

Roles: A Four-Dimensional Analysis

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Abstract. In ontology the underlying nature of things is sought. Thus it is that the roles things play can sometimes be neglected. Some different sorts of things that get called roles: places in relations, ways of participating in activities, and ways of being a part of a system, are considered. Roles are then analysed from a 4-dimensional and extensional perspective. We find that in individuals a role is a state of some individual that participates in a relationship or an activity, whereas with classes it is the class itself that participate in a place in a relation. In systems (both social and functional roles) we find that roles are replaceable parts of the system that are the purpose the part plays in the whole. A 4-dimensionalist ontology of roles, linked to an upper ontology is presented, and this is used to set out the key properties of roles as found here and by others.

Keywords. ontology, 4-dimensionalism, role.

Introduction

In ontology the underlying nature of things is sought. Thus it is perhaps not surprising that the roles things play has been, or at least seemed to the author, to have been relatively neglected or thought to be insubstantial. Further, the work that has been done presents divergent views on the nature of roles.

In this paper I examine some different sorts of role, and develop a 4-dimensional² analysis of them including a 4D ontology linked to an upper ontology. This is then used to set out the key properties of roles, and is compared to the properties and questions set out by others [11],[12].

1. Roles Found in Literature and Industry

A particularly good survey of the literature on roles can be found in Steimann [11], and a significant study has been done by Loebe [3].

In the literature, a number of different sorts of role are recognized:

1. Relational Roles (e.g. Loebe [3], Masolo et al [3], Sowa [5])
2. Participating or Processual Roles (e.g. Loebe [3], Sowa [1])
3. Social Roles (e.g. Loebe [3], [12] Masolo et al [6], Smith [7], Mizigouchi [13])
4. Functional Roles (e.g. ISO 15926 [8])

Steimann [11] has identified a number of properties of roles, which Loebe [12] has developed further, but rather posing questions. These are presented in Table 1.

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² A good description of 4-dimensionalism can be found in [1] and [2].

Table 1: Properties of roles as identified by Steimann and Loebe

Steimann	Loebe
<ol style="list-style-type: none"> 1. A role comes with its own properties and behaviour. 2. Roles depend on relationships. 3. An object may play different roles simultaneously. 4. An object may play the same role several times, simultaneously. 5. An object may acquire and abandon roles dynamically. 6. The sequence in which roles may be acquired and relinquished can be subject to restrictions. 7. Objects of unrelated types can play the same role. 8. Roles can play roles. 9. A role can be transferred from one object to another. 10. The state of an object can be role-specific. 11. Features of an object can be role-specific. 12. Roles restrict access. 13. Different roles may share structure and behaviour. 14. An object and its roles share identity. 15. An object and its roles have different identities. 	<ol style="list-style-type: none"> 1. Roles as individuals vs. roles as universals [1,14,15]³. Do role individuals exist or are roles a specific kind of universals? 2. Role identity [14,15]. Do roles have an identity different from their players? 3. Dependence, relational nature of roles, and contexts [2]. In which ways do roles depend on other entities? 4. Roles with own properties and behavior [1,11]. Do all roles come with their own properties and behavior? 5. Dynamicity and anti-rigidity [4,5,6,9]. In which way are roles considered “dynamic”? Does anti-rigidity apply to all roles? 6. Role-playing roles [8,9]. Can roles play roles? What relations among roles exist in general? 7. Multiplicity of roles [3,4,7,9]. To how many roles of how many types can natural universals be linked? How many roles can be played by instances of natural universals? 8. Generalization hierarchies with roles [13]. How can role and non-role terms be arranged in a single generalization hierarchy? 9. Role abstraction and complementary roles. Why is abstraction among relational and processual roles reasonable? What should complementation mean on the universal level? 10. Pure roles. What is the difference between roles like <i>child</i> and <i>son</i>? 11. Integrating roles with qua-individuals. Should role individuals be identified with qua-individuals? 12. Meta-level status of roles. From a meta-level perspective on the model presented, are role-individuals genuine entities?

Some questions about which there does not seem to be consensus are:

1. Are these different sorts of role (a particular role playing) individuals or classes, and if individuals, abstract or concrete?
2. Are role types, specializations of base types or not (e.g. is *employee* a specialization of *person*?)
3. Is a role identical to the object playing the role (see Steimann {14,15} in Table 1.

2. Roles in Relationships

I want to start by distinguishing between how something is represented, and what something is. For example, it is quite possible for an activity to be represented by a

³ The numbers refer to the numbering of the Steimann properties.

relation, with each of the roles played in the activity represented by a place in the relation. This, however, does not make an activity a relation. An activity is an individual that causes change. On the other hand, a relationship is something static, that holds for the period of its validity. Again, a relationship may, or may not, be represented by a relation (an alternative for example would be to represent the relationship by a class, and the roles played in the relationship by relations). Here I am talking about relationships and activities, rather than relations.

In the 4-dimensional paradigm with extensionalism, the primary objects are either spatio-temporal extents, or classes, where each has its extension as its basis for identity. Thus I will consider three types of relationship:

1. Relationships between individuals.
2. Relationships between an individual and a class.
3. Relationships between classes.

2.1. Roles of Individuals in relationships

I shall start with a space-time diagram of ownership as an example relationship between individuals, **Figure 1**.

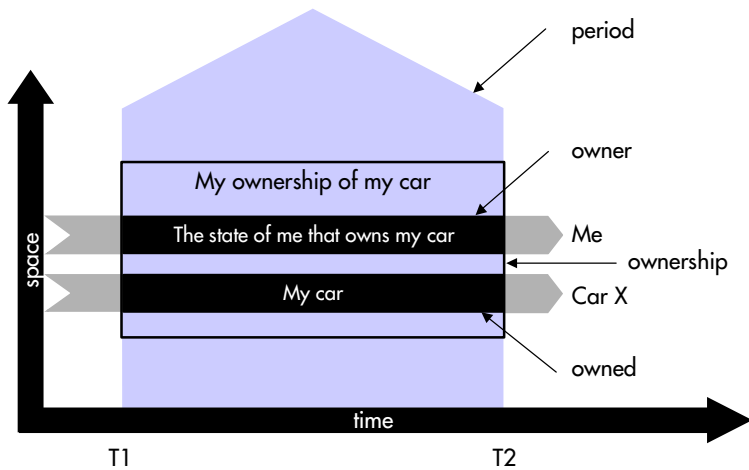


Figure 1. A space-time map for a relationship between individuals

The figure illustrates the ownership of my car by me. The grey chevrons represent me for the whole of my life and car X for the whole of its life, the chevrons indicating that the start and end are beyond the limits of this diagram. The black rectangles represent the state of me that owns my car and the state of car X owned by me (my car) respectively, and the empty black box represents the aggregation of those states that together constitute the ownership relationship. Notice that the relationship is itself a spatio-temporal extent. The arrows show a classification of each state by the appropriate class, in the case of the black rectangles these are classes of role. The light grey vertical chevron represents the period that the relationship is a spatial part of. Notice how much of what one might ordinarily think of as a simple relationship is in fact made up of whole-part relationships.

A special case of this pattern is whole-part. This is illustrated twice over in **Figure 1**, as the owned and owner roles are parts of the ownership relationship, and in turn the ownership relationship is part of the period that the ownership occurs in.

What you will notice here is that a complex relationship between individuals has been decomposed into a number of either classification or composition relationships. I conjecture that this is the case for all non-primitive contemporaneous relationships between individuals (an example of a non-contemporaneous relationship would be one between a history teacher and Napoleon when the teacher was talking about Napoleon). Masolo [4] and Kozaki [10] find similar results.

2.2. Roles in Relationships Between Individuals and Classes

Figure 1 also illustrates an example of a relationship between a class and an individual, that of classification, represented by the arrows in the figure. Classification is a special case, since it is a primitive relationship that is required to be able to say anything. However, it illustrates the nature of relationships between individuals and classes. The key element is that of temporality. The relationship is between the state of the individual (role) for which the relationship is true and the class. In the case of classification, this supports the extensionalism of classes, since rather than the membership of a class changing over time, the states, which incorporate the period of validity, are simply members of the class, which is then an eternal statement. Although classification is a special case, this pattern holds for other relationships between individuals and classes.

2.3. Roles in Relationships Between Classes

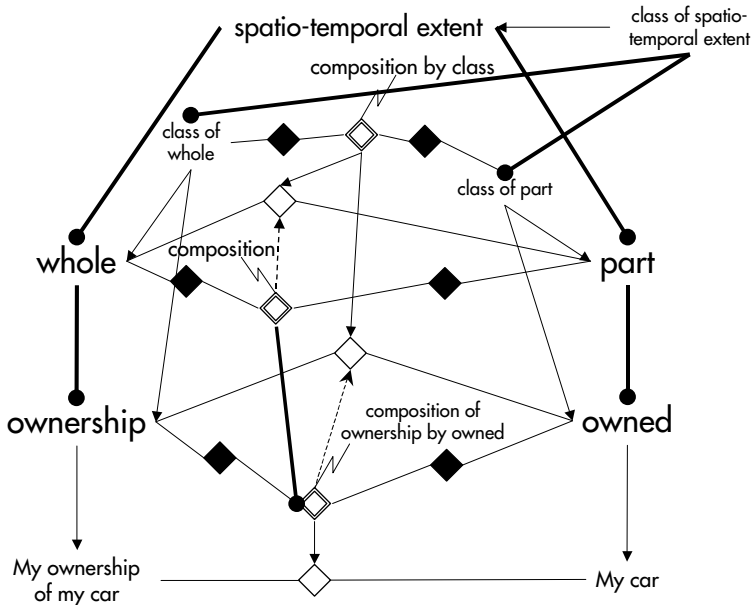


Figure 2. An illustration of relationships between classes

Figure 2 gives examples of relationships between classes. Building on the example above. The notation is as follows⁴:

- A single line diamond represents a simple relationship, with lines linking to the related objects,
- A double diamond represents a class of relationship, i.e. a set of relationships,
- A black diamond represents a relationship between a class of relationship and a class of role that participates in member relationships,
- The dashed arrow represents the implication that a relationship exists between the roles related to the class of relationship,
- The thick lines represent a specialization relationship, with the subclass at the lollipop end,
- The lightning strike is a call out to the name of the object.
- As in **Figure 1** an arrow represents a classification relationship, with the member at the arrowhead end.

Starting at the bottom of the diagram we find the relationship between my ownership of my car, and my car. This relationship is classified as a composition of ownership by owned relationship. This class in turn is related to the classes ownership and owned, indicating they are the classes of role played in the composition of ownership by owned relationships. Moving up the diagram again, we see that composition of ownership by owned is a specialization of composition, and that ownership is a specialization of the class of role, whole, and owned is a specialization of the class of role, part. Finally, we can see that both whole and part are specializations of spatio-temporal extent.

Now in addition, there is a relationship between the classes ownership and owner, and another one between whole and part. These are both implied by the classes of relationship at the other end of the dotted arrow. Now with a relationship between classes, it is the classes themselves that play the role. This is because classes are timeless, so if the relationship is true it is always true. Just as with the relationship between individuals, there is also a class of relationship for the relationship between classes. This is composition by class, and is shown near the top of the diagram. The relationships above are shown as members.

3. Roles of Individuals in Activities

Figure 3 illustrates the way that roles occur in an activity. This example is for the replacement of a pump impeller. The notation is the same as in **Figure 1**. First someone makes a request in the engineering department to someone in the purchasing department of the customer organization for a new impeller. Then the purchasing department of the customer organization places an order with someone in the sales department of the supplier organization. The sales organization then requests delivery of the impeller to the customer organization by delivery, who executes the delivery which is received by the customer organization. The impeller is then installed (details not shown).

The roles in the activity are the states of the objects whilst they are participating. The activity consists of the roles participating in the activity. It is noticeable that the

⁴This notation is based on that used in [8] to illustrate instances of the data model.

pattern of roles in activities is the same as the pattern for relationships between individuals. The difference between them is that an activity causes change, and the participations in the activity are themselves activities, whilst a relationship is about something constant.

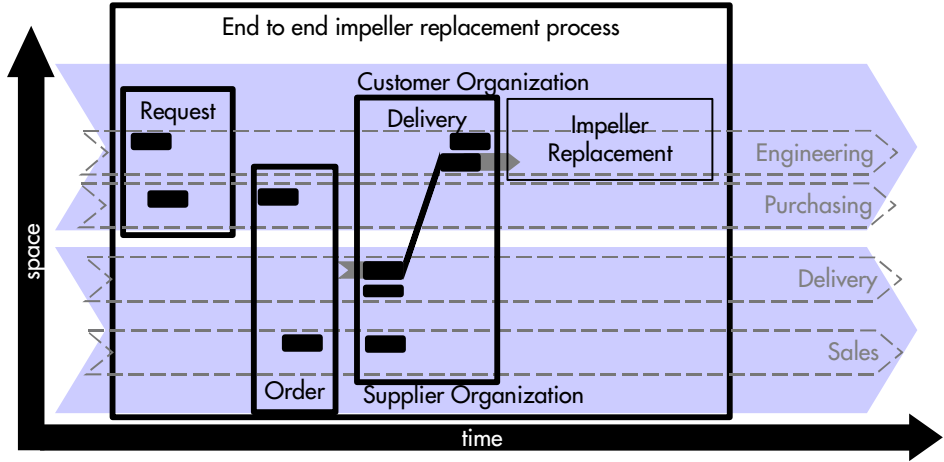


Figure 3. An example of roles in an activity

4. Roles as Replaceable Parts in Systems

As we shall see, in a 4-dimensional analysis, social roles and functional roles share the same pattern, so, whilst considered separately, they are brought together under a more general heading.

4.1. Social Roles

A social role is a role in human affairs that is defined independently of the person who fulfills the role, and, from time to time, the person who fills the role may change. Examples include the Lord Mayor of London, the President of the United States, and the Secretary to the Head of Department in the School of Computing at the University of Leeds.

A 4-dimensional analysis of social roles was presented in [11]. The example used there is illustrated in **Figure 4** below.

The figure shows that Bill becomes president for a period of time, i.e. a state of Bill is also a state of the President of the United States. When Bill leaves office George replaces him, and he is then president for a period of time, i.e. a state of George is also a state of the President of the United States. There are four things to note here:

1. That a social role consists of the temporal parts of those who play the role whilst they are playing it,
2. That a social role can change all its parts at once, and survive that change, unlike ordinary physical objects,

3. That a social role can go through a period of non-existence, if for example there is a gap between one person leaving office, and another taking the office up,
4. If there is no United States, there is no President of the United States, i.e. the social role is dependent on the social system that it is a part of. (Mizigouchi [13] also recognizes the dependence of social roles, but only puts that dependence on a context, rather than explicitly recognizing it is on the social system it is part of.)

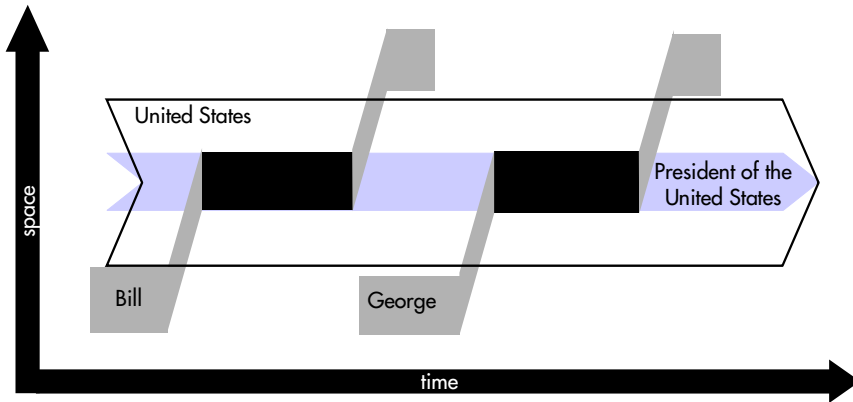


Figure 4. Space-time map for President of the United States⁵

A consequence of this is that it makes sense to talk about shaking the hand of the President, because the President is a real physical object, though not an ordinary physical object.

4.2. Functional Roles

A functional role is a part of a functional object, that can be wholly replaced, and yet retain identity. Examples are: the offside front wheel of a car, the port engine of a plane, or the pump at the bottom of a distillation column on a process plant.

This last example, taken from [8] and [9] is illustrated in **Figure 5** below.

The Crude Distillation Unit has a pump at the bottom of a distillation column, labeled P101. A pump, with manufacturers serial number, Pump 1 is installed as P101, and operated as such by the plant operators. They are concerned with the availability of P101, not which pump is installed there. However, the maintenance engineers record maintenance against Pump 1. Now at some point in time, Pump 1 breaks down and is replaced by Pump 2. The operators continue to operate the replacement pump as P101. Maintenance repair Pump 1 and perhaps install it in some other process plant performing another duty.

As with the social role, things to note are:

1. That a functional role consists of the temporal parts of those physical objects that play the role whilst they are playing it,

⁵ Whilst this figure shows the general pattern, where a social role may go through a period of non-existence between one incumbent leaving office, and another taking office, in the case of the President of the United States there are rules such that whatever should happen to the present incumbent, there is always someone who is the President.

2. That a functional role can change all its parts at once, and survive that change, unlike ordinary physical objects.
3. That a functional role can go through a period of non-existence, if for example there is a gap between one physical object being removed, and another being installed.
4. The existence of the functional role (P101) is dependent on the existence of the Crude Distillation Unit.

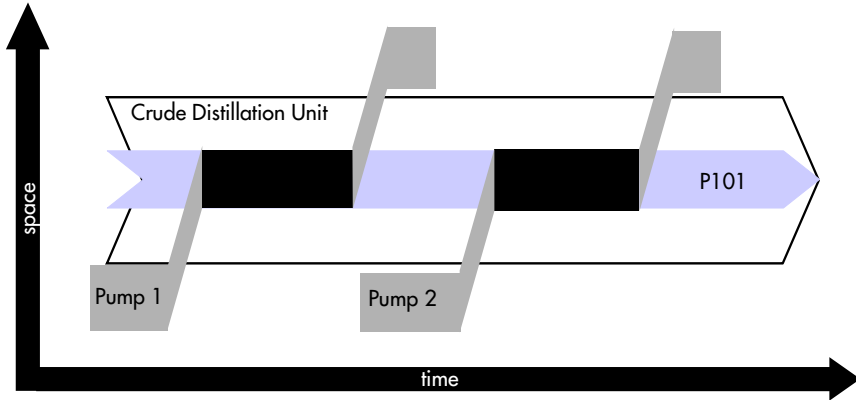


Figure 5. The replacement of a pump in a process plant

It seems to be particularly difficult to come to terms with periods of non-existence. How can something not exist when I can talk about it? This is understandable, however, we do not find it difficult to talk about historical things that do not exist now. Perhaps a better way to understand temporary non-existence is a practical one. If you are a plant operator, and you are asked to start up P101 when there is nothing installed there, you will not be able to do it. The reason you will not be able to do it is because at that time it does not exist.

4.3. Similarities and Differences Between Functional and Social Roles

The general pattern of social roles and functional roles is clearly the same. The difference is just the level of reality at which the system operates. Indeed, one can look at other levels of reality and see that systems with replaceable parts can exist at those levels too. A particular case in point is biological systems, where an organ is a replaceable part of a living creature.

5. A 4-Dimensionalist Upper Ontology of Roles

Having analyzed with examples the spatio-temporal patterns of different sorts of role, I now present an ontology based on that analysis as an extension to a 4 dimensionalist upper ontology. This is shown in **Figure 6** below. The thick lines show subtype/supertype relationships with the subtype at the lollipop end. Thin lines show relations, which, when the line is solid are mandatory at the sharp end. Relation names are read from the sharp end to the lollipop end.

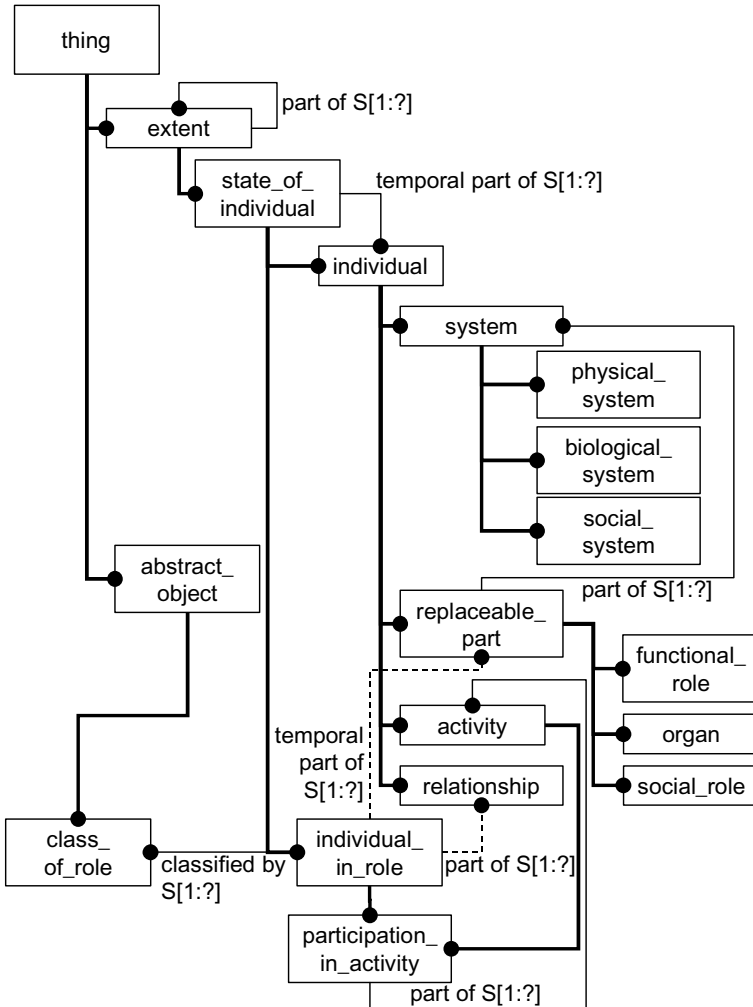


Figure 6. The 4-dimensionalist basic upper ontology for roles

A **thing** is anything that exists, real or imaginary. A thing may be either an **abstract object** or an **extent** (but not both). **Abstract objects** are either relations or classes (only a subtype of class is shown here). An **extent** is any spatio-temporal extent, i.e. any arbitrary piece of space-time, which does not even have to be contiguous.

An **individual** is an **extent** that is something for the whole of its life, the ordinary objects and activities that we recognize. The subtypes of **individual** considered here are:

- **system**, which is an organized or connected group of objects, and may be a **physical system**, a **biological system**, or a **social system**;
- **replaceable part**, which is a *part of* at least one system, and may be a **functional role**, an **organ**⁶, or a **social role**;

⁶ **Organ** is only an example of a biological **replaceable part**, not all biological **replaceable parts** are necessarily organs.

- **activity**, which causes change;
- **relationship**, which is an unchanging state of at least two **individuals**.

State of individual is any temporal part of an **individual**, and so **individual** is itself a subtype of **state of individual**, since it is a maximal state. An **individual in role** is a **state of individual** that is playing a role. This may be *part of a relationship*, or *temporal part of a replaceable part*. An **individual in role** is *classified by a class of role*, which is a subtype of **abstract object**.

A **participation in activity** is any **individual in role** that is also an **activity**, and is a *part of* an **activity**. It is the **individual** whilst they participate in the **activity**.

6. Discussion

In section 1 I noted the properties and questions that Steimann and Loebe have raised about roles. Now that I have constructed a 4-dimensional ontology of roles, I consider the consequences for these, making the following statements for the ontology I have constructed.

1. A role (**individual in role**) is a **state of individual** that is a separate object with separate identity from the **individual** playing the role. As such it has its own properties and behavior. Steimann {1,10,11,14,15}, Loebe {1,2,4,10⁷,11⁸,12}.
2. A role (**individual in role**) is existence dependent on both the **individual** that plays the role, and the **relationship**, **activity**, or **system** that the role is part of. Steimann {2}, Loebe {3}.
3. Since there is no restriction on one **state of individual** temporally overlapping with another, an object may play the same role many times or different roles simultaneously. Steimann {3,4}, Loebe {7}
4. A role (**individual in role**) is a *temporal part of* the **individual** playing the role. Steimann {5}, Loebe {5}⁹
5. The sequence in which roles may be acquired and relinquished can be subject to restrictions. Steimann {6}.
6. **Individuals** of unrelated type may play the same role. Steimann {7}, Loebe {7}.
7. Roles (**individual in role**) can play roles. There is nothing to prevent one **individual in role** being a *temporal part of* another, which is what it means in 4D for one role to play another. Steimann {8}, Loebe {6}.
8. For a **replaceable part**, all of its parts may be replaced, and it may go through periods of non-existence. Steimann {9}, Loebe {7}.
9. One type of role may be a subtype of another, and hence may share structure and behavior. Steimann {13}, Loebe {8,9}.
10. An **activity** or **relationship** is constructed from the **individual in roles** that participate in them. Loebe {9}.

It is particularly noticeable that very many questions raised are answered by understanding that a role is a state of the individual playing the role.

⁷ Not all **state of individual** are **individual in role**, so child is a **state of individual** that is not a role, whilst son is an **individual in role**.

⁸ Qua-individuals seem to be invoked when 3 dimensionalists really need states.

⁹ Dynamicity and anti-rigidity make no sense in a 4D ontology.

7. Conclusions

Four different types of role, relational, participating, social, and functional, have been analyzed from a 4-dimensional perspective. We have seen that roles played by individuals consist of states of the individuals playing those roles. In particular, social and functional, but also participating roles can have all their parts change at once, and survive that change, unlike ordinary physical objects. We have also seen that role classes, rather than being specializations of the class of thing that plays the role, are specializations of states of those things. Finally, we have been able to show how this ontology exhibits all the properties and answers all the questions posed by Steimann and Loebe.

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