Applied Ontology 2 (2007) 127–158
IOS Press

Abstract vs. social roles – Towards a general theoretical account of roles

Frank Loebe

Research Group Ontologies in Medicine (Onto-Med), Institute of Medical Informatics, Statistics and Epidemiology (IMISE), University of Leipzig, Haertelstr. 16-18, 04107 Leipzig, Germany
Tel.: +49 341 9716161; Fax: +49 341 9716130; E-mail: frank.loebe@imise.uni-leipzig.de

Abstract. For decades, roles have been discussed and applied in different ways in various fields of computer science, but apparently no consensus on their understanding is available. Thus, role terms like "patient", "runner", or "factor" qualify for further investigation, which aims at covering and generalizing recurrent understandings and uses of roles. The generality of roles suggests their inclusion in top-level ontologies. This paper extends and refines analyses of roles for the top-level ontology General Formal Ontology (GFO). The primary foundation of this account comprises the notions of *role*, *player*, and *context* and their interrelations, associated with situations of, for instance, some human who plays a patient role in a hospital context. Further, a classification of roles is introduced, which at top distinguishes two role types: *abstract roles*, providing a means of viewing something in a context, and *social roles*, which are complex social objects in vaguely defined contexts. These types are mixed in the literature, and their differences restrict the theory common to all roles. Based on this framework, the paper discusses controversial issues of roles, demonstrating the expressiveness of the overall account, which allows for fine-grained distinctions and the integration of prior work.

Keywords: Roles, social roles, top-level ontology

1. Introduction

Just as the phrase "to play a role" is certainly one of universal applicability, notions of roles pervade many different areas. Until recently, they often exhibit an auxiliary flavor with respect to basic notions like class, object, or others. Furthermore, terms which are frequently understood as roles lack a simple, general principle to identify them as such – a problem which does not seem to exist for mass terms like water or sand, which can be detected based on the question of whether they are countable. But looking at terms like student, customer, patient, factor, and driver, it is less clear why these are roles, whereas human, stone, university, and book are not, and why adult and child can be seen to be roles as well as not to be of this kind.

On a more general level, roles seem to take a "contradictory" position. For instance, they classify entities which "actually" are something different. From an object vs. property point of view, many roles appear like objects since they are complex and have properties themselves. But they also depend on other entities, for instance, there were no students without humans. This proposes an understanding as a property, such that altogether they seem to be somewhat in between objects and "simple" properties. Seen from a temporal angle, most roles exhibit a more dynamic and less stable character compared to those entities which play roles. Human beings can become students several times during their life, for example.

Recently, there is also an increasing interest in settling role-related issues from an application perspective. This becomes clear by the acknowledgment of high relevance of roles for modeling and representation in several fields. In particular when dealing with top-level ontologies, an adequate account of roles may occupy a very basic position therein. In Loebe (2003) we have made an attempt to characterize the notion of roles in a general manner, for integration into the General Formal Ontology (GFO) (Herre et al., 2006), which is a top-level ontology. This has yield a very broad notion of roles incorporating fairly distinct types, which has been refined in Loebe (2005). In the current paper we present this proposal in a heavily revised form, and focus on the elaboration and interpretation of recurrent problems and analytical issues concerning roles. Furthermore, the impact and relevance of our model for applications in modeling and programming is briefly discussed.

The organization of the paper is as follows. This introductory section provides the ontological and terminological background for the remainder of the paper, as well as a selection of primary literature which was used in the development of our account. In the next section we introduce our analysis and classification of roles in its present form, augmented by an extensive example illustrating all types of roles. Section three is devoted to the discussion of twelve particular issues in the light of our analysis, among them the existence and identity of role individuals and their relation to qua-individuals, dynamicity and anti-rigidity of roles, dependence, pure roles, etc. Moving to more practical aspects, the fourth section is concerned with the specific appearance of roles in the HL7 health care standard (HL7, 2005), and a more general perspective on roles in programming languages. The paper concludes with summarizing remarks and future directions.

1.1. Ontological and terminological preliminaries

The ontological background for this work is primarily provided by the General Formal Ontology (GFO), a top-level ontology being developed by the Research Group Ontologies in Medicine[1] (Herre et al., 2006; Heller & Herre, 2004). It introduces a number of top-level categories and basic relations, integrating categories based on several distinctions, such as the contrast between objects and processes. We briefly present the main notions from GFO that are necessary for our purposes and relate some of them to more common terminology in object-oriented (OO) modeling and programming languages as well as to terms established in philosophy.[2] To provide an initial intuition, Table 1 lists examples for the most specific GFO categories considered herein, and links to corresponding OO notions.

A first distinction is made in GFO based on the relation of *instantiation*. *Instances* instantiate *universals*,[3] which is an intensional relation. Hence there are distinct universals which share the same *extension*, i.e., the same set of instances. *Individuals* (also called particulars in the philosophical literature) are specific instances which cannot further be instantiated. The category of individuals is extensionally disjoint with the category of universals. Since there may be *empty* universals which have no instances, individuals cannot be defined as all those instances which do not have instances themselves. Instantiation is an atemporal relation, which is possible in connection with persisting entities due to the account of identity over time in GFO (see below). Relating to OO terms, individuals correspond to objects, and universals to classes.

[1] http://www.onto-med.de

[2] In either case this indicates close similarity among terms rather than a strict correspondence. Especially concerning philosophical theories, many elaborated accounts with a limited focus exist. However, integrating many of these into a single system leads to conceptual deviations even if a particular theory is intentionally referred to.

[3] In order to align with more common terminology, this use of "universal" deviates from its specific meaning in the recent version of GFO (Herre et al., 2006), corresponding to the notion of "category" therein.

Table 1
Basic ontological categories of GFO with examples and correspondences with object-oriented (OO) terminology

GFO Category	Examples			OO terminology
Universal	*cf. below, in a universal reading*			Class, Type
Abstract individual	the number two		π	Object, Datatype member
Process	a fall	a walk	an operation	Object
Object	a stone	a human	a patient	Object
Property	a color	a weight	a patient id	(Attribute)
Relation	close to	child of	treated by	Link (Association)

Examples are specified by terms denoting universals of the corresponding categories. OO correspondences are to some extent approximate. Abstract individuals may be modeled as objects or datatype members. Processes and GFO objects are not distinguishable as OO objects, at least in class diagrams. Attribute is related to property because attributes correspond to property universals, and there are no OO counterparts for property individuals. Link and association are specified for relation since relation individuals correspond to links, and associations are OO equivalents of relation universals.

The distinction between individuals and universals can be combined with most other notions, and for readability we either leave it to context or, if necessary, clearly indicate which reading applies. For instance, "apple" allows for two interpretations which are made precise by referring to "apple universal" or "apple individual", respectively.[4] In particular, this indeterminate use of language is sometimes also applied to the term "role", where we assume the existence of role individuals and role universals, a choice discussed in Section 3.1. For *role individual*, the literature provides terms like *qua-individual*, *adjunct instance* or *role* itself; analogously, for *role universal* there are *role type*, *role class*, *role kind*, etc., again including *role* itself.

Continuing with the classification of individuals in GFO based on their relationship to time and space, individuals are further distinguished into *space-time entities*, *concrete individuals* which are in space and/or time, and *abstract individuals* which bear no direct relation to spatial or temporal entities. For instance, numbers fall into this category. For concrete individuals the relation to time yields further distinctions: entities which are extended in time, but not fully present at single *time boundaries* (intuitively speaking, time points) are called *processes*; entities which exist at a single time boundary are *presentials*. GFO provides a specific account of identity over time (cf. Haslanger (2003) and Noonan (2005), Section 5, for a general discussion), which integrates processes, presentials, and *persistants*. The latter are a specific kind of universal capturing the diachronic identity of a number of presentials. Accordingly, with respect to each time boundary, persistants are instantiated at most once. This approach differs from the dyadic distinction between perdurants and endurants. However, for the sake of simplicity, in the sequel we mostly refer to *objects* as entities which fully exist at time boundaries and can persist through time, leaving the more fine-grained distinction of presentials and persistants aside. Objects *participate* in processes and, in a sense, they are contained in processes because the latter are understood as four-dimensional entities occupying space-time. Presentials can be seen as boundaries of processes at particular time points. In object-oriented modeling, an explicit distinction between objects (in the sense mentioned here) and processes is often not available, at least in class diagrams.

[4]The way of using language indeterminately with respect to instantiation is inspired by Genilloud & Wegmann (2000), mentioning that commonly in natural language the same term denotes some instance of a universal or some subuniversal of it. Leaving interpretation to context does not mean that "apple" refers to the disjunction of "apple universal" and "apple individual". Instead, one or both substitutions may be reasonable, but an active interpretation is required by the reader, e.g. to read verbs as relations between individuals, on the one hand, or as relations between universals, on the other.

Two remaining categories of interest for our discussion are *properties* and *relations*, which exist likewise as individuals and universals.[5] Entities have properties, in general denoted by *has-property*, whereas for objects it is more precisely captured by the basic relation of *inherence*. For example, an individual red may inhere in an individual apple. Relations connect several entities, but their account is based on the notion of roles and will be discussed below. Here just note that *relator* is a GFO specific term for relation individuals. Properties and relations are considered as spatially non-extended entities, in philosophical terms they can be understood as tropes and relational tropes, respectively, cf. Bacon (2002). Thinking in OO terms, property universals correspond to (and are typically modeled as) attributes, relation universals to associations, and relators to links.

1.2. Selected literature on roles

Roles are discussed in a plurality of areas. Introductory or review style literature which covers all major areas in equal depth is hardly available. Masolo et al. (2004) contains a short overview of role-related literature which is the broadest in thematic scope we are aware of. In conceptual, data, and object-oriented modeling, Steimann (2000b) has become a kind of standard reference, which also provides links to many approaches.[6]

Our own analysis is also primarily based on computer science literature, much of which is presented in detail in Loebe (2003). The study is further supplemented by some works from the fields of linguistics (Parsons, 1990), sociology (Biddle, 1979), and philosophy (Searle, 1995). Especially in philosophy, we are not aware of genuine accounts of roles. Instead, related aspects appear in discussions of other notions, where one should mention at least relations, tropes, and qua-individuals. For the latter, Masolo, Guizzardi, Vieu, Bottazzi, & Ferrario (2005) provides some introductory discussion in the context of an own account of roles.

For computer science, we name a few selected references from several fields, which are relevant for our analyses. In *Knowledge Representation* and *Knowledge Engineering*, works of Guarino and collaborators (Guarino, 1992; Guarino & Welty, 2001; Masolo et al., 2004, 2005; Guizzardi, 2005, 2006) as well as of Sowa (2000) turn out to be most influential for role analysis. The fields *Conceptual Modeling* and *Object-Oriented Modeling and Programming* have seen a large number of publications concerned with roles, where Steimann (2000b) is a good place to start with. Two approaches which we explicitly take into account are Wieringa, Jonge, & Spruit (1994) and Dahchour, Pirotte, & Zimányi (2004). Some design patterns also refer to role modeling, cf. Gamma, Helm, Johnson, & Vlissides (1994) or the Role-Object Pattern of Bäumer, Riehle, Siberski, & Wulf (2000). Moreover, the field of *Aspect-oriented Programming* is closely related to roles, cf. Hanenberg & Unland (2002) and Herrmann (2005). Another separate branch with respect to the role notions employed is *Agent-Oriented Modeling*, e.g. Wooldridge, Jennings, & Kinny (2000), or with (Kendall, 1999) one which partially draws on the notion of roles in sociology.

Finally, some examples of examined representation languages where roles appear as syntactic elements are the Unified Modeling Language (UML) (Rumbaugh, Jacobson, & Booch, 1999; OMG, 2006), description logics (Baader, Calvanese, McGuinness, Nardi, & Patel-Schneider, 2003), scripts (Schank & Abelson, 1977) and topic maps (Pepper & Moore, 2001).

[5] In the context of GFO, the term "property" is used synonymously with "quality". This is a more narrow reading than another one frequently used in philosophy, where properties also include universals.

[6] For readers of German, Section 3.3 of Steimann (2000a) contains short presentations of many approaches rather then just linking to them.

2. A general approach to roles

2.1. Basic notions

The analysis of the literature, driven by the search for an integrated approach to roles, results in an account of roles which in its most abstract form involves three recurrent, interrelated notions shown in Fig. 1.[7] *Roles* form the central and mediating element of this model, and they require a *player* as well as a *context*. In the following, the relation between players and roles is called *plays* (sometimes also called *fills* or *hasRole* in the literature), that between roles and contexts *role-of*.

Some examples may provide an initial intuition. First, assume that John is a student, a standard example when dealing with roles. The term student refers to a role played by the human being John within a university context, for instance. If, in addition, John works in a company, there he might play the role of an employee. Somewhat less common, when John moves a pen, he can be said to play the role of a mover in the context of the overall movement process. Another example refers to the fact that two is a factor of four. Yet, we argue that factor is a role term whose context is provided by the relationship being a factor of. The number two plays this role in relation to four, whereas four plays the role of a multiple in relation to two. This example may be considered more debatable than others, but in spite of the incompletely resolved ontological status of numbers it is included in order to demonstrate the intended range of applications of our model.

From these examples the question arises which general characterizations can be given for roles. For instance, one may postulate an existential dependence of a role on its player and its context, and provide an axiom of this form:[8]

$$\forall x\big(\text{Role}(x) \leftrightarrow \exists yz(\text{plays}(y,x) \wedge \text{roleOf}(x,z))\big). \tag{1}$$

However, this characterization does not capture the distinction of role individuals and role universals to which we commit (see Section 3.1 for a discussion of this commitment). All three notions of Fig. 1 come in an individual and a universal flavor, e.g. there are context individuals and context universals. We do not introduce new terminology for these two levels in the text or the UML diagrams, but only in the formalization where $\cdot^{\mathcal{U}}$ indicates categories and basic relations on the universal level, $\cdot^{\mathcal{I}}$ those on the individual level. Given this distinction, formula (1) needs to be understood on the individual level:

$$\forall x\big(\text{Role}^{\mathcal{I}}(x) \leftrightarrow \exists yz\big(\text{plays}^{\mathcal{I}}(y,x) \wedge \text{roleOf}^{\mathcal{I}}(x,z)\big)\big). \tag{2}$$

There is a peculiarity regarding players at the universal level, exemplified in the student example by the question of how the universals human being and student are related. Indeed, a human being *can* but *need not* play a student role. Analyzing the notion of player at the universal level thus leads to *player*

Fig. 1. Basic role model. It relates roles with two recurrent notions from the literature: player and context.

[7] All figures except for Fig. 4 use UML notation, cf. Rumbaugh et al. (1999).

[8] We use formulas of standard first-order logic in formalizations, where unary predicates correspond to GFO categories, n-ary predicates to basic relations (for $n \geqslant 2$). Mnemonic predicate names are used without explanation, where obvious.

universals – universals of entities actually playing role individuals – and *natural universals*. The latter are often called type, natural type or natural kind, referring to a universal whose instances can play roles.[9] Frequently, natural universals are universals of entities which are defined with respect to internal aspects, like qualities or their mereotopological structure. It is one of the most salient features of role accounts in computer science to contrast roles with natural universals, in order to express restrictions on the players of certain roles. Put differently, natural universals are a means to refer to potential players of a role. Again, role universals also induce universals of role players, i.e., universals whose instances are *actually* playing a role. If John plays a role of a student, he is considered a player (of the student role). This is not the case for Mary who is not a student. Moreover, the fact that roles *can* but *need not* be played, understood in a temporal or modal reading, is considered as a necessary feature for roles in many approaches. Dynamicity and modality are indeed very common for many roles, nevertheless we believe that they are too restrictive for a general account of roles which shall cover all given examples. Section 3.5 discusses this issue further, whereas we leave it aside before.

The resulting model is depicted in Fig. 2, where :: represents instantiation. The universal-level interpretation of plays and role-of differs from their individual readings. On the universal level, both relations restrict relationships among individuals. In brief, $\text{plays}^{\mathcal{U}}$ links natural universals to role universals for which the former provide potential players. The $\text{roleOf}^{\mathcal{U}}$ relation connects role universals to actual context universals, thus expressing the fact that such context individuals are composed of such role individuals. Formulas (3) and (4) formalize these restrictions:

$$\forall xy\big(\text{Role}^{\mathcal{U}}(x) \wedge \text{Nat}^{\mathcal{U}}(y) \wedge \neg\text{plays}^{\mathcal{U}}(y,x) \rightarrow \neg\exists uv\big(u :: x \wedge v :: y \wedge \text{plays}^{\mathcal{I}}(v,u)\big)\big), \tag{3}$$

$$\forall xy\big(\text{Role}^{\mathcal{U}}(x) \wedge \text{Ctxt}^{\mathcal{U}}(y) \wedge \text{roleOf}^{\mathcal{U}}(x,y) \rightarrow \forall z\big(z :: y \rightarrow \exists u(u :: x \wedge \text{roleOf}^{\mathcal{I}}(u,z))\big)\big). \tag{4}$$

Given some fixed role universal x, formula (4) positively states that every instance z of a context y which is itself linked to x by $\text{roleOf}^{\mathcal{U}}$ must be related to a role instance u of x via $\text{roleOf}^{\mathcal{I}}$. This form is not adequate for the potential character of $\text{plays}^{\mathcal{U}}$, because a natural universal y may be $\text{plays}^{\mathcal{U}}$-related to the role universal x, but instances of y need not play role individuals of x. Thus only a weakened form is used to express the constraint that if y cannot play roles of type x ($\neg\text{plays}^{\mathcal{U}}(y,x)$), then no instance of y plays any role individual instantiating x.

Next we focus on the relations at the individual level. With respect to *role-of*, a context is to be understood as a more comprehensive whole in which a role may be interpreted as a part. Indeed, assuming a very general notion of part-of, one can consider role-of as a specialization of part-of. For certain roles, one can also say that contexts emerge from the existence of the roles. Hence, in some cases, a mutual existential dependence of roles and contexts applies. As yet we cannot illustrate this by the above examples because this requires a better understanding of the ontological nature of the contexts. The examples indicate that the nature of contexts can be very diverse, e.g. the context can be a *relation* as in the two–four example, or a *process* as in the mover example.

For the *plays* relation the situation is even less clear in this general setting. We hold that no uniform account can be given like in the case of role-of, apart from mentioning that players are "determined" by roles but not vice versa. That means, role individuals contribute to the characterization of their players in

[9] There are several terms in the literature which are more or less synonymous, e.g. *natural type* (Guarino, 1992), *natural kind* (Wilkerson, 1995), *phenomenon* (Sowa, 2000, p. 80), *base classifier* in UML (Rumbaugh et al., 1999, p. 194 ff.), *basic concept* in Kozaki, Kitamura, Ikeda, & Mizoguchi (2002) and Sunagawa, Kozaki, Kitamura, & Mizoguchi (2005), or *object class* like in Dahchour et al. (2004).

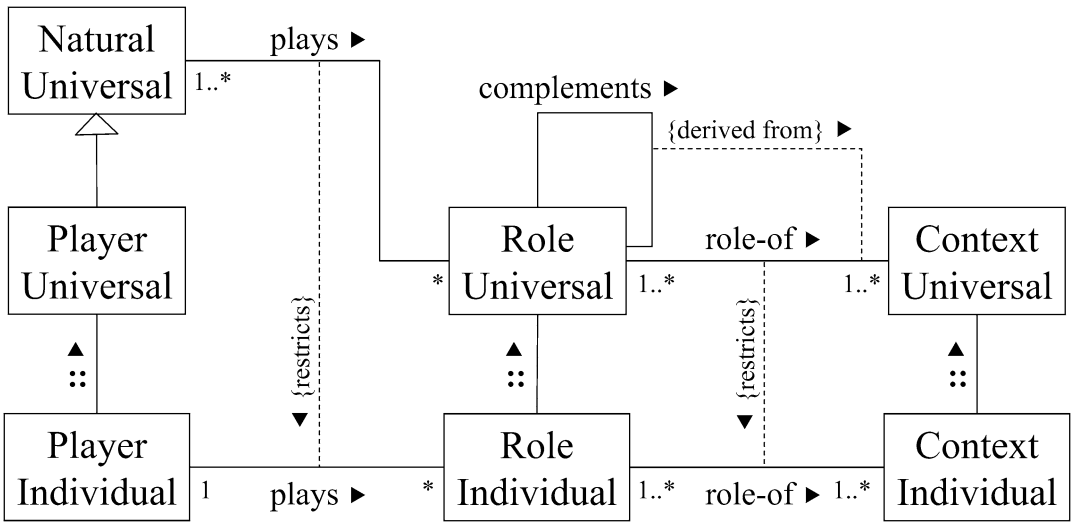

Fig. 2. Extended role model. This captures the primary entities of the framework, distinguishing them as individuals and universals. The symbol :: represents instantiation.

a similar way as properties to their bearers. In contrast, in order to comprehend a specific role individual r one must primarily understand the universals that r instantiates and the context of r, whereas knowing the player of r does not contribute much.

In order to gain a better understanding of the plays relation and the role-of relation with respect to individuals, we examine types of roles and consider their integration with hindsight.

2.2. Role types

The first question concerning the classification of roles is whether players, contexts, or both should form the basis for the classification. Following the literature, the relationship between roles and players generally appears as a rather loose one, exemplified by criteria like "Objects of unrelated types can play the same role" (Steimann, 2000b). In contrast, due to the characterization of roles as part-like with respect to their contexts, it appears reasonable to classify roles by a reflection of these context categories. Regarding the literature, speaking abstractly of contexts appears to be a rather novel aspect of our approach, since most formalisms explicitly or implicitly refer to only one of the following role types or do not supply an integrated view on their role notions. An exception to this is Sunagawa et al. (2005), cf. p. 138, which speaks likewise of roles and contexts and advocates the same idea of organizing roles by means of their contexts, see Section 3.3.

For our classification of roles we consider top-level ontological categories into which contexts may fall. Studying the literature we have found that contexts of roles belong to the categories of relations, processes, and (social) objects, all of which can formally be understood as categories in the General Formal Ontology (GFO). Accordingly, three role types can be defined informally as follows:

- *relational role*: corresponds to the way in which an argument participates in some relation;
- *processual role*: corresponds to the manner in which a single participant behaves in some process;
- *social role*: corresponds to the involvement of a social object within some society.

Let us first sort the examples with respect to these types. Two as a factor of four refers to a relationship, hence factor is considered a relational role universal, whereas John's moving some pen is categorized as

a process, hence mover turns out to be a processual role universal, equal to the moved. Finally, student should be classified as a social role universal because the context is provided by some (university) society.

The presented classification is not expected to be complete since new kinds of entities may prove to be contexts for new types of roles. Moreover, this classification is based on the categories provided by GFO, which yields more general types compared to those presented in Sunagawa et al. (2005), e.g. action context role and task context role. That means, we expect that their role types are subsumed by ours, e.g. the named types by the notion of processual roles. Given these qualifications regarding completeness, the detailed discussion of our role types starts with contexts being relations.

2.2.1. Relational roles

For relational roles, it is important to note the affinity of relations and properties. Intuitively speaking, relations may be understood as properties which apply to more than one entity. Accordingly, relational roles are special properties, and the *plays* relationship between entities and relational roles is thus subsumed by the has-property relation of GFO, which for objects corresponds to inherence:[10]

$$\forall xy\big(\text{Ent}^{\mathcal{I}}(x) \wedge \text{RelRole}^{\mathcal{I}}(y) \rightarrow \big(\text{plays}^{\mathcal{I}}(x,y) \leftrightarrow \text{hasProperty}^{\mathcal{I}}(x,y)\big)\big), \tag{5}$$

$$\forall xy\big(\text{Obj}^{\mathcal{I}}(x) \wedge \text{RelRole}^{\mathcal{I}}(y) \rightarrow \big(\text{plays}^{\mathcal{I}}(x,y) \leftrightarrow \text{inh}^{\mathcal{I}}(y,x)\big)\big). \tag{6}$$

These subsumptions imply the existential dependence of relational roles on their players, as required above. Moreover, the *non-migration principle* which applies to properties therefore applies to relational roles as well:

$$\forall xyz\big(\text{RelRole}^{\mathcal{I}}(y) \wedge \text{plays}^{\mathcal{I}}(x,y) \wedge \text{plays}^{\mathcal{I}}(z,y) \rightarrow x = z\big). \tag{7}$$

The distinctive feature of relational roles compared to "usual" properties like weight or age is an additional dependence on "complementary" relational roles.[11] Assume, for example, that John is medically treated by Sue, i.e., there is a relator (a relation individual) connecting John and Sue such that John plays the role of the patient and Sue that of the attending physician. Here, the particular patient role of John and the physician role of Sue are interdependent, and either is dependent on its player. By means of role-of these two roles form a relator which connects John and Sue.[12]

The view of *role-of* as subsumed by a general notion of part-of may appear debatable in particular for relational roles and relators, due to the question of what a part of a relator should be. We consider relational roles as homogeneous, "indivisible" entities which form "atomic" parts of relators. Moreover, we conjecture that relators are mereologically extensional with respect to their roles. Speaking of parts of relators may seem even more counter-intuitive if abstract relations are considered, like in the above two–four example. Here, the factor role individual of two together with the multiple role individual of

[10] More precisely, the inverse of the plays relation is subsumed by inherence, because it refers to the property in its first argument, whereas plays does so in the second.

[11] The *complements* relation on the individual level as referred to here is not shown in Fig. 2 for the sake of clarity. The universal level reading is discussed in Section 3.9.

[12] It should be stressed once more that here we refer to role individuals, even in phrases like "patient role of John". Actually, the term "patient" refers to a role universal. However, in English there are no common means to refer to role individuals directly, i.e., they can only be described by phrases like above. This is similar for individual properties, as well.

four form a particular relator between two and four. Moreover, the factor role individual of two with respect to eight is different from the role individual of two with respect to four.

In spite of this possibly uncommon view, relational roles have definitely found their place in modeling and representation, and there they exhibit the character of parts with relations as their wholes, cf. role-names and association ends as parts of associations in UML (Rumbaugh et al., 1999, p. 414), roles in the associations of Topic Maps (Pepper & Moore, 2001), and rolesets in the Common Logic effort (ISO/IEC JTC 1/SC 32, 2006). Again, our understanding of relations is similar to that in the aforementioned modeling languages. Relations connect arbitrary entities and appear fairly unstructured themselves, apart from their roles. They can be used to close analyses at a level of detail considered appropriate. For instance, one may refer to a patient-of relation in order to avoid detailed modeling of a patient as a social object (cf. also social roles below and Section 2.4). Accordingly, it seems that the term relational role is to some extent used differently in Guizzardi (2005) and Masolo et al. (2005, 2004), in our terms possibly a mixture of relational and social roles. For example, this impression arises from the fact that Masolo et al. (2005) speaks of attributes of roles which would be more applicable to the notion of social role herein, see Sections 2.2.3 and 3.4.

2.2.2. Processual roles

This type of roles derives from processes, which supply the context for processual roles as in the case of the mover example. Here, *role-of* is more convincingly seen as a special part-of relation than for relational roles. In contrast to *temporal* parts of processes, processual roles "slice" processes with respect to the dimension of participants. When John moves his pen, he and the pen form participants of that process, and the processual role which John plays captures what John does in that participation. Thinking of a mime who moves an imaginary pen should be a good illustration of the notion of a processual role.

Since their contexts are processes, processual roles are parts of processes and therefore processes themselves. There is a mutual interdependence among all processual roles of a process (e.g., the mover and the moved from above). This in turn yields a distinction among processes such that independent and dependent processes exist, and an independent process p can be split into interdependent processes $q_1, \ldots, q_n$ – its processual roles – based on the participants of p.

For processual roles, the *plays* relationship is subsumed by *participation*, $\text{partic}^{\mathcal{I}}(x, y)$:

$$\forall xy\big(\text{Obj}^{\mathcal{I}}(x) \wedge \text{ProcRole}^{\mathcal{I}}(y) \wedge \text{plays}^{\mathcal{I}}(x, y) \rightarrow \text{partic}^{\mathcal{I}}(x, y)\big). \tag{8}$$

It is specific for an object x playing a processual role y that at any instant of time one will find exactly one and the same object x as the only participant of y.[13] Furthermore, participation of some object in arbitrary processes is intimately tied to the processual roles of those processes:

$$\forall xy\big(\text{partic}^{\mathcal{I}}(x, y) \leftrightarrow \exists z\big(\text{ProcRole}^{\mathcal{I}}(z) \wedge \text{plays}^{\mathcal{I}}(x, z) \wedge \text{roleOf}^{\mathcal{I}}(z, y)\big)\big). \tag{9}$$

Processual roles should not be confused with any means of viewing their players. For instance, if we look at the processual role played by John when moving a pen, this is not to be understood as referring to some kind of view on John which selects properties relevant for that process, like some strength, abilities, or others. Such a view on John is possible, yet it is based on a different relationship to the process which does not fit the part-of reading of the relation between a role and its context. Moreover, it seems

[13] This uniqueness ignores granularity issues of processes and processual roles, which remain to be studied in the future.

that processual role individuals are primarily dependent on their players rather than on their contexts, because in a sense these roles are "defined" by their players. However, specifications of processual role universals refer to the appropriate context universal rather than to any natural universal actual players may fall into.

2.2.3. Social roles

Social roles are the third type of roles identified from the literature. Regarding the *plays* relation, applied to social roles, two options are typically discussed. One is instantiation, reading "John is a student" as "John is an instance of the universal student". However, in that case the notions of role universal and player universal would collapse. At this point, we simply reject this option and refer to the discussions in Sections 3.1 and 3.2. Instead, we advocate that a genuine notion of playing a social role is required, which is vaguely similar to inherence but viewing roles as "complex properties". What is further relevant here is the fact that social roles are often defined with their own properties, relations and processes in which they (may) participate, cf. Steimann (2000b). Further support of this view can be found in philosophical positions on social reality and ontological levels, cf. Searle (1995) and Poli (2001). According to Searle, material objects serve as the foundation for social objects, however, a social object is different in that a new status-function is imposed on the material object. The locution "X counts as Y (in context C)" is introduced to explain this connection. We adopt this view by reading "counts as" as our plays relation (denoted by plays_{soc}) and "in context" as role-of (role-of_{soc}).

The theory of ontological levels as advanced by Poli provides another underpinning to social roles (Poli, 2001, 2002). We cannot introduce the complete idea of ontological levels in detail here, but roughly speaking, several levels of entities are assumed, among which specific forms of categorial and existential dependence exist. Ontological levels introduce an orthogonal dimension for ontologies compared to common category hierarchies like GFO. Three coarse-grained levels – called strata – are the material, the mental, and the social stratum. The plays relation for social roles appears to span from the material to the social stratum. However, it seems that social roles cannot be tackled by ontological levels only, e.g. due to the fact that the notion of natural universals in the sense of Guarino & Welty (2001) or Wilkerson (1995) is broader than just capturing entities of the material level. *Customer* is a good example in this connection, since not only (material-level) humans can be customers, but also (social-level) companies.

Social roles appear to be the least understood role type in our model. For instance, switching to *role-of*, we must admit that contexts remain fairly obscure for social roles. Searching for better examples than a "university society" as the context for students proves to be hard. Currently, we stick to the phrase "belonging to a (social) context" for role-of in the social case, which others have also referred to as *patterns of relationships*, cf. Sowa (2000), Masolo et al. (2004) and Section 3.3. Organizations or institutions are a tempting alternative to explain contexts, e.g. proposed in Colman & Han (2007), but this may turn out to be too restrictive in a general approach, thinking of examples like pedestrian. Social descriptions have been proposed as another alternative in Masolo et al. (2004) and Bottazzi & Ferrario (2005), seemingly linked to the notion of a *meta-physical context*, which is described as "a theory that provides definitions of concepts, to be used as a background for the interpretation of certain states of affairs" (Masolo et al., 2004, p. 270). Although this route of analysis may prove fruitful in general, most examples of social descriptions as contexts provided by the authors, like the Italian constitution, fail to satisfy the part-of reading between roles and their contexts. In general, we expect that social roles must be treated within a comprehensive ontology for the social stratum. First steps are made in this direction, cf. Searle (1995) and Bottazzi, Catenacci, Gangemi, & Lehmann (2006), but many problems have not yet been resolved.

2.3. Abstract roles vs. social roles

The analysis up to this point is summarized in Table 2. The table is arranged according to the basic player–role–context model from Fig. 1, hence the relevant role type for each line is contained in the central column.

There are some differences in aligning social roles with the general model of roles, players, and contexts in the same way as compared to relational and processual roles. The contexts of social roles are much harder to grasp, and the overall introduction of these roles depends on the distinction of ontological levels (or something similar), which is not the case for relational and processual roles. This indicates that social roles may have a different status.

Due to their similarity, relational and processual roles are subsumed by a role type called *abstract roles* which is contrasted with social roles. Abstract roles can be functionally characterized in a uniform manner, namely as a mechanism of viewing some entity – namely the player – in a defined context, i.e., in a more complex entity with interrelated other "notional components". Put differently, players of abstract roles are looked at in an *external* manner in contrast to viewing them as self-contained entities focusing on their *internals* like their properties or parts.

This general reading of abstract roles is contrasted with *social roles*, which capture certain individual objects on a social ontological level, hence exhibiting a dependence on other objects (frequently, but not exclusively from the material level) which "count as" (Searle, 1995) something else.[14] Due to being objects, social roles have their own properties, relations, and processes in which they participate. Relations and processes seem to be of prior relevance for social roles, which is also argued for in Searle (1995), p. 58 ff. In a sociological, role-theoretic understanding, roles are even identified with "patterns of behavior", cf. Biddle (1979). Viewing a patient as a social role, i.e., as a social object with possibly some assignments in the form of rights, norms or duties makes it hard to determine clear complements as compared to relational roles in a patient–physician relation, for instance. Indeed, social roles rather aggregate various relational and processual roles. Accordingly, for an understanding of social roles, the context becomes rather vague and implicit, and the focus shifts to the internals of social roles as well as to their relations to players, cf. also Colman & Han (2007).

Regarding the considerations in this section, Fig. 3 shows the hierarchy of role types in our framework. Despite the differences among the specific types, Fig. 2 can be applied to each of them. That means, for relational roles exist player, role and context individuals as well as universals just as is the case for processual and social roles. In a sense, this general characterization which covers all roles is fairly minimal. However, encouraged by the diverging ontological categories of contexts, we believe that it will be hard to find further commonalities, especially between abstract and social roles. It may thus be

Table 2
Summary of restrictions of player and context categories based on role types

Player	Plays	Role	Role-of	Context
Entity	plays	Role	role-of	Entity
Entity	has-property	Relational role	part-of	Relator
Persistant	partic	Processual role	part-of	Process
Object	plays_{soc}	Social role	role-of_{soc}	Social individual

[14] Note that in addition to objects, "counts as" seems to be applicable at least to processes. However, as indicated in Table 2, we argue that social role terms exclusively apply to objects, whereas the case of processes requires further analysis.

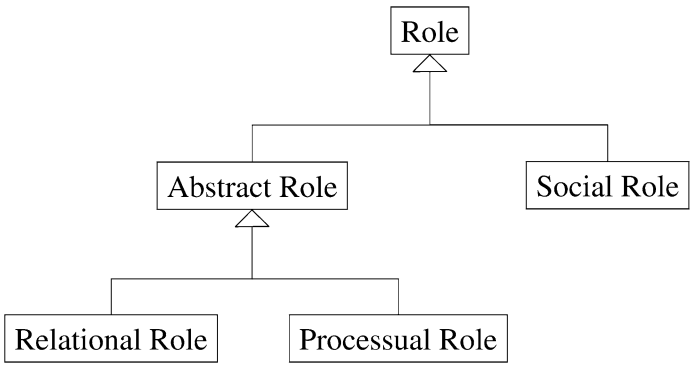

Fig. 3. Types of roles.

difficult to add much more to a general theory of roles, at least as long as a similarly broad range of examples is to be covered.

2.4. A comprehensive example

Figure 4 illustrates an analysis in the domain of clinical trials in terms of our role model. The situation can be described as follows:

> John is a patient in the clinical trial CLL9. He has the patient identifier 1054B32 and is treated within the trial by the physician Sue.

The primary organization of the figure corresponds to the distinctions between individuals and universals (vertically separated along the instantiation symbols ::) and between material and social entities (horizontally, sue is the right-most material entity). On the lower left-hand side, John and Sue are represented as individual humans john and sue.

Next, consider the term "patient", which is understood as a social role universal here, instantiated by patient john. The latter exhibits a property – 1054B32, approximated as an instance of the universal Patient ID.[15] In a sense, representing patient as a social role instead of a relational role is a modeling decision. The other option had been to model patient as a relational role in some relation to the clinical trial. This would have been appropriate in order to stop the analysis, but here patient as well as clinical trial are to be further analyzed.

The context for the social role patient john is provided by cll9 which instantiates Clinical Trial (Context), a social object universal. cll9 is very closely related to the actual trial process (the unnamed instance of Clinical Trial), but it is not considered the same herein. Rather, that context object appears to emerge from the interaction of people involved in planning and execution of the trial, and it does not have that outstandingly temporal nature of the trial process. The trial process itself is a social process with a material reflection. We are not aware of a suitable, compact term for this type of entity, therefore an instantiation of an unnamed universal is depicted for this reflection process (a line to the trial process is omitted). joe and sue participate in that process (on the material level), hence it serves as a context of processual roles for each of them (the processual role of sue is not shown due to space constraints).

[15]This example is chosen since it is common in modeling and due to our lack of a convincing non-relational social property, and it is described in this way for simplicity. Clearly, a proper ontological analysis of IDs will involve much more, e.g. symbols and denotation. We decided for the simplification, however, in order to not distract from the purpose of the overall example.

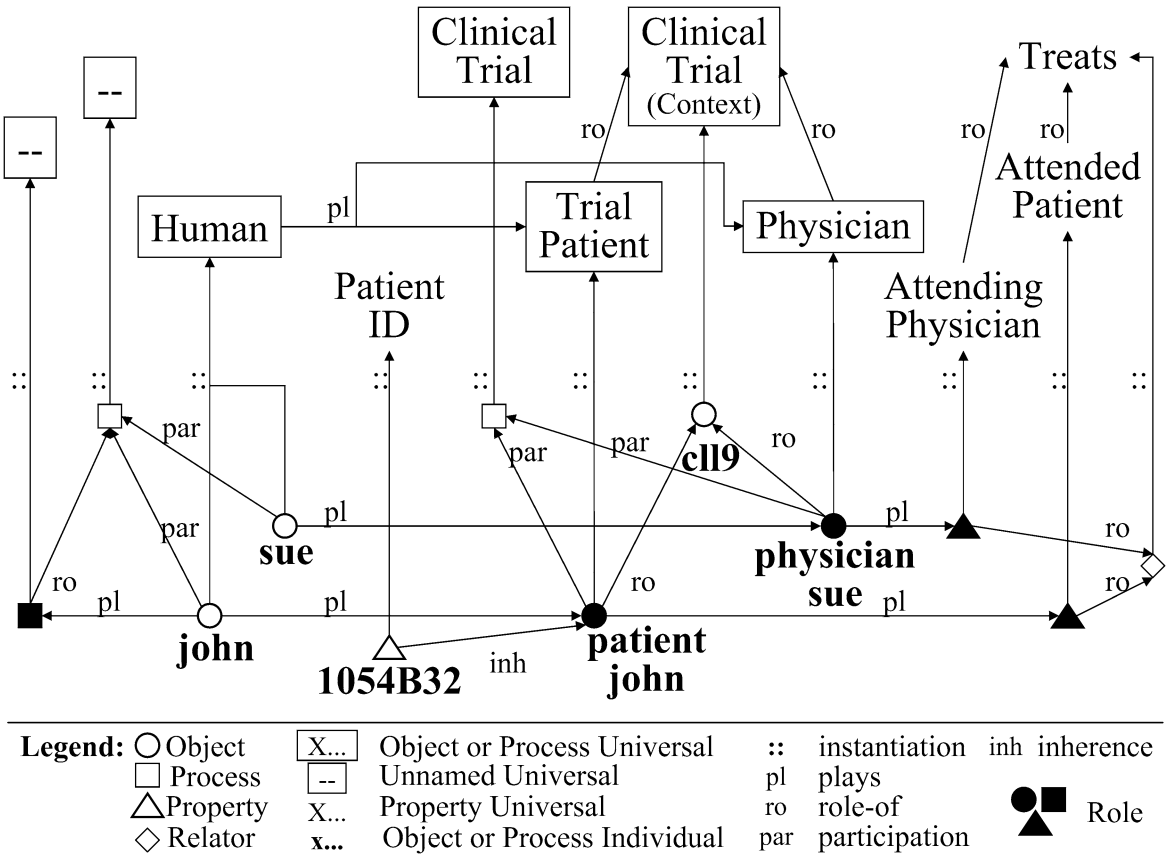

Fig. 4. A comprehensive example involving roles of all types. It represents an analysis of a situation described as: "John is a patient in the clinical trial CLL9. He has the patient identifier 1054B32 and is treated within the trial by the physician Sue.".

Sue also plays a social role, because for the physician sue the same arguments apply as for patient john above. In contrast, the fact that Sue treats John is not further analyzed and thus modeled as a Treats relator with two relational roles. In addition to the individual level interconnections, several constraints are expressed by means of universal-level plays and role-of connections. In this simple example it can easily be verified that the individual level satisfies all of them.

This example demonstrates two aspects of our role account. On the one hand, it provides various distinctions which allow for fine-grained analyses, even if some ontological problems remain, like the interrelation of Clinical Trial and Clinical Trial (Context). On the other hand, it is hardly directly applicable as such to modeling. Support for the presented distinctions within representation mechanisms is required for this, either directly, e.g. by extending UML with stereotypes as in Guizzardi (2005), or by offering formalisms which can hide very fine distinctions, e.g. between social roles and their players, but which resolve them based on the structure of expressions, for instance. The notions presented in the next section may initially contribute to this.

2.5. Role holder and role closure

The distinction between roles (e.g. patient) and their players (e.g. man) results in a lack of an integrated view on entities which combine material and social properties. However, the latter are common

in conceptual modeling, to some extent due to handling roles implicitly.

Sunagawa et al. (2005) presents the notion of a *role holder* which bridges this gap. Intuitively speaking and in terms of our model, a role holder can be understood as the combination of a natural universal and one of its assigned role universals.[16] We illustrate the idea for social roles in an object-oriented setting. Class M models a natural universal man with certain attributes $a_1, \ldots, a_k$, and class P models a social role universal patient with attributes $a_{k+1}, \ldots, a_n$. The idea of a role holder provides the modeler with a construct which has the attributes $a_1, \ldots, a_n$. Thus, the modeler can use arbitrary attributes and attribute combinations without paying attention to addressing the role or the player.

The notion of role holder can easily be re-discovered in our model, even from an ontological perspective. Moreover, we generalize this notion in our framework in a principled way, resulting in the notion of *role closure*.

Firstly, there are interpretations on the individual and the universal level, because in addition to the universal level approach of Sunagawa et al. (2005), one may also consider combinations of a player individual and a role individual, like a combination of John and his particular patient role. Secondly, instead of restricting to a single role, on the individual level one may consider the combination of a player and *all* of its roles. For instance, one can look at John (as a player) in combination with all of his roles, e.g. including being patient in two different hospitals, being an employer of some house maid, being a husband, and so forth. Indeed, this combined entity may be understood as a configuration in GFO, and it may be an even better understanding of "John" than the one considering John as a human being only, because for the former the roles of John appear like properties of John. We call this kind of entity *role closure*. Note that lifting this construction to the universal level does not appear reasonable, because the result would be a combination of a natural universal and all role universals it may provide players for. As yet, we do not see any use case for this kind of construction.

Next it is instructive to study each specific role type with regard to the notions of role closures and role holders, in order to determine the underlying ontological entities. Applied to *relational roles*, the role closure of some player actually collapses with that very player, because the plays relation corresponds to has-property, which is an "internal" relation. For example, assume that some relational role individual r is played by an object x. The object x itself comprises a number of internal entities, especially all its parts and inherent properties. Hence it already includes r, and the above construction of role closure does not add anything to x. Likewise, the role holder boils down to a single "internal" fact of x, namely that it is playing the relational role r. Therefore, for relational roles these notions are no extension to our model.

For *processual roles*, it is not clear to what extent it should be useful to consider a complex of some object and all processual roles of it, for instance, complexes of John breathing, sitting on a chair, and reading a book (concurrently, and even less clearly at different times).[17] The same applies to the notion of role holder.

Again, *social roles* make a difference because they are objects like their players, yet different from them, and both come equipped with a set of own properties and behavior. The latter is also an assumption taken in Sunagawa et al. (2005). Under these circumstances, considering a role holder is of interest on

[16] Sunagawa et al. (2005) do not consider role individuals distinct from player individuals, but refer to roles as a kind of universals. Further, some of the textual descriptions in Sunagawa et al. (2005) sound as if by "role holder" they are referring to player universals rather than to the notion of role holder adopted here, e.g. in "By a role holder, we just mean that the instance is playing a role.". However, other places suggest the reading as dealt with in this section, see the aspects on properties below.

[17] It seems that without involving different levels of (part-of) granularity in viewing these processes, it is hard to differentiate these roles on the individual level.

the universal level, whereas the role closure is highly reasonable on the individual level, in the sense as discussed above, exemplified by John playing patient, employer, and husband roles. If each of these are considered to be social roles, on the one hand they act as objects with own properties, on the other hand they act as determiners for the role closure entity, like "complex properties". As such, role closures form a useful extension of our previous role model, in that they allow for an integrated view on objects involving several ontological levels (Poli, 2001).

Interestingly, role holder universals are created by inheritance in OO generalization hierarchies where natural universals and social role universals are not separated. Returning to the example with classes M and P from above, if P specializes M and there is attribute inheritance, within P and for its instances all attributes $a_1, \ldots, a_n$ are accessible. Guizzardi (2006) presents another ontologically founded approach to account for this, see also Section 3.8.

Finally, one difference with the view of Sunagawa et al. (2005) remains, namely that roles and players may share properties. Referring to an example in (ibid.), teacher and human may each be characterized by a name, but an instance of human playing the role of a teacher has a single name property. We object to this view on the individual level, i.e., one and the same name property cannot belong to both the player and the role individual.

3. Role features and issues

This section provides further explanations of the approach proposed in Section 2 and relates it to previous work by focusing on commonly discussed features and problems of roles. In particular, we refer to the feature lists of Steimann (2000b) and Masolo et al. (2004). The following issues are dealt with (numbers in brackets refer to the criteria in Steimann (2000b), where applicable):

1. *Roles as individuals vs. roles as universals* [1,14,15]
   Do role individuals exist or are roles a specific kind of universals?
   This discussion includes a treatment of the *counting problem* (Gupta, 1980; Wieringa et al., 1994; Guizzardi, 2006).
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 child and son?
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?

3.1. Roles as individuals vs. roles as universals

This appears to be one of the most frequent issues in role-related literature, with two options. (1) One may assume role individuals and role universals, which is the view assumed in the previous section. (2) "Role" can be understood as a term for a certain kind of universals, without admitting instances of roles which are different from their players, i.e., the plays relation coincides with instantiation, and the categories of player and role in Fig. 2 collapse.

Conceptually, these options are mutually exclusive and one of them should be chosen. For relational and processual roles the first option results from the categories providing contexts, because relators and processes are individuals. For social roles, one observes that recent object-oriented works directly advocate the first option from above (Dahchour et al., 2004), whereas in knowledge representation, Guarino and colleagues (Guarino, 1992; Masolo et al., 2004, 2005) clearly promote the second option, which may also be attributed to Sowa (2000), p. 81.[18] However, Masolo et al. (2004, 2005) concede that it may be useful to consider individuals which they call *qua-individuals* and which seem to correspond to role individuals (see also Section 3.11). Moreover, Guizzardi (2005, 2006) attempts a harmonization of the two options for relational roles. Accordingly, the existence of role individuals (or "equivalent" but differently named entities) appears to become accepted.

Studying the underlying reasons, there are situations which can be better modeled or even necessitate that role individuals are at hand which differ from player individuals. For instance, they are required in connection with *multiple instantiation*, as discussed with respect to multiplicity issues in Section 3.7. Role individuals further allow for a solution of the famous *counting problem* (Gupta, 1980; Wieringa et al., 1994; Guizzardi, 2006). The problem refers to an appropriate understanding of a combination of sentences like the following:

1. Bus provider X serves 1000 passengers per week.
2. Every passenger is a person.
3. Bus provider X serves 200 persons per week.

If sentence 2 is taken literally and passenger is interpreted in one and the same way in sentences 1 and 2, a conflict arises from the combination of all three sentences. The solution we can propose in the given framework interprets passenger in the first sentence as a role universal Q, passenger in the second sentence as Q's corresponding player universal P. Thus, the apparent conflict disappears if it is possible

[18] Sowa's hierarchies of categories also suggest the first option (ibid., p. 87 and 502 ff.), such that it is not completely clear to us which option Sowa advocates.

to count individuals instantiating Q.[19] This solution is basically analogous to those given in Masolo et al. (2005), Guizzardi (2005), and in agreement with these works we are not aware of a solution which works without individuals of Q.

The counting problem illustrates that disambiguation of natural language statements involves ontological assumptions, like the one of role individuals and role universals, which have an impact on appropriate interpretations. For example, for roles it is often required that "different entities can play the same role", which can be read meaningfully in at least three ways in our account of roles:

(1) "different entity individuals can play different role individuals of the same role universal";
(2) "different natural universals provide players for the same role universal";
(3) "different entity individuals can play the same role individual".

A fourth reading applies if role individuals are rejected, roles are considered as types of universals, and plays means instantiation, stated in 4 directly and rephrased in our terms in 5:

(4) "different entity individuals can instantiate the same role";
(5) "different entity individuals can instantiate the same player universal".

In our theory, the fifth reading is a weakening of the first and the third one above, because both involve plays links to role individuals, which instantiate a role universal. Hence, instantiation of the corresponding player universal is implied. In Section 3.7 we discuss that all these interpretations are admissible in our model.

One drawback of role individuals is a multiplication of entities (cf. Masolo et al. (2004), p. 276), i.e., that apart from John there are further entities, like the role(s) of John as a student, or even more entities if role holders and other combinations of players and roles are taken into account (cf. Section 2.5). However, we consider this conceptually appropriate and would prefer to tackle the arising complexity by "intelligent" representation formalisms. Ideas for this may be drawn from the common use of natural language terms for both role universals as well as the player universals which they induce, like the subuniversal of humans presently playing a student role. For instance, the term student in the phrase "all students should now leave the room" needs to be understood as a player universal, whereas "all students have a registration number" refers to the corresponding social role universal. If we generalize this example and move to object-oriented role models, bi-directional *delegation* mechanisms (Dahchour et al., 2004) appear conceptually more appropriate than uni-directional ones. In brief, delegation is a method by which objects or roles can forward messages (method calls) to their corresponding roles or objects, respectively. Uni-directional delegation typically restricts forwarding from roles towards objects, but as argued above, at least natural language usage suggests a need for both directions.

In summary, an approach which comprises (equivalents of) role individuals and role universals appears more adequate to us than one limited to role universals alone, and it is recently becoming more accepted in the literature.

3.2. Role identity

An issue from the object-oriented field which is closely related to the previous section is whether there is *role identity* in addition to object identity (Steimann, 2000b), i.e., do roles carry their own identity?

[19] We have not yet specified a particular type of role for Q. Depending on the underlying definitions of passenger, one may choose social roles for referring to an institutionalized reading of passenger, or processual roles for counting transportation events. In the latter case, and in addition referring to social passenger roles, one may count social roles playing processual ones (on the social level) or one may count material entities (on the material level).

Advocating role individuals implies the acceptance of role identity for abstract roles, because entities of different basic categories cannot be claimed to have a common identity. Furthermore, we consider the choice of role identity more adequate for social roles, as well. For example, someone studying twice at the same university with a long break in between will formally be a different student than the first time (e.g. identifiable by a different registration number). Thus, in general, different identity criteria apply to roles and their players.[20] However, the notion of role closure may be used to provide a unified view, where one may define identity with respect to a complex of one player and its roles. That would be similar to the claim of role identity being a "non-issue" in Herrmann (2005). Herrmann states that, literally, a player and its roles are mutually distinguishable, but that it would be conceptually adequate to have a comparison operator which does not distinguish a player from its roles. In our terms, this corresponds to providing a purely player-based identity criterion for the role closure.

3.3. Dependence, relational nature of roles, and contexts

The dependent character of roles is commonly agreed upon in the literature. In this connection, dependence usually refers to some other entity than the player. A problem we see is the interpretation of the kind of entities that appear in various approaches to account for this dependence, which further results in role individuals instantiating very different categories. Of course, in our approach *context* is employed to express this form of dependence, which is rather a theory-internal label for these entities (see also Section 3.12). In particular, we see no adequate use of existing theories of context to account for this dependence comprehensively, cf. Akman & Surav (1996), Bouquet, Ghidini, Giunchiglia, & Blanzieri (2003), Serafini & Bouquet (2004) and the use of metaphysical context in Masolo et al. (2004). Instead, our classification of roles indicates that there is no single kind of roles, and no unique kind of entities on which roles depend. Steimann (2007) also acknowledges that not all roles are of social character. Sunagawa et al. (2005) is the only account of roles we are aware of which explicitly makes a similar distinction of contexts (and of the role-of relation, for which the authors introduce "part-of" and "participate-in").

Frequently, one meets phrases involving "relation", a "relational character", or "patterns of relationships" to address the dependence of roles, cf. Sowa (2000), Guarino (1992), Masolo et al. (2004), Kozaki et al. (2002). This is adequate as long as relations themselves have an equally abstract meaning as our context. However, if they are distinguished from other ontological categories like in GFO, we believe that the relation-based definition is invalidated, because it then coincides with our relational roles, no longer covering the other types.

Another route to a stronger theory of contexts could be to reduce certain types of roles to others. Relations and relational roles may appear suitable in this respect, possibly because potentially every entity can further be analyzed, requiring relations to connect its "constituents". This would only be acceptable if a comprehensive reduction of a basic category to another were attainable, for example reducing processes to relations. Such a reduction would then include processual roles as well; however, those issues are far beyond the scope of this paper.

3.4. Roles come with own properties and behavior

The commonly stated feature of roles having own properties and behavior is primarily integrated into our account of social roles. In particular, social roles may participate in processes at the social

[20] Certainly, in many cases identity criteria of roles are coupled with those of their players. For instance, a registration number may be reused within the same university, yet reuse creates different student roles based on distinct players.

ontological stratum and they may exhibit intrinsic, non-relational properties. At first glance, this seems to lose the contextuality of such properties, thinking of patient IDs with respect to distinct hospitals. However, each hospital forms a different social context and creates its own patient role individuals. In general, the context for intrinsic properties of social roles can be gained from these roles, such that the properties themselves are contextual only in a derived sense.

Considering relational and processual roles, we see no immediate use cases of properties for these. In principle, GFO allows for properties of properties as well as of processes, and thus implicitly for properties of relational and processual roles. However, "own behavior" is not applicable for processual roles because they are processes themselves. As mentioned earlier, one must distinguish a processual role from the view on some object playing that processual role, where the view carves out properties of the object with an influence on its behavior in the process.

3.5. Dynamicity and anti-rigidity

The dynamic and modal character of roles appears commonly accepted, cf. criteria 4, 5 and 9 in Steimann (2000b) or Masolo et al. (2004). Dynamicity here refers to the idea that entities can acquire or lose roles during their lifetime. As such, this feature can only apply to objects which are in time and persist. For instance, the number two cannot acquire or lose its role of being a factor of four, because it is atemporal. For persisting entities, this criterion applies to all roles types. That means, players may enter or lose relations, start or stop to participate in processes, and adopt or drop some social role. Such changes can be modeled in GFO similarly to changes of properties, for example, based on the GFO account of persistence (Herre et al., 2006) which cannot be presented in detail here.

In addition to dependence, Nicola Guarino has proposed *anti-rigidity* as a criterion in order to distinguish role universals from other kinds of universals (Guarino & Welty, 2001), which may be understood as an extension of dynamicity towards a modal account. A universal U is rigid if for each of its instances it is essential to instantiate U. It is anti-rigid if for each of its instances it is not essential to be an instance of U.[21] For example, it is not necessary for any human to be a patient or a student – even in the case that someone is a patient from birth on due to some chronic illness. Now, literally, role universals as proposed here are not anti-rigid, because role universals refer to different individuals compared to the players of roles. However, the definition of anti-rigidity can be applied to player universals. Accordingly, player universals may be anti-rigid, whereas natural universals are usually rigid. Therefore, anti-rigidity is still applicable in our approach, in a derived sense.

However, if anti-rigidity is seen as a necessary condition for roles (players), in our opinion there are a few cases where this rules out certain roles. The role child should be an illuminating example, understood as someone who was born by a human.[22] According to this definition each human is necessarily a child. In the case of processual roles, one may also find processes for which it is necessary for certain individuals of natural universals to participate in, for instance breathing for humans. The above example of two being a factor of four is another case – of course, only if factor is accepted as a role on an intuitive basis. We argue that these examples refer to roles, because there is an intuitive difference between a human and a child, or a number and a factor – the latter are dependent on at least a player and a context (which are distinct), whereas the former appear independent in this respect. Steimann (2005), p. 133, seems to account for this as well by stating that "[...] all [OO] objects play roles whenever they

[21] Note that anti-rigidity is a proper specialization of the negation of rigidity. Moreover, for a recent elaboration of rigidity the reader is referred to Welty & Andersen (2005).

[22] We consider the definition of child as a human aged under 18 as a different concept.

participate in relationships [...]", assuming an unrestricted view on relations, including atemporal and essential relations.

In spite of these arguments, dynamicity and modality are very important features of many roles in general, and possibly of all social roles in particular. They influence applications, cf. calls for dynamic classification of OO objects, etc., and must therefore be analyzed further. Anti-rigidity is clearly a good test for determining whether some notion is a role, because it provides a hint if anti-rigidity is satisfied. Nevertheless, there are roles – entities with specific dual dependences – which do not satisfy anti-rigidity, but should be accounted for ontologically.

3.6. Role-playing roles

"Roles may play roles" is the eighth criterion in Steimann (2000b), exhibiting unresolved issues. In general, our framework must admit role-playing roles, in the sense that social role individuals, e.g. instantiating project leader, may participate in relations and processes, hence they may be playing relational or processual roles on the social ontological level. However, usually the question of role-playing roles relates to social roles, e.g., to the question whether an employee plays the role of a project leader, or whether it is merely required that a specific human playing a project leader role must in addition play an employee role. Masolo et al. (2004), for example, considers only the latter case to be the correct understanding. However, Searle (1995), Chapter 4, discusses the idea of iterated applications of his "X counts as Y" formula, which would correspond to one social role directly playing another (all on the individual level). Some further considerations can be found in Loebe (2003), Section 3.5.4, yet likewise without a clear solution. Moreover, admitting role-playing roles would not contradict the discussion of further inter-role relationships (see Dahchour et al. (2004), Sunagawa et al. (2005) for notions like *role evolution* or *role aggregation*). Due to the lack of evidence and strong arguments for either case, the question remains open in our current theory.

3.7. Multiplicity of roles

Let us reconsider the link between natural universal and role universal in Fig. 2. In its weakest form, the reading is such that individuals of some natural universal can be player individuals for some role, but there may be other, unspecified natural universals from which players could be recruited. Stronger interpretations restrict all players of a role to belong to one of those natural universals specified within a model, hence applying a closed-world assumption to models in this respect. Some proposals even admit only a single natural universal for a role, e.g. Dahchour et al. (2004), which we consider too restrictive, though. Instead, the multiplicities chosen for that link reflect the idea that roles can be played by different types of entities, as well as entities of one and the same type may play different roles. Natural universals are not optional for role universals, because role individuals are dependent on their players, hence every role universal can be restricted.[23]

We have noted in Section 3.1 that natural language formulations of role features require careful reading, because they can often be applied to the universal and the individual level. In addition to the universal level multiplicities just discussed, the relation between natural individuals and role individuals have not yet been settled for our account, because Fig. 2 does not contain the former explicitly. Their assignment

[23] Here we assume a common most general category like entity, on which one can always "fall back" when lacking a more specialized natural universal. Such a category is often left implicit in modeling, in which case optionality for natural universals may be likewise appropriate.

involves the applicability to the universal and/or the individual level and a temporal character. Omitting the temporal nature for a moment, we can capture the following criteria in Steimann (2000b) in terms of our role model as follows (numbers in brackets link to the enumeration of Steimann):

1. Different entities can play the same role. [7]
   (a) Different natural individuals can play different role individuals instantiating the same role universal.
   (b) Different natural universals can provide players for the same role universal.
   (c) Different natural individuals can play the same role individual.
2. An entity can play different roles simultaneously. [3]
   (a) A natural individual can play different role individuals (instantiating the same or different role universals).
   (b) A natural universal can provide players for different role universals.
3. An entity can play the same role several times, simultaneously. [4]
   (a) A natural individual can play different role individuals instantiating the same role universal.

All readings specified above apply in our model. Reading (3a) is a special case of (2a). (1c) is debatable because we require the dependence of role individuals on a single player. However, in order to allow for this reading we can take the temporal dimension into account: it is still conceivable for temporally extended role individuals that they undergo *role transfer*. For example, an individual prime minister role may be viewed to continue even if its player changes. Of course, the latter is only possible for persisting social roles, since all role individuals are dependent on exactly one player at a time (cf. the non-migration principle for relational roles and the definition of processual roles in Section 2.2.2). Moreover, role transfer requires role identity (see Section 3.2) which cannot be based on the player of the role in this case.

The multiplicities discussed above often lead to the assumption that the availability of multiple inheritance and multiple instantiation would already be a conceptual solution to hierarchies which include role and non-role terms. First, this is not correct without an implicit assumption that multiple instances are kept separate – which for roles is an analog to role identity. This is necessary, for example, in order to know which attribute-value pairs belong to which object. Moreover, multiple instantiation is sometimes claimed to be dispensable. For instance, Masolo et al. (2004) conjecture that multiple instantiation in the context of roles could be tackled in every case by specializing role universals. For example, if someone claims to have two president roles, he is actually referring to two specific and distinct roles. We disagree with this view. For instance, one may hold two mail accounts at the same mail provider, which means that there are two mail account owners played by the same human. Returning to inheritance, the next section resumes the discussion with "integrated" generalization hierarchies and analyzes solutions in terms of our role model.

3.8. Generalization hierarchies with roles

Without awareness of roles, one frequently encounters generalization hierarchies with role and non-role terms. Attempts to relate customer, person,[24] and organization within a single hierarchy is a prototypical example of this problem. In the subsequent discussion, first we restrict to a purely extensional

[24] We treat person in the following discussion as a natural universal (on a social ontological level, hence as a social object), although from a general perspective, person can be analyzed as a social role whose corresponding natural universal could be

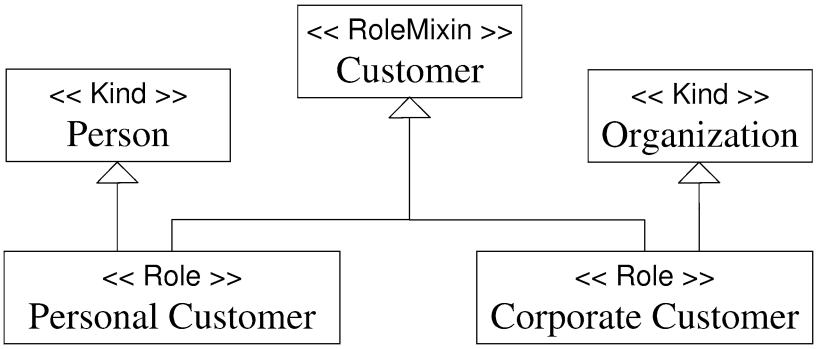

Fig. 5. The *roles with disjoint allowed types* design pattern, adapted from Guizzardi (2005), p. 111. This is a methodological proposal for the problem of generalization hierarchies with role and non-role terms, applied to customer (role) as well as person and organization (not roles). Stereotypes are kept from the original.

view on universals and generalization, i.e., approximating terms like customer as sets of instances and reflecting generalization by the subset relationship among these sets. Thereafter, intensional aspects will be covered.

The extensional view is extensively discussed in Steimann (2000b), Section 3.2, with the solution to separate hierarchies of natural and role universals (types and roles, in Steimann's terminology). Guizzardi (2005), Chapter 4, and Guizzardi, Wagner, Guarino, & Sinderen (2004) reject this solution in the context of UML modeling since it requires a radical revision of the UML meta-model. Instead the authors propose the so-called *roles with disjoint allowed types* design pattern which is depicted in Fig. 5.[25]

By means of the framework proposed in Section 2, the solutions of Steimann and Guizzardi et al. can be unified. In both cases, we re-interpret the role notion in Steimann (2000b), Guizzardi et al. (2004) as referring to player universals, because both works adhere to the position of "roles as types" which does not distinguish role universals from player universals. In addition we include our role notion, e.g. for customer. The resulting Fig. 6 closely resembles Fig. 5, but also links with Steimann's discussion. In the latter, Steimann argues that *statically*, roles are supertypes of natural universals because every person and every organization *can* play the role of customer, while *dynamically*, roles are subtypes because every actual customer is either a person or an organization. Now, the static view is reflected by the natural universal social object related to the role universal customer via the plays relation. It is indeed the task of natural universals in our theory to provide this reading of a "potential customer". The dynamic view is captured by the notion of a player universal, because these collect all players of a particular role. Accordingly, customer as well as personal customer and corporate customer are all player universals in this interpretation.[26]

What has been discussed so far can be applied to all types of roles we have presented. Now let us try to integrate the intensional aspects of universals in the style of object-oriented systems, i.e., by means of OO attributes (i.e., properties) and behavior (roughly, processes in which an object participates). Accordingly, the following primarily applies to social roles. From an intensional point of view, the

termed human being. On the other hand, the former position is also supported by the iteration of the "X counts as Y in C" formula (Searle, 1995, Chapter 4).

[25]The actual solution in these works is based on intensional universals, which will be discussed below. The given stereotypes in Fig. 5 were kept from the original figure. They denote meta-categories described in Guizzardi (2005), but cannot be explained in detail here.

[26]For the difference between customer and personal customer see the notion of *pure roles* in Section 3.10.

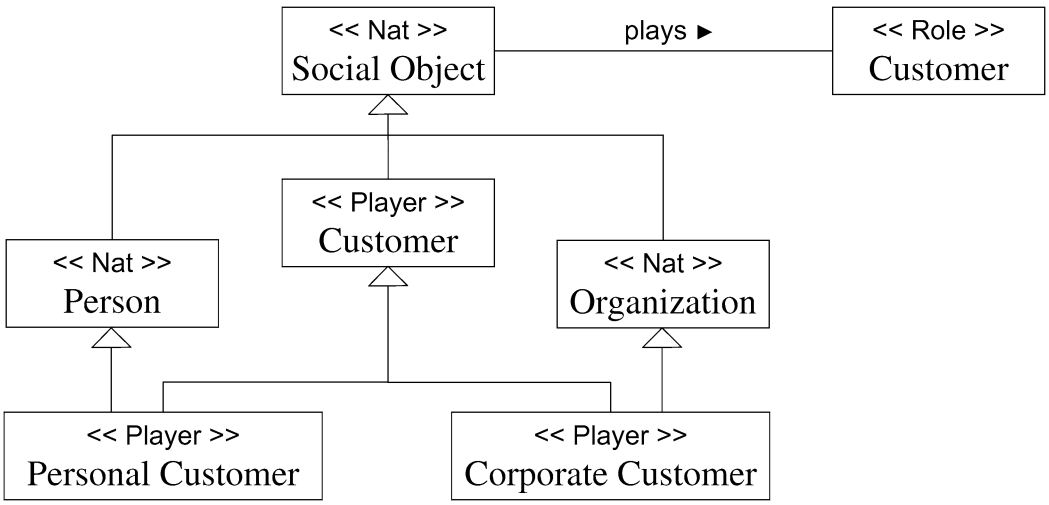

Fig. 6. The generalization problem re-interpreted in our framework, cf. Fig. 5. Stereotypes specify the assignment to categories of our model (Player, Role, and Nat for natural universal).

question arises why Fig. 6 is correct, e.g., assuming attribute inheritance along generalization links. It is adequate, because player universals do not add any attributes to natural universals. Player universals are best understood as extensional classification devices, whereas role-related properties only appear in role universals. An identifier of a customer, its date of entry, etc. all appear in the role customer in Fig. 6, but not in the player customer. Due to our decision to keep role individuals distinct from instances of natural universals also for social roles, role universals themselves cannot directly be inserted into hierarchies of natural universals.

What can be done in order to establish generalization hierarchies whose elements comprise role-specific properties together with properties of natural universals is to consider hierarchies among role holder universals (see Section 2.5). The Role and RoleMixin classes in Fig. 5 are then understood as role holder universals. This allows for another view on Guizzardi et al. (2004), Guizzardi (2005), which may be even more appropriate, since Guizzardi (2006) necessitates this view. Pure role holder hierarchies may be a solution for modeling which avoids the above doubling of player and role hierarchies, where the solutions in Guizzardi (2005) rest on a solid theoretical basis. Nevertheless, to some extent problems with role holder hierarchies initiated OO research on roles, cf. Dahchour et al. (2004). We expect that a few problems cannot be addressed by role holder hierarchies only, e.g. simultaneously playing several roles of the same kind[27] or dynamic classification, but this requires clarification in future work.

3.9. Role abstraction and complementary roles

The previous section has dealt with generalization hierarchies including role and non-role terms. In this section we leave natural universals aside and look at abstraction among role universals only. First of all, abstraction is possible for all three specific role types. In order to see why this is reasonable for processual, and in particular for relational roles, as well, liftings of the role-of relation and of role *complements* to the universal level are considered.

[27] This would require multiple instantiation, but this is problematic for role holder universals, because only the role parts need to be instantiated multiply.

On the individual level, complementation is straight-forward: role individuals are connected via role-of with a certain context, and all roles which belong to that context complement each other. Now the question arises how to define the notion of *complement* for a given role *universal*. An instructive illustration of the problem is provided by kinship relations (hence speaking about relational roles), e.g. asking for roles which are complementary to the father role. There are several possibilities, comprising child, son, or mother, among others. This shows the requirement to explicate role complements also among universals, for which we introduce the notion of *role base* in detail in Loebe (2003), Section 3.3.3. Analogously to the individual level, this can be achieved by assigning role universals to context universals. As a trivial example, father and son may be assigned to the context of the father-son relation. This is further an example where the context is prior to determining the role.

Another example can be derived from the sentence "John is a student of mathematics at the University of Leipzig.", leading back to role abstraction. The sentence is analyzed by means of two relations, student-subject (denoted by R_a, its relator by r_a) and student-institution (R_b and r_b, respectively). First, in r_a John plays a relational role q_{a1} and the subject of maths plays its complementary role q_{a2}. Secondly, in r_b John takes the role q_{b1}, whereas q_{b2} is played by the university. In both cases the roles of John, q_{a1} and q_{b1}, could be termed a student role in natural language, as we have done above. However, one cannot directly conclude that q_{a1} and q_{b1} are instances of a single role universal Q_x, because they appear in different contexts. That means q_{a1} and q_{b1} instantiate distinct universals Q_{a1} and Q_{b1}, in conformance with the two different relators r_a and r_b as their contexts, instantiating R_a and R_b, respectively. A description of R_a on a universal level involves the complementary role universals Q_{a1} and Q_{a2}; likewise for R_b, Q_{b1}, and Q_{b2}. But given these two role universals Q_{a1} and Q_{b1}, the initially assumed role universal "common" to both relations, Q_x, can now be abstracted as a universal subsuming Q_{a1} and Q_{b1}.

3.10. Pure roles

The last two examples indicate that subsumption among role universals exists for all role types, e.g. a father is a parent, and a son is a child. One can observe further differences among these role universals. Figure 2 requires that all role universals are restricted by some natural universal, but there are some whose definition is purely context-based and which are therefore called *pure roles*, whereas others involve definitional reference to specific characteristics of their players, called *impure roles*. A prime example of a pure relational role is part, for which impure subroles frequently relate to special domains, e.g. to time for temporal part. Another field of examples is found in kinship terms: starting from relational role universals like parent, child (roles of the parent-of/child-of relation), and sibling (roles of the sibling-of relation), various impure role universals arise, duplicating each pure role by a gender-based distinction of the players. This includes terms like mother, daughter, sister, father, son, and so on.

The difference between *Role* and *RoleMixin* in Fig. 5 appears to grasp a very similar distinction, because one criterion for being a Role (in our terms, a player universal) is to have a unique Kind (a natural universal) as supertype, according to Guizzardi (2005). This restriction is similar to the abovementioned definitional reference to players.

3.11. Integrating roles with qua-individuals

Masolo et al. (2005) introduces two proposals on combining "relational roles" with "qua-individuals", where the first analysis in Masolo et al. (2005), cf. Fig. 1 therein, can be very directly mapped to our

general role model (Fig. 2). In general, however, there is no unique understanding of the notion of qua-individual. Without familiarity with all philosophical roots of qua-individuals, one can observe that several specialized notions have developed in different contexts. There is a varying degree of the flexibility of this notion up to the general idea of qua-phrases, i.e., phrases of the form "x qua y". This includes expressions like "to be good qua cook" or "John qua male" which are not within the scope of this paper. A discussion of these from a knowledge representation perspective can be found in Sowa (2000). For a deeper elaboration on the notion of qua-individuals including philosophical connections the reader is referred to Masolo et al. (2005) and Poli (1998). But even within Masolo et al. (2005), neither view of qua-individuals fits our notion of relational roles exactly. The first are described to be "bundles of tropes", the second as "genuine entities with additional properties with respect to role players". From our point of view, both characterizations would rather refer to social roles than to relational roles, indicated by the reference to own properties. Altogether, some skepticism remains for us as to how well roles and qua-individuals can be integrated in terms of their philosophical background theories.

3.12. Meta-level status of roles

Instead of applying our model to other theories, we finally briefly test it for roles itself. It turns out that actually all notions in Fig. 2 are roles themselves, from a meta-level perspective. That means, the notions of role, player, and context are not considered to refer to entities in their own right, but themselves refer to roles which certain entities play with respect to each other. As shown in Table 2 (Section 2.3), possible natural universals for the role of providing a context are relation, process, and social entity. Moreover, the table also indicates that even the relationships plays and role-of have a role-like character, with relations identified in different connections playing them. The same consideration seems to apply to roles as well, which is also mentioned in Steimann (2005), p. 135. This further explains the distinct ontological nature of entities instantiating the presented role types. Put differently, the commonality of calling relational roles, processual roles, and social roles "roles" is not due to their actual structure.[28] Rather, it is derived from the use of role terms, i.e., due to instantiating role universals in the context of the theory presented. This perspective is fairly close to the notion of metaphysical context in Masolo et al. (2004), p. 270, and it will be important to expand these initial impressions and study their consequences.

4. Towards applications

Up to this point, our role model has only been employed with respect to problems within the theory of roles, like the *counting problem* in Section 3.1 and the problem of *generalization hierarchies with roles* in Section 3.8. Here we sketch two applications with more practical orientation, on different levels of generality. A particular standard in the health care domain is analyzed first. Subsequently, we comment on relations to programming models involving roles, from a more general perspective. A "reverse" application of our analysis in terms of supplying a methodology would be another desirable application, but must remain for future research, which may be reasonably pursued in close alliance with other ontology-based approaches like Guizzardi (2005).

[28] In spite of this, some novel categories like processual roles have been discovered in terms of role analysis, which may be relevant in other respects. For these it may be reasonable to consider renaming them with respect to their structural features.

4.1. Roles in health care: the HL7 standard

Medical information systems largely involve social notions, in particular various roles in which people occur in health care situations. HL7[29] is one representative from which the impact of roles for medical data exchange is obvious. The Reference Information Model (RIM) of HL7 is an object-oriented model defined as "[...] a static model of health and health care information as viewed within the scope of HL7 standards development activities" (HL7, 2005). It is developed and maintained by HL7, expressed in UML diagrams and additional documentation. "Role" is one of the RIM core elements, and the top-level structure of this model exhibits an interesting match with the role types provided in Section 2.

We briefly introduce the RIM notion of Role[30] and its related classes (HL7, 2005), illustrated in Fig. 7. Role together with Participation mediate between Entity and Act. Entity in RIM comprises physical things, organizations, or places. The class Act is used to represent records of intentional actions in the health care domain. In between, the Role notion serves to identify entities from the perspective of some competency. This competency is issued by another Entity scoping that Role. For instance, in order to be identifiable as a physician, this role may require some hospital as its scoper. Only Entities in Roles can participate in Acts, but still in numerous ways. Correspondingly, Participation describes specific ways of how an Entity behaves in an Act. To make the distinction between Role and Participation clear, HL7 (2005) states that "Participations represent performance while Roles represent competence. Participations specify the actual performance of an Entity in a certain Act [...]". Like for Role, for Participation a notion of scoping is defined where the scope is provided by the Act under consideration. In addition to these general classes, HL7 (2005) provides large classifications, for instance of Participation types, which can be used in specific messages.

Modeling a patient for which a message is to be transmitted in conformance with the HL7 standard provides an example for these notions. Patient would be a Role which is played by a human (an Entity) and scoped by that health care organization (another Entity) from which the patient receives services. With respect to some particular treatment (an Act), a person in the role patient participates in a certain form in that Act, for instance being the one who is physically examined.

Considering the top-level, the RIM approach to roles can be compared to our role model. Obviously, RIM introduces a distinction between natural universals and roles by the separation of Entity and Role. The relations of scoping in RIM reflect our notion of context. With role types available, it is obvious that a distinction is made between a scope in a social sense (due to the *scopes* relation in Fig. 7) and the scope for a Participation as provided by an Act. Acts should be understood as processes in the General Formal Ontology[31], thus Participation corresponds to processual roles. With respect to social roles and the question of whether Entity and Role refer to the natural universals and social roles, or to the integrated view

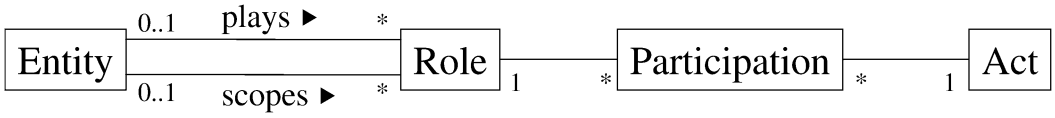

Fig. 7. Roles in the HL7 Reference Information Model (RIM), adapted from HL7 (2005). Unnamed links originate from RIM, where they are identified via the classes they connect.

[29] http://www.hl7.org/

[30] Terms starting with capital letters refer to RIM model elements.

[31] This appears appropriate for our comparison, although the RIM documentation also explicitly refers to documentation aspects of Acts, viewing Acts as records of intentional actions and linking this with speech act theory.

of a role closure instead, the RIM documentation suggests a tendency towards social roles. Apart from the top-level structure, the HL7 RIM is clearly a domain-specific model. For example, this is obvious from attributes of Role, like name, statusCode, certificateText, effectiveTime, etc. Another difference with respect to the model proposed herein can be found in some of the multiplicities, for example that each Participation is scoped by a single Act. However, we believe this to be an implementation-based constraint rather than a conceptual one, since the RIM documentation on Participation also considers subactivities (Act components). A processual role of an activity can also be a role of a subactivity, which would mean to link it with more than one Act.

Altogether, roles in RIM seem to fit the proposed role approach fairly well, in particular as it covers two of our role types. This supports the view of the medical domain being sufficiently complex to require even fine-grained modeling distinctions. The proximity of both models may further turn out to be advantageous concerning reuse and information integration across domain boundaries, and it should be instrumental if information models can be linked with top-level approaches clearly and without extensive effort.

4.2. Programming with roles

Moving to another field, many contributions in Boella, Odell, Torre, & Verhagen (2005) are concerned with the introduction of either constructs called "roles" in modeling or programming languages, e.g. powerJava (Baldoni, Boella, & Torre, 2005) or ObjectTeams/Java (Herrmann, 2005), or to use roles in the interpretation of certain language constructs. The same applies to the broader context of object-oriented, agent-oriented, as well as aspect-oriented programming, some representatives of which we mention in Section 1.2. Much more complete lists of references can be found in Steimann (2000b), Dahchour et al. (2004), for instance. In general, one important (intended) function of our theory is to provide a means for aligning and integrating different approaches from a conceptual perspective, analogous to the case of HL7 above.[32] However, due to the plurality just mentioned, we will not consider further particular formalisms here, but instead discuss the relationship between roles and more implementation-oriented notions in general.

Various combinations of roles with implementation-oriented notions have been proposed, for instance in connection with the use of inheritance (Van Paesschen, De Meuter, & D'Hondt, 2005), interfaces (Steimann, 2001), or aspects (Herrmann, 2005). However, although in all these cases it seems appropriate to refer to roles as motivation, we are cautious in trying to identify any of these notions with roles.

We can illustrate our concerns by an issue motivating Van Paesschen et al. (2005), which relates to the problem of joint hierarchies of role or player universals and natural universals. In this regard, Van Paesschen et al. (2005) discusses how role features can be understood as a special case of the *subtype-supertype paradox*, which refers to *implementing* conceptual subtypes as implementation supertypes. Van Paesschen et al. (2005) argues that the paradox applies to roles (viewing these as a kind of OO classes): for two given classes C and D, the problem is that the state of objects of C is more general than that of D, whereas the behavior of C is more specific than the one of D. Put more abstractly, this yields another reading of roles being supertypes statically, but subtypes dynamically in Steimann (2000b), where "statically" refers to the state of an object, "dynamically" to the behavior of it (see Section 3.8). This conflicts with the standard notions of inheritance in class-based modeling, where state

[32] This applies to distinct formalisms as well as to a single formalism like UML Rumbaugh et al. (1999), OMG (2006). Concerning the latter one should study at least the notions of *rolenames*, *collaboration roles*, *actors*, and *qualifiers*. For a longer discussion based on an earlier version of our theory, see Loebe (2003), Section 4.2.1.

as well as behavior is inherited from a superclass to its subclasses. For instance, according to the above argument, a person in a manager role should inherit the properties of managers (which requires manager to be a superclass of person), however, the behavior of managers may be more specific than that of person (thus manager should be a subclass of person).

Van Paesschen et al. (2005) offers a flexible way of "implementing roles" such that the resulting system satisfies many role requirements. Nevertheless, we do not see new analytical insights on roles, assisted by Van Paesschen et al. (2005) due to their comprehension of roles as *conceptual* subtypes. Such approaches should not be confused with analyses, and the implementation objects which are used (prototypes in the particular case) and their constructions must be explained appropriately in terms of analytical notions. In this case, the general subtype-supertype paradox is only indirectly related to roles. It arises from a particular use of inheritance which actually departs from generalization; cf. also Marcos & Cavero (2002) for an argument for a clear separation of inheritance hierarchies and conceptual taxonomies.

Similarly to inheritance, aspects and interfaces come with their own motivations and features which allow one to express roles in their terms. For example, Hanenberg, Stein, & Unland (2005) proposes a foundation for the comparison of role and aspect-oriented approaches, in an aspect-oriented setting. In this connection, the authors show a strict difference between aspects and the roles of Kristensen & Østerbye (1996).

Altogether, the identification of roles with any well-known implementation-oriented notion does not appear appropriate at the present stage.

5. Conclusion

5.1. Summarizing remarks

The main contributions of this paper can be summarized as follows. First, we presented a general account of roles involving the notions of *player*, *role*, and *context* as well as their interrelations on an individual and universal level. Moreover, a classification of roles is provided, dividing roles into *social* and *abstract roles*, and the latter further into *relational* and *processual roles*. This classification is a refinement of the one developed in Loebe (2003) insofar as abstract roles appear as a novel, functionally defined role type. Moreover, the importance of contexts for social roles is recognized to be weaker than for abstract roles. On the contrary, abstract roles are understood as a mechanism for viewing something in a given context. In addition to Loebe (2005) and inspired by Sunagawa et al. (2005), the notion of *role holder* has been integrated and extended to *role closures* in a principled manner.

The second major part of the paper comprises a discussion of a variety of commonly required role features, most of which are integrated into our approach. Moreover, relationships to the literature are permanently established. In our opinion, it turns out that the aspects of abstract and social roles are intermingled in the literature, especially concerning relational and social roles. For example, from a general perspective, the given characterization of roles is in line with those of Sowa (2000), Guarino (1992), Masolo et al. (2004), Kozaki et al. (2002), who refer to a dependence of roles on (patterns of) relationships to external entities. But here relationship needs to be understood as general as our context. However, if relations are understood as a certain modeling element, possibly in distinction from processes or other ontological categories, we propose to not follow this relation-based definition anymore, because this would cause coincidence with our relational roles, no longer covering the other

types. Furthermore, a distinguishing feature from many other approaches is that the dynamic and modal nature of roles is assessed to be very important and relevant, but not *necessary* in general in order to identify roles, see Section 3.5.

Altogether, an expressive account of roles has been provided which should be general enough to integrate others, e.g. more specialized approaches with a focus on one of our role types. The major claim we argue for is that there are different types of roles, each of which exhibits its specific characteristics. A unification of these types does not appear reasonable, unless one takes a very abstract perspective (illustrated in Fig. 2). A single "correct" understanding of terms like student is thus not available in our framework. Instead, several variants are offered and can be evaluated against a given purpose.

5.2. Future work

Of course, many aspects which are treated in the previous sections require further elaboration, relating to a theoretical extension of this work. In particular, we feel the need for an extended understanding of social roles in the context of a theory of social reality. In this connection, closer relations to the theory of ontological levels should be established (Poli, 2001). Moreover, social processes are not yet sufficiently analyzed. These may further relate to an extension of the notion of roles or to the introduction of a related concept, based on the "X counts as Y in C" locution in Searle (1995). In addition, interconnections among relational and social roles derived from a term like student need to be integrated into our framework, following the routes of Masolo et al. (2005), Guizzardi (2005, 2006), which rest on partially different assumptions.

Furthermore, an active area for the application and extension of roles is the ontological theory of functions. Intuitively, it is plausible that roles and functions are closely related. Recent analyses have shown that this is indeed the case, for instance, roles can be employed in function specification (Burek, 2007; Burek et al., 2006). The notion of processual roles appears highly relevant in this connection. In addition, the interplay of processual roles and processes on different levels of part-whole granularity requires deeper analysis.

Another line of extension of this work leads to more technical issues. In general, the presented model could be integrated into representation formalisms or methodological approaches. In this regard, however, first we consider it more important to supply a machine-processable formal characterization of the framework which may then be used for automated or semi-automated integration purposes, for example.

Acknowledgments

We would like to thank the members of the Research Group Ontologies in Medicine (Onto-Med) for maintaining a stimulating environment, and in particular, Patryk Burek and Robert Hoehndorf for helpful comments on earlier versions of the manuscript. Moreover, we are grateful to the reviewers for their challenging comments, the provision of enlightening references, and the indication of many points for clarification.

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