Knowledge Structuring Process of Sustainability Science based on Ontology Engineering

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ABSTRACT

In the process of establishing Sustainability Science (SS), we need to reconstruct a knowledge related to SS. In this paper, we introduced the approach of ontology engineering as a technology for organizing knowledge of SS. In this paper, we attempted to extract general and highly versatile concepts on SS through a series of dialogs among experts in the relevant fields. We have reached, to some extent, concensus over the upper-level classifications of *Problem*, *Countermeasure*, and *Evaluation*.

OBJECTIVE

Establishing a new scientific base is needed in order to cope with impending problems concerning a long-term global sustainability. Emerging “sustainability science” (SS) is one of the representative and ambitious attempts for building a new discipline in this context. In the process of pursuing SS, we need to reconstruct a knowledge platform that enables us to replace the current piecemeal approach with one that can develop and apply comprehensive and multidimensional solutions to these problems. Sharing explicitly structured knowledge on SS among scientists from various disciplines is crucial to facilitating collaboration for the development of interdisciplinary SS.

We focuses on the approach of ontology engineering in order to organize knowledge of sustainability science in terms of general and highly versatile concepts. In SS it is often difficult to identify the problem to solve. We cannot take a quantitative approach because concepts and their relationships are not clear. One effective approach is to use a tool for supporting the thinking process for identifying what to solve. For example, use of an ontology can help modelers select appropriate variables during the construction of a simulation, and ontology engineering can also help them combine models constructed separately. Furthermore, an ontology functions as the platform for smoothing communication among stakeholders. Ontology engineering is characterized as a tool for supporting thinking. Therefore, we set the goal of proposing the structuring process of the ontology for SS (SS ontology).

The process of structuring knowledge based on ontology engineering is considered to include the following three steps: extracting the general and highly versatile concepts on SS, constructing SS ontology with these concepts, and examining the conformity of SS ontology. In this paper, we especially focused on the first step, and aimed at extracting the general and highly versatile concepts on SS based on a series of dialogs among experts' in the relevant fields. As an another approach, extracting these concepts based on data obtained by text-mining approach is found, but this result will be reported in a future paper.

FRAMEWORK OF STUDY

(1) Ontology-Based Knowledge Structuring

Information technology (IT) provides effective methods for knowledge structuring. One of the key technologies for organizing a conceptual world is ontology engineering, which is expected to contribute to the structuring of the knowledge in the target world. Ontology is defined as an “explicit specification of conceptualization” by Gruber (1993). In other words, a target world is captured by the author of the ontology. Construction of a well-designed ontology presents an explicit understanding of the target world that can be shared among people. That is, the essential conceptual structure of the target world is understood through its ontology. Based on ontology engineering, a wide range of knowledge can be organized in terms of general, highly versatile concepts and relationships. Ontologies also provide flexible expressiveness that can convey social phenomena, which are difficult to formulate with quantitative methods. On the basis of these observations, we adopted an ontology-based approach to systemize knowledge for knowledge structuring of SS.

An ontology consists of concepts and relationships that are needed to describe the target world. One of the main components of an ontology is a hierarchy of concepts representing things existing in the target world that are determined to be important and organized by identifying is-a relationships between them. For example, an is-a relationship declares that Air pollution is a kind of Problem. In the is-a relationship, the generalized concept (e.g., Problem) is called a super concept and the specialized concept (e.g., Air pollution) is called a sub concept. Thus, an is-a hierarchy describes the categorization of the concepts. For instance, Problem is subdivided into sub concepts such as Air pollution and Water pollution. The introduction of other relationships refines the definition of the concepts. For example, part-of relationships, which are also called has-part relationships, and attribute-of relationships are used to show the concept's parts and attributes, respectively. These relationships can be used to explicate the is-a relationships that give the categorization.

(2) Basic Structure of SS Ontology

Due to the emphasis on the problem-solving approach of SS (Clark 2007), Problem and Countermeasure against a problem are two of the SS ontology's top-level concepts. Also, when trying to solve a problem, a goal or goals for countermeasures must be set, and the existing conditions and impacts of the countermeasures must be evaluated explicitly or implicitly. Post evaluation as well as prior evaluation may result in finding a new problem. Thus, we include Goal and Evaluation in the top-level concepts of the ontology.

In addition, we set Domain Concept as another top-level concept. In the SS ontology, the knowledge in the domain is not organized by individual fields or disciplines such as energy, climate, population, policy, or laws. Instead, it is organized by more general concepts, such as objects, activities, situations, and attributes, on the basis of ontology engineering theory (Mizoguchi 2003; Mizoguchi 2004a; Mizoguchi 2004b) .

In the theory of ontology engineering, an ontology is composed of domain-specific concepts under the upper level concepts, which are highly domain-neutral. In this way, the ontology is organized in a domain neutral manner. Our ontology consists of five top-level concepts: Goal, Problem, Countermeasure, Evaluation and Domain Concept. Although they are SS-specific, they are sufficiently generalized to be independent of the targeted domains. Furthermore, while concrete occurrences and activities can be the sub concepts of Domain Concept, these concepts do not depend on the context of problem solving. By describing the world using two types of super concepts, domain-independent and domain-dependent, we can represent any kinds of countermeasures for sustainability that we would like to show. Domain-specific knowledge seen from a specific viewpoint can be represented by combining these concepts. Also, such a conceptual system can support generation of ideas for new concrete countermeasures that were not conceived of when the system was initially designed.

(3) Procesures of Structuring Concepts

In order to systematize the concepts on SS we attempted to design is-a relationships by extracting the concepts on SS as an initial step. Designing other relationships was left as a future challenge.

On structuring the sub concepts of *Problem*, we classified these concepts based on the properties of the problems because the kinds of problems are considered to be able to be clasified into their targets and properties, while the targets belong to the spcific domain. Likewise, on structuring the sub concepts of *Countermeasure*, we classified these based on the behavior for implementing countermeasutes.

To implement these operations, we conducted the experts' workshop. We systematized concepts on SS using an ontology development tool named Hozo[1], which is based on fundamental theories of ontology engineering for capturing the essential conceptual structure of the target world.

PROCESS OF SYSTEMATIZING CONCEPTS

The experts' workshop was held twice. Table 1 shows these outlines. The participants consisted of the six assistant professors measuring the fields related to SS. Their specialized fields and records of attendance were shown at Table 2. The 1st workshop aimed at extracting concepts and systematizing temporarily, and the 2nd workshop was targeted at improvemeting the sturucture and adopting to the format based on the theory of ontology engineering.

In the 1st WS, discussion was conducted by writing down the concepts on SS on cards. Extracting concepts was practiced according to the following themes: eco-energy, eco-process, eco-design, future scenarios, institutional design, sustainability assessment and human security. These themes are the field of research conducted in the Research Institute for Sustainability Science (RISS), Osaka University. On extracting concepts, it was allowed to show concepts without taking care of the theory of ontology engineering because it was necessary that multiple ideas occurred to participants freely as an initial step of the workshops. Systematizing was then implemented by grouping in the way like KJ method, a technique to reach concensus. In the 1st WS, we extracted 527 concepts. Photo

1 http://www.hozo.jp/

1 presents the picture of the 1st WS.

In the 2nd WS we demonstrated the work of systematizing was conducted using Hozo. During the workshop, participants had an opportunity to practice according to ontology theory. Also, in this workshop, we raised new concepts in addition to those from the first workshop.

Table 1 Outlines of Experts' Workshops

WS	Date	Contents
1st workshop	12/15/2007 (AM10:15-PM7:00)	① Extracting the concepts on SS ② Concensus Building on Intermidiate Concepts
2nd workshop	7/12/2008 (AM10:30-PM6:30)	① Improvement on the sub concepts of *Goal* ② Improvement on the sub concepts of *Problem* ③ Improvement on the sub concepts of *Countermeasure* ④ Improvement on the sub concepts of *Evaluation*

Table 2 Participants of Experts' Workshops

Name	Field	Records of Attendance	
		1st WS	2nd WS
M	Environmental Risk, Environmental Psychology	○	○
H	Resource Management, Arban Environmental Engineering	○	○
Y,Yo	Environmental Engineering, City Energy System	○	○
Y,Yu	Environmental System, Resource Circulation	○	○
U	Behavioral Game Theory	Part 1	Part2 and 3
K	Enivironmental Planning, Town Development co-existing with nature	○	○

Photo 1 Scene of the1st WS

CLASSIFICATION OF EXTRACTED CONCEPTS

(1) Structure formed from two times' workshops

Fig 1 shows part of the concepts systematized in the workshops. This structure, organized basically based on the theory of ontology engineering,is yet in the trial stage. Specifically, the concepts in the structure require to be broken down into farther categories according to some systematic patterns. Furthermore, it is necessary to change the structure of the concepts by using the theory of engineering ontology.

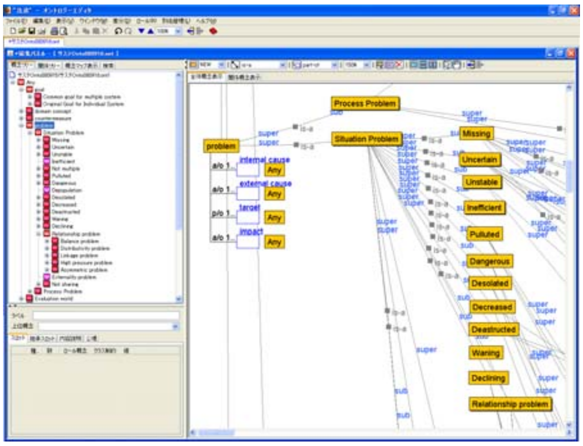

Fig.1 Situation of Structuring after Two Series of WS

(2) Results of Concept Classifying and Challenges

We discussed ①the concept classifications and their hierarchy and ②the future tasks for classification on the sub concepts of *Goal*, *Problem*, *Countermeasure*, *Evaluation*. We have not yet delt with *Domain Concept*, but you can refer to Mizoguchi(2005) for its sub concepts.

Selection criteria of ① are [1]concept classifications shown by the identical expression format in the same hierarchy and [2] concept classifications selected by the members in the monthly workshops organized by the Research Institute for Sustainability Science (RISS) at Osaka University. We didn't post the concepts which do not meet the criteria, [1] and [2] even if they are in the same hierarchy as the posted one.

1) Goal

In the monthly WS, we have agreed to break down *Goal* into *Earth system goal*, *Social system goal* and *Human system goal*. We also selected *Low-Carbon Society* and *Resource Circulating Society* as the sub concepts of *Social system goal*. Further discussion is still necessary to determine the number of hierarchy in which these concept groups should be set. Specifically, we need to examine whether we should set *Original goal for individual system* as a super class of *Earth system goal*, *Social system goal* and *Human system goal*, and *Common goal for multiple system*. If *Common goal for multiple system* is set, we still need to determine the corresponding sub concepts.

Another issue is that even is we set a sub concept of the specic system's goal , the concept is closely often related to other systems. For example, *Multiple Lyfestyles* can be the sub concept of *Social system goal* now, but this concept is closely related to *Human system goal*. Further discussion is needed about this point.

2) Problem

Investigating the properties of problems in the monthly WS, we have determined to classify *Problem* into *Situation* and *Process*. Table 3 shows the concepts at third-level and fourth-level of which fatal problems are not indicated. We need to select from these concepts in third and fourth levels in the next step.

It is a future task that the concepts in the same level weave what indicate the properties of problems with what indicate the kind of problem. For example, the *Uncertain* and *Relationship problem*,are both in the third level.

Table 3 Situation of Classification on *Problem*

<table>
<tr><th>Second-level</th><th>Third-level</th><th>Fourth-level</th></tr>
<tr><td rowspan="3">Situation problem</td><td rowspan="2">Missing
Uncertain
Unstable
Inefficient
Polluted
Dangerous
Desolated
Decreased
Destroyed
Waning
Declining
Externality problem</td><td>※

※ means the parts which is not suffciently sort out to show at this table/.</td></tr>
<tr><td rowspan="2">Balance problem
Distributivity problem
Linkage problem
High pressure problem
Asymmetric problem</td></tr>
<tr><td>Rrelationship problem</td></tr>
<tr><td>Process problem</td><td colspan="2">※</td></tr>
</table>

3) Countermeasure

We have agreed to classifty Countermeasure into *Future-oriented countermeasure*, *Present/Ongoing countermeasure* and *Past-oriented countermeasure* at second-level.

Future-oriented countermeasure includes the activities which are intended to change the present situation in the future. These activities don't change the current world. On the other hand, in *Present/Ongoing countermeasure*, the activities are intended to change the present situation or the world. Based on these classification, *Make Scenario*, *Plan* and *Educate* were selected as sub concepts of *Future-oriented countermeasure* whereas *Prevent* was selected as a sub concept of *Present/Ongoing countermeasure*. Further, *Change life* and *Change life* cycle were chosen as sub concepts of *Present/Ongoing countermeasure* involving time-lag. *Past-oriented countermeasure* includes activities which should be conducted at present toward an incident occurring in the past.

Table 4 Situation of Classification on *Countermeasure*

<table>
<tr><th>Second-level</th><th>Third-level</th><th>Fourth-level</th></tr>
<tr><td>Future-oriented countermeasure</td><td>Educate
Make Scenario
Plan
Design</td><td rowspan="2">Complex type countermeasure

Individually corresponding countermeasure</td></tr>
<tr><td rowspan="3">Present/Ongoing countermeasure</td><td>Technology-based countermeasure</td></tr>
<tr><td>Action-based countermeasure</td><td rowspan="3">Manage
Control
Act
Adjust
Share
Propose
Discriminate
Produce
Support
Offer
transfer
try
Get involved</td></tr>
<tr><td>Change life
Change life cycle
Prevent
Review
Decrease
Reuse
Link</td></tr>
<tr><td>Past-oriented countermeasure</td><td>Compensate</td></tr>
</table>

Table 4 shows the concepts at the third-level and fourth-level of which fatal problems are not indicated. We need to investigate these concepts and the corresponding levels in the next step.

4) Evaluation

In the monthly WS, we determined to set *Evaluation World* as a top-level concept. We also decided to move *Evaluation* to the second–level. The other concepts at this level include *Evaluation model*, *Evaluation Method*, *Evaluation standard* and *Evaluation perspective*. Also, we broke down Evaluation into *Situation Evaluation* and *Performance Evaluation*. We are currently adding new concepts and improving the structure on the sub concepts of *Evaluation*.

CONCLUSION

This paper aimed at extracting the general and highly versatile concepts on SS based on a series of dialogs among experts' in the relevant fields. We summarize the result as follows.

First, we structured sustainability by holding two workshops. Second, we reached, to some extent, concensus over the upper-level classifications of *Problem*, *Countermeasure*, and *Evaluation* including second and third level. We also agreed that *Earth System Goal, Social System Goal* and *Human System Goal* are contained in the second or the third level. Third, we successfully extracted concepts about *Problem* and *Countermeasure* in accordance with the theory of engineering ontology. Yet, further work is necessary to continue to sort out the concepts and their levels in the whole ontology trees.

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