Chapter 1
Representing and Utilizing Changing Historical Places as an Ontology Time Series

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Abstract Place names and their geographical coverage change in time. This causes problems when retrieving information content related to different times. Geo-content is usually indexed using place names of the time of indexing (e.g. a photo of the 1968 upraise of Czechoslovakia indexed then) or of the time that the content has been used or created (e.g. a spear used in the Punic Wars in 146 BC in Carthago but indexed at a later time using place names of that time). Finally, end-users may query content in terms of contemporary place names (e.g. Check Republic or Slovakia) or overlapping historic names of different times (e.g. Roman Empire). This chapter presents an ontology-based approach to this problem. The idea is to represent and maintain a time series of spatial ontologies in terms of easily manageable local spatio-temporal changes from which the actual time series ontology can be generated automatically with semantic enrichment. This ontology can then be used for indexing and for mapping spatio-temporal regions and their names onto each other. As a proof-of-concept, the system has been applied to modeling the history municipalities of Finland in 1865–2010. We present the model, a tool for maintaining the change history in a user-friendly way, transformation of the place change history into an ontology time series with semantic enrichment, and publication of the ontology as a ready to use ontology services on the web with AJAX, Web Service, and REST interfaces. The system has been applied in the semantic cultural heritage portal CultureSampo for semantic search and recommendation, as well

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as an external service for indexing cultural heritage content, and for query expansion search in a legacy cultural heritage database system.

1.1 Introduction

Metadata on the Semantic Web is based on referencing to concepts of ontologies [26, 34]. There are lots of databases and repositories available for current places, such as GeoNames[1]. Dealing with historical geographical content adds the temporal dimension and notion of change to geographic information systems (GIS). For example, a reference to “Germany” or “the U.S.” may refer to different regions (e.g. Germany in 1943 vs. 1968), depending on the time of reference.

There are vocabularies and ontologies describing historical places, such as the Thesaurus of Geographical Names (TGN)[2]. From a geographical viewpoint, such vocabularies typically tell the part-of hierarchy of places, and a coordinate point of the place or its polygonal area, various metadata for human users, and an identifier for referencing the concept. For example, in TGN the entry for the city ’New York’ list its various names, such as ’New Amsterdam’ and ’Big Apple’, tells its hierarchic position in the U.S. (e.g. that it belongs to the state of New York) and additional larger regions, place types (e.g. city, port, national capital in 1778, etc.) and references to literal and other sources explaining e.g. the alternative names, such as ’New Amsterdam’ (historical place) in more detail.

1.1.1 Limitations of Historical Geo-vocabularies

If content is annotated with a current or a historical place name and queried with the same name, stored content can be found. However, names have multiple meanings (e.g. Paris in France vs. Paris in Texas) and places can be annotated and referred to using geographically overlapping concepts with different names. In a time perspective, a region R can be referred to in principle by any region name at different granularity levels that has at some point of time overlapped R. For example, Helsinki in Finland, can be referred to by any regional boundaries of the city since its establishment in 1550, by the various incarnations of the neighboring regions annexed to Helsinki, by different regions of Sweden before the Napoleonic wars, by Russian regions in the 19th century, by regions of independent Finland since 1917, and by EU nomenclature since 1995. A simple approach used e.g. in TGN is to associate names with alternative names, but this is problematic when the same area or its part can be referred to by *different* overlapping places. A part-of hierarchy eases the pain w.r.t. regions and subregions, but even then there is the problem that the hierarchy

[1] http://geonames.org/

[2] http://www.getty.edu/research/conducting_research/vocabularies/tgn/

is time dependent. For example, New Amsterdam has been part of the Netherlands, but is used as an alternative name for contemporary New York in TGN. The city was renamed 'New York' only in 1664 by the Duke of York under the British rule. Also many other relations of regions change in time. For example, New York used to be the capital of the U.S. but is not any more.

For a more accurate and machine interpretable representation of historical places, the notion of a spatio-temporal named region during a period of time is need. Relating such regions or places ontologically with each other is needed in information retrieval, because the end-user may not use the same place names in search queries that are used in annotations, but only related place names. More generally, ontological, topological and other relations between historical places are needed in order to link semantically related content with each other in applications, such as recommending systems and semantic portals of cultural heritage [16].

1.1.2 Research Questions

From the perspective of the Semantic Web, this need creates new research questions, such as:

- **Spatio-temporal ontology models** How to represent geo-ontologies of spatio-temporal places that change in time?
- **Spatio-temporal ontology maintenance** How to maintain spatio-temporal ontologies that change in time?
- **Annotation support** How to support content creation using such ontologies, so that correct references to places in time can be made?
- **Application** How to utilize such spatio-temporal ontologies in applications for e.g. querying, recommending, content aggregation, and visualization?

1.1.3 Chapter Outline

In this chapter an approach is presented addressing these research questions. We first formulate a model for representing spatio-temporal regions as an ontology time series. We present methods for creating such ontologies based on geographical changes and incomplete data—a typical situation when dealing with historical places. This part of the chapter is based on and presents an overview of a series of papers published by the authors earlier, especially [23, 25], with some extensions. In particular, we emphasize aspects related to creating historical geo-ontologies based on incomplete knowledge. After this an ontology service is presented by which the ontology can be published easily and used in external legacy systems and applications as a service [39]. Two applications of the ontology are discussed: a semantic portal for cultural heritage [18] and a query expansion service [40] attached to a legacy application on the web.

The work is part of the national FinnONTO project (2003–2012)[3] aiming a building a national semantic web infrastructure [19].

1.2 A Model for Spatio-temporal Ontology Time Series

Major goals and motivations for developing the spatio-temporal ontology model are:

1. **Accurate annotations.** Facilitate more accurate content descriptions in metadata using spatio-temporal regions.
2. **Semantic search.** Facilitate search by query or document expansion in applications, based on spatio-temporal relations.
3. **Semantic linking.** Facilitate finding and aggregating related content in applications, based on spatio-temporal relations.
4. **Semantic enrichment.** Facilitate enriching of the ontology automatically by reasoning. A human developer does not need to describe everything explicitly in the ontology, but part of the properties and relations can be created by the machine based on the semantics.
5. **Visualization.** Facilitate using ontological structures in user interfaces, e.g. the part of hierarchy at different times.

To achieve these goals, spatio-temporal regions and their collections are used as annotation concepts with persistent URIs, and are defined and related to each other by a time series of ontologies. We focus on representing *spatio-temporal regions* (STR). “Region” is a commonly used geographic term in different branches of geography. Regions can be defined based on various features and include e.g., political, religious, natural resource, and historical regions[4].

Regions of different kinds can be characterized from a spatio-temporal point of view by the following core properties: name, time span, size, and polygonal area. Regions can be related with other by topological relations [5], such as

1. the part-of relation defining hierarchies,
2. overlap relation telling how much regions overlap, and
3. other relations, such as neighbor-of, near-by etc.

These relations are potentially useful in query expansion [20, 3] and in semantic linking on a spatial dimension. For example, when searching for castles in Europe, it makes sense to return castles in different countries that are part of Europe. However, from an IR query expansion point of view, it is not always clear when the relations can be used. For example, when querying documents about the EU, one probably is not so interested in documents about the member states but documents about the EU as a whole. Here recall is enhanced but at the cost of precision. In this chapter

[3] http://www.seco.tkk.fi/projects/finnonto/

[4] http://en.wikipedia.org/wiki/Region

we assume that the ontology is applied wisely in situations where utilizing a relation matches the needs of the application case.

In below, our spatio-temporal ontology model is first outlined, and after this the problem of creating it from partial geographical data available.

1.2.1 A Model of Ontology Time Series

A major reasoning task in our ontology model is to compute the overlap relation between the regions in an ontology. This relation is represented by the properties *overlaps* (covers) and its reverse *overlappedBy* (coveredBy). Assume that the area of a region A is 100, the area of B is 200, and that the shared common area C of A and B is 50. Then A overlaps B by C/B=0.25 and B overlaps A by C/A=0.5. If a query uses the concept A that overlaps B, then content annotated using B could be returned and the hits can be sorted in the order of relevance based on the degree of overlap (here 0.25). On a temporal dimension, regions can be related through the overlap of their co-existence in time.

In an ideal situation, the polygons of the regions in an ontology are known. Then the overlap relation between all pairs of regions can be computed straightforwardly. Furthermore, based on polygons of regions, additional topological relations, such as neighbor-of, east-of etc. can be reasoned/computed, and the ontology be enriched. However, a key problem here in practice is that polygon data is not always available, which is especially common when dealing with historical places. In many cases the polygon of a region may not even be known or its boundaries are uncertain. Then one has to start ontology creation from what data is available, enrich the knowledge by whatever means are available, and be content with a final partial model, too. A major benefit of using ontologies for representing spatio-temporal regions is that semantics enable automatic enrichment of human input knowledge, saving time and money in content creation, and facilitating implementation of more "intelligent" applications.

The central concept in our ontology model is the STR. It has three core properties: 1) a name by which the region is referred to, 2) a bounded geographical polygonal area, and 3) a time interval that the region with the name existed without change w.r.t. name and time. Each spatio-temporal region has an identity of its own and is labeled as: $placename(begin, end)$. For example, 'Helsinki(1931-1945)' refers to the region of Helsinki from 1931 to 1945. Depending on the application, an STR has additional spatio-temporal properties and semantic relations with other spatio-temporal regions, such as size, part-of, neighbor-of etc., and domain specific properties, such as population, main religion, natural resource type, etc.,

A collection of spatio-temporal regions with the same place name can constitute a *spatio-temporal spaceworm* that essentially defines a region over time. For example, the city of 'Helsinki' as an administrative area can be defined as a spaceworm defined by its constituents: 'Helsinki(1550-1639)', 'Helsinki(1640-1642)', 'Helsinki(16431905)', 'Helsinki(1906-1911)', 'Helsinki(1912-1926)', 'Helsinki(1927-1930)', 'Helsinki(1931-1945)', 'Helsinki(1946-1965)', 'Helsinki(1966-2008)', and 'Helsinki(2009-)'. The region of Helsinki is defined by the union of these STRs.

The ontology in our model is essentially defined as a set of STRs and space-worms. At each moment t the world consists of the regions $\{placename(x,y)|x \leq t \leq y\}$. Therefore, at any point in time t when a region change takes place, i.e. when at least one STR is created ($placename(t,x)$) or vanishes ($placename(x,t)$), a different new set of STRs defines a *period ontology O* describing the world until the next change.

A period ontology is characterized by the properties of its regions. The relations between the regions that can be defined according to the application needs. In our case ontology for the Finnish historical municipalities (to be presented later), for example, we represent countries, provinces, and municipalities as STRs. A country is divided exhaustively into a set of provinces, and each province into a set municipalities using the hierarchic part-of relation.

The temporal sequence of period ontologies defines an ontology time series. It is intuitively a sequence of partonomies. Each period ontology is valid between two nearest subsequent changes. However, STRs in the partonomies are related with each other globally by the overlap relation. If two regions do not overlap, the degree of overlap is 0, a value in (0,1) is used if they share area, and value 1 means a total coverage.

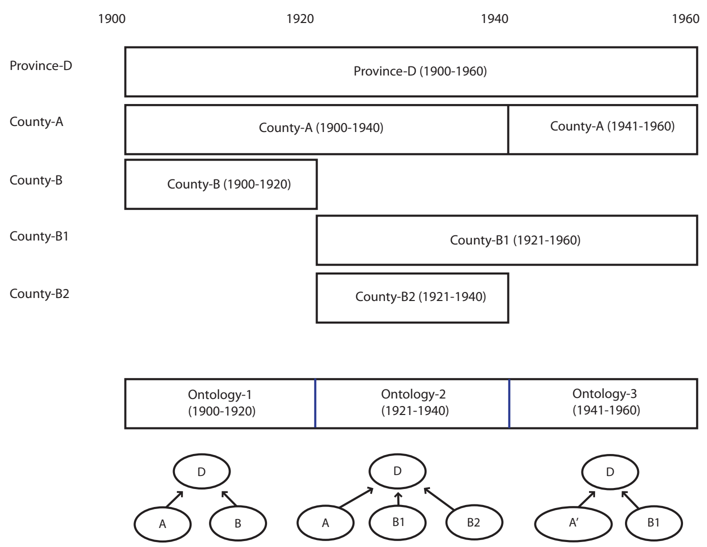


Fig. 1.1 Example of an ontology time series based on two regional changes.

For example, Fig. 1.1 depicts a situation, where a province D that consists of two counties A and B is established at 1900. County B is split into two counties B1 and B2 on January 1 in 1921, and on January 1 in 1941 county B2 is merged into A. The spaceworms of the provinces and the counties involved are depicted as horizontal boxes in a row stretching over time. For example, spaceworm A has two constituents. The graph tells the following story: County B vanishes as a result of a split into counties B1 and B2 in 1921. In 1941, B2 vanishes, because it is merged into A. At this point a new constituent is created for A because of the change in the area of the region A, but the new incarnation 'County-A (1941-1960)' is still a member of the spaceworm of County-A because B2 merges into A without changing the name of A. In the lower part of the figure, the part-of hierarchy of each period ontology is visualized as an ontology time series. Here shorthand node labels A, B, B1, and B2 refer to the corresponding STRs above, and A' to 'County-A (1941-1960)' that includes the region of B2.

The ontology time series is used for annotating content by spatio-temporal regions, when dealing with temporal materials. For example, a film about Helsinki during the Winter War in 1939 would be annotated by the resource 'Helsinki(1931-1945)'. When a generic reference to a region is made without considering the time dimension, the spaceworm resource can be used, e.g. when annotating a book about Helsinki at different times. The major benefit of using the ontology is that resources in annotations are now more accurate (e.g., modern Helsinki covers a much wider area than the historical versions of Helsinki), they can be associated with time, and they can be related with each other through the part-of, overlap and other relations. This facilitates query expansion and semantic linking of regions even if their names are different.

1.2.2 Enriching the Ontology

A major benefit of the model outlined above is that the ontology can be enriched semantically using reasoning. This can be especially useful when only partial or inexact knowledge about places is available, which is typical when dealing with historical data. Uncertainty may be related to any core property of an STR: name, area, and time. In the following, we focus on the problem of dealing with incomplete information about the polygonal areas and spatial relations of STRs. For representing uncertainty in names, properties such as skos:altLabel or skos:hiddenLabel of the SKOS vocabulary standard[5] can be used. A way to represent uncertainty in interval end-points is to use four-point intervals, as suggested e.g. in the CIDOC-CRM standard[6].

If historical documents do not specify the geographical boundaries of a region, qualitative information about spatial changes may still be available. In our case study

[5] http://www.w3.org/2004/02/skos/
[6] http://www.cidoc-crm.org/

[25], for example, polygons of older incarnations of municipalities were not available (or digitization was not possible), but usually the sizes of the areas (in km^2) and change events, such as emergence of a new county by merging two old ones at a certain year, were known. We therefore postulated that a spatio-temporal ontology, as described above, has to be created based on several datasets that may be more or less complete when starting ontology creation:

1. Repository of regions (R) defining the name, type, size, and time interval of STRs, and application specific features.
2. Repository of regional changes (RC): explicit information about how regions e.g. are established, vanish, split, and merged.
3. Repository of polygons of regions (PR): the coverage of STRs.
4. Repository of topological relations between STRs (TR): additional relations between STRs, as needed in applications.

The final RDF ontology consists of an union of these components enriched by additional triples generated by reasoning. Let us assume that R is fully specified. Then the ontology can be enriched as follows:

1. Time series. Based on R, the ontology time series can be generated by splitting the time line at each STR interval limit, and collecting overlapping STRs into period ontologies.
2. Based on RC and PR, additional polygons in PR can be generated. For example, the polygon of a merged STR is the union of the polygons of its constituents.
3. Based on RC and PR, topological relations can be generated.

As an example of generating topological relations in this framework, [23] presents a method for determining the overlap relation between STRs based on R and RC. The result is basically a *regions* $\times$ *regions* matrix defining the degree of overlap relation between all pairs of regions: given a region its overlaps w.r.t. other region can be read from the corresponding row in the table instantly. The relation was can be populated into the RDF base as a set of *overlaps* property triples, or its inverse *overlappedBy*.

	D	A	A’	B	B1	B2
D=100	1	1	1	1	1	1
A=40	40/100	1	40/60	0	0	0
A’=60	60/100	40/60	1	20/60	0	1
B=60	60/100	0	20/60	1	1	1
B1=40	40/100	0	0	40/60	1	0
B2=20	20/100	0	20/60	20/60	0	1

Fig. 1.2 Overlap relation based on the changes of the ontology of Fig. 1.1, and known areas of the regions listed in the leftmost column. A’ refers to County-A after the merge.

For example, given the RC illustrated in Fig. 1.1, the overlap table of Fig. 1.2 can be computed. On the leftmost column the areas of the STRs in Fig. 1.1 are given. For example, since B (area 60) is split into B1 (40) and B2 (20), B2 overlaps B by their shared area, i.e. by 20/60=1/3.

1.3 Case Study: Historical Finnish Municipalities

The model and methods described in the previous sections were applied to create the Finnish Spatio-temporal Ontology SAPO[7], an ontology time series of Finnish municipalities over the time interval 1865–2007 [25]. Also since 2007, the model has been kept in concordance with later changes of administrational regions and municipalities in Finland. Most Finnish municipalities have overcome some kind of areal changes, many of them several times after their establishment. Figure 1.3 shows in dark color municipalities that haven't had any changes since 1865 [24].

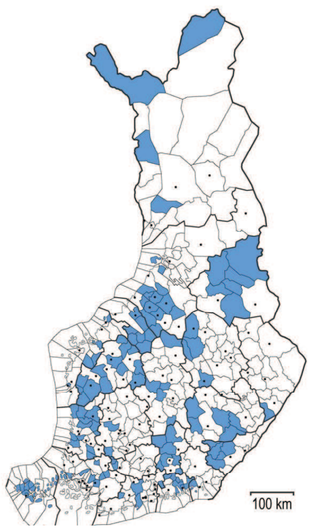


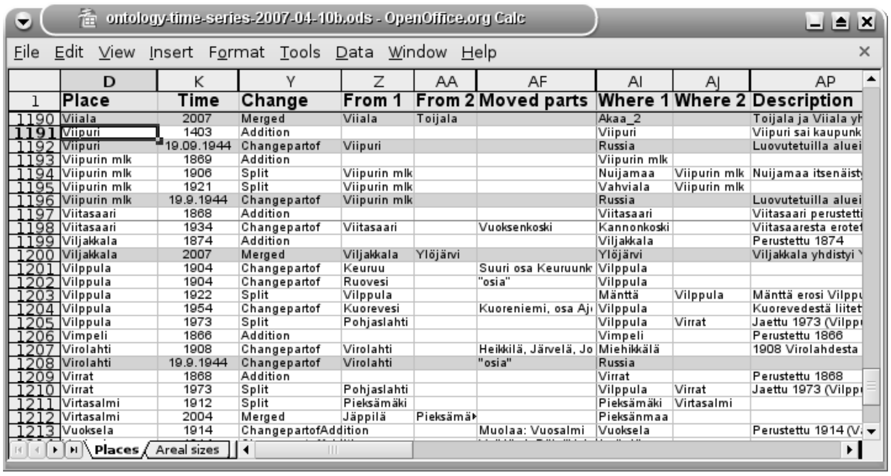
Fig. 1.3 Regional changes are common in Finland: dark color indicates municipalities whose name or area has not changed since 1865. Courtesy of the National Land Survey of Finland.

SAPO is an instance of the general problem of modeling boundary changes of provinces, municipalities, and other regions in different countries. For example in

[7] http://www.seco.tkk.fi/ontologies/sapo/

Japan the number of municipalities has declined from about 71,000 in 1889, to about 1,700 in 2008 [2]. During this period many old municipal names were dissolved, and various new names were generated. In Japan, from the year 1999 until 2008, a total of 598 municipalities were formed by merging existing ones, out of which 330 kept their existing names and 268 got new names.

1.3.1 Developing the Ontology



	D	K	Y	Z	AA	AF	AI	AJ	AP
1	Place	Time	Change	From 1	From 2	Moved parts	Where 1	Where 2	Description
1190	Viiala	2007	Merged	Viiala	Toijala		Akaa_2		Toijala ja Viiala yh
1191	Viipuri	1403	Addition				Viipuri		Viipuri sai kaupunk
1192	Viipuri	19.09.1944	Changepartof	Viipuri			Russia		Luovutetuilla aluei
1193	Viipurin mlk	1869	Addition				Viipurin mlk		
1194	Viipurin mlk	1906	Split	Viipurin mlk			Nuijamaa	Viipurin mlk	Nuijamaa itsenäisty
1195	Viipurin mlk	1921	Split	Viipurin mlk			Vahviala	Viipurin mlk	
1196	Viipurin mlk	19.9.1944	Changepartof	Viipurin mlk			Russia		Luovutetuilla aluei
1197	Viitasaari	1868	Addition				Viitasaari		Viitasaari perustetti
1198	Viitasaari	1934	Changepartof	Viitasaari		Vuoksenkoski	Kannonkoski		Viitasaaresta erotet
1199	Viljakkala	1874	Addition				Viljakkala		Perustettu 1874
1200	Viljakkala	2007	Merged	Viljakkala	Ylöjärvi		Ylöjärvi		Viljakkala yhdistyi Y
1201	Vilppula	1904	Changepartof	Keuruu		Suuri osa Keuruunk	Vilppula		
1202	Vilppula	1904	Changepartof	Ruovesi		"osia"	Vilppula		
1203	Vilppula	1922	Split	Vilppula			Mänttä	Vilppula	Mänttä erosi Vilppu
1204	Vilppula	1954	Changepartof	Kuorevesi		Kuoreniemi, osa Aj	Vilppula		Kuorevedestä liitet
1205	Vilppula	1973	Split	Pohjaslahti			Vilppula	Virrat	Jaettu 1973 (Vilpp
1206	Vimpeli	1866	Addition				Vimpeli		Perustettu 1866
1207	Virolahti	1908	Changepartof	Virolahti		Heikkilä, Järvelä, Jo	Miehikkälä		1908 Virolahdesta
1208	Virolahti	19.9.1944	Changepartof	Virolahti		"osia"	Russia		
1209	Virrat	1868	Addition				Virrat		Perustettu 1868
1210	Virrat	1973	Split	Pohjaslahti			Vilppula	Virrat	Jaettu 1973 (Vilpp
1211	Virtasalmi	1912	Split	Pieksämäki			Pieksämäki	Virtasalmi	
1212	Virtasalmi	2004	Merged	Jäppilä	Pieksämä		Pieksänmaa		
1213	Vuoksela	1914	ChangepartofAddition			Muolaa: Vuosalmi	Vuoksela		Perustettu 1914 (V

Fig. 1.4 Maintaining SAPO-ontology as a spreadsheet table.

In our case, the information available in the outset was lists of municipalities at different times telling e.g. the areas of the regions, to which province they belonged, and how new municipalities were formed or old ones were changed. For example, it may be known that a new municipality was formed by merging two old ones together. Based on research on old geographical books, lists, and other data, the first version of the repository of regions R and regional changes RC could be created.

In RC seven fundamental change types were identified. Table 1.1 lists them as well as the counts of change instances in our dataset (in 2007):

Initially no polygons were available for calculating the overlaps. However, the sizes of the STRs were known as well as local changes, which made it possible to compute the global overlap relation using the model and methods discussed above.

Region polygons (RP) were not available and therefore not used in determining the overlap relation. However, polygons for contemporary municipalities were later acquired from the National Land Survey of Finland, and in old maps geographical boundaries of some areas could be seen at certain time points. To enrich the on-

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

Table 1.1 Different types of regional changes of municipalities between 1865 and 2007 in Finland.

tology, polygons for two historical period ontologies were digitized by hand based on old maps. Based on these polygons and the change history, additional polygons could be computed by a set of reasoning rules. After this, the time series was published as a service using the ONKI ontology service [41]. A large amount of content in the final published ontology has not been created by a human ontologist but by the machine, based on the semantics of the ontology.

1.3.2 Content Creation Process

An easy to use way to encode the information about regional changes (RC) was to create a spreadsheet, where each row represents a spatio-temporal change. The columns represent the properties of the changes, such as the type of the change, time, and regions involved, implementing the metadata schema for regional changes. Figure 1.4 shows a screenshot of the metadata of changes. Different schema fields, such as ’Place’, ’Date’,’Change’ (type), and ’Moved parts’, are represented as columns, and are filled up with unique references to resources or with other values. STRs are referred to by their names (including the time interval). For example, the split of ’Viipurin mlk (1869-1905)’ into ’Nuijamaa (1906-1944)’ and ’Viipurin mlk (1906-1920)’ is seen on the row 1194, and the annexing of ’Viipurin mlk’ from Finland to Russia on 1944-09-19 is on the row 1196. Most changes have also a natural language explanation of the event for human users.

The process from the spreadsheet, maintained by a human cataloger, to the publication of the ontology time series proceeds in the following steps:

1. The spreadsheet is saved in CSV format.
2. A script transforms the CSV form into RDF.
3. Overlap relations of spatio-temporal regions are computed as explained above, and represented as properties of the regions.
4. Additional information concerning the metadata can be added to the knowledge base, such as boundaries of regions as polygons at certain points of time.

5. The ontology is enriched further by reasoning new polygons based on known polygons and the change history.
6. The ontology is enriched further by reasoning additional topological relations between the STRs, e.g. that two municipalities are neighbors.
7. The ontology time series is generated from the change history, one period ontology for each two subsequent changes.
8. The time series is published using ONKI ontology service (to be explained in more detail below).

The methods for enriching and creating an ontology time series from the spreadsheet CSV metadata were implemented using Java and Jena Semantic Web Framework[8]. The resulting RDF repository contains 1105 different changes and 976 different STRs of 616 different historical and modern places (spaceworm), meaning that each place has on average 1.58 temporal parts. For example, the spaceworm resource 'Viipurin mlk' includes the STRs 'Viipurin mlk (1869-1905)', 'Viipurin mlk (1906-1920)', 'Viipurin mlk (1921-1943)', and 'Viipurin mlk (1944-)'. The temporal parts and their partonomy hierarchies in the RDF repository constitute 142 different temporal period ontologies between the years 1865 and 2007, each of which is a valid model of the country during its own time span.

1.4 Publishing the Ontology as an ONKI Service

The ONKI Ontology Service [41] is a general ontology library that acts as a publishing channel for ontologies and provides functionalities for accessing them using ready-to-use web widgets as well as APIs for both humans and machines. ONKI supports services such as content indexing, concept disambiguation, searching, and (URI) fetching. The service is based on ontology and domain specific implementations of ONKI servers which conform to the ONKI application interface [42]. This means that it is possible to provide a single web widget to access all ontologies, and at the same time, provide domain-specific user interfaces and technical implementations optimized for ontologies of different sizes, modeling languages and principles.

ONKI SKOS [39] is an ontology server supporting thesaurus-like ontologies especially in content indexing. ONKI SKOS can be used to browse, search and visualize any vocabulary conforming to the SKOS recommendation, and also RDF(S) and OWL ontologies with additional configuration. ONKI SKOS does simple reasoning, e.g. transitive closure over class and part-of hierarchies. The implementation has been tested using various ontologies, such as the Finnish Spatio-temporal Ontology SAPO.

ONKI SKOS Browser (see Figure 1.5) is the graphical user interface of the ONKI SKOS server. It consists of three main components: 1) *concept search with semantic autocompletion*, 2) *concept hierarchy* and 3) *concept properties*. When typing text to the search field, a query is performed to match the concepts' labels. The result

[8] http://jena.sourceforge.net/

list shows the matching concepts, which can be selected for further examination. The search can be further narrowed by restricting the search to concepts of a certain type or to a desired subtree of the ontology. When a concept is selected, its concept hierarchy is visualized as a tree structure, and its properties are shown as a table.

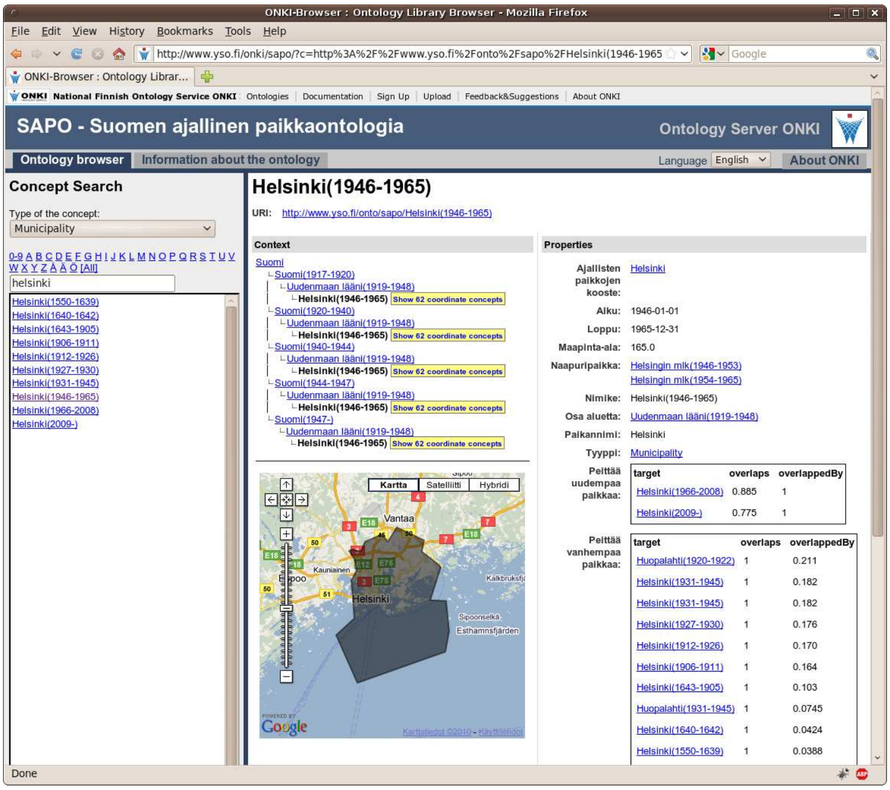


Fig. 1.5 Browsing SAPO with the ONKI SKOS Browser.

In Fig. 1.5 user has searched all the temporal municipalities whose name starts with a string “helsinki”, referring the the spaceworm ’Helsinki’. Matching STRs are shown, after each input character, as a list of choices on the left. In this case, the user has already selected the STR ’Helsinki(1946-1965)’ for inspection and visualization. The part-of relations of the STR are shown as a hierarchy tree on the right— ’Helsinki(1946-1965)’ is part of the province ’Uudenmaan lääni(1919-1948)’, which is part of several spatio-temporal incarnations of the country Finland. The geographical region of the place is shown as a polygon on a Google Maps[9] view. On the right hand side, neighbouring and overlapping municipalities are shown. For

[9] http://maps.google.com/

example, ’Helsinki(1946-1965)’ overlaps ’Huopalahti(1920-1922)’ with a weight 1, since Huopalahti has been annexed to Helsinki.

The ONKI Ontology Services can be integrated as mash-ups into applications on the user interface level (in HTML) by utilizing the ONKI Selector, a lightweight web widget providing functionalities for accessing ontologies, e.g., for content annotation purposes. The ONKI Selector depicted in Fig. 1.6 can be used to search and browse ontologies, fetch URI references and labels of desired concepts, and to store them in a concept collector in HTML code. The selector, depicted in Part 1 of the figure, is an extended input field. It consists of the following components that can be configured of left out depending on the application case: ’Ontology selector’ (on the right) for selecting an ontology (or several ones),’Search field’ for finding concepts using autocompletion, ’Language selector’ for multi-lingual ontologies, and ’Open ONKI Browser button’, by which the ONKI Browser (Fig. 1.5) can be opened for concept input. Part 2 of the figure illustrates using the autocompletion facility, and in Part 3, a concept selection has been made, and the concept is seen above the selector in the Concept collector. It can be removed from there by pushing the remove button [$\times$], or edited using the ONKI Browser by pushing the link ’change’.

When the desired concepts have been selected with the ONKI Selector they can be stored into, e.g., the database of the application by using an HTML form. Either the URIs or the labels of the concepts can be transferred into the application providing support for the Semantic Web and legacy applications. For browsing the context of the concepts in ontologies, the ONKI SKOS Browser can be opened by pressing a button. Once suitable concepts are found, they can be fetched from the browser to the application.

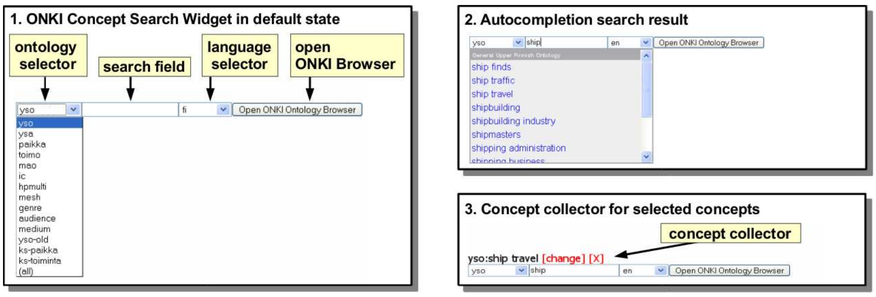


Fig. 1.6 Using the ONKI Selector.

ONKI Ontology Service provides for machine usage APIs which can be used for, e.g., querying for concepts by label matching, getting properties of a concepts, and getting metadata about an ontology. The ONKI API has been implemented in three ways: as an AJAX service, as a Web Service, and a simple HTTP API.

1.5 Applications

1.5.1 CultureSampo

SAPO ontology is in use in the semantic portal “CULTURESAMPO—Finnish Culture on the Semantic Web 2.0”[10] [18] that contains hundreds of thousands of cultural heritage content items of different kinds from different organizations and the public. The systems uses SAPO ontology for providing the end-user with following functionalities:

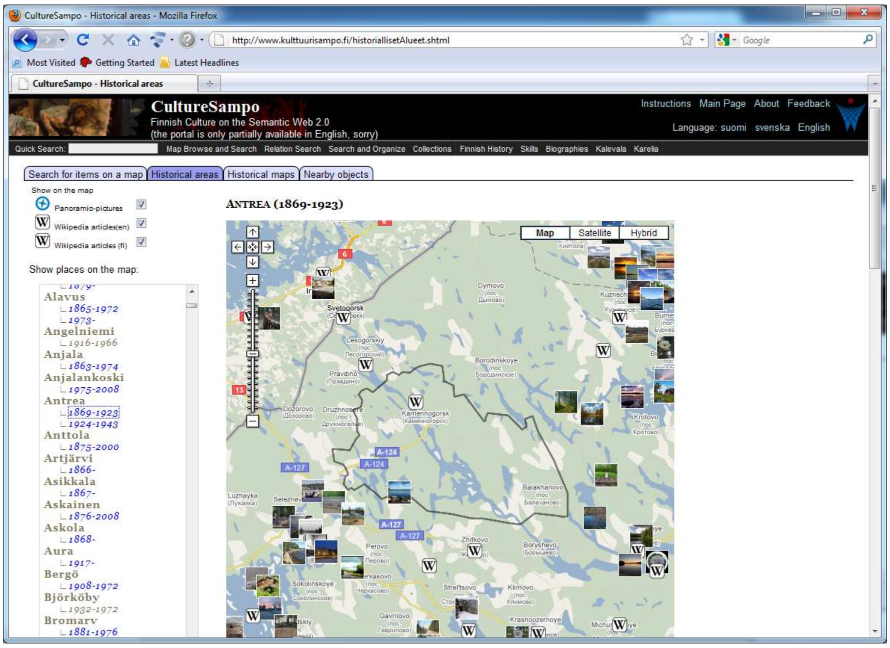


Fig. 1.7 The user has selected historical ’Antrea (1869-1923)’ on the left, and the area is shown on the map with articles from Wikipedia and photos from Panoramio.

1. Old places are of interest of their own—just knowing where and when they existed is already valuable. In CULTURESAMPO, old places of SAPO can be found as an index; by clicking on a name, the area is shown on a map with other content. For example, in Fig. 1.7 the user has selected the historical municipality of ’Antrea (1869-1923)’ in the index on the left, and the system shows its boundaries on the map.

[10] http://www.kulttuurisampo.fi/

2. Information based on coordinates can be associated with regions by showing them simply on a map, as customary in traditional Google Maps applications. In Fig. 1.7, links to contemporary datasets are provided on maps, in this case Wikipedia articles and Panoramio[11] photos related to the area. In CULTURESAMPO also modern places that are inside the polygonal boundaries of the historical region can be retrieved, and can be used to browse the map (this feature is not seen in the figure). For modern places the ONKI-Geo [17] ontology service is used.

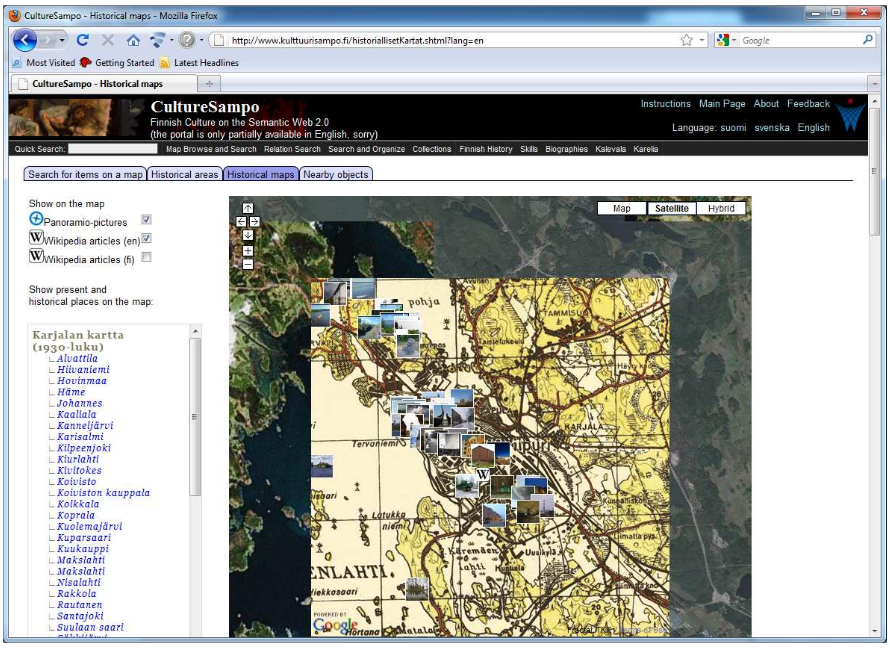


Fig. 1.8 Old maps overlayed transparently over contemporary maps and satellite images show historical changes.

3. STRs can be used as a basis for semantic recommending, based on the metadata such as time and topological relations. In Fig. 1.8, the user has selected to view the STR 'Viipuri(1920-1944)'. The system shows content related to it through semantic associations, including folk poems, music, artifacts, paintings etc. Fig. 1.9 shown these recommendations as symbol links; these recommendations can be found in the view of Fig. 1.8 under the map (scrolling down is needed). Also content from historical regions that overlap 'Viipuri(1920-1944)' are listed as recommendations. The overlaps are based the global overlap table derived from

[11] http://www.panoramio.com/

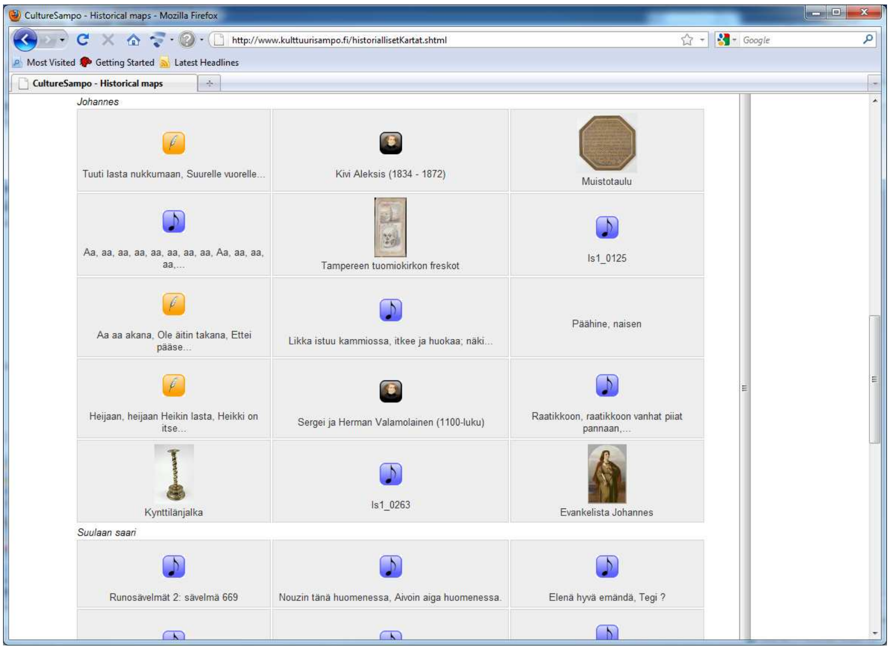


Fig. 1.9 Semantic recommendation links related to ’Viipuri(1920-1944)’.

the change history of municipalities. In recommending, the CULTURESAMPO knowledge base is used as a SPARQL end-point.

4. Visualization of historical changes. Fig. 1.8 depicts the Temp-O-Map system [22] in CULTURESAMPO that utilizes the ontology time series in visualizing historical and modern regions on top of maps and satellite images. Historical places, i.e. STRs, can be selected from a drop-down menu on the left. Here the temporal constituent ’Viipuri(1920-1944)’ of ’Viipuri’ is selected. By viewing old and contemporary maps on top of each other gives the user better understanding about the history of the region. In this case the Viipuri area was annexed to the Soviet Union after the World War II, and many old Finnish place names were changed in new Russian ones and are also now written using Cyrillic alphabet. In the middle, a smaller rectangular area is shown with a semi-transparent[12] old Karelian map that is positioned correctly and is of the same scale as the Google Maps image. In order to move around the user is able to use the zooming and 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 20^{th} century covering the area of the annexed Karelia region before the World War

[12] We use transparency libraries provided by http://www.kokogiak.com/ which allow the alteration of the level of transparency.

II. The maps were digitized and provided by the National Land Survey of Finland[13]. In addition, a geological map of the Espoo City region in 1909, provided by the Geological Survey of Finland[14], was used. This application is also included in the CULTURESAMPO portal.

1.5.2 Semantic Query Expansion Service

For demonstrating the utilization of ontology services in query expansion, we extended the ONKI Selector widget with functions for expanding input queries, and integrated it with the search interface of an exisiting legacy search system on the web, the Kantapuu.fi service [40]. Kantapuu.fi contains tens of thousands of artifacts, photos, literary works, and other archived material from various Finnish museums. The content is related to the history of forestry.

The original user interface of Kantapuu[15] is a web user interface for searching and browsing for museum collections using simple matching algorithm of free text query terms with the index terms of collection objects. In the new interface[16], input fields of the original form are replaced by ONKI Selector widgets. When a desired query concept is selected from the results of the autocompletion search or by using the ONKI Ontology Browser, the concept is expanded. The expanded query expression is the disjunction of the original query concept and the concepts expanding it, formed using the Boolean operation OR. The query expression is placed into a hidden input field, which is sent to the original Kantapuu.fi search page when the HTML form is submitted. The ontologies used in the query expansion are based on the vocabularies used in annotation of the items, namely the Finnish General Upper Ontology YSO, Ontology for Museum Domain MAO[17], and Agriforest Ontology AFO[18]. The Finnish Spatio-temporal Ontology SAPO is used for expanding geographical places as query terms by utilizing the spatial overlap relation between temporal parts of places.

An example query is depicted in Figure 1.10, where the user is interested in old publications from Joensuu, a municipality in Eastern Finland. The user has used the autocompletion feature of the widget to input to the *keywords* field the query term "publicat". This string has been autocompleted to the concept *publications*, which has been further expanded to its subclasses (their Finnish labels), such as *books*. Similarly, the place spaceworm *Joensuu* has been added to the field *place of usage* and expanded with the STRs it overlaps.

[13] http://www.maanmittauslaitos.fi/default.asp?site=3
[14] http://en.gtk.fi
[15] http://www.kantapuu.fi/, follow the navigation link "Kuvahaku".
[16] A demonstration is available at http://www.yso.fi/kantapuu-qe/
[17] http://www.seco.tkk.fi/ontologies/mao/
[18] http://www.seco.tkk.fi/ontologies/afo/

The result set of the search contains four items, from which two are magazines used in Eno (a municipality overlapping Joensuu) and the rest two are cabinets for books used in Joensuu. Without using the query expansion the result set would have been empty, as the place *Eno* and the concept *books* were not in the original query.

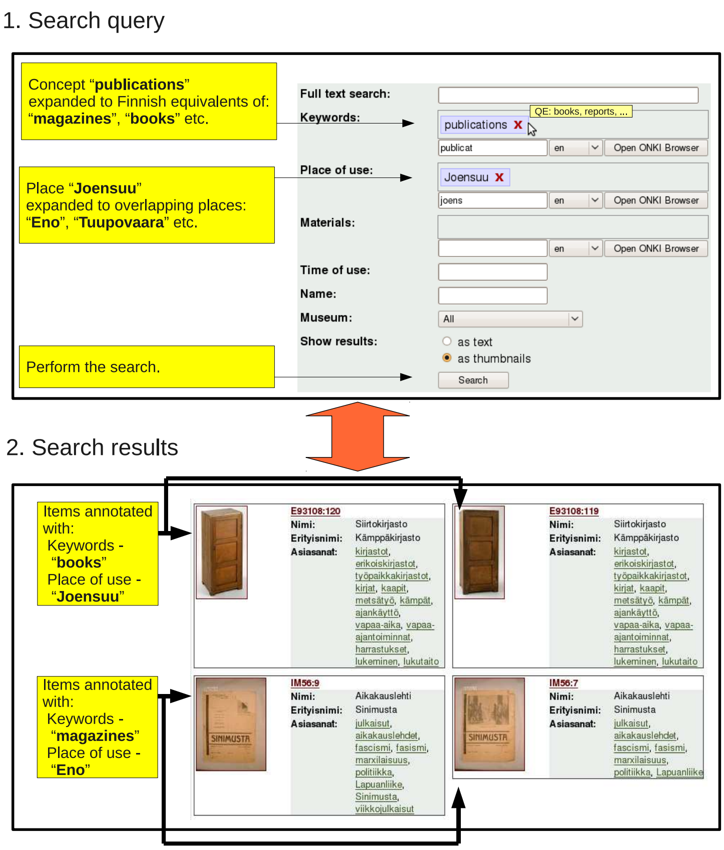


Fig. 1.10 Kantapuu.fi system with integrated ONKI widgets.

Expanding queries using the spatial overlap relation between places is often useful for enhancing recall, but may decrease the precision of the query by introducing irrelevant query terms. For example, if a user is interested in historical items found in a place A, which overlaps a place B only a little, he may not appreciate search results concerning items found in the parts of the place B that do not overlap the place A and are far from it. To manage situations like these, query expansion has been made transparent to the user. The user is always able to view the expansion, select whether to use query expansion or not, and remove the suggested query expansion concepts from the query if needed.

1.6 Discussion

In conclusion, we briefly review answers to the research questions set in section 1.1.2, discuss related work, and outline directions for further research.

1.6.1 Research Questions Revisited

- **Spatio-temporal ontology models** We presented a simple model for representing geo-ontologies of spatio-temporal places that change in time, based on the notion of spatio-temporal regions and ontology time series they implicitly define. STRs with the same name define a place as a spaceworm. From a philosophical viewpoint, the notion of a place, say 'Germany', is a complex spatio-temporal structure with associated cultural heritage content, history, perspectives, opinions etc. Although our model is too simple to represent all that, it is a step forward by addressing explicitly the question of representing regional changes in time, and by making it possible to associate STRs with cultural heritage content through metadata and other ontologies.
- **Spatio-temporal ontology maintenance** A model for maintaining spatio-temporal ontologies that change in time was presented. A key idea here was to create a database of local regional changes that are usually more easily available from historical documents than e.g. polygons. Based on the change history, the complex ontology time series can be generated automatically. Combined with additional information resources such as polygons, the knowledge base can be enriched further by reasoning, based on semantics.
- **Annotation support** In our view, correct and accurate content creation is a most critical part in creating semantic portals. Therefore, indexing with semantic web resources should be supported at the time of cataloging the content in the organizations that know their content best. In this paper, ONKI ontology service was presented as a means to support content creation using ontologies, so that correct references to places in time can be made.
- **Application** Utilization of spatio-temporal ontologies in querying, recommending, content aggregation, and visualization was shown by two examples on the web: a cultural heritage portal and a query expansion service for a legacy system were presented. Although not formally evaluated, these proof-of-concept systems illustrate the potential of utilizing spatio-temporal ontologies. The applications can be used e.g. 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.

1.6.2 Related Work

Spatio-temporal ontologies for geographic information have been discussed and developed before, especially from a philosophical and foundational viewpoint, and using formal logic approaches [33, 35, 46, 11, 4]. In contrast, the model presented in this chapter is practical, based on simple spatio-temporal relations, and with a focus on the overlap-relation in an ontology time series.

Research on spatio-temporal databases concerns database concepts capturing spatial and temporal aspects of data, including geometry changing over time [32]. Our model is dealing with similar problems but the approach is based on semantic web techniques and ontologies [34], with a focus on dealing with incomplete data, reasoning, data integration, and web applications.

In GIS systems, overlap of physical areas is usually determined by representing the real world in terms of intersecting polygons [43, 37]. However, in application cases like ours, such geometrical modeling may not be feasible because precise geometrical information is not available or it could be difficult to create and computationally difficult to use.

Traditions in ontology versioning [28] and ontology evolution [29] are interested in finding mappings between different ontology versions, doing ontology refinements and other changes in the conceptualization [27, 36], and in reasoning with multi-version ontologies [15]. In ontology mapping research, there have been efforts to do mappings based on probabilistic frameworks [31]. Means for handling inconsistencies between ontology versions [13] have been developed. Methods for modeling temporal RDF have been proposed recently [12]. In contrast to these works, our approach is merely about the evolution of an 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.

Ontology library systems have been proposed for publishing ontologies and providing services for accessing them. Based on reviews on ontology libraries [9, 1], the main focus in previously developed systems tends to be in supporting ontology development rather than in providing services for using the ontologies. Although ONKI Ontology Service provides support for the whole ontology life cycle, a major contribution of ONKI is the support for content annotation, information searching and other end-user needs as integrable web widgets and APIs.

Compared to general RDF search engines [8, 6] and ontology servers [30, 7], ONKI Ontology Service is based on an idea of a collection of domain-specific ontology servers providing user interfaces and services suited for ontologies of a given domain. E.g., geographical regions in spatial ontologies can be visualized on a map view.

In information retrieval query expansion techniques have been proposed to solve problems related to the user's ability to represent her information needs in a query adequately [44]. Query expansion can be based on a corpus, e.g. analyzing cooccurrences of terms, or on knowledge models, such as thesauri [45] or ontologies [44]. Methods based on knowledge models are especially useful in cases of short, incomplete query expressions with few terms found in the search index [44, 45].

A spatial query can explicitly contain spatial terms (e.g. Helsinki) and spatial relations (e.g. near), but implicitly it can include even more spatial terms that could be used in query expansion [10], e.g., neighboring places. Spatial terms—i.e. geographical places—do not exist just in space but also in time [21]. Thus, relations between historical places and more contemporary places can be utilized in query expansion. In the ONKI Semantic Query Expansion Service we have used the spatial overlap relation between places to expand the spatial query terms. As query expansion may cause uncontrolled expansion of result sets, thus causing potential loss in the precision of the query [38, 14], the query expansion has been made transparent and controllable to the user.

1.6.3 Future Work

We are currently extending the SAPO ontology to include smaller and older regions. Our RDF repositories already include tens of thousands of places that are being mapped on SAPO and a modern geo-ontology of Finland that consists of hundreds of thousands of places. The idea in a longer perspective is create an ever growing open source RDF repository of historical places in Finland, and link them with international sources, such as TGN and GeoNames.

A further research direction would be 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.

Acknowledgements

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[19] http://www.seco.tkk.fi/projects/finnonto/

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