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Research Article

A Task-Based Ontology Approach to Automate Geospatial Data Retrieval

Nancy Wiegand
Land Information & Computer Graphics Facility
University of Wisconsin-Madison

Cassandra García
Land Information & Computer Graphics Facility
University of Wisconsin-Madison

Abstract
This paper presents a task-based and Semantic Web approach to find geospatial data. The purpose of the project is to improve data discovery and facilitate automatic retrieval of data sources. The work presented here helps create the beginnings of a Geospatial Semantic Web. The intent is to create a system that provides appropriate results to application users who search for data when facing tasks such as emergency response or planning activities. In our task-based system, we formalize the relationships between types of tasks, including emergency response, and types of data sources needed for those tasks. Domain knowledge, including criteria describing data sources, is recorded in an ontology language. With the ontology, reasoning can be done to infer various types of information including which data sources meet specific criteria for use in particular tasks. The vision presented here is that in an emergency, for example, a user accesses a Web-based application and selects the type of emergency and the geographic area. The application then returns the types and locations (URLs) of the specific geospatial data needed. We explore the abilities and limitations of the OWL Web Ontology Language along with other Semantic Web technologies for this purpose.

1 Introduction

Geospatial data are produced and disseminated by many government agencies. Such data are important in decision-making and can be vital in emergencies. The National Research Council has recognized the need for geospatial data in responding to crises (NRC 2003, 2006). However, although large amounts of data are produced, potential

Address for correspondence: Nancy Wiegand, Land Information & Computer Graphics Facility, 550 Babcock Drive, University of Wisconsin-Madison, Madison, WI 53706, USA. E-mail: wiegand@cs.wisc.edu

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users may still have difficulty searching for geospatial data sources over the Web due to not knowing where data are stored (Reitsma 2003). As a result, many data seekers use a general Internet search engine to search for geospatial data (Schutzberg 2003). Better methods are needed for effective search and dissemination of geospatial data.

Furthermore, we observe that many searches for geospatial data are for tasks, such as emergency response or land use planning, that need the same types of data with just the location varying. As a result, we propose a task-based Semantic Web model to help automate the process of finding geospatial data sources.

Current approaches to geospatial data discovery do not use ontologies that fully characterize data or formalize the relationships between concepts, including specifications of what data are needed for particular tasks. This means that others have to re-think what data sources are needed when faced with the same task. In addition, a large amount of knowledge regarding geospatial data now resides only with data producers and other geospatial specialists. Formalizing a knowledge base will aid nonspecialists as well as GIS specialists in locating appropriate geospatial data, allowing re-use, and enabling agents to automatically locate data sources. We believe this knowledge base will be very valuable.

In a Semantic Web, data and information are marked up so that machines can interpret and manipulate the contents (Berners-Lee et al. 2001, Shadbolt et al. 2006). Formal representation languages such as RDF or OWL provide meaningful mark-up. Also, resources in a Semantic Web are identified by Universal Resource Identifiers (URIs) enabling linking, reference, and retrieval. Ontologies are another component of a Semantic Web and provide a standard for conceptualizing and referring to domains of interest. Using established ontologies, mark-up, and URIs, associations can be made between otherwise disparate data on the Web.

Ontologies also help with semantic interoperability. First, an ontology provides established terms to which every application can conform. Also, an ontology serves as an authority to which alternate terminology can be mapped when applications have not conformed to the same terms. Such mappings provide resolution for semantically heterogeneous data sources. In addition, ontological mapping information can be used to broaden the scope of keyword queries and resolve synonyms to improve searching in a Geospatial Semantic Web as proposed, for example, in Hochmair (2005).

In this paper, however, we focus on using ontologies in combination with a task-based approach to enhance geospatial search. We present a prototype for an overall system design to store and retrieve geospatial data according to the Semantic Web vision of objects, links, and ontologies. We present the idea in this project by explicitly associating data with concepts such that a semantic resolution component is not needed here although it would be needed for automatic harvesting of data.

In our Geospatial Semantic Web, we provide automatic machine processing for data retrieval. The vision is that in an emergency, for example, a Web-based application takes in information on geographic area and type of emergency and then returns the types and locations of the specific geospatial data needed. To achieve this, we use emerging Semantic Web languages, tools, and rule engines. In particular, we design a conceptual model using the OWL Web Ontology Language (Bechhofer et al. 2004) and the Protégé system (Knublauch et al. 2004) and use Jess (Friedman-Hill 2000), a rule-based engine for processing information. Section 2 of this paper discusses geospatial portals, and Section 3 introduces ontologies. Related work is found in Section 4. Our project is described in Section 5, and Section 6 offers a conclusion.

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2 Portals – Advantages and Limitations

The development of geospatial portals, along with geospatial data standards, has revolutionized the way geospatial data are distributed and accessed. The National Spatial Data Infrastructure (NSDI) was initiated to support public and private sector applications of geospatial data. An evolution of the NSDI is the Federal Government's Geospatial One-Stop portal (GOS, http://www.geodata.gov). According to Tang and Selwood (2005), portals may become the fundamental way in which geospatial data are published and shared. Using portals, geospatial information can be accessed more easily, a broader range of information can be made available, and the time and effort involved in finding geospatial data are reduced. Geospatial portals are, inarguably, a very useful asset to GIS users.

However, despite the advantages of geospatial portals, it can still be difficult to find data resources. Current search portals rely only on metadata and do not support formal semantics. As a result, the user is forced to resort to guessing and using rudimentary syntactic means to try to find the desired data (Farrugia and Egenhofer 2002). For example, searching in the GOS portal using the keywords "Fire Response" returns different data sets and services than when the search terms "Fire Emergency" are used. This demonstrates a problem for novice portal users who may not know which keywords to use or may not even know they should try many keywords. In a recent study conducted to test the ease with which users could find data from a variety of data portals, over a quarter of participants failed to find pre-selected data sets known to exist within the portals (Hochmair 2005). Problems cited included "too many filters" and "unclear keywords."

Another complication is that the number of search results can sometimes be overwhelming. Portal users may spend a great deal of time sifting through undesirable query results before finding the desired data set. This problem can be compounded by the fact that some of the coordinates entered in metadata to determine place actually cover a much greater area than the actual data. So, the user not only has to sort through unwanted data sets returned due to keyword selection but also unwanted data sets due to imprecise coordinate documentation. While this problem could be addressed by more careful metadata creation, that is a somewhat idealistic solution, and it would be better to have additional measures to cope with such issues. More targeted search is needed, especially in emergency situations.

Table 1 compares the current portal approach to a task-based system. Establishing formal relationships between a type of task and the types of data sources needed adds a level of organization to the data. Also, generic ontological relationships are pre-established, augmenting metadata values and limiting reliance on bounding box coordinates. Problems of semantic heterogeneity may be eliminated, and subsumption reasoning is used to answer queries. Inference engines are able to perform complex reasoning over ontological information.

3 Ontologies

Ontologies have been proposed as a tool for knowledge management (Fensel 2001). An ontology is a description, in a formal, machine-readable format, that expresses concepts including the types of entities, attributes, relationships, and values found in a domain.

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Table 1 Comparison between current portals and a task-based ontology system

Current Portal Design	Task-Based System
Limited data source organization	Additional level of data source organization using task-based information
Limited use of values in metadata fields to locate data	Uses metadata values along with a task-oriented approach based on ontology restrictions and rules
Uses bounding box coordinates to locate data	Uses a place ontology with synonyms, region names, and explicit relationships to data sources
Uses a relational DBMS to store and search metadata in a straightforward manner	Uses an enhanced system with ontologies, rules, deductive reasoning, and a general knowledge base

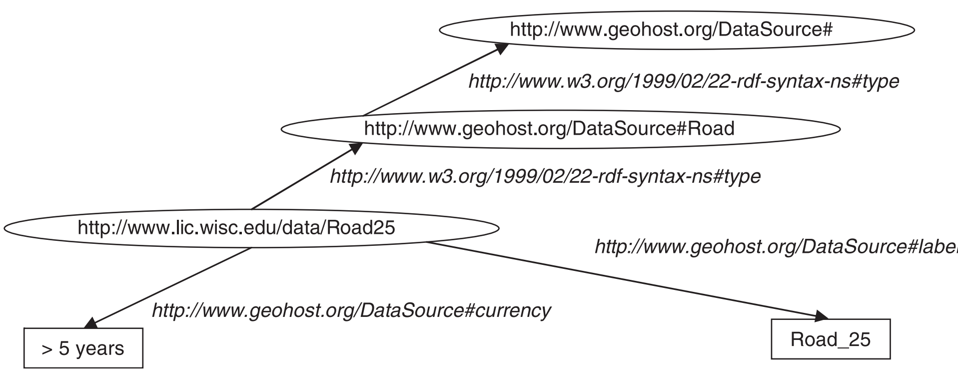

Figure 1 RDF graph representing the Road_25 data source

OWL (Bechhofer et al. 2004) is the latest W3C Web Ontology Language being developed by the Semantic Web community as a knowledge representation formalism to represent the meaning and structure of data and help create a web of information. OWL is a vocabulary extension of RDF (Resource Description Framework). RDF, which is based on XML, uses triples of object, property, and value to form statements about resources. Figure 1 shows an RDF graph describing a local data set as an instance of type Road, which itself is of type Data Source. Linking a data source to a generic description (ontology) that characterizes objects of that type provides machine-understandable information.

In our project, we use OWL because it builds on RDF and RDF Schema to provide an extension of information available in an RDF graph, such as Figure 1. OWL adds relations between classes and also allows inferencing on the semantics involving, for example, subclass information and class designation for individuals. In our approach, we assume each data set is explicitly linked to its theme type (as in Figure 1) and also linked to types representing other data source characteristics, such as file type. This enables subsumption (reasoning over subclass information) to be used to determine the

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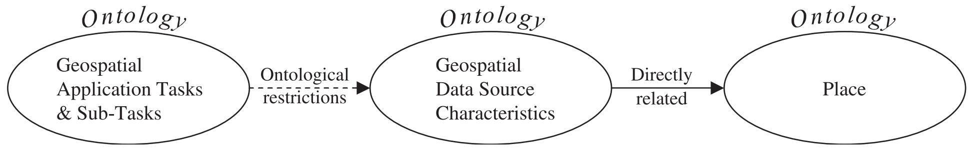

Figure 2 Independent ontologies related for automated searching

answer to a query. We also use OWL's "someValuesFrom" property to restrict associations between different classes.

One of the values of using ontologies is that base domain information can be described independently of a particular application. In this way, ontologies can be re-used and multi-purpose. This is contrary to a database management system approach in which limited information is modeled in the schema for a specific purpose (Spyns et al. 2002). For our application, we use multi-purpose, independent ontologies between which we establish formal relationships (Figure 2).

4 Related Work

The Wine Agent example from the Protégé group initially served as a model for the conceptual design of our project (Wine Agent). In that application, separate ontologies for food and wine are brought into one knowledge base with the additional information as to what type of wine should be served with a specific type of food. This information is modeled using ontological restrictions over four possible wine characteristics such as color. Then given a specified meal type, the JTP reasoner deduces the type of wine to be served. For the project here, we analogously model separate task and data source ontologies along with restrictions on types of data sources needed for a given task. Some changes had to be made, however, to this basic model as will be discussed later.

Geospatial and related communities are developing domain ontologies. Raskin and Pan (2005) developed a collection of ontologies called Semantic Web for Earth and Environmental Terminologies (SWEET) to aid in the search for Earth Science data. Part of the SWEET ontology for Phenomena may possibly be used in our task ontology, such as the Emergency Management Natural Events category with the hierarchy: SevereWeatherPhenomena – StormSurge – Flood. Mizen et al. (2005), at the UK Ordnance Survey, developed a hydrography ontology and researched methodologies to help domain experts create ontologies. Others, including Malyankar (2002), investigated methods to automatically create ontologies. Our future plan to capture domain knowledge using Wikis also has potential to facilitate creation of ontologies.

Kolas et al. (2005) define types of ontologies that could support a geospatial semantic system, and Kavouras et al. (2005) developed a methodology for comparing categories in geographic ontologies. An ontology driven GIS is proposed in Fonseca et al. (2002). They are motivated to integrate different types of geographic information and assume communities of interest will be committed to common ontologies that can be browsed by the user.

In the effort to improve search for geographic resources, Cai (2002) discusses the special characteristics of geographic information for information retrieval (IR), i.e. spatial footprints in addition to thematic content, and that IR methods often use a vector space model whereas GISs use a geographic model focused on geographic space.

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He presents a prototype GeoVSM system with an interface that uses both models combined by links. The SPIRIT spatial search engine (Jones et al. 2004) incorporates ontologies, geographic footprints, and spatial indexing to build a search engine targeted to spatially related data. They also perform spatial query expansion using an ontology of place (Fu et al. 2005). Their ontology and use of spatial terms such as *near* and *far* can express semantic differences based on context. They are building a place ontology for the UK, which could serve as a model for other countries.

For a U.S. place ontology, we find promise in the work of Arpinar et al. (2006) who begin to develop SWETO-GS, a geospatial extension to the Semantic Web Technology Evaluation Ontology (SWETO). They plan to use information from the Geographic Names Information Service provided by the USGS. Once fully developed, this may be used by our project as a place ontology to which data and tasks could be georeferenced.

Others focus on the problem of finding geospatial data. A portal for a public commons of geographic data has been proposed to help solve the problem of data not being easily available to potential users (Onsrud et al. 2004). They recognize the difficulties of making known and sharing spatial digital products, especially local data. Although they focus on the ease of creating metadata and preserving ownership and lineage of data sources, they note that obtaining access to data for a particular need is currently difficult. Partially, this is because data reside on local servers, and, although technically accessible, it is unknown to others. Nevertheless, they state the need for, but do not develop automated searches to reach geographic data sets.

Needs for geospatial semantics in searching the Web for data sources are also discussed in Egenhofer (2002). He mentions the unique task-based nature of geospatial data retrieval that is not now accommodated over the Web. He focused on spatial relations to be able, for example, to find data on "lakes in Maine". Our system would directly retrieve the appropriate data sets because the instance representing each data set is instantiated to be of one or more themes (i.e. lakes) and is also directly related to a place.

Ontology-enhanced search and information retrieval has received more attention in other domains, such as medicine. For example, in an early work (McGuinness 1999), an ontology-enhanced search for primary care medical literature is presented. The proposed search application addresses the need for a form of search that does not rely solely on keywords, which can be problematic because of misspelling or because a relevant document or data file may not contain the keyword. To relate to our project, if someone requires data for responding to a fire, data such as roads or building occupancies will be needed, both of which are unlikely to have the word "fire" in their metadata. McGuinness also seeks to filter medical literature based on quality and recency. Again, this is similar to the need presented here of filtering geospatial data on fields such as accuracy and currency, but with the differences that there are many fields and some of them are not straightforward, e.g. different kinds of geospatial data accuracy.

To help organize and find data, other methods have been used, such as browsing the organizational structure of the data sources. This is done in the Geospatial Information Data Base System (GIDB) (Wilson et al. 2003) in which there is a hierarchical categorization for data products that a user can browse to select a data source. For example, if a user chooses "vector", then the user can select a database, then a library, then a particular coverage such as wind. Other techniques to categorize data can be used to facilitate searching. Kokla and Kavouras (2001) use Formal Concept Analysis to decompose geographical categories into a set of simpler, unambiguous fundamental categories (semantic factors) in the process of creating a concept lattice.

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Interoperability in general has been pursued by the spatial community for some time (Bishr 1998, Goodchild et al. 1999). An advance was made by the Open Geospatial Consortium (OGC) in developing the Geography Markup Language (GML) (Cox et al. 2004) as a standard means to express spatial data. The next step was work on semantic heterogeneity. For example, furthering the idea of a National Spatial Data Infrastructure (NSDI), a global vision of a spatial data infrastructure (GSDI) has been put forth (Nebert 2004). Among other technical specifications being developed to allow such national and global sharing of information, *semantic registries* are proposed to mediate over metadata content. That is, although FGDC metadata tags, for example, are standardized, the content for metadata fields may contain regional-specific or otherwise heterogeneous terms, which limits success in search requests. It is suggested that data and semantic models also be published with data sources, along with, if possible, mappings to national schemas and definitions.

Farrugia and Egenhofer (2002) discuss four presentations of semantics on the Web. Of the four, we focus on two, mainly the "simple metadata" which describes the geographic data sets and "logical (model-theoretic) semantics" which are employed in our model by the creation of task and data source ontologies expressed in OWL. Rodriguez and Egenhofer (2003) extended similarity measures for entity classes in single ontologies to multiple ontologies, such as WordNet and SDTS. Janowicz (2005) suggested using thematic roles to obtain better semantic matching. A method using Internet querying has also been proposed to improve search for geospatial data. That is, XML search and query engines have been developed (e.g. Naughton et al. 2001) along with XML query languages (i.e. XQuery (Fernandez et al. 2005)). Internet DBMS technology enhanced with semantic integration facilities, as in Wiegand and Zhou (2005), would allow full querying of metadata files resulting in targeted searching if metadata were published on the Web. Lutz and Klien (2006) focus on the problem of semantic heterogeneity in geographic information catalogues and propose a new method for general ontology-based information retrieval. They constrain their application to search for only one dataset at a time but acknowledge that, practically, a user may need a variety of datasets to satisfy a search query. Although not the focus here, such work on semantic integration will be useful to augment the searching presented in this paper. In this paper, we focus on illustrating the Semantic Web vision for geospatial data in which objects are described using ontologies and linked to other objects, allowing machine processing.

5 Our Approach

We leverage new Semantic Web technologies for geospatial data discovery and eventual querying. Specifically, we build a prototype subset of a Geospatial Semantic Web targeted toward searching for geospatial information. Included in the Web are prototype ontologies of tasks, data sources, metadata, and places, along with relationships between them.

5.1 Task-based

According to Timpf (2001), tasks guide cognition in a given situation, and task ontologies are needed in GIScience as well as domain ontologies for knowledge sharing, interoperability, and re-use of services. In this paper, we focus on tasks as they relate to data sources.

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Table 2 Selected emergencies and types of geospatial data needed: Task-Data matrix (subset)

Example Data		Example Emergencies			
Data Theme	Data Sub-Theme	Wildfire	City Fire	Earthquake	Flooding
Elevation	Digital Elevation Model	✓			✓
Hydrography	Flood Zones				✓
	Storm Surge Inundation Areas				✓
Transportation	Airports	✓		✓	
	Road (Centerlines)	✓	✓	✓	✓
	Boat Navigation				✓
	Evacuation Routes	✓	✓	✓	✓
	Pipelines			✓	
Other	ANSS real-time earthquake data			✓	
	MODIS Fire Imagery (USDA)	✓			
	Wind Data	✓	✓		

The need for up-to-date geospatial data in emergency situations is now widely recognized. For the natural disasters of 2005, some needed information was distributed through disaster-specific channels created on GOS. However, availability of data is not the only issue. Emergency responders may not be familiar with data standards nor the appropriateness of certain data sets for a particular task and will benefit from guidance. Due to the critical nature of emergency response, responders rarely have time to sift through extensive query results. Increased specificity of search results and ease of obtaining those results is crucial. For example, for the 9/11 GIS response, "staff did not have the time or understanding of the data requirements for an event of this magnitude" (Langhelm 2004, p. 3). With an emergency task-based system, the search results will be appropriate to the situation, increasing efficiency. Responders will not have to re-think what data sources and specific data characteristics are needed each time they are faced with a task. Thus, it is worthwhile to formally delineate tasks and their relationships to types of data sources. Table 2 is a subset of a sample matrix we compiled for data needed in emergencies. The full matrix is in Appendix A.

5.2 Overview of the Architecture

Figure 3 is a diagram showing how users, data providers and domain experts interact with the task-based search application. The application denoted by the dashed rectangle is the focus of this paper. Although implemented in Protégé, the framework can be extended to be a stand-alone service on the Web or be embedded into existing geospatial portals, such as GOS, to add a new dimension to traditional portal search strategies.

Users, shown in the upper left-hand corner of Figure 3, access the task-based search application to search for geospatial data. Using the GUI, the user selects the type of task and enters the location involved. As explained further in Section 5.6, the application then calls the rule engine, which inferences over a knowledge base using rules having specifications for a metadata search. The rules are generically written with variables (i.e.

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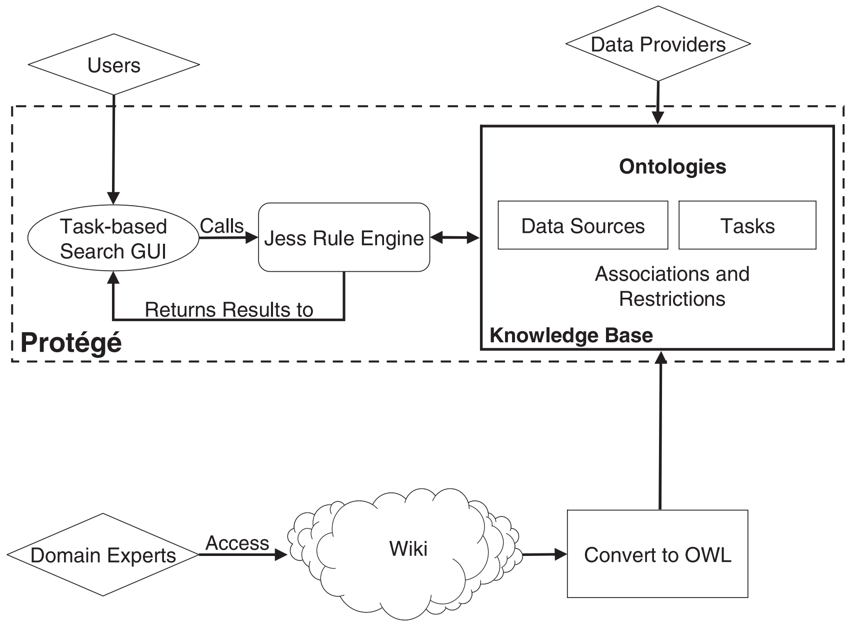

Figure 3 Architecture for task-based searching

parameterized) such that new values for task type and location can be substituted on each execution. Once metadata files describing appropriate data for the task are found and processed, the URLs of the data sources are extracted and output as a search result.

Data providers, shown in the upper right-hand corner, supply the data needed by the user and the associated descriptive metadata. Our system uses metadata characteristics such as theme, currency, precision, and accuracy, in addition to location information, to determine whether or not a data set is appropriate for a task.

Domain experts, shown in the bottom left-hand corner of the diagram, are valuable in developing the knowledge base to determine the types of data sets and characteristics needed for particular tasks. To expand our current knowledge base, we have started to experiment with a collaborative process using Wiki technology in which experts assign types of data sources, such as "road data" or "land use data" to types of tasks such as "fire emergency response" or "flood response". This information informs the pre-established restricted relationships in the knowledge base. The domain experts also specify more complex requirements for geospatial restrictions, such as accuracy. This information is used to form the rules that inference over metadata. Figure 4 shows our current Wiki design for capturing domain expert knowledge.

5.3 Conceptual Model

Figure 5 shows our base conceptual model of the domains. We combine ontologies of tasks, data sources, metadata, and places in a knowledge base along with associations. The components of these ontologies are represented as OWL classes and subclasses. The arrows represent OWL properties, and the diamond arrow shows a transitive property. The ontologies are each explained in the following subsections along with the modeling restriction mechanism placed on the "Needs" object property to allow deductive reasoning.

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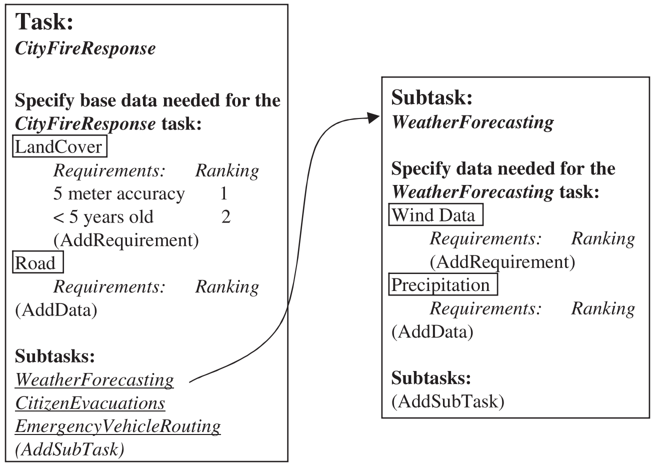

Figure 4 Wiki structure to collect domain expert knowledge

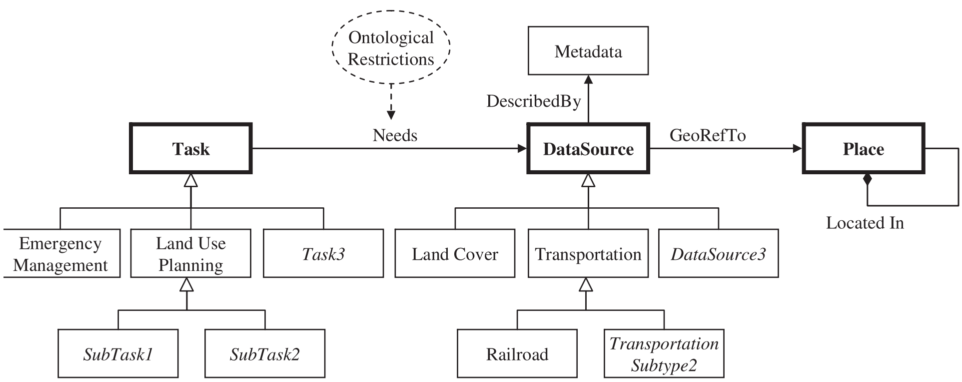

Figure 5 UML diagram of the ontology domains

5.3.1 Task ontology

To develop a task-based geospatial data retrieval system, we use a task ontology based on the Homeland Security Working Group's (2005) symbology reference categorization shown in Figure 6a. Emergency management, for example, is further broken down into incident management and responses to natural events. In our application, the categorization of the types of tasks must go down to the lowest level needed to discriminate between the types of data sources that would be useful for that type of task.

5.3.2 Data source ontology

Geospatial data sources can be characterized in many ways. As a start, we delineated geospatial data using the framework data types of the FGDC to which we added additional categories (Figure 6b). A complete ontology characterizing geospatial data would have many factors (classes), not just theme. There could be classes for raster, vector, shapefiles, etc., as well as separate classes and descriptions for special types of

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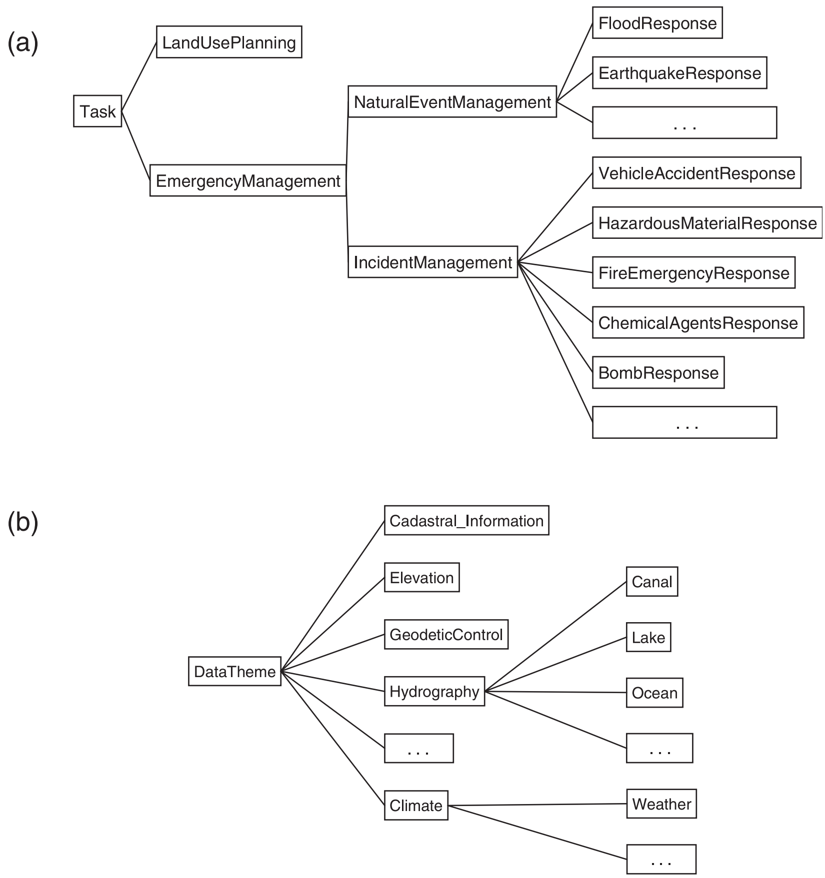

Figure 6 (a) Ontology of tasks, and (b) data source ontology

well-used data such as TIGER files and USGS topographic maps. Instance data would belong to many classes and be part of a complex web. For example, a particular land cover data set would primarily be of type Land Cover but could also be a member of the classes for vector, shapefile, 90% attribute accuracy, and so on. Subsumption reasoning, instead of an SQL query, is then used to determine whether a data set meets various specifications. For automatic reasoning to be effective, a full data source ontology needs to contain a complete characterization of the descriptive factors of geospatial data. Such an ontology is worthwhile for domain experts to develop because it would be extremely useful for many geospatial applications.

5.3.3 Metadata and place ontologies

We assume that each data source is described by metadata. Metadata instances are generated in the system for each data source. We use FGDC metadata as an upper level model for a metadata ontology. Other metadata formats that could be used include ISO 19115 and Dublin Core.

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We model location as a place and, for now, assume place instances come from a hierarchically organized taxonomy of names, such as the Geographical Names Information System (GNIS) of the USGS. However, our intent is to use a full place ontology, as in Kauppinen and Hyvönen (2005). We assume such a place ontology will have nicknames and region designations and include an OWL transitive Located In property as shown in Figure 5. Explicit transitive relationships will add more knowledge so that when data cannot be found for a particular place, a query or rule will be able to find data for higher level jurisdictions.

We currently use the value in the Place Keyword in the metadata files to relate data sources to location because a full place ontology does not yet exist. However, we propose using a modeling design in which each data source is directly related (using an OWL object property, e.g. GeoRefTo) to a place as shown in Figure 5. We believe that this type of modeling will more accurately return data sources than the current portal method of associating bounding box coordinates with each data source. That is, when an instance is created for a new data source, it is linked using an OWL object property to a place in the place ontology.

5.4 Modeling Restrictions Between Tasks and Data Sources

We use the description logic modeling power of OWL DL to restrict the types of data sources needed for each type of task. In OWL, a property restriction is a type of class description that describes an anonymous class by placing constraints on the class extension (the set of individuals associated with the class). Property restrictions can specify value or cardinality constraints and be applied to datatype or object properties. Here, to restrict the types of data sources needed for each type of task, we use the OWL "someValuesFrom" value constraint applied to an object property.

For example, the following formal statement restricts the types of data needed for a fire response task to only include roads, land cover and hydrography: "∀ needs (RoadData U LandCoverData U HydrographyData)". This places a restriction on the "needs" object property between the task class and the data source class (Figures 5 and 7) and states that all values for this restricted relationship must be of a type listed and not of other types. The following OWL notation uses the "someValuesFrom" constraint to place the restriction.

```
{property restrictions on an anonymous subclass}
<owl:Class rdf:ID= "FireEmergencyResponse">
  <rdfs:subClassOf rdf:resource= "#IncidentManagement"/>
  <rdfs:subClassOf>   {anonymous subclass}
    <owl:Restriction> {restrict to need roads, etc}
      <owl:onProperty rdf:resource= "needs"/>
        <owl:someValuesFrom rdf:resource= "#RoadData"/>
        <owl:someValuesFrom rdf:resource= "#LandCoverData"/>
          . . . {other restrictions}
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
```

5.5 Discussion

We intended to maximize the use of inherent modeling capabilities within OWL, such as levels of subclassing and someValuesFrom restrictions, to avoid hard-coding criteria in

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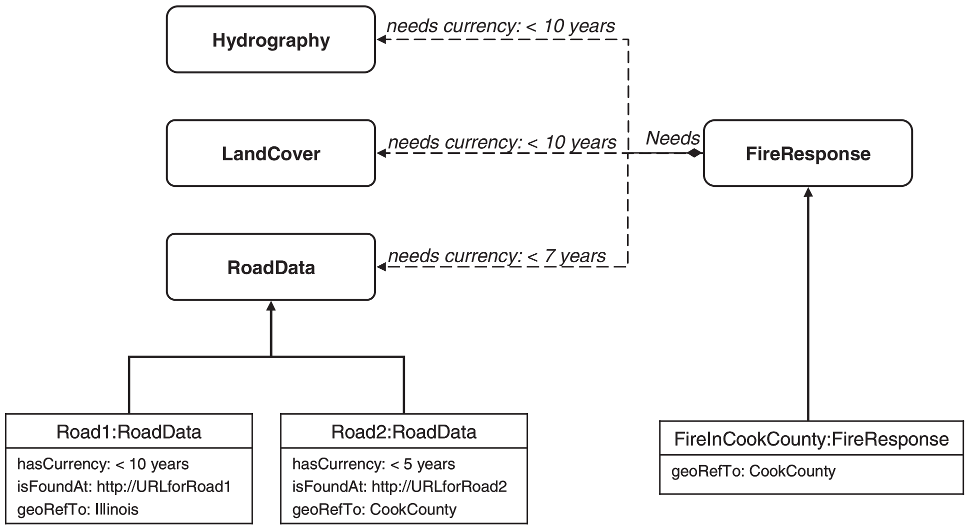

Figure 7 Diagram showing classes, instance data, and task-data restrictions

rules or queries as much as possible. That is, the value of establishing a full ontology with relationships and restrictions is to fully record, within the ontology itself, all the needed information. Then, instance data can be declared as being of multiple subclasses, and basic inferencing over inherent type information (using subsumption) would determine result sets, as in (Wine Agent). This is sufficient and functional in our application to the extent of finding, for example, a data source of type road and also of type shapefile.

However, when using OWL to further describe geospatial data, a variety of shortcomings become apparent. Geospatial data, in particular, need multiple selection criteria, including those on numerical categories. It can become unwieldy to declare numerous corresponding subclasses. Also, subclasses declared for numerical properties may have artificial ranges, e.g. verticalAccuracy1mTo5m. For geospatial data, comparison operators (e.g. verticalAccuracy < 5) are more practical, especially because different types of geospatial data can be described by characteristics such as attribute accuracy, spatial accuracy, pixel resolution, and scale, and the range of acceptable values will vary greatly depending upon the task for which the data are used. Instead of only using the inferencing capabilities of an OWL reasoner, we needed to incorporate the use of rules. The use of rules enables multiple criteria and comparisons, but then less ontological information is stored. In the end, we kept the association between tasks and data sources within the ontology but used rules to filter further metadata criteria.

5.6 Prototype

We prototyped our application in Protégé OWL 3.1.1, an ontology editor (Knublauch et al. 2004), to demonstrate the advantages of task-based data retrieval. Protégé allows creation and basic querying of ontologies, as well as importing external ontologies. However, ontologies often need to be augmented with rules (Bishr 2006). Rules are helpful in a variety of ways, for example, to state general knowledge such as all topographic maps are related to elevation or that satellite imagery before a certain year or

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of a certain type has a particular resolution. We used rules, however, to process and filter data because we could not fully use subsumption reasoning.

We used the Jess rule engine (Friedman-Hill 2000), via the JessTab plugin (Eriksson 2003) to augment Protégé's capabilities. JessTab automatically converts an OWL knowledge base to Jess assertions. Jess allows structural queries on the ontology/knowledge base in addition to querying the instance data. We wrote rules in Jess to perform inferencing over our ontologies. However, JessTab does not currently translate object property restrictions, e.g. the someValuesFrom constraint, to Jess assertions. To get around this, we created general task and data source class instances on which to place correspondences. The correspondence between these general instances was then used to find individual metadata instances, which were then filtered based on the restrictions specified in the ontology.

To illustrate the functionality of our prototype, we present the following rules and screen capture. User input for place and task are assigned using *defglobal* statements. In this example, the user has chosen the "FireEmergencyResponse" task for the place "Cook County." The rule "find-metadata-for-task" uses the specified task (?*task*) to access the needed data types ($?data) for that task type. For each type of data source, the embedded query "search-by-theme" uses theme keywords supplied by the list of needed data to find metadata that match each keyword (?tkwd) and the specified place (?*place*). As can be seen in the output below, once the appropriate metadata instance matching the specifications is identified, the URL to the data source is returned.

Begin Screen Capture:

```
Jess> (defglobal ?*place* = "Cook County")
TRUE
Jess> (defglobal ?*task* = "FireEmergencyResponse")
TRUE
Jess> (defquery search-by-theme "Finds metadata with a given theme keyword"
      (declare (variables ?tkwd)) (object (mdPlace ?*place*) (mdTheme ?tkwd)
      (mdURL ?url) (mdDate ?date) (:NAME ?name)))
TRUE
Jess> (reset)
TRUE
Jess> (defrule find-metadata-for-task (object (:NAME ?*task*)(needs $?data)) =>
      (foreach ?element $?data (bind $?it (slot-get ?element dataKeyword)) (foreach
      ?element2 $?it (bind ?result (run-query* search-by-theme ?element2)) (while
      (?result next) (printout t "The name is" (?result getString name) "and can be
      found at" (?result getString url)"" crlf)))))
TRUE
Jess> (run)
The name is met_CookCountyWetlands and can be found at
      http://www.isgs.uiuc.edu/nsdihome/browse/cook/wtldspy.e00
The name is met_CookCountyRoads and can be found at
      http://www.isgs.uiuc.edu/nsdihome/browse/cook/roads.e00
The name is met_CookCountyStreams and can be found at
      http://www.isgs.uiuc.edu/nsdihome/browse/cook/streams.e00
The name is met_CookCountyFloodzones and can be found at
      http://www.isgs.uiuc.edu/nsdihome/browse/cook/fldzones.e00
```

End Screen Capture.

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The significance of the above rules is that they are fully parameterized to work for any place or task. This is necessary to automate the process of data retrieval. Also, restrictions on additional criteria for accuracy or currency can easily be added to the above code.

To alleviate the complexity of writing Jess rules, we investigated SWRL (SWRL 2004), a recent W3C standard rule language designed for the Semantic Web. In SWRL, users write Horn-like rules to reason about OWL individuals. A Protégé SWRL editor has been developed as an extension to Protégé-OWL (Protégé SWRL Editor). One of the goals of SWRL is to permit interoperability between SWRL and existing rule engines. Work has been performed to integrate the SWRL editor with the Jess rule engine, turning SWRL rules into Jess rules (O'Connor et al. 2004). Further, a SWRLJessTab plugin has recently become available in Protégé. SWRL should make writing future rules more intuitive.

5.7 Future Work: Ranking

It is possible that data matching the specified criteria may not be found. Therefore, we propose a ranking of the data requirements determined by the domain experts in order of importance as shown in Figure 4. As future work, a full expert system could execute a sequence of rules to find the next most appropriate data set. For example, perhaps the domain experts state that a city fire emergency response requires land cover data created within the past five years and with five meter accuracy, but the search finds no metadata meeting those criteria. The application then determines that the next best available data set is for a land cover data set generated seven years ago with a listed accuracy of 20 m. The user would be given a link to the alternate data set and alerted that it does not fulfill all of the requirements. A full expert system with rankings provides a tremendous advantage as the user would not have to perform subsequent broader searches when the first search fails or make the initial search requirements so broad such that many inappropriate results are returned.

5.8 Evaluation

Our system is effective based on the proper delineation of tasks and subtasks (a task ontology), a completely descriptive data source ontology, and relationships between them. Emergency management personnel have recognized the value of geospatial data, and this type of information is now being compiled. Also, because, on input, we assume that data instances are explicitly declared to be of the appropriate types in the data source ontology and directly related to an instance in a place ontology, we are not currently burdened with the issues involving semantic heterogeneity, such as a theme keyword of "street" needing to be mapped to "road". However, if data were automatically harvested and literal terms were used to categorize the data, synonyms and other forms of semantic resolution would be needed. For now, we assume the data provider matches the data source to the appropriate subtypes in the data source ontology. In this paper, rather than working on resolving semantic heterogeneity, we focus on creating a base Semantic Web for geospatial data, mirroring the Semantic Web discussed in section 1 in which resources are linked to other resources and to ontologies.

One of our premises is that there is a common relationship between task types and data source types regardless of location. However, if different locations need different types of data, then additional rules could be added to the system.

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It is not possible to directly evaluate our system compared to retrieving data in a portal (e.g. GOS). This is because GOS is not task-based. It relies on metadata searching and does not contain a knowledge base with formal relationships between types of tasks, data, and locations. For example, a search in GOS for downloadable data related to "fire emergency" in Cook County, IL has no results. In GOS, a user must already know each type of data needed and search for it separately (e.g. search for roads in Cook County, then land cover, etc). A task-based system automatically does the searches together.

6 Conclusions

Compared to existing data discovery methods, there are several advantages to creating a geospatial task-based knowledge formalism using ontologies. Currently, searching for geospatial data can be overwhelming when one does not know exactly which keywords to use. It can also be time-consuming to sift through undesirable results due to either poor keyword selection or bounding coordinate discrepancies within metadata. In contrast, emergency responders need quick and specific search results directing them to data needed for particular tasks. The system described here lowers the threshold of expertise needed to find data, which can be extremely important when select personnel are not readily available.

The ontologies (e.g. for tasks and data sources) are created independently of how they will be used. In this paper, the ontologies are then related in the effort to automatically find needed data sources for a task. The effort to create such a knowledge base is worthwhile because of the potential re-use for similar tasks at varying locations. The independent ontologies and their associations are also available for other kinds of processing, including those currently unknown. We believe the development of a full data source ontology by domain experts that completely describes geospatial data characteristics will be extremely useful for this and many other applications. Also, the knowledge bases formed for tasks, data sources, and relationships between them will permanently capture information that now only resides with relatively few geospecialists.

The task-based approach adds a level of organization to help target search over the multitude of geospatial data and types of data that exist. Task-based information can be formalized such that automatic processing can be done. Our framework is implemented using Protégé OWL 3.1.1 and the Jess rule engine to illustrate a working prototype. Rules are parameterized to accept any location and type of task. Although we were following a conceptual model to do subsumption reasoning to find search results, we had to modify that approach because geospatial data have so many search characteristics and there is a need for numeric comparisons.

The contribution of this paper is to bring the idea of a Semantic Web into the geospatial realm. In a Geospatial Semantic Web, geospatial resources are linked to other resources and to ontologies that allow fuller descriptions of the resources and automatic machine processing.

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Appendix A

Selected Emergencies and Types of Geospatial Data Needed: Task-Data Matrix

		Example Emergencies[3]						
Data Theme[1]	Data Sub-Theme[2]	Volcano	Airborne Plague	Wildfire	City Fire	Earthquake	Flooding	Tornado
Geodetic Control	Benchmarks							
	PLSS							
Orthoimagery	Orthophotos	✓	✓	✓	✓	✓	✓	✓
Elevation	Elevation/DEM	✓		✓			✓	
Hydrography	Rivers	✓		✓	✓		✓	
	Lakes	✓		✓			✓	
	Dams	✓		✓			✓	
	Flood Zones						✓	
	Water Supply Watersheds						✓	
	Hurricane Storm Surge						✓	
	Inundation Areas							
	Coastal Wetlands		✓					
	Inland Wetlands		✓					
Transportation	Airports		✓	✓		✓		✓
	Interstates	✓	✓	✓	✓	✓	✓	✓
	Road (Centerlines)	✓	✓	✓	✓	✓	✓	✓
	Traffic	✓			✓	✓	✓	✓
	Flight Paths							✓
	Boat Navigation						✓	
	Railroads							
	Evacuation Routes	✓	✓	✓	✓	✓	✓	✓

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Appendix A *Continued*

Data Theme[1]	Data Sub-Theme[2]	Example Emergencies[3]						
		Volcano	Airborne Plague	Wildfire	City Fire	Earthquake	Flooding	Tornado
Cadastral Information	Townships							
	Parcel Info/Ownership/Occupancy		✓		✓	✓	✓	✓
	Fire/Law Enforcement Response Districts		✓		✓	✓	✓	✓
	Land Cover/Land Use	✓		✓	✓		✓	✓
Administrative Units	Political Boundaries		✓	✓	✓		✓	
Other: Uncategorized	Debris Flow	✓					✓	
	Pipelines					✓		
	Environmentally Sensitive Areas							
	Population	✓	✓	✓	✓	✓	✓	✓
	Quaternary Faults					✓		
	Plate Boundaries					✓		
	Neotectonic Plates					✓		
	US Seismic Hazards					✓		
	ANSS real-time earthquake data					✓		
	Global Seismic Hazards					✓		
	Home-Cared Patients		✓		✓	✓	✓	✓
	Incidence And Symptoms – To Determine If There Has Been An Outbreak (Description Tied To Geographical Location Of Possible Outbreak)		✓					
	Infected Materials Disposal Sites		✓					
	Animal Operations		✓					
Other: Structures	Drug Stores/Clinics		✓					

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Appendix A *Continued*

Data Theme[1]	Data Sub-Theme[2]	Example Emergencies[3]						
		Volcano	Airborne Plague	Wildfire	City Fire	Earthquake	Flooding	Tornado
	Sterile Supplies Stockpiles (Gloves, Syringes, Etc)		✓					
	Meeting/Gathering Places	✓	✓		✓	✓	✓	✓
	Schools	✓	✓		✓	✓	✓	✓
	Churches	✓	✓		✓	✓	✓	✓
	Healthcare Facilities		✓		✓	✓	✓	✓
	Location Of Vaccinations And Travel Routes To Facilities		✓					
	Pharmaceutical Stockpiles		✓					
	Water/Sewer Treatment Plants				✓	✓	✓	
	Power Lines	✓		✓	✓	✓		✓
	Water Utilities- Incl. Hydrants	✓		✓	✓	✓	✓	
	Sewer Lines					✓	✓	
	MODIS Fire Imagery From USDA Forest Service			✓				
Other: Weather	Precipitation	✓	✓	✓	✓		✓	✓
	Weather Warnings		✓	✓	✓		✓	✓
	RAWS current weather data		✓	✓	✓		✓	✓
	Nexrad		✓	✓	✓		✓	✓
	Wind Data		✓	✓	✓			✓

This chart was compiled based on website investigations, news articles, email conversations and personal judgment.
[1]The first seven themes are the FGDC framework categories http://www.fgdc.gov/framework/. The last three were added based on additional needs for specific emergencies.
[2]Some of the Data Sub-Themes were compiled by consulting websites including: http://www.nconemap.com/onemapstandards/, http://www.fs.fed.us/r1/mftc/index_home.shtml, and articles: http://www.rshgs.sc.edu/Resources/USC_State Survey EMA Offices for Geospatial Technology_Dec202005.pdf, http://www.state.mn.us/intergov/metrogis/data/info_needs/emergency_prep/steering/03_0606.pdf, and Version 2 of the California GIS Strategic Plan (CA_GIS_Strategic_Plan_v2a.pdf) no longer available online.
[3]Emergencies were selected to highlight a variety of data needs.

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