Understanding Knowledge Representation in the Knowledge Management Environment: Evaluation of Ontology Visualization Methods†

Jong-Ae Kim

Department of Library and Information Science, College of Humanities,
Kyonggi University, San 94-6 Eui-dong Young-tong-gu Suwon-city Kyonggi-do,
South Korea 443-760 <jongaekim@kgu.ac.kr>

Jong-Ae Kim is assistant professor of the Department of Library and Information Science in the College of Humanities at Kyonggi University, South Korea. She received her Ph.D in information studies from Florida State University in 2005. She began her career as a librarian at Korea Development Institute in 1997. She also worked as a system integration consultant at Dongbu Information Technology. Her research interests include information services, knowledge management, and usability assessment.

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ABSTRACT: The application of effective mechanisms for organizing knowledge has been of great concern to help the user discover and share knowledge. Ontology provides the foundation for knowledge organization and sharing by supporting the specification of knowledge structure. The visualization of ontology provides new possibilities for presenting knowledge representation, but the effectiveness of visualization has not been proven. This study examines user performance and perception with ontology visualization methods and provides suggestions for the design of ontology visualization. Differences in user performance based on ontology visualization methods were examined in terms of task completion time and frequency of interaction. Also user perceptions on the usability of ontology visualization methods were examined in terms of ease of use, comprehension of visualization style, comprehension of properties, and subjective satisfaction.

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1.0 Introduction

The organization of vast human knowledge to make it accessible by diverse users has been of continuous interest (Jurisica et al. 2004). Knowledge organization is crucial for successful knowledge dissemination and sharing because the application of effective mechanisms for organizing knowledge can reduce the considerable time and effort needed to discover and share knowledge. Although knowledge representation tools such as dictionaries, thesauri, taxonomies, and index terms have been traditionally used to organize and retrieve human knowledge, they have limitations in describing the semantics of knowledge. Compared to those other knowledge representation forms, ontologies allow for description of higher degrees of associated relationships between concepts, thus supporting semantic searching (Angrosh and Urs, 2006). The use of ontologies in knowledge-based systems enables the specification of knowledge structure in a domain and facilitates computerized reasoning for semantic searching. Thus it provides the foundation for knowledge sharing and collaboration by facilitating effective communication between various groups and domains.

Ontology visualization has been widely implemented as a way to provide users with effective and consistent views (Wu et al. 2001). Although the visualization of ontology provides new possibilities for presenting knowledge representation, the effectiveness of visualization has not been proven. The visualization of ontology may require additional visual literacy on the part of users who are unfamiliar with visualization interfaces. The results of the studies examining the effectiveness of ontology visualization are inconclusive. Katifori and Halatsis (2007) point out that there are not many comparative evaluations on the effectiveness of ontology visualization methods for different tasks and with different user groups. This study aims to examine how users perceive and utilize the ontology structure and annotations included in it. It examines user performance and perception with ontology visualization methods and provides suggestions for the design of ontology visualization.

2.0 Ontology as knowledge representation in the knowledge management environment

Ontology is originally a division of philosophy focusing on the study of the nature of being and existence. It studies the structure of the world by determining what entities and types of entities exist (Harrocks 2008). Theories of ontology explain "what constitute the world and its objects" (Hjørland and Hartel, 2003, 239). That is, ontological theories explain reality and how it is structured. In information science ontology has been used to refer to a collection of entities and their relationships in a certain domain. Gruber (1994) defines ontology as "a formal, explicit specification of a shared conceptualization." In this definition, conceptualization means an abstract view of some phenomenon which identifies concepts and relationships between them. Explicit and formal denote that knowledge representation of a shared conceptualization should be explicitly defined and machine processible. Ontology is based on a shared understanding in a domain, which means an agreement over the concepts and relationships by the experts of the domain (Perez-Soltero et al. 2009). Also it is represented in a machine-processible format to be shared and retrieved using computers.

Ontologies support mapping of concepts into knowledge structures, thus providing context to the concepts in information retrieval (Madalli 2006). The richness in the semantics of ontologies enriches the organization and retrieval of knowledge in knowledge-based systems. Heterogeneous knowledge from different domains is difficult to compare, both for humans and computers, because the knowledge is represented in various lexical forms (Bodenreider and Stevens, 2006). Semantics represented in ontologies help humans and computer systems share common vocabularies and make inferences about knowledge in the domain.

Ontologies have been widely adopted in various areas including knowledge description on the semantic Web, knowledge management, medical informatics, and electronic commerce (Evermann and Fang 2010). They serve as common knowledge representation frameworks to support knowledge sharing and searching. Hjørland and Hartel (2003) consider the semantic relation between two concepts as the basic unit in knowledge organization and point out that such relations are implied by theories. This assertion is based on realism as stated by Thomas Kuhn (1970). Kuhn emphasizes that ontologies are implied by theories and paradigms. He nevertheless points out that nature cannot be confined indefinitely in arbitrary structures constructed by scientists. Hjørland and Hartel also assert that many such semantic relations can be primarily understood as domain specific, rather than being established by universalistic assumptions. Different approaches or paradigms exist in all domains of knowledge. Because of difficulties in identifying all of them, knowledge organization systems tend to be biased toward some philosophical position (Hjørland 2008). Thus it is crucial to mediate between different views and consider the goals of knowledge organization systems.

With the emergence of the semantic Web, the importance of ontologies has been increasingly recognized to support semantically enhanced searching. The semantic Web facilitates meaningful retrieval of the contents on the Web on the basis of semantic knowledge representation. For successful semantic searching, it is crucial to make the knowledge representation structured and processible. More meaningful knowledge representation can be supported by higher-level semantics. Using ontologies can help build semantic knowledge representation and draw semantic inferences for meaningful retrieval. Ontology-based knowledge representation supports intelligent reasoning and improves the breadth and accuracy of search results, thus providing an effective and efficient environment for knowledge organization (Benson 2011). Kraines et al. (2008) suggest basic assumptions for ontologies to effectively support semantic searching. First, the concepts of knowledge in a particular domain are provided through an explicitly defined ontology and represented in a computer-processible format. Second, ontologies formalize the semantic meaning of domain knowledge, thus enabling systems to perform the reasoning tasks. Third, ontologies provide a vocabulary of classes and properties allowing for semantic descriptions.

Recently the use of ontologies has markedly increased in both the academic and industry sectors. In the academic sector ontologies have been adopted to promote knowledge sharing by supporting interoperability for integrating knowledge bases from different domains. As interdisciplinary research increases and the divisions of knowledge fields expand, it has become crucial to support the communication of expert knowledge to enable collaboration between researchers from different fields. As expert knowledge created in the academic sector has grown exponentially, researchers have confronted difficulties in integrating all of it. Ontology allows for the description of knowledge structure and the representation of shared concepts and relationships of knowledge, thus facilitating successful discovery and sharing of knowledge.

Ontologies have also been adopted within industrial environments. In recent years, the ability to acquire, evaluate, use, and share knowledge has been recognized as an important factor in gaining organizational competitiveness. As systems are developed and maintained in decentralized manners, semantic heterogeneity is inevitable (DeRidder 2007). Standardized knowledge representation based on ontology enables the sharing of information and interoperation across distributed systems. In knowledge management in the corporate environment, ontology may provide a common understanding of knowledge structure, thus improving the corporate communication processes.

3.0 Ontology and its visualization

An OWL ontology consists of three components: individuals, properties, and classes. They roughly correspond to instances, slots, and classes in Protégé frames. The definitions of the components are as follows. Individuals refer to perceived objects which exist in the world, and classes are sets of enumerated individuals that are grouped according to their common attributes. Properties refer to relationship between individuals or between individuals and data values (Kim and Beck, 2006).

The adoption of ontologies provides common annotations and structure in storing, processing, and visualizing the large amount of complex data. Ontologies propose new possibilities for knowledge representation, but they also bring new challenges for visualization. In ontology visualization, knowledge structure of an ontology is usually visualized as semantic nets with nodes representing concepts and the arcs indicating relationships. Jia et al. (2010) point out that it is hard for one single visualization method to fulfill all requirements or support all types of tasks effectively, suggesting the need to provide multiple methods for ontology visualization. According to Katifori and Halatsis (2007), ontology visualization methods may be grouped into the following categories based on their visualization type:

- Indented list: The indented list presents the taxonomy of ontology in a Windows Explorer-like tree view.
- Node-link and tree: In the node-link and tree view, ontology is represented as a set of interconnected nodes, which may be generally expanded and retracted by the user.
- Zoomable view: The zoomable view presents child nodes nested inside their parent node and allows the user to zoom in and out of the nodes.
- Space-filling: The space-filling view presents the nodes by subdividing the screen space. The size of each subdivision depends on the attributes of the node such as the number of child nodes.
- Focus + Context and distortion: This view presents context and focus at the same time by displaying the node in focus enlarged, and the rest of the nodes placed around it.
- Information landscape: The information landscape view presents color- and size-coded 3D objects on a plane using the landscape metaphor.

Some studies have been conducted to evaluate the usability of visualization methods of ontology editors. Garcia-Barriocanal et al. (2005) evaluated several representative ontology editors and suggested the implications for improvements in browsing mechanisms, help systems, and visualization metaphors. Pointing out that few studies had been conducted to evaluate ontology visualization tools' suitability for various ontologies and user groups, Katifori et al. (2008) investigated the suitability of ontology visualization methods for users who were not familiar with the structure of the visualized ontology. They assessed the appropriateness of each visualization method for different tasks based on task completion times, success rates, and user comments and reactions. Lambrix et al. (2003) compared ontology development tools for bioinformatics. They evaluated the user interfaces using the REAL (Relevance, Efficiency, Attitude, and

Learnability) approach. In terms of visualization, they assessed if the users got a good overview over the ontology and its components. Storey et al. (2004) explored the use of visualization as a cognitive aid for managing ontologies and knowledge representation. They found that no single visualization method would fit all users and tasks requiring visualization and suggested the need for more empirical work. The results of the studies investigating the usability of ontology visualization methods have been inconclusive. More in-depth research is needed with regards to user performance and perception to improve our understanding of the users of ontology editors.

4.0 Method

In this study two ontology visualization methods, the tree view and the nested composite view in Jambalaya plugged in Protégé, were examined in terms of user performance and perception. Protégé is an open source platform providing tools to construct, edit, and visualize ontologies. It is the leading ontology editor applied to a wide range of domains. One of the strengths of Protégé is its extendibility based on an open architecture using plug-ins that provide various functionalities. Jambalaya, plugged in Protégé, provides an extensible visualization environment for understanding, exploiting, and navigating ontologies (Rubin et al. 2006). In Jambalaya, classes and individuals are represented as nodes and the relationships are presented with directed arcs.

In the tree view of Jambalaya, classes and individuals are represented as nodes and directed arcs show the relationships of classes and individuals. Different types of nodes may be distinguished by different colors. The tree view provides the users with an overview of the width and depth of the hierarchy and the general nature of the relationships between entities. As the mouse brushes over an individual node or arc, a small tooltip window displays the label of the node or property (Storey et al. 2001).

The nested composite view represents classes and individuals as nodes and distinguishes their types using different colors. In the nested composite view, subclasses are nested within their superclass node and individuals are also nested inside their class node. Properties between classes and individuals are represented as directed arcs between nodes. A user can zoom in and out of the nodes in the nested graph.

For this study the MGED (Microarray Gene Expression Data) ontology was visualized using Jambalaya. The MGED ontology, developed by the MGED Society Ontology Working Group, provides a common terminology and structure for describing microarray experiment data, thus supporting greater opportunities for discovery and sharing of high-throughput biological data (Microarray Gene Expression Data Society, 2011). Microarray experiment data are highly context-dependent. The repositories for microarray data need to include the details of the samples, treatments, array layout, and information on other factors affecting the results as well as summarized descriptions of the experiments (Stoeckert et al., 2002). The data from various microarray experiments tend to be described in different terminologies and structures due to their unique needs and restrictions, thus hindering searching and sharing of microarray data. The MGED ontology contributes to knowledge sharing in microarray research by providing a formal specification for shared conceptualization of the domain.

4.1 Measures

In this study the dependent variables to assess user performance and perception with the tree view and the nested composite view were measured as follows. Task completion time was measured as the time taken to complete four tasks with each of the two visualization methods. It was recorded in timestamps in the screenshots saved by Captivate 4 software. Table 1 presents the tasks that the participants conducted with each of the two visualization methods. Frequency of interactions refers to the number of times that a participant interacts with the tools. It was measured as the number of screenshots saved every time a participant manipulated the ontology visualization tools. The user perceptions on each of the two ontology visualization methods were measured with 5-point Likert scale questions in terms of ease of use, comprehension of visualization style, comprehension of properties, and subjective satisfaction (Table 2). The respondents were asked to rate how strongly they agreed by using the scale ranging from 1, strongly disagree, to 5, strongly agree.

4.2 Data collection

The participants in this study consisted of undergraduates in library and information science at a major university in the central region of South Korea. The experiment period lasted for about two weeks. Prior to each session in the experiment, a pre-test questionnaire was distributed to identify the charac-

Task	
Task 1 :	Identify subclasses of the "BioAssayPackage" class.
Task 2 :	Verify a property of "Experiment" and "BibliographicReference."
Task 3 :	Identify classes or individuals which the "BioSequence" class has at least one kind of.
Task 4 :	Identify classes or individuals that have at least one kind of "URI."

Table 1. Tasks given for the experiment

Variable	Question item
Ease of Use	This visualization tool is easy to use.
Comprehension of visualization style	The visualization style implemented in this visualization tool is easy to understand.
Comprehension of properties	It is easy to identify the properties of classes and individuals.
Subjective satisfaction	Overall I am satisfied with this visualization tool.

Table 2. Post-test questionnaire items

teristics of the participants. Also the participants were provided with a brief instruction on ontology and its visualization tools. Subsequently the participants were asked to perform the tasks given using the tree view and the nested composite view. For the experiment, four tasks were selected to examine the participants' understanding and performance with the ontology visualization tools. The tasks were selected to examine the users' interaction with the visualization tools to discern the hierarchical structure of the ontology, identify the properties, and check the existential restrictions. After finishing the tasks given, the participants responded to the post-test questionnaires that were composed of 5-point Likert scale questions on the usability of the two visualization methods and open-ended questions for qualitative evaluations.

The experiment in which two systems were tested one after the other may result in bias because the participants tend to perform better with the system they use later. To avoid these order effects, the participants were divided into two groups in this study. The first group was instructed to use the tree view first, and the second group was instructed to use the nested composite view first. The participant interactions with the ontology visualization tools were recorded in screenshots with Captivate 4 software. The software supports capturing screenshots when the interactions between user and system occur.

5.0 Results

The data analysis was conducted using SPSS (Statistical Package for Social Science) v.14.0. The frequency analysis was conducted to examine the characteristics of the participants. The differences in usability between the two ontology visualization methods were examined using t-tests. In addition, t-tests were conducted to find out if there were order effects on the differences between the two ontology visualization methods. Next, the differences in user performance by task were investigated.

5.1 Characteristics of the participants

A total of 20 students majoring in library and information science participated in this study. Table 3 presents the descriptive statistics of participant characteristics. Eighty-five percent of the participants were female, and 15 percent were male. Eighty-five percent and 15 percent of the participants were juniors and seniors respectively. Of the participants, 50 percent reported having experience with using electronic thesaurus previously, and 50 percent reported that they had not. In regards to experience with ontology visualization tools, none of the participants reported that they had experiences with using the tools.

Participant characteristics	Frequency	Percentage
Gender		
Male	3	15%
Female	17	85%
Major		
Library and information science	20	100%
Year		
Junior	17	85%
Senior	3	15%
Experience with using electronic thesaurus		
Yes	10	50%
No	10	50%
Experience with using ontology visualization tools		
Yes	0	0%
No	20	100%

Table 3. Descriptive statistics of the participants (n=20)

5.2 *Differences in usability of the ontology visualization methods*

Table 4 indicates the results of the t-tests to examine the differences between the tree view and the nested composite view in terms of user performance and perception. In task completion time and frequency of interactions generated by the participants while performing the tasks given, the tree view (M=302.75; M=52.66) was found to be higher than the nested composite view (M=141.60; M=23.61) and they showed statistically significant differences ($p<.001$).

User perceptions on usability of the two ontology visualization methods were analyzed based on the data collected from the post-test questionnaires. The participants rated the nested composite view higher in terms of ease of use (M=4.10), comprehension of visualization style (M=4.15), comprehension of properties (M=4.05), and subjective satisfaction (M=4.00). The significant differences in user perceptions were found for the two visualization methods ($p<.001$).

5.3 *Analysis of the differences based on the experiment order*

The order effect refers to a bias in the user's interpretation and performance depending on the order of presentation of information (Deese & Kaufman, 1957). To compensate for the order effect in this study, half of the participants (n=10) conducted the tasks using the tree view first and the other half (n=10) conducted the tasks using the nested composite view first. The t-tests were used to find if there were differences in user performance and perception depending on the experiment order when using each visualization method.

5.3.1 *Order effects on user performance and perception with the tree view*

Table 5 presents the results of the t-tests to examine whether there are differences in user performance and perception with the tree view based on the experiment

Variable	Tree View (n=20)		Nested Composite View (n=20)		t	p
	M	SD	M	SD		
Task completion time	302.75	111.610	141.60	78.248	5.287***	.000
Frequency of interactions	52.66	24.971	23.61	15.683	4.406***	.000
Ease of use	2.15	1.040	4.10	.788	-6.683***	.000
Comprehension of visualization style	2.60	1.188	4.15	.745	-4.944***	.000
Comprehension of properties	2.65	1.089	4.05	.887	-4.457***	.000
Subjective satisfaction	2.20	.834	4.00	.795	-6.990***	.000

***$p<.001$

Table 4. Differences in usability of the ontology visualization methods

Variable	When the tree view is used first (n=10)		When the nested composite view is used first (n=10)		t	p
	M	SD	M	SD		
Task completion time	337.73	146.296	267.77	46.657	1.441	.167
Frequency of interactions	57.38	32.491	47.95	14.539	.837	.413
Ease of use	2.30	1.059	2.00	1.054	.635	.534
Comprehension of visualization style	2.60	1.430	2.60	.966	.000	1.000
Comprehension of properties	2.70	1.160	2.60	1.075	.200	.844
Subjective satisfaction	2.50	.850	1.90	.738	1.686	.109

Table 5. User performance and perception with the tree view: Comparison by experiment order

order. In task completion time when using the tree view, the group that used the tree view first (M=337.73) spent more time completing the tasks than the group that used the tree view later (M=267.77), but no statistically significant difference was found ($p>.05$). In frequency of interactions when using the tree view, the group that used the tree view first (M=57.38) made more clicks to complete the tasks than the group that used the tree view later (M=47.95), but there was no statistically significant difference ($p>.05$). In terms of user perceptions of ease of use, comprehension of visualization style, comprehension of properties, and subjective satisfaction, no statistically significant differences were found between the two groups ($p>.05$).

5.3.2 *Order effects on user performance and perception with the nested composite view*

Table 6 shows the results of the t-tests to examine the differences in user performance and perception with the nested composite view depending on the experiment order. In task completion time with the nested composite view, the group that used the nested composite view first (M=186.95) spent more time in completing the tasks than the group that used the nested composite view later (M=96.25). There was a statistically significant difference between the two groups ($p<.01$). This result suggests that the participants that used the tree view first became familiar with ontology visualization and the tasks given, thus performing better when using the nested composite view in the second session. In frequency of interactions with the nested composite view, the group that used the view first (M=29.23) made more clicks to complete the tasks than the group that used the view later (M=18.00), but no statistically significant difference was found ($p>.05$). In user perceptions of ease of use, comprehension of visualization style, comprehension of properties, and subjective satisfaction with the nested composite view, no statistically significant differences were found ($p>.05$).

5.4 Differences in user performance by task

The t-tests were conducted to find the differences in user performance by task based on the visualization methods. Table 7 presents the results of the t-tests to examine the differences in task completion time by task when using the tree view and the nested compos-

Variable	When the tree view is used first (n=10)		When the nested composite view is used first (n=10)		*t*	*p*
	M	SD	M	SD		
Task completion time	96.25	56.131	186.95	72.145	-3.138**	.006
Frequency of interactions	18.00	11.180	29.23	18.006	-1.675	.111
Ease of use	4.10	.568	4.10	.994	.000	1.000
Comprehension of visualization style	4.10	.568	4.20	.919	-.293	.773
Comprehension of properties	4.00	.816	4.10	.994	-.246	.809
Subjective satisfaction	4.00	.667	4.00	.943	.000	1.000

**$p<.01$

Table 6. User performance and perception with the nested composite view: Comparison by experiment order

Task	Tree view (n=20)		Nested Composite view (n=20)		*t*	*p*
	M	SD	M	SD		
Task 1	362.80	203.213	51.50	32.571	6.764***	.000
Task 2	258.90	220.251	206.75	231.753	.729	.470
Task 3	517.60	129.477	266.10	195.655	4.794***	.000
Task 4	71.70	91.575	42.05	26.737	1.390	.173

***$p<.001$

Table 7. Differences in user performance by task (Task completion time)

ite view. For Tasks 1 and 3, the participants completed the tasks more quickly using the nested composite view (M=51.50; M= 266.10) than the tree view (M=362.80; M=517.60), and there were statistically significant differences ($p<.001$). For Tasks 2 and 4, the participants spent less time completing the tasks using the nested composite view (M=206.75; M=42.05) than the tree view (M=258.90; M=71.70), but no statistically significant differences were found ($p>.05$).

Table 8 shows the results of the t-tests to investigate the differences in interaction frequencies by task between the two visualization methods. For Tasks 1 and 3, the nested composite view (M=11.15; M= 43.85) showed fewer interaction frequencies than the tree view (M=63.70; M=90.60), and there were statistically significant differences ($p<.001$). For Tasks 2 and 4, the participants completed the tasks with fewer interaction frequencies using the nested composite view (M=30.90; M=8.55) than the tree view (M= 46.10; M=10.25), but no statistically significant differences were found ($p>.05$).

The significant differences in user performance in conducting Task 1 suggest that the participants perform better in identifying subclasses when using the containment metaphor than the tree metaphor. No statistically significant differences in user performance with Task 2 may be because both methods use the directed arcs to represent the properties between classes and individuals. For Task 3, the participants had difficulties in identifying the properties between classes and individuals using directed arcs. They had trouble with brushing over each of the arcs to identify the properties. They had more difficulties in identifying the properties using the tree view, resulting in the statistically significant difference between the two visualization methods. The participants performed better in identifying the properties for Task 4 due to possible learning effects from Task 3 previously conducted. However the results from Task 4 indicated no statistically significant differences between the two visualization methods.

5.5 Open-ended responses on usability of the ontology visualization methods

The open-ended responses addressing the usability of the tree view and the nested composite view were categorized into the strengths and weaknesses of each method. Unitization and categorization suggested by Lincoln and Guba (1985) were used for qualitative analyses of the data collected from the open-ended questions in the post-test questionnaires. The results of open-ended responses denoting user perceptions of the usability of the tree view are presented in Table 9.

Task	Tree view (n=20)		Nested composite view (n=20)		*t*	*p*
	M	SD	M	SD		
Task 1	63.70	43.524	11.15	8.524	5.299***	.000
Task 2	46.10	41.668	30.90	35.995	1.235	.225
Task 3	90.60	33.301	43.85	39.424	4.051***	.000
Task 4	10.25	12.789	8.55	10.076	.467	.643

***$p<.001$

Table 8. Differences in user performance by task (Frequency of interactions)

	Category	Frequency	Percentage
Strengths	It provides an overview.	11	55%
	It is easy to comprehend the hierarchical structure of the ontology.	7	35%
	It enables to directly access to an entity of interest at the first step.	1	5%
Weaknesses	The overview of the ontology is too complicated to identify individual classes and properties.	18	90%
	The manipulation for zooming is not easily controllable.	6	30%
	It is difficult to comprehend the properties in the ontology.	6	30%
	It is hard to perform the tasks without using a class browser.	3	15%
	It is difficult to identify individuals of the same class.	2	10%

Table 9. Open-ended responses on usability of the tree view

As the strengths of the tree view, the respondents pointed out the provision of an overview, ease of comprehension of the hierarchical structure, and support for the direct access to an entity of interest. The weaknesses were categorized into the complicated overview, difficulties with control of the zoom, difficulties with comprehension of the properties, the need of the support of a class browser, and difficulties with identification of individuals in the same class.

The results of open-ended responses on the usability of the nested composite view are presented in Table 10. As the strengths in usability of the nested composite view, the respondents pointed out the ease of identification of properties, comprehensibility of visualization style of hierarchy, ease of identification of classes and individuals, intuitive interface, and simple initial view. As the weaknesses, the respondents indicated not getting an overview, inconvenience in clicking sequentially, and complicated visualization of properties due to the shape constrained in a quadrangle.

6.0 Conclusion

The tree view provides a good overview when the size of ontology is relatively small, but it becomes difficult to get an entire overview when the ontology gets larger. It is effective at displaying a simple hierarchical structure, but it gets cluttered and complicated as the number of entities increases. Although the provision of an overview of ontology can be strength, the users may not get much information from a complicated and densely-plotted display of the overview. They tend to be overwhelmed by the complicated image of ontology visualization and have difficulties to move to an entity that they want to identify. Thus it may be helpful to provide a confined view to a limited part of the entire ontology structure as needed to help the users get a comprehensible view of their interest. In this study, the participants identified the outgoing arcs relatively easily, but had difficulties in identifying the incoming arcs. Displaying only associated entities separated from the entire ontology may resolve this problem by reducing the user's cognitive effort. It enables provision both of an overview and of details.

In order to support the users in moving directly to an entity they want to identify, it is crucial to provide the search functionality and text-based browsable list to supplement the visualization of ontology. Also, the participants of this study expressed frustration when the manipulation for zooming was not controllable. In order for the users to be able to interact with ontology visualization tools more effectively, it is necessary to support their orientation when they zoom in and out of the structure of the ontology.

In addition, the visual cues such as colors, sizes, and dimensions may not support intuitive interpretation on the user's part and may require additional memory. The provision of text-based representations such as labels may help the users interpret the knowledge representations described in ontologies more readily. Although many ontology visualization tools provide labels when one brushes over them, it is recommended that they be presented more thoroughly. It may also be helpful to allow the users to turn off or on the function for displaying the labels. The scalability has always been a challenging issue in the discussion of ontology visualization. Further study is needed to examine whether or not the findings of this study hold true with larger-size ontologies.

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	Category	Frequency	Percentage
Strengths	The identification of properties in the ontology is easy.	12	60%
	The visualization style of hierarchy is easily comprehensible.	9	45%
	It is easy to identify classes and individuals.	7	35%
	The interface is intuitive, so an initial use is easy.	4	20%
	It is easy to identify subclasses and individuals of the same class.	3	15%
	The initial view is not complicated.	3	15%
Weaknesses	It is difficult to get an overview.	7	35%
	It is cumbersome to click sequentially to move to a class that is not adjacent.	5	25%
	The visualization of properties is complicated due to the shape constrained in a quadrangle.	2	10%

Table 10. Open-ended responses on usability of the nested composite view

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