][28], but we will try to achieve some generally accepted criteria for what makes a good ontology [1]: 1. Clarity and Objectivity, 2. Completeness, 3. Coherence 4. Maximum monotonic extendibility, 5. Minimal ontological commitments, 6. Ontological Distinction Principle, 7 Diversification of hierarchies, 8. Modularity, 9 Minimization of the semantic distance between sibling concepts 10. Standardization of names. For this work Protégé 3.0 was chosen as a modeling environment. Before we start presenting the ontology, there are some general discussions we have to undertake about the nature of the maps and some central concepts and what we are trying to model.

2.2.2 Real Estate and Land Parcels

The main concept in the maps is the real estate and its resources. Of the resources the land each estate possessed is most important, especially the infields. The infields consist of the fields and the meadows. Real estate is in the Swedish Encyclopaedia (NE) defined as “a unit of immovable property (land) established by a set of rule of law”. In the Swedish law, there is no explicit definition of what a real estate is, but it is normally said that “Every legal real estate must be entered in the national cadastre (real-estate register)” [5]. The definition shows that research around real estate is in a very high degree a multi disciplinary involving law, economics and political science. Stubkjaer [24] lists these areas as the ones which have to be involved when trying to establish an ontology of real estate. In our case, when we are dealing with a situation 300 years ago, we have to add discipline of history as the main subject, when trying to establish what constituted a real estate on Gotland around the year 1700. Basically the same definitions could probably be used for this time period, but there are no explicit definitions made by Swedish historians about the concept of real estate 300 years ago in Sweden. Among historians by trade there seems however to bee a generally accepted fact, that a real estate is land registered in a Cadastre or other historical documents with equivalent status and different types of real estate are surrounded with different kinds of laws, practice, tax rules etc.

This ontology can not have the scope of an real estate ontology for Gotland, since the objective is to keep it as close to the original source, the maps, as possible. Smith & Zaibert [22] distinguishes three different aspects when studying landed property; the geographical, the ontological and the cognitive aspect. In this work it is the geographical aspect which deals with how the real estate is related to the land itself, that is in focus and not the ontological aspects of what a real estate really is or the cognitive which is closely related to cultural issues. The concept of real estate must, however, play an important part, since the surveyors had it as a central concept. The real estate concepts we use in this ontology do not cover all aspects of a real estate, since not all aspects of the real estate are in the maps or known.

A modern digital Cadastre for Sweden is developed, but this have a very different focus, with the administrative and transaction parts as core classes [25]. A modern cadastre have many functions for handling processes and administrative work. This makes it more of a SPAN-ontology, which models processes, as explained below. This ontology can however be aligned, on some parts, with our ontology for temporal studies.
2.2.3 Space and Time

The land belonging to the estates is mapped in land parcels. The land parcels as we see them in the maps are no natural phenomenon. They are man made artifacts, so called \textit{fiat objects} of a social nature. This means that the objects limits, boundaries, are not natural, but rather decided by humans based on social criteria. The opposite of fiat objects is \textit{bona fide objects} or boundaries, that are natural, like rivers, shorelines etc [21]. In our case fiat objects can be made up from both fiat- and bona fide boundaries, e.g. when a meadow goes down to the shore.

These land parcels, themselves fiat object, form another fiat object, the real estate itself, which is the mereological sum of all the estates land parcels outer boundaries. This can be of scattered land parcels and thus, forms a fiat object of a “higher-order” [21].

A real estate does not only have an extension in space but also in time. Most of the estates we meet in the maps still exists today and was formed long before the creation of the maps. This is also true for some of the land parcels. The temporal nature of an estate, and a land parcel, is that it has a beginning and an end, and can during its life cycle change its nature and boundaries, but it is in any given time wholly present. The last property makes it an endurant, as opposed to a perdurant which is never wholly present in any given time. The ontology we are making can be regarded as an SNAP-ontology. The maps are just a snapshot in time of enduring objects. This is in contrast to SPAN-ontologies which are dealing with perduring objects. SPAN-ontologies are used more to model processes etc. [4]. To analyze how these enduring objects, real estates and other features, behave over time is not necessary for this work since we only work with one time-index. This is however something that has to be addressed when several time indices along the same spatial region is involved, e.g. if we introduce another map series of a later date. This is something that will be done in future work.

2.2.4 Uncertainty

Every UoD has some amount of uncertainty in different aspects. When dealing with a UoD created more then 300 years ago, the uncertainty is, more or less, everywhere. You can group the uncertainty into two major groups. The first one deals with uncertainties you can expect in any material of maps and descriptions, also modern ones. This we call \textit{normal uncertainty}. The other group of uncertainties is related to the historical dimension of the UoD, which we call \textit{historical uncertainty}. To the latter kind is, for example, the discussion above about what constitutes a real estate in 17\textsuperscript{th} century or what the measurement unit “Manslätt” was, which is used for measuring meadows, and other measurement units which today is not fully understood. Uncertainties of these kinds require the methodology and toolboxes of history to analyze. But a full understanding will most likely not be reached. The source material is mostly to scarce. For this work these uncertainties is something we have to accept. For those cases where there have been a need to dig deeper in a concept, we rely on research already done by scholars of history and adjacent disciplines.

Among the general uncertainty are the semantic problems with unclear or multiple meanings of concepts or terms used. In a contemporary material, this can in many cases be handled by communicating with the creators of the material. In a historical material this can be a two folded problem with both the general uncertainty kind and the historical uncertainty kind, as in the uncertainty around the concept of “deserted”, that is used for farms or land parcels. It can have many meanings and not all are fully un-
understood [27]. Also many of the quantifications are expressed in a qualitative manner, like some, few, many or big, small and some are expressed in numbers, in descriptions of the same kind of features, etc, etc.

Some of these normal uncertainties can be dealt with using various methods. This is a big area of research and numerous theories and methods are developed, for example Probabilistic or Logical reasoning [7]. However, this is a problem hard to tackle and something which we believe is a non trivial problem to solve in any trustworthy way accepted by scholars of the humanities. This is very essential, since they are the assumed users of the system and, at least in Europe, quantitative methods are not always accepted among scholars of history and adjacent disciplines. This goes probably in an even higher degree for “letting the computer do the interpretations”.

2.2.5 Completeness and Coherence
One of the requirements of an ontology is for it to be complete and coherent, as mentioned in section 2.2.1. For this OWL, which is based on Descriptive Logic (DL) was tried in the modeling process [2]. It was however not possible to use formal logic, due to the nature of the UoD. We will exemplify why it is not possible to use DL on these maps and use the concepts of FIELD and FARMS in our examples.

<table>
<thead>
<tr>
<th>10 Guffrede</th>
<th>a Crown farm with the hide 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>a Hemåker</td>
<td>is of gravel and mould with flat rock underneath. Fraudulent, is harmed by dryness during dry (years), sowed with 1 lop (1/4 of a barrel)</td>
</tr>
<tr>
<td></td>
<td>The fields of this farm is annually sowed in two field rotation with rye, easy to ploughed and 1 acre can, with a good pair of draught-animal, be ploughed per day</td>
</tr>
</tbody>
</table>

Table 2 A very good, but unusual, field description. There are more fields and resources to this farm (translated)

Table 2 shows a very good description of one of the fields belonging to a farm. It contains nearly all the information ever noted for a field, but this is unusual. Normally only parts of this information is noted for a field. There is a great variation on what information the field descriptions contain and different combinations of the above are noted. In the worse cases the information is only a name and acreage, as in table 3.

<table>
<thead>
<tr>
<th>13 Hessle</th>
<th>Crown farm, ½ hide and all deserted</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Stufåker</td>
</tr>
<tr>
<td>B</td>
<td>Lilla åker</td>
</tr>
</tbody>
</table>

Table 3 A very poor field description on a deserted farm

There are two properties which are found in every instance of a field. They are acreage and name. These could then be set as necessary & sufficient conditions for that class, and thus defining it. We believed it was only fields that had acreage in the
specified units. This was an approach that we hoped to follow for most of the concepts. The problem is that the maps are so full of exceptions and anomalies that it could not be accomplished. In the case of the fields, it turned out that one of the surveyors calculated all land parcels in these units and thus acreage in tunnlend or kappland/kannland did not define a field. Another example was the farm concept, which we believed could be defined with the necessary & sufficient condition of all having a hide (mantal), which is what defines a farm [20]. Other agricultural estates are not supposed to have hides at this time (in the 1740’s all Vicarages and Crown estates gets a hide). However, it turned out that some farms lacked a hide and some vicarages had a hide.

Features of different concepts found in the maps are defined by the fact that someone states that this is a feature of this kind. A field is always a field no matter what it is used for or even if it has not be ploughed in 40 years (such examples exist). This is probably because many of the features, mostly the infields, are noted in older cadastres, which the surveyor had access to. The infields where also tax objects and their status could not easily be changed. The surveyor then describes it in a manner that he uses for fields. The problem is that this manner is not coherent among the different surveyors or even the same surveyor. It seems like every time there are something unusual to tell about a feature, they tend to note the anomalies and forget the regular descriptions.

This fact that actually no properties or combinations of them, where found which could be used for any necessary and sufficient conditions for any concept lead us to abandon OWL and descriptive logic. The main point with using logic is to be able to reason about the ontology [23]. This was not possible, at least not in any significant degree. Trying to impose some kind of logic to the ontology would compromise the most fundamental goal of the ontology; the ambition of keeping it as close to the original maps as possible. For this reason the standard features, without logic, of Protégé was chosen because they are enough and more easily understood.

3 The Ontology of the GM1700 maps

The ontology consists, at present, of 536 frames divided into 232 classes, 83 slots, 2 facets and 219 instances not including the system frames. The full ontology can be downloaded or viewed at www.hgo.se/~gustaf/ontology/GM1700_ontology.html. There are 9 root classes of which 2 are core classes, modeling all the central concepts. The remaining 7 classes models smaller concepts found in descriptions of the core features or are created for design purposes and clarity of the ontology [13].

The concept of Ru has partly already been described. It has two subclasses; RealEstates and NonRealEstates. Siltberg [20] identifies the following real estate types to be present on Gotland, according to the cadastres of 1654 and 1747: Farms, Sites, Free soils, Floating soils, Outland soils, Hospitals soils, Other Lands (= Common lands, Grazing lands, Woods, Meadows), Islands, Fisheries, Lime works, Mills.

For this work, we use Siltberg’s categorization of real estates, with some additions and alterations. The real estate types of Grazing lands, woods and meadows are grouped under the superclass OtherEstate, but not common lands. This is because common lands are not so unusual and can be of any type of land, but the other ones
are of land types that exist as classes under \texttt{LANDPARCELS} and are very rare (10 instances altogether 1654). Also two estate types are added; \texttt{CROWNESTATE} and \texttt{PARISHESTATE}. This is because the two biggest agricultural estates on the island are owned by the Crown and the estates owned by the Church are all regarded as farms by Siltberg for practical reasons. Further more, there are \texttt{RUS} of free soils, floating soils, outland soils, hospitals soils, common lands, where it is not absolutely clear if they are one or more estates, but to clarify this is a research endeavor of its own, and for this ontology we regard them as one estate if they are noted under one \texttt{RU}.

The class \texttt{NONREALESTATES} is created for all the \texttt{RUS} where features are listed under it for other reasons then forming an estate. This can be that they belong to an estate situated in another parish or there status is unknown.

The other core root class is the one covering all features found in the maps, the class \texttt{FEATURES}. It is subdivided into the classes \texttt{MAPPEDFEATURES}, \texttt{UNMAPPEDFEATURES} and \texttt{NAMEDPLACES}. The class \texttt{UNMAPPEDFEATURES} is created for concepts found in the descriptions of real estates and land parcels and are linked to them. These are the concepts (classes) of \texttt{TAXES} and \texttt{DOCUMENTS}. The class \texttt{NAMEDPLACES} holds all the instances of places mentioned in the texts. These named places can in many cases be found in the maps and in some not. For those found in the maps, a geometry can be assigned, or if the named place is a \texttt{RU} or \texttt{MAPPEDFEATURES} that already exists as an instance that instance can be selected.

The \texttt{MAPPEDFEATURES} class is subdivided into the \texttt{DESCRIBEDFEATURES} which contains all the features described in the text part and is mainly linked to the maps via the code marking system. Here the inconsistency of the maps is also notable, since not all features supposed to have code markings, have one. This is due to various reasons. It seems like it mostly depends on which surveyor carried out the mapping. Some are more careful then others in this respect. Examples of mapped features are the classes \texttt{LANDPARCEL} and \texttt{OTHERESTATERESOURCES}. The latter is often linked to the map via the \texttt{NAMEDPLACES} class. The subclasses of the class \texttt{UNDISCRIBEDFEATURES} hold all map features not described in the text part. They can be roads, fences, other buildings, text written in the map itself, etc.
3.1 Value Partitions

Value partitions are classes or instances used to describe the values of qualities that other concepts can take. Classes will typically be used representing a continuous space which is partitioned by the values in the collection of values. This is used because the classes can be subdivides and thus refining the values in a continuous way. Instances are used when a enumerated list is primarily wanted, since instances cannot be refined [18].

It is normally advised against using both types of value partitions in the same ontology, yet this is done here. The class \textsc{ValuePartitions} and its subclasses are enumerated lists of all the values different concepts can take. The classes \textsc{ProductsAndLivestock} and \textsc{DescriptiveWords} and their subclasses are a maybe not genuine value partitions, but act as such. The difference between these classes and commonly used value partitions is that they have slots which can hold quantitative values or values from the class \textsc{ValuePartitions}. This can be explained with an example.

\textsc{Beams} is a subclass of \textsc{WoodProducts} under the class \textsc{ProductsAndLivestock}. \textsc{Beams} hold all the varieties for the concept beams we can find in the descriptions of taxes (as a tax commodity) or woods (as a product) and also meadows (as a product). A description can be something like “Tax is paid with some beams...” or “Stoore forest...small beams, saw logs...”. The class \textsc{Beams} have the slots qualitativeAmount and qualitativeSize which can take instances from the classes \textsc{QualitativeAmounts} and \textsc{QualitativeSizes} respectively, which are subclasses of \textsc{ValuePartitions}. The class \textsc{Beams} also have the slot quantitativeAmountInteger, because some times the value can be the number of beams produced. In this fashion we can create all the values needed to describe all the variations of the concept beams. The number of values are not known, but judging from the sample descriptions, there are not so many variations for the different concepts modeled in this way.
3.2 The remaining classes

The remaining root classes are Persons, Measurements, Geometries and FarmSpecifics. The class Persons is very straightforward and contains all the persons mentioned in the maps (subclass NaturalPerson) and also the legal persons (subclass LegalPerson) existing at that time (the Crown, the Church and the Hospital). The natural persons are mostly owners and lesasers of farms. Measurements holds all the Acres, PlowingTimes and Length found in the maps, in respective subclasses. The class Geometries is not meant for instantiations, since creating geometries in an ontology would be very complex and without meaning. Every node would need an instance of its own with its coordinates. The class is only made for modeling purposes, to show which concepts can have geometries and of what kind. Class FarmSpecifics is created for design purposes, since a FarmEstate can be divided in many shares, which have different owners and lesasers, hide, soil nature etc. One FarmEstate can have relations to many FarmSpecifics. Some VicarageEstate also have one relation to FarmSpecifics, since they have a hide as explained above.

4 Conclusions and future work

The ontology created for the GM1700 maps does not meet all the requirements for an ontology presented under section 2.2, but this is seldom the case.

a) Clarity and objectivity is for this ontology the most vital requirement and it is covered as far as possible, when dealing with a historical material.

b) Completeness and coherence are not possible to meet as explained above. The structure of the maps is far too inconsistent and incoherent to allow any formal logic and inference.

c) Maximum monotonic extendibility we believe that the ontology can be extended in a way which will not need the revision of existing definitions. If new concepts are found in the maps, they can simply be added in the existing hierarchy.

d) Minimal ontological commitments and modularity is irrelevant in this case, since the ontology is about one single world and one module.

e) Ontological distinction principle is met since the basic assumption in environment used is that all classes are disjoint.
f) Minimization of the semantic distance between sibling concepts is met as far as can be expected with this kind of UoD, where there is a large heterogeneity among the concepts.

g) Standardization of names have, when possible, been done but the readability and easiness to understand the names of the concepts have been in focus.

We believe that the important items are met, except the coherence and completeness, which are impossible to fulfill in this UoD without compromising the objectives of the ontology or without extensive research within the field of history, as explained in section 2.2.5.

We believe that the main purpose of the ontology is achieved with the presented ontology. These are the objectives of presenting how the maps are organized and what concepts they contain and how these concepts are related to each other. As an domain model for a database implementation it will also be appropriate.

The next phase in this work will be mapping this ontology to a ER-database model and implementing it in a database. Then the geometrical side of the maps will be handled. This concerns mostly how to best handle the uneven distribution of errors which is a known problem with old maps.

Further ahead in the future, is the introduction of later map generations. These are made for different purposes, mainly as tools for land redistributions under different acts of parliament, and thus have different focuses. Whether these can be fitted in this ontology or if new ones have to be created and all of them aligned, remains to be investigated.

References


Appendix B
Paper 2

Ontology as Conceptual Schema in Database Modelling of Historical Maps

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Ontology as Conceptual Schema in Database Modelling of Historical Maps

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Abstract. Sweden has an enormous treasure in its vast number of large-scale historical maps from a period of nearly 400 years. These are frequently used in temporal studies and different kinds of historical and archaeological research problems. A full and systematic analyse of this material from a data modelling perspective has not been conducted. In a prior article, a conceptual analysis resulting in an ontology for the Gotlandic maps of 1693-1705 (GM1700) was presented. In this paper it is demonstrated how this ontology can be used as a conceptual schema for a logical E/R database schema. The Ontology is described in the terms of the Protégé meta-model and the E/R schema in UML. The mapping between the two is a set of elementary guidance rules, which is easy for a human to comprehend, but hard to automate. The E/R schema is implemented in a DBMS- and a GIS system.

Key words: Ontology, database modelling, schema mapping, historical maps.

1 Introduction

Sweden has an enormous treasure in its vast number of large-scale historical maps from a period of nearly 400 years. These maps are regularly used for temporal studies in many disciplines and different kinds of historical and archaeological research problems. A full and systematic analysis of the maps, for the purpose of data modelling, has not been conducted. When dealing with a knowledge domain like Swedish historical maps, where a semantic and conceptual analysis is needed in depth, to create an ontology is best for the full understanding of the domain -we use the term ontology in the meaning of an ontological static model of a domain. Sweden’s diversity and regional heterogeneity together with the different purposes of the mappings during hundreds of years makes the different maps very time- and regional dependent in concepts. Frisk [6] has identified three levels of information in historical maps; map specific-, generation specific- and general information. The map specific is information you could find in one or a few maps. A map generation is a
series of maps created with the same objectives during a shorter period. The general information can be found in all historical maps.

To capture all concepts in an all-embracing ontology and still be able to identify concepts from different map series would not be practical to our mind. It is better to have different ontologies for different map generations and -series, and sometimes, individual maps need an ontology of their own. Then you can conceptually analyse each map series and -generation at a time and in analyses with extension in time and space, the concepts in different ontologies can be aligned and mapped to each other. This is the basic idea and main strength of ontologies, to be able to define concepts and make conceptual alignment possible. An ontology is, as we see it, also easier to query for terms and concepts and to visualise as a knowledge model. We have developed an ontology for one map series of approximately 350 individual maps covering the entire island of Gotland in the Baltic, made around the year 1700, henceforth referred to as GM1700. This ontology is described in more detail in a prior paper [21]. The ontology is meant as a generic knowledge model for the GM1700 for all kinds of applications and analysis. The assumed users are researchers in history, archaeology, human geography and adjacent disciplines. For most researchers in the humanities and social sciences the access to the unadulterated source is vital, which makes it vital to keep the original information structure of the maps in the ontology.

In this paper, we will show how this ontology also can be used as a conceptual schema in a database modelling process and be mapped straight to a logical database schema with the help of some elementary mapping rules. The modelling process is very data oriented, since the views and exact research questions the system is designed for are not known at modelling time. The purpose is to be able to create views and queries based on the research questions at hand. Our aim is to make these maps available in a relational database that can be trusted by the assumed users mentioned above.

To use of historical maps are since a long time standard procedure in many domains in Sweden. Since so many populated areas have at least one historical map they are consequently of great importance as sources for historical knowledge of that area. They are frequently used in different studies for a variety of problems. Examples are the archaeological phase of preliminary investigations in construction planning and cultural heritage management. It is also used extensively in academic research in archaeology, geography, history, linguistics etc. Examples of research areas are, naming customs, agricultural development, ownership, spatial distribution of historical phenomena, etc. Several projects have been conducted to find ways for digitizing the GM1700 and other Swedish large-scale maps. For example the Mark Databas Gotland project at Stockholm University [24], KartGIS, LiM project, Landskapsprojektet and Digitala Historiska Kartor (DHK) by Riksantikvarieämbetet (The National Board of Antiquities) [6]. The majority of agencies and researchers who have dealt with digitalization of historical maps, have done so from a need to solve some specific problem, mostly concerning landscape analysis which mainly uses the geometrical and land use -aspects of the maps, not the text descriptions. A project at Riksarkivet (The National Archives of Sweden) [17] has its focus on the text descriptions of one map series but the geometrical aspects of the maps are not handled. In our project both the text and geometrical aspect is handled.
1.1 Universe of Discourse

In Sweden, the domestic map making 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 large-scale maps depict the landscape at land parcel level, normally in scales between 1:4 000 and 1:8 000, and have an enclosed text description.

From 1628 until early 1900's most of the rural areas in Sweden and towns were mapped in large-scale maps [22] [23]. The results of all Swedish mapping conducted during several centuries are kept in various archives today and can be counted in millions (including duplicates). They do not only depict the geometrical properties of what is mapped, but also describe them in text descriptions.

The first large scale mapping of the Gotland was conducted between 1693 and 1705 (approx.). The purpose of the mapping was taxation and to gain knowledge about Gotland [25]. The maps are made in the scale of 1:8 000 with 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. There can be some variations in the
2 Ontology as Conceptual Schema

Using ontologies when modelling a domain and/or to develop a knowledge model results in a generic domain model that can be used in many applications. We believe an ontology to have many similarities with a conceptual model used in database modelling, even if differences exist. Most of these differences are concerned with the objectives and usage of the two, but also differences in modelling primitives exist when a Frame based meta-model - from the KR-tradition of Artificial Intelligence (AI) - is used to build the ontology [8] [12]. Traditionally, conceptual models for databases are expressed in other meta-models, like Object Oriented (OO), Extended Entity Relationship (EER) or the Entity Relationship (ER).

In our work, the ontology is the conceptual schema. Ontologies based on the Frame paradigm also makes the conceptual model semantically richer, since the Frame paradigm has more expressiveness than the traditionally used meta-models and can be used as both a conceptual model and meta-data. Since we aim to store the maps in an ordinary relational database, some kind of mapping must be conducted between the ontology and the E/R based logical database schema. The differences between the two meta-models - the frame-based used in the ontology and the E/R based used in the logical database schema - can be overcome by some elementary mapping rules, described below.

The ontology made for the GM1700, is modelled in Protégé, which uses an implementation of the Frame paradigm, OKBC. The Frame paradigm can support logic, axioms, etc. The full power of Protégé implementation of the Frame paradigm was not possible to use because of the illogical nature of the UoD, which is very incoherent and incoherent. For example features of different concepts found in the maps are defined by the fact that someone states that this is a feature of this kind, not by its properties. It also seems as if every time there is something unusual to tell about a feature, the surveyors tend to note the anomalies and forget the regular descriptions. This made the mapping between the two different models easier than expected, since less primitives and terms of the Protégé meta-model have to be mapped to the E/R meta-model.
3 Mapping the Ontology to an E/R Schema

Our ontology and logical database schema are two different models of the GM1700. These models are expressed in two different meta-models (data modelling languages). These meta-models give the terms and primitives they support for a description of the world including what it consists of and how it can be structured. To map different meta-models to each other a meta-meta-model is needed that specify how these meta-models relate to each other and how the different primitives and terms of the different meta-models can be mapped to each other (see figure 2).

Research based on Bunge's or/and Chisholm's Ontologies has been conducted by, among others, Milton & Kazmierczak [15] [14] to investigate if they can serve as an ontological foundation for such a meta-meta-model. This is a novel field of research, at least concerning mapping ontologies based in the KR tradition and database models in the data modelling traditions as Baclawski et al [2] points out. They also argue that an extension of UML is needed to support a full and complete mapping between most KR languages and UML.

The Logical database schema in our work is developed in E/R –with UML notation and the ontology is modelled in the Protégé implementation of OKBC. There are several ways of conducting this transformation between these different meta-models. Most research efforts made on mapping between ontologies and E/R schemas are made in the reverse direction, which is from E/R schema to ontology to be used on the Semantic Web. Two examples of this approach are given in [26] and [1].

In mapping between different meta-models, three main approaches exist: Manual, automatic or semi-automatic. Most research has focused on finding algorithms for automated mapping and is in most fundamental parts similar and, to our belief, produces similar results. This kind of mapping is a very complex task, which Baclawski et al [2] shows in their paper. There are several papers describing algorithms and automated methods for mapping between different meta-models. In [8] they set up some mapping rules very similar to ours, but without the generalization/specialization mappings needed for mapping to an E/R schema. In [7] they automate the specialization of deeply nested subclasses, but at a predefined depth for all subclasses.

Different automated approaches described in [10] [11] were tried. The result is very rough and needs extensive manual post-processing to get a usable E/R logical database model. All the generalization and specialization needs to be carried out manually. There are other tools based on similar approaches, which was not tested in this work, but judging from the description, they would produce a result with similar drawbacks [3]. The result of the automated transformation is merely the ontology expressed in a different modelling language (meta-model) not a logical database model (see figure 2). We choose to do the transformation and mapping manually because the mapping of an ontology (and most conceptual schemas) to an E/R logical database schema is more of an art than an engineering task, especially the specialisation/generalisation.
3.1 Our Mapping Principles

In all essential parts, the Frame paradigm is very similar to the Object-paradigm and is based on the same data model [9] [12]. Since not all primitives and terms in Protégé’s meta-model, where used in our ontology the process of mapping the ontology to an E/R-based logical database schema was very much like mapping from an EER-schema to an E/R-schema.

There are differences between the two meta-models we had to consider. In the Frame-paradigm, there are no such things as relationships and associations as in the E/R meta-model. In the Frame-paradigm, relationships are created either in the hierarchical structure using subclasses or using slots. Slots describe both properties (attributes) of a class and binary relationships between instances [5]. The former are in Protégé called Primitive slot and the latter Instance slots.
Mapping the specialization and generalization of the class hierarchy in the ontology to the E/R schema is handled in the same way as mapping an EER-schema to an E/R schema. Handling the binary relationships created with instance slot can also be handled in a straightforward way. Attributes of the relationship is modelled with subslots of the relationship. In addition, we set up the following rules as guidelines: If the cardinality is set as single, it models a 1:1 relationship in E/R and if it is multiple, it is a 1:N relationship. A property (facet) of slots implemented in the Protégé meta-model is inverse slots for creating reciprocal relationships between two classes. This feature can be used to model N:M relationships if the relationship is multiple at both ends.

3.2 The Mapping

Performance issues like response times and other such things were not considered in the modelling process. The usage of the database will be of the nature where these things have little importance. Even if we say, that we have a data oriented view towards the information and there are no predefined views and queries for the database, it is inevitably so that our expert knowledge of the domain is of course effecting both the modelling of the ontology and the mapping to the database. The 256 classes in the ontology were mapped to 30 tables (entity types) in the E/R schema according to our mapping rules and the mapping rules for class hierarchy mapping from E/R to E/R as described above. In the following, the more important decisions are accounted for. We use the terms class (from the OO-paradigm) and concept (from the Frame-paradigm) more or less inseparably.

In the ontology, there are three core classes, REGISTRATIONUNIT, FEATURES and PRODUCTSANDLIVESTOCK. They reflect, what we believe, is the land surveyors view of their task, which was to map all fiscal units (REGISTRATIONUNITS) and its resources (FEATURES) and what they produced (PRODUCTSANDLIVESTOCK). In the logical schema the REGISTRATIONUNIT is one table, TblRegEnhet\(^1\) and the subclasses is discriminated by two type-attributes. The class FEATURES have many different subclasses of which not all are represented in the in the database, but only in different GIS-tables. These are the subclasses of NAMEDPLACE and UNDESCRIBEDFEATURE. This makes it unnecessary to have the two abstract class levels of FEATURES and MAPPEDFEATURES in the schema. Most features are in the subclass at the third level, DESCRIBEDFEATURE that is modelled in the table TblBeskrivetObjekt, which have two weak child tables modelling the subclasses of OTHERESTATERESOURCES (TblAndraResurser) and LANDPARCELS (TblMarkområden). TblMarkområden has two weak child tables containing the attributes for fields (TblAkerSpec) and acreage (TblAreal). This solution was chosen because the fields have many attributes, that are not present in the description of other land parcels and the units and way of expressing the acreage differs for different types of land parcels. The subclasses of TblAndraResurser are discriminated with a type attribute. The final core class, PRODUCTSANDLIVESTOCK gets a table of its own, TblProduktion and one child table

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\(^1\) The ontology is available in both English and Swedish, since it is possible to have multiple languages in Protégé. The logical database schema and the database itself are both made in Swedish, since we assume the usage to be mainly in Sweden.
for the class SEAWEEDFERTILIZER, which is very special and quite rare. Even if there is a great verity of products and measurement units, both quantitative and qualitative mentioned in descriptions we felt it best to keep it together. The inconsistency and illogical structure of the maps are also visible here, since nearly anything can be produced anywhere, contrary to what you might expect. For example, a meadow can produce hay, grassing, timber and ag (sawgrass used for roof covering).

Most other concepts are minor ones found in the descriptions of the core classes and simply get a table of its own with the subclasses as type-attributes and relationships to the respective core class. Some concepts and properties in the ontology can be found in either of the descriptions of the two core concepts, REGISTRATIONUNITS and DESCRIBEDFEATURES, thus having relationships to both. These are the concepts of TAXES, DOCUMENTS, NOTABLEEVENTSORANNOTATIONS and PERSONS and the multi-valued property of featureName. The class VALUEPARTITIONS is what it says, just value partitions with values that attributes can take and its subclasses are different lookup tables for different attributes. How they are used is explained in [21].

Between the two tables, TblBeskrivetObjekt and TblRegEnhets, there are five different relationships. These are the relationships of list, uses (1:1:M), paysTo, partOf and litigation (N:M). The relationship paysTo is modelled with an intermediate table, TblBetalarTill, with two attributes hyra (rent) and hyresEnhet (rentUnit). The relationships of list, uses and partOf models the fact that a resource is always listed under a registration unit, but can be used or owned by some other registration units. The relationship partOf is in the ontology modelled with a reciprocal instance slot, multiple at both ends, since co-ownership can exist. This makes it an N:M relationship in the schema. The same goes for the relationship of litigation, which models the fact that a resource, mainly land parcels, held by one estate, can be claimed by other estates. Instead of modelling these two N:M relationships separately, they are joined in one relationship with one intermediate table, TblDelAv and a role-attribute is used to separate the two relationships, called roll. This attribute can take the values of “owner” or “litigator”. This makes also sense, since all ownership matters now are gathered in one relationship, as shown in fig3. The table of TblRegEnhets has also two many-to-many recursive relationships that each gets a table of their own.
3.3 The Demonstration System

The implemented demonstration system is divided into two parts, the database system and the GIS system. The maps where scanned and georeferenced into the Swedish National reference system RT 90 and then vectorized and stored in the GIS-tables with the code markings as primary key attributes. The mapped features that lack text descriptions have no relationships to the DBMS tables. They are only represented by appropriate geometries.

In our system all information in the original maps, both text description and geometries in the map itself is handled. Almost any query you can put to the original maps, you can put to our database. Several researchers, from the 1930’s and onwards have extensively queried the GM1700 for different data, each for their own research problem [13] [16] [4]. This have been a very time-consuming process for each researcher, since they have not been able to profit much from what their predecessor made, but have been forced to go trough all the maps again in the archives for the data needed for their research question.

Visualization of historical maps is very common, but is mostly done in a simple fashion. It is very common to drape the historical map on a Digital Elevation Model (DEM), maybe with some additional layers, but it rarely goes beyond this level. Our system, which captures nearly all map-specific information, is very well suited for data mining and more advanced visualizations of the results from such analysis. We advocate a more advanced use of historical maps in databases and GIS-system, which involves data mining and statistics to reveal more deeply nested knowledge and relationships. The result of these analyses can be visualized in powerful ways.

As an example, we use a visualization of the scattered-ness of farms. This can be very useful in so-called retrogressive analysis, in which the maps, together with other data, are used to recreate the situation hundreds or even thousand years before the creation of the maps [19]. In figure 5, we show a map of how the different farms land parcels are distributed. This can be used in analysis of abandoned farmsteads. A more thorough explanation of this will be presented in a forthcoming paper.
4 Discussions and Future Work

When dealing with a knowledge domain like historical maps, where the semantics and conceptual analysis is needed in depth, creating an ontology is a better method than an ordinary domain model, based on the OO-paradigm or E/R-paradigm, for understanding of the domain. Frame-based ontologies are richer in semantics and the tools developed are more suited for semantic analysis.

One of the main benefits of using ontologies as a methodology for conceptual modelling cannot be fully understood by modelling only one map series. The difference between different Swedish historical map-series can be quit extent. To model all the variations in the different historical map series there is a need for several ontologies. Each modelled as a knowledge domain of its own, which can in a much easier way be semantically aligned and mapped to each other than database schemata can. One of the fundamental ideas behind ontologies is their ability to map semantics of concepts in different knowledge domains to each other, as pointed out by [18]. This is a great improvement as to how the modelling of different databases for Swedish historical maps has been conducted in the past, normally based on the lowest common denominator. This approach leads to a loss of information, understanding and knowledge of the different map series.
The ontology serves many purposes. It is first a knowledge model of the domain of the GM1700 map series and secondly a conceptual schema and meta-data for the E/R logical database schema from which the implemented database is made.

The mapping of ontologies to database models is quite a new research area. Most of it is at present focused on finding algorithms for automating the process. Eventually this research will bridge the two traditions of ontologies and database modelling, and to our belief ontologies or at least the ideas behind ontologies, with their rich semantics, will be a standard procedure in database modelling as well.

By setting up some elementary manual mapping rules, this mapping is not more difficult than any other such mapping and an ontology can be mapped directly into a logical E/R-schema and thus utilize all the benefits of using an ontology in the domain modelling process. This mapping is always more of an art than an engineering task and includes many decisions and tasks that can hardly be automated. Our elementary mappings rules do not cover all terms and primitives in the two metamodels, since only some of them are present in our two models.

In this paper only some brief examples on how the system and information can be used is shown. In the near future, a publication will be made to show some more extended examples of different research problems the system can help solving. Later ontologies for other map series will be created and aligned.

References

9 Karp, Peter D. 1993. The Design Space of Frame Knowledge Representation Systems. SRI AI Center Technical Note # 520

- 196 -
Appendix C

Paper 3

Example Applications of Historical Maps in GIS and Databases.
Gustaf Svedjemo, Erland Jungert 2007. Submitted to ScanGIS 2007, 5 - 7 September 2007, Ås, Norway
Example Applications of Historical Maps in GIS and Databases

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Abstract. Historical maps are a vital and often use source in a verity of disciplines and applications. Since a decade or two, they have moved in to 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 for 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. Together with the map are text descriptions of the mapped features. These text descriptions are 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 a prominent one, with the
(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 a prominent one, with the mapping as basis for setting taxes. Gotland and other incorporated parts became in large extent mapped in this period [17] [19].

The results of all 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, but only sporadically, based on private initiatives by single land owners, and not by the Crown, 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. The former project only deals with the maps from the first phase of Swedish large-scale mapping between 1633 and 1655. The project is still running, but the database application and conceptual analysis is very poorly documented. The only documentation is the logical database schema, which can be hard to interpret without being part of the database modelling process. The focus of the project is the text descriptions. The geometrical objects of the maps are not handled. The only link between the database and a map are the coordinates for each settlement unit, normally a village, and some other features like mills, etc. Most features like the land use and fencing are not georeferenced. The text descriptions of these first Swedish large-scale maps were very brief and short, as seen in table 1.
<table>
<thead>
<tr>
<th>Code marking</th>
<th>Original text in Old Swedish</th>
<th>Translated into modern English by the authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nye Berqwara j Kinnewaldz Häredt J Skatelöfz Sochn vthi Smålandh</td>
<td>New Bergwara in Kinnewaldz hundred in Skatelötz parish in Småland (province)</td>
</tr>
<tr>
<td>2</td>
<td>Vthsäde … 18 t(unno)r</td>
<td>Sowing 18 (barrels)</td>
</tr>
<tr>
<td>3</td>
<td>Vthsäde … 18 t(unno)r</td>
<td>Sowing 18 (barrels)</td>
</tr>
<tr>
<td>4</td>
<td>Vthsäde till haśle … 5 1/4 t(unn)a J alla gerden befnis leer jord medh sandh bebländat</td>
<td>Sowing for hassle 5 ¼ barrel In all fields is there clay soil mixed with sand</td>
</tr>
<tr>
<td>5</td>
<td>Engh tillsammans recknis på begge sider om åån, fääs när medelmätigh gräßwext ähr… 166 laß</td>
<td>Meadow together counted on both sides of the river, on average growth it yields 166 (wagon) loads</td>
</tr>
<tr>
<td>6</td>
<td>Åålafiske.</td>
<td>Eel fishing</td>
</tr>
<tr>
<td>7</td>
<td>Betishagar.</td>
<td>enclosed pasture-land</td>
</tr>
<tr>
<td>8</td>
<td>Platzien som Hans Nåd will låta bygga såtisgården.</td>
<td>The place where His Grace wants to build the manor</td>
</tr>
<tr>
<td>9</td>
<td>Quarn.</td>
<td>Mill</td>
</tr>
<tr>
<td>10</td>
<td>Holmar, huilka säges tillförne hafwer waren een kongzgård bygdh och skulle wara nedsunkin.</td>
<td>Islet, of which it is said have been built with a State demesne which is sunken down</td>
</tr>
<tr>
<td>11</td>
<td>Engh huilken hafwer een tidh waren bergat vthaf bruksfolket wid Huseby. Godh Lägenheet med bööke ekeskogh och annor nödtortigh skogh såsom och med vthmark. Åhr och lägenheet att göra meer äker.</td>
<td>Meadow, which has been for a while harvested by the workers from Huseby God place with beech, oak and other scanty wood and outlying land. There is room for more fields.</td>
</tr>
<tr>
<td>12</td>
<td>Engh hagar.</td>
<td>Meadow enclosed pasture.</td>
</tr>
<tr>
<td>13</td>
<td>Vthmark.</td>
<td>outlying land</td>
</tr>
</tbody>
</table>

Karttext: Text in the map
Lacus Salen | Jgla siön | Lake Salen | Jgla lake |

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 project identified three levels of information in historical maps; map specific-, generation specific- and general information. The map specific information you find in one or a few maps. A map generation is a series of maps created with the same objective during a shorter period of time, e.g. *Storskifte, Laga skifte* (these examples are two different land reforms in Sweden). The general information can be found in all historical maps. The focus for the DHK-project was the
general information. The method used was to analyse the concepts found in many of the historical maps to find the lowest common denominator behind these concepts. This means that a lot of map- or generation specific information is hard or impossible to handle in their model. The general information can be divided into the following themes: Types of land, land use, topography, hydrology, constructions, administrative divisions (at mapping time) and soil assessment. The analyses also focused on identified 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 in the GIS- or database system. Mostly it is the land parcels, building sites, etc. Not much of the text description is handled, and when it is, it is in a very simple database manner. Our project have a wider scope and attempts to learn more about the maps and text descriptions themselves and model how these maps are organized. We analyse what concepts they contain and what these concepts mean 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 text descriptions. Since the concepts are in focus, an ontology is made over the Universe of Discourse, which will be further explained below. The ontology is a domain model/conceptual schema which is used as basis for a database model to enable the storing of these maps and all the information in databases as close to the original structure as possible. 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.

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 in what 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 made the map [20]. An amateur researcher, Jakob Ronsten, have made transcripts of all the text descriptions. If you compare the text description in fig 1 of the GM1700 with the description of the oldest maps from the Swedish mainland, the older geometrical cadastres in table 1, you see the richness in the text description of the GM1700 compared to the older geometrical cadastres.
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.

1.2.1 The database modelling process of the GM1700

When dealing with a knowledge domain like historical maps, where a semantic and conceptual analysis is needed in depth, it is a better method to create an ontology than an ordinary domain model/conceptual schema that is based on the for the understanding of the domain. A Frame-based ontology is richer in semantics and the tools developed are more suited for semantic analysis. We also believe that visualization and understanding is simpler for non-computer experts, like domain experts, when ontology engineering tools are used. The ontology over the GM1700 is presented in the first article [23].

One of the main benefits of using ontologies as a methodology for conceptual modelling cannot be fully understood by modelling only one map series. The difference between different Swedish historical map series can be quite extent, because the different maps are created in great distance in space and time and are also made for different purposes. With the diversity and heterogeneity of Sweden's provinces and regions, the semantics is very rich and regional dependent. The semantic of the concepts have also changed over time. To model all the variations in the different historical map series there is a need for several ontologies. They can, in a much easier way be semantically aligned and mapped to each other than “traditional” database models can. One of the fundamental ideas behind
ontologies is their ability to map semantics of concepts in different knowledge domains to each other, as pointed out by [21]. By the use of ontologies as a modelling tool for different historical map series, each map series can be modelled as a knowledge domain of its own. The different ontologies can be aligned, mapped to each other or merged for creating a top level ontology for Swedish historical maps. This is a great improvement as to how the modelling of different databases for Swedish historical maps has been conducted in other projects.

The Ontology serves many purposes. It is first a knowledge model of the domain of the GM1700 map series and secondly a conceptual schema and data dictionary for the logical E/R schema from which the implemented database is made. Since we aim to store the maps in an ordinary relational database, some kind of mapping must be conducted between the ontology and the E/R based logical database schema. The differences between the two meta-models of the ontology and the logical database schema can be overcome by some elementary mapping rules, described in [24].

2 Usage of historical maps in GIS

Historical maps are in most cases used in GIS-systems in the same fashion and for the same purposes as in the analogue pre-GIS days. This is to produce map overlays that can be compared with other maps over the same area (other historical or modern ones) 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 of the historical development and interpretation of an areas development 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 concerned 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 are draped over a Digital Elevation model (DEM) or in 3-D as a fly-through etc. Also the capability of modern GIS-system to distribute the maps and 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, the DHK model must be extended or new ones created.

2.1 **Extended use of historical maps in GIS**

In the remaining part of the paper we will give some brief examples of extended use of historical maps in GIS in using more of the statistical and calculative powers, together with visualisation, of GIS. We have a firm belief that with the increased skills and knowledge in GIS by researcher in the humanities that have taken place during the past years, the usage of GIS 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, but serves merely as some examples. Some of these examples could only be performed with a database model, which also models the map-specific information, as our model do. Due to the lack of access to scanned maps, the pilot system only contains data from one parish, Fröjel. This limits what we can do to demonstrate the possible analyses you can do with our map-specific model. For many studies you need a sample larger then just one parish. One of the unique features for the GM1700 is its coverage of a whole region, the island of Gotland, during a short time period. The maps are very fragile and you need very sophisticated scanners. The Lantmäteriverket (The Swedish National Land Survey Agency), who are keeping most of the maps have a national project for scanning all historical maps in their archives. The Gotland archive is due to be scanned in 2008. Some information from the GM1700 map series is already digitised in GIS-layers in a prior, smaller project, by the Department of Human Geography at Stockholm University in the 1980’s [26]. We will also use these layers.

2.1.1 **Retrogressive studies -Scattered-ness of land parcels**

The geometrical cadastres from the 17th and 18th century depicts the situation and features in Swedish villages or farms, which had bearing for the contemporary society and administration. The state of affairs showed in the map 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. One of the leading names in this field was Prof Hannerberg, who made many studies based on metrology, since he had a firm belief that the size and placement of village sites and field parcels where formally organized and based on measurements. He meant that 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 farmsteads 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 is often used in retrogressive studies, like [13] [10].

To graphically display the location of each farms land parcel, simple techniques based on SQL joins together with other basic GIS-functions can be used. The result is very easy to interpret and the visual power is vast, as shown in fig 3. 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 infeld have been requisitioned by the neighbouring farmsteads, probably due to desertion for some reason.
Figure 2 Maps showing areas which can contain sites of ancient, abandoned farms
2.2 Hypothesis testing - 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 made 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 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. 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, were 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.
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
2.3.2 Predictive modelling

The need and demand for 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 were tested, to identify archaeological sensitive areas, based on the methods developed and tested in another 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 into four major themes, according to Kvamme [14]: Environmental variables, cultural and social factors, positional characteristics 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.

![Figure 5 Prediction map for Iron Age house foundations based on independent variables from the GM1700.](image)
In Gotland there are several researchers who have noticed that there is a correlation between “Kämpegravar”, which are Iron Age house foundations with dating a 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.

### 2.3.3 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 Majvor 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.
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 that is 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 have mainly been about 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 parts of our examples, but we have focused in using them to highlight and display the more deeply nested knowledge that is only visible after the information have been processed and analysed.

Some of these analyses are only possible 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, is there any special distribution 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. Further more, all the places the farms had fishing and hunting rights could be visualised and analysed.

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 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 in clarify and revealing the true nature of this state 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 good examples on how properly modelled historical maps can be used in a variety of different applications and problems. The examples we have given are of course not a comprehensive set of analyses you can perform. This is largely an undiscovered area of research and we hope many others will follow in our steps and try to reveal more knowledge in historical maps with 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 then a traditional conceptual model, focuses on the ability to map concepts from different maps to each other. Maybe the most natural would have been for us to create two ontologies over two different map generations/series, to show this capability. 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. The aim is to enable temporal studies over an area. This is a none-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 a operating unit consisting of different parts of many fiscal units.
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Sweden has an enormous treasure in its vast number of large-scale historical maps from a period of 400 years. These maps are made for different purposes, that we call map series. The maps are also very time and regional dependent with respect to their concepts. A large scanning project by Lantmäteriverket will make most of these maps available as raster images. In many disciplines in the humanities and social sciences, like history, human geography and archaeology, historical maps are of great importance as a source of information. They are used frequently in different studies for a variety of problems. A full and systematic analyse of this material from a database perspective has so far not been conducted. During the last decade or two, it has been more and more common to use data from historical maps in GIS-analysis. In this thesis a novel approach to model these maps is tested. The method is based on the modelling of each map series as its own ontology, thus focusing on the unique concepts of each map series. The scope of this work is a map series covering the province of Gotland produced during the period 1693-1705. These maps have extensive text descriptions concerned with different aspects of the mapped features. Via a code marking system they are attached to the maps. In this thesis a semantic analysis and an ontology over all the concepts found in the maps and text descriptions are presented. In our project we model the maps as close to the original structure as possible with a very data oriented view. Furthermore; we demonstrate how this ontology can be used as a conceptual schema for a logical E/R database schema. The Ontology is described in terms of the Protégé meta-model and the E/R schema in UML. The mapping between the two is a set of elementary rules, which are easy for a human to comprehend, but hard to automate. The E/R schema is implemented in a demonstration system. Examples of some different applications which are feasibly to perform by the system are presented. These examples go beyond the traditional use of historical maps in GIS today.

**Keywords**
Ontology, knowledge modelling, database modelling, schema mapping, historical maps, geographical information systems, GIS
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