

A Model of Roles in Ontology Development Tool: Hozo

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Abstract. One of the major roles of ontology is to properly represent the underlying conceptual structure of the messy world reflecting the reality as much as possible. All the existing ontology building tools are designed to help people develop such a good ontology. However, few of them can deal with roles adequately. For example, the functionality OWL provides for role representation is theoretically inadequate. Needless to say, the world is full of roles such as wife, teacher, president, fuel, food, product, output, height, etc. Although there have been extensive theoretical research on roles, we do not have a comprehensive and usable theory yet. We have already developed an ontology development/use tool: Hozo with usable functionality to deal with roles. Although Hozo allows users to represent roles better than other existing tools, its theoretical foundation is left unclear and it has 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 clarification of role properties and requirements on the model of roles. Establishment of a computational model of roles contributes effectively to building a good ontology because it provides us with useful guidelines for dealing with view- and context-dependencies related to roles.

1. INTRODUCTION

The world is full of roles. This is why in-depth understanding of roles is critical to ontology development. Roles are different from so-called natural types (referred to as basic concepts in this paper) in the way of losing its identity, while basic concepts such as human cannot lose its identity without dying (disappearing from the real world), roles can lose its identity without dying. For example, a teacher can stop being a teacher without dying. This is explained by one of the essential characteristics of roles, that is, roles are *played* by some entity like a teacher is played by a human. However, it is impossible to find a player of a human.

Context dependence is another important characteristic of roles and it explains how and why an entity changes its role to play according to the context it depends on. For example, a *man* would be regarded as a *teacher* in a *school* and as a *husband* in his *marital relationship*. While such roles can be modeled in connection with time, the context-dependence with the way of participation is also a crucial factor for capturing roles.

The research of roles has been done seriously to date and a lot of achievements are already obtained [5, 6, 10, 11, 16, 17, 18]. However, there is no satisfactory theory and model which cover all the characteristics of roles and answer questions of counting problem, universal vs. particular problem, etc. Roles are so complex that we still need to invest our effort in capturing them as a whole. We need a sophisticated theory and model of roles not only for scientific necessity but also for providing people with a usable tool/language which can take care of roles are needed to build

realistic ontologies. OWL¹ has been extensively used in ontology development and ontology exchange. Although it is useful as an interlingua of ontology sharing, it is not enough for representing roles. To use OWL for role representation, we need representation patterns strongly supported by a convincing theory and a model [9, 15].

Improper modeling of roles will greatly influence the semantics of *is-a* hierarchy of concepts [6]. We focus here on the semantics that an instance of a concept must be always an instance of its super-concept. For example, in WordNet², Dairy Product and Food are treated as hypernyms of Yogurt. If role concepts are not discriminated from basic concepts and these lexical hyponymies among the words are regarded as *is-a* relations among concepts, instances of Yogurt are always regarded as instances of Dairy Product and Food as well. In such a model, however, we may often have to struggle for faithful representation of events in the real world. To represent that some yogurt has been eaten, we delete the instance of Yogurt. And, it in turn means deleting an individual as an instance of Dairy product and Food, which is totally OK. However, in the case where a yogurt has rotted and become inedible, we need to manage instances more sophisticatedly. Because the instance of Yogurt has lost its identity as Food but keeps one as Dairy Product, we cannot simply delete the instance of Yogurt; we can delete, if possible, only the instance of Food, but should not the instance of Dairy product. Such management of an instance model might force us to make different semantics of *is-a* relation and to establish routines for ad-hoc management of instances. Such a strategy detracts from the value of an ontology, which ensures consistency of an instance model. Moreover, it is difficult in such a model to represent the instance of Yogurt changes its roles to play such as Load, Merchandise, Foodstuff, etc. according to changes of its contexts or aspects. It is advisable for a computer model and an ontology behind it to correspond to the real world as faithfully as possible.

On the other hand, based on fundamental theories of roles in an ontology [5, 7], we can differentiate clearly role concepts (e.g. Food) from the others (basic concepts) and can cope with the problems caused by adulterating role concepts and the others. For example, the hyponymy between Yogurt and Food is not regarded as in an *is-a* relation. And, we acquire a consistent policy to manage instances of yogurt and food consistently. It is not easy but worth for ensuring quality of an ontology as a backbone of an instance model to differentiate role concepts from others and organize them.

We have developed an ontology development/use tool: Hozo with usable functionality to deal with roles. Although Hozo allows users to represent roles better than other existing tools, its theoretical foundation is left unclear and it has 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.

This paper is organized as follows: The next section summarizes of characteristics of roles and issues to cover the model we develop which is discussed in Section 3. Section 4 discusses the way Hozo, our ontology development/use environment, deals with compound roles and instance management. Section 5 analyzes the proposed model in terms of the characteristics and requirements discussed in Section 2. Related work is discussed in Section 6 followed by concluding remarks.

¹ <http://www.w3.org/TR/owl-ref/>

² <http://wordnet.princeton.edu/>

2. CHARACTERISTICS AND ISSUES OF ROLES

Before discussing our role model, we clarify what characteristics roles have and what problems we try to solve. The characteristics discussed in Section 2.1 is not exhaustive and a modified version of the summary presented by Steinmann in [18]. 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, there can be an informal definition such as

An entity which is played by another entity in a context.

By “context”, we mean something as a whole including a relation on which the former “entity” is defined. Having this informal definition of role in our mind and referring to the seminal survey paper [18], we can enumerate important characteristics of roles as follows:

- (1) Roles are anti-rigid [6]
A role is a property that is contingent(non-essential) for all its instances.
- (2) Roles are dynamic [11]
An entity can start/stop to play a role and a role can be played by multiple players.
- (3) Roles are externally founded [5, 11]
Roles necessarily need some external concepts to define them.
- (4) Roles are dependent on the context in which they are defined
Teacher roles depend on a school, medical doctor and nurse roles on a hospital, husband/wife on a marital relation, etc. They are specified according to their way of 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 at the same time.
- (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 are different from each other.
- (7) A role can play another role
Rigorously speaking this statement is not accurate. In our terminology introduced in the next section, it should be stated as: “A role holder can play another role concept”. A human can play Japanese citizen role and the Japanese citizen can play the Japanese Prime Minister role. This example shows what is playing the Japanese Prime Minister role is not a Japanese citizen role but a Japanese citizen which we call a “role holder” rather than a “role”.
- (8) A role is played by multiple entities at the same time.
Although it is true for drama roles such as Hamlet, it does not apply to common roles such as teacher, wife/husband, president, etc. Some people might think Citizen role is played by many people at the same time. However, the citizen roles played by persons are different individuals because each of them has its own identity. Citizenship ID is not attributed to each person as a player but with the citizenship role.
- (9) Some features of an entity playing a role can be role-specific.
In the bicycle case, the attribute of “maximum length of riding time” could be associated with

the person who is playing the Rider role. And, the attribute is useless when he/she does not ride a bicycle.

- (10) A teacher is a teacher while sleeping [10].

Although it 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, teacher role as a vocation comes mainly from the staff membership of a school which is steady, while pedestrian role comes from participation in the context of the temporary action which the person is performing.

2.2 Issues of roles

In addition to the above list of role properties, there remain more theoretical issues to be solved. The following is 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 [19]. The new role model is required to solve this problem without any conflict with other characteristics.

- (2) Universal vs. Individual [10]

There is a view which considers a role as a universal and whose instantiation is done by being played by an entity (an individual). However, there is another view of this issue, that is, an instance of role can exist without being played by any others. The latter view might be correct in the case of school teacher role whose instance seems to exist when a school exist even when no one is playing the role, while it might be incorrect in the case of husband/wife role which seems to disappear when they are un-played, that is, divorced. We need a convincing explanation for this.

- (3) Sophisticated 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 semantics of part-whole relation, since many of the roles are specified within a context of a whole and roles are often attributed to parts.

- (4) Enumeration of role types

As Loebe tries to design top-level categories of roles [10], it is critical for us to know what variety there are about 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 teacher role, which is a typical role, is dependent on school and teaching action contexts. We need a model to deal with those compound roles.

3. ROLE MODEL

3.1 Fundamental scheme of our role model

The fundamental scheme in which we capture roles is the following (see Fig. 1):

“In Osaka high school, John plays a teacher role-1 and then becomes a teacher-1”.

This can be generalized as

“In a school, a person plays a teacher role³ and then, becomes a teacher”.

By **play**, we mean “act as”, that is, it contingently acts as the role (role concept). By “**teacher**”, we mean a human who is playing a teacher role.

Here, we introduce a couple of important concepts to enable finer distinction 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, a potential player plays a role (role concept) and then becomes a role holder.”* By **context**, we mean something to be considered as a whole. It includes entity and relations. **Role concept** is defined as a concept played by something in a context. So, it essentially depends on the context. By **potential player**, we mean a thing which is able to play a role concept. In many cases, basic concepts (natural types) can be a **potential player**. In this example, we say a person can play a teacher role. And, when a person is actually playing a teacher role, he/she becomes a teacher **role holder** by which, we mean an entity that is playing a role concept. This means the conventional concept, **Player**, is divided into two: One is a **potential player** and the other is a thing which is playing a role (**role-playing thing**). This distinction is based on that of class level and instance level, which is one of the key concepts in our model which can resolve the universal vs. particular issue. In other words, the conventional **player** link is divided into two kinds: one is *playable* link (class level) and the other is *playing* link (instance level). **Role holder** is neither specialization of Potential player nor that of role concept, but an abstraction of **role-playing thing** which is an individual to the class level, which is the heart of our Role model. 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 roles into two kinds: **role concept** and **role holder** in our model. While role concept at the class level is equal to Role in the conventional sense, that at the instance level is not equal to that of Role which is understood as something being played. In our model, role concept can be instantiated without being played. While the term “**Role**” is the target of the research of roles, at the same time, it 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:

In Osaka High School, there is a vacancy on a teacher position. John fills it, and then he

³ When we mention a particular role, we put “role” after the role name like “teacher role”.

becomes a teacher of the school.

Fig.2 shows the conceptual framework of role in Hozo. There are properties of teacher role, person and teacher role holder. They are divided into three groups. Properties in Group A are determined by the definition of role concept itself independently of its player. The second Group B is shared by both of the role concept and the player, and some of them come from the role concept and some from the player. And, the last Group C is what the role concept does not care about. A role concept is defined by describing Group A properties together with some from Group B which are shared by a potential player but come originally from the role concept. Its player is defined by oneself context-independently and is used as a constraint of the potential player of the role concept. And, the role holder is defined as a result of the above two definition operations and eventually includes all of the three kinds of properties. Therefore, the individual corresponding to a teacher role holder is the compound of these two instances and is totally dependent on them.

3.2.2 Role concept and its dependency on the context

The teacher example in the above is elaborated and generalized in the following manner. Firstly, if Osaka High School does not exist, the instance of the teacher role never exists. In general, any instance of a role concept cannot exist without an instance of its context. This dependency applies to all types of role concepts. Secondly, a vacancy on a teacher post arises when the teacher role is not played. Such a vacancy supports the existence of an instance of a role concept. Furthermore, it means that role concept has two states: played and not played. It can exist in the un-played state because some properties including the essential property of the role concept, for the example of teacher role, subject, class and teaching function, can be determined independently of whether it is played or not. More apparent example is a drama role. Hamlet role exists independently of it is played by an actor or not. But name or age of the teacher cannot be determined until someone plays.

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

The observations that an individual role holder is the compound of the instances of role concept and its player, and that it essentially depends on them are true to all the cases of Roles. However, there are two cases concerning the dependency between the instances of role concept and potential player according to the semantics of part-whole relation of the context. In one case, the existence of individuals of role concept is independent of that of the player. In the teacher case, for example, both of the instances of teacher role and person exist independently of each other. In other words, an individual of teacher role can exist if the school exists at all as it is. In the case of wife role, however, contrary to the teacher case, an individual of wife role cannot exist independently of the existence of its individual player because marital relation, the context in this case, cannot exist without the person who plays the wife role. This is because of the difference of part-whole semantics between marital relation and school which are context of these role concepts. In general, role concepts based on a relation has essential dependency not only on the context (relation) but also on the existence of its players because the existence of relations are dependent on their participants. Such semantics of part-whole relation is extensively discussed in [20].

3.2.4 Identity and existence of a role holder

Assume John is a teacher. John is no longer a teacher when the position of the teacher John fills disappeared, John quits the teacher role, or John dies. In general, an individual role holder

disappears in these cases: an instance of a role concept disappears, an instance of a player stops playing the role or an instance of a player disappears. This is understood from that an individual of a role holder is composed of individuals of a role concept and its player as far as the playing relation is valid as discussed in 3.2.1. This observation suggests the identity (ID) of the individual of the role holder is a function of the IDs of the role concept (ID_{Role}) and of the player (ID_{Player}). That is, $ID_{Role\ holder} = f(ID_{Role}, ID_{Player})$ in which both arguments are mandatory for $ID_{Role\ holder}$, in which “ f ” is bijective (surjective and injective).

3.2.5 Categories of role concepts

Role concepts are classified by their context-dependency. Role concepts are recognized in a context. So, in order to classify them according to categories of contexts, we can utilize their foundation. For example, task knowledge for solving problem can be discriminated from domain knowledge of a target world. Then, we can identify task-specific roles such as symptom role in a fault diagnostic task and conclusion role in a reasoning task. And, in a functional context in the artifact world, a steering wheel role (played by a wheel) and a level-control valve role (played by flow-control valve) are classified into a functional role. Note here that we do not claim artifact is role. A wheel is a wheel and a flow-control valve is a flow-control valve in its nature, that is, a flow-control valve cannot stop to be a flow-control valve without being broken, but a level-control valve can stop to be so without losing its identity. We are claiming that they can play another role according to functional contexts. Likewise, we can classify role concepts into an action-related role, a relational role and so on. Although enumeration is not exhaustive, Fig. 3 lists typical top-level categories of role concepts.

3.2.6 A primitive and a compound role concept

Teacher is recognized not only as a staff member of school but also as a person who teaches students. So, teacher role is compound of school staff role and teaching agent role. Next example is Japanese prime minister. It can be said in our terms that Japanese Prime Minister Role can be played by Japanese Citizen who is played by a human.

In such a manner, some roles need to be played together with other roles. And, in some cases, a player stops playing one of the roles, and then, some of others will automatically be un-played. This relation between roles is discussed in other researches as “requirement” [11] and “roles can play role concepts” [18]. For example, let us consider a peer tutoring context in group learning in which all members are learners. A learner is expected to play “peer tutor” role to learn by “learning by teaching” strategy. Peer tutor role depends on both of learning context and teaching context. So, here, we can identify two kinds of role concepts according to complexity of their context dependencies. There are primitive role concepts and compound role concepts. The former has single context dependency and the latter has multiple-context dependency.

Our framework can model compound roles which are understood as “Role holders can play other role concepts”. Fig.4 shows an example of that only Japanese citizen can be Japanese prime minister. A Japanese citizen role is defined dependently on Japanese political system as its context. And, Japanese prime minister role is defined as a role which has to be played in Japanese ministry context, not by a Japanese citizen role but a Japanese citizen, as a role holder. So, Japanese prime minister depends on these two contexts.

4. ROLE AGGREGATION AND INSTANCE MANAGEMENT

4.1 Organizing role concepts according to classification of their contexts

In this section, we summarize the way of organization of role concepts discussed in [15]. In our role modeling framework, **Role** class is defined at the top of the hierarchy of role concepts (see Fig.5) which has three slots: **context**, **holder**, **role part**. The first is related by a *participate-in* (*denoted as p/i in Hozo*) relation and describes in what context the role concept is defined. The second is also related by a *participate-in* relation and shows a basic concept which can play the role concept. The third is related by a *part-of* (*denoted as p/o in Hozo*) relation and associated with role aggregation. Each **role** class can have multiple parts as its components to represent it as a compound role (see 4.2).

As an upper ontology is useful to understand the world and helpful to build an ontology, role organization benefits from its upper ontology [10]. As discussed in 3.2.5, the categories of role concepts can be used as upper ontology of roles. In Fig. 5, an **Action Context Role** and an **Organization Context Role** are defined and classified into a **Role** as a top-level category of the hierarchy. The conceptual structure of top-level role concepts is analog to that of their potential players such as **Action** and **Organization** in the hierarchy of basic concepts.

4.2 Aggregation of role concepts

Because some roles are conceptualized from several viewpoints and depend on several contexts, they are difficult to organize simply according to their contexts. For example, a **Teacher** is recognized not only as a **Teaching Agent** but also as a **School Staff member**. In order to organize such role concepts which depend on several contexts, we need to consider how to represent and manage such multiple context-dependence. Then, we devised the idea of **Role Aggregation**: a framework for organizing role concepts which depends on several contexts according to their essential dependencies. Role aggregation is represented in both hierarchies of basic concepts and role concepts. And they share the same semantic information on role aggregation. Fig. 7 shows two portions of hierarchies to explain role aggregation.

We already discussed a basic way of how to model “Roles play another role” by using a role holder as a potential player of another role. We have used the way of representing compound roles in Hozo (See Fig. 6) and have confirmed it works. In Fig. 6, “Class constraint” corresponds to “potential player” in our model. However, it has a problem in human interface. In such modeling, hierarchical structure of roles are hidden in the hierarchy of basic concepts because all role concepts are defined within the basic concepts as its context as shown in Fig. 6. This is why we introduced an explicit hierarchy of roles shown in Fig. 5. The following is mainly a description of how to model roles using *is-a* hierarchy of roles shown in Fig. 5.

One of the key steps is decomposition of context dependencies into primitives. As examples described above, contexts dependences are generally decomposable. And, for each of the most primitive context, we can recognize a role concept which depends only on it. By a **primitive role concept**, we mean such a role concept depending on a single context. To summarize the way of role aggregation, we here organize an example of role concept which depends on two contexts. To begin with, the most essential context is chosen among the two contexts after investigating and

decomposing the context dependence of the role concept⁴. Among the two contexts of **Teacher Role**: an **Organization** and a **Teaching Action**, let us determine that the former is the essential (primary) context and the latter the secondary one. And then, two primitive role concepts are identified; a **Staff Role** and a **Teaching Agent**. They depend on each of those contexts respectively.

Following the current Hozo way of role definition shown in Fig. 6, a **Teacher Role** is defined as a specialized role concept of a **Staff Role** with a class constraint (Potential player) of **Teaching Agent** (role holder) defined elsewhere (Fig. 7-a). This implies **Teacher Role** is defined as a role concept which depends on both contexts of a **Staff Role** and of a **Teaching Agent Role**, that is, a school and teaching action. Fig. 7-b shows a new and alternative way of role modeling in the hierarchy of role concepts using *is-a* and *part-of* relations. In this modeling way, **Teacher Role** is defined as a sub-concept of a **Staff Role** through *is-a* relation with a role part of **Teaching Agent Role** which would be defined as a subclass of Agent role which is not shown in the figure. **Role Part**, which is explained in 4.1, is a primitive role concept to be used as a part of a compound role concept. In this example, **Teaching Agent Role** is the secondary role part. In this way, users can add role parts to constitute the desired role concept.

In our framework of role aggregation, an essential context is decided for each role concept. Otherwise, without such a decision, it is possible to merge context-dependences also in a framework of multiple inheritances. However, we do not take multiple inheritances to aggregation of role concepts in our model.

4.3 Instances of Role concepts

In this section, we discuss what characteristics of instances of role concepts should be represented in the instance model. An instance model provides us with semantics of classes and individuals by specifying their interdependencies concerning their appearance and extinction. It is indispensable for application of ontologies developed and for clarification of the strategy for treatment of roles.

While we have investigated basic issues of role concepts in Section 2, the discussion does not include consideration of role concepts which depend on multiple contexts. So, in this section, we generalize the framework of role concepts. In the following, **R** denotes a role concept, **C₁...C_n** its depending contexts, **R₁...R_n** primitive role concepts aggregated for definition of the role concept **R** and **P** a concept referred to as the class constraint(or Potential player) of the role concept.

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

An instance of **R** exists if (and only if) all instances of **C₁...C_n** are instantiated. When, at least, one of them is deleted, so does the instance of **R**.

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

An instance of **R** is dealt with as a defective instance by itself. When instances of **R₁...R_n** as constituents of **R** are played by the same instance of **P**, a role holder of **R** is concretized by aggregating them to be a complete individual corresponding to **R**.

⁴ The most essential context is decided by developers of an ontology. We do not discuss or conclude generally what the essential context should be. Based on the relativity of essence, we think that, essences of concepts are decided by the developers intended as far as the decision is consistent in the whole ontology.

(C) Extinction of a role holder

A role holder of **R** is composed of both instances of **R** and **P**. Let **R_i** and **P_i** denote instances of **R** and **P**, respectively. Then, there are four cases in which the role holder disappears: (1) **P_i** has disappeared. (2) **R_i** has disappeared. (3) **P_i** has stopped playing **R_i**. (4) At least, one of role concepts of **R₁...R_n** has disappeared.

5. ANALYSIS OF THE ROLE MODEL

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

5.1 Characteristics

(1) Roles are anti-rigid [6]

A potential player plays a role concept only in a context. From the definition of “play”, it is apparent that the role and/or its properties cannot be the essential properties of the player, and hence Roles (Role concepts) are anti-rigid to the players in our model.

(2) Roles are dynamic

From the definition, the player easily stop/start 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 the issue is about not “role type” but “individual role”, then we need discussion, since it depends on the types of the role. For example, in the case of student role, no person can play the same student role multiple times because every individual student role has a different ID. 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 [14] 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. While the same citizenship of Japan might look it is possible to be played by multiple persons, it is not true because each citizen has its own ID to distinguish one from others⁵. In the case of a drama role,

⁵ See Fig. 2. This ID belongs to Group B property coming from the role concept.

such as Hamlet, it is a bit problematic, since Hamlet is already an instance and it can still be played by multiple entities at the same time. See (6).

(8) A role can play another role

Yes, in our model, as discussed in 3.2.6, this is modeled by using a role holder of a role concept as a potential player in another role concept. This topic is further discussed in 4.2.

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

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

(10) A teacher is a teacher while sleeping.

Partly yes. It is tightly related to the semantics about “play” relation or equivalently about “the way of participation” in the context. Many of the typical cases are informally covered by our model. It is related to the upper ontology of roles. As the difference between teacher role and pedestrian role has been discussed in 2.1, the extent of the validity in terms of time is specified by category to which the role concept belongs to. In the case of organizational roles, the participation is steady and it lasts until the player leaves the organization. In the case of process-related role, it is temporary. Although it might look the issue is resolved, it actually includes a tough issue. We need a rigorous definition of the semantics of *play* relation and/or *the way of participation* in the context, which will be revisited in the concluding remarks.

5.2 Issues as requirements to solve

(1) Counting problem

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

(2) Universals vs. particulars

The problem to answer is if the following view is OK or not: “A role is considered as a universal and whose instantiation is done by being played by an entity (an individual)”. This issue seems to be a bit complicated or confusing after we introduced our terminology, since what is meant by “role” in the question becomes ambiguous. Our model views that an instance of role concept can exist without being played by any player and when it is played by something, then it becomes an individual role holder. This becomes possible by the distinction between role concepts and role holder, since it enables to detach the instantiation operation of the role concept from the playing operation. Fig. 2 shows this clearly. In our terminology, the next issue is whether role holder is a Universal or not and what is its instance. Our answer to the question is that role holder exists both in the universal (class) level and the particular (instance) level, however, they are not totally equal to an ordinary universal or an ordinary particular in the sense that the class-level thing cannot be directly instantiated and that both class-level and instance-level things are heavily dependent on role concept and potential player. Role holder as a particular has to be made by composing individuals (particulars) of corresponding role concept and potential player. And, the role holder at the universal level is an abstraction of the individual role holder made that way.

(3) Sophisticated instance management

We have found that instance management is a crucial topic to establish a solid theory and

model of roles. The Universal vs. Particular issue is a typical one which shows the importance of understanding of the roles at the instance level. We have discussed the instance management issue in 4.3 to some extent and clarified typical dependencies between role-related individuals with necessary management operations. As stated in 2.2, this issue is related to the semantics of part-whole relation. One of the key ideas of our role model is that role concepts are attributed to parts of the context (whole/relation) which the parts belong to. Therefore, we need a theory which explicitly explains the relations of parts and roles.

(4) Enumeration of role types

Although not exhaustive, we top-level categories of role concepts by investigating the characteristics of the context they depend on. An interesting extension of our understanding of roles is ***attribute role*** presented in the bottom of the categories of role concepts above the dotted line in Fig. 3. It says that *height* is a role concept played by length. For example, the height of a block depends on how it is put and it is properly represented by the model shown in Figs. 1 and 2 and by Hozo tool. Although this idea looks a bit odd, our idea is the following: Once we come up with an acceptable model of roles, we could consider *things that can be successfully modeled by the model as Roles*. Following this observation, height is a role concept because height is successfully represented in our model.

(5) Compound roles

We have briefly discussed role aggregation for representing compound roles in 4.2. Detailed discussion on this topic has been done in [EKAW06 or AAAI]. The authors believe the role aggregation model satisfactorily represents compound roles.

6. Related Work

Guarino and his colleagues aim to establish a formal framework for dealing with roles [6, 11, 12]. And Gangemi and Mika introduce an ontology for representing a context and states of affairs, called D&S, and its application to roles [3, 4]. Their research is 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; that is, context-dependence, specialization of roles, and so on. According to their theory, our framework can be reinforced in terms of axioms. They describe specialization and requirements as kind 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 describe clearly 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 which has complicated context-dependences, they only point out a requirement relation. Our notions differ from their work on other two points; that is dynamics of a role and 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, their framework deals with time-dependency explicitly. Secondly, we distinguish role concepts and role holders [7, 8]. On the basis of this distinction, we propose a tool for properties and relations on roles, such as an aggregation of role concepts. Masolo, et al. introduce a new kind of entity, called qua-individuals, to solve counting problem [Masolo 054]. They discuss that 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 like similar to role holder, but it is unclear how to create their instances and identities and role holder does not produce such problems that qua-individual would cause. As Loebe tries to design top-level categories of roles [10]. He discusses it based on the characterization of roles as being determined by context, and he shows three role types: *relational role*, *processual role* and *social role*. His approach is similar to our way of role organization on its top-level. In addition to them, 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 in that a Thing is classified into an Entity and a Role in [2]. And, he gives an Agent and an Instrument as sub-concepts of a Role. However, he does not clarify a point of view for organizing them. To our knowledge, they are regarded as being organized according to their manner they participate in their contexts.

Breuker develops ontologies for legal domains based on epistemology and discusses characteristics of roles in [1]. He also mentions adulteration between a role itself and playing role and others between a role and its player. We share his notion in discriminations of these concepts and differentiate a role concept, a class constraint and a role holder from one another [7, 8]. He describes two kinds of roles; as a concept and as a relation. However, he does not organize them in more detail. And, in contrast of that he defines roles according to behavioral requirements and so on, we allow developers of an ontology to define role concepts just as the developers intended because it is outside the scope of our research to discuss how to conceptualize roles.

Next, we focus on distinction between our framework and one of OWL provides. In Fig. 8, we represent our role model in OWL. We define *hozo:BasicConcept* class and *hozo:RoleConcept* class to express basic concepts and role concepts. And 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 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 without identity.

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 **to play operation**. We explained how these characteristics contribute to solving typical role issues with all the characteristics shown in 2.1. However, we have also 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 each other, the first issue is the most serious among them. In order to clearly understand *playable*, *playing*, *depend-on* relations, we need to investigate when and how the related instances appear and disappear in what interdependence. Although we discussed the issue in 4.3 to some extent, it is apparent that we need more discussion on it. Fig. 8 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 is directly influences on the semantics of “*playing*” relation. In this paper, we considered **car driver role** is only valid while he/she 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 in the high way, though when he/she reaches the destination, then he/she stops being a car driver. The general principle that “to belong to an organization is steady and participation in a process is temporal” seems 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 the coverage of part-whole and role theories. I mean, how we can state a role theory independently of the semantics of the part-whole relation. For example, we state that an individual of a role concept can exist as far as the instance of its context exists and it can have *played* or *un-played* state. It applies to teacher role case but does not to 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 ontology of representation. Although we have our own [14], there is no established ontology of representation yet. Following our ontology of representation, Hamlet as a role is an instance 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 is the instance of Hamlet. For those who commits to such a view, what we discussed at (6) in 5.1 would be incorrect. In addition to those listed in the above, identification of top-level categories of roles is worth to investigate further. Especially, the question about “**attribute role**” is really a role or not, and other candidates such as **the sick, beginner, boy**, etc. are of value to discuss. Although the instance management procedures discussed in 4.3 and the explicit organization of role concepts in a hierarchical manner discussed in 4.2 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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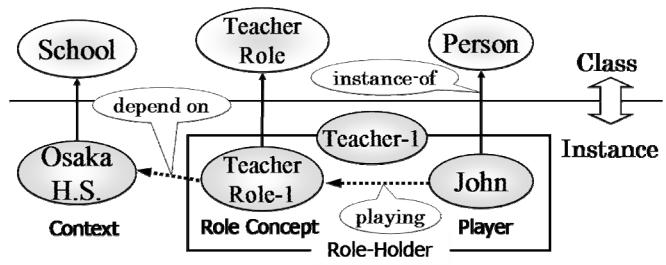


Fig. 1 Fundamental scheme of a role concept and a role holder

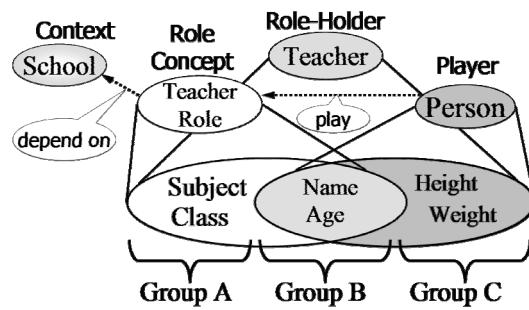


Fig. 2 Conceptual framework of a role

■ Primitive role
• Task role
➤ Symptom role (Fault diagnosis)
➤ Conclusion role (Reasoning)
• Functional role
➤ Steering wheel role (Steering function)
➤ Level control valve: played by a flow control valve (Function) (flow-control valve is built to be for flow-control intrinsically, but there is None built for level-control valve)
• Action-related role
➤ Agent role (Any action)
➤ Teaching agent role (Teaching action)
➤ Target object role (Action object)
• Process-related role
➤ Product role (Final output)
➤ Residue role (How it is processed)
• Organizational (Social) role
➤ Staff role, Employee role
➤ Student role, Nurse role (Composite)
• Relational role
➤ Friend role (friendship)
➤ Husband role, Wife role (Marital relation)
• Attribute role
➤ Height role: played by length (it depends on how to put, say, a cube)
■ Composite role
• Manager (Employee and agent role of management)
• Prime minister (Diet member and Citizenship)

Fig. 3 Categories of role concepts

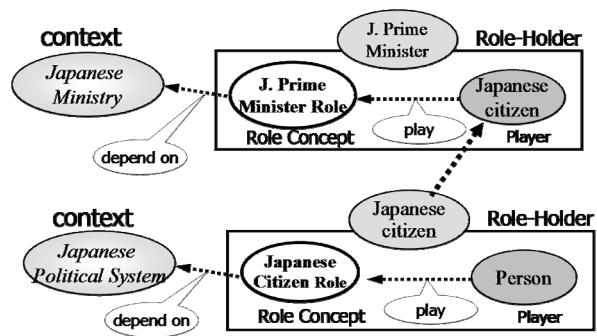


Fig. 4 Compound Roles

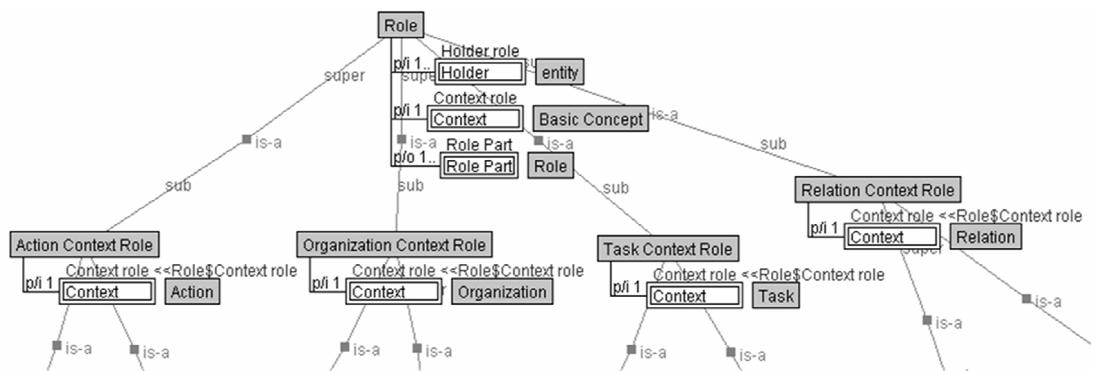


Fig. 5 An example of the hierarchy of role concepts

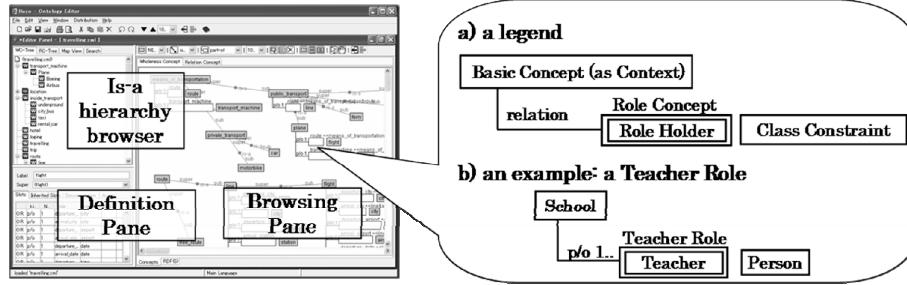


Fig. 6 Ontology Editor in Hozo and its form of presentation for definitions of role concepts

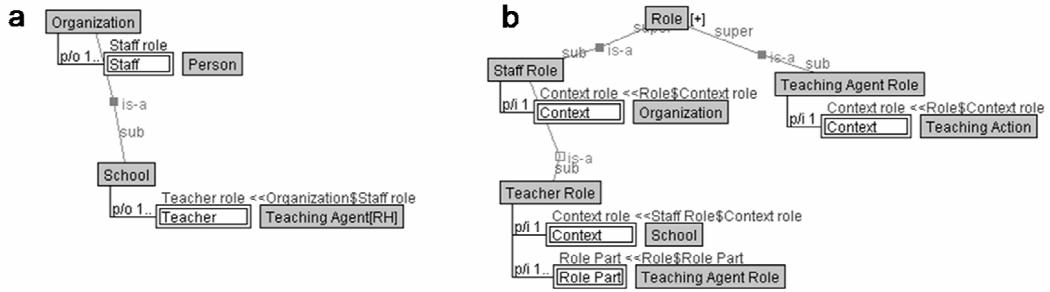


Fig. 7 An example of Role Aggregation

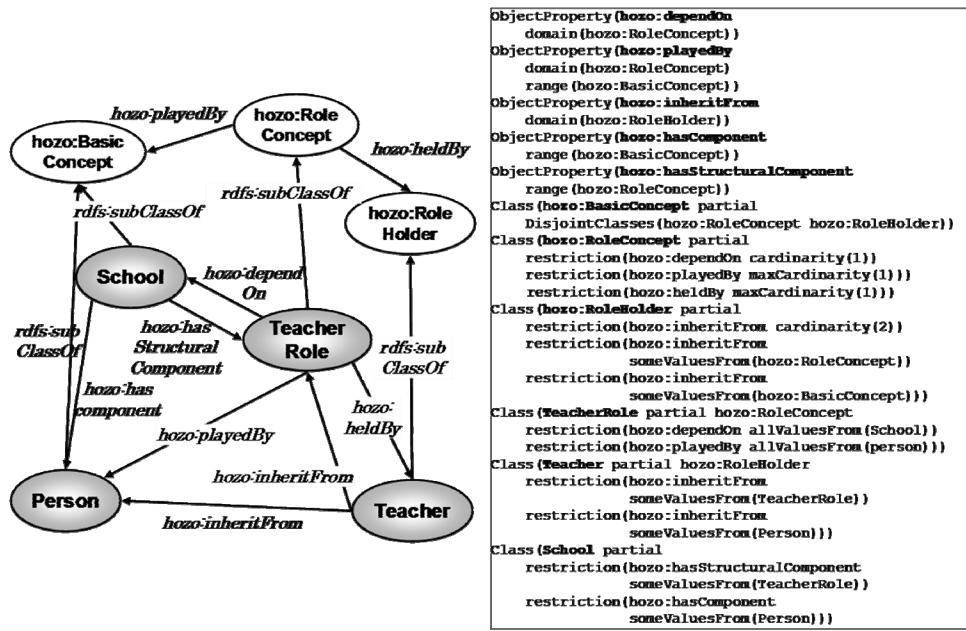


Fig. 8 Role representation in OWL