

Creating and Using Geospatial Ontology Time Series in a Semantic Cultural Heritage Portal

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Abstract. Content annotations in semantic cultural heritage portals commonly make spatiotemporal references to historical regions and places using names whose meanings are different in different times. For example, historical administrative regions such as countries, municipalities, and cities have been renamed, merged together, split into parts, and annexed or moved to and from other regions. Even if the names of the regions remain the same (e.g., “Germany”), the underlying regions and their relationships to other regions may change (e.g., the regional borders of “Germany” at different times). As a result, representing and finding the right ontological meanings for historical geographical names on the semantic web creates severe problems both when annotating contents and during information retrieval. This paper presents a model for representing the meaning of changing geospatial resources. Our aim is to enable precise annotation with temporal geospatial resources and to enable semantic search and browsing using related names from other historical time periods. A simple model and metadata schema is presented for representing and maintaining geospatial changes from which an explicit time series of temporal part-of ontologies can be created automatically. The model has been applied successfully to represent the complete change history of municipalities in Finland during 1865–2007. The resulting ontology time series is used in the semantic cultural heritage portal CULTURESAMPO to support faceted semantic search of contents and to visualize historical regions on overlaying maps originating from different historical eras.

1 Introduction

Geospatial ontologies define classes and individuals for representing e.g. geographic regions, their properties, and mutual relationships. By sharing ontological resources in different collections and application domains, interoperability in terms of geographical locations can be obtained, and intelligent end-user services such as semantic search, browsing, and visualization be facilitated [9,24,23]. For example, in the semantic portal

MUSEUMFINLAND¹ [10] a location partonomy² was used for annotating museum artifacts with metadata about the place of manufacture and the place of usage.

A lesson learned during this work was that geography changes rapidly, which makes it hard 1) to the content annotator to make correct references to spatiotemporal regions and 2) to the end-user to understand the changes in historical geography and, as a result, to formulate the queries. For example, many artifacts in MUSEUMFINLAND originate from regions that no longer exist and/or have not been a part of Finland but of Russia after the Second World War. Finding the right names for querying, understanding to which regions on the map the names refer to at different times, and understanding how old historical names relate to modern Finnish and Russian geography creates, at the same time, both a semantic challenge for the technology and an important part of useful content to learn when using the portal.

This paper addresses two essential needs from the end-user point of view when using historical geographic regions in a cultural heritage portal:

Ontology-based spatiotemporal search. It is necessary to be able to use both historical and modern regions as search concepts e.g. in a view-based, or multi-facet search [7,20,18,6]. The idea is that regions offer one view to a content and they can be used to select a subset of the content by specifying constraints. For example, selecting “Finland (1945-)” from a facet view would refer to a part of Europe relating to the modern post-war Finland.

Visualization of concepts. It is necessary for the end-user to be able to see where the historical regions are on the map in a proper temporal context. Moreover, there should be a way of visualizing the spatial relationship between the old regions and the modern ones on the maps in order to relate history with the world of today. Creation of several layers of information on maps is a common way to visualize maps [3] and related content at the same time. In our case, we decided to apply this idea to overlaying historical and modern maps to visualize spatiotemporal relationships of regions, and to display related cultural content on the maps. Such map visualizations also help in finding the right concepts for a search and for presenting the search results.

To successfully meet the above needs the following requirements can be set for the ontology creation and management:

1. Concepts representing the regions from different time intervals need to be identified by URIs, put into a valid spatial part-of hierarchy, and mapped with each other in the temporal dimension.
2. Essential geographical properties, such as coordinates of points or polygonal boundaries, time span, size, and names of the historical regions, need to be assigned to the URIs of the regions.

To meet these requirements, it is essential that a geospatial ontology used in a semantic cultural system can represent change in time [15]. In current historical geo-vocabularies

¹ <http://www.museosuomi.fi>

² This partonomy is a part-of hierarchy of individuals of the classes Continent, Country, County, City, Village, Farm, etc.

and ontologies, such as the Getty Thesaurus of Geographic Names (TGN)³, historical regions may be found, but the aspect of change is usually missing. For example, in the TGN the historical city of “Rome” in Italy has an entry as an inhabited place, but its development from an Etruscan city of the 8th century BC to its declination in 330 AD is described only as a piece of literal text.

In this paper, we present a simple metadata schema and a model for representing geospatial changes and for maintaining them as an RDF repository. A method for constructing a time series of geospatial, temporal ontologies (an ontology time series) from the filled metadata schema is discussed, and a reasoning mechanism to infer properties (size), relationships, and mappings between spatiotemporal regions is then presented. To test and evaluate the approach, the system was used in a case study of creating a complete model of the changes of the Finnish municipalities in 1865–2007. Finally, we present how the resulting ontology time series has been applied to creating intelligent services and map-based visualizations in the semantic cultural heritage portal “CULTURESAMPO—Finnish Culture on the Semantic Web”⁴ [12].

2 Modeling Geospatial Changes

2.1 Analysis of Change Types

We analyzed the kinds of regional changes of municipalities in Finland⁵ between years 1865 and 2007. Table 1 lists the change types found and their quantities.

Table 1. Different types of regional changes between 1865 and 2007 in Finland

Change type	Quantity
<i>Establishment (A region is established)</i>	508
<i>Merge (Several regions are merged into one)</i>	144
<i>Split (A region is split to several regions)</i>	94
<i>Namechange (A region changes its name)</i>	33
<i>Changepartof (Annexed (to a different country))</i>	66
<i>Changepartof (Annexed (from a different country))</i>	1
<i>Changepartof (Region moved to another city or municipality)</i>	256
Total sum	1102

An example of a merge is depicted in Figure 1. In the year 1922 Nummi-Pusula was formed via the unification of two former municipalities, Nummi and Pusula. This means that the old notions of Nummi and Pusula became obsolete after 1922, and the new concept of Nummi-Pusula was introduced.

In Figure 2, there is an example of a split. Pirkkala was split into two municipalities, Pohjois-Pirkkala and Etelä-Pirkkala in 1922. In Figure 3 there are two examples of

³ <http://www.getty.edu/research/tools/vocabulary/tgn/>

⁴ <http://www.kulttuurisampo.fi>

⁵ As collected by the Geological Survey of Finland.

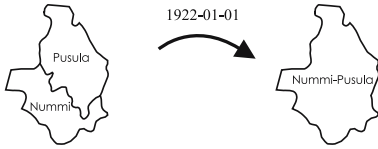


Fig. 1. An example of a merge

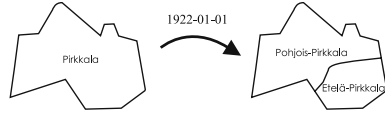


Fig. 2. An example of a split

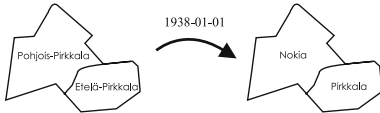


Fig. 3. Two examples of name changes

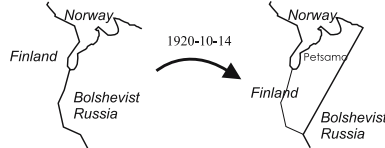


Fig. 4. An example of a change where a part of a region is moved

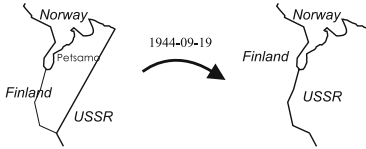


Fig. 5. Another example of a change in a partition hierarchy

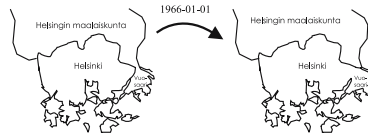


Fig. 6. A third example of a change in a partition hierarchy

name changes. In year 1938 Pohjois-Pirkkala was renamed Nokia. At the same time, its neighbor Etelä-Pirkkala was renamed to Pirkkala. Finally, in Figures 4, 5 and 6 there are three different examples of changes in a partition hierarchy. Figure 4 depicts a change where Petsamo was annexed from Russia to Finland in 1920. Figure 5 depicts a change where Petsamo was annexed from Finland to USSR in year 1944. Finally, Figure 6 depicts a different change: Vuosaari was moved from Helsingin maalaiskunta to the city of Helsinki in year 1966.

These changes always change not only the sizes of the regions in question but also the partition hierarchy. This means that from year 1865⁶ until 2007 there are 142 different kind of partition hierarchies of historical "Finlands".

Modeling all these different 142 temporal partition hierarchies of Finland, the resources and their mutual relationships, as separate ontologies by hand would be hard. Instead, we propose utilization of a simple schema for representing changes, and using an automated process for generating the different partition hierarchies.

2.2 A Schema for Representing and Maintaining Changes

The change types of Table 2 can be represented in terms of a few metadata fields (elements) listed in the Metadata Schema of Changes (see Table 2). An other metadata

⁶ In year 1865 first municipalities were established in Finland.

Table 2. The Metadata Schema of Changes. Cardinalities are presented in the column C

Field	Definition	C	Value range
<i>identifier</i>	Identifier for a change (automatically generated)	1	Change ontology
<i>date</i>	The date of the change	1	W3CDTF (ISO8601) ⁷
<i>place</i>	Place field	1	Location ontology
<i>place type</i>	The type of the place	1	Location ontology
<i>change type</i>	The type of the change	1	Change type ontology (either establishment, merge, split, namechange, or changepart, (see Fig. 1–6))
<i>from</i>	From where there are areas moving to in the change	1..*	Location ontology
<i>to</i>	To where there are areas moving to in the change	1..*	Location ontology
<i>movedpart</i>	Which part(s) are moving in the change (if they can be named) Note: Only used for changepartof	0..*	Location ontology
<i>description</i>	Description of a change	1	String

Table 3. The Metadata Schema of Current Places

Field	Definition	C	Value range
<i>identifier</i>	Identifier for a place	1	Location ontology
<i>place name</i>	Current place ⁸ .	1	Location ontology
<i>size</i>	Size of the place in square kilometers	0..1	Double
<i>partof</i>	Which other administrative region this region is a part of	1	Location ontology
<i>point</i>	Representative point of the place	0..*	ISO 19107, WGS84
<i>polygonal boundaries</i>	Polygonal boundaries of the place	0..*	ISO 19107, WGS84
<i>maps</i>	Maps of the place	0..*	Map ontology

schema, the Metadata Schema of Current Places is meant for maintaining the contemporary places, like cities, municipalities and countries (see Table 3) and the Metadata Schema of Historical Places for properties such as boundaries of historical regions (see Table 4). Note that the last two schemas are very similar and could also be integrated.

Different fields of the Metadata Schema of Changes, such as *place*, *date*, *change type* and *from* and *to*-fields are filled up with the changes and resources they concern. For example, a change concerning the annexing of Petsamo from Finland to USSR on 1944-09-19 has an own instance conforming to the metadata schema, with the corresponding fields filled up (*from*=*Finland*, *to*=*USSR*, *movedpart*=*Petsamo*, *date*=*1944-09-19*, and so on). Notice that for each region modified by a change, a separate instance conforming to the metadata schema is created.

⁸ For an implementation as an XML Schema Date, see <http://www.w3.org/TR/xmlschema-2/>

Table 4. The Metadata Schema of Historical Places

Field	Definition	C	Value range
<i>identifier</i>	Identifier for a place	1	Location ontology
<i>place name</i>	Place name	1..*	Location ontology
<i>size</i>	Size of the place in square kilometers	0..1	Double
<i>partof</i>	Which other administrative region this region is part of	0..1	Location ontology
<i>point</i>	Representative point of the place	0..*	ISO 19107, WGS84
<i>polygonal boundaries</i>	Polygonal boundaries of the place	0..*	ISO 19107, WGS84
<i>measurement date</i>	Date when the properties were valid (e.g. boundaries)	1	W3CDTF (ISO8601)
<i>maps</i>	Maps of the place	0..*	Map ontology

3 Creating an Ontology Time Series and Overlap Mapping

The previous section described three schemas used for creating an ontology time series. An ontology time series [15] defines a set of geospatial ontologies, including partonomy hierarchies for different time spans. This knowledge is represented in terms of RDF triples [1], where a resource (subject) is characterized by an identity (URI) and related property (predicate) values (object) in the form $\langle \textit{subject}, \textit{predicate}, \textit{object} \rangle$.

The following example motivates the creation of different temporal ontologies. Let us assume two RDF triples represented in a table, utilizing the name space *dcterms* of Public Core Metadata Terms⁹ and another namespace *location*:

Subject	Predicate	Object
location:Monrepos	dcterms:isPartOf	location:Vyborg
location:Vyborg	dcterms:isPartOf	location:Russia

These triples could come from an RDF repository containing a traditional partonomy hierarchy that define the fact that the famous park Monrepos is a part of the city called Vyborg which in turn is a part of Russia. This is true for the ontology of the year 2007. However, the two RDF triples

Subject	Predicate	Object
location:Monrepos	dcterms:isPartOf	location:Viipuri
location:Viipuri	dcterms:isPartOf	location:Finland

define the historical fact that Monrepos is a part of Finland—this was true in 1921–1944. As we can see, these two sets of RDF triples would confuse a reasoner and the end-user, because *location : Monrepos* would be a part of two non-intersecting regions *location : Russia* and *location : Finland* (assuming that *dcterms:isPartOf* is transitive).

To overcome this problem, our ontology time series is populated with different *temporal parts* of places which are described by a metadata schema. Examples of temporal

⁸ Present in year 2007 as of writing this paper.

⁹ <http://dublincore.org/documents/dcmi-terms/>

parts of *location:Viipurin mlk* are *location:Viipurin mlk (1869-1905)*, *location:Viipurin mlk (1906-1920)*, *location:Viipurin mlk (1921-1944)* and *location:Vyborg(1944-)*. All these temporal parts have different polygonal boundaries, different sizes, and some of them are also in a different partonomy hierarchy. The ontology population process proceeds in the following way.

First, a place is created in the RDF repository (like *location:Viipurin mlk*). Based on the two sequential changes in the Metadata Schema of Changes for Viipurin mlk, that happened e.g. in 1906 and in 1921, a temporal part *location:Viipurin mlk (1906-1920)* is created and added to the union of ¹⁰ *location:Viipurin mlk*. Similarly, by examining the next two sequential changes concerning the place, additional temporal parts (like *location:Viipurin mlk (1921-1944)*) are created. If there are no more changes for that place, then the place has ceased to exist (like *location:USSR (1944-1991)*) or it is a contemporary one (like *location:Helsinki (1966-)*). Whether the place is a contemporary one is checked from the Metadata Schema of Current Places.

Second, the properties for the temporal parts of places are retrieved from the Metadata Schema of Current Places and from the Metadata Schema of Historical Places, depending whether the place in question is an existing one or has ceased to exist. This phase creates RDF triples representing, for example, the polygonal boundaries, the center point, the size, and partonomical relationships of the temporal part of the place. For example, two different partonomy hierarchies of our previous example of Monrepos is defined by four triplets

Subject	Predicate	Object
<i>location:Monrepos(1921-1944)</i>	<i>dcterms:isPartOf</i>	<i>location:Viipuri(1921-1944)</i>
<i>location:Viipuri(1921-1944)</i>	<i>dcterms:isPartOf</i>	<i>location:Finland(1921-1944)</i>
<i>location:Monrepos(1991-)</i>	<i>dcterms:isPartOf</i>	<i>location:Vyborg(1991-)</i>
<i>location:Vyborg(1991-)</i>	<i>dcterms:isPartOf</i>	<i>location:Russia(1991-)</i>

In addition, there are triples defining that different temporal parts of Monrepos belong to the same union of *location:Monrepos*, and triples defining different properties for temporal parts.

A temporal ontology [15] includes all temporal parts (of places) of some time span. For example, a temporal ontology of the year 1926 would include *location:Viipurin mlk (1921-1944)* because the year 1926 is within the range 1921–1944. Furthermore, the ontology contains all the partonomical relationships of those temporal parts that are valid during its time span.

Next, when all the places, their temporal parts and properties are created in the ontology time series, a model of changes is created based on the fields of the Metadata Schema of Changes. In each change there is something *before* the change (like *location:Viipurin mlk (1869-1905)*) and something *after* the change (like *location:Viipurin mlk (1906-1920)*). This is expressed with properties *before* and *after*. In practice, the following types of RDF triples are added to the repository:

¹⁰ owl:unionOf is used, <http://www.w3.org/TR/owl-guide/>

Subject	Predicate	Object
change:change15	change:before	location:Viipurin mlk(1869-1905)
change:change15	change:after	location:Viipurin mlk(1906-1920)
change:change15	change:after	location:Nuijamaa(1906-1944)
change:change15	change:date	"1906-01-01"
change:change15	change:changetype	change:split

These triples are used as an input for a previously published method [14,15] to create a *global overlap table* between different temporal parts in the ontology time series. This table tells how much each place overlaps with the others. The repository is filled by following kind of triples based on the global overlap table calculation:

Subject	Predicate	Object
overlapping:overlap31	overlapping:overlaps	1.0
overlapping:overlap31	overlapping:overlappedBy	0.3131
overlapping:overlap31	overlapping:argument1	location:Viipurin mlk(1869-1905)
overlapping:overlap31	overlapping:argument2	location:Nuijamaa(1906-1944)

For example, since the size of Nuijamaa (1906-1944) is 407 square kilometers and the size of Viipurin mlk (1869-1905) is 1300 square kilometers, Nuijamaa overlaps Viipurin mlk by value $407/1300 = 0.3131$ and is overlappedBy by Viipurin mlk by value $407/407 = 1.0$ after the split (cf. the example above).

The Figure 7 illustrates the global overlap table by depicting overlaps with colors between a selected set of regions. The black color indicates a full 100% overlap between the temporal parts and the white color a 0% overlapping, accordingly. Different shades of grey indicate the level of overlapping: the darker the box, the greater is the overlap. From this illustration it is easy to see the mutual asymmetric overlaps between the temporal parts, and that the overlap-relation in this case is fairly complicated.

4 Creation of a Finnish Spatio-Temporal Ontology

The metadata schemas and methods described in the previous sections were implemented to create a *Finnish Spatio-temporal Ontology*, an ontology time series of Finnish municipalities over the time interval 1865–2007.

The metadata schemas were implemented as a spreadsheet tables¹¹ for easy editing. Figure 8 shows a screenshot of the Metadata Schema of Changes. Different schema fields, such as *place*, *date*, *change type*, *from*, and *to*, are filled up with resources and values. For example, the split of Viipurin mlk (1869-1905) into Nuijamaa (1906-1944) and Viipurin mlk (1906-1920) is seen on the row 1197, and the annexing of Viipuri from Finland to USSR on 1944-09-19 is on the row 1195. Most changes have a natural language explanation of the event.

The methods for creating an ontology time series from the metadata schemas were implemented using Java and Jena Semantic Web Framework¹² [2]. The resulting RDF

¹¹ We used the freely available OpenOffice Calc (<http://www.openoffice.org/>)

¹² <http://jena.sourceforge.net/>

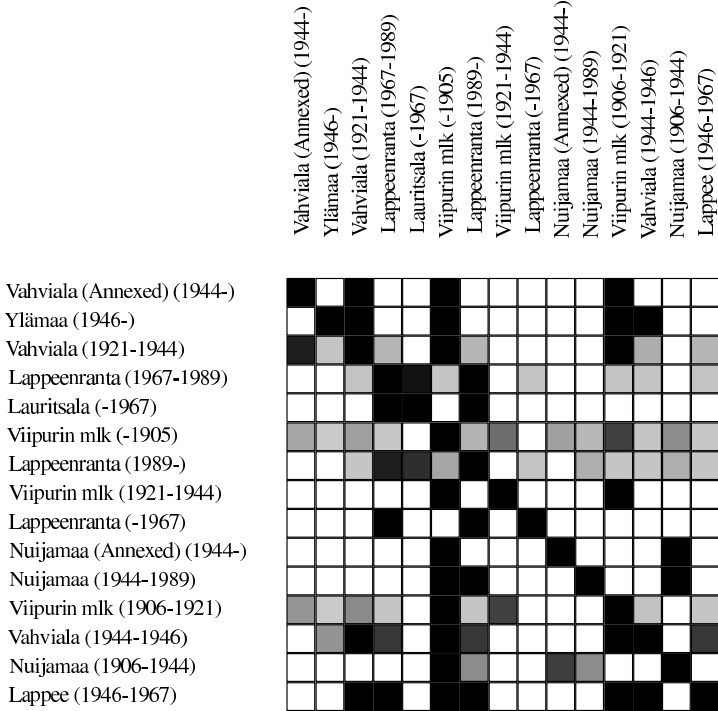


Fig. 7. Overlaps between temporal parts of places visualized using colored boxes. The black color indicates a full 100% overlap between the temporal regions and the white color a 0% overlap, accordingly. Different shades of grey indicate the level of overlap between regions: the darker the box, the greater is the overlap between the regions.

1	Place	Date	Change type	From 1	From 2	Movedpart	To 1	To 2	Description
1194	Viipuri	1403	Establishment				Viipuri		Viipuri sai ke
1195	Viipuri	1944-09-19	Changepart	Finland		Viipuri	USSR		Luovutetuilla
1196	Viipurin mlk	1869	Establishment				Viipurin mlk		
1197	Viipurin mlk	1906	Split	Viipurin mlk			Nuijamaa	Viipurin mlk	Nuijamaa its
1198	Viipurin mlk	1921	Split	Viipurin mlk			Vahviala	Viipurin mlk	
1199	Viipurin mlk	1944-09-19	Changepart	Finland		Viipurin mlk	USSR		Luovutetuilla
1200	Viitasaari	1866	Establishment				Viitasaari		Viitasaari pe
1201	Viitasaari	1934	Changepartof	Viitasaari		Viitasaari: Vuoksenkoski	Kannonkoski		Viitasaarest:
1202	Viljakkala	1874	Establishment				Viljakkala		Perustettu il
1203	Viljakkala	2007	Merge	Viljakkala	Ylöjärvi		Ylöjärvi		Viljakkala yh
1204	Vilppula	1904	Changepartof	Keuruu		Suuri osa Keuruunkylää "osia"	Vilppula		
1205	Vilppula	1904	Changepartof	Ruovesi			Vilppula		
1206	Vilppula	1922	Split	Vilppula			Mänttä	Vilppula	Mänttä erosi

Fig. 8. A set of changes collected as a spreadsheet table

repository contains 1105 different changes and 976 different temporal parts of 616 different historical and modern places, meaning each place has on average 1.58 temporal parts. For example, the place resource *location:Viipurin mlk* got the temporal parts *location:Viipurin mlk (1869-1905)*, *location:Viipurin mlk (1906-1920)*, *Viipurin mlk (1921-1943)*, and *location:Viipurin mlk (1944-)*. The temporal parts and their partonomy hierarchies in the RDF repository constitute 142 different temporal ontologies between the years 1865 and 2007, each of which is a valid model of the country during its own time span.

5 Applications for Spatiotemporal Search and Visualization

Two case applications were created to utilize the resulting ontology time series in real application scenarios. The first one uses partition hierarchies of different time spans in faceted search facilitating ontology-based spatio-temporal search. Both historical and modern regions can be used as search categories. To illustrate this, in Figure 9 two categories corresponding to temporal parts of *location:Helsinki*, namely *location:Helsinki (1966-)* and *location:Helsinki (1640-1946)* are selected in a search facet, and related items from cultural collections are retrieved.

This functionality is included in the semantic CULTURESAMPO portal [12] that currently contains over 32 000 distinct cultural objects. The annotations of the objects were enriched automatically by comparing the time span and place of each annotation with those of the temporal parts of places. If they overlapped and place names matched, then the annotation was enriched accordingly. CULTURESAMPO also allows for searching with places on a map as illustrated in Figure 11. By clicking a place on a map, the items annotated with that place are retrieved and shown on the right side of the map. Furthermore, the user can formulate a search query as a polygon by pointing out n points on a map. All the places that have a point inside that polygon are retrieved and the content related to those places are listed on the right side of the page.

Our second application [13] utilizes the ontology time series in visualizing historical and modern regions on top of maps and satellite images. This answers to the need for visualizing spatiotemporal places: it is necessary for the end-user to be able see where the historical regions are on the map in a proper temporal context. Figure 12 illustrates the application. Historical regions, i.e. temporal parts of places, can be selected from a drop-down menu on the left. Here a temporal part *location:Viipuri(1920-1944)* of *location:Viipuri* is selected. As a result, the polygonal boundaries of Viipuri (1920–1944) are visualized on a contemporary Google Maps satellite image, map, or on a historical map. In addition, modern places from ONKI-Geo [11] that are inside the polygonal boundaries of the historical region are retrieved in a mash-up fashion, and can be used to browse the map. The content related to *location:Viipuri(1920-1944)* is listed in this view on the right. Furthermore, content from historical regions that overlap *location:Viipuri(1920-1944)* are listed as recommendations. The overlappings are looked up from the global overlap table.

Historical maps can be shown on top of the contemporary maps, as depicted in Figure 10. In the middle, a contemporary satellite Google Maps image of the city of Viipuri in the Karelia region is shown. In the middle, a smaller rectangular area

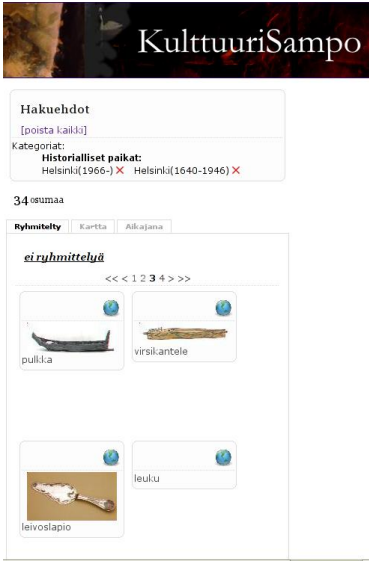


Fig. 9. Temporal parts of places used as a search constraint in CultureSampo

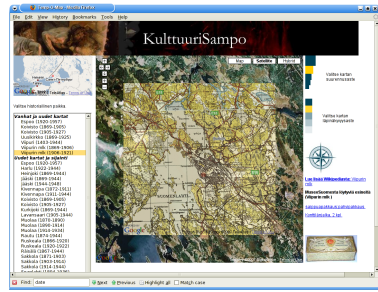


Fig. 10. Using multiple maps simultaneously. A historical Karelian map depicting the city of Viipuri is shown semi-transparently on top of a modern satellite image provided by the Google Maps service. Temporal parts of places on the left can be used to select different maps. The search for cultural artefacts can be constrained in this view by pointing our *n* points on a map.

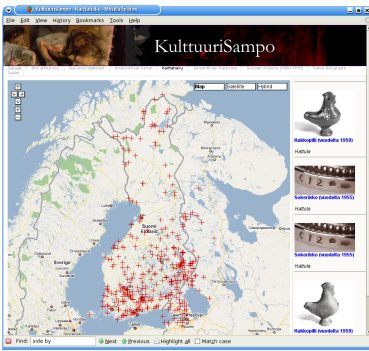


Fig. 11. A search with regions without temporal extensions

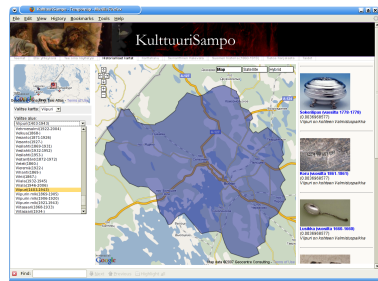


Fig. 12. Temporal parts are used to visualize polygonal boundaries of historical regions in CULTURESAMPO and for searching historical artifacts

is shown with a semi-transparent¹³ old Karelian map that is positioned correctly and is of the same scale as the Google Maps image. This smaller view shows the old Viipuri, an old Finnish city that nowadays is a part of Russia. The place cannot be found in current maps as it was, which makes it difficult for modern users to locate the place geographically. In order to move around the user is able to use the zooming and

¹³ We use transparency libraries provided by <http://www.kokogiak.com/> which allow the alteration of the level of transparency.

navigation functions of Google Maps and the historical view is automatically scaled and positioned accordingly.

To provide the historical maps, we used a set of old Finnish maps from the early 20th century covering the area of the annexed Karelia region before the World War II. The maps were digitized and provided by the National Land Survey of Finland¹⁴. In addition, a geological map of the Espoo City region in 1909, provided by the Geological Survey of Finland¹⁵, was used. This application is also included in the CULTURE-SAMPO portal [12].

6 Conclusions

6.1 Contributions

This paper presented an analysis of change types in historic regions, a model of changes based on the analysis and an ontology time series from the model, and a practical tool for maintaining the RDF repository of changes. We have also successfully applied an existing method [15] to create a global overlap table from the repository of changes. We have evaluated the usability of the resulting ontological structure—the ontology time series—in two real life applications for information retrieval and for visualization in a semantic cultural heritage portal.

These applications can be used for teaching where historic regions have been and how they are related with each other in a partonomy hierarchy. The visualization is made using a rich set of historic maps, modern maps, satellite images, and polygonal boundaries. In addition, the applications can be used for retrieving historical cultural content related to the regions. The relationship is explicated for the user indicating whether the content has been found, used, manufactured, or located in a specific region.

Old maps and names on them could be of substantial benefit when using visualization in annotating or searching content in cultural heritage systems. The idea of using overlaid transparent maps is useful 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). We believe that map-based views of historic locations together with rich, precisely, and spatio-temporally annotated cultural content offer a good use case of semantic web technologies for solving real life interoperability and information retrieval problems.

6.2 Related Work

Traditions in ontology versioning [17] and ontology evolution [19] are interested in finding mappings between different ontology versions, doing ontology refinements and other changes in the conceptualization [16,22], and in reasoning with multi-version ontologies[8]. In ontology mapping research, there have been efforts to do mappings based on probabilistic frameworks [21]. Means for handling inconsistencies between ontology versions [5] have been developed. Methods for modeling temporal RDF have been proposed recently [4].

¹⁴ <http://www.maanmittauslaitos.fi/default.asp?site=3>

¹⁵ <http://en.gtk.fi>

In contrast to these works, our approach is merely about the evolution of ontology time series that is due to changes in the underlying domain. Hence it should not be confused with ontology versioning, database evolution, or ontology evolution even if changes are considered in all of these approaches as well. Each temporal member ontology in a time series is a valid, consistent model of the world within the time span it concerns, and may hence be used correctly in e.g. annotation.

6.3 Future Work

In the future, we would like to investigate whether the methods and tools presented in this paper could be generalized to other domains, where concepts overcome changes affecting their extensions, properties, or positions in ontological hierarchies and structures.

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¹⁶ <http://www.seco.tkk.fi/projects/finnonto/>

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