Description of social-ecological systems framework based on ontology engineering theory

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Prepared for delivery at the Workshop on the Ostrom Workshop (WOW5) conference,
Indiana University Bloomington, June 18–21, 2014.

1. Introduction

There are a variety of research methods in the field of commons and collective action. By means of these methods various perspectives towards a particular field is provided, but it is difficult to share these perspectives among researchers in different domains smoothly. In addition, it is also difficult for a practitioner to distinguish a difference between the perspectives that researchers have. The social-ecological systems (SESs) framework supports sharing the perspectives by providing the common items (Figure 1, 2).

However, in order to facilitate collaboration certainly the method to share mutual difference between perspectives more explicitly is necessary. For example, our knowledge-sharing will be ensured from the procedural aspect if we can mutually compare the conceptual models proposed by different stakeholders or experts in different domains. Ontology engineering, which is one of the base technologies in semantic Web technology, is a method to design some sort of guideline facilitating knowledge-sharing, and supports to build case-specific modelling same as Schlutüter et al.(2014) discusses. In addition, Fray et al.(2012) , for example, deals with the structuration of SESs framework by neural network, while ontology engineering structures the SESs framework based on concept definition by means of a role concept.

On the other hand, the collaboration method with ontology exactly corresponds to design-oriented approach, which supports problem-solving in a particular case of SESs. The designed ontology also needs including the concepts corresponding to problem-solving approach. As such an ontology we have been developing the ontology dealing with the Sustainability Science (SS) (Kumazawa et al.(2014)). This ontology is named the Sustainability Science Ontology (hereinafter, the SS ontology). In this paper we focus on sustainable design of SESs based on the SS ontology, and we especially aim at describing the framework of SESs by means of an ontology. For this purpose, we first define the concepts reflected by the items in the SESs framework and incorporate these into the SS ontology. Second, we discuss a variety of semantic relationships between the items in the SESs framework by means of the constructed SS-SESs ontology.

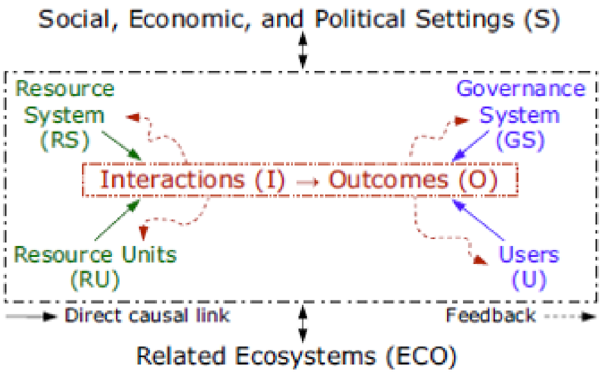


Figure 1 SESs framework (first tier)

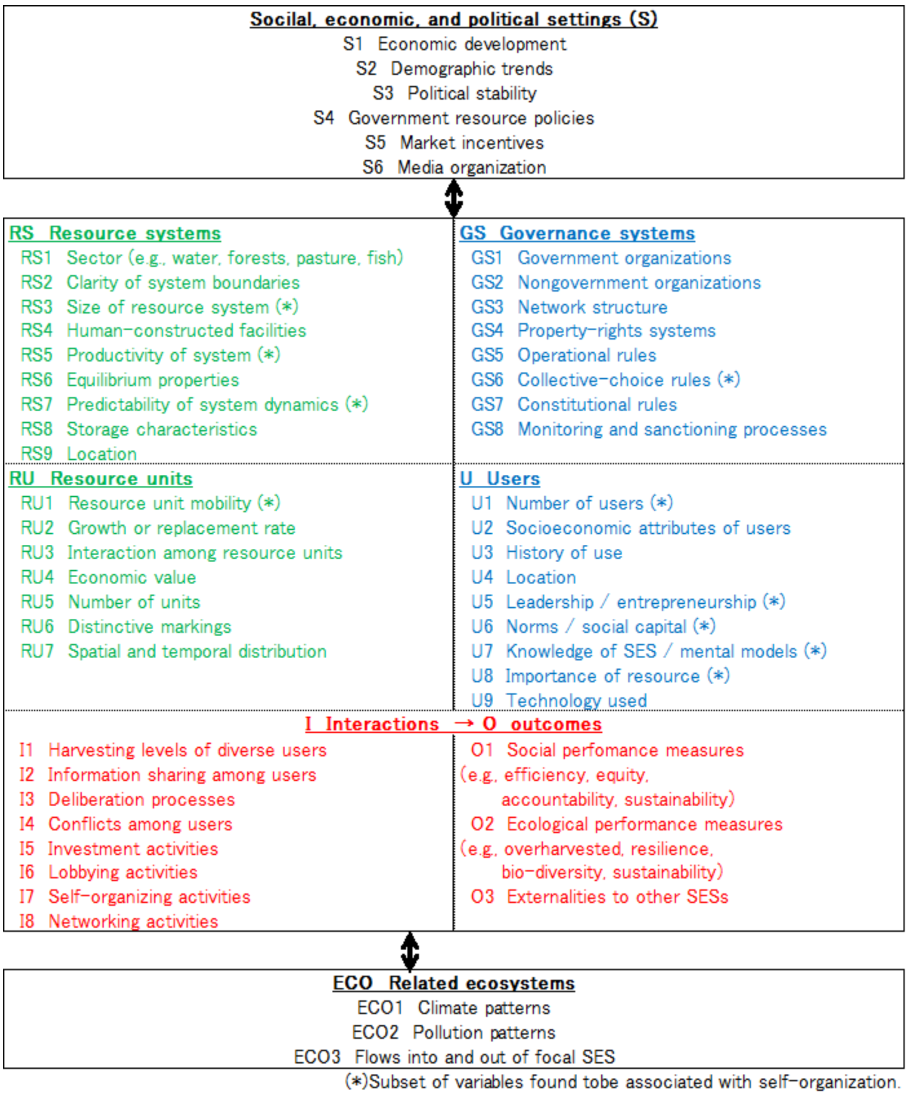


Figure 2 SESs framework (second tier)

2. Sustainability Science and ontology engineering

2.1. What is ontology engineering?

In the artificial knowledge field ontology is defined as "explicit specification of conceptualization" (Gruber(1993)). Ontology engineering is the key method for information technology which people and computer both can understand. An ontology consists of concepts and relationships that are needed to describe the target world. It provides common terms, concepts, and semantics by which users can represent the contents with minimum ambiguity and interpersonal variation of expression. It is expected to contribute to the structuring of the knowledge in the target world. Construction of a well-designed ontology presents an explicit understanding of the target world. An ontology, however, is identified not by the form of the knowledge, such as description languages and representation forms, but by the contents of some described knowledge and the roles that some described knowledge plays.

2.2. Sustainability Science ontology (SS ontology)

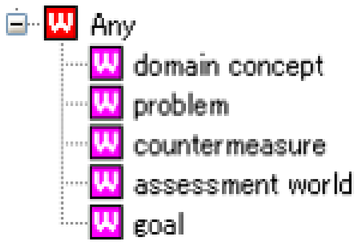
SS seeks to clarify the complexities in sustainability issues and attempts to provide comprehensive approaches to solving sustainability issues (Kates et al. 2001; Kates 2011; Komiyama and Takeuchi 2006). The main characteristics of an SS ontology can be seen in its attempt to simultaneously conceptualize two different aspects of its static domain and the dynamic process of problem solving as targets. Hence, two kinds of top-level concepts shall be set in the SS ontology: one is *domain concept* as a top-level concept of the SS domain and the others are *goal*, *problem*, *countermeasure*, and *assessment* as top-level concepts of problem-solving. *problem* covers problems related to sustainability. *Countermeasure* covers countermeasures implemented for problem-solving. *Assessment* covers concepts to understand present situation and state of the achievement. Goal covers concepts as controls for comparing with present states/situations (Figure 3）.

We constructed an SS ontology using the Hozo ontology development tool, which is based on fundamental theories of ontology engineering. Figure 4 shows the concept definition by means of Hozo. In Figure 4, *is-a* relationships describes the categorization of the concepts. Meanwhile, the introduction of other relationships including *part-of* relationships (*has-part* relationships) and *attribute-of* relationships refines the definition of the concepts. In Figure 4 *target* includes a concept dependent on a context, called a role. The greatest characteristic of Hozo is to be able to deal with a role concept. A role concept enables us to create a model to explicate what plays a role. For example, human, fruits or heating oil can play a role of teacher, food and fuel respectively. Making full use of this characteristic, we are attempting to define the concepts as strictly as possible in the SS ontology.

In the present implementation, the SS ontology has more than 4,500 classes and 13 hierarchical levels. Specifically, we introduce concepts based on a literature survey and experts' workshops. In addition, we systematize these concepts based on 36 discussions among experts in SS and knowledge science held during monthly workshops (Kumazawa et al. 2008, 2009b).

We constructed the *domain concept* conforming with YAMATO (Mizoguchi 2010, Mizoguchi 2012), which is a top-level ontology being developed at former Mizoguchi Laboratory, Osaka University.

The *domain concept* class is divided into the *attribute*, *quantity*, *abstract object*, *concrete object*, *substrate*, and *spatial region* classes. *Concrete object* is further classified into *object* and *occurrent* classes. *Occurrent* is divided into the *process* and *event* classes. *Event* is divided into the *change* and *ordinary event* categories. In addition, *value* is a subclass of *quantity* (Figure 5).



- *Domain concept* is the top-level concept of SS domain including *object*, *process*, *state* and *attribute*.
- The other concepts are the top-level concepts of the knowledge required for problem solving. The definitions of these four concepts provide criteria for classification into the subconcepts of these.

Figure 3 Top-level concepts of the SS ontology

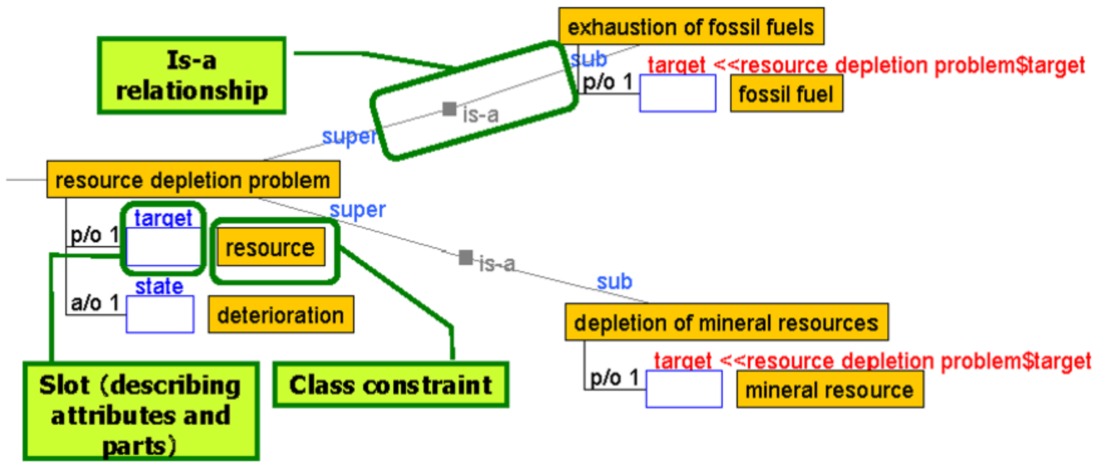


Figure 4 Concept definition using Hozo

- an example extracted from the SS ontology under construction process

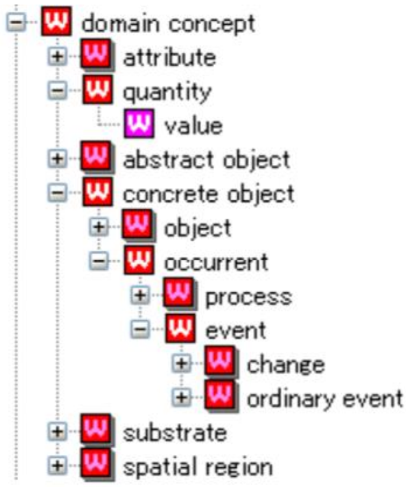


Figure 5 Subconcepts of *domain concept* in the SS ontology

3. Description of SESs framework based on ontology engineering theory

3.1. Concept definition and structuration

We attempt to define the subconcepts of *domain concept* by conceptualizing the items proposed in the SESs framework. This updated ontology is temporarily named the SS-SES ontology. As a first step for this updating, we additionally introduce/reflect the concept structure of the YAMATO in order to define the items in the SESs framework more accurately. The newly added concepts are, *semi-abstract*, *dependent entity* and *dissective*. *Semi-abstract* and *dependent entity* are the subconcepts of *domain concept*, while *dissective* is the subconcept of *concrete object* (Figure 6).

As a next step we add the concepts corresponding to the items in the SESs framework according to the definitions of the upper concepts. We show the subconcepts of *object*, *occurrent*, *semi-abstract* and *dependent entitiy* in Figure 7, 8, 9 and 10, respectively.

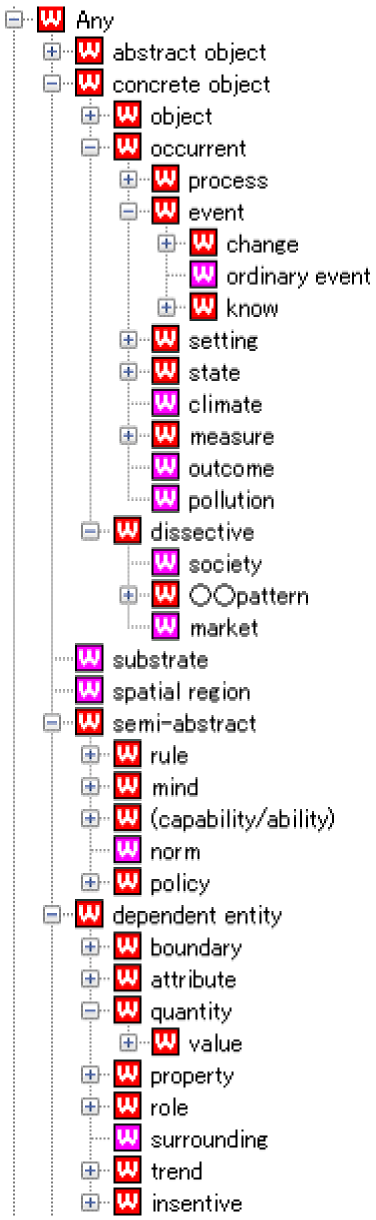


Figure 6 Result of improvement on the subcencept structure of *domain concept* [1]

[1] **But *know* needs review because this concept is defined as a subconcept of process in the YAMATO.**

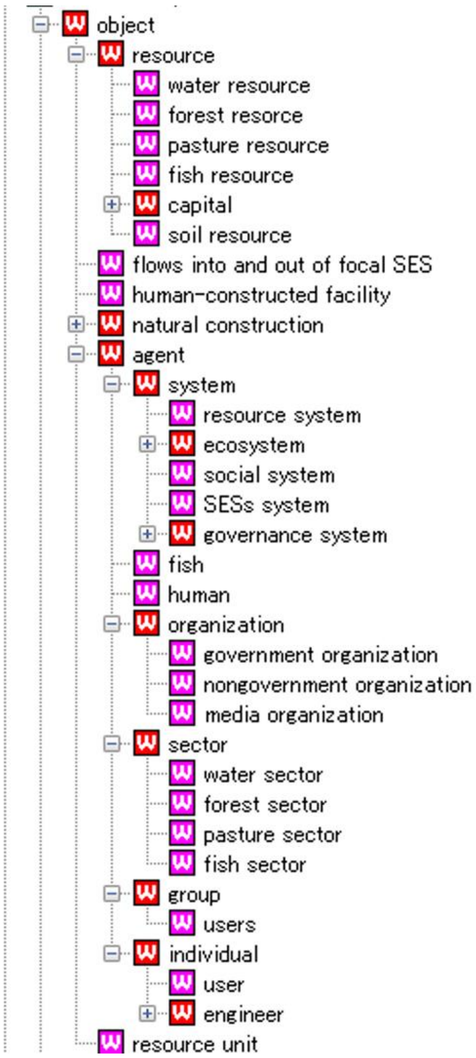


Figure 7 Subconcepts of *object*

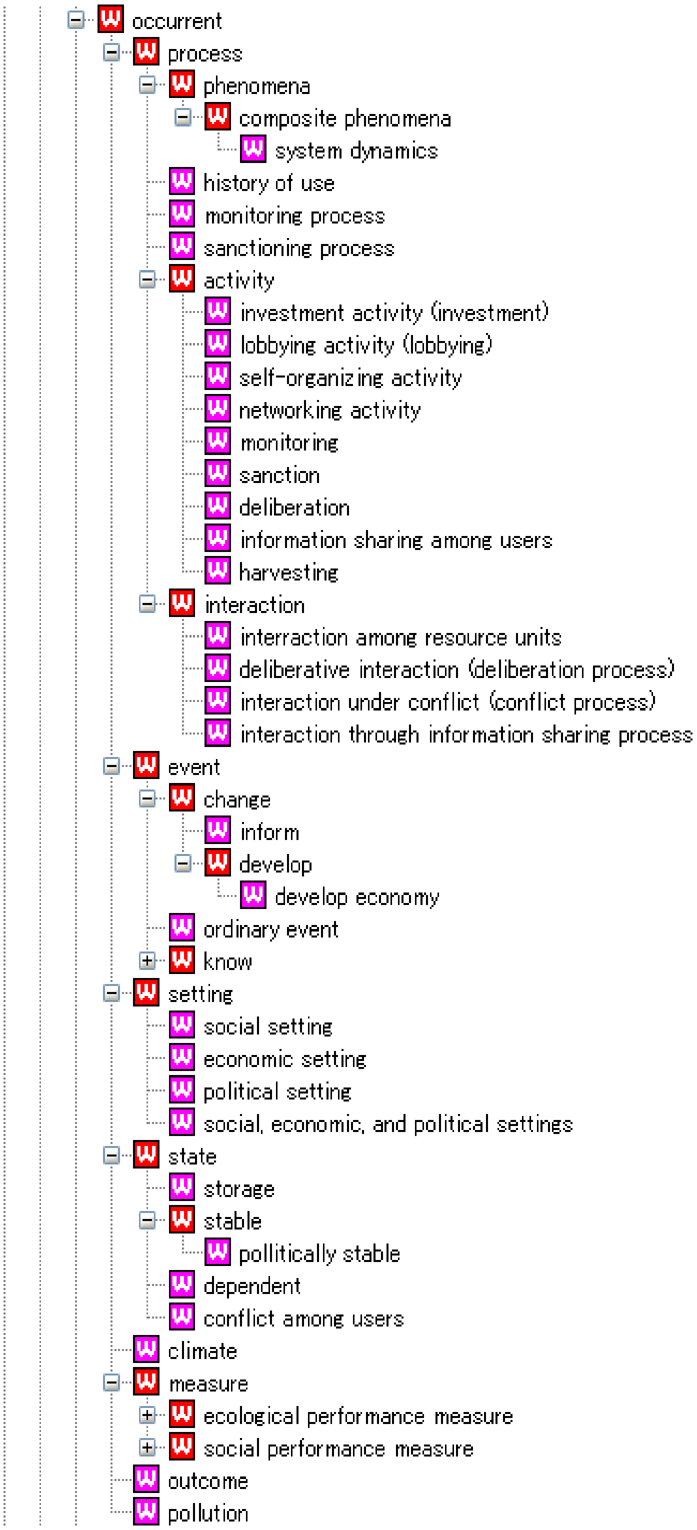


Figure 8 Subconcepts of *occurrent* [2]

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[2] **But *know* needs review because this concept is defined as a subconcept of process in the YAMATO.**

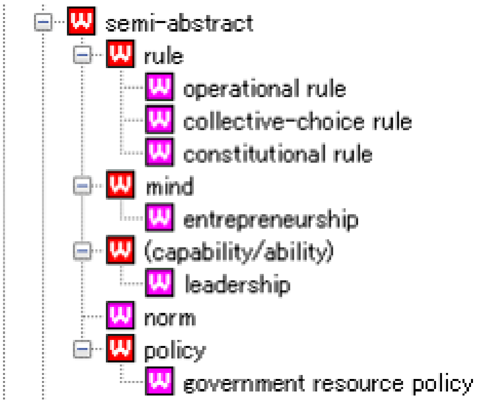

Figure 9 Subconcepts of ***semi-abstract***

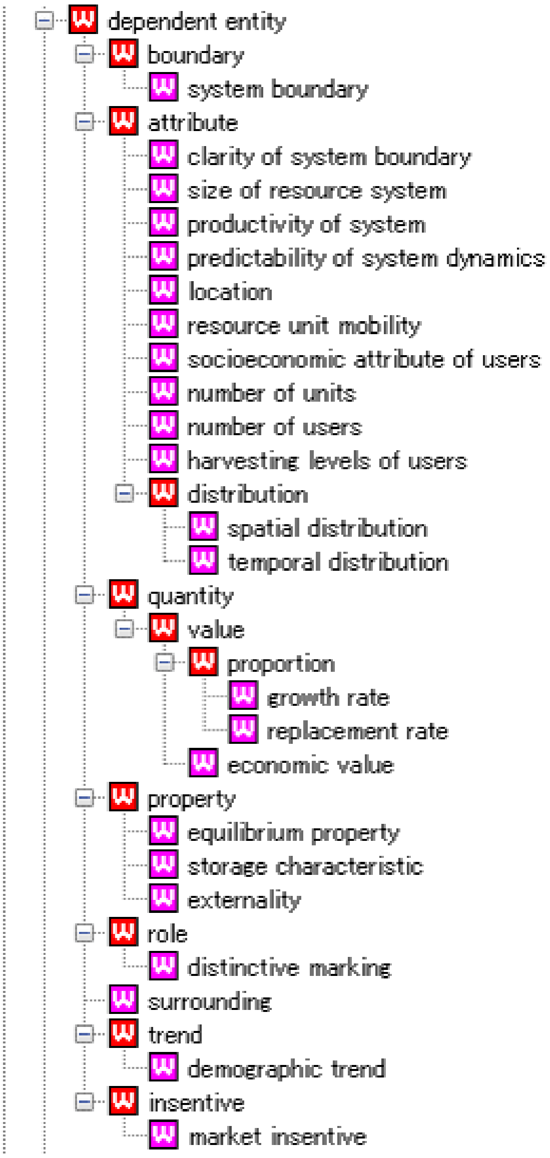

Figure 10 Subconcepts of ***dependent entity***

3.2. Relationship with SESs Framework

As a first step for defining SESs system we explicate what system means. The YAMATO doesn't define *system* but many items related to system is included in the SESs framework. Therefore, we define *system* as a subconcept of *object*. The concept of system is defined by the role of *system boundary* and *surrounding*. The definition of system and its subconcepts are shown in Figure 11. In addition, *society* is the subconcept of *dissective* set at the subconcept of *concrete object* according to the YAMATO. This definition is explicating the difference between *society* and *social system*.

The figure 1 shows that SESs framework consists of the following elements: interaction process consisting of I and O, system boundary, Direct causal link, Feedback, RS, RU, GS, GU, S and ECO. RS, RU, GS and GU mean the subsystems of the first tier, while S and ECO mean the external system of the SESs system. As these elements play roles of SESs system, we define SESs system by setting the slots of *subsystem*, *interaction process*, *external system*, *SESs system boundary*, *direct causal link* and *feedback* as *part* slots (Figure 12). By referring to these slots we are able to trace the SESs framework.

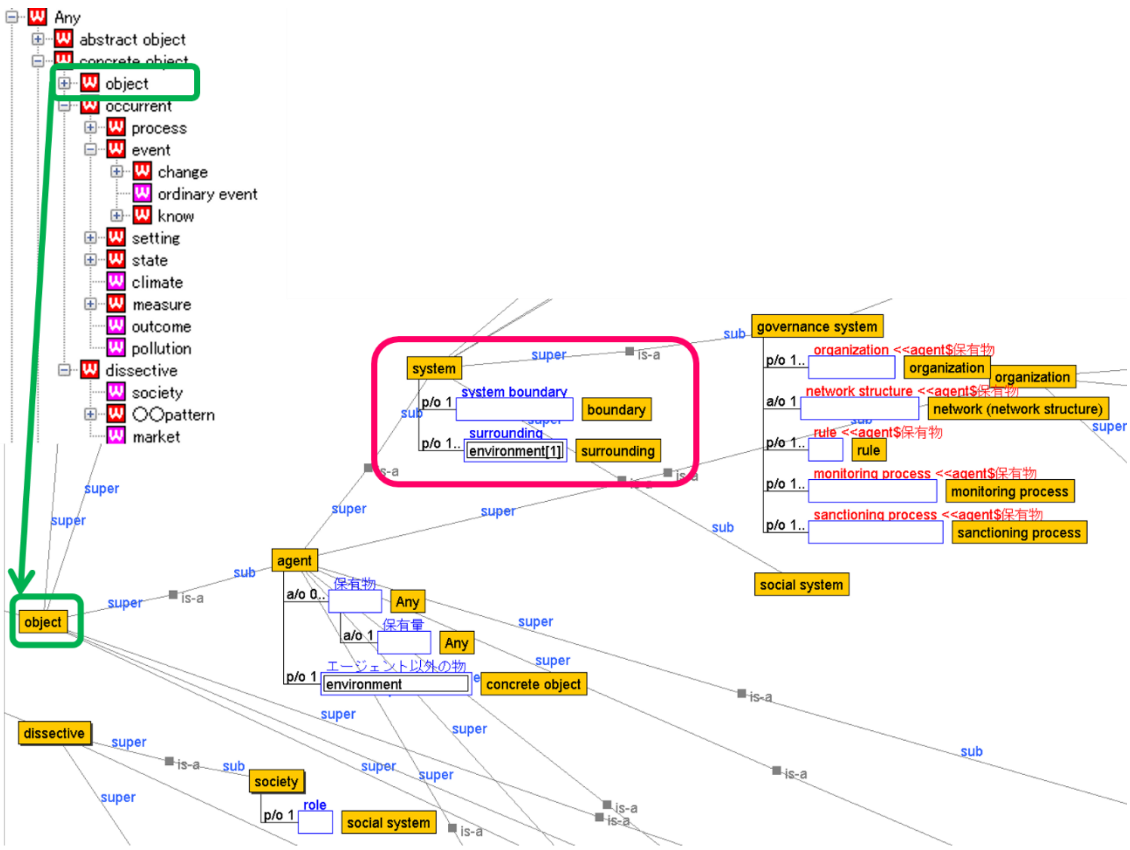

Figure 11 Definition of *system* and its subconcepts

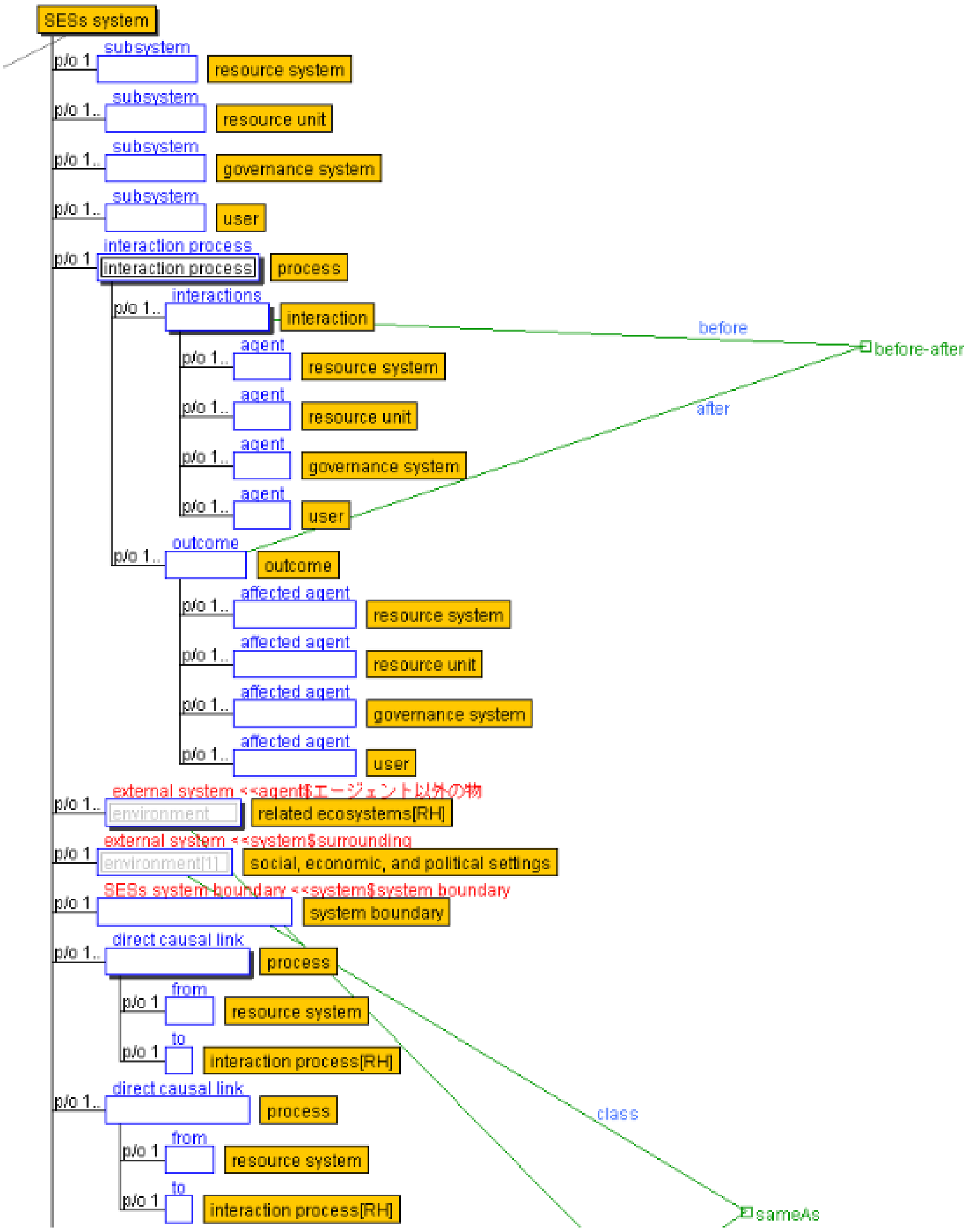

Figure 12 Definition of *SESs system* (a part of the structure)

4. Relationships between items in the SESs framework using SS-SESs ontology

In this section we examine the semantic relationships between the concepts defined in the SS-SESs ontology. The semantic relationships are shown by *is-a* relationships and by role concepts explicating *part-of/attribute-of* relationships.

As a result of ontology construction, we found that the concepts corresponding to the first tier items are basically linked with the concepts corresponding to the second tier items by *part/attribute-of* relationship as is shown in Figure 13. On the other hand, we also found that *governance system* and *interaction* are linked with the concepts corresponding to the second tier by *part/attribute-of* relationship as well as by *is-a* relationship (Figure 14). In addition, we found a lot of cases with the linkages by the combination of *part/attribute-of* relationship and *is-a* relationship between the concepts corresponding to the first tier and the second tier. Regarding these cases, there are two patterns: one starts from *part/attribute-of* relationship, the other starts from *is-a* relationship as shown in Figure 15.

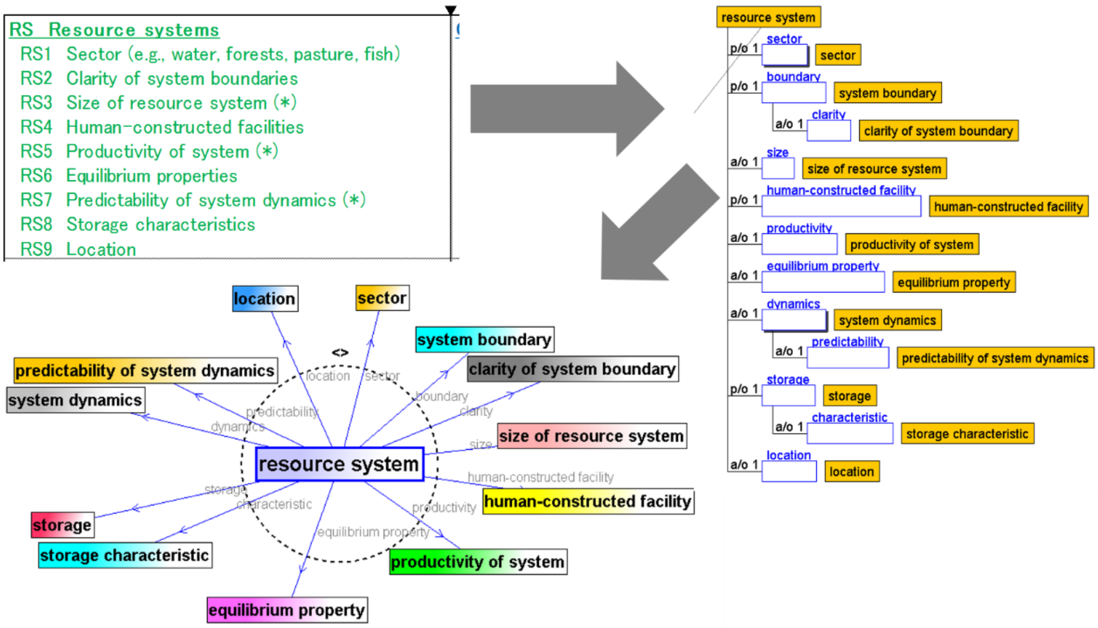

Figure 13 The concepts in the first tier are basically connected with the concepts in second tier by *part/attribute-of* relationship – case of *resource systems*

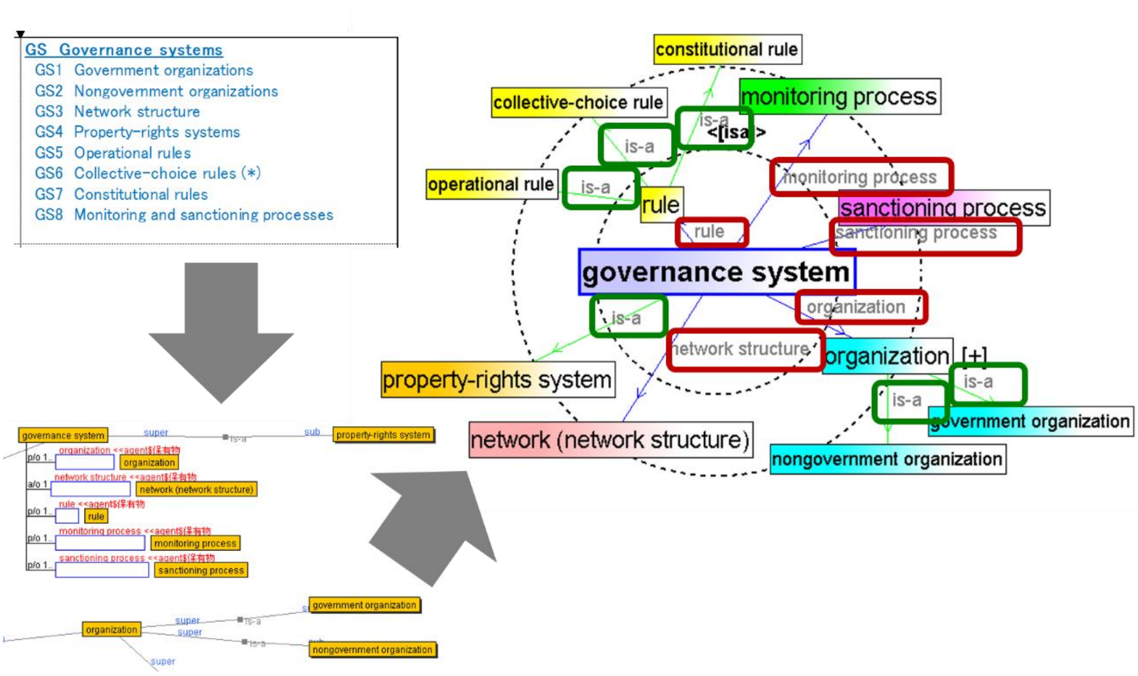

Figure 14 Difference between *is-a* relationship and *part/attribute-of* relationship

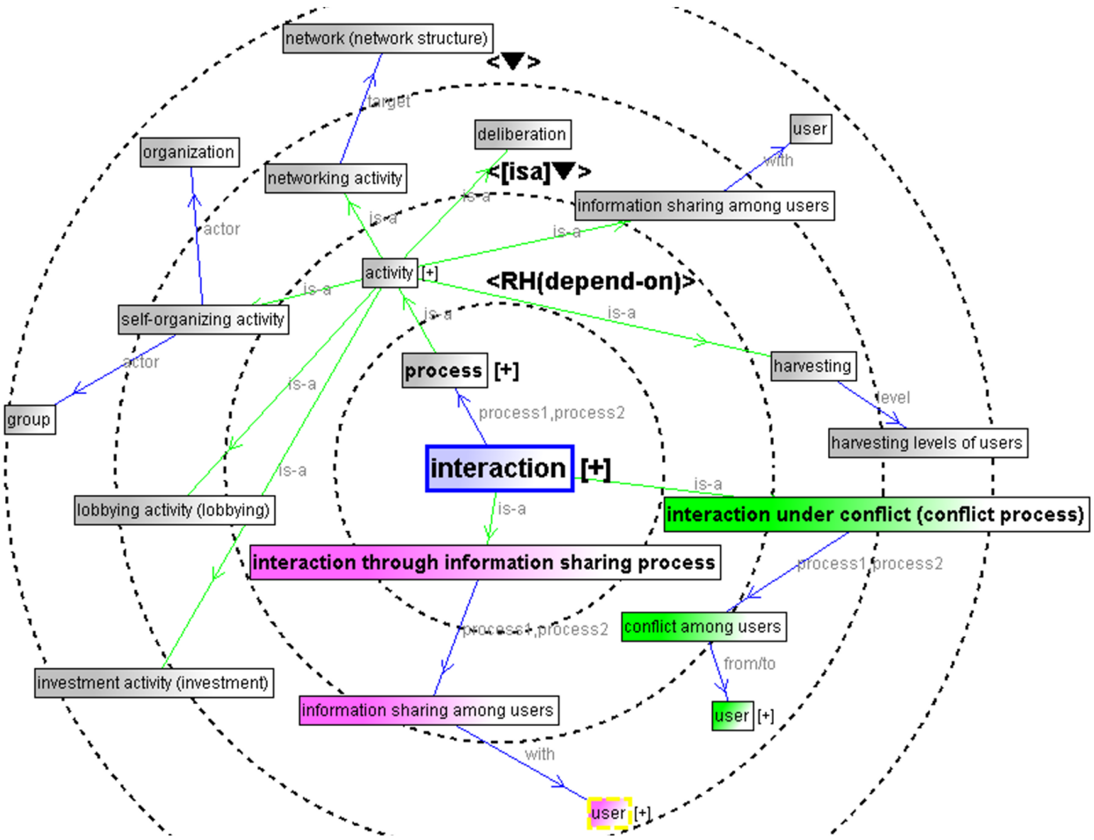

Figure 15 Combination of *is-a* relationship and *part/attribute-of* relationship – case of *interaction*

5. Conclusion

This present paper focused on sustainable design of SESs based on the SS ontology, and discussed how to describe the framework of SESs by means of an ontology. The results are as below. First, we defined the subconcepts of domain concept in the SS ontology according to the SESs framework. Second, we found a variety of semantic relationships between the items in the SESs framework by means of the constructed SS-SESs ontology.

As a result of constructing the SS-SES ontology we found the following three points: First, we found that the concepts corresponding to the first tier items are basically linked by part or attribute relationship. Second, we also found that a part of the cases has semantically different relationships between the same tiers. Third, we found the linkages including multiple kinds of semantic relationships.

In the future, we will gather all kinds of field information in the cases which need analyzing sustainability of SESs, and define the newly extracted concepts as subconcepts of the SS-SESs ontology. In addition, we will implement designing the collaboration process which a forum for dialog between practitioners and researchers and the structured ontology functions organically with each other.

Acknowledgement

This present research was supported by JSPS KAKENHI Grant Number 24710054 and Inamori Foundation. We gratefully acknowledge the helpful discussions with the development group (General manager: Prof. Riichiro Mizoguchi (Japan Advanced Institute of Science and Technology)) members of the SS ontology.

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