Ontology-based Modeling and Visualization of Cultural Spatio-temporal Knowledge

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Abstract

Geographic knowledge is essential in handling a large variety of resources, including cultural contents such as museum artifacts, maps, books, photographs, and videos. The metadata of such resources often need to refer to a geographic entity or region, for example to the place where an artifact was produced, used, or found. In this paper, we examine how geographical knowledge may be represented ontologically to enable different types of searches, visualization, and inference in cultural semantic portals and other semantic geo-applications. In particular, we show how change in time between historical regions can be explicated as an ontology and be used for reasoning. Regarding search and visualization, we show how maps of different time periods can be visualized as transparent overlays on top of Google Maps, how cultural content can be visualized on them, how geo-based queries can be formulated based on maps, and how additional services, such as a meta-search system, can be integrated in the mash-up system. The work presented is being integrated at the practical level in the cultural semantic cross-domain portal CultureSampo.

1 Introduction

A large proportion of cultural resources such as artifacts, collections, books, photographs, and videos are geographically referenced and thus should be identified by search terms that refer to locations (Jones et al., 2001; Stuckenschmidt and Harmelen, 2004). This is because they are produced, found or used in those locations, or they have some other relationship to the location in question. By georeferencing the resources (Schlieder et al., 2001), different spatial queries can be enabled in order to find interesting connections.

The term georeference refers to the act of assigning locations to geographic objects, which are entities representing some part on or near the Earth's surface. The simplest form of georeferencing is place naming. However, the problem of representing this geographically referenced knowledge is complex due to many reasons. Place names are usually unique only within an area or domain of the Earth's surface (e.g. city name is usually unique within the domain of a state) and they may become obsolete through the time. For example, different countries and other regions are merged, split and renamed due to reorganizations at the social and cultural levels thus causing new territorial shapes. Place names may also have different meaning to different people, and within the different contexts they are used. Well-known systems for georeferencing uniquely across domains are postal codes and geographic coordinate systems (the system of latitude and longitude), from which the former is based on a human activity and the latter one on physical features (Longley et al., 2001; Mark et al., 2001).

Ontology-driven information systems (Guarino, 1998) have been proposed to provide means to represent and manage this kind of complex knowledge. The idea behind modern systems is to (Visser, 2004) "geo-enable" the Web and allow for complex spatial information and services accessible and useful with all kinds of applications e.g. from library systems to museum systems.

In information systems, the term ontology should be considered as a synonym to *conceptual model* in a way that it is independent of its philosophical roots (Welty and Guarino, 2001). The idea is that modeled ontologies capture the properties, classes and their mutual relationships (Guarino and Welty, 2002) — i.e. the essential semantics of the Universe of Discourse (UoD). For example, the *spatial overlap* of regions (Visser, 2004; Stuckenschmidt and Harmelen, 2004) is important in a sense that it affects the way ontological annotation of resources should be made.

This knowledge concerning geographic, spatial entities has to be represented in a machine-understandable, reusable and shareable way so that it can be used, for example, in the Semantic Web (Berners-Lee, 1998; Berners-Lee et al., 2001) as ontologies.

In this paper we examine how ontological knowledge can be used in order to visualize different kinds of georeferenced information and to enable different precise searches and meta searches. We are especially interested in how the results could be used at a practical level in a cultural semantic cross-domain portal such as CULTURESAMPO (Hyvönen et al., 2006) and in creating a prototype of a national geo-ontology server.

In essence, we propose that the following spatio-temporal, ontological issues should be handled in a state-of-the-art-system.

1. Ontological representation of spatial entities and their mutual relationships.

2. Inference based on explication of complex knowledge. We will show how knowledge about historical changes in regions can be modeled and utilized in information retrieval.

3. Visualization of semantic web content on maps. We show how cultural content can be visualized on maps by using Google Maps as an external service.

4. Multi-map visualization by using different kinds of maps simultaneously. It is shown how maps of different time periods can be used by using transparent overlays, which gives the end-user a kind magnifying glass to zoom into history.

5. Polygon-based searches. We will illustrate how to express polygons, and map them into ontological location individuals (instances) such as cities, in order to annotate and search semantic content.

6. Combining map visualization with other services. Visualization on the map can be easily combined with other services. As a demonstration of how this can add value, a meta search service implemented on top of the semantic portal MuseumFinland (Hyvönen et al., 2005) is presented.

In the following we will overview how we have addressed these issues by creating ontologies, reasoning engines and building working demonstrations using existing portals.

2 Representation of Ontological Relationships

Spatial structures and their mutual relations are clearly the most essential form of geographic knowledge. The principles by which the geographic domain - and geo-ontologies - are primarily structured from the theoretical viewpoint are topology (the theory of boundaries, contact and separation), mereology (the theory of part/whole) and geometry (Mark et al., 2001). This is because geographic objects are not merely located in space; they are tied intrinsically to space inheriting many of the structural properties from the Earth's surface. Reasoning in terms of *part-of* relationships is powerful and appears to be well-suited for geographic representation and inference. Part-of relationships are used for containment hierarchies and are closely related to representation of different types of administrative hierarchies. However, mereology alone cannot deal with some very basic spatial relations, such as the relations *within*, *contains*, and *overlaps*, and this is where topological reasoning is required (Casati et al., 1998; Mark et al., 2001; Jones et al., 2002).

There has been an active philosophical discussion about the essential spatial relations (e.g. in (Varzi, 1996)) and different attempts to formalize the relations, such as RCC-8 (Randell et al., 1992) and (Egenhofer, 1989). Furthermore, methods to measure spatial relevance, such as topology (of neighboring regions), directions (of related regions), and distances (between regions) combined with partonomical relevance (cf. (Stuckenschmidt and Harmelen, 2004), chapter 8) have been developed.

Semantic web ontologies represent geographic knowledge (among other types of knowledge) in terms of the Resource Description Framework (RDF) (Brickley and Guha, 2004) and the Web Ontology Language (OWL)[1]. RDF and Uniform Resource Identifiers (URI) form the basis of the Semantic Web. OWL and RDF are used for defining concepts and metadata, and URIs are used for identifying resources used in the descriptions uniquely.

As a part of our research, we are developing[2] a Finnish geo-ontology SUO (Suomalainen paikkaontologia) using Semantic Web technologies RDF and OWL. According to the plans SUO-ontology will model different classes of geographical places - either man-made or natural - and their topological and mereological relations, as well as relations defining coordinate-based geometry for points, curves and polygons. Currently SUO includes approximately 150 classes such as *city*, *province*, *graveyard*, *lake* or *river*. These classes will be populated with thousands of instanses from the Place Name Register[3].

3 Explicating Change of Regions

Geographic regions change over time. Regions, for example, are split and merged due to various reorganizations at the social and cultural levels. For example, in 1991 East Germany and West Germany were merged to form Germany, as depicted in figure 1.*West Germany*, *East Germany* and *Germany* are here individuals of an ontology. The x-axis depicts time and the y-axis the relative areas of the countries. The history is full of events like this (Smith and Brogaard, 2003). Budapest was formed via the unification of former towns Buda and Pest, the Czech Republic and Slovak Republic were formed through the separation of Czechoslovakia, and so on. This kind of spatial changes of individuals at the geographical, social and cultural levels are problematic from the information annotation and retrieval viewpoint. Content is annotated by using historical and contemporary concepts and names. However, when querying, concepts and names from other time periods may be used, which leads to low recall and precision.

Figure 1: Germany, East Germany and West Germany over time and space.

To address the problem we developed an ontological method (Kauppinen and Hyvönen, 2006, 2005) for representing spatio-temporal changes in regions that essentially define a geo-ontology time series. The figure 2 illustrates the steps of using the method. In the initial data of ontological changes are maintained as a spreadsheet table to ease the editing [4]. Each change, such as a merge or a split of two counties, is represented by a line in the table and is called a "change bridge".

This table is then transformed automatically into RDF-form representing the changes and regions involved. A set of rules is used to construct temporal regions based on the change information. As a simple example, since we know that an administrational region of Viipuri has changed both in 1906 and in 1921, the area of Viipuri has remained the same between (the beginning of) 1906 and (the end of) 1920 and hence a temporal region Viipuri (1906-1920) is created. In a similar manner the rule set is used to construct all the other temporal regions in the ontology time series. At the next phase, the essential properties are inferred for these temporal regions. We declared that the essential property (Guarino and Welty,

[1] http://www.w3.org/2001/sw/

[2] We have used The Protégé Ontology Editor available at (http://protege.stanford.edu/).

[3] Place Name Register was obtained from the National Land Survey of Finland

[4] We have used the freely available OpenOffice Calc (http://www.openoffice.org/) but there are other alternatives available as well.

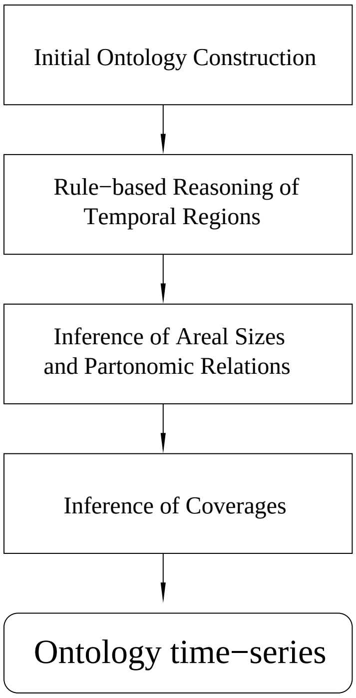

Figure 2: Process of creating an ontology time-series.

2002) for each region is the size of the area. For example, since we know that the area of Helsinki has been measured during the year 2005, we can infer that a temporal region Helsinki (1966-NOW) has this areal value as it has remained the same between 1966 and now. Each temporal region in the system has an own identifying URI. This means that if the area of a region changes, there will be a new URI corresponding to a new region with the new value for the size of that area.

An inference engine then reasons the coverages (i.e., how much a region X *overlaps* an other region Y, and vice versa) between all temporal regions of the ontology. The calculation is based on the initial sizes of the regions and their change history. The coverages cannot be calculated directly based the actual polygons of the regions, because these are not known, only the sizes and the changes. In the below, the basic steps of the method are shortly described.

1. Local Bridges. Changes are modeled as individuals of basic change classes, such as split and merged.

2. Local Coverings. The bridges represented in RDF are transformed into a form where the local coverings are made explicit using the sizes of geospatial resources.

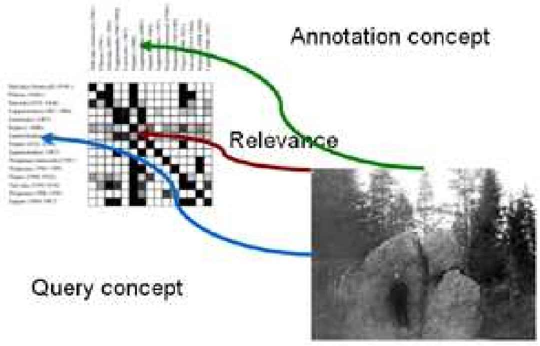

Figure 3: Annotation and indexing concepts matched.

3. Global Coverings. Global overlaps are calculated by chaining local coverings and by considering different change paths between concepts.

4. Visualization of global coverings.

With the method, it has been calculated, e.g., that the temporal region Lappeenranta (1989-) covers 12% of the temporal region Viipuri (-1906). The global coverage information can be used to match annotations and queries, as depicted in figure 3. For example, the photo depicted in the figure is stored in a database of the Geological Survey of Finland GTK (Väätäinen, 2004). According to the attached metadata, the photo is taken within the region Viipuri (-1906). This means that there is a 12% change that the photo is actually within the boarders of the current city of Lappeenranta in Finland. This may be a surprise to many, since Viipuri was annexed to the Soviet Union after the World War II. The explanation is the annexed Viipuri constitutes a temporal region that is different from Viipuri (-1906).

The method is being applied to construct a complete Finnish time-location ontology (Suomen Ajallinen PaikkaOntologia, SAPO) of counties and communes since the mid 1800's, and to maintain the ontology in the future. It has already been identified (Väätäinen, 2004) that from the beginning of 20th Century there are already over 1100 changes (such as creation, merge, split, and name change) in Finnish communes.

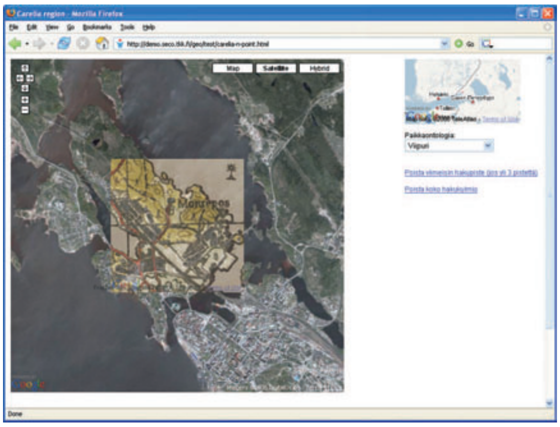

Figure 4: Using multiple maps simultaneously. A historical Karelian map depicting the park of Monrepos in Viipuri is shown semi-transparently on top of a modern satellite image provided by the Google Maps service.

4 Visualization using Multiple Simultaneous Maps

In order to visualize historical geo-content annotated according to old temporal regions and place names, historical maps are needed. On the other hand, also the current view of places is usually needed at the same time to bridge the conceptual cap between regions of different era. To facilitate this, we created a scheme for using several overlaying maps simultaneously in visualizations. Creation of several layers is a common (de Berg et al., 2000) way to make maps more readable.

The maps and satellite images of the Google Maps service were used as the contemporary view. To provide the historical view, we used a set Finnish maps from the early 20^{th} century covering the area of the annexed Karelia before the World War II. The maps were digitized and provided by the National Land Survey of Finland[5]. In addition, a map of the Espoo region in 1909, provided by the Geological Survey of Finland, was used.

Figure 4 illustrates our scheme. On the left, a satellite Google Maps image of the contemporary Viipuri region is shown. In the middle, a smaller rectangular area is shown with a semi-transparent[6] old Karelian map that is positioned correctly and is of the same scale as the Google Maps image. This smaller view shows the park of Monrepos in Viipuri, a famous Finnish pre-war cultural site that nowadays is a part of Russia. The place cannot be found in current maps as it was, making it difficult for modern users to locate the place geographically. Old maps and names on it could be of substantial benefit when using the visualization in annotating or searching content by maps in systems such as CultureSampo (Hyvönen et al., 2006). The simultaneous views are useful also when comparing geo-information from different eras (e.g., how construction of cities has evolved) or from different thematic perspectives (e.g., viewing a geological map on top of a satellite image).

In order to move around the user is able to use the zooming and navigation functions of Google Maps and the Karelian view is automatically scaled and positioned accordingly. In order to facilitate this, the Karelian maps were processed according to the following steps:

1. Cropping and conceptualization of the map images. The digitized maps had a lot of useful information in addition to the actual maps in the image files. For example, the place name, scale, old coordinates etc. This knowledge was extracted and represented as an ontology. Additional information in the margins of the map images were cropped away.

2. Projection of the images. Projection was done manually by adjusting the images by dragging and stretching them in an image editing program individually using reference points. One could also use a specialized GIS software to do the projection conversion. However, when this was tested, no clear benefits were obtained. For example, relative positional accuracy between the satellite images and the projected map images did not increase remarkably and the process was rather time consuming.

3. Renaming the image files according the Google Maps API specifications.

4. Publishing of the image files on a public web server.

5 Using Points to Explicate a Search Area

Geographic objects are traditionally modeled as points, lines, polygons or fields in spatial databases. Depending on the information a point carries, it can be either an entity point, a label point or an area point.

[5] http://www.maanmittauslaitos.fi /default.asp?site=3
[6] The level of transparency can be altered in the demonstration.

An entity point represents the coordinate position of a point entity such as a tower, a label point carries textual information of the object in question and an area point represents the center point coordinates of a polygon (Zhang and Goodchild, 2002). There has also been discussion (Schlieder et al., 2001) about extending ontologies (gazetteers) with more exact positions like a point or polygon in a given coordinate reference system. For representing areas, polygons would clearly be most satisfying.

However, polygon data is (Schlieder et al., 2001) often 1) proprietary or 2) may be unavailable for e.g. historic regions. Furthermore, 3) detailed polygon data is computationally expensive to process and 4) the exactness of the polygon data should be set to a needed abstraction level. Area points are more widely available. In Finland, names and coordinates are available in the Place Name Register produced by the National Land Survey of Finland.

We have created a method, *n-point search*, for searching this kind of coordinate data. A search query in this method is done by pointing out n points on a map. The user clicks on the map and a polygon is formed, accordingly.

The idea is that the n points define either a simple polygon (without an inner ring) or a complex polygon (with 1...n inner rings) that bounds the search area in question. In other words, the defined polygon can be either complex, concave or convex. If an area point of a certain place is found inside the user-given polygon, it is retrieved and added to the results. Matching places were found using the Jordan Curve Theorem (Haines, 1994).

N-point search would also support the polygon overlays if the regions would be modeled as polygons. This would lead even more precise search results, but in our case such polygon data is not available currently. However, in the future we plan to create polygons and use them as well.

We have also created a special handling for two special cases, namely, for those cases where $n = 1$ or $n = 2$. If $n = 1$ a circle is drawn around the point 1 and the places that are inside the circle are retrieved. An alternative treatment for the $n = 1$ situation would be to find the nearest places. Naturally both of these treatments could be offered for a user. And if $n = 2$, we create a bounding box, where point 1 and point 2 are the opposite corners, e.g. South-West and North-East corners, of the search area.

We have implemented the n-point search as a Google Maps application where Scalable Vector Graphics (SVG) (Ferraiolo et al., 2003) is used for drawing the polygon as an other transparent layer on top of a map. An example of using the n-point search is depicted in figure 5. The n polygon corners are depicted as small crosses. The system has found out three historical communes of the annexed Karelia, Viipuri, Makslahti, and Koivisto, whose center points are situated within the user-specified search polygon.

In the future, we plan to use the idea of user-defined polygons also in ontology population and in annotating contents.

Figure 5: Search results using the n-point search: Viipuri, Koivisto and Makslahti are matched.

6 Combining Visualization with Other Services

Visualizations on the map can be combined interactively with services on the web. In this section it is shown how cultural content can be projected on a map service as interactive elements that can be used to invoke related services, such as search engines.

To test this idea, we have built an application that uses Google Maps API[7] to visualize hundreds of Finnish locations on a zoomable map. User can search information from different portals with location names just by clicking the location on a map.

Figure 6 depicts the idea. On the left pane, a Google Maps view is shown where the red buttons represent Finnish communes and other places of interest. The user has clicked on a button on Helsinki. As a result, the system has queried MuseumFinland (Hyvönen et al., 2005) with the the concept of "Helsinki" as either the place of manufacture or place

[7]http://www.google.com/apis/maps/

Figure 6: A searchable map interlinked with the semantic portal MuseumFinland.

of usage of the artifacts included in the semantic portal. The result is shown on the right pane. In addition, a bubble with several links is opened on the left. The links are search requests to different search engines where the location selected is used as a query parameter.

The search engines engaged in the application include, in addition to the default search engine MuseumFinland, for example Wikipedia[8], Google Images [9], Muisti-project cultural portal[10] and the Old photos service [11] provided by the Geological Survey of Finland.

The search links are created automatically by constructing a search query to the search engines. For example, since the URL's of Wikipedia are simple and permanent, and include the keyword at the end of the URL, the corresponding place name could be used as the keyword. For the capital of Finland, Helsinki, for example, the system guessed that it has a Wiki page *http://en.wikipedia.org/wiki/Helsinki* which happens to be the case. By selecting the link, this page is shown on the right pane instead of the MuseumFinland page. Also an automatic linking to the www-pages of the municipalities in Finland is provided.

However, there are two problems with this approach: First, the automatically constructed link or query may lead to a non-existing page or it might return empty results. For example, some Wikipedia pages may be missing. Nevertheless, this way people can be guided to the corresponding Wikipedia page to contribute their knowledge about places. Second, place names have several meanings that cannot necessarily be disambiguated. For example, "Nokia" is a city in Finland, a telecom company, a person, and an animal in Finnish. Semantic disambiguation could be made, if the services were supporting ontology-based querying based on URIs. For example, when using MuseumFinland this would be possible because the system supports search based on concepts (URIs) in addition to literal keywords.

In the "Geo-MuseumFinland" application of figure 6 places are visualized on the map and used for constructing queries to search engines. We also made a related application for the semantic portal CULTURESAMPO (Hyvönen et al., 2006) where search hits are visualized in the same vein. CULTURESAMPO uses a place ontology that is based on the one used in MuseumFinland and defined in RDF. Language (OWL) (Smith et al., 2004). However, the original place ontology did not have any coordinates. The place ontology was therefore enriched by introducing a *hasCoordinatePoint*-property and by extracting values for these properties from the Place Name Registry obtained from the National Land Survey of Finland. The result is a visualization of the search results on the map. The implementation was done as a Google

[8]http://www.wikipedia.org/
[9]http://images.google.com
[10]http://www.lib.helsinki.fi /memory/etusivue.html
[11]http://www.gtk.fi /palvelut/info/geokuvat/index.php

Maps application where Ajax[12] is used for data interchange of search results between the browser and the server. The figure 7 shows how the search results are visualized as interactive buttons. The user has clicked on a button depicting the hits related to the city of Outokumpu, and a bubble is opened with links to the actual artifacts, in this case two basins ("vati"). By selecting a link, the user will get a more detailed explanation about the item, and semantic recommendations to related materials customary.

Figure 7: Visualization of search results in semantic portal CULTURESAMPO.

7 Conclusions

In this paper we examined how ontological knowledge can be used in order to represent and visualize different kinds of georeferenced data and to enable searches. We proposed and demonstrated explication of complex spatio-temporal relations between geographical objects, search based on spatio-temporal ontologies, query formulation based on maps, and visualization of historical contents on old and contemporary maps.

The systems overviewed will be used when creating geo-based applications and tools within the the National Semantic Web Ontology Project in Finland[13], especially in CULTURESAMPO and in creating a prototype of a national geo-ontology server.

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[12]http://en.wikipedia.org/wiki/AJAX
[13]http://www.seco.tkk.fi /projects/fi nnonto/
[14]http://www.seco.tkk.fi /projects/fi nnonto/

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