Chapter 13
Geographic Ontology

Hongwei Li

13.1 Introduction

Ontology is a concept that originated in the field of philosophy; ontology describes the nature of things and is generally understood to be the science of existence, or a philosophical study of the nature of being; ontology is an interpretation or explanation of an objective existence that is concerned with the abstract nature of objective reality, and it belongs to the branch of metaphysical theory. This concept, which has existed for more than 2000 years in western philosophy, is still a hot topic discussed by philosophers.

The understanding of ontology in academia is very different and far from consensus. Nevertheless, this does not prevent the continued popularity of the ontology concept and its research in various fields. In addition, ontological research in computational linguistics, artificial intelligence, knowledge engineering, databases and other fields is particularly hot and supported by the National Natural Science Foundation of China, the State "863" Project and many other research projects, and the field of ontology has achieved a series of research results, with much focus on this area in academic circles. The main reason for the rise in ontology studies in the field of science and technology is that semantic web, semantic modeling and semantic integration require ontology as the basic theory to support development.

According to the analyses and research of scholars, ontology first appeared in the field of science and technology in 1984 and was put forward and defined in 1991. Since then, the definition of ontology has been increasingly clarified. In general, the definition of ontology contains 4 main aspects: conceptualization of abstract models of phenomena in the objective world, which abstract the domain knowledge individually into a definite object; a clear definition, that is, the concepts of each object and the relation between them are reasonably defined; formalization, that is, accurate mathematical descriptions of concepts and their relationships are required and computer

H. Li (✉)
Information Engineering University, Zhengzhou, China

J. Wang and F. Wu (eds.), *Advances in Cartography and Geographic Information Engineering*, https://doi.org/10.1007/978-981-16-0614-4_13

readable levels should be reached; shareability, i.e., the knowledge reflected in the ontology is recognized by all its users (including experts in domains and general users). In short, the applications of ontological ideas in the field of science and technology involve using an object-oriented method to restore the existing knowledge, information and data into a reasonable semantic system so that they can be processed in computers and be shared by people.

The classification system of ontology varies due to the starting point and basis of classification. The most representative is the division of ontology based on the degree of detail and the degree of dependence (Guarino 1994), which divides ontology into three types of different abstract level ontologies: top-level ontology, domain ontology and task or application ontology. Top-level ontology studies generic concepts; domain ontology studies specific domain concepts; and application ontology is geared toward specific applications.

13.2 Development Process

The introduction of the ontology concept into the field of geographic information science occurred in recent years, reflecting a shift in the research focus from the previous emphasis on the formalization of computer models to the present focus on the spatial domain itself (Du 2001). When ontology was introduced into the field of geographic information science, the concept of geographic ontology (geo-ontology) emerged naturally. It is a special domain ontology, which has its own characteristics in addition to the basic features of general domain ontology. We define geographic ontology as studying the detailed connotation and hierarchical relationship of geospatial information concepts at different levels and in different application directions in the field of geographic information science, and we semantically identify the ontological concept. Geographic ontology abstracts knowledge, information, and data about geographic science into objects (or entities) of consensus and form a system in accordance with certain relationships; further, conceptual processing and explicit definitions are also given, and the formal representation of theories and methods are adopted.

A geographic ontology domain can be represented by a 5 tuple GO = (GCD, GRD, GFD, GID, GAD), where GO represents geographic ontology, GCD is the definition of a series of geographical concept or classes, GRD is the definition of a series of geographical relations, GFD is the definition of a series of geographical functions, GID is the definition of a series of geographical concept instances, and GAD is the definition of a series of geographical axioms.

A geographical concept or class has a wide range of meanings and can be used to refer to anything in the geographical world; it is a collection of geographical entities or geographical phenomena with the same attributes, which includes two categories: geographical entities and entity attributes. Mountains, rivers, seas, hills, plains, deserts, swamps, forests, crops, wind, rain, snow and frost are concrete examples of the concept of geographical entities, while altitude, sediment concentration, flow rate, sea surface temperature, area, forest volume, crop yield, wind speed, rainfall and so on are specific examples of the concept of geographical entity attributes.

Geographical relations represent the interaction of geographical concepts, formally defined as subsets of n-dimensional Cartesian products, including two classes of basic relations, namely, spatial and non-spatial relations. There are 3 basic spatial relations among geographical concepts, namely, topological relations, sequential relations and metric relations. Non-spatial relations include 4 basic types, namely, part-of, kind-of, instance-of and attribute-of. Topological spatial relations represent spatial relations among geographical entities, such as adjacency, inclusion and intersection; sequential spatial relations refer to the spatial arrangement of geographical entities, namely, the orientation relations between entities, such as front and back, left and right, east and west, north and south, etc.; metric spatial relations mainly refer to the distance relation between geographic entities; part-of represents the relation between a part and the whole of a geographical concept, for example, the Taiwan Province is a part of China; kind-of represents the inheritance relationship between geographic concepts, similar to the relationships between the parent class and subclasses in object-oriented relationships, for example, a perennial river and seasonal river are subclasses of a river; instance-of represents the relationship between geographical concept instances and geographic concepts, similar to the relationship between objects and classes in an object-oriented relationship, for example, the Beijing Shenyang Expressway is an instance of a highway; finally, attribute-of represents that a geographical concept is an attribute of another geographical concept, for example, the concept “flow” is a property of the concept “river".

A geographical function is a special kind of geographic relationship in which the preceding n-1 elements can uniquely determine the nth element. For example, on a given DTM surface, the geographical coordinates X and Y can uniquely determine the Z value (which can be an elevation or a certain concentration of chemical substances), and then, there exists a functional dependency between the geographical concept Z and X and Y.

In practical applications, it is not necessary to construct ontology in strict accordance with the above 5 tuples, and the relationship between concepts is not limited to the two basic categories and 7 basic relations. In addition, the instance-of in instances and non-spatial relations seem to have a possibility of repeated definitions, which should be paid attention to in the construction of geographical ontology.

With regard to ontology and its research in the field of geographic information science, overseas studies occurred earlier and more literature and achievements have been made; China’s research in this field started in the early twenty-first century, which was less than 10 years, but the progress is unusually rapid, and some preliminary theories and application results have been obtained.

In search of the Wanfang database and VIP database, the first formal thesis related to geographical ontology was ‘Resource and environment information classification and coding and their relationship with geographic ontology’ written by He et al. (2003), in which the concept of geographic information ontology was discussed, and a suggestion to use information ontology technology to classify resource and environment information was proposed. In Ren (2003), the problem of ontology-based distributed information access and interoperation was studied, and an ontology-based framework for interoperable systems was constructed, including a source system directory, search engine, shared ontology service, mapping service, ontology interface, source level local ontology set, user query interface, etc. Cui (2004a) completed his first doctoral dissertation on geographic ontology, which was the research topic of the semantic integration and interoperation of geographic information system based on ontology. Sun et al. (2004) summarized the studies on geographical ontology. Wang et al. (2004) proposed an ontology-based middleware for geographic information systems (GISs), which was located between the GIS platform and the application program, and the semantic interpretation of spatial data was realized through an ontology library and an ontology server, and then, the tight integration of the GIS application system was realized. In An et al. (2004), an ontology-based method for describing and discovering network geographic information services was proposed, a concept layer and an application layer were used to describe geographic information services, and after the service was published, the degree of matching between a service and user was judged by measuring the input and output parameters in the service description and the function description in the user requirements; finally, the service discovery was implemented. In Cui (2004b), a new approach for interoperation between information systems using data mining and ontology was proposed, where semantic transformation between different spatial information systems was implemented through ontology-based logical reasoning, and the transformation set was determined from the candidate set by using data a mining technique; additionally, the result of the operation was returned to the user, and thus, the interoperability of the spatial information system was accomplished; finally, the robustness and flexibility of the interoperation of the spatial information system were improved. In Wang et al. (2005), the problem of semantic heterogeneity in the process of system integration was discussed, the possibility of using ontology to solve semantic heterogeneity was analyzed, and a method for building ontology in a data integration environment was described. In Wu et al. (2005), an information integration method based on hybrid ontology was studied, and through mapping between global ontology and local ontology, a unified interface for data accessing was provided to enable users to access semantically relevant data. In Tan et al. (2005), a geospatial information system interoperability based on standard spatial ontology and hybrid semantic ontology was proposed, and through ontology collaboration, heterogeneous spatial information interworking based on standard spatial ontology and spatial information reclassification, as well as semantic interoperability based on the hierarchical matching of heterogeneous semantic ontology were realized. In Jing et al. (2005), the meaning and levels of geospatial information sharing were analyzed, and referring to the research idea of semantic web, a framework for semantic sharing of geospatial information was established, and finally, ontology-based concepts and methods were proposed to formally define the domain knowledge and solve the problem of the semantic ambiguity of geographic entities in geospatial information research.

If the introduction of ontology to the artificial intelligence field is mainly based on the purpose of knowledge sharing and reuse, then the ontology of geographic information science has the dual meaning of both philosophical ontology and information ontology. Philosophical ontology focuses on the geographic object domain itself, mainly involving the research of geographical concepts, categories, relations and process, and the spatiotemporal ontology, uncertainty ontology and scale ontology are also important embodiments of philosophical ontology. Through the study of philosophical ontology, especially the design of geographical categories and entity types in the geographical object domain, the purpose is to produce a better understanding of the structure of the geographical world, provide a more rational conceptual model for the development of GIS, and finally avoid the large contrast between the existing data model and the spatial cognition mechanism of human beings.

Geo-ontology is a domain ontology, which acquires consistent knowledge in the domain of geography, and this knowledge is not private for an individual and can be accepted and shared by a community.

The purpose of building geo-ontology is to define a common vocabulary for researchers who need to share information in the geographic domain, which includes the definition of concepts in the geographical domain and the relationship between concepts; further, a common understanding of structured geographic information is shared among people or software Agents to support the reuse and analysis of geographic domain knowledge, as well as for other purposes.

First, geo-ontology can share the common understanding of structured geographic information among people or software Agents, which is one of our common goals in the field of geographic information science research. For example, suppose several different websites contain geospatial information or provide navigation and geographic information services; if these sites share and publish the same underlying ontology for all the terms they use, then computer Agents can extract and integrate information from different sites. These Agents can use this integrated information to answer the user's request or use this information as input for other applications.

Second, geo-ontology supports the reuse of geographic domain knowledge. Geographical information has the characteristics of socialization, accounting for approximately 80% of the Earth's information. The widespread use of geographic information is the driving force behind today's geo-ontology research. For example, many different domain models need the concept to express geographic space; if a researcher develops a geo-ontology that includes location information, directional information, and coordinate reference information and others can reuse it in their domain, then we can integrate the geo-ontology with other existing ontologies to describe each part of a wider range of applications. In addition, geo-ontology supports the reuse of expert knowledge and expands it to describe areas of interest for people.

Third, the creation of geo-ontology makes explicit assumptions about the geographic domain, which is the basis for the implementation of geo-ontology. If knowledge in the geographic domain changes, then geo-ontology will likely be able to adapt to these changes more easily, thereby changing these hypothetical expressions. Typically, at the programming language level of knowledge about the real world, the expression of hypothetical hard code not only makes these putative codes difficult to understand but also makes these assumptions difficult to change, and especially for those without programming experience, it is harder to make changes at the code level. Furthermore, explicit specification of geographical domain knowledge is useful for new users who have to understand the meaning of terminology in the geography domain.

Fourth, Geo-Ontology can separate domain knowledge from actionable knowledge, which is another common use of ontology. We can describe the configuration task of a GIS component based on the requirement specification of GIS development, and we can finish the configuration by using a program that has nothing to do with the product or its components.

Fifth, geo-ontology can help us analyze the knowledge in the field of geographic information. Once the specification of a term display can be exploited, it is possible to analyze domain knowledge in a geographic area. Formal analysis of the term set is of great value in the need to reuse existing ontology and extend them.

13.3 Development Process

The research of geographical ontology in China started in the early twenty-first century, and the related research results can be found in much of the literature since 2000. By summarizing the literature over the last 10 years, we find that achievements have been made in theoretical research and method exploration, but there is no practical system. Specific studies and results are primarily reflected in the following aspects.

13.3.1 Reviews of Studies on Geographical Ontology

The domestic research on geographical ontology started later than in other countries. Based on reading a large amount of literature and data, many scholars have created a general description of the international research progress of geographical ontology and played an active role in guiding Chinese scholars to study geographical ontology.

In the article "Geo-ontology, geographical information ontology" (Sun 2004), the ontology of geographic information was systematically explained, and the main research content, hotspots, research plans and research directions of geographic ontology were discussed in detail. In Wu et al. (2006), a human-Earth relationship discussion based on subject-human and geo-ontology was made through the analysis of geo-ontology and ontology, the relationship among geo-ontology, scientific ontology and philosophical ontology was discussed, the differences and relationships among geo-ontology and classes and metadata were analyzed, and then, a new model of "human-land-GIS", which considered geo-ontology to be the core, was constructed; the model was divided into two parts of cognition and reproduction and consisted of the core ontology model and human cognitive layer, GIS model layer and "geo learning" phenomenon and their relational layer; taking the subject-human cognition as the main line, the functions and relations of each module in the model were discussed, and the future development direction was pointed out.

In Chen et al. (2006a, b), the definition of ontology in the scientific domain was deeply analyzed, and on this basis, the definition of geographical ontology was given, the research significance of geographic ontology was discussed, the major international planning and academic conferences related to geographical ontology were cited, and the progress in the research and application of geographical ontology at home and abroad was analyzed in detail; finally, it was pointed out that geographic ontology was a new and developing field in geographic information science, and China should keep up with the research trends of international geographical ontology and actively carry out research on geographical ontology theory, methods and applications. In Xu et al. (2007), a new architecture of GIS was proposed for the application of ontology in GIS. In Li Hongwei et al. (2008), the software engineering method of GIS development based on ontology was discussed, and on the basis of analyzing the general methods of traditional information system development, the evolution from GIS modeling to ontology-based information system modeling was discussed, an ontology-based two-layer structure system for GIS development was constructed, the technical approach of geographic information searches based on ontology was discussed, and the mapping between ontology and the concept paradigm was analyzed and summarized.

13.3.2 Research on Geographic Ontology and Geographic Information Classification

Classification is the most basic reflection of a human's cognition and perception of geographical objects. When people face complex geographical environment objects and their relationships, the first thing they think of is the division of class, grade and attribution; thus, through the process of "cognition, practice, recognition and repractice", a basic geographic information classification system was summarized and perfected according to the characteristics and rules of geographical objects, and finally, the standardization of the geographic information classification was realized. The application of geographic ontology to geographic information classification is said to be the promotion of geographic information classification in cognitive methodology. In He (2003), the classification and coding of resources and environmental information and its association with geographical ontology were studied. It was pointed out that using geographical ontology to classify and encode resources and environmental information was prospective research work. In Li et al. (2004, 2005, 2006), based on an analysis of the existing classification methods of geographic information and according to cognitive classification and taxonomy, ontology classification methods were discussed in detail; taking drainage in natural geographical elements as an example, an experimental study of ontology classification was carried out; then, the concept of geographic information was divided into two categories: meta concept and compound concept; based on certain constraints and according to the meta attributes of the geographical information concept, the classification of basic geographic information was realized by way of formalization. In Li et al. (2007, 2009), the classification and hierarchical representation of land use data based on ontology were studied; a concept in the hierarchical system of geographic data described by OWL was used to navigate to its parent concepts or sub concepts, and by merging elements in a geographic element class associated with all the sub concepts of a geographic concept in a geographic ontology, the combination of geospatial data contents was realized; finally, by categorizing the elements in a geographic element that was associated with a geographical concept in the geographical ontology as the element classes that are associated with their sub concepts, the specialization of geospatial data contents was realized. It was pointed out that the classification and hierarchical representation research of geographic data based on the ontology method was a useful supplement and enriched the current visualization methods of geospatial data.

13.3.3 Research on Construction of Geographical Ontology

The construction of geographic ontology is the key step in applications of geographic ontology. The construction of geographic ontology is a very complicated task; it needs to be based on the cognition of geographical objects and not be done by a person or a geographic community alone; only those individuals, organizations and institutions engaged in the study of geographical ontology together are able to make breakthroughs. At the same time, the construction of geographic ontology is one of the key issues for semantic sharing. Domestic research on the construction of geographical ontology is very dispersed, the research results are mostly in experimental ontology in related papers and writings, which are relatively simple and ideal, and it is hard to find a large-scale geographical ontology project. In Huang et al. (2004), several simple geographic ontologies were constructed by using OWL language, and the way to construct the ontology for a geographic information service was explained. In An et al. (2006), geographic ontology was established based on GIS, the concept of geographic ontology was compared from two aspects of structure and semantics, and the similarity calculation was implemented and used to judge the relationships among various geographical concepts. In Han et al. (2006), the establishment of domain ontology for railway line selection was discussed, and a comprehensive solution for railway intelligent line selection was put forward. In Liu et al. (2007), a generalized geographic name and its ontology was studied, and the corresponding conceptual models and logical models were given; then, the generalized geographic name ontology was described from the aspects of the generation method of generalized place names, describing objects, geographic scope, information groups and ambiguity caused by context, and so on; finally, a logic model that was easy to implement in the information system was established by using UML language. In Li et al. (2008), a conceptual framework and a structure for place name ontology were studied, the concept design of place name ontology was carried out, a conceptual framework and design method for constructing geographical name ontology by comprehensively using place name dictionary and geographical thesaurus were proposed; it was pointed out that the place name ontology was composed of three kinds of geographical ontology: geographical entity, entity type, and spatial relation, and its structure design was introduced in detail. In Bian et al. (2008), the problem of how to construct location ontology for geographical knowledge base was studied, which laid the foundation for solving the spatial location, expression and retrieval of geographic knowledge in the geographic knowledge base. Taking the Liaodong Bay as an example, a bay geographic ontology was constructed by Du et al. (2008), and a conceptual model that reflects the hierarchy of the bay's geographic entities was established, which was used for gulf data organization and data management.

13.3.4 Research on Spatial Data Organization, Management and Expression Based on Geographic Ontology

Spatial data organization and management was the core content of GIS, which involved the expression of geographic objects, entity modeling, database design and so on. The introduction of geographic ontology into spatial data organization and management provided a richer choice of methodology. In view of the deficiency of OWL language to express geographic ontology, Huang et al. (2005) proposed to construct some formal axioms about spatial properties and spatial relations with the help of three theoretical tools, that is, mereology, location theory and topology, and then, they added these new axioms to the OWL axioms to build the geographic ontology, which represented its spatial properties. The tests proved that the formal representation mechanism was feasible and could effectively describe the spatial properties of geographic ontology. In Wang et al. (2006), the key factors affecting multiscale representations from road features were analyzed. It was considered that multiple abstraction and representation schemas were caused by inconsistent conceptual cognition, abstractions and representation rules, which was a natural ontological problem when ascertaining multiscale entities and relations from multiscale representations. Thus, an ontological solution based on the natural principle was provided to accommodate the inconsistent conceptual cognition, in which cartographical natural rules served as a basic and general guideline in modeling multiscale representations. Based on these strategies, multiscale objective abstractions and quantitative representations were implemented in the following steps, namely, smallest visible object (SVO) measurement, geometry type abstraction, and semantic relation investigation. Thus, it was followed by a detailed description of multiscale geometrical abstract type and entity hierarchy during road network multiscale conceptual views, as well as the hierarchical semantic relations at both the feature class level and representation level, which provided a unified and objective multiscale conceptual view for multiscale road network modeling. In Zheng et al. (2006), a formal approach based on DL ontology was presented to support multiple representation, which virtually implied the capability to model and access geographic information flexibly under different resolutions or different viewpoints. As an explicit specification of conceptualization, ontology was adept in semantic expression and played a key role in information sharing and integration. It was a promising means to construct a conceptual data model close to geographic reality based on formal ontology. To formalize the basic topological relationships between regions and the varying semantics due to different viewpoints or levels of abstraction, two extensions to the classical description logics about the concrete domain and context were created. With extensions to DLs and context, a framework for the multirepresentation geo-ontology (MRGO) was finally proposed. It provided a consolidated and logic-based foundation for the flexible representation of semantic multiplicity, as well as consistent modeling of geometric multiplicity. According to Yang et al. (2007), the design of spatial databases was often challenged by opposing needs, such as the expertise need or the corporate need, and the ontology-oriented heuristics design of the spatial database balanced these needs by exploiting a domain ontology model. Thus, a practical spatial database system was completed. Practical applications showed that the mechanism was feasible. According to Su et al. (2007), aiming at deficiency of building conceptual model of spatial database with the E-R model, the ontological ideology and methodology were introduced into the geographic information domain. The exact meaning and its formal represented language of geographic ontology were discussed. The characteristics of the spatial E-R model were clarified and the relationship between geographic ontology and the spatial E-R model was analyzed. The concept of designing the spatial E-R model based on geographic ontology as a semantic foundation was presented. In addition, a method of establishing conceptual model of a spatial database by designing a spatial E-R model from geographic ontology was introduced with an example of irrigation ontology represented by expanded OWL. According to Du et al. (2008), the bay was a complicated multisource, multidomain, multifeature and multihierarchical system, and its way of spatial data organization was crucial to building a digital bay. The paper used the idea of geo-ontology to represent the bay and put forward a new spatial data organization method based on geo-ontology based on the analysis of the layer-oriented and feature-oriented way of spatial data organization, as well as metadata technology. The steps in the method were as follows: first, the bay ontology was modeled, which included a conceptual model reflecting the hierarchy of the bay well. Then, a spatial database of the bay, which was based on geo-ontology, was reconstructed according to the mapping relationship between the bay concepts and existing multisource geo-datasets. Thus, the integration and management of the multisource spatial data for the sea area, land area and intertidal zone was realized. In the third part of the paper, the Liaodong Bay was taken as a case study, and its related multisource spatial data was well organized using the above method. The result showed that using the idea of geo-ontology to organize and manage the geospatial data was helpful for the understanding of users from different domains and was good for the semantic sharing and interoperation of the spatial information of the bay.

13.3.5 Research on Geographic Information Retrieval and Geographic Knowledge Query Based on Geographic Ontology

Geographic information query and retrieval is the most basic and common function of GISs. The introduction of geographical ontology theory and methods is not to overthrow the existing theories and technologies in GISs but to explore a new method for the effective organization, management and scheduling of geographic information and to provide more efficient geographic information services. Therefore, geographic information retrieval and geographic knowledge query are still the important contents of ontology-based GISs. Wang et al. (2004) believed that spatial information querying methods in traditional GISs had many limitations, their operation was complicated, the presentation of querying results was highly formalized, and their user interfaces were so complex that they were not suitable for most people or decision making; an ontology is a formal, explicit specification of a shared conceptualization, and as a tool for conceptual modeling, which can describe information system on a semantic and knowledge level, it is quite suitable for information retrieval on the semantic and knowledge level. In their paper, they developed a new spatial information query method, named ODSKQ, which means ontology-driven spatial knowledge query. The ODSKQ method was built directly for users who did not have special knowledge on GIS, and it used natural language to describe querying conditions. The result of querying are highly synthetically and knowledgeable, providing users direct answers while hiding the complicated calculation and reasoning processes; it is indeed a highly humanized, intelligent spatial querying method. At the end of the paper, they took spatial query of resources and environment domain in the coastal zone as an example to verify the possibility and usefulness of ODSKQ, and the result showed that the ODSKQ method was very useful and powerful in the process of solving spatial problems. Fu et al. (2006) described a design idea and process of the intelligent information retrieval based on semantic web technologies in detail and proposed a framework of an ontology-based information retrieval system. What is more, the paper also provided an analysis of the implementation technologies based on an application of the geographical information domain. Yu et al. (2006) built an Ontology-based Geographic Information Inquiry System (OGIIS). The process is outlined as follows: at first, the geographic ontology instance was created by using the Geo-Ontology Building Algorithm (GOBA) and was based on reference ontology; then, indexes were built and inference was done on the geographic ontology instances; through reasoning and semantic description, OGIIS performed precisely and intelligently. In his dissertation for the degree of master of science, Li (2007) discussed several methods that improved query efficiency, including optimized query, expanded query and presentation of query results-based geographic ontology, as well as designing and realizing an urban geographic information query prototype. This prototype system benefitted from the recall in the traditional information system to query spatial information (that is, input vocabularies or sentences) and satisfied people's custom queries and reduced difficulties for users in query spatial information. At the same time, the dissertation explored the problems of using ontology to optimize and expand queries and realized intelligent spatial information query knowledge and semantic levels.

13.3.6 Research on Geographic Information Sharing and Interoperation Based on Geographic Ontology

Geospatial information sharing is an important part of GIS research. The development of the GIS has a nearly 20-year history in China. Over the course of development, for various reasons, there exist some phenomena, such as different understanding of geographical objects, different data definitions, different data modeling methods, different geographic data organizations, different spatial data formats and so on, which form the so-called "information isolated islands", and this leads to difficulty in sharing geographic information. In this context, a great deal of research has been conducted on the sharing and interoperability of geographic information. Especially today, network technology is highly developed and increasingly popular, and the interoperability of geographic information has been increasingly conspicuous. How do we freely exchange all the information about the Earth? How do we collaboratively run the software that manipulates the information over the network to accomplish the task of communicating and cooperating with two or more than two entities in a heterogeneous environment and realize the blending and matching of each component of the information system freely? This is the goal of geographic information sharing and interoperability. Geographic ontology contains rich semantic information, which makes the definition and representation of geographical concepts clear. It brings new opportunities for the realization of geographic information sharing and interoperability. The research of spatial information sharing and interoperation based on geographical ontology has achieved fruitful results. On the basis of analyzing the ontology-based information system, Cui (2004a, b) introduced an interoperability mechanism, which used ontology and OIL as the foundation. Through integrating the ontologies that were linked to the sources of geographic information, multisource geographic information was integrated dynamicity and openly based on its meaning and the efficiency and accuracy of the interoperability of GIS was improved. In Jing et al. (2005) explored geospatial information semantic sharing based on ontology and Agent; they discussed the connotation and layers of geospatial information sharing, made use of semantic web research and presented the research framework of geospatial information sharing. To solve the ambiguous meaning of geospatial information research and application, the ontology concept and method were adopted and domain knowledge was formally defined. Furthermore, the authors discussed how to support semantic information sharing and interoperation among users; they presented query information and semantic mapping based on Agents to clarify the different understanding among geographical information communities and obtained a common meaning and realization of information. Li et al. (2005) applied ontology to achieve the semantic integration of the intelligent transport system. The thesis built the basic noumenon, the domanial noumenon and the applied noumenon oriented to the semantic integration of China, as well as introduced the noumenon classification, studied the expression methods and advanced the framework based on the noumenon according to the national intelligent transport system architecture. Tan et al. (2006) developed heterogeneous spatial information systematic interoperability based on Bayes data classification and ontology and presented a feasible scheme for ontology-based semantic interoperation between heterogeneous GISs. The concept matching of heterogeneous spatial information was obtained by the ontology, and the Bayesian classification technique was used to classify the geo-ontology objects. By using this technique, the semantic interoperation between the heterogeneous GISs was obtained. Wang et al. (2006) proposed that ontology should be introduced to GIS, such as construction of ontology, aimed at the difficulty in data exchange and data sharing for different GISs. The data and information sharing as well as the accomplishment of different functional modules in ODGIS could be solved by means of the interoperabilities among different ontologies. Cui et al. (2007) studied the semantic interoperability of Geo-Agent based on ontology to meet the semantic requests of GISs, and the concept of the ontology-based Geo-Agent (geography Agent) was defined. Using Geo-Agent, the geography data were encapsulated by geography ontology so that a conceptual interface was exhibited to other Agents. The semantic relationships among the GIS nodes were built by logical reasoning. A virtual environment was established after all GIS nodes were integrated into a global ontology by using the semantic relationships. An example was given; the example provides details on how the Geo-Agent could transparently and effectively access the information and serve as a semantic tool for the decision support system. In Wu et al. (2007), the research on ontology-based heterogeneous spatial data integration was carried out, the framework of spatial data integration based on ontology was improved, and integrated experimental research was conducted. Guo et al. (2008) studied the integration method of hydrologic feature data based on ontology. In the paper, the basic concepts, components and construction methods of geo-ontology were briefly introduced. The integration framework of geospatial data based on geo-ontology was presented. The geo-ontology integration was a hybrid architecture based on the common intension properties template. Finally, taking the class of dry shoal, which is an element in hydrologic feature, as a case study, the progress of geo-ontology integration and the data transition method were realized. The difficult problem of data sharing caused by semantic heterogeneity was solved in this way.

13.3.7 Research on Geographic Information Services and Their Compositions Based on Geographic Ontology

The basic purpose of GIS is to provide users with rich, practical and easy to use geographic information services. The form and content of providing geographic information services by GISs has also undergone profound changes, from data services to functional services, service composition, personalized services, etc., and its standardization degree is becoming increasingly higher. However, one problem that cannot be ignored is that while providing a variety of services, the GIS has been faced with the confusion of semantic problems. The introduction and application of geographical ontology theory and methods can make up for the lack of semantic information, which will help GISs to provide better geographic information services. Geographic information services and their combination based on geographic ontology has become the focus of research in recent years. Chen et al. (2006a) implemented spatial information web services based on ontology. To improve the interoperation of spatial information, a new solution to implementation of discovery and retrieval for spatial information web services based on ontology technology was proposed. After the knowledge expression of web services capacity using web ontology language for services (OWL-S) was introduced, an architecture for spatial information interaction was constructed, and a semantic matchmaker based on ontology was added into the traditional service registry center in the architecture. A practical process of service request under the framework of spatial information web services was given in the framework of standard open GIS consortium (OGC) web services. The results showed that the ontology technology could extend the semantics of web services, reuse the same or similar web services, and improve the efficiency of reasoning. In Le et al. (2006), geo-ontology instances search for QA-based mobile spatial information service was studied. Based on the technology of the common search engine, the paper defined several spatial semantic roles and instance expression patterns according to geographic ontology, and large quantities of geo-ontology instances were searched by means of spatial semantic annotation, semantic phrase recognition and pattern match. It also provided QA-based instance service for mobile user with the help of semantic web technology. The preliminary experiment showed good precision, but the recall rate needed to be further improved. Jiang et al. (2007) designed geo_DataType ontology and geo_ServiceType ontology. An approach for geospatial web service discovery was proposed, in which geospatial web services were described and advertised by OWL-S, and then, a matching degree was ranked according to the input/output and service category for requested and advertised service descriptions to implement web services discovered automatically. Semantic heterogeneity from various fields still could not be solved by the existing GridGIS resource sharing technique, and for that reason, the method of constructing distributed ontology was discussed, and a framework of GridGIS service discovery based on semantic similarity matching was proposed by Rao et al. (2007). The transmission mechanism of spatial information service was studied in Chen et al. (2007), the idea of setting up relevant ontology for each process to implement information conversion was put forward, and then, a solution for the intelligent service of spatial information was explored. Cheng et al. (2008) proposed a design method for the geographic information service discovery component based on ontology, which combined ontology-based metadata and ontology-based query to improve the query efficiency and accuracy of network geographical service discovery based on the OGC standard. In Li et al. (2008), the geographic information web service automatic composition based on task-ontology was discussed, the semantic relationships between specific task-ontology concepts were analyzed, and the technical routine of web service matching was described. The concept of service composition implementation matching rules was defined, and the steps of geographic information web service automatic composition algorithm were discussed. By this research, users could find all service composition projects that satisfied the requirements from the existing web services and chose the best service composition project by comparing service the composition implementation matching rules. The research played an important role in the computer explanation of semantics on geographic information web services. Wang et al. (2008) studied the key technologies in the automatic discovery and composition of geographic information services based on the semantic web, which are listed as follows: semantic geographic information service description of OWL-S, OWL-S geographic information service description supported by extended UDDI, geographic information service matching algorithm for similarity computation of geometric distance, and semantic geographic information service composition based on multi-Agents.

13.3.8 Research on Spatial–temporal Geographic Ontology and Its Reasoning

Spatial features are unique to GISs. Spatial features refer to the geometric features of space, such as location, shape and size, as well as the spatial relationship with adjacent objects. The spatial characteristics of topology, geometry, location and orientation have an important and even decisive influence on the construction of geographical ontology, and it is also the essence of geographic ontology, which is different from the general information ontology. Temporal features reflect the temporal evolution of geographical objects, and temporal ontology is an important aspect in the study of geographical ontology. Spatial–temporal geographical ontology comprehensively reflects the temporal and spatial features of geographic objects and is the basis of spatial reasoning. In the paper, Research Progress in Spatial–Temporal Reasoning, Liu et al. (2004) believed that temporal and spatial reasoning were two important parts of artificial intelligence and that they had important applications in the fields of GIS, spatial–temporal database, CAD/CAM, etc. The development of temporal reasoning and spatial reasoning was discussed from three aspects: ontology, representation model and reasoning methods, and the research progress of spatial–temporal reasoning was summarized. The problems in the current research were discussed and the future directions were pointed out. Xu et al. (2005) studied spatial–temporal ontology and its application in GISs. They analyzed the spatial–temporal characteristics of GIS, introduced the cellular automata, proposed a formal definition of spatial–temporal ontology and a method based on spatial–temporal semantic granularity, discussed an integrated GIS architecture based on ontology and semantics, preliminarily implemented the creation and browsing of the railway passenger traffic spatial–temporal ontology, and realized the sharing and reuse of ontology among the GIS subsystems by integrating bidirectionality in an experimental railway GIS project. Min et al. (2006) introduced the basics of geographical spatial–temporal ontology, which included the primitive, property and representation models of temporal ontology and spatial ontology. Then, the research progress in geographical spatial–temporal ontology was reviewed. The problems in the current research were discussed and the future directions were pointed out. Based on the background of GIS ontology theory, Wang et al. (2007) used the representation and reasoning solution based on ontology and SWRL to realize spatial relation representation and reasoning in the tour map of Xi-an based on ontology. The results showed that combining ontology description language and SWRL to represent the conceptions and rules in spatial relation representation and reasoning not only improved the interoperability between the rules and ontology but also helped to quickly and dynamically update the spatial relation information in the geographic information ontology base.

13.3.9 Research on the Geospatial Semantic Grid

In 2000, Berners-Lee, founder of the World Wide web, proposed the concept of the semantic web and its seven-layer architecture at the world XML conference, in which the function and value of ontology were fully embodied. He believed the semantic web would be the next generation Internet. The main purpose of the semantic web was to enlarge the current WWW, and the web semantics information would be understood by computers and enable easy communication and cooperation between human and computer. In his proposed semantic web architecture, Berners-Lee gave a detailed description of the hierarchical relationships in the semantic web, and on this basis, ontology and logic inference rules were constructed to implement semantic-based knowledge representation and reasoning. In the semantic web, all the information was added with clear semantic information so that an Agent (intelligent Agent) could processes the resources on the network automatically. In this seven-layer architecture, the fourth layer was about the ontological vocabulary, which was used to define shared knowledge. Ontology revealed more complex and abundant semantic information between the resource itself and among resources, and as a result, the structure and content of the information were separated, and the information was completely formalized so that the information on the Internet could be understood by computers. After the seven-layer architecture of semantic web was put forward, researchers engaged in geographic information services at home and abroad and transplanted it into the field of geographic information science; combined with the practical application requirements of geographic information services, the concepts and architectures of spatial information, semantic grid and geospatial semantic web were put forward, which promoted the development of geographic information science to a certain extent. According to Cui et al. (2005a), to meet the semantic request of the geography information systems, the concept of the semantic-based spatial information grid (SSIG) was defined and the method to build SSIG was advanced. Using this method, SSIG could be built as following three steps: the first was that GIS data were encapsulated by geography ontology so that a conceptual interface was exhibited to the grid management layer; the second was that the semantic relations of the GIS nodes were built by logic reasoning; and finally, all GIS nodes were integrated into SSIG by using the semantic relations. A virtual environment was established after SSIG was built. The virtual organization lightened the burdens of guests and the data access procedure was transparent to guests, that is, guests could access information from remote sites using the current disk. An example was provided in the paper, which showed a detailed way to design and build SSIG. In conclusion, SSIG could improve the ability of the integration and interoperability of GISs. In Cui et al. (2005b), to meet the semantic demand of the spatial information grid and expand the data types of computer grid, the ontology and LDAP (lightweight directory access protocol) were combined to create a resource management system for the spatial information grid. The LDAP could filter the nature of the local ontology systems to construct a virtual organization, which provided a global directory service. The result showed that the semantic grid of the spatial information system, which combined ontology and LDAP, could improve the integration and interoperability of the spatial information grid. In Li et al. (2006), to integrate spatial information systems, the geographic ontology and geographic grid were used, and the spatial information system grid (SISG) was built by using the geographic ontology and grid. The geographic ontology was used to describe the meaning of the geographic objects, and the geographic grid was used to manage, index and store spatial information. SIMG could integrate the spatial information system and improve the sharing and utilizing of spatial information. Li et al. (2008) discussed in detail the basic and core issues of geospatial semantic grid research-semantic analyses of the fundamental geographic information. By exemplifying inland hydrological categorization in the domain of the fundamental geographic information in China, a discussion was made on the ambiguous semantics of the normative definitions of categories in some specifications. Ontology was regarded as an effective means to overcome semantic barriers in the domain of geographic information. A paradigm of formal semantic analyses of geographic information was put forward in the paper in terms of the formal ontology. With conceptualization of a category, attributes of a category were used for expressing its semantics. By examining the given hydrological categories, the formal semantics of each geographic concept were explicitly specified by a set of the defined ontological properties over its attributes.

13.4 Problems and Prospects

At present, experts and scholars from the field of geography, cartography and GIS, database technology, computer technology and artificial intelligence have been aware of the enormous potential and application prospects of geographic ontology research; however, the research achievements of geographical ontology are still mostly theoretical research and exploration; several small-scale experimental systems have been designed and implemented, but a large geographical ontology project has not yet appeared; the application system of geographic information services based on geographic ontology is rare; compared with foreign research in the same field, there is a large gap. The main reason is that there is not enough research, and studies are scattered and lack coordination. The atmosphere of joint research is far from being achieved, and there is a lack of a corresponding mechanism. In view of the distribution of research power, at present, the research units studying the theory and method of ontology mainly include Wuhan University, Peking University, Institute of geography of Chinese Academy of Sciences, Institute of Remote Sensing Applications of Chinese Academy of Sciences, and School of Surveying and Mapping of Zhengzhou Information Engineering University.

In the future, the research of geographical ontology should focus on the following aspects.

1. **Combined research with the semantic web**

After the semantic Internet is proposed, the underlying domain ontology must be well defined so that the semantic web can be constructed smoothly. The foundation of the semantic Internet is ontology. To make formal ontology understandable to computers, it must be used to define the meaning of data and metadata in Internet resources. As an important resource of the semantic Internet, it is an important subject for geographic information science to integrate geographic information resources into the semantic web. Abstract and construction of geographical ontology is its important foundation. How do we make geographic data and information run on the global information grid? Realization of geospatial data sharing and interoperation needs to be supported by the ontology database to establish a unified semantic network for the semantic description and transformation of the same object in different specialized spatial databases.

2. **Semantic interoperability between GISs**

Realizing the sharing and interoperation of geographic information resources is an important development direction in GIS. From the perspective of information, to realize interoperability of two systems, their information models must be interoperable; and to realize interoperability of information models, the two systems must be syntactically and semantically interoperable. Syntax interoperability refers to the problem that information in two systems are flow and processed using the same structure, which has been basically solved. Semantic interoperability indicates that the two systems have the same semantic understanding of information flow and processing.

3. **Change from data construction to both data and geographical ontology construction.**

Geo-data is a digital record of geographic concepts or geographic entities, reflecting the spatial, attribute and temporal characteristics of the recorded object. Geographical ontology is a knowledge architecture of geographic concepts or geographic entities, which contains rich semantic information, including entity type ontology, spatial relationship ontology and entity element ontology, reflecting the hierarchical relationship, subordinate relationship, and co-location relationship of geographic concepts or geographic entities. The synchronous record and construction of data and geographic ontology embodies the unification of the formalization of geographic concepts or geographic entity data models and the formalized knowledge of the spatial object domain itself.

4. **Semantic modeling in Earth sciences.**

The modeling of the Earth system requires the aid of ontology to enable models in different domains to interact, be reused, and share with each other. In describing these processes, it is necessary to describe the behavior of the process, the temporal and spatial characteristics, and the relationships to those of other processes. The collection of process descriptions forms a process library and becomes the basis for the simulation framework. The use and expression of semantics in Earth system modeling will enhance people's ability to study and investigate the environment systematically. The semantic web provides a new approach for the various solutions we described, as well as platforms, models, and useful model results.

13.5 Representative Publications

(1) ***Research on the integration and sharing of coastal zones and offshore scientific data*** (Du Yunyan, Zhou Chenghu, Su Fenzhen et al. Maritime Press, Beijing, November 2005)

This book is divided into 9 chapters and discusses the integration of coastal and offshore data based on geographical ontology. Among them, Chapter 1 discusses the concept of geographic ontology and its research progress at home and abroad and puts forward the problem of constructing the integration and sharing platform of coastal zones and offshore scientific data based on geographical ontology. In the fifth chapter, the method of spatial data integration based on geographic ontology is studied, and a spatial data integration framework based on geographic ontology is proposed; taking land use ontology and data integration as an example, the method of spatial data integration and transformation based on geographical ontology is studied; in the sixth chapter, based on the establishment of geographical ontology, the conceptual model of coastal zone and offshore area is given, and the ontology-based spatial data integration, display and query methods for coastal zones and offshore are analyzed and discussed; in the fourth section of the seventh chapter, a prototype system of coastal zones and offshore data integration platform based on geographic ontology is implemented, including the function design and technical realization of the prototype system; Chap. 8 is an application example of the data integration platform that was established in the seventh chapter, which takes the Fujian province coastal zone as the research object, and the bay spatial database based on ontology is established.

(2) ***Key issues and applications in geographic ontology*** (Huang Maojun. Press of University of Science and Technology of China, Hefei, December 2006)

The whole book consists of 7 chapters. Chapter 1 introduces the current situation and progress of geographical ontology research at home and abroad; Chap. 2 is entitled "philosophy ontology, information ontology and space ontology", which puts forward the profound connotation of geographical ontology, and points out that geographical ontology covers the 3 aspects of philosophy ontology, information ontology and spatial ontology; Chap. 3 discusses the logical structure and establishment method of geographic ontology, that is, based on a comprehensive summary of existing ontology construction methods, a general method for building geographical ontology is summarized; Chap. 4 is the analysis of OWL's ability to represent geographic ontology semantics, pointing out that OWL is the ideal language to express the geographical ontology, but it needs to be extended; Chap. 5 is entitled "the formal expression mechanism of spatial features of geographical ontology", in which 3 theoretical tools are proposed, namely, integration, topology and position theory, and formal spatial features and spatial relation axioms are constructed and added to the modeling primitives of OWL so that spatial features can be expressed in the geographical ontology constructed by OWL; Chap. 6 is about the ontology-based map service and its improvement; the chapter proposes a solution based on geographic ontology and points out that network map services are facing outstanding problems and cannot provide effective query services, so a comprehensive utilization ontology and web mining technology are proposed to improve the QoS of the network map query; and finally, Chap. 7 discusses the future research direction of geographic ontology.

(3) ***Geographic ontology and geographic information service*** (Li Hongwei, Cheng Yi, Li Qinchao. Xi'an Map Publishing House, Xi'an, April 2008)

This book explains the exact meaning of geographic ontology and its role and significance in the field of geographic information science. The basic theoretical problem of geographic information services based on ontology-semantic inconsistency are emphatically discussed, that is, using the concept lattice and formal concept analysis (FCA) method, the problem of semantic inconsistency is studied deeply with examples; the conceptual design of geographic domain ontology is implemented, and a framework of three-layer ontology is proposed. Ontology-semantic relations, including semantic similarity, structural similarity and semantic relatedness, are comprehensively analyzed, which lays the foundation for solving the problem of geographic information web service matching and discovery; the semantic description of ontology web services is described; using the web service ontology OWL-S, which is based on OWL language; a prototype of land use information display and query service based on ontology is implemented; the ontology-based geographic information service composition is discussed; GIS engineering based on ontology is summarized; and finally, the future directions of geographic ontology are discussed. This book shows the research potential and value of ontology in the field of geographic information science.

References

An, Y., Bian, F., & Guan, J. (2004). Geo web services description and discovery based on ontology. *Geomatics and Information Science of Wuhan University, 29*(12), 1063–1066.

An, Y., Bian, F., & Guan, J. (2006). Design and comparison of geo-ontology in GIS. *Geomatics and Information Science of Wuhan University, 31*(12), 1108–1111.

Bian, F., Mei, K. (2008). Building location ontology for geographic knowledge based. *Geomatics World, 6*(4), 27–32, 39.

Chen, J., Yang, S., & Li, C. (2006a). Implementation of spatial information web services based on ontology. *Journal of Zhejiang University (Engineering Science), 40*(3), 376–380.

Chen, J., Zhou, C., & Wang, J. (2006b). Advances in the study of the geo-ontology. *Earth Science Frontiers, 13*(3), 81–90.

Chen, Y., Cui, T., & Guo, Li. (2007). Research of transmission mechanism of spatial information intelligent service based on ontology. *Science of Surveying and Mapping, 32*(6), 8–9, 13.

Cheng, G., Du, Q., & Cai, Z. (2008). Ontology-based component designed of geographic information discovery. *Journal of Geomatics, 33*(2), 31–33.

Cui, W. (2004a). *Using ontology to achieve the semantic integration an interoperation of the geography information system.* Doctoral Dissertation of Wuhan University.

Cui, W. (2004b). Ontology-based GIS interoperability. *Journal of Geomatics, 29*(1), 20–22.

Cui, W., & Jiang, T. (2005a). Method to build semantic-based spatial information grid. *Journal of Wuhan University of Technology (Transportation Science & Engineering), 29*(3), 421–424.

Cui, W., & Li, D. (2005b). Geography ontology and LDAP directory service. *Journal of Wuhan University of Technology (Transportation Science & Engineering), 29*(4), 491–494.

Cui, W., & Jiang, T. (2007). Semantic interoperability of Geoagent based on ontology. *Engineering Journal of Wuhan University, 40*(1), 126–129.

Cui, W., Jiang, T., & Zhang, D. (2004). Using data mining and ontology to realize interoperability geographic information systems. *Journal of Wuhan University of Technology (Transportation Science & Engineering), 28*(1), 118–121.

Du, Q. (2001). *Study on linguistic characteristics and automatic understanding mechanism of spatial information.* Doctoral Dissertation of Wuhan University.

Du, Y., Zhang, D., & Su, F. (2008). Geospatial data organization of the bay based on the Geo-ontology: A case study of the liaodong bay. *Journal of Geo-Information Science, 10*(1), 7–13.

Fu, Y., Jin, L., & Wang, K. (2006). Design and implementation of ontology-based information retrieval system. *Application Research of Computers, 23*(11), 155–157.

Guarino, N. (1994). The ontologic level. In R. Casati, B. Smith, & G. White (Eds.), *Philosophy and the Cognitive Science* (pp. 443–456). Vienna: Holder-Pichler-Tempsky.

Guo, L., Cui, T., & Liu, G. (2008). Geo-spatial information integration framework and realization on ontology. *Journal of Geomatics Science and Technology, 25*(6), 462–465.

Guo, L., Liu, C., & Chen, Y. (2008). Study on the integration method of hydrologic feature data based on ontology. *Geomatics World, 6*(2), 42–47.

Han, C., Yi, S., & Lv, X. (2006). GIS based railway location intelligent environment and domain ontology modeling method. *China Railway Science, 27*(6), 84–90.

He, J., Li, X., & Bi, J. (2003). Research on classification and coding of resources and environment information and its association with ontology. *Geomatics World, 1*(5), 6–11.

Huang, M., Du, Q., & Du, X. (2005). Formal representation of spatial properties of geographic ontology. *Geomatics and Information Science of Wuhan University, 30*(4), 337–340.

Huang, M., Du, Q., & Wu, Y. (2004). A preliminary study on geographic ontology and its application. *Geography and Geo-Information Science, 20*(4), 1–5.

Jiang, L., & Gong, J. (2007). Geospatial web service description and discovery based on OWL-S. *Geomatics & Spatial Information Technology, 30*(5), 19–22, 27.

Jing, D. (2005). *A research on Geo-spatial information semantic expression and service based on ontology*. Doctoral Dissertation of Institute of Remote Sensing Applications, Chinese Academy of Sciences.

Jing, D., & Wu, F. (2005). Geo-spatial information semantic share on base of ontology and agent. *Geomatics World, 3*(4), 35–38.

Le, X., Yang, C., & Liu, D. (2006). Geo-ontology instances search for QA-based mobile spatial information service. *Chinese High Technology Letters, 16*(11), 1107–1112.

Li, D., & Cui, W. (2004). Semantic grid of spatial information. *Geomatics and Information Science of Wuhan University, 29*(10), 847–851.

Li, D., & Cui, W. (2006). Geographic ontology and SIMG. *Acta Geodaetica et Cartographica Sinica, 35*(2), 143–148.

Li, H., Cai, C., & Li, Q. (2009). The application of Jena in spatial information query and reasoning based on geo-ontology. *Engineering of Surveying and Mapping, 18*(5), 5–9.

Li, H., & Li, Q. (2009). The classified and hierarchical presentation of land-use data based on ontology. *Areal Research and Development, 28*(1), 82–85.

Li, H., Li, Q., & Duan, J. (2008). Research on GIS development methods based on ontology. *Computer Applications and Software, 25*(11), 69–70, 127.

Li, H., Yuan, Y., & Meng, C. (2008). Research on geographic information web service composition based on task-ontology. *Computer Applications and Software, 25*(7), 165–166, 176.

Li, L., & Wang, H. (2006). Classification of fundamental geographic information based on formal ontology. *Geomatics and Information Science of Wuhan University, 31*(6), 523–526.

Li, L., Zhu, H., & Wang, H. (2008). Semantic analyses of the fundamental geographic information based on formal ontology: Exemplifying hydrological category. *Acta Geodaetica et Cartographica Sinica, 37*(2), 230–235, 242.

Li, Q. (2007). *Research on ontology based geographic information retrieval method*. Master thesis of the Information Engineering University.

Li, S., & Gao, J. (2008). Conceptual framework of the ontology of place and its components. *Journal of Geomatics Science and Technology, 25*(3), 164–167.

Li, Y., Zhai, J., & Chen, Y. (2005). Using ontology to achieve the semantic integration of the intelligent transport system. *Information Technology, 29*(6), 10–13.

Liang, R., Li, S., & Li, W. (2010). Research on data management and retrieval service based on toponym ontology. *Journal of Information Engineering University, 11*(2), 175–179.

Liu, D., Hu, P., & Wang, S. (2004). Research progress in spatio-temporal reasoning. *Journal of Software, 15*(8), 1141–1149.

Liu, Y., Zhang, Y., & Tian, Y. (2007). On general place names and the associated ontology. *Geography and Geo-Information Science, 23*(6), 1–7.

Min, M., Tan, C., & Jiang, L. (2006). Research progress in geographical spatio-temporal ontologies. *Journal of HuaZhong Normal University (Natural Sciences), 40*(1), 132–137.

Rao, Y., & Liu, P. (2007). Study on architecture of Grid GIS services discovery based on ontology. *Geomatics World, 5*(4), 45–48.

Ren, M. (2003). *Research and implementation on the key technologies of the distributed UGIS*. Doctoral Dissertation of East China Normal University.

Shi, Z. (2004). Ontology scientific translation. *China Terminology, 6*(4), 13–14.

Su, L., Zhu, Q., & Chen, Y. (2007). Conceptual modeling of spatial database based on geographic ontology. *Computer Engineering, 33*(12), 87–89.

Sun, M., Chen, X., & Zhang, F. (2004). Geo-ontology. *Geography and Geo-Information Science, 20*(3), 6–11, 39.

Tan, X., & Bian, F. (2005). Heterogeneous spatial information interoperability based on cooperative ontologies. *Geomatics and Information Science of Wuhan University, 30*(2), 178–181.

Tan, X., & Bian, F. (2006). Heterogeneous spatial information system semantic interoperability based on Bayes data classification and ontology. *Geomatics and Information Science of Wuhan University, 31*(8), 724–727.

Wang, A., & Li, D. (2006). Knowledge sharing in construction of ontology-based geographic information system. *Journal of Northeast Forestry University, 34*(6), 107–109.

Wang, G., & Bian, F. (2008). Research on automatic discovery and composition of geographic information service based on semantic Web. *Science & Technology Information,* (6), 102.

Wang, H., Li, L., & Wang, Z. (2005). Classification tiers of fundamental geographical information based on ontology. *Geomatics World*, *3*(5), 27–30.

Wang, H., & Cao, H. (2007). A solution to spatial relation representation and reasoning based on ontology and SWRL. *Microelectronics & Computer, 24*(7), 166–168, 172.

Wang, J., Su, F., & Du, Y. (2004). Study on spatial knowledge querying methods based on ontology. *Journal of Geo-Information Science, 6*(4), 93–99.

Wang, S., & Liu, D. (2004). Ontology based geographical information system middleware. *Computer Engineering and Applications, 40*(22), 9–21.

Wang, Y., & Meng, H. (2006). Ontological analysis on entity and relation from multi-scale road representations. *Journal of China University of Mining & Technology, 35*(5), 689–694.

Wang, Y., Lu, Z., & Chen, Y. (2005). An ontology-based approach to data integration. *Computer Engineering and Science, 27*(6), 67–69.

Wu, H., & Xing, G. (2005). Research on technology of information integration based on ontology. *Journal of Computer Applications, 25*(2), 456–458.

Wu, L., Xu, L., & Chen, X. (2006). Human-earth-GIS relations discussion based on subject-human and Geo-ontology. *Geography and Geo-Information Science, 22*(1), 1–6.

Wu, M., Song, X., & Cui, W. (2007). On ontology-driven heterogeneous geographic data set integration. *Geomatics and Information Science of Wuhan University, 32*(10), 915–918.

Xu, J., & Zhao, Z. (2007). Ontology based geographical information system and its system structure research. *Microprocessors, 28*(4), 100–103.

Xu, W., Huang, H., & Qin, Y. (2005). Research on Spatio-temporal ontology and its application in Geographic information system. *Journal of the China Railway Society, 27*(4), 119–124.

Yang, J., Li, Y., & Cai, G. (2007). Heuristics design of spatial database based on ontology-oriented. *Application Research of Computers, 24*(5), 24–26.

Yu, W., Cao, J., & Chen, J. (2006). Distributed geographic information retrieval based on the geospatial semantic web. *Computer Engineering and Applications, 42*(30), 6–9.

Yu, W., Cao, J., & Chen, J. (2007). Geographic information retrieval and ranking based on ontology. *Computer Engineering, 33*(21), 157–159.

Zheng, M., Feng, X., & Jiang, Y. (2006). A formal approach for multiple representations in GIS based on DL ontologies. *Acta Geodaetica et Cartographica Sinica, 35*(3), 261–266.