Understanding Semantic Web Applications

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Abstract. Ten years have passed since the concept of the semantic web was proposed by Tim Berners-Lee. For these years, basic technologies for them such as RDF(S) and OWL were published. As a result, many systems using semantic technologies have been developed. Some of them are not prototype systems for researches but real systems for practical use. The authors analyzed semantic web applications published in the semantic web conferences (ISWC, ESWC, ASWC) and classified them based on ontological engineering. This paper is a review of application papers published in Semantic Web conferences. We discuss a trend and the future view of them using the results.

Keywords: Ontology, Knowledge modeling, Knowledge Management

1. Introduction

About 10 years after the birth of Semantic Web (SW), advocated by Tim Berners-Lee, fundamental technologies such as RDF(S) and OWL have been developed as well as their application systems. So many research and development projects on the basis of SW technologies have produced various applications from prototypes at the laboratory level to the practical full-scale systems. A survey report [1] says that about 300 companies provide SW technology related products. In spite of so many efforts on research and development of SW technologies, "Killer Application" of SW is still unknown [2]. Therefore, it would be beneficial for us to get an overview of the current state of SW applications to consider next direction of SW studies to realize semantic technologies which enhance utilization of knowledge on the web. Some researchers have already broadcasting information about SW studies (e.g., [3]), exhaustive information about each study makes it difficult to see and analyze the state of SW studies at a glance.

Fundamental features of SW include enabling computers to process semantics on various resources of WWW annotated by metadata, which is in turn defined by ontology. Since ontology is a fundamental and important technology for SW applications, this paper analyzes them from the view point of ontology. Especially we focus on "What type of ontologies is used" and "How ontologies are used." Following sections analyze the current state of SW applications to propose several directions for future research. Specifically, we classified 190 SW applications which utilize

Table.1. The number of SW applications which is analyzed in this paper.

Conferences	Dates	Venues	Number of Apps
International Semantic Web Conference (ISWC)			
ISWC2002	Jun. 9-12, 2002	Sardinia, Italy	9
ISWC2003	Oct.20-23, 2003	Sanibel Island, FL, USA	19
ISWC2004	Nov. 7-11, 2004	Hiroshima, Japan	18
ISWC2005	Nov. 6-10, 2005	Galway, Ireland	25
ISWC2006	Nov.5-9, 2006	Athens, GA, USA	26
ISWC2007& ASWC2007	Nov.11- 15, 2007	Busan, Korea	18
European Semantic Web Conference (ESWC)			
ESWC2005	May29-Jun.1, 2005	Heraklion, Greece	24
ESWC2006	Jun.11-14, 2006	Budva, Montenegro	11
ESWC2007	Jun. 03 - 07, 2007	Innsbruck, Austria	17
Asian Semantic Web Conference (ASWC)			
ASWC2006	Sep.3- 7, 2006	Beijing, China	23

ontologies extracted from international conferences on SW (Table 1)[1]. In this paper, SW and ontology engineering tools such as ontology editors, ontology alignment tool, and so on, are not the target of the analysis because we focus on applications which utilize ontologies.

2. Related Work

Some researchers discuss trends and future prospects of Semantic Web and its applications. Alani et al. consider a killer application for SW from a viewpoint of business community [2]. They discusses that opportunities to make progress on cost, communities, creativity and personalization are important for appearance of a killer apps. And they argue SW researchers should focus on the four important areas. Léger et al. present 16 use cases from enterprises which are interested in SW technology and analyze 4 of them in detail [4]. Based on the analysis, they determine 12 knowledge processing tasks required in industry. These researches focus on specifying the requirement for SW applications in industry. We focus on analysis of the current state of SW applications in academic communities.

Motta and Sabou examine the current SW applications and introduce seven dimensions for analogizing them [5]. They compare some older and newer systems which they call the next generation of SW applications. As the result, they conclude that SW applications will have to deal with increasing heterogeneity of semantic sources and new web technologies such as social tagging and web services. We focus on usage of ontologies which are discussed in one of their dimensions because it is a key technology for all SW applications.

Some researchers analyze and classify ontology-based applications. Uschold and Jasper classify ontology applications scenarios in three categories: 1)neutral

[1] ESWS2004 is excluded because it has been a symposium, not a regular conference.

authoring, 2)common access to information, and 3)indexing for search [6]. Mizoguchi enumerates the role of an ontology as follows: 1)a common vocabulary, 2)data structure, 3)explication of what is left implicit, 4)semantic interoperability, 5)explication of design rationale, 6)systematization of knowledge, 7)meta-model function, and 8)theory of content [7]. Kitamura discuss role of ontology of engineering artifacts mainly in knowledge modeling and categorize them into 1)shared vocabulary and taxonomy, 2)conceptual (standard) data schema, 3)metadata schema for documents, 4)semantic constraints for modeling, 5)generic knowledge and patterns, 6)interoperability and integration, 7)communication support and querying, 8)capturing implicit knowledge, and 9)basis of knowledge systematization [8]. We refer to these categories to consider types of usage of ontology and introduce 9 types discussed in next section.

3. The Method for Analyzing SW Applications

Fundamental feature of SW is to enable machines to process semantics on various resources of WWW by giving machine-readable meta-data, which is defined by ontology, to the resources. Since ontology is a fundamental and important technology for SW applications, we analyze them from the view point of ontology. Ontologies can be classified into several "types" according to several features: number of concepts, usage of models, target domain, depth of hierarchy, etc. An appropriate type of ontology for an application is specified by requirements of the application. Especially, quality of semantic information required for the application, i.e., intended semantic processing, constrains the type of the ontology.

This research analyzes SW applications from the view point of "Usage of ontology" and "Type of ontology used." In this section, the authors propose several types for both viewpoints with guidelines and classify ontology-based applications.

3.1 Types of Usage of Ontology for a SW Application

According to the application purpose, usage and requirements of the ontology differ. Here we introduce 9 types of usages. Basically, a SW application is categorized to one of the types. Some SW applications which use ontology for multiple ways are categorized to multiple categories.

(1) Usage as a Common Vocabulary

To enhance interoperability of knowledge content, this type of application uses ontology as a common vocabulary. Since this is the most fundamental and common usage for the following all categories from (2) to (9), applications in which ontologies play mainly a role to unify the vocabulary are categorized here. In life science, some large scale ontologies, such as GO[2] and SNOMED-CT[3] have been developed and used

[2] http://www.geneontology.org/
[3] http://www.ihtsdo.org/

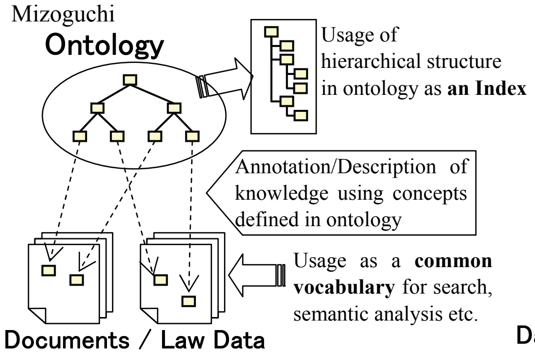


Fig.1. Usage as a Common Vocabulary / an Index.

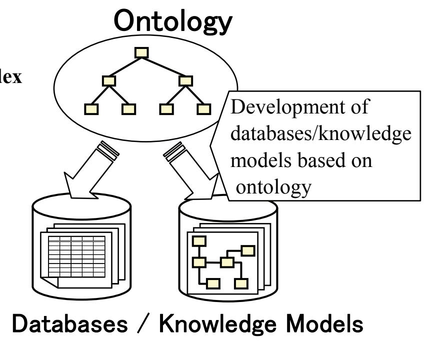


Fig.2. Usage as a Data Schema / a Rule Set for Knowledge Models.

as common vocabularies for a long time. Recently, many SW applications use Linked Data[4] as represented by DBPedia[5] for sharing and connecting information on the SW.

(2)Usage for Search

With appropriate metadata, we can realize search systems which use semantic information for searching. It depends on the metadata and the ontology to what extend the application can deal with the deep semantics. This is one of the most typical usages, thus an application whose main function is search will be categorized here. The function of semantic search is realized in some applications, such as a knowledge portal [9] and a knowledge management system [10], at early stage of SW. Recently, some semantic search services for web such as Powerset[6] and Hakia[7] are published.

(3) Usage as an Index

An application which uses ontologies as indexes for knowledge resources belongs to this category. An ontology is a system of vocabulary, thus the index becomes systematized one. Difference between this category and the categories (1) and (2) is that applications of this category utilize not only the index vocabulary but also its structural information (e.g., an index term's position in the hierarchical structure) explicitly when accessing the knowledge resources (Fig.1). For example, a semantic navigation system for information services [11] and a semantic view-based search engine [12] which navigates users utilizing such indexes with contextual structures defined by ontology are categorized here.

(4) Usage as a Data Schema

Applications of this category use ontologies as a data schema to specify data structures and values for target databases. Hierarchy of the ontologies specifies instances as data values, and each of the concept definitions specifies data structures (Fig.2). Typical applications of this category are a system for exchanging

[4] http://linkeddata.org/
[5] http://wiki.dbpedia.org/
[6] http://www.powerset.com/
[7] http://www.hakia.com/

bibliography through network [13], various kinds of data management systems using semantics defined ontologies [14, 15, 16], and so on.

(5) Usage as a Media for Knowledge Sharing

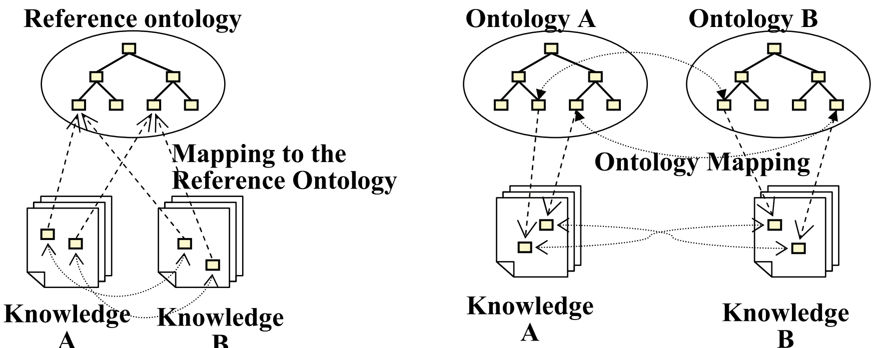
Applications of this category aim at knowledge sharing among systems, between people and systems, or among people using ontologies and instance models about the target knowledge. Generally speaking, almost ontological systems aim at such knowledge sharing. To avoid confusion, this category includes such applications that stress enhancement of interoperability among different systems: applications for knowledge alignment, systems for knowledge mapping, communication systems among agents, support systems for communication, etc. From technical viewpoints, both of (i)ontology mapping systems using a reference ontology (Fig.3(a)), and (ii)systems which align ontologies behind the target knowledges and map target knowledges via the aligned ontologies (Fig.3(b)) are categorized here. For example, [17] takes the former approach to integrate distributed systems using a reference ontology which is called mapping ontology, and [18] takes the latter method to generate proper queries for web-based malls which have different product categories.

(6) Usage for a Semantic Analysis

Reasoning and semantic processing on the basis of ontological technologies enable us to analyze contents which are annotated by metadata. One of the most typical methods for such analysis is an automatic classifier for concept definitions using inference engines. For example, [19] discusses how SW technology can be used in biology to automate the classification of proteins through an experiment. Other examples are statistical analysis systems, validation system for scientific data (e.g. experimental result) [20]. Some applications have visualization tools for supporting the analysis [21]. Among the search systems in category (2), those systems which employ such ontological analysis belong to this category.

(7) Usage for Information Extraction

Applications which aim at extracting meaningful information from the search result are categorized here. Recommendation systems [22] which filter search results are



(a) Knowledge Sharing through a Reference Ontology

(b) Knowledge Sharing using Multiple Ontologies

Fig.3. Usage as a Media for Knowledge Sharing.

example of the extraction. Other examples are a system extracting product features from web pages [23], a service which summarizes blogs and get useful information of products such as the total reputation and related products [24]. Comparing to other "search" categories, applications of the category (2) just output search results without modifications. Applications of the category (6) add some analysis to the output of (2), while those of this category (7) extract meaningful information before outputting for users.

(8) Usage as a Rule Set for Knowledge Models

We can use instance models, which are built upon definition of classes in ontologies, as knowledge models of the target world. In other words, we can use ontologies as meta-models which rule the knowledge (instance) models (Fig.2). Relations between the ontologies and the instance models correspond to that of the database and the database schema of category (4). Compared to the category (4), knowledge models need more flexible descriptions in terms of meaning of the contents.

From the viewpoint of ontology engineering, one of the most intrinsic roles of ontology is to rule knowledge models. For the purpose, a heavy-weight ontology which models the world appropriately with deep semantics helps the knowledge modeling and reasoning at a deeper level. For example, enterprise systems for healthcare delivery [25], scientific knowledge sharing [26], and e-government service [27] are developed based on ontologies. On the other hand, sometimes light-weight ontology helps them at a shallow level when the target world is large, shallow model is enough for reasoning and an efficient processing method is needed. Semantic MediaWiki[8] [28] is a typical example of the application.

(9) Usage for Systematizing Knowledge

Ontology provides semantic relationships among concepts. Putting them as the core conceptual structure, we can organize concepts of the target world which in turn becomes systematized knowledge. Referring to the concepts organized in ontology, we can build systems for managing knowledge. Typical applications of this category include integrated knowledge systems of category (1) to (8) such as knowledge management systems and contents management systems [29, 30].

3.2 Types of Ontology

This section categorizes ontologies without depending on target domains and their description languages. We introduce 5 categories from the viewpoint of semantic feature of ontologies. Although this categorization shares the way of thinking with an ontology spectrum by Lassila and McGuninness [31], our categorization does not have strict definitions because we focus on rough survey of ontologies used in applications. We are planning to refine the ontology types in the future.

[8] http://semantic-mediawiki.org/

(A) Simple Schema

This category includes simple schemas such as RSS and FOAF[9] for uniform description of data for SW applications, although they are not called ontology in a strict sense.

(B) Hierarchies of *is-a* Relationships among Concepts

One of the most fundamental elements of ontologies is a set of concepts identified in the target world with a hierarchical structure based on “is-a” relationship (rdfs:subClassOf of RDF(S) and OWL). Some portal sites navigate users by a menu with hierarchically organized topics, which is a kind of ontologies, is sometimes called light-weight ontology.

(C) Relationships other than “*is-a”* is Included

Ontologies can define concepts more explicit by using various relationships such as “part-of” (whole and part) and “attribute-of” (property). Ontologies of this category contains “is-a” relationships plus other various ones. Properties of RDF(S) or OWL are used for representing such relationships.

(D) Axioms on Semantics are Included

In addition to descriptions of the relationships of the category (C), ontologies can specify further constraints among the concepts or instance models by introducing axioms on such semantic constraints. Axioms on ontologies of this category include constraints about order such as transitivity and reflexivity, exclusivity of an instance, and so on. In case of OWL, constraints about relationships such as “transitiveProperty” and “inverseOf”, constraints about sets such as “disjointWith” and “one of” are categorized to the axioms of ontologies in this category.

(E) Strong Axioms with Rule Descriptions are Included

Some ontologies require strong axioms which are necessary for further description of constraints on the category (D). Ontologies with rule descriptions, for example, by KIF or SWRL, are categorized here.

3.3 Steps for Analyzing SW Applications from Ontological Viewpoint

Three of the authors analyzed 190 papers introduced in section 1 according to the following steps:

(1) Giving short explanations about the application (One sentence for each).
(2) Identifying the usage of ontology (section 3.1)
(3) Identifying the target domain.
(4) Identifying types of ontology (section 3.2)
(5) Identifying the language for description
(6) Identifying the scale of ontology (number of concepts and/or instance models)

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[9] http://www.foaf-project.org/

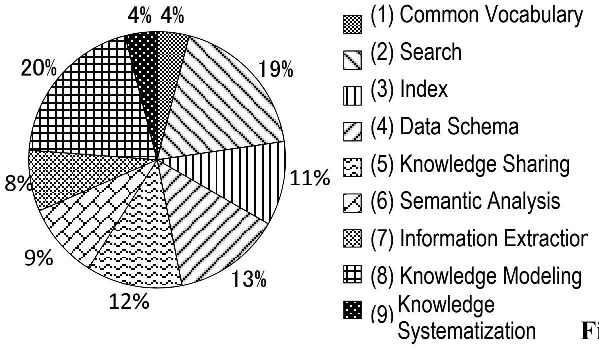

Fig.4. The distribution of types of usage of ontology

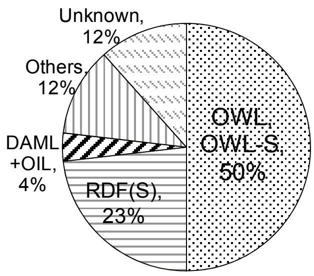

Fig.5. The proportion of ontology description language.

On the way of this analysis, the authors discussed about the criteria for classification of applications interactively. The rest of this paper describes the result.

4. Results of Analysis and Considerations

4.1 Distribution of Types of Usage of Ontology

Fig.4 shows the distribution of types of usage of ontologies in the systems presented in the papers surveyed. This graph shows that there is not so big difference among the ratios of each type of usage. However, comparing the amount of the applications from types (1) to (7), which deal with “data” processing, and the those from types (8) to (9), which explicitly deal with “knowledge” processing, most of current studies in the Semantic Web application deal with “data” processing on structured data.

4.2 A Correlation between the Types of Usage and the Types of Ontology

Table.2 constitutes the relations between the types of usage and the types of ontology. We see from Table 2 and Fig. 4 that most of the Semantic Web applications use

Table.2. A Correlation between the Types of Usage and the Types of Ontology.

	The Types of Ontology					
	(A) Simple Schema	(B) Is-a Hierarchies	(C) Other Relationship	(D)Axioms	(E) Rule Descriptions	Total
(1) Common Vocabulary	0	4	7	0	0	11
(2) Search	1	2	43	4	1	51
(3) Index	0	3	23	3	0	29
(4) Data Schema	0	0	32	5	0	37
(5) Knowledge Sharing	1	0	31	1	0	33
(6) Semantic Analysis	1	1	21	3	0	26
(7) Information Extraction	1	2	15	3	0	21
(8) Knowledge Modeling	0	1	36	9	8	54
(9) Knowledge Systematizatio	0	2	8	1	0	11
Total	4	15	216	29	9	273

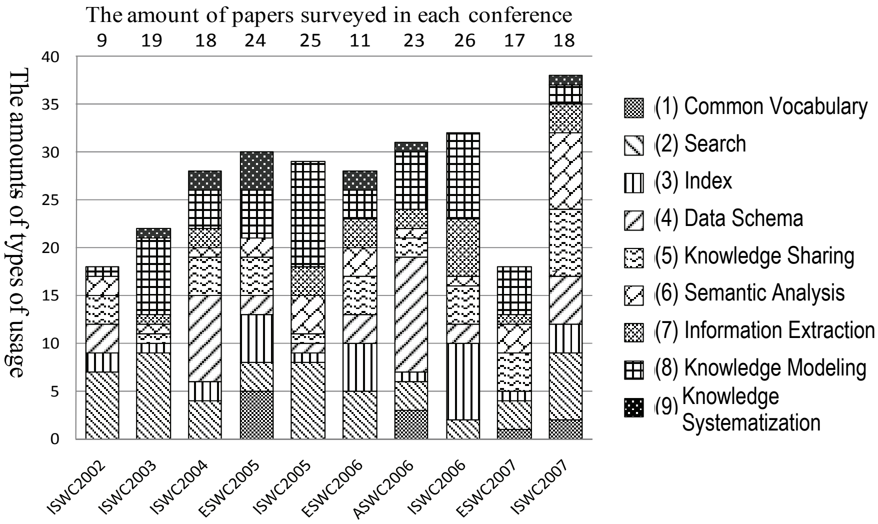

Fig.6. The conference-by-conference transition of the types of usage

ontologies including a variety types of relations, that is, not only is-a relation but also the other relations. On the other hand, a few ontologies have complex axioms. However, only based on papers in the proceedings, it was very difficult for authors to properly assess whether an ontology contains axioms for semantic constraints or not. On this matter, we need further analysis of the axioms defined by each ontology. In addition, the more semantic processing the type of usage requires, that is, as the number of the type of usage raises, the more detailed definition the ontology requires.

Fig. 5 shows the proportion of the usage of ontology description language[10]. Almost half of the systems use OWL or extended OWL. RDF(S) takes second place. This shows OWL is steadily lying as the foundation of the standard for the ontology description language. Yet it is unclear which sublanguage of OWL (i.e., Lite, DL or Full) is used in the ontology because most of papers do not specify the type of sublanguage in them.

4.3 The Conference-by-Conference Transition of the Types of Usage

Fig. 6 shows the conference-by-conference transition of the types of usage in the systems. In this chart, the conferences are sorted by the date therefore we can see the transition of semantic web application during the past five years. Although the amount of papers surveyed in each conference except ISWC2002 and ESWC2007 is about 20 and not so different from each other, the amount of types of usage are increasing year by year. This is because the development research of semantic web applications has matured for several years and still more features have been built in each system. Especially, while there is no significant change in the use of ontology as

[10] An ontology used in an application fall into a single category according to ontology description language. Especially, distinction between the categories of RDF(S) and OWL/OWL-S is made by the usage of only RDF(S) or including OWL/OWL-S if only a little. If it uses both of RDFS and OWL, for example, it is classified into OWL/OWL-S.

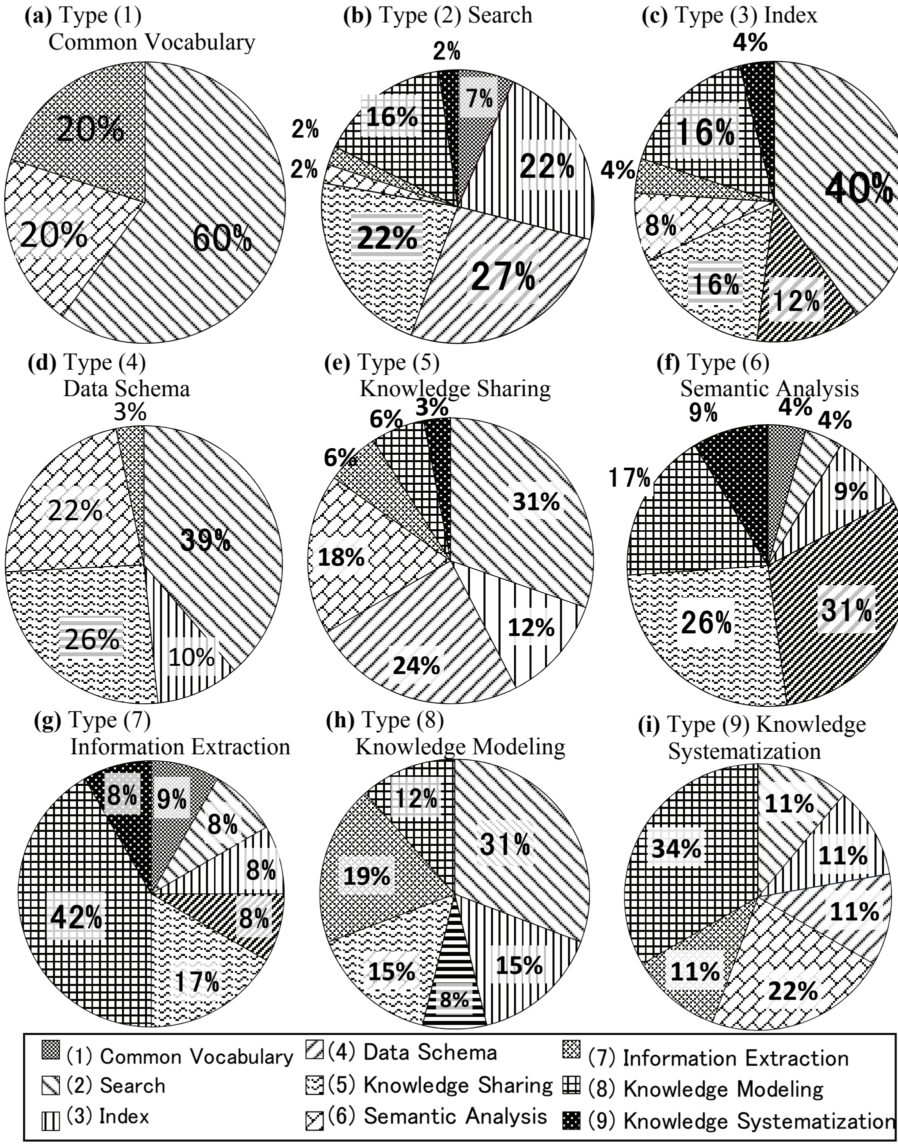

Fig.7. The combinations of the types of usage

vocabulary or for retrieval ((1)-(3)), the numbers of the use for higher-level semantic processing ((4)-(9)) are increasing gradually.

As discussed in the section 4.1, there is only a moderate increase in the use of ontology for knowledge processing. We understand this indicates the difficulty of the development of applications with knowledge processing. In other words, currently the mainstream of Semantic Web application development focuses on data processing, and overcoming the difficulty of knowledge processing might be a key to create killer applications.

4.4 The Combinations of the Types of Usage

As mentioned in section 3.1, an SW application might use ontologies for more than two purposes. However, among the nine types of usage of ontology, not all the combinations are found in applications and type-combination appearing in an application varies according to each type. Fig.7 shows such distributions of usage type combination for each usage type. For example, Fig.7(a) shows the distributions of the percentages of appearance of usage types (2), (6) and (7) together with type (1)[11]. Since the 3 types (i.e. (2), (6) and (7)) are usages mainly for semantic retrieval, common vocabularies tend to be used for search systems. However, the pie chart of usage type (2) for search in Fig.7(b) shows that the usages are combined with also others. For example, the combinations of usage type (2) for search and type (5) usage as a media for knowledge sharing imply integrated search across several information resources. Furthermore, Fig.7(g) shows that type (7) usages for information extraction are combined with type (8) usage as a rule set for knowledge models more frequently in compare with type (2) and (6). It shows that type (7) information extraction needs more detailed description of semantics than type (2) simple search and type (6) semantic analysis. The chart of type (9) usage for systematizing knowledge (Fig.7(i)) shows that the usages are combined with all other types systematically. This trend is consistent with description in section 2.1.

4.5 Application Domains

Fig.8 shows the distribution of the types of usage per a domain. Domains in which many applications have been developed are multimedia (image, movie, music, etc.), services (both of web services and services in the real world), software development, knowledge management, bioinformatics and medical care. In the domains in the business area, a variety of systems focusing on a particular subject, for example, product management, business process, and so on, have been developed. On the other hand, general-purpose systems, which are not focusing on a particular domain or subject, have been also developed. In Fig. 8, such systems are distinguished in the following ways; systems dealing with academic information such as papers and conference, or systems dealing with web resource and systems dealing with the other information. The distribution of the types of usage in each domain is not so different from each other. Therefore, semantic web technology is used in a variety of domains at all levels.

Here, we pick up several domains and discuss the distribution in detail. Fig. 9 shows the percentages of the type of usages in several domains which we can find In the software and service domains, the percentage of type (8) usage as a rule set for knowledge models is higher in comparison with scientific domains (scientific information, bio and medical). It implies that more heavy weight ontologies are developed in the software domain.

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[11] The usage type (1) (usage as common vocaburay) does not cooccur with many of the other usages because we classified the applications into this type only if ontologies play mainly a role to unify the vocabulary in it.

- In the business and bio domains, the percentage of usages for type (6) semantic analysis and type (7) information extraction is high. It implies that the needs of information analysis are higher in the domains than in others.

Furthermore Table.3 shows the transition of the type of usage in multimedia domain. We can see a trend that the numbers of the use for higher-level semantic processing (types (4)-(9)) are increasing gradually.

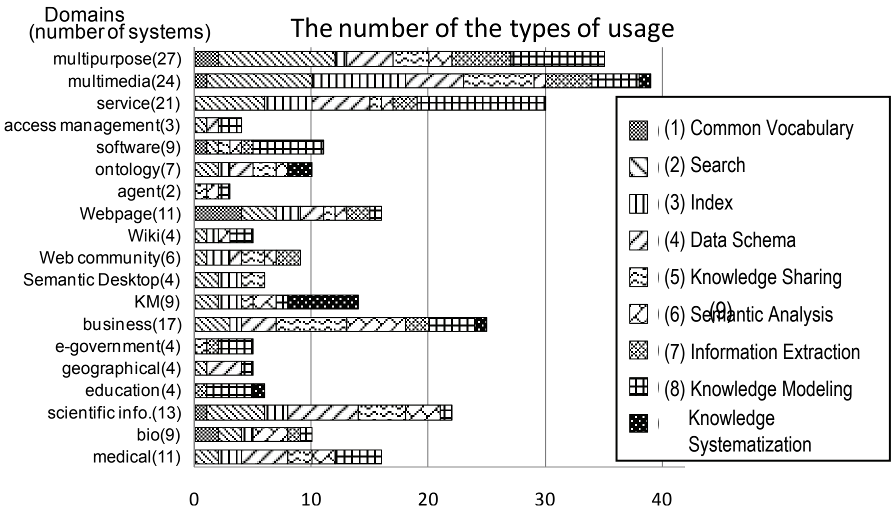

Fig.8. The distribution of the types of usage per a domain

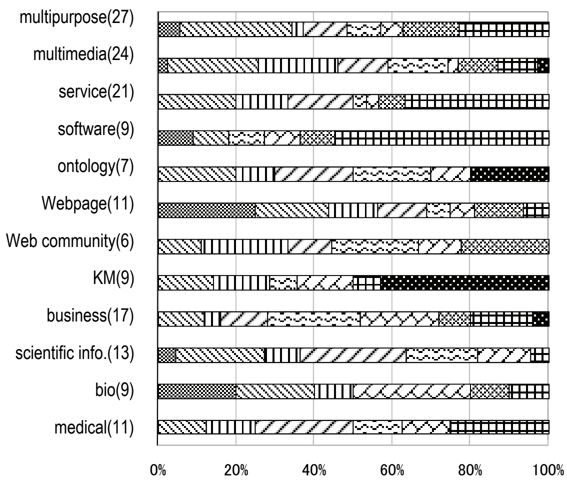

Fig.9. The distribution of the types of usage per a domain (2)

Table.3. The transition of the type of usage in multimedia

	The Type of Usage								
Confrences	1)	2)	3)	4)	5)	6)	7)	8)	9)
ISWC2002		✓	✓						
ISWC2003		✓							
ISWC2003		✓							
ISWC2003		✓							
ISWC2004		✓	✓	✓	✓				
ISWC2004		✓		✓					
ESWC2005			✓						
ESWC2005				✓	✓				
ESWC2005	✓								
ISWC2005			✓					✓	
ISWC2005		✓							
ISWC2005		✓							
ESWC2006		✓		✓	✓				
ASWC2006				✓					
ASWC2006				✓					
ISWC2006					✓				
ISWC2006			✓						
ISWC2006		✓				✓			
ISWC2006		✓							
ESWC2007					✓				
ESWC2007			✓					✓	
ISWC2007		✓	✓						
ISWC2007		✓						✓	
ISWC2007		✓			✓			✓	✓

4.6 Numbers of Concepts and Instances in Each Ontology

Generally, the size of an ontology and the numbers of instances used as metadata are expected to vary widely depending on the scale of an application. We cannot analyze the correlation of them enough because the number of concepts and instances are not written clearly in each paper surveyed. As far as what can be read out from the papers, many systems recently developed use the existing large-scale ontologies (or thesauri) such as DOLCE[12], WordNet[13] and DBPedia. Some systems use their own ontologies but it is difficult to analyze them because most of papers state only the outline of the ontologies. Some ontologies are available on the web so that we will be able to do further analysis with the ontologies downloaded from the sites.

5. Concluding Remarks and Future Work

For the purpose of providing basis for finding next direction of SW applications, this paper surveyed and analyzed the present state of SW applications from the viewpoint of usages and types of ontologies. Since the authors have depicted both strong points and weak points of current SW applications, we plan to continue additional survey and analysis of SW applications for future SW conferences and others related to SW, and report them at http://www.hozo.jp/OntoApps/. At the same time, we also plan to refine the viewpoints for the analysis proposed in this paper as follows.

1. Refinement of ontology types (cf. Section 3.2)

As described in section 3.2, we focus on semantic components of ontologies for their classification. To make relationships between type of the ontologies and usage of the ontologies in SW applications clearer, we need to classify ontologies in more detail. We plan to introduce a metadata set for such a classification proposed by [32], or formal types of ontologies in [31, 33], for example. Since applications which use existing ontologies or "Linked data" are increasing today (cf., section 4.5), survey on such existing resources is necessary.

2. Analysis on development process of ontologies and instance models

Since development process of ontologies and/or instance models is an important factor of development of SW applications, we plan to incorporate relevant viewpoints for further classification. For those applications which require deep and specialized knowledge (e.g. [19, 25]), domain experts commit ontology development. On the other hand, ontologies are (semi-)automatically built for those applications which require both scalability and wide range of knowledge on the web (e.g.[23, 24]).

To maintain SW applications, mechanisms for adding instance data are important and there are various approaches according to the applications' domains and/or goals. In some SW applications, an annotator creates metadata for additional instance data. While SemanticWiki [28] refers to collaborative knowledge, PiggyBank[34] creates instance data from existing databases efficiently. Furthermore, some applications aim

[12] http://www.loa-cnr.it/DOLCE.html
[13] http://wordnet.princeton.edu/

at managing the lifecycle of ontologies and instances [35]. Viewpoints which differentiate these methods should give other perspectives for classification.

3. Classification of applied semantic technologies

SW applications require many other technologies: ontology development, semantic search by ontologies, inference mechanisms for DL, ontology matching, etc. Viewpoints about the applied technologies should be important issues. As a long term goal, the authors aim at supporting SW application development by providing an ontology of SW applications. For the development process, the ontology will help comparison among existing systems and a new system to be developed. Furthermore, guidelines for SW application development such as appropriate ontology type, usage and peripheral technologies, will be provided by the ontology.The result of our analysis is available at the URL, http://www.hozo.jp/OntoApps/.

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