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Construction and application of formal ontology for mine

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Abstract: Digital mine is the only way for the development of mining industry in China. Due to lack of appropriate standards and norms, and different awareness in the field of digital mine among academia and industry insiders, the meaning for digital mine is still unclear. Starting from the nature of mining and removing of views of specialized fields, this paper constructs formal ontology for digital mine and proposes the four levels for it. The ontology clarifies the concept world for digital mine, defines the meaning of concepts and relations clearly, provides a reference for the standard construction for digital mine and provides a unified semantic framework for the integration of heterogeneous mine data. Meanwhile, it can provide formal reasoning knowledge for expert system of digital mine and improve the intelligence and automation while the machine automatically interpreting and processing mine spatial data.

Key words: Digital mine; formalization; ontology; concept world; semantic share

1 Introduction

The degree of digital construction for mine marks the development level of a national mining industry. China is a big country of mining, whose gross reserves of mineral resources account for 14.64% of the total reserves of the world, ranking the third in the world, however, the digital and automation level of mine in China is still far behind those in Canada, Chile and other mining countries [1−2].

Digital construction of the mine has caused attentions of mine operators, researchers and even nations, a large number of researchers have proposed definition of the digital mine, basic framework, key technologies, its main functions from the perspective of their own profession [2−7]. WU [2] described that digital mine, with mine spatial data warehouse being its core, which is a complex great system comprised of data obtaining, integrated dispatching, engineering application, data processing and data management systems, and has data resource, information reference and opened platform as the three characteristics. ZENG et al [3] made a seven layers model for digital mine; LU et al [5] put forward the concept of smart mine. The two basic platforms of uniform transmission network and uniform data warehouse were proposed for the realization of digital mine by ZHANG et al [7]. So far, because of mining related in many industries and the cognition limitations from perspective, application purpose, specialized profession and other conditions, the understanding of digital mine is inconsistent, therefore a well-recognized definition for digital mine can not be formed.

From the application point of view, many systems are built. As the digital mine are built for different types and different business sectors of mine, the technical route taken and the application platform vary widely, so that the current systems are difficult to be integrated and the various information resources can not be shared. It’s difficult to form unified, real-time and automated management platforms for digital mine.

The root causes of the phenomenon above-mentioned are the complexity of the giant system of mine. In this paper, the theory and methods of ontology

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are used to reveal the nature of mine from its complex representation and identify the most basic and stable concepts, relationships, constraints and so on. In this way, a cross-industry and specific applications, shared conceptualization world of the mine will be built as the semantic basis for a variety of digital systems and integrated automation system for mines. And it also provides basic reference for the construction of standards and specifications for digital mine.

2 Analysis of mine connotation

To create a digital mine, it must firstly clarify the meaning of mine. Ore mine is the sites for exploitation of ore and production for mineral raw materials, and is a discrete production system targeted for the development of resources, where the main job is in the depths of the surface with complex geological conditions, poor environment, complex process, and with disasters occurring often.

As for different types of mines, their design requirements, mining technology, disaster prevention and control are different. So it is the first step to classify the mine to find the basic characteristics for describing the nature of mine. Mines can be divided into coal, metal and nonmetal mines according to their minerals. Coal mines are mined and processed for coal, while metal and nonmetal mines are mined for metal ores, radioactive ores and other non-metallic minerals (except coal).The main difference between the two types of mines is that there are no dangers of gas explosion in non-coal mines.

Mines are divided into open pits and underground mines, according to different mining ways. Open pit mine is mined for near-surface and shallow buried deposit, which has better safety conditions, and is easy for mining mechanization and automation. The situations of underground mines are more complex, their production systems are divided into ground systems and underground systems. Wellhead buildings and facilities, ground transportation system, production plants, tailings, buildings for office and living, and so on, form the ground systems.

Mine workings are main working places for underground production systems, according to the nature of work, the system is divided into: transportation and lifting system, ventilation system, power supply system, water supply and drainage systems, gas monitoring system, grouting systems, communication systems, gas transmission system. In addition to the production system, the underground system has also established six refuge systems for the staff, which include monitoring system, personnel positioning system, emergency system, air pressure and self-help system, water supply and rescue system and communication contact system.

These systems cover the basic contents of mining activities. With regardless of forms of mines, they are inseparable from these contents. Below, a unified, shared conceptual model will be created on the basis of these elements, which lays the foundation for common understanding and digital construction for the whole mine and its related phenomena.

3 Ontology overview

Ontology is often regarded as the backbone of the western tradition of philosophy or the first philosophy. With the development of technology, the ontology is introduced by artificial intelligence for knowledge representation and knowledge organization, and therefore its meaning changes.

GRUBER [8] proposed that ontology is an explicit specification of a conceptualization; while STUDER et al [9] made its definition that the ontology is a formal, explicit specification of a shared conceptualization, which is a more widely accepted definition for the ontology.

The ontology as modeling tools to describe field concept in level of semantic and knowledge, its goal is to capture the knowledge of related fields and to provide a common understanding of knowledge in this area through the formal description of concepts and relationships between them. The ontology was gradually introduced to geographic information science, and a large number of scholars studied the geographical ontology. The relevant information, data and knowledge in the field of geographical science are abstracted into a consensus conceptual system [10−13].

The mine ontology which is a filed ontology, is an extension of the geographical ontology in the mining areas and used to describe the terms and relations of mining-related fields. The ontology constructs share the formal concepts and relations system for the mining areas, which provide a unified semantic specifications and infrastructure framework for the various exchanges within the field and the integration and interoperability of heterogeneous mining data and clarifies mine knowledge structure to reduce the semantic conflict during the process of integration [14].

4 Designs and implementation of mine ontology

4.1 Method for construction of mine ontology

Mine ontology is mainly based on geographic ontology idea, to establish a basic knowledge base for field of mine and construction of the expression model of mine information. The work is carried out as follows: ontology analysis, description, evaluation, establishment, test and applications, as shown in Fig. 1.

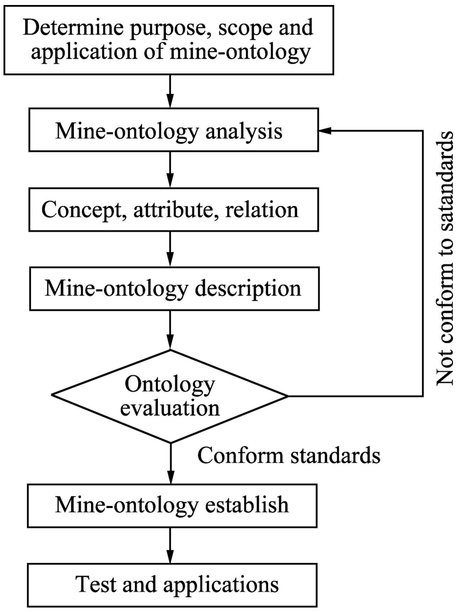

Fig. 1 Construction process for mining ontology

1) Clarify the purpose of mine ontology: building concept world for digital mine, support information sharing and interoperability in semantic and knowledge level.

2) Analyze the mines and their phenomena and classify them.

3) Analyze the concepts and relations involved in mine and list the terms.

4) Define the concepts and their relations.

5) Evaluate the ontology, examine whether the ontology meets the standard of clarity, consistency, perfection, expansibility, and so on. If it does not conform to the standards, then carries on the analysis and adjustment, until the ontology accords with the required standard.

6) Form the formal standard, make it the base of sharing and interoperation, and describe each concept and relationship formally by logical language.

7) On base of the formal ontology, build the preliminary experimental system; test the information integration and sharing methods which base on mine ontology.

4.2 Framework of mine ontology

According to Guarino's theory about hierarchy for ontology, the ontology can be divided into four levels: the top ontology, domain ontology, task ontology and application ontology [14]. Conceptualization world for mines are also composed of four levels of ontology, as shown in Fig. 2.

4.2.1 Top ontology

Time and space are fundamental to any forms of physical existence. Time and space ontology which is not limited to specific issues and areas can be the top ontology of all systems of physical forms. In the mining system it is mainly used to describe space forms and time status of the different kinds of production systems and the refuge systems.

4.2.2 Domain ontology

1) Type ontology

Classification of the world is the most fundamental and effective way to understand the world, the type ontology is used to reflect the nature of the mine and the essential difference among different mines, as shown in Fig. 3.

2) Mine workings ontology

Workings ontology is extension and the specific embodiment of the spatial ontology in the mine field, for

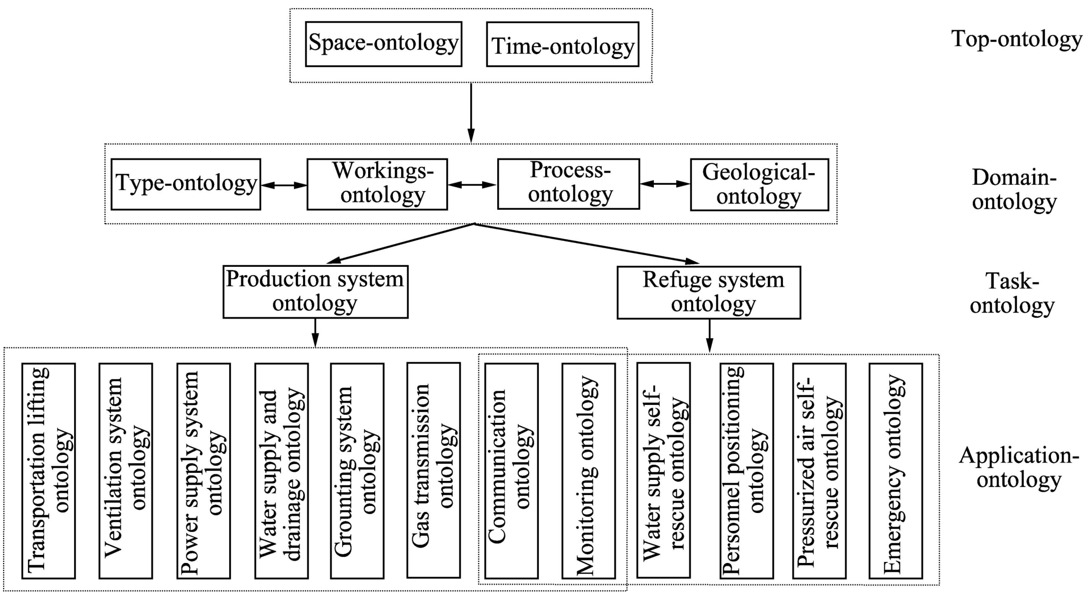

Fig. 2 Basic composition for mine ontology

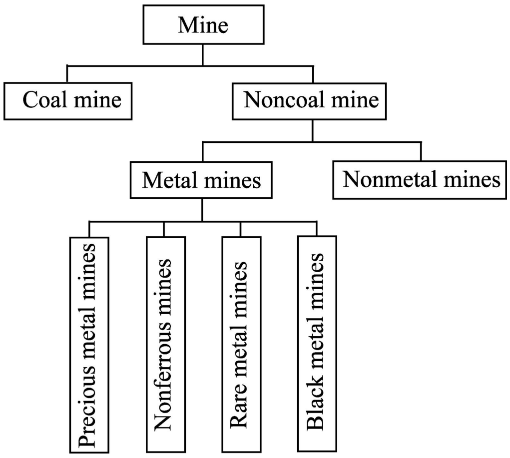

Fig. 3 Hierarchy for mine types in mine ontology

example, the vertical shaft is main capacity for the lifting system, the wind well is part of the ventilation system.

3) Process ontology

As a production system, mining consists of a number of mutual complex processes. Process ontology is used to accurately describe the various terms in the production process and the linkages between them.

4) Geological ontology

Geological environment is an important factor in the construction of mines, as well as mineral resources exploration and exploitation activities may also cause environmental damage to the geology in the mine. Before mine closure, the Mine operators must carry out the obligations of treatment and recovery for the mine geological environment. Composition of the geological ontology and its hierarchical structure are proposed, while the basic terminologies and their logic relations in geological exploration and geological structure are provided.

4.2.3 Task ontology

The purpose of mine construction is the exploitation of mineral resources. Production is the main task of mining, at the same time it is important to ensure safety of personnel. So that safety and efficiency are two important tasks of mine production, and thus the production system ontology and refuge system ontology are established, which are applied for the formal description for kinds knowledge from the various process in mines.

4.2.4 Application ontology

Application ontology is the realization of task ontology in various applications. According to the specific circumstances of mine, these applications are also different. Through a lot of comparison and analysis, twelve common application ontology such as transportation and lifting ontology are proposed, which can be added or deleted according to the need of specific application.

4.3 Concepts and property selection for mine ontology

4.3.1 Concepts

Mine ontology concepts are chosen by analyzing literature, standards, norms related to mines and completed system for digital mines with help of expert knowledge. The results are a list of related concepts, which have clear definitions and form a hierarchy structure. Fig. 3 shows the hierarchy for mine types in mine ontology and Fig. 4 shows the hierarchical relationships between concepts of mine workings. Table 1 lists the key concepts definitions by natural language from mine ontology, which provides a basic description of the mine workings.

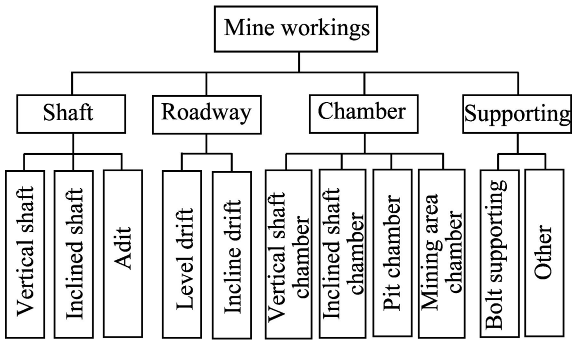

Fig. 4 Hierarchical relationships among concepts of mine working

4.3.2 Property chosen for concepts

Property is the features of concept, which can be used to distinguish between the concepts expressed by itself.

According to the Stanford Encyclopedia of Philosophy , property plays an important role in explaining things around us and has the ability to identify the things around [15]. The research on the differences of properties is useful for the definitions of geographical concept [16]. There are many types of properties, which describe different aspects of the concept.

When determining the properties for the concept, the essential properties, which exist with the existence of things in all cases, are given priority to choose. For example, metal mineral resources are the essential properties of the metal mines. Next, characterizing properties and mass properties are chosen, such as the section shape of the mine workings and its height.

4.4 Relationship analysis for concepts

When an object becomes properties of another's, these two objects have established a relationship. In the mine ontology, two main relations among objects, ordinary semantic relations and spatial relationships, are concerned.

Table 1 Part terms for mine workings ontology

Concept	Definition
Mine workings	For the purpose of coal mining, transportation, improve operations, a series of channels and chambers in general.
Shaft	Refers to vertical shaft and inclined shaft, including the dark well.
Vertical shaft	Service for the coal, facilities, personnel lift and the ventilation; it is the drilled vertical channel through ground in the Stratum.
Inclined shaft	Service for the coal, facilities, personnel lift and the ventilation, it is the drilled inclined channel through ground in the Stratum.
Adit	Service for the coal, facilities, personnel lift and the ventilation, it is the drilled horizontal channel through ground in the Stratum.
Roadway	It is to serve the underground mining, horizontal or inclined channel which is cut in the rock or seam and do not lead to ground directly.
Level drift	Nearly horizontal roadway
Incline drift	The roadway of obvious slope
Chamber	The specific drift of smaller length and larger sections.
Supporting	Maintain the stability of mine workings surrounding rock in the general.
Bolt supporting	Firm the supporting of mine rock by bolt.

The establishment of the semantic relations has strengthened the relations between concepts, and is helpful for the organization and management of ontology. In mine ontology, the ordinary semantic relationships mainly include the following six relations.

1) Is-a: the father-son relationship of two concepts, such as mine and metal mines relations.

2) Part-of: the relation between part and whole. A mine is constituted by multiple other objects, such as the relationship between the shaft body and the shaft.

3) Intersect-of: two concepts' extensions intersect, such as the intersection between underground mines and metal mines.

4) Equal-of: two geographical concepts have same connotation and denotation, such as vertical shaft and shaft.

5) Instance of: the instantiation relationship between the concept and concrete object, such as the Wangjialing mine is an instance of coal mine.

6) Disjoint-of: the concepts essentially repel each other. Any instance only belongs to one of concepts with the mutex relations. The mutex relationships should be explicitly declared, which plays an important role in inspecting ontology consistency and preventing the conflicts of ontology semantic. For example, the metal mines that belong to noncoal mines are mutually exclusive to coal mine.

4.5 Spatial concepts and relations in mine ontology

Spatial ontology describes and restrains all kinds of spatial locations and spatial relations related to mine production process. According to the spatial characteristics of mine geographical elements, basic spatial concepts are shown as follows.

1) Point: 0-dimension spatial object which only has position but no size and can be used to describe control point information;

2) Simple line: 1-dimension spatial object can be used to describe a continuous space object in a certain direction, such as the roadway midline;

3) Simple face: 2-dimension spatial object can be used to describe regular or irregular surface, such as the section of roadway;

4) 3-dimensional object: whose boundaries are surface objects, such as chamber.

Spatial relations can be roughly divided into topological relations, the orientation relations, metric relations, which are important contents of spatial ontology. The topological relationship refers to invariables in the topological transformations, such as the adjacent and connecting relations between objects; The orientation relations refer to objects' some sequences in space, such as before and after, north and south, etc; Metric relations refer to describing relations between spatial objects with some measure scale, such as distance.

4.6 Formalization for mine ontology

In this paper, OWL is adopted as the ontology description language and edits the ontologies in the frame of Protégé-OWL. OWL recommended by W3C, it is a language for ontology in the Semantic Web, it takes

RDF and RDF-S as the foundation, further strengthened expression and the reasoning ability for domain knowledge. Through the boolean operators (conjunction, disjunction, negation), OWL may recursively construct the complex kind, the language elements have also considered the existential restrictions, value restrictions and cardinal restrictions, functional restrictions and so on. At the same time, OWL can describe the attribute's characteristics such as transitivity, symmetry, function and so on, and state equivalence or disjointness between concepts, attributes and individuals. With this language, different concepts can be compared by reasoning device, which is the basis for semantic query. The ontology construction for mine is not an overnight but a long-term work, with improvement of knowledge of the mining areas and the emergence of new knowledge, mine ontology also need to be constantly maintained and updated.

4.7 Mine knowledge description using ontology

The purpose of building ontology is to describe unified conceptualization world with formal language, and provide consistent semantic foundation for the sharing and interoperability of mine information. Here, using central water pumping house as an example to explain knowledge description method based on the of mine ontology. The central water pump room includes the main chamber, with wells, bibulous well, with roadway etc, and while pump, drains, cable, electrical equipment are placed in the main chamber. The main properties of a chamber are cross-section shape and its clear height, etc. The above knowledge involves concepts of Water Pump Room, Chamber, Pump and relations of part-of, inside-of, has-section-of and property of has-height-of.

5 Conclusions

Starting from the basic meaning of mine, analyzing the basic types of mines, mine production system, refuge system, mine's operating environment, the conceptual world of mine based on ontology theory and methods are proposed, and the basic concept frame for the standardization of digital mine and formal knowledge base for expert system for mine were provided. Currently, the knowledge base of ontology is mainly used for semantic description and simple semantic reasoning. In the future, more axioms and rules will be created for mine knowledge, and logical reasoning ability will be enhanced by using rule engines.

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