

The model of roles within an ontology development tool: Hozo

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Abstract. One of the major goals of ontology is to represent properly the underlying conceptual structure of the messy world reflecting the reality as much as possible. Ontology building tools should be designed to help developers create good ontologies. However, few of them can deal with roles adequately. Needless to say, the world is full of roles (e.g., wife, teacher, president, fuel, food, product, output, height) although there has been extensive theoretical research on roles, we do not yet have a comprehensive and usable theory yet. Our group has already constructed an ontology-development tool known as Hozo which has the ability to deal with roles. However, although Hozo allows users to represent roles better than other existing tools, the underlying theoretical foundations are still unclear and there is some room for improvement concerning the generality of how to deal with roles. In this paper, as an extension of the Hozo framework for roles, we present a framework for organizing role concepts according to their context dependencies. We also focus on the clarification of role properties and requirements on the model of roles and on the feedback obtained from Hozo-based ontology building experiences. Establishment of a computational model of roles contributes to building good ontologies because such a theory would provide useful guidelines for dealing with view-related and context-dependent distinctions related to roles.

1. Introduction

The world is full of roles. This is why in-depth understanding of roles is critical to ontology development. They are often understood as types, which differ from so-called natural types (referred to as basic concepts¹ in this paper) because of their dynamic nature – while instances of basic concepts such as *human* cannot stop being instances of such concepts without “dying” (disappearing from the real world), in the case of a *teacher* role, a human can stop being a teacher by just *leaving the role* without losing its identity. This is explained by one of the essential characteristics of roles, that is, roles² are *played* by some entity (e.g., when we say that an instance of human is a *teacher* we mean that the teacher role is played by a human). However, it is impossible to find a player of *human*.

Context dependence is another important characteristic of roles, which explains how and why an entity might change the role it plays according to a particular context. For example, a *man* would be regarded as a *teacher* in a *school* and as a *husband* in his *marital relationship*. While such changes can be modeled in connection with time, context-dependence is also a crucial factor.

¹Exactly speaking, by basic concept, we mean natural types plus artifacts, in other words, non-role entities.

²By role here, we mean role concept in our terminology. Term “role” is so ambiguous currently which is why we wrote this paper.

1 Research on roles has been progressing seriously in the latest years, and a lot of achievements have
2 already been obtained (Guarino, 1992; Guarino, 1998; Loebe, 2007; Masolo et al., 2004; Sowa, 1995;
3 Sowa, 2000; Steimann, 2000). However, there is no satisfactory theory or model able to cover all the
4 characteristics of roles and to account for issues such as the counting problem, the nature of roles as
5 “universals” or “particulars”, etc. Roles are so complex that we still need to invest our effort in capturing
6 them as a whole. We need a comprehensive theory and model of roles not only for scientific necessity,
7 but also for providing ontology developers with usable tools and languages that can take care of those
8 roles that are needed to build realistic ontologies. OWL³ has been used extensively in ontology develop-
9 ment and ontology exchange. Although OWL is useful as an interlingua for ontology sharing, it is not
10 sufficiently expressive for representing roles. To use OWL for role representation, we need representa-
11 tion patterns strongly supported by a convincing theory and a model (Kozaki et al., 2006; Sunagawa et
12 al., 2006).

13 Improper modeling of roles will greatly influence reasoning and truth-maintenance along *is-a* hier-
14 archies (Guarino, 1998). Let us take the common example: *<teacher is-a human>*. Assume John is a
15 teacher of a School. Given the usual semantics of *is-a*, since John is an instance of *teacher* then he is
16 also an instance of *human* at the same time. When he quits being a teacher, he cannot be an instance of
17 *teacher* so that you need to delete the *instance-of* link between John and *teacher*. However, you have to
18 restore an *instance-of* link between John and *human*, otherwise John dies. If we are only interested in
19 property inheritance between human and teacher, the relation *<teacher is-a human>* seems to be valid
20 because any teacher is a human in any case. However, if we think of essential property and/or identity
21 criterion of classes, then we can understand the relation is inappropriate and would cause such a prob-
22 lem. To avoid such a difficulty, you could introduce an ad-hoc routine which restores John instance.
23 However, the problem is not how to restore and to cope with the difficulty, but how to differentiate the
24 cases where you need restoration from those you do not, since if *<John instance-of human>* *<human*
25 *is-a animal>* is the case, you need no restoration, since if John stops to be a human, then he is not an
26 animal either. Similarly, it would be difficult for a model with no idea of roles to represent changes in
27 the roles played by John (e.g., *teacher, husband, patient*) according to contexts or aspects.

28 On the other hand, based on fundamental theories of roles in an ontology (Guarino, 1992; Kozaki
29 et al., 2000), we can clearly differentiate roles (e.g., *teacher*) from the other concepts (basic concepts),
30 coping therefore with the problems above. It is not easy but worth for ensuring quality of an ontology as a
31 backbone of an instance model to differentiate role from other concepts and organize them appropriately.

32 The ontology development/use tool we have developed, Hozo, has the ability to deal with roles. How-
33 ever, although Hozo allows users to represent roles better than other existing tools, the underlying theo-
34 retical assumptions are still unclear, and there is some room for improvements concerning the generality
35 of how to deal with roles. In this paper we aim at clarifying Hozo’s theoretical assumptions about roles,
36 presenting at the same time an extension to its current framework in order to organize role concepts
37 according to their context dependencies.

38 This paper is organized as follows. The next section summarizes the characteristics of roles and the
39 main open issues, addressed in more detail by the model we have developed, discussed in Section 3. Sec-
40 tion 4 discusses the way Hozo deals with compound roles and instance management. Section 5 analyzes
41 the proposed model in terms of the characteristics and requirements discussed in Section 2 together with
42 lessons learned. Related work is discussed in Section 6, followed by a step towards formalization of the
43 proposed role model together with concluding remarks.

45 ³<http://www.w3.org/TR/owl-ref/>.

2. Characteristics of roles and open issues

Before discussing our role model, we clarify what characteristics roles have and what problems we are trying to solve in our work. The characteristics discussed in Section 2.1 are not exhaustive and they are a modified version of the summary presented previously by Steimann (2000). Section 2.2 summarizes the issues to be solved by our role model.

2.1. Characteristics of roles

Although there is no universal definition of roles, we can assume the following as an informal definition:

A role is an entity that is played by another entity in a context.

By “context”, we mean something as a whole including a relation in which the former “entity” is defined. Having this informal definition of role in our mind and referring to the seminal survey paper (Steimann, 2000), we can enumerate some important (although sometimes controversial) characteristics of roles as follows:

- (1) Roles are anti-rigid (Guarino, 1998):
A role is a property that is contingent (non-essential) for all its instances.
- (2) Roles are dynamic (Masolo et al., 2004):
An entity can start and stop to play a role and a role can be played by multiple entities.
- (3) Roles are externally founded (Guarino, 1992; Masolo et al., 2004):
Roles necessarily need some external concepts to define them.
- (4) Roles are dependent on the context in which they are defined:
The role of teacher depends on a school or a locus of instruction; the role of medical doctor or of nurse depends on a hospital; that of husband or wife on a marital relation. Roles are specified according to the nature of entity’s participation in the context.
- (5) An entity can play multiple roles at the same time:
A man can be a husband, a professor and dean simultaneously.
- (6) An entity can play the same role type many times:
A person can become a student more than once. Those instances of student role would be different from each other except in resumption cases.
- (7) A role can play another role:
Rigorously speaking this statement is not accurate. In our terminology that we will introduce in the next section, we would state: “A role holder can play another role concept”. A human can play the *Japanese citizen* role and a Japanese citizen can play the *Japanese Prime Minister* role. This example shows what is playing the *Japanese Prime Minister* role is not the *Japanese citizen* role, but a Japanese citizen which we call a “role holder” rather than a “role”.
- (8) A role can be played by multiple entities at the same time:
Although it is true for drama roles such as Hamlet, it may not apply to common roles such as teacher, wife/husband, president, etc.
- (9) Some features of an entity playing a role can be role-specific:
Nickname is a typical example. The nickname as a teacher would be different from that as a husband.

(10) A teacher is still a teacher while sleeping (Loebe, 2007):

Although this is true for the teacher case and some others, it does not apply to all types of roles. A pedestrian is not a pedestrian while sleeping, since the pedestrian role is effective only when a person is participated in the walking action in a traffic system. He/she becomes a driver (not a taxi or truck driver) when he/she stops walking and starts driving a car. As will be discussed later, the teacher role as a vocation comes mainly from the staff membership of a school which is steady and long-lasting, while the pedestrian role comes from participation in the context of the temporary action which the person is performing.

2.2. Open issues

Despite the above list of role characteristics clarifies many aspects concerning the nature of roles, there remain several theoretical issues to be solved. The following ones are typical ones:

(1) Counting problem:

The number of passengers taking a certain means of transportation in one week may be greater than the number of individual persons traveling with that means during the same period (Wieringa, de Jonge & Spruit, 1995). A new role model is required to solve this problem without any conflict with other characteristics.

(2) Universals vs. Individuals (Loebe, 2007):

There is a view that considers a role to be a universal, which is played by being instantiated by an individual. In this view there is no difference between role instantiation and the played-by relation. However, there is another view of this issue, according to which an instance of role can exist without being played by anything. The latter view seems to be correct in the case of the *school teacher* role, whose instance seems to exist when a school exists even when no one is playing the role. We need a good model of role instantiation. Furthermore, while a specific *teacher* role like *teacher at Osaka school* seems to exist without being played by any person, specific marital roles such as *husband of Mary* or *wife of John* seem to disappear when they are un-played, that is, when the people divorce.⁴ We need a convincing explanation for this as well.

(3) Instance management:

We need a sophisticated instance management as the basis of a model of roles. In spite of its potential importance, this issue has not been discussed extensively to date. It is a topic related to part-whole relation, since many of the roles are specified within a context of the whole and roles are often attributed to parts. For example, the teacher role is a part of a school, the husband and wife are part of a married couple, front wheel is a part of a bicycle, etc. All these role concepts are played by a part of a whole which is considered as a context which is discussed below.

(4) Enumeration of role types:

As Loebe tries to design top-level categories of roles (Loebe, 2007), it is critical for us to clarify what are the possible varieties of roles just like we need a good upper ontology for in-depth understanding of the world.

(5) Compound roles:

Many roles are dependent on more than one context. Even the teacher role, which is a typical role, may be dependent on school and teaching action contexts. We need a model to deal with those compound roles.

⁴When John is looking for his wife, his wife role seems to exist with un-played. But, the wife role is one in an imaginary world. Imaginary world problems should be clearly distinguished from the reality and is out of our scope.

3. Role model

3.1. Fundamental scheme of our role model

The main goal of this paper is to present a model for role representation. Although we use many roles as examples, defining each role rigorously is not our main purpose. We believe that defining a specific role, say, teacher role, precisely without any disagreement is another issue.

The fundamental scheme of roles at the instance level is the following (see the lower diagram in Fig. 1):

*In Osaka high school, John plays teacher role-1 and thereby becomes teacher-1.*⁵

This can be generalized to the class level (see the upper diagram in Fig. 1)

In schools, there are persons who play teacher roles and thereby become teachers.

By **play**, we mean that something “acts as”, that is, it contingently acts as according to the role (role concept). By **“teacher”**, we mean a class of dependent entities which roughly correspond to persons who are playing teacher roles and which are often called *qua individuals* (Masolo et al., 2005).

Here, we introduce a couple of important concepts to enable finer distinctions among role-related concepts:

Role concept, Role holder, Potential player and Role-playing thing.

In the above example, these terms are used as “*In a context, there are potential players who can play role concepts and thereby become role holders*”. By **context**, we mean a class of things that should be considered as a whole. A context includes entities and relations. **Role concept** is defined as a concept whose entities are played by some entity within a context. So, it essentially depends on the context. By **potential player**, we mean a class of things which are able to play an instance of a role concept. In many cases, basic concepts (natural types) can be used to denote classes of **potential players**. In this

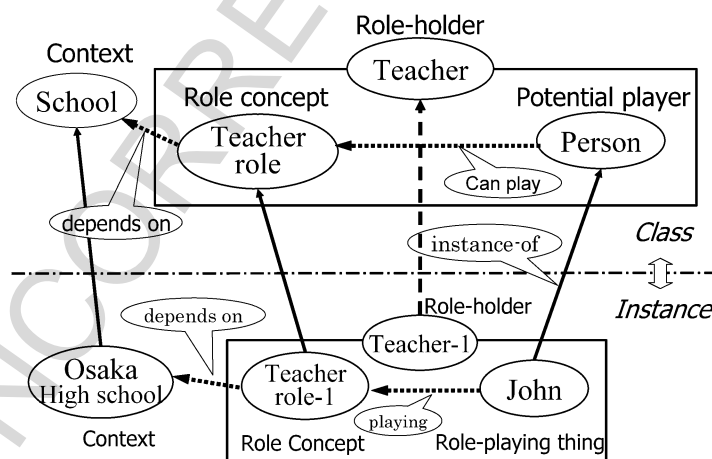


Fig. 1. Fundamental scheme of a role concept and a role holder.

⁵We do not mean John and *teacher-1* have the same identity. We assume that natural language expressions like “*John is a human*” and “*John is a teacher*” do not reflect the same semantic model and we define rigorously the semantics of the latter one below.

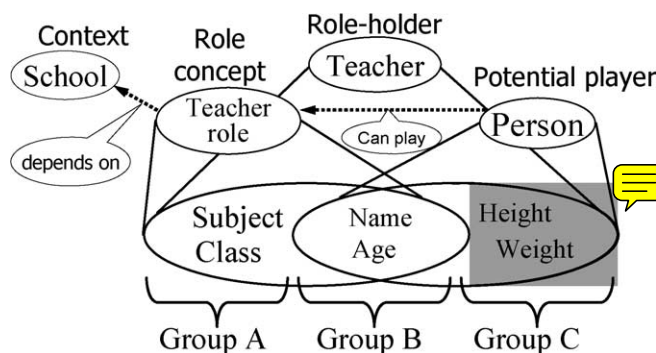


Fig. 2. Conceptual framework of a role.

example, we say a person can play an instance of a teacher role. In particular, John is actually playing a specific teacher role *teacher role-1*. By doing so, he/she is associated with the instance *teacher-1*, an individual teacher **role holder**. This means the conventional notion of *role player*, is divided into two: one is the class of **potential players** at the class level, the other is the actual **role-playing thing**, i.e., the entity playing the role at the instance level. This distinction is one of the key devices in our model which can resolve the universal vs. particular issue. At the same time, the conventional *player* link is divided into two kinds: one is the *can-play* link (at the class level) and the other is the *playing* link (at the instance level). A **role-holder** class is a class of dependent entities like *teacher-1*. As such, it is neither a specialization of a **potential player** class (e.g., *person*) nor that of a **role concept** class (e.g., *teacher role*), but an abstraction of a composition of a **role-playing thing** and an instance of **role concept**, as is shown in Figs 1 and 2, which is the heart of our Role model. The link from *Teacher-1* to *Teacher* is a broken arrow rather than a solid one like *instance-of* link to show the relation is not completely same as *instance-of* relation in Fig. 1. Our model and tool do not allow people to directly instantiate role holder classes because the individual role holder as a dependent entity to be instantiated inherently requires first an instance of a potential player class and of a role concept class. Then, when the *playing* link is asserted, it virtually acquires the three kinds of properties shown in Fig. 2 as explained in Section 3.2.1. This is why role holders are dependent entities. The operation of role holder making is realized by *inheritFrom* property in OWL expressions in Fig. 9. All the concepts introduced here are core of our role model and contain rich implications which are elaborated in the following sections.

The above shows that we divide the conventional notion of “**Role**” into two kinds: **role concept** and **role holder** in our model. Therefore, our model of roles does not have the concept of “**Role**” explicitly. In particular, it is understood conventionally that a role existing at the instance level must be something being played by something, since people understand the role instantiation and the action of playing the role as happening at the same time. In contrast, in our model a role concept can exist at the instance level without being played, since it depends only on its context and not on its player.


While the concept of *role* is the target of the ontological research on roles, at the same time, this term has been the source of confusion, since it hides the difference between role concept and role holder. We will show that this distinction resolves many of the problems discussed to date.

3.2. Elaboration of the role model

3.2.1. A conceptual framework of roles

Let us take an example:

1 *In Osaka High School, there is a vacancy on a teacher position. John fills it, and thereby he becomes*
 2 *a teacher of the school.*

3 Figure 2 shows the conceptual framework of the role model in Hozo. There are two kinds of properties:
 4 those ed to the teacher role and those common to all persons. When an entity plays a role, it must
 5 possess both of them. These properties can be divided into three groups. Properties of Group A are those
 6 which only appear in the role concept definition, and do not appear in the definition of its potential
 7 players. Properties of Group B shared both by the role concept and by the potential players. The last
 8 Group C includes the properties of the potential players that the role concept does not care about (i.e.,
 9 they do not appear in its definition). A role concept is defined by describing properties of Group A
 10 together with the ones of Group B. These properties are shared with a potential player but some of
 11 their values might come from the role concept. Its potential player class is defined by itself context-
 12 independently and is used as a constraint for the potential player of the role concept. Furthermore, the
 13 role holder concept derived from the above two definition operations and includes all the three kinds of
 14 properties. Therefore, the individual corresponding to a teacher role holder, a sort of *qua individual*, is
 15 the union of the properties of these two instances and is totally dependent on them.

17 3.2.2. Role concept and its dependency on the context

18 The example of the teacher discussed above can be elaborated and generalized in the following man-
 19 ner. Firstly, if Osaka High School does not exist, the instance of the teacher role never exists. In general,
 20 any instance of a role concept cannot exist without an instance of its context. This dependency applies to
 21 all types of role concepts. Secondly, a vacancy in a teacher post arises when the instance of the teacher
 22 role is not played. Such a vacancy supports the existence of the role concept. Furthermore, it means that
 23 the role concept has two states: played and not played. It can exist in the un-played state because some
 24 values of some properties including those of the essential properties of the role concept (for example, in
 25 the case of the teacher role, subject, class, and so on) can be determined independently of whether it is
 26 played or not. A more apparent example is a drama role. The Hamlet role exists independently of being
 27 played by an actor or not. But name or age of the teacher cannot be determined until someone plays it.

29 3.2.3. Dependency of role concept and potential player based on the semantics of part-whole relation

30 The observations that an individual role holder is – in a sense – the compound of the instances of role
 31 concept and its player, being essentially depending on them, are true to all the cases of roles. However,
 32 there are two cases concerning the dependency between a particular role concept and potential player
 33 according to the semantics of the part-whole relation of the context. In one case, the existence of the role
 34 concept is independent of that of the player. In the case of the teacher, for example, both of the instances
 35 of the *teacher role* and of the *person* exist independently of each other. In other words, a teacher role
 36 can exist if the school exists. In the case of the *wife role*, however, contrary to the case of the teacher,
 37 an instance of *wife role* cannot exist independently of the existence of its individual player because
 38 the marital relation, the context in this case, cannot exist without the person who plays the wife role.
 39 This difference is caused by the difference of part-whole semantics between marital relation (or married
 40 couple) and school which are the contexts of these role concepts. Let us explain the case of the married
 41 couple instead of the marital relation to make the explanation easier. For short, the reason why wife role
 42 disappears when it is not played by anyone is not because its existence is dependent on the player but
 43 because the un-played situation (divorce) destroys the context (married couple) on which it essentially
 44 depends. In general, role concepts whose context is such a whole that is essentially based on a binary
 45 relation has dependency not only on the context but also on the existence of its players because the very
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1 existence of the instantiated relations is dependent on their participants (players). Such semantics of
 2 part-whole relation is extensively discussed in Winston, Chaffin & Herrmann (1987). 2

3 3.2.4. Identity and existence of a role holder 3

4 Assume John is a teacher. John is no longer a teacher when the teacher position John fills disappears,
 5 when John quits the teacher role, or when John dies. In general, an individual role holder disappears in
 6 the following cases: an instance of the role concept disappears, an instance of the player stops playing
 7 the role or an instance of the player disappears. This is understood because that an individual role holder
 8 is dependent on the individuals of a role concept and of its player as far as the playing relation is valid
 9 as discussed in Section 3.2.1. This observation suggests that the identity (ID) of the individual of the
 10 role holder is a function of the IDs of the role concept (ID_{Role}) and of the player (ID_{Player}). That is,
 11 $ID_{Role\ holder} = f(ID_{Role}, ID_{Player})$ in which both arguments are mandatory for $ID_{Role\ holder}$, and in which
 12 “ f ” is bijective (surjective and injective). 12

13 3.2.5. Categories of role concepts 13

14 Role concepts are classified in accordance with the contexts on which they depend. Role concepts are
 15 recognized in a context. So, in order to classify roles according to categories of contexts, we can utilize
 16 their foundation. For example, in problem-solving, task knowledge can be discriminated from domain
 17 knowledge. Then, we can identify task-specific roles such as symptom role in a fault-diagnostic task
 18 and the conclusion role in a reasoning task. In a functional context in the domain of artifacts, a steering
 19 wheel role (played by a wheel) and a level-control valve role (played by flow-control valve) are classified
 20 as functional roles. Note here that we do not claim that any artifact is a role. A wheel is a wheel and
 21 a flow-control valve is a flow-control valve in its nature, that is, a flow-control valve cannot stop to be
 22 a flow-control valve without being broken, but a level-control valve can stop to be so without losing
 23 its identity. We are claiming that artifacts can play alternative roles according to functional contexts.
 24 Likewise, we can classify role concepts as action-related, relational and so on. Although enumeration is
 25 not exhaustive, Fig. 3 lists typical top-level categories of role concepts. 25

26 3.2.6. Primitive and compound roles 26

27 Teachers can be recognized not only as staff members of a school but also as people who teach stu-
 28 dents.⁶ Thus, the teacher role can be interpreted as a compound of the school staff role and the teaching
 29 agent role. Another example of a compound role is that of the Japanese prime minister. It can be said in
 30 our framework that the Japanese Prime Minister Role can be played by Japanese Citizens, whose roles
 31 are played by humans. 31

32 In such a manner, some roles need to be played together with other roles. In some cases, a player stops
 33 playing one of the roles, and then, some of others automatically will no longer be played according to
 34 their interdependencies. Such relationships between roles are discussed by other researchers in terms of
 35 “requirement” (Masolo et al., 2004), or in terms of the possibility that “roles can play role concepts”
 36 (Steimann, 2000). For example, let us consider a peer tutoring context in group learning, in which all
 37 participants are learners. A learner is expected to play *peer tutor* role and learn by “learning by teach-
 38 ing” strategy. The *peer tutor* role depends on both the learning context and the teaching context. Thus,
 39 we can identify two kinds of role concepts according to the complexity of their context dependencies:
 40 (1) primitive role concepts and (2) compound role concepts. The former has a single context-dependency
 41 and the latter has multiple context-dependency. 41

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 45 ⁶We do not claim this is the only interpretation of teacher role. Our intention is to present how to model compound roles.
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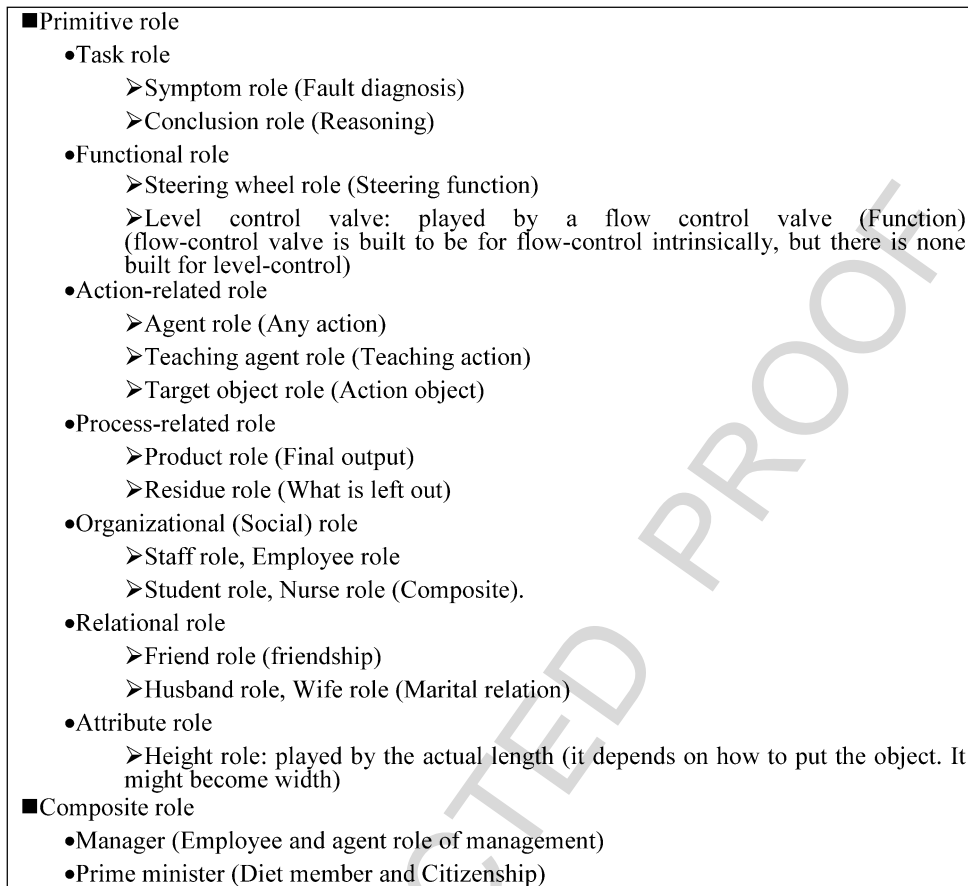


Fig. 3. Categories of role concepts.

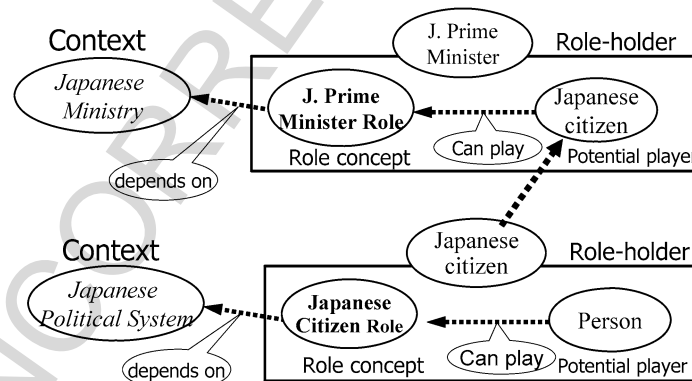


Fig. 4. Compound roles.

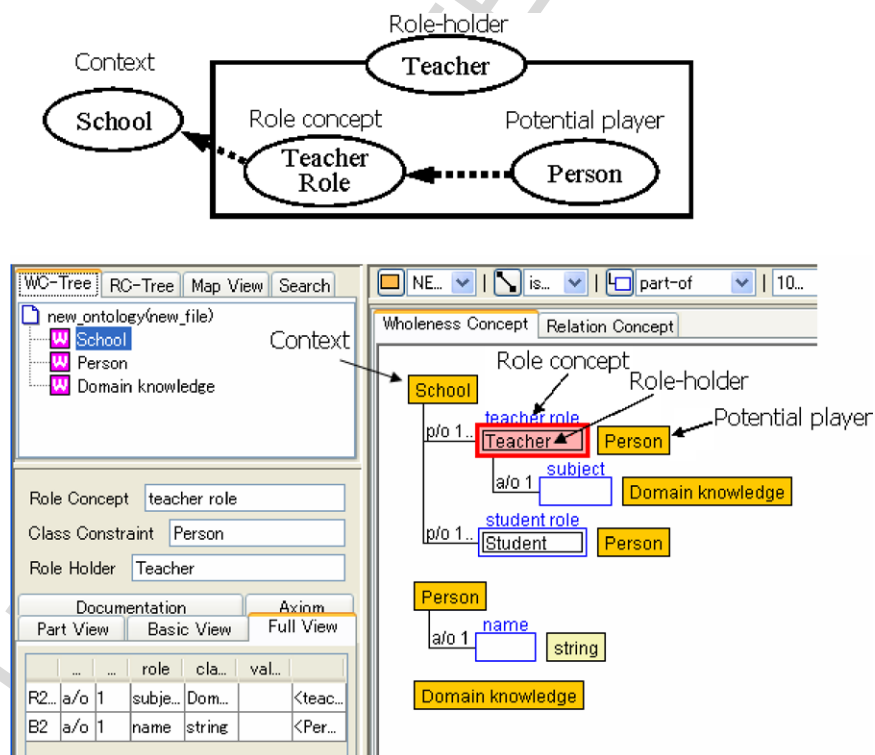
Our framework can model compound roles in which “role holders can play other role concepts”. Figure 4 shows an example in which only a Japanese citizen can be Japanese prime minister. The role of *Japanese citizen* is defined to be dependently on the Japanese political system as its context. Furthermore the role of Japanese prime minister is defined as a role which has to be played in the context of Japanese

1 ministry, not by a Japanese citizen *role* but a Japanese citizen, as a role holder. Therefore, the *Japanese*
 2 *prime minister* role/role holder depends on these two contexts.

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 5 **4. Role aggregation and instance management**

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 7 *4.1. Hozo's representation of our role model*

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 9 Before we will discuss role aggregation, we will explain Hozo's way of representing our role model.
 10 Figure 5 shows the correspondence between the model and the corresponding Hozo representation.
 11 Because Hozo is based on frames, the representation is rather straightforward. Let us explain Hozo's
 12 representation conventions by using the example shown in Fig. 5. In Hozo each concept defined as a
 13 class is represented in a rectangle like *School* and *Person*. Each class is defined by specifying its parts
 14 and/or attributes as slots. *School* is here defined as an entity composed of teachers and students where
 15 *teacher role* and *student role* are role concepts played by individuals specified by the rectangle at the far
 16 right, instances of *Person* in this case. The basic philosophy behind our role model is that, in principle,
 17 all parts of a whole have their own roles to play in the context of the whole. However, manifestation of
 18 the role depends on the case at hand. The roles of *wifelhusband* are so salient that both wife and woman
 19 (husband and man) are clearly distinct. However, in reality this is not always the case. In the case of *front*
 20 *wheel* role of a bicycle, for example, the degree of salience is medium. The least salient cases, which are
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 Fig. 5. Hozo representation of our role model.

1 the majority, include the role played by trees in a forest. We do not have to associate any role with a tree
 2 in a forest. A tree is a tree.⁷

3 The *Subject* is an attribute of the *teacher role*.⁸ *Teacher* and *Student* are role holders at the class level
 4 and defined exactly according to the model we propose. That is, all the individual *Teachers* are defined as
 5 the aggregation of slots of *teacher role* and individuals of the class of *Person*. The lower left pane shows
 6 the slots of role holder selected in the right pane. As you would expect, the slots are *subject*, coming from
 7 *teacher role*, and *name*, coming from *Person*. Hozo does not allow users to define role holders directly,
 8 since they are just the union of the properties of the associated role concept and potential player. As
 9 shown in Fig. 5, the key idea of class definition in Hozo is that all concepts, which can theoretically be
 10 parts of something, are defined independently of the possible wholes they belong to, and each class as
 11 a whole is defined by specifying the roles whose parts play. In other words, all the class definitions in
 12 Hozo are reciprocal, in the sense that a whole (*School*) is defined in terms of its parts (*Person*) playing
 13 their own roles, and at the same time, the roles (*teacher role*) played by the parts (*Person*) are defined
 14 there under the context of the whole (*School*).

16 4.2. Organizing role concepts according to the classification of their contexts

18 In this section, we summarize our organization of role concepts (Sunagawa et al., 2006) and introduce
 19 the necessary notation to understand the Hozo role-aggregation model. In our role-modeling framework,
 20 we use the term **Role** to denote a generic role concept class. This class appears at the top of our hierarchy
 21 of role concept (Fig. 6), and has four slots **Potential player**, **Context**, **Role part** and **Role holder name**.
 22 The first is related by *participate-in* (denoted as *p/i* in Hozo) relation and shows a basic concept or a *role*
 23 *holder* which can play the role concept (**Role**). The second is also related by *participate-in* relation and
 24 describes in what context the role concept is defined. The third is related by a *part-of* (denoted as *p/o* in
 25 Hozo) relation and associated with role aggregation. The fourth is related by an *attribute-of* (denoted as
 26 *a/o* in Hozo) relation and shows the name of the role holder. Each **role** class can have multiple parts as
 27 its components to represent it as a compound role (see Section 4.3).

28 As an upper ontology is useful to model the world and helpful to build an ontology, understanding
 29 roles benefits from its upper ontology (Loebe, 2007). As discussed in Section 3.2.5, the categories of
 30 role concepts can be used as upper ontology of roles. In Fig. 6, **Action Context Role**, **Organization**

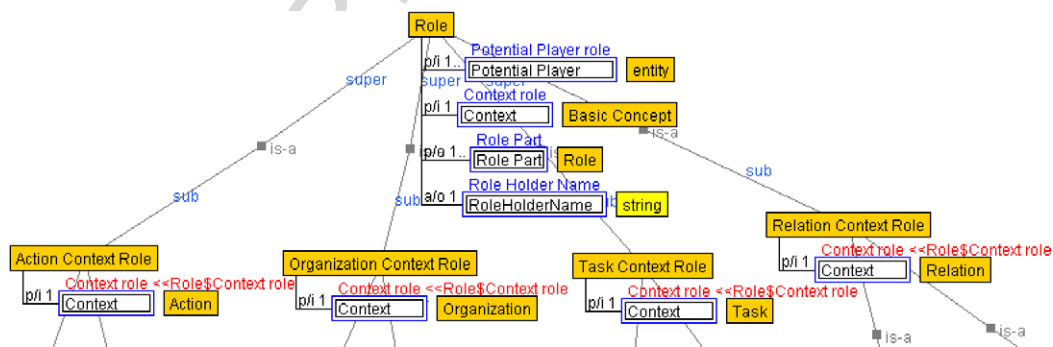


Fig. 6. An example of the hierarchy of role concepts.

⁷Each tree has the role of *member* of a forest. However, it is generic and common to all parts of any whole.

⁸Slots can have slots in Hozo.

1 **Context Role**, **Task Context Role** and **Relation Context Role** are defined and structured as top-level 1
 2 categories of the hierarchy. The conceptual structure of top-level role concepts is analog to that of their 2
 3 potential players, such as **Action** and **Organization** in the hierarchy of basic concepts. 3
 4

5 **4.3. Aggregation of role concepts** 5
 6

7 Because some roles are conceptualized from several viewpoints and depend simultaneously on several 7
 8 contexts, it is difficult to organize them according to single context-dependency. For example, a **Teacher** 8
 9 can be recognized not only as a **Teaching Agent** but also as a **School Staff member**.⁹ In order to or- 9
 10 ganize such role concepts which depend on several contexts, we need to consider how to represent and 10
 11 manage such multiple context-dependence. Thus, we introduce the idea of **Role Aggregation**: a frame- 11
 12 work for organizing role concepts which depend on several contexts according to their essential depen- 12
 13 dencies. Role aggregation is represented in both hierarchies of basic concepts and role concepts. The 13
 14 two hierarchies share the same semantic information on role aggregation. Figure 7 shows two portions 14
 15 of hierarchies to explain role aggregation. 15

16 We already discussed a basic way of how to model “Roles play another role” by using a role holder as 16
 17 a potential player of another role. We have used the way of representing compound roles in Hozo (see 17
 18 Figs 4 and 7(a)) and have confirmed it works through experience. However, the approach has a problem 18
 19 from the perspectives of the human–computer interface. In such modeling, the hierarchical structure of 19
 20 roles is hidden in the hierarchy of basic concepts because all role concepts are defined within the basic 20
 21 concepts as their contexts as shown in Fig. 7(a). This is why we introduced an explicit hierarchy of roles 21
 22 as shown in Fig. 6. The following is a description of how to use Hozo to model roles using the *is-a* 22
 23 hierarchy of roles shown in Fig. 6. 23

24 One of the key steps is the decomposition of context-dependencies into primitives. In the examples 24
 25 described above, contexts dependences are generally decomposable. And, for each of the most primitive 25
 26 contexts, we can recognize a role concept depending only on it. By a **primitive role concept**, we mean a 26
 27

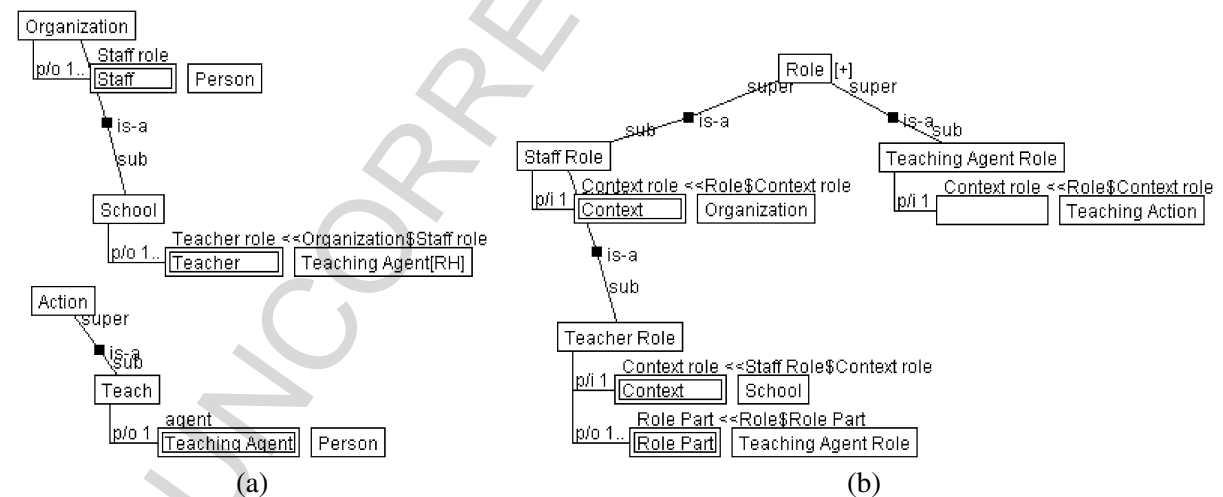


Fig. 7. An example of role aggregation.

⁹Note that we do not intend to rigorously define what a teacher role is at all. Our main purpose is to develop a model to cope with such roles that depend on multiple contexts.

1 role concept that depends on a single context. To summarize the process of role aggregation, we present
 2 here an example of role concept which depends on two contexts. To begin with, the most essential
 3 context is chosen among the two contexts after investigating and decomposing the context-dependency
 4 of the role concept.¹⁰ Among the two contexts of **Teacher Role: Organization** and **Teaching Action**,
 5 let us assume here that the former is the essential (primary) context and the latter the secondary one.
 6 Then, two primitive role concepts are identified; **Staff Role** and **Teaching Agent Role**. They depend on
 7 their own contexts, of course.

8 Following Hozo's role definitions shown in Fig. 5, **Teacher Role** is defined as a specialized role
 9 concept of a **Staff Role**, with the **Teaching Agent** role holder as Potential player as defined below
 10 (Fig. 7(a)),¹¹ this implies that **Teacher Role** is defined as a role concept depending on both the contexts
 11 of a **Staff Role** and of a **Teaching Agent Role**, that is, a school and teaching action. Figure 7(b) shows
 12 a new and alternative way of role modeling in the hierarchy of role concepts using *is-a* and *part-of*
 13 relations. In this approach, the **Teacher Role** is defined as a sub-concept of a **Staff Role** through an *is-a*
 14 relation, with a role part of **Teaching Agent Role** which would be defined as a subclass of Agent role
 15 which is not shown in the figure. **Role Part**, which is explained in Section 4.2, is a primitive role concept
 16 to be used as a part of a compound role concept. In this example, **Teaching Agent Role** is the secondary
 17 role part. In this way, users can add role parts to constitute the desired role concept.

18 In principle, we could adopt a multiple inheritance mechanism for role organization instead of the role
 19 aggregation method described above because both are theoretically equivalent and roles do not cause the
 20 difficulties caused by basic concepts discussed in the introduction. The reason why we organize roles in
 21 a single inheritance hierarchy like basic concepts is twofold:
 22

- 23 (a) To show the essential properties of each role explicitly;
- 24 (b) To have the same philosophy as that of basic concepts.

25 4.4. Instances of role concepts

26 In this section, we discuss the characteristics of instances of role-related concepts. An instance model
 27 specifies the interdependencies between classes and individuals, especially concerning the appearance
 28 and extinction of individuals. It appears as indispensable for the concrete application of ontologies, and
 29 for a clarification of the nature of role instances.

30 In our investigation of basic issues of role-related concepts in Section 2, we did not discuss role con-
 31 cepts depending on multiple contexts. So, in this section, we generalize the framework of role concepts.
 32 In the following, **R** denotes a role concept, C_1, \dots, C_n the contexts it depends on, R_1, \dots, R_n the prim-
 33 itive role concepts possibly composing the compound role concept **R**, and **P** is a concept considered as
 34 the potential player of **R**.

35 (A) Dependence of instances of role concepts on their context:

36 An instance of **R** exists if (and only if) all instances of C_1, \dots, C_n are instantiated. When any of
 37 them ceases to exist, so does the instance of **R**.

38 (B) Dependence of instances of role concepts on their players:

39 An instance of **R** is dealt with as a defective instance by itself. When instances of R_1, \dots, R_n as
 40

41
 42
 43
 44 ¹⁰The most essential context is decided by developers of an ontology. We do not discuss or conclude generally what the
 45 essential context should be. Based on the relativity of essence, we think that, essences of concepts are decided by the developers
 46 intended as far as the decision is consistent in the whole ontology.

constituents of **R** are played by the same instance of **P**, **R** is concretized by aggregating all of them (instances of $\mathbf{R}_1, \dots, \mathbf{R}_n$) to be a complete instance corresponding to **R**.

(C) **Extinction of a role holder:**

A role holder of **R** is composed of both instances of **R** and **P** by combining all of their slots. Let r and p denote instances of **R** and **P**, respectively. Then, there are four cases in which the individual role holder disappears: (1) p disappears, (2) r disappears, (3) p stops playing r and (4) any of the compounding role concepts $\mathbf{R}_1, \dots, \mathbf{R}_n$ disappears.

5. Analysis of the role model

We analyze here the proposed role model in terms of the characteristics and requirements discussed in Section 2.

5.1. Characteristics

- (1) Roles are anti-rigid (Guarino, 1998):

A potential player plays a role concept only in a context. From the definition of “play”, it is clear that the properties related to the role cannot be essential properties of the player, and hence roles (role concepts) are anti-rigid.

- (2) Roles are dynamic:

From the definition, the player easily stops/starts to play role concepts. A role concept can be played by multiple players one after another. So, roles are dynamic in our model.

- (3) Roles are externally founded:

Yes, role concepts are necessarily defined by referring to a part(s) or a participant(s) of a whole/relation as a context in our model.

- (4) Roles are dependent on the context in which they are defined:

Yes. See (3).

- (5) An entity can play multiple roles at the same time:

Yes, there is no restriction in our model concerning the time about the event of playing role concepts.

- (6) An entity can play the same *role type* many times:

Yes, there is no restriction for this in our model. However, if we extend this characteristic to individual roles, then we need discussion, since an individual role’s ability to be played many times may depend on its type. For example, in the case of student role, we may assume that no person can play the same student role multiple times because every time he/she becomes a student, the individual student role has a different ID except resumption cases. In the drama role case, however, one can play the Hamlet role as an individual role multiple times. This difference comes not from the model of roles but from the ontological nature of the type of the role concept. In this case, Hamlet role is a *representation* which is different from the normal categories such as object, process, etc. Each individual Hamlet played by different actors are “*realization*” rather than *instantiation*. See Mizoguchi (2004) for details about ontology of representation.

- (7) A role is played by multiple entities at the same time:

Yes, there is no restriction about this in our model. If any, a restriction comes from the ontology our model might commit to. For example, a teacher role-1, which is an individual, of a school-1 cannot be played by multiple players at the same time theoretically. However, in the case of a drama role, such as Hamlet, it can be played by multiple entities at the same time. See (6).

1 (8) A role can play another role: 1

2 Yes, in our model, as discussed in Section 3.2.6, this is modeled by using a role holder as a 2
3 potential player in another role concept. This topic is further discussed in Section 4.3. 3

4 (9) Some features of an entity playing a role can be role-specific: 4

5 Yes, as shown in Fig. 2, some properties coming from the role concept are shared with the role 5
6 player as its own properties in our model. 6

7 (10) A teacher is a teacher while sleeping: 7

8 Partly yes. It is tightly related to the semantics of the “play” relation or equivalently of the “way 8
9 of participation” in the context. Many of the typical cases are informally covered by our model. 9
10 It is related to the upper ontology of roles. As discussed in Section 2.1, the extent of the playing 10
11 relationship validity in terms of time is specified by the category to which the role concept 11
12 belongs to. In the case of organizational roles, the participation is steady and it lasts until the 12
13 player leaves the organization. In the case of process-related roles, it is temporary. Although it 13
14 might look like the issue is resolved, there remains actually a tough issue. We need a rigorous 14
15 definition of the semantics of *play* relation and/or *the way of participation* in the context, which 15
16 will be revisited in the concluding remarks. 16

17 5.2. Issues as requirements to solve 17

18 (1) Counting problem: 18

19 Because our model distinguishes two types: role concept and role holder and has the identity 19
20 definition of role holder, $ID_{\text{Role holder}} = f(ID_{\text{Role}}, ID_{\text{Player}})$, we can correctly count the number of 20
21 passengers and that of persons independently without causing additional side effect. For example, 21
22 when we need to count the number of passengers, we use the $ID_{\text{Role holder}}$, and when we need to 22
23 count the number of persons, we use ID_{Player} instead of $ID_{\text{Role holder}}$. 23
24

25 (2) Universals vs. particulars: 25

26 The problem to answer is if the following view is OK or not: “A role is considered as a universal 26
27 whose instantiation is done by being played by an entity (an individual)”. This issue seems to be 27
28 a bit complicated or confusing after we introduced our framework, since what is meant by “role” 28
29 in the question becomes ambiguous. Our model views that an instance of role concept can exist 29
30 without being played by any player and when it is played by an entity, then it (the thing made by 30
31 combining the instance of the role concept and that of the player) is associated with an individual 31
32 role holder. This becomes possible by the distinction between role concepts and role holder, since 32
33 it enables to detach the instantiation operation of the role concept from the playing operation. 33
34 Figure 2 shows this clearly. 34
35

36 In our framework, the next issue is whether a role holder is a Universal or not and what is its 36
37 instance. Our answer to the question is that a role holder exists both at the universal (class) level 37
38 and at the particular (instance) level, however, they are not totally equal to an ordinary universal or 38
39 an ordinary particular, in the sense that the class-level thing cannot be directly instantiated to make 39
40 an individual role holder and that both class-level and instance-level things are heavily dependent 40
41 on role concept and potential player. In short, a role holder is a dependent entity is like *qua* 41
42 *individual* (Masolo et al., 2005). This dependency is so essential that the existence of individual 42
43 role holder needs that of potential player and that of role concept before it appears. This is the 43
44 reason why a role holder cannot be instantiated independently. An individual role holder has to be 44
45 made by virtually composing individuals (particulars) of corresponding role concept and potential 45
46

1 player. And, the role holder at the universal level is an abstraction of the individual role holder
2 made that way.

3 (3) Sophisticated instance management:

4 We have found that instance management is a crucial topic to establish a solid theory and model
5 of roles to explain their dynamic nature. The Universal vs. Particular issue is a typical one which
6 shows the importance of understanding the roles at the instance level. We have discussed the in-
7 stance management issue in Section 4.4 to some extent and clarified typical dependencies between
8 role-related individuals with necessary management operations. As stated in Section 2.2, this is-
9 sue is related to the semantics of part-whole relation. As discussed in Section 4.1, one of the key
10 ideas of our role model is that role concepts are attributed to parts of the context (whole/relation)
11 which the parts belong to. Therefore, we need a theory which explicitly explains the relations of
12 parts and roles.

13 (4) Enumeration of role types:

14 Although not exhaustive, we defined top-level categories of role concepts by investigating the
15 characteristics of the context they depend on. An interesting extension of our understanding of
16 roles is, say, *attribute role* presented at the bottom of the categories of primitive role concepts
17 in Fig. 3. It says that *height* would be a role concept played by length. Similar examples include
18 depth (played by length), age (played by year), rated voltage (played by voltage), etc. Other types
19 of roles include the sick (a sick person), beginner, child, etc. Because all of the players of the
20 first group are not entities and the contexts of the second group are vague, they do not fit the
21 definition of roles. However, all of them still have a possibility to cover by our framework. In-
22 depth investigation on the comprehensive typology of roles contributes to the establishment of
23 convincing theory of roles.

24 (5) Compound roles:

25 We have briefly discussed role aggregation for representing compound roles in Section 4.3. De-
26 tailed discussion on this topic has been done in Sunagawa et al. (2006). The authors believe the
27 role aggregation model satisfactorily represents compound roles.
28

29
30 *5.3. Lessons learned*

31
32 It is true that our role model is heavy for novice users. However, it is necessary for building a good
33 ontology to appropriately reflect the real world in it. As stated earlier, the world is full of roles. Hozo
34 has been used for years by many users including those out side of our group. We received both positive
35 and negative feedback about the treatment of roles. Positive comments include that users really enjoy
36 the power of its role modeling function which is unrivaled. On the other hand, a major complaint is that
37 it is cumbersome to deal with roles properly. Typical examples include medical doctor and nurse roles
38 played by persons. People hesitate to deal with them as roles when they build an ontology of hospital.
39 In a hospital ontology, doctor and nurse roles seem to behave like basic concepts. Hozo methodology
40 is flexible in role representation to cope with such situations. That is, Hozo only requires users to be
41 consistent when they determine essential properties of basic concepts and allow users to model roles as
42 basic concepts if those roles are rigid enough like basic concepts in the domain they are interested in.
43 In a hospital ontology, a doctors is always a doctor and so is a nurse. So, we usually recommend users
44 to deal with such roles as basic concepts. However, such an ontology would encounter a difficulty in
45 modeling doctors who get sick and go to hospital to see another doctor as patients.
46

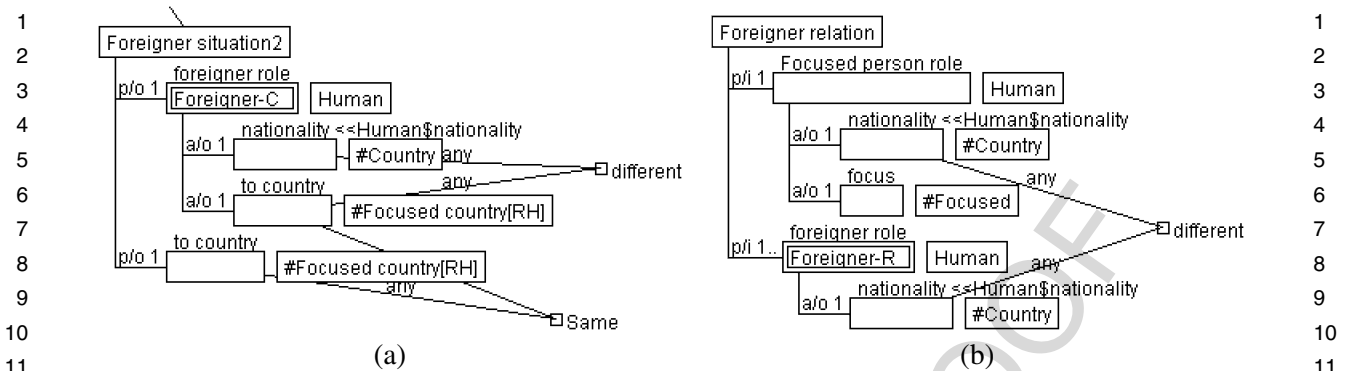


Fig. 8. Foreigner role representation.

In a CSCL setting, learners are often asked to play a tutor role as explained in Section 3.2.6. In the case of ontology of collaborative learning, learner role could be modeled as a basic concept. However, peer tutor, peer tutee, etc. are necessarily modeled as role concepts played by learners, since they change their roles for each collaborative learning session.

A second major complaint is the difficulty of finding an appropriate context for role concepts. Although the teacher role case is somewhat problematic because people might think it is defined as teaching agent role, most of the examples used in this paper thus far are not hard. In general, for people who learned the top-level categories we enumerated, context identification is not very hard. However, we can show a very hard example: Foreigner. The foreigner role is essentially viewpoint-dependent. Anyone can be a foreigner at any time when he/she is viewed from the countries different from his/hers. We temporarily defined four kinds of Foreigner role. Two of them are shown in Fig. 8. A context which would be found first might be *Foreigner relation* shown in Fig. 8(a). *Foreigner-R*¹¹ which stands for Foreigner role holder defined using Foreigner relation as its context. Figure 8(b) shows one of the three definitions using specific situations where foreigner role pops up people’s mind. They are (1) human-based, (2) country-based and (3) human & country-based situation. The second is defined in the context where a country is focused on explicitly. Such a foreigner as a role holder, called *Foreigner-C*, is defined as a human who plays foreigner role whose nationality is different from the focused country.

Because serious instance management is not fully developed yet, we do not have informative experience of instance level behaviors of our model.

6. Related work

Guarino and his colleagues aimed to establish a formal framework for dealing with roles (Guarino, 1998; Masolo et al., 2004; Masolo et al., 2005). Gangemi and Mika introduced an ontology for representing contexts and states of affairs, called D&S, and its application to roles (Gangemi et al., 2002; Gangemi & Mika, 2002). Their research was concerned with formalities and axioms of an ontology. In contrast, we do not formalize role concepts, because our goal is to develop a computer environment for building ontologies. Our notions of role concepts share a lot with their theory of roles, especially

¹¹Suffix R and C indicate it is based on Relation and focused Country, respectively.

context-dependence and specialization of roles. According to their theory, our framework can be reinforced in terms of axioms. They describe specialization and requirements as kinds of sub-class relations between role concepts. The former corresponds to *is-a* and the latter to role aggregation in our framework. However, they do not recognize that *is-a* relations between role concepts are established only if the two concepts share the same category of context-dependency. While we have discussed how to define a role concept with complicated context-dependences, they only point out a requirement relation. Our notions differ from their work on other two points: the dynamics of a role, and the clear discrimination of a role from its player (role holder). Firstly, we focus on context-dependence of a role concept and its categories. So, time dependence of a role concept is treated implicitly in our framework because an entity changes its roles to play according to its aspect without time passing. As opposed to this, the framework by Guarino and colleagues deals with time-dependency explicitly. Secondly, we distinguish role concepts from role holder concepts (Kozaki et al., 2000; Kozaki et al., 2002). On the basis of this distinction, we have developed a tool for properties and relations on roles, such as an aggregation of role concepts. Masolo et al. introduced a new kind of entity, called qua-individuals, to solve the counting problem (Masolo et al., 2005). According to them, qua-individuals would be created each time an entity is classified by a role. So if a person plays two roles, the qua-individuals of the person would be created twice, and he/she would be counted three times as a person and the two roles. Qua-individuals seem to be slightly similar to role holder, but it is unclear how to create their instances and identities, while the notion of role holder does not produce such problems that qua-individual would cause.

Loebe has attempted to design top-level categories for roles (Loebe, 2007). He discusses them based on the characterization of roles as being determined by context, and he proposes three role types: *relational role*, *processual role* and *social role*. His approach is similar to our way of role organization at the top-level. In addition to this, we have found more types and discussed compound roles which are dependent on several contexts.

Fan also recognizes the importance of constructing a hierarchy of role concepts based on differentiation of them from the others, and shows an example where a Thing is classified into an Entity and a Role in Fan et al. (2001). Moreover, he sees Agent and Instrument as sub-concepts of a Role. However, he does not clarify a way for organizing them. To our knowledge, they are regarded as being organized according to the manner they participate in their contexts.

Breuker develops ontologies for legal domains based on epistemology and discusses characteristics of roles in Breuker & Hoekstra (2004). He also mentions adulteration between a role itself and playing role and others between a role and its player. We share his idea of discriminating among these concepts and differentiating role concepts, class constraints and role holders from one another (Kozaki et al., 2000; Kozaki et al., 2002). He describes two kinds of roles; as a concept and as a relation. However, he does not organize them in more detail. While he defines roles according to behavioral requirements and so on, we allow ontology developers to define role concepts just as they intend, because it is outside the scope of our research to discuss how to conceptualize roles.

7. Concluding remarks

We have proposed a role model and discussed its key ideas such as (a) decomposition of **role** into **role concept** and **role holder** and (b) distinction between **instantiation** and **playing** relationships. We explained how these characteristics contribute to solving typical role issues concerning the characteristics

shown in Section 2.1. However, the explanation has been done at the conceptual level and needs further effort to make the semantics clearer.

7.1. A step towards formalization

We here focus on formalization of our role model in terms of OWL. In Fig. 9, we represent our role model in OWL. We define *hozo:BasicConcept* class and *hozo:RoleConcept* class to express basic concepts and role concepts. So, the domain of *hozo:dependOn* property is a *hozo:RoleConcept*. Here, we emphasize that role concepts are dealt with not as an *owl:ObjectProperty* but as an *owl:Class*. A *hozo:playedBy* property represents a relation between classes of role concept and classes of potential player. Its domain is *hozo:RoleConcept*, and its range is *hozo:BasicConcept*. The definition of *hozo:RoleConcept* has a restriction on this property, and there the property indicates role-playable thing discussed in Section 2.2. And when a relation between an instance of role concept and player is represented as a *hozo:playedBy* property, the property means a *playing relation* between them. And a *hozo:RoleHolder* class represents a role holder. It is composed of a role concept and a player, and *hozo:inheritFrom* property expresses its semantics that only definitions (properties) are inherited. The OWL specification shown in Fig. 9 represents a typical interpretation of our model which corresponds to one which does not allow multiple players to play an individual role concept at the same time. Its further specification needs to be done using a rule language, say, SWRL, which is an on-going work to be published in another paper.

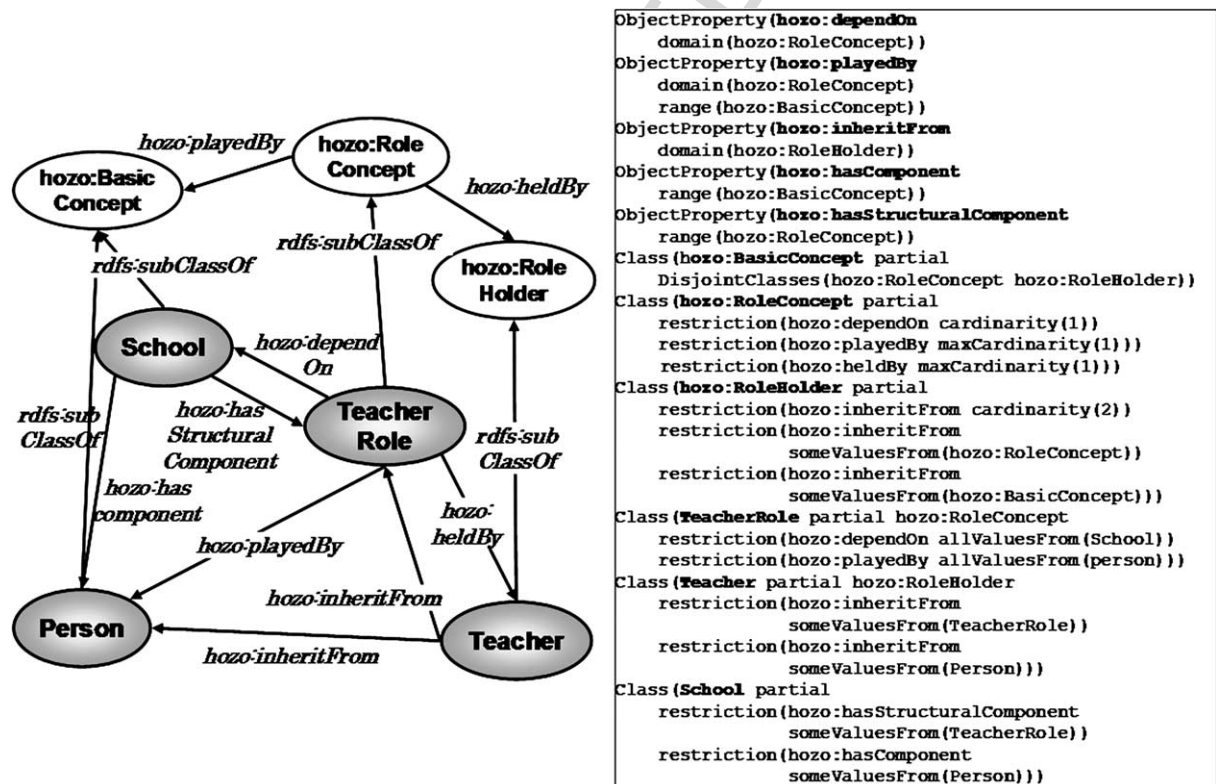


Fig. 9. Role representation in OWL.

7.2. Further discussion

We have found some new issues during the course of the discussion. They are summarized as follows:

- (1) The importance of instance management.
- (2) The semantics of *playing* relation.
- (3) Clarification of part-whole semantics and the dependency of roles on it.
- (4) Drama roles.

Although all the four are interrelated, the first issue is the most serious among them. In order to clearly understand *can-play*, *playing*, *depends-on* relations, we need to investigate when and how the related instances appear and disappear in what interdependence. Although we discussed the issue in Section 4.4 to some extent, it is apparent that we need more discussion on it. Figure 9 shows a result of the research toward this direction, but we are still on the way. The second issue is related to the time scope of participation. How much extent the participation is valid. This directly influences on the semantics of “*playing*” relation. In this paper, we considered **car driver role** is only valid while somebody is driving a car. Precisely speaking, however, it is not true. A car driver is still a driver when he/she goes to toilet in a service area on the highway, though when he/she reaches the destination, then he/she stops being a car driver. The general principle that “belonging to an organization is static and participating in a process is dynamic” seems intuitively correct but it is not always correct. We need to devise a sophisticated instance management procedure together with the validity management of *playing* relation (participation) to the context. The third issue has already been discussed rather extensively in the paper. The issue might be the boundary between part-whole theories and role theories. We mean, how we can state a role theory independently of the semantics of the part-whole relation. For example, we state that a particular role concept can exist as far as its context exists, and it can have a *played* or *un-played* state. This applies to the teacher role case but not to the husband/wife case, since an un-played state of husband means non-existence of the context (marital relation). However, if we consider that is out of the scope of the theory of role, then the above statement keeps its validity. The fourth issue is rather complicated because it is related to the ontology of representation. Although we have our own theory (Mizoguchi, 2004), there is no established ontology of representation yet. Following our ontology of representation, Hamlet as a role is an individual, and the performance of Hamlet seen in many theaters are its realization. However, there is another view of this: each performance of Hamlet seen in many theaters can be an instance of Hamlet. For those who commit to such a view, what we discussed at (6) in Section 5.1 would be incorrect. In addition to those listed above, further top-level categories of roles are worth to investigate further. Especially, the question whether an “**attribute role**” is really a role or not, and other examples such as **sick**, **beginner**, **boy**, etc. are of value to discuss. Although the instance management procedures discussed in Section 4.4 and the explicit organization of role concepts in a hierarchical manner discussed in Section 4.3 are not completely implemented yet, Hozo, which is available at: <http://www.hozo.jp/>, provides functionality to deal with roles based on the model discussed in this paper.

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