A Quality Assurance Framework for Ontology Construction and Refinement

Mamoru Ohta, Kouji Kozaki and Riichiro Mizoguchi

Abstract The quality of an ontology is an important factor that determines its utility. In order to assure its quality, in addition to form-based evaluation as to whether the ontology being constructed is written properly in terms of its form (syntax), content-based evaluation as to whether the ontology properly represents the target domain, whether the ontology actually serves for problem solving, etc. is also necessary. In this study, we investigate a framework for quality assurance of ontologies in Hozo, which is an environment for building/using ontologies that are being developed by the authors. As form-based evaluation, Hozo provides various assistance functions for properly editing an ontology in compliance with the rules. As content-based evaluation, Hozo introduce a method for supporting ontology evaluation thorough conceptual maps which are generated according to the user′s viewpoint.

Key words: building ontologies, ontology evaluation, development support system.

1 Introduciton

With the recent trend toward the increasing use of information in technical domains, a strong demand is arising for systematization of knowledge in various technical domains. Ontology engineering is an approach of interest for systematization of knowledge, and ontologies are being constructed in various domains such as medical science, bioinformatics, nano-technology, education, environmental engineering and so on. With this background, there is a demand for development of methodologies and tools for assisting the construction of good ontologies by experts in individual domains, as well as ontology experts.

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The quality of a constructed ontology is an important factor that determines its utility. In order to assure the quality of an ontology, it is necessary to evaluate whether the ontology is written properly and to reflect the result in the construction task. Generally, ontology evaluation is roughly classified into two kinds: form-based (syntax) evaluation and content-based (semantic) evaluation. In the form-based evaluation, generally, formal approaches are employed; for example, in the case of the Web Ontology Language (OWL), contradictions are detected through reasoning processing based on description logic (DL). In the content-based evaluation, on the other hand, manual approaches are employed, such as demonstrating validity by applying a model based on the ontology to actual problem solving in the target domain or by creating an organization of domain experts for content-based evaluation[1]

This paper discusses a framework that is being developed for quality assurance of ontologies in Hozo[2], an environment for building/using ontologies that is being developed by the authors. Sect. 2 discusses a framework of editing assistance and consis-tency verification, which is introduced in Hozo for the purpose of form-based evaluation. Sect. 3 discusses a refinement assisting method based on a concept map, which is introduced in Hozo for the purpose of content-based evaluation, with several examples of its use in practice. Sect. 4 discusses comparison with related work. Lastly, Sect. 5 summarizes the achievements of this research and concludes this paper with further issues to be addressed.

2 A Framework for Form-based Ontology Evaluation

As a quality assurance effort in the construction phase, it is necessary to verify whether the ontology that has been constructed is written properly in terms of its form (syntax). At this time, as well as whether the individual concept definitions are written properly in compliance with the description form, it is necessary to verify whether the ontology as a whole does not include inconsistencies among the concept definitions. A construction tool requires assisting functions mainly for properly editing an ontology in compliance with the rules. In order to perform form-based evaluation of an ontology by using a computer, there are two approaches: one is to perform checking in advance during editing and present errors, and the other is to verify consistency after editing and correct errors. In the framework adopted by Hozo, it is possible to use these two approaches selectively case by case; i.e., emphasis is placed on editing assistance during editing.

Thus, in this research, first, items that are to be verified in relation to the ontology rules were enumerated (32 items in total). As a function for assisting ontology editing, the items were classified into items that should at least be satisfied during editing, with which preferably errors should be presented as soon as detected (25 items), and items with which the consistency of the ontology as a whole is to be verified after editing and errors are to be presented after editing (27 items).

Hozo employs goal-oriented reasoners to assure fast consistency-check at the cost of completeness. Therefore, Hozo has 32 native reasoners corresponding to each item. We believe each of the reasoners is straightforward and needs no detail explanation. Apparently, all the reasoners are fired when consistency-check is done after editing, while some of them are fired in the course of editing process.

2.1 Ontology Editing Assistance

Hozo provides various assistance functions that help the user who constructs an ontology to properly edit the ontology in compliance with the rules. For example, when assisting slot specialization, in order to write the definition properly in compliance with the rules, during editing of a slot, a list of candidates of slots that can be inherited from the upper concept is presented so that the user can select and edit one of the candidates. On the other hand, in the case of some particular items, such as reference to an undefined concept, instead of requiring proper description, for example, an alert is presented in a different color, so to make the disturbance of the users thinking minimum. Furthermore, Hozo has an assisting function that prevents loss of consistency among concepts during modification of the description, such as modification of a concept name or modification of an inheritance relationship.

Hozo assures the quality of an ontology by using assistance functions for maintaining consistency so that the ontology doesn't include contradictions when existing concepts or slots are modified, as well as when new concepts are defined.

2.2 Consistency Verification after Ontology Editing

The editing assistance described above serves to prevent errors to some extent; however, there are errors that cannot be prevented since it is not possible to check consistency before finishing editing of a single concept. For example, while modification and deletion of concept definitions are repeated, in some cases, the relationship among the concepts is modified, resulting in loss of consistency of the ontology as a whole. Furthermore, there are cases where errors for which alerts were issued but that were disregarded during editing remain without being corrected. In order to overcome these problems, a scheme that ensures the consistency of the ontology as a whole after editing is necessary. Thus, the authors implemented functions for verifying the consistency of the ontology as a whole after editing and for presenting the results regarding items that are to be verified but were not covered by the assistance during editing. The verification results are presented as a list and the user can collect them by using a special wizard which assists correction of verification errors.

These consistency verification functions were developed by using ontology processing APIs HozoCore and Reasoner, which are software modules developed for computer processing of a Hozo-specific theoretical framework.

2.3 Evaluation of Ontology Editing Assistance

As an experiment for evaluating improvement in ontology quality in terms of formal aspects rather than content validity, we conducted a comparative experiment as to whether any improvement in the quality of the ontology construction work was achieved between before and after the implementation of the editing assistance functions described in Sect. 2.1. The subjects were graduate students with no advance knowledge of ontology. The procedure of the experiment was as follows. First, an explanation of ontology and a lecture of how to use Hozo were given in advance. Then, regarding a certain theme (vehicle ontology), the subjects were formed into groups each consisting of three subjects in such a manner that personal variation of knowledge was minimized, and each group constructed an ontology of vehicle using Hozo. In order to verify quality improvement, in the evaluation experiment, the same task was undertaken before and after the improvement with the tool to different subjects in different years. As the results of the experiment, the number of concepts, the number of slots (using inheritance or not), the number of relational links, and the number of errors in the constructed ontology were counted. Regarding the number of errors, the ontology consistency verification function described in Sect. 2.2 was used. In general, a quantity of concepts and slots in ontology building has little to do with quality of the ontology. But in this experiment, because subjects are true beginners who had never built any ontology, the primary issue for them was to acquire basic skills as to how to define concepts in consideration of attribute inheritance, and hence quality of ontology is the secondary issue. Therefore, if they could define more concepts and slots which are regarded as rather meaningful using property inheritance from their super concepts, it could be understood that the improvement contributed to improvement of the usability of Hozos editing operations which would be needed to build high quality ontologies later on. This is why we can evaluate how Hozo was improved in terms of the above items in this experiment.

Table 1 shows the results of the experiment. Due to differences in the number of subjects, all the values of the results were calculated by averaging the values of individual groups. Compared with the version before the improvement, the number of concepts, the number of slots generated, and the number of relational links in the ontology all increased. Furthermore, the number of slot specializations increased considerably. This is conceivably attributed to improvement in slot specialization operations, for which editing was not easy before the improvement. Furthermore, the number of ontology consistency errors decreased, indicating that well-formed definitions of concepts were increased. These results indicate that beginners were able to generate a lot of high quality concepts and relational links. It means that the editing assistance functions contribute to quality assurance for ontology.

Table 1 Results of the examination for evaluating improvement in ontology quality.

Subject	number of Basic Concepts	number of Slots	number of Specialized Slots	number of Relational Links	rate of Format Errors
Before improvement (*1)	27.27	21.09	9.82	0.82	10.30%
After improvement (*2)	34.38	29.54	17.54	1.23	4.94%
Rate of change (%)	26.08%	40.05%	78.63%	50.43%	-52.09%

*1: examination before improvement (13 groups, 39 examinees)
*2: examination after improvement (15 groups, 45 examinees)

3 A Method for Content-based Evaluation

As a quality assurance effort in the refinement phase, it is necessary to evaluate whether the ontology is designed properly in terms of its content (semantics) in addition to the form-based evaluation described in Sect. 2. In this case, methods employed include evaluation by experts in the target domain, verification based on use cases, and evaluation based on the results of application to actual problem solving. A subject of this study is to clarify the method that supports domain experts to confirm and evaluate contents of ontologies. In content-based evaluation, an ontology is evaluated from various viewpoints that include validity of concept definitions and is-a hierarchy classification, validity of relationships among concepts and ability to solve problems. We focus the validity of relationships among concepts because it is one of the main contents of ontology.

For the evaluation of relationships among concepts in an ontology by domain experts, it is important that domain experts can see the relationships from viewpoints according to interests of them. Therefore, Hozo adopts a method for assisting ontology refinement work with a conceptual map generated by exploration and visualization in accordance with the aim of ontology construction and refinement. Although details of the method cannot be described due to space limitation, its outline is as follows. At first, the user selects a concept as starting point for exploring the ontology. Then the system traces relationships (properties) and extracts related concepts according to the user's intention and/or aim. There are several ways to trace relationships. For example, the most primitive one is to follow properties from its domain to range. The user can explore the ontology by choosing combinations of the starting point and the ways to follow relationships. The result of ontology exploration is visualized as a conceptual map. The domain experts can evaluate the ontology thorough the conceptual map instead of checking the ontology directly. This section discusses two cases that we actually applied content-based evaluation with this method to the ontology construction.

3.1 Application to Construction of Sustainability Science Ontology

The knowledge structuring research group at Osaka University Research Institute of Sustainability Science (RISS) has been working on construction of a sustainability science ontology in which knowledge in a variety of domains related to sustainability science in the environmental field is organized in a domain-independent form[3]. In this project, we suggested a basic framework in which maps can be generated from various viewpoints according to interests of experts in an overview of ontology[4].

In the construction phase, the group worked on construction and refinement of the ontology by generating a conceptual map from the constructed ontology and confirming whether the target knowledge was successfully represented as an appropriate map. Furthermore, we applied a similar method in enriching the existing sustainability science ontology mainly with concepts related to the biofuels. 1) First, a domain expert created 29 typical scenarios about production and usage of biofuels before enriching the ontology. 2) Then, on the basis of these scenarios we enriched the existing ontology, to add concepts and relationships appearing in the scenarios. 3) In the refinement tasks, we verified the ontology with the ontology exploration tool, to generate conceptual maps in which the contents of the original scenarios were reproduced (Fig. 1).

As a result, the group was able to perform semantic evaluation of the enriched ontology while maintaining consistency with the existing ontology, demonstrating the effectiveness in the construction and refinement tasks. In these tasks, since the scenarios that are to be represented in the form of a concept map involve a variety of content, there was a strong demand that a method in which the viewpoint used to generate a conceptual map should not have any limitation, and hence our tool has been designed to give users perfect freedom in exploration of the ontology.

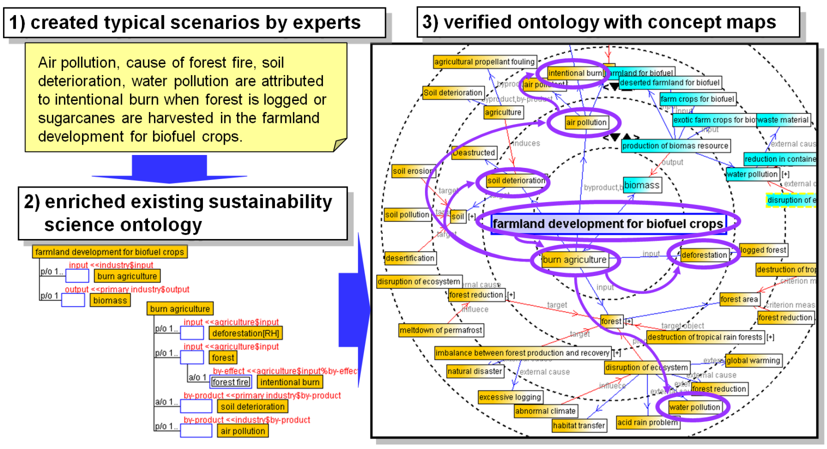

Fig. 1 Example of concept map generated by a typical scenario

3.2 Concept Map Generation in Construction of Clinical Ontology

In the Project for Research and Development of Medical Knowledge Infrastructure Database for Medical Information Systems by the Ministry of Health, Labour and Welfare, assuming its indispensable role as an information infrastructure technology for integrated management and sophisticated information analysis of electronic data ranging over multiple domains in clinical medicine, a comprehensive ontology for clinical medicine is being constructed for the first time in Japan [5]. The proposed tool has been extensively used as discussed in the following.

3.2.1 Assistance for Construction and Refinement of Ontology for Connections in Human Body Structure

In the clinical ontology, regarding connective relationships in the human body structure, a common concept construct "Port" is introduced so that various connective relationships, for example, functional connections for passing fluids or signals, such as blood vessels or nerves, mechanical connections, such as connections between bones and joints, and spatial connections representing positional relationships, can be dealt with in isomorphic frames. Accordingly, it is possible to perform reasoning with a computer about links between functional connections, such as the vasculature or the nervous system, or links between bones. In the current implementation, regarding the connective relationships in the human body structure, an ontology for connective relationships involving the circulatory system (arteries and veins), the main nervous systems throughout the body, and the skeletal muscles has been constructed. The numbers of concepts defined in the ontology for the connective relationships are about 11,000 for the circulatory system, including both the arteries and the veins, and about 7,500 for the nervous systems, and the numbers of connective relationships for these systems are about 8,600 and about 3,200, respectively.

In the ontology for connections in the human body structure, in order to confirm whether the connective relationships are properly described in terms of content, the contents described at the destinations of connection ports of the human body constructs are tracked sequentially. As a matter of practice, however, it is substantially impossible to confirm more than 10,000 connective relationships in the human body structure by manually tracking the concept definitions. Thus, in order to confirm that the connective relationships in the human body structure are properly described and to refine the ontology, it is required to perform necessary exploration automatically and to visualize the results in a form easy to recognize for the user.

Thus, in order to meet such a need, we created a special tool that performs exploration to track connection ports representing connective relationships in the ontology describing the human body structure and that visualizes the results for confirmation of the connective relationships in the human body structure (Fig. 2). It means the tool generates conceptual maps by focusing on a common upper level conceptual structure in connective relationships in the human body. This tool is developed as a Java application using JUNG[6]and it supports several visualization forms. In the screen shot shown in Fig. 2, the connective relationship of ”Aorta” starting from the ”Heart” is visualized. By starting from ”Heart” and proceeding to ”Vascular connection”, it is understood through the visualization that ”Aorta” branches at the ”Aorta branch” and ”Artery” extends to ”Femoral artery”.

By visualizing the connective relationships of the human body constructs in the clinical ontology as described above, it becomes easier to intuitively understand the description and to find errors in the concept descriptions. Actually, together with experts, we confirmed the connective relationships of ”Artery” by using the visualization tool and discovered that a connective relationship of blood vessels that were supposed to be connected had not been described.

3.2.2 Application to disease concepts

We also applied the visualization tool described in Sect. 3.2.1 to construction and refinement of disease concepts in a clinical ontology and performed verification. A disease in the clinical ontology is considered as a sum of a series of state transitions, including their causes and intermediate states, and a resulting state caused thereby, and a disease concept is defined as state changes commonly observed among patients who develop the disease. Furthermore, an ”Abnormal state” constituting the disease is a generalization of possible states that patients experience, and is defined as a concept having two abnormal states ”Cause” and ”Result” as attributes. Therefore, it is possible to find all possible abnormal states that patients may experience by tracking ”Cause” and ”Result” attributes in the abnormal states.

In the current implementation, diseases in twelve diagnostic sections have been defined, amounting to a total of about 6,000 diseases. In refining the disease concepts, tracking and confirming a series of abnormal states that patients may experi-

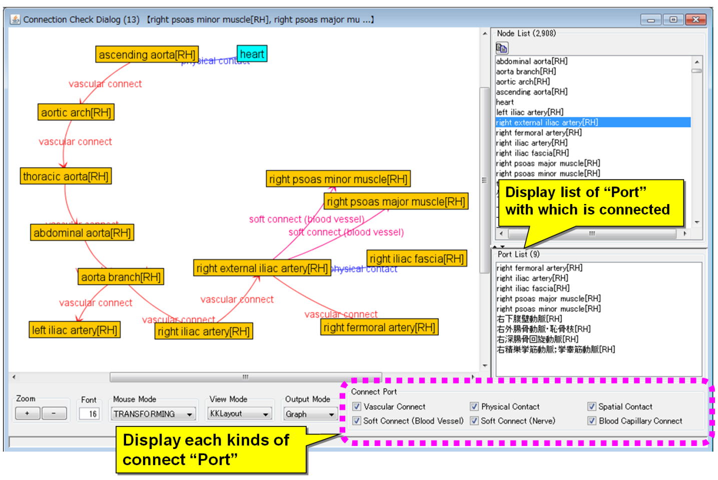

Fig. 2 visualization tool which represent connective relationships in human body structure.

ence was necessary to understand all definitions of a disease concept. In the similar method described in Sect. 3.2.1, a tool for exploring and visualizing state changes among all possible abnormal states in the ontology of disease concepts is created, and it was possible to confirm state changes among the possible abnormal states, as well as the definitions of the disease concepts.

4 Related Work

The method proposed through this research will be further clarified in terms of differences from related research. In form-based evaluation in the ontology construction phase, it is the case with many ontology construction tools that errors are rejected during editing so that an ontology will be edited in compliance with the rules, and consistency is verified after editing. The user must strictly write the ontology without errors during editing, raising a concern that this laboriousness could inhibit conception by the user. Furthermore, OWL-based construction tools often employ reasoners based on description logics (DLs) for consistency verification, such as FaCT++[7], RacerPro[8]and Pellet[9]. In Hozo, consistency verification is performed only minimally during editing, tolerating specific types of errors so as not to inhibit conception by the user, thereby maintaining a certain level of quality of the ontology. As for the items that are to be verified but were not covered during editing, the ontology as a whole is verified after editing. By dividing verification into that during editing and that after editing, the quality of the ontology is assured effectively. Furthermore, since special concept representations are adopted in relation to the reasoner, a special reasoning method is proposed in accordance with the differences in ontology models, and the reasoner is implemented within the construction tool. Hozo Reasoner has 32 native reasoners corresponding to each item for assuring fast consistency-check without logical computation like DLs.

In content-based evaluation in the ontology refinement phase, since judgements based on expert knowledge and experience are required, it is difficult to assist refinement by using a computer. For this matter, in order to assist refinement, proposed approaches for assisting experts understanding of the description of an ontology include an approach in which an ontology is visualized to promote intuitive understanding[10], and an approach in which an ontology is described in a form similar to a natural language by using a control language and the ontology is translated into a formal ontology description through computer processing[11]. There are some approaches that construction tools built into a visualization tool as extension to verify or analyze a ontology such as TGVizTab[12]. However, we focus not on visualization but on exploration of ontologies according to the users' viewpoints. The features of our method are functions for searching for necessary information according to their viewpoint and assisting to understand content of an ontology by expressing conceptual maps for search results. The examples of applications described in this paper demonstrate that the framework itself to search and create conceptual maps at the users' viewpoint is versatile, although partially dependent on the target ontology, and that sufficient effect can be expected. We are sure that a method for content-based evaluation with conceptual maps has sufficient effect.

5 Conclusion

This paper has discussed the authors' efforts with the environment for building/using ontologies: Hozo as a framework that supports quality assurance in the ontology construction and refinement phases, and demonstrated that the methods contributed to quality assurance when actually applied to the ontology construction process.

As a further issue to be addressed, further improvement in the methods for quality assurance in the ontology construction process is needed. Specifically, regarding form-based evaluation, a conceivable approach is to provide appropriate guidance so that even a domain expert who is not familiar with ontology can write properly from the ontology perspective. Regarding content-based evaluation, it is necessary to evaluate our method to be applied to the ontology constraction in other domains. We also have the issue to develop a assistance method for correcting contradictions found in the generated concept map and reflecting the corrections in the ontology.

Acknowledgements This research was partly supported by the Ministry of Health, Labour and Welfare on Japanese Government as Development business and research of ”Medical-knowledge-based database for medical informatics system.”, the Environment Research and Technology Development Fund (E-0802) of the Ministry of the Environment, Japan.

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