GEOGRAPHICAL SEMANTIC REPRESENTATION FOR COLLABORATIVE EMERGENCY SERVICES

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ABSTRACT:

Geographical semantic representation, which aims at enhancing geospatial data model and facilitating information sharing and exchange, has been a hot topic in the realm of geographic information science. The research summarized here is to advance a geographical semantic representation framework to support geo-collaboration, focusing on how to take full advantage of Ontology and Web Services technologies to overcome the flaws of current WebGIS in the distributed cooperative computing model and application model, and make it better to serve collaborative GIS applications, such as collaborative emergency services. We considered a simplified evacuation scenario of toxic gas dispersion, following the proposed solution, the orchestration of application services based on semantics was conducted and illuminated.

1. INTRODUCTION

Geographical semantic representation, which aims at enhancing geospatial data model and facilitating information sharing and exchange, has been a hot topic in the realm of geographic information science for the last decade [Tryfona and Sharma, 1996; Bishr, 1998; Smith and Mark, 1998; Fonseca, Egenhofer, Agouris, et al., 2002; Zheng, 2006].

With rapid development of internet and the prevalent electronic business pattern, B2B, collaborative GIS is emerging and gaining more and more attentions [Zheng, 2006]. Urban Emergency management is a typical collaborative GIS application. Many social departments would participate in immediately and behave as dynamic, multi-institutional virtual organizations (VOs) [Foster, Kesselman, Tuecke, 2002] to deal with emergency event collaboratively once disaster occurs. In such cooperative work environment, some spatial decision-support operations do need interactions between business partners, which are usually geographically distributed. The interactions can be defined as a strict work flow and shared by every participant, joining them together on solving more complicated problems. It is of great significance to access and integrate distributed geospatial data and services effectively from different information providers in accordance with workflow.

Geographical information sharing and collaboration requires agreement on meaning or interpretation of data in the specific domain. Geographical semantics is about understanding of GIS contents, and capturing this understanding in formal theories [kuhn, 2005]. It is reasonable to suppose that embedding explicit semantics on general geospatial data representation will help to improve common understanding and facilitate incorporating geospatial information services (GIServices) with E-Business flow seamlessly. As an explicit formal specification of a shared conceptualization [Gruber, 1993], ontology is adept in semantic expression and plays a key role in semantic-based information sharing and integration. Indeed there is currently a significant amount of effort being expended in the development of geographic ontologies and semantics in GIS community [Bishr, 1998; Kuhn, 2001, 2003, 2005; Mennis, 2003; Soon and Kuhn, 2004; Tryfona and Pfoser, 2005; Zheng, Feng, Jiang, et al., 2006]. In parallel, the potential for GIS to be the collaborative application environment among distributed agencies has also been widely discussed [Cai, 2005; MacEachren, Cai, Sharma, et al., 2005; Hopfer and MacEachren, 2007].

Our concern is with geographical semantic formalization and sharing in distributed, collaborative application environment. Towards the goal of improving geo-information collaboration and interoperability in urban emergency management, this paper is intended to present an integrated solution to enable geographical semantic representation with ontologies and facilitate GIServices integration and collaboration through semantic sharing. The rest of this paper is organized as follows: the next section describes methodology of the research. Geographic Ontology, Web Services, and the application in our work are discussed. Section 3 presents a general geographical semantic representation framework based on service oriented architecture (SOA) to support distributed collaborative GIS application. Some implementation issues of semantic representation are discussed. In section 4, a simplified evacuation scenario of toxic gas dispersion is introduced and the orchestration of application services based on formal semantics is conducted and illuminated. Section 5 comes to a conclusion with an outline of future work.

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2. METHODOLOGY

Two crucial technical issues are involved in our work: geographical semantic formalism, and geographical semantic sharing to enable service-oriented Geo-Collaboration [Cai, 2005; MacEachren, Cai, Sharma, et al., 2005] in distributed computing environment. We explored combining Ontology and Web Services technologies to provide an integrated semantic-based framework for collaborative GIS application, mainly by ontology-driven semantic formalism and sharing geographical semantics under Web Services architecture.

2.1 Semantic Representation Based on Ontologies

Semantic research in GIS community has to tackle some major issues concerning the characteristics of geographic concepts, which implicates the task of establishing a geographic ontology. Generally, the design of geographic ontologies should take into consideration the fact that geographic entities interrelate, participate in processes, present variation of properties and values, etc. The task of defining geographic concepts, determining relations among them, and finally establishing axioms, necessitates a comprehensive examination of the semantics of all that constitutes geographic space. Using current web-based Ontology description language, such as OWL [Harmelen, Hendler, Horrocks, et al., 2004], domain knowledge can be logically formalized and shared through internet among different development groups that work on different application tasks of the same domain.

Geographic concepts are an integral part of geographic ontology as they stand for mental representations of all possible things (real or abstract) that exist or may exist. Therefore, the core problem of geographical semantic representation is the formalization of geographic concepts, which form the backbone of knowledge base about the domain or task setting. Current effort of geographic ontologies design pays more attentions on the static and structural domain knowledge, containing a view of the world that has less to do with human activities than existing data holdings. These, in turn, are usually based on map contents rather than on an analysis of actual user needs. In order to enhance geo-information exchange at different levels of semantic granularity, two important elementary geographic concepts, geoFeature and geoOperation, are advanced in our approach to describe basic data semantics and behaviour semantics separately in GIS application domain. Moreover, both geoFeature and geoOperation are not strictly limited to describe spatial concepts, which will help to deal with geospatial and other resources uniformly.

2.2 Semantic Sharing with GIServices

GIS has been evolving from GISystem to GIServices rapidly [Gong, Jia, Chen, et al., 2004]. To share geospatial data through internet, the Open Geospatial Consortium (OGC) has developed a series of web-based interoperability standards and protocols, for example, Web Coverage Services (WCS), Web Feature Services (WFS), Web Map Services (WMS) and Web Processing Services (WPS). They allow seamless access to geospatial data in a distribute environment, regardless of the format, projection, resolution, and the archive location. Now OGC web services are widely used in geospatial communities and are forming basis of the new-style WebGIS applications.

One important obstacle to integrate GIServices in distributed computing environment is that different systems use different concepts and terms for describing service interface. In our work, explicit semantics of interface elements, especially input or output parameters and constraints of geoOperations, are formalized and embedded into GIService description. Geographic ontologies are designed to define the vocabulary of unambiguous domain related concepts, and meanings of the geographic concepts anchored in consensus domain knowledge. This common understanding of the terms and concepts that describe given domain is especially important in distributed, collaborative computing environment where the clients may be geographically distant from each other and working on heterogeneous software platforms and programming environments.

3. GEOGRAPHICAL SEMANTIC REPRESENTATION FRAMEWORK

3.1 General Framework

According the above ideas and methodologies, an integrated semantic representation framework is given based on service oriented architecture in this section (Figure 1).
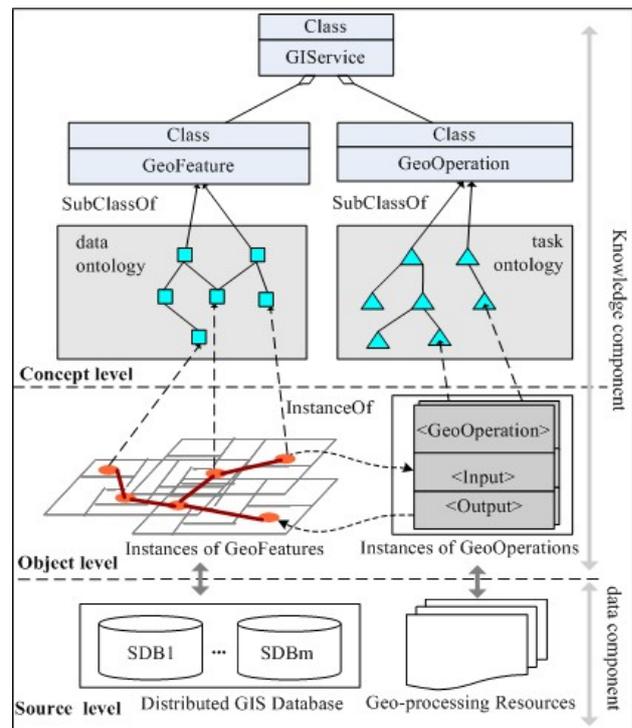

Figure 1. Service-oriented geographical semantic representation framework

The framework is composed of two distinct, yet interrelated, components: the Data component and the Knowledge component. The Data component represents the raw and uninterpreted geospatial resource, which can be organized into spatial database or files geographically distributed. The Knowledge component, defined by DL-based ontologies, represents the logical semantic knowledge derived from uninterpreted geospatial resource. Furthermore, geographical knowledge can be described at two levels of abstraction: object level and concept level. The former describes the extension knowledge (ABox) about instances and how they interrelate.

The later describes the intension knowledge (TBox) about geographic concepts. Both of them constitute the knowledge base (<TBox, ABox>) of a particular domain or task setting, so that different contents can be easily matched when integrated.

Based on the proposed framework, explicit semantics could be formalized and embedded on the top of general representation, which will increase the usability of geospatial resources, furthermore, facilitate sharing and exchange through service composition in cooperative computing environment. The implementation of geospatial data semantics and geospatial function semantics will be briefly discussed in the following subsections.

3.2 Geospatial Data Semantics

The geospatial data semantics refers to the meanings or interpretations of geographical data in the view of information representation. In the proposed framework, geographic concepts extending from geoFeature constitute the geo-data concept lattice, which usually describes the static structural domain knowledge.

Figure 2 shows a section of geo-data ontology about chemical hazards. Some geographic concepts, for example, ChemicalFacility, ThreatArea, as well as the relations and properties, are described by OWL. In distributed collaborative environment, different ontologies can be developed according as levels of abstraction. Then domain knowledge can be shared and reused through concepts extension (is-a) and aggregation (part-whole) within or across ontologies. In this example, both POI and AOI are defined in another ontology, GeoOnto, and they are all derived from geoFeature.

```
<owl:Class rdf:about="#SpecialLocations">
  <rdfs:subClassOf rdf:resource="#DomainConcepts"/>
  <rdfs:subClassOf rdf:resource="http://www.lsgis.nju.edu.cn/
  Opengiser/GeoOntologies/GeoOnto.owl#POI"/>
</owl:Class>

<owl:Class rdf:ID="ChemicalFacility">
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/
  XMLSchema#string">facilities producing chemical gas
  </rdfs:comment>
  <rdfs:subClassOf rdf:resource="#SpecialLocations"/>
</owl:Class>

<owl:Class rdf:about="#ThreatArea">
  <rdfs:comment rdf:datatype="http://www.w3.org/2001/
  XMLSchema#string">dangerous area caused by toxic gas dispersion
  </rdfs:comment>
  <rdfs:subClassOf rdf:resource="#Scenarios"/>
  <rdfs:subClassOf rdf:resource="http://www.lsgis.nju.edu.cn/Opengiser/
  GeoOntologies/GeoOnto.owl#AOI"/>
</owl:Class>
```

Figure 2. Geospatial data semantic representation based on geoFeature

3.3 Geospatial Function Semantics

Geographic concepts extending from geoOperation constitute the geo-task concept lattice, which describes the dynamic, task-related knowledge of application domain. From service-oriented perspective, every geoOperation can be viewed as a function of geo-data, with input or output parameters wrapped as

geoFeatures. It is designed to formalize the user actions in geospatial space. The semantic relations between actions or geoOperation can be divided into four different relationships with entailments: troponymy, Proper inclusion, backward presupposition and Causation [Kuhn, 2001]. Similar to METEOR-S [Akkiraju, Farrell, Miller, et al., 2005], some semantic tags are added to web service description language (WSDL) in our work to provide explicit semantic description of service interface, including input, output parameters and the constraints of operations. So, GIServices described by this model would be easily discovered and composed with the help of consistent semantics.

Figure 3 shows a simple example of geospatial function semantic representation. In this example a geoOperation concept, identifyThreatArea, is defined to formalize an action in geospatial problem-solving environment. The input and output parameters of geoOperation refer to geo-data ontologies for capturing explicit semantics. And some constraints to execute the operation are also defined by two tags, precondition and effect.
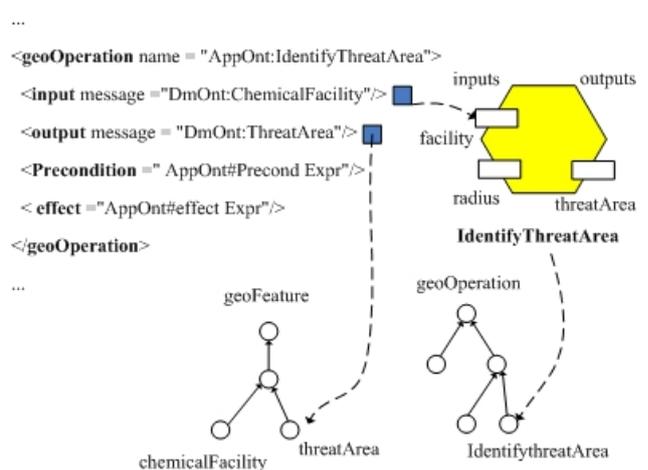

Figure 3. Geospatial function semantic representation based on geoOperation

4. CASE STUDY: COLLABORATIVE EMERGENCY SERVICES

4.1 Application Scenario

This example is motivated by the need to support geospatial information sharing and collaboration among emergency virtual organizations. GIS and geospatial information are indispensable in all stages of emergency management, involving immediate response, recovery, mitigation and preparedness. Collaborative emergency management requires multiple individuals and organizations sharing information, expertise, and resources in support of rapid situation assessment and decision-making. It relies upon geospatial information to depict geographical distribution of events, its cause, affected people and infrastructure, and available resources.

Here we consider a simplified evacuation scenario of toxic gas dispersion, posed by the related GIServices and collaboration through formal semantics. When a toxic gas leakage detected in some chemical facility, many social departments cope with

each other, while dealing with large amount of geospatial data and functions to provide spatial decision-making support. For example, weather department is to provide meteorological data around the chemical facility, such as wind speed, wind direction and temperature and so on. Environment department takes on simulation of toxic gas dispersion with meteorological parameters and other factors. With the support of dispersion map of toxic gas, more rational emergency plan would be made to guide evacuation and relief of the disaster.

4.2 GIService Collaboration and Integration

Based on the presented solution, a formal emergency evacuation plan about the motivating example is developed as service chains. Some web services, including geo-information services and IT web services, can be chained together with the help of explicit semantic description and finally translated into executable web services flow by BPEL4WS [Curbera, Goland, Klein, et al., 2002]. In our prototype system, geospatial data services are constructed in GeoServer, the popular open source GIS Server. Other IT web services and modules are mainly developed in lightweight J2EE Environment, Eclipse and Tomcat are chosen. And geographic ontologies are developed with Protégé 2000.
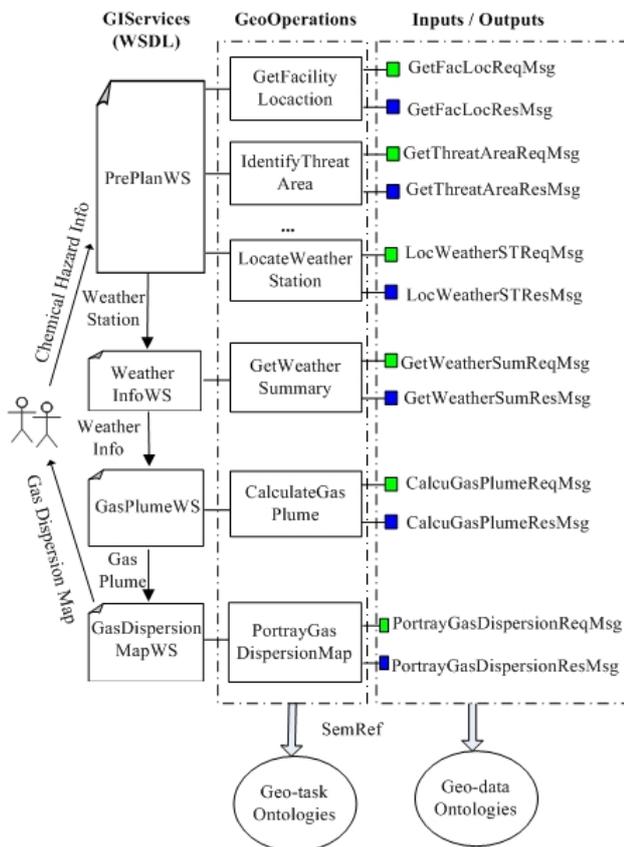

Figure 4. Chaining GIServices based on ontological semantics

Figure 4 describes the collaborative emergency services of application scenario. four application services are listed in this figure, including evacuation preplan service (PreplanWS), weather information service (WeateherInfoWS), gas plume simulation service (GasPlumeWS), and gas dispersion portrayal service (GasDispersionMapWS). The above distributed services are hosted by different people or agencies within the emergency virtual organization. Every service is described by a WSDL document, within which interface is presented for remote call regardless of platform implemented. The input and output parameters of services are referenced to particular concepts of geo-data ontologies, while the operations of services referenced to particular concepts of geo-task ontologies. With the support of ontological semantics, distributed services can be chained according to data flow. The principle and basic process is briefly described as follow.

When gas leakage detected and reported, the chemical facility is located and symbolized on map rapidly. Service PreplanWS contains many geoOperations. IdentifyThreatArea operation will be called to identify the directly threatened area of the disaster. The weather stations around the facility can be searched and returned by LocateWeatherStation operation. Given meteorological and terrain parameters around the facility, Gas Plume Simulation Service is executed to calculate the toxic gas plume. The Gas Dispersion Portrayal Service is to produce visualization of toxic gas dispersion while gas plume is calculated. Finally, supported by gas dispersion map, Evacuation Plan Service can be invoked again to determine the secondly threatened area, and more rational evacuation plan would be made. The case study shows that semantic-embedded GIServices are more flexible to collaborate, and the proposed solution can integrate distributed geospatial resources and services in loosely coupled way and bring them into business process seamlessly.

5. CONCLUSIONS AND FUTURE WORK

Urban emergency management is a typical distributed collaborative GIS application, characterized by data-intensiveness, distribution of resources, and cooperative work. To facilitate geospatial information sharing and collaboration in emergency management activities, this paper explored combining Ontology and Web Services technologies to support geo-collaboration. Two elementary geographical concepts, geoFeature and geoOperation, were advanced to describe basic data semantics and behaviour semantics separately in GIS application domain, and an integrated geographical semantic representation framework was proposed and designed based on service-oriented model. Based on the proposed solution, we considered a simplified evacuation scenario of toxic gas dispersion, and the orchestration of semantic-embedded GIServices was conducted and illuminated. The result shows that the distributed geospatial data and services could be integrated and collaborated in loosely coupled way. The proposed solution is feasible and effective to enable Geo-Collaborative emergency services.

The future work includes the full implementations of the proposed framework. Meanwhile, we are currently exploring incorporating Grid computing technologies to provide a more robust service infrastructure for collaborative GIS applications. More efforts will be put on the collaborative application mode of Grid-enabled GIServices in support of semantics.

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