Geospatial Semantic Interoperability Based on Ontology

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Abstract  In GIS field, great varieties of information from different domains are involved in order to solve actual problems. But usually spatial information is stored in diverse spatial databases, manipulated by different GIS platforms. Semantic heterogeneity is caused due to the distinctions of conception explanations among various GIS implements. It will result in the information obtaining and understanding gaps for spatial data sharing and usage. An ontology-based model for spatial information semantic interoperability is put forward after the comprehensive review of progress in ontology theory, methodology and application research in GIS domain.

Keywords  ontology; GIS; interoperability; semantic heterogeneous

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Introduction

With the continuing development of GIS technology and its application research, people have gradually recognized the importance of GIS interoperability among heterogeneous systems, services and data sets. Nowadays most GIS application systems can support interoperability in physical level and data formats, such as web protocol, hardware, OS, spatial data file and DBMS, etc. There is still no any system can completely achieve semantic interoperability[1].

Many researchers have put forward several ideas with regard to information interoperability. In solving heterogeneous database, federated databases method is the dominative one. This method requires administrators or users to recognize semantic and expressive heterogeneity at first, and then use this mode to solve information heterogeneity. May Yuan[2] adopted a kind of global conceptual model to represent spatial information and other relevant content. Some others use “semantic mediator” to realize semantic interoperability. With the development of ontology theories and relevant technologies, some ontology-based approaches have been brought in GIS field, and inclined to get highly concern, such as Max Egenhofer’s on ontology-driven geographic information integration[3-5], Cui Wei’s GIS semantic integration and interoperability[6], Ding Li’s spatial information interoperability frame in semantic web[7], Tan Xicheng’s method of spatial information interoperability based on cooperative ontologies[8], Wang Jinggui’s geospatial data integration based on geo-ontologies[9], and so on.

A model is put forward for spatial information semantic interoperability in this study. A case study “ChinaRegion” is made to detailedly demonstrate...
OWL (ontology web language) description methods in geo-ontology applications. A prototype system of spatial information semantic reasoning and querying was designed and developed, and a case study of “cities in Western China” is presented in order to evaluate the feasibility and validity of the research model.

1 An ontology-based model for spatial information semantic interoperability

1.1 Spatial information semantic interoperability model

Ontology, as a shared concept model, can be used to define and specify spatial data semantically as well as machine understandably. By reasoning and querying this explicit description, GIS system can not only exactly understand input data, but also help users gain required data conveniently, in a certain sense, help realize spatial information interoperability at semantic level. In this study, a model for spatial information semantic interoperability based on ontology is designed, with three levels: GIS application level, ontology level, and data level (Fig. 1).

1) GIS application level. In this level all sorts of GIS system application are included, such as data acquiring, data preprocessing, data storing, data retrieving and analyzing, image displaying and interacting, map publishing and information services, etc.

2) Ontology level. ① Ontology: aiming at different application level and requirements, hybrid ontology should be needed. According to Guarino\cite{10,11}, he classified ontology depending on concrete targets-ontology can be divided into four types, top-level ontology (describe the most common concepts and relation among concepts), domain ontology (describe concepts and their relations in certain domain), task ontology (describe concepts and their relations for certain target or certain behavior), and application ontology (describe concepts and their relations relying on certain domain and target). ② Ontology reasoning and querying: using ontology to realize semantic querying for spatial data, that is, through reasoning ontology-the formally explicit, machine understandable description-to obtain implied, potential knowledge. Ontology reasoning is a process of understanding ontology knowledge by computer. One of purposes to use ontology is to make information machine understandable through formal description of knowledge and intelligence. To ontology builders, reasoning is to investigate conflicts within ontology or among ontologies during integration; to ontology users, the main function of reasoning is to obtain implicit concepts and relations in knowledge, and to use the information in problem solving. ③ Ontology construction and maintenance: domain experts should be required to join in ontology construction, and ontology

![Fig.1 A model for spatial information semantic interoperability](image-url)
should be improved and extended if necessary.

3) Data level. GIS application system is closely related with spatial data. This model use ontology as “medium” to semantically describe spatial information, through ontology reasoning and querying to enhance interoperability of spatial information. By ontology, GIS system can semantically employ and manage local spatial data as well as use data supplied by other systems, even distant systems, at the same time, these data can be organized and integrated with ontology to ensure which data are required, how to get them under semantic coherence.

1.2 Ontology case study: ChinaRegion

OWL is recommended by W3C (World Wide Web Consortium) as the standard language for describing ontology in semantic web. In this paper, we choose OWL DL to implement case study and use Protégé 2000 to code ontology.

In this segment a ontology about regions in China is built. Considering geo-domain specialized requisition and integration between geo-ontology and geo-entity, we distinguish three main upper concepts as upper common classes: SpatialThing, SpatialRelation and SpatialData.

1) SpatialThing (Fig.2), which will distinguish different subclasses, such as GeometricThing, Border and Place (e.g. GeographicalRegion, EcologicalRegion). GeometricThing is an abstract class of geometry objects. Geometry objects are important entities in geo-domain, their dimension features should be considered (e.g. Point, Curve, Surface, GeometryCollection, etc). From class GeographicalRegion, we can identify more detailed subordinate classes, such as LandBody, WaterBody. Similarly, class LandBody can find its child classes.

2) SpatialRelation, which is an abstract class of relations among spatial things. In this specific case three spatial relations are considered, Direction (e.g. north, south, east, west), Distance (e.g. far, closeo), and Topology (e.g. include, inside, contain, overlap, meet). For example, Xianning and Wuhan are instances of City, Hubei is an instance of Province. Their distance relation between each other, like “Xianning” closeo “Wuhan”, “Wuhan” closeo “Xianning”, “closeo” has symmetry feature. The topological relation, like “inside”, “include”, they are inter-inverse features. In this case, “Xianning” inside “Hubei”, “Hubei” include “Xianning”.

3) SpatialData, which an abstract class of geo-data properties, includes data name (hasName), data stored format (format, e.g. Access database, text, XML), data theme (aboutWhat), data range (aboutWhere), etc. Any instance of SpatialData is designed to support projecting an actual dataset existing in databases. Any instance of SpatialData is designed to connect with GeographicalRegion instance by property “aboutWhere”, in order to integrate datasets and ontology. For example (Fig.3), “hbpopdb” is an instance of SpatialData, hasName points out its name is population dataset of Hubei Province, aboutWhat connects it with “population”, format expresses that is “accessformat”, aboutWhere describes that is about “Hubei” area. Because spatial data format is quite different with default standard data type in OWL, we designated class “DataFormat” to describe spatial data format, each instance is one of types of spatial data format, like instance “accessformat”.

2 Prototype system

Case question: If users want to know “which capital cities are in Western China”.

GIS traditional method: GIS system manager will create a special attribute form to record stored dataset. When users query this question, system will search all of attribute forms to check whether the same attribute field (Western China) exists, if exists, system will return the result from database, if not, the result
will be embarrassed. Unluckily, usually users can not get desired answer, because “Western China” is described in natural language, and most of attribute fields are set by abstract words, like country, city, province, etc. Users can acquire answers, unless system manager add a new field in database. If we solve the problem in this way, it means many fields should be added, when other questions are asked.

Ontology driven method: as to the above question, we can easily use the case study “ChinaRegion” ontology. In this ontology (Fig.4), “China” is an instance of “Country”, “WesternChina” is an instance of “GeographicalRegion”, “Gansu”, “Yunnan”, “Xinjiang”, “Shanxi”, etc, provinces located in Western China, are instances of “Province”, objectproperty “include” makes connection between “WesternChina” and all relevant provinces. In the same way, “Xining”, “Kunming”, “Urumqi”, “Xi’an”, etc, are instances of “city” connecting with the above province instances as sequence by “include”. In “ChinaRegion” ontology, “WesternChina”, provinces belong to Western China, and their “include” relations are all explicitly defined, we can use the prototype system to query this question.

1) Input query requisition “WesternChina”, “include”, “city” to query “capital cities in Western China”.
2) Returned result: in Fig.5 those star symbols stand for appropriate cities.

References

[1] Bishr Y(1998) Overcoming the semantic and other barriers to GIS interoperability[J]. Int J Geographical Information Science, 12 (4):299-314
[2] Yuan M(1998) Development of a global conceptual schema modelling for geographical application[OL]. http://www.ncgia.edu
[3] Fonseca F, Egenhofer M, Davis C(2000) Ontology-driven information integration[C]. AAAI-2000 Workshop on Spatial and Temporal Granularity, Austin, Texas, USA
[4] Fonseca F T, Egenhofer M J, Agouris P, et al.(2002) Using ontologies for integrated geographic information system[J]. Transactions in GIS, 6 (3):231-257
[5] Fonseca F T, Davis C, Câmaras G(2003) Bridging ontologies and conceptual schemas in geographic information integration[J]. Geoinformatica, 7(4):355-378
[6] Cui Wei(2004) Using ontology to achieve the semantic integration and interoperation of the geography information system[D]. Wuhan: Wuhan University (in Chinese)
[7] Ding Li(2004) Spatial information interoperating framework research in semantic web[D]. Beijing: Peking University (in Chinese)
[8] Tan Xicheng, Bian Fuling(2005) Heterogeneous spatial information interoperability based on cooperative ontologies[J]. Geomatics and Information Science of Wuhan University, 30 (2): 178-181 (in Chinese)
[9] Wang Jinggui(2005) Geospatial data integration based on geo-ontologies[D]. Beijing: State Key Lab. of Resources and Environmental Information System (in Chinese)
[10] Guarino(1998) Formal ontology and information systems [C]. Formal Ontology in Information Systems, Amsterdam, Netherlands
[11] Guarino N, Welty C (2000) A formal ontology of properties[C]. The 12th International Conference on Knowledge Engineering and Knowledge Management, Juan-Ies-Pins, French Riviera