The ontological properties of social roles in multi-agent systems: definitional dependence, powers and roles playing roles

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Abstract. In this paper we address the problem of defining social roles in multi-agent systems. Social roles provide the basic structure of social institutions and organizations. We start from the properties attributed to roles both in the multi-agent systems and the Object Oriented community, and we use them in an ontological analysis of the notion of social role. We identify three main properties of social roles. First, they are definitionally dependent on the institution they belong to, i.e. the definition of a role is given inside the definition of the institution. Second, they attribute powers to the agents playing them, like creating commitments for the institutions and the other roles. Third, they allow roles to play roles, in the same way as agents do. Using Input/Output logics, we propose a formalization of roles in multi-agent systems satisfying the three properties we identified.

Key words: multi-agent systems, ontologies, social roles, input/output logics

1. Introduction

The social structures developed in multi-agent systems (MAS) are often proposed in the design of open systems as a solution for controlling the autonomy of the different participants (Artikis et al. 2002). A key notion in the social structure of a MAS is that of social role. Social roles allow to specify the activities delegated by a social institution to individuals to achieve its purpose, while abstracting from the individuals which will eventually play them. The description of a social role is given in terms of rights, permissions and obligations (Pacheco and Carmo 2003), expectations, standardised patterns of behaviour (Esteva et al. 2001), social commitments (Cavedon and Soneberg 1998; Fasli 2001), or goals and planning rules (Dastani et al. 2004).

Though social roles have such a central position in MAS coordination, there are still several open problems. First, the desired properties are not clear, and it is not clear how to realize desired properties. Second, normative descriptions are mostly limited to rights, while the notion of power is relevant as well.

We extend the notion of social role in Agent Oriented systems (AO), and to make it more precise we use ideas and concepts from the properties of roles discussed in the Object Oriented paradigm (OO). A side-effect is that a unified model of roles in AO and OO has an impact not only in AO, but also in OO. Roles are central not only in MAS, but also in Object Oriented modelling and programming. Roles in OO are used to dynamically add behaviours to objects, to factorise features of objects like methods or access rights, to separate the interactional properties of objects from their core behaviour, and to allow exogenous coordination (Baldoni et al. 2007).

Thus the research question of this paper is: how to model the essential properties of social roles? This question can be articulated in the following subquestions:

1. How to model that roles are always involved in a relationship with another entity, which seems to come first? Roles belong to organizations and institutions which define them; hence, they are social roles.
2. How to model that social roles are associated to powers in the institution they belong to? Concerning the normative positions, social roles go beyond only rights and permissions.
3. How to model that roles can play roles as an agent? Social roles should be considered as a kind of agent.

Besides treating roles as in both AO and OO as first class citizens of the theory, here social roles are treated as agents. However, social roles are not autonomous, and they should therefore be treated as agents of a special kind. We call this methodology the agent metaphor. Though at first sight social roles are anything but agents we treat social roles as agents because we attribute mental attitudes to agents, as done by (Boella and van der Torre 2004a); this has as additional benefit that we can reuse for social roles existing theories, models and tools developed for agents. Analogously, social institutions can be described in the agent metaphor as agents to which mental attitudes are attributed. We apply the methodology used by Boella and van der Torre (2006c, d) to describe and reason about other social entities like groups, virtual communities, contracts, and normative multi-agent systems.

In this paper, we use the term social role to restrict the scope with respect to a more general notion of role. For instance, roles in linguistics are intended as thematic roles, like agent, object of a verb. In ontologies, Loebe (2005) considers also functional roles, like being a factor of a number, and

processual roles, like being the mover of an object. The term social role does not conform entirely to its meaning in social theory, but it has now established itself in MAS and ontologies (Loebe 2005; Masolo et al. 2004).

In the next sections we analyse how roles are modelled in different areas and the properties which are commonly attributed to roles, in particular, in AO and OO. Then, we present their basic properties in our model: the definitional dependence in Section 3.1, the powers of roles in Section 3.2 and roles playing roles in Section 3.3, where the agent metaphor is further discussed. Then, in Section 4 we present our formal model of roles in MAS.

2. Roles, under different perspectives

The notion of role is ubiquitous not only in many areas of artificial intelligence, but also in many other fields of computers science, like programming languages, software engineering, coordination, databases, security, multi-agent systems, computational linguistics, conceptual modelling, formal ontology, and also in other scientific fields, like sociology, cognitive science, organizational science and linguistics. At least three different viewpoints characterize research on roles. First, roles as named places in relationships (in linguistics, databases and conceptual modelling); second, roles as dynamic classification of entities (especially in programming languages and databases); third, roles as instances to be adjoined to the entities which play the role (especially in ontologies, MAS and programming languages).

The different connotations given to the concept of role in these disciplines only partially overlap, and the notion of role deserves to be analysed separately in each of them. In this paper, despite the extensive analyses carried on thus far, we identify new distinguishing properties of roles whose usefulness goes beyond MAS.

In programming languages, roles have been introduced to allow objects to extend their behaviour dynamically, as soon as they enter a new context of interaction. Moreover, this concept is used to model real world situations including roles like customer and seller (Dahchour et al. 2002).

In ontologies, roles have been introduced as a further representation primitive besides the usual distinction made between entities and predicates. The major features of roles in this area are the fact that an object can belong both to a natural type (representing its essence) and to several role types that depend on an accidental relationship to some other entity. Indeed, roles are considered existentially dependent on their players and, sometimes, also on some other concept used in their definition, e.g. the role student depends on the concept of university (Masolo et al. 2004).

In security, roles have been used in the Role Based Access Control (RBAC) model (Sandhu et al. 1996). Access rights are associated with roles

and users are made members of appropriate roles, thereby acquiring the roles' permissions. Moreover, roles have been used to distribute the authorizations to manage the roles themselves. Therefore, RBAC allows to model security from the perspective of the enterprise, because security modelling is aligned to the roles and responsibilities in the company.

In multi-agent systems, roles have been introduced in order to constrain the autonomy of agents and to control their emergent behaviour in multi-agent systems by means of the notion of organization (Ferber et al. 2003; Zambonelli et al. 2003). According to Zambonelli et al. (2003) "a multi-agent system can be conceived in terms of an organized society of individuals in which each agent plays specific roles and interacts with other agents".

The notions of institution, organization and role are part of the socially oriented metaphor used in agent theory. Thus, in MAS, roles are called social roles. It is not clear, however, if the ontological assumptions behind this kind of entities are the same which underlie objects and agents. Many approaches recognize as properties of social entities being the addressee of obligations (Dastani et al. 2004), the delegation mechanisms among roles (Grossi et al. 2005), etc. Moreover, organizations are modelled as collections of agents, gathered in groups (Ferber et al. 2006), playing roles or regulated by organizational rules (Zambonelli et al. 2003).

Finally, communication among agents in a MAS is often associated with the roles agents play in the social structure of the systems. The GAIA methodology (Zambonelli et al. 2003) proposes interaction rules to specify communication among roles, the ROADMAP methodology (Juan et al. 2002) specifies in the social model the relations among roles, and in AALAADIN (Ferber et al. 2003) interaction is defined only between the roles of a group: "the communication model within a group can be more easily described by an abstracted interaction scheme between roles like the 'bidder' and the 'manager' roles rather than between individual, actual agents".

In this paper, we focus on roles as they have been introduced in multi-agent systems, starting from an analysis of the properties which have been attributed to roles also in object-oriented languages, so to open a wider perspective on this concept and enhance its applicability.

3. Properties of roles

In their survey about roles in MAS (Cabri et al. 2004) identify several properties attributed to roles, which are illustrated in Figure 1. There are two problems. First, it is not clear which model of role can support all these properties. The second problem is that rights (property 6) are a too limited notion. It suffices for role-based access, but in general we also need powers to specify normative positions.

1. Agents can play multiple roles, and in some approaches they can even have to play a role.

2. Roles are views on agents.

3. Individual are uncoupled from roles. E.g., attributes like wage are associated to the employee role rather than to individuals.

4. Roles enhance reusability: the same role can be used by different agents.

5. Roles define expected behavior and obligations. E.g., a program chair is expected and obliged to select the papers of a conference.

6. Roles define sets of rights and permissions. E.g., the access rights.

7. Roles embed behavior specific to a context, like a group, which forms a subenvironment of coherent roles.

8. Roles define common interactions and embed information and capabilities needed to communication and coordination. E.g., the roles of auctioneer and bidder in an auction, each with their possible moves.

9. Promote an organizational view of the system, where roles are coordinating rather than coordinated entities.

Figure 1. The properties of roles in AO.

The properties attributed to roles in the Object Oriented community are summarized by Steimann (2000). In Figure 2, we show here how these properties are also relevant for agents by giving some examples. These properties only partially overlap with the previous list. In particular, Properties 5–9 of Figure 1 assume that agents are autonomous, they can violate obligations, they interact with each other, and they form social institutions like organizations and groups. The properties discussed in OO are more precise and talk about roles as adjunct instances to objects (11), states of roles (7), sequences of acquisitions (6), identity (14), polymorphism (7) and other phenomena, and thus address the first problem discussed in the paragraph above. However, they do not help with the generalization of rights to other powers. Moreover, these more precise descriptions also give rise to two new questions. First, the fact that roles depend on relationships with other entities implies that these entities are more basic than roles. Second, roles playing roles imply a kind of role hierarchy. Groups and contexts are not sufficient to model all aspects of this. We need to model role as a non-autonomous notion of agent.

Thus, there are three open problems: how to define dependencies of social roles on relationships, how to extend normative positions from rights to powers, and how to model social roles as agents that play roles. These issues are discussed in the following three sections. We support these properties by means of an ontological analysis of the notion of social role. Roles deserve an ontological analysis in that they are among the basic notions of an ontology besides the notion of natural type, substance, property, and relation.

1. A role comes with its own properties and behavior. Hence, it is a type. E.g., a director of a department commands other members and makes buy-orders.

2. Roles depend on relationships: e.g., a student is related to a school, etc.

3. An object may play different roles. E.g., a person can be both a student and an employee.

4. An object may play the same role several times. E.g., a person can hold several employments.

5. An object may acquire and abandon roles dynamically. E.g., a person can acquire the role of student or of employee.

6. The sequence in which roles may be acquired and relinquished can be subject to restrictions. E.g., a person becomes a teaching assistant only if it is a student.

7. Objects of unrelated types can play the same role. E.g., both a person and an organization are customers.

8. Roles can play roles. E.g., an employee can be a project leader: a role of the employee.

9. A role can be transferred from one object to another. E.g., the salary of an open position may be specified independently of the person that will be employed.

10. The state of an object can vary depending on the role in which it is being addressed: this should be viewed as a separate instance of the object. E.g., an employee has an address per job and also a private one.

11. If an object plays several roles simultaneously, it responds according to the role in which it is being addressed. E.g., an person gives the address of the employee it is playing.

12. Roles restrict access. This corresponds to an object having different perspectives, facets, or aspects. E.g., the private phone number of an employee can be invisible when the person is playing the employee role.

13. Different roles may share structure and behavior. This usually means that role definitions inherit from each other. E.g., the role student can have associated the behavior of giving exams, and more specific roles (like first year student) inherit this behavior.

14. An object and its roles share identity. Since roles do not exist by themselves they cannot have an identity.

15. An object and its roles have different identities. This view solves the so-called counting problem. E.g., the number of passengers of an airline can be greater than the number of person who travelled with it.

Figure 2. The properties of roles in OO.

Ontological analysis aims at identifying the metaproperties distinguishing roles from those other notions, as done by Masolo et al. (2004).

3.1. DEFINITIONAL DEPENDENCE

Organizational theory considers social roles as a way to structure organizations so to distribute responsibilities. Thus, for organizational theory, roles

exist only in function of the organization they belong to. This feature has been recognized also by ontological analysis of roles. Guarino and Welty (2002) notice two characteristic properties of roles distinguishing them from natural types: roles are non-rigid entities and do not exist independently from other entities. Rigidity means that an entity can stop to play a role without losing its identity. For example, a person can stop being a student, but not a person.

The dependence of a role, as suggested by the work of Sowa (2000) and Guarino and Welty (2002), is a consequence of the fact that a role is meaningful only in the context of a relationship with another entity. This property is also called foundation: a role must always be associated with another entity through some relationship. Some hints of this ontological property of roles could already be found in the literature. In the traditional approach to roles in linguistics, words are always related to other words: every word in a sentence has slots to be filled by others; e.g. a verb like eating has an agent and patient role. In conceptual modelling, in UML a role is correlated by an association to other roles. In Agent-UML a role is related to a group (Bauer et al. 2001).

The dependence of a role from another entity is not contingent, but it rests in the definition itself of the role. For this reason, Fine (1995) introduces the following notion of dependence: "to say that an object x depends upon an F is to say that an F will be ineliminably involved in any definition of x". This notion is elaborated by Masolo et al. (2004) into the notion of *definitional dependence*: e.g. the definition of the concept of student makes reference not to a specific school but to the concept of school, the employee to the concept of organization, the director to the concept of department, the president to the concept of (presidential) state, etc.

We believe, however, that this definitional dependence should be interpreted in an even stronger way. First of all, not only social roles all depend on other entities, but the entities they depend on all belong to a common category; they all are social entities: groups, organizations, departments, states, etc. In a word, *social institutions*. Second, not only social roles do not exist without social entities, but, in turn, roles are essential to them: there is no presidential state without the definition of a president, no school without the definition of a student. Hence, we adopt a stronger notion of definitional dependence. We say that the definition of the social institution (F) the social role x belongs to contains the definition of the role (x). For example, the social role of president of a presidential state is defined in the constitution of that state. The role president does not exist without a state and its definition, but also the state itself is not the same without the role of president: its definition would be different.

3.2. ROLES, POWERS AND INSTITUTIONS

According to Property 6 of Figure 1 rights and permissions are a funda-mental feature of normative positions of roles. Rights are used to regulate access to resources by agents playing roles, e.g. in role based access control (RBAC). However, the terms right and permission often should be inter-preted in the sense of *institutional power*. The notion of power is relevant here, since, e.g. a director of a department has not only the right to give commands to the employee, but, above all, it has the power to do so. But, as witnessed also by Dastani et al. (2004)'s survey, the MAS model of role is mostly limited to rights. Moreover, in Figure 1, roles are associated to new capabilities. In Figure 2, roles are associated with behaviours (1). Roles as a way of grouping context-dependent behaviour do not explain why we need roles to do this grouping and not simply the notion of class, albeit a dynamic one. We claim that the reason is that these capabilities have a peculiar character: they are powers.

   Again, some insights can be gained by considering which capabilities are added to a social role. They can be grouped in three categories:

– Actions of the role that are recognized as actions of the institution: e.g. a director's signature on a buy-order is considered as a commitment of its department to pay for the requested item.
– Actions of the agent playing the role that can modify the state of the role itself. For example, a director can commit itself to new responsibilities.
– Interaction capabilities with other roles in the same institution. An agent in a role can send a message to another role, e.g. a director can give a command to an employee.

Not only social roles do not exist without social entities, but the role cannot do any (institutional) action without the consent of the social entity they belong to. The reason is that social entities are not material entities: agents playing roles cannot do anything for affecting them.

   Social institutions are socially constructed entities which exist thanks to the collective acceptance by agents of the regulative and constitutive rules regulating them. In particular, they are created by means of the notion of constitutive rule introduced by Searle (1995). Searle argues that there is a distinction between two types of rules:

> Some rules regulate antecedently existing forms of behaviour. [...] Some rules, on the other hand, [...] create the possibility of or define that activity. The activity of playing chess is constituted by action in accordance with these rules. The institutions of marriage, promising [...] are systems of such constitutive rules or conventions.

Constitutive rules are of the form "such and such an X counts as Y in context C" where X is any object satisfying certain conditions and Y is a label that qualifies X as being something of an entirely new sort: an institutional fact. Examples of constitutive rules are "X counts as a presiding official in a wedding ceremony", "this bit of paper counts as a five euro bill" and "this piece of land counts as somebody's private property".

Thus, institutions are composed of regulative and constitutive rules. But since social roles are defined by the institution they are defined in turn in terms of constitutive rules and regulative rules attributed to them by the institution. Since constitutive rules are at the basis of an institution and of roles, an agent can act in the institution only if for the institution the agent's actions "count as" some institutional fact. In this sense, the new capabilities added by the role are given by the institution; the role is empowered by the institution: the actions of a role "count as" (Searle 1995) actions of the institution itself.

We can explain the three different kinds of powers discussed above as different kinds of constitutive rules. First of all, actions of the player of the role "count as" institutional facts according to some constitutive rule of the institution. So it can affect the institution. Second, if the constitutive rules creating an institutional fact belong to the role the agent it is playing, the agent can affect its role. Third, if the constitutive rule belongs to some other role of the institution, the agent in playing its role can affect this other role.

The effects of the action of a player of the role are not limited to making true institutional facts. Institutional facts can have, in turn, an effect on the institution and on the roles, via other constitutive rules introducing new constitutive and regulative rules. For example, the signature of the director "counts as" the commitment of the department (i.e. a new obligation) to pay for the delivered goods. Moreover the command of the director "counts as" an obligation for the members of the department.

Finally, note that if we consider the possibility that a role is changed by the exercise of a power from another role we admit implicitly that a role is not only a type specifying the behaviour expected by the player. Rather, a role is an instance with its own state. This state specifies the expected behaviour of an agent, and this specification can vary over time according to the exercise of power by the player, the institution and by other roles.

The counterpart of strong definitional dependence and its ability to make roles access the institution's state, in the Object Oriented world, is that roles should be defined in the definition of an object, i.e. a class, that determines its scope: all roles should be encapsulated in other classes.

3.3. ROLES PLAYING ROLES

Another important feature of roles is that roles can play roles as well. For example, an employee can be a project leader, a member of the board can be the CEO of an enterprise, etc.

Roles are usually played by agents: a person can be an employee, a member of a club, of a board or a member of parliament. But how can a role play a role? This is possible only if an agent and a role share some properties. As we will see in the next section, this is possible in our model since roles are described as agents, i.e. they are attributed mental attitudes as well. Note that in many models, e.g. Dahchour et al. (2002), roles do no play roles, and a role like project leader is modelled simply as specification of the employee role. However, this solution relies on a type specification hierarchy of roles and requires introducing dynamic reclassification. Instead, our approach does not require this feature, but it allows to create a hierarchy among roles: the hierarchy is based on the inherently dynamic played-by relation between roles and agents, rather than on a specification relation.

The methodology of our work is inspired to the agent metaphor of (Boella and van der Torre 2006c). In that paper, we model entities of social reality like groups, normative systems, organizations and roles as agents. The ontological claim is that social reality is difficult to understand for humans, even if humans themselves create it. Hence, to understand social reality humans resort to metaphorically mapping the social domain in a better-known domain: the domain of agents. Social entities exist because they are collectively accepted by agents (Searle 1995). To define the behaviour of social entities, they are collectively attributed by the agents' mental attitudes.

This metaphorical mapping allows to explain the features of social entities in terms of the features of agents. In particular, in this mapping a social institution can be considered as an agent where the regulative norms, like obligations and permissions, are mapped into the goals of an agent; the constitutive norms creating powers are mapped into the beliefs of the agent.

Moreover, the institution, as a normative system, is supposed to have an autonomous behaviour as an agent has: it aims at restoring the regularities prescribed by norms by means of monitoring violations and sanctioning them. The metaphor, however, stops here since social entities cannot act in the world. Monitoring and sanctioning are carried out by real agents.

Roles in sociology are often described as expected behaviour. To describe behaviour, agent theory uses beliefs, desires and goals. Hence, roles can be considered as agent descriptions. This is different from the fact that roles are also played by agents, their actors. Since roles are considered as agents, they can play roles in turn. In the metaphorical mapping of (Boella and van der Torre 2004b) the role's expertise is represented by beliefs of the agent and its

responsibilities as the goals of the agent. To play a role an agent has to adopt the goals representing its responsibilities and to carry out them according to the beliefs representing its expertise: the player has to act *as if* it had the beliefs and goals of the role.

In the same way as social entities are constructed by the collective attribution of mental entities by agents, roles exist only because they are attributed mental attitudes by the institution they belongs to. The institution is thus defined by its beliefs and goals representing constitutive and regulative rules and by the beliefs and goals it attributes to its roles. While (Boella and van der Torre 2004b) focus on responsibilities of roles, in this paper we focus on their powers.

4. Formalization of roles

In this section we introduce our model of roles and institutions.

First of all, a set of propositional variables X describes the different aspects of the world, and rules $Rul(X)$ are used to represent mental attitudes.

Second, we consider different sorts of agents A. Besides real agents RA (either human or artificial) we consider as agents in the model also social institutions SA, like groups, normative systems and organizations, and roles RO composing the structure of agents in SA.

By mental attitudes we mean beliefs B, desires D and goals G. Mental attitudes are described by rules. Moreover, different mental attitudes are attributed to the agents by the agent description relation AD. It associates to each agent a set of beliefs, desires and goals. Moreover, AD associates also agents to agents, because groups, normative systems, organizations, and roles as agents exist only as profiles attributed to them by real agents. So social institutions and roles exist only as they are described as agents by real agents, according to the agent description relation.

The following definition introduces multi-agent systems:

DEFINITION 1 (*MAS*). Let X be a set of variables. The set of literals built from X, written as $Lit(X)$, is $X \cup \{\neg x \mid x \in X\}$; the set of rules built from X, written as $Rul(X) = 2^{Lit(X)} \times Lit(X)$, is the set of pairs of a set of literals built from X and a literal built from X, written as $\{l_1,..., l_n\} \to l$. We also write $l_1 \wedge ... \wedge l_n \to l$ and when $n = 0$ we write $\top \to l$.

A multi-agent system MAS is a tuple $\langle RA, SA, RO, X, B, D, G, AD, MD, \geq, I, PL \rangle$ where:

- The real agents RA, social institutions SA and roles RO, propositional variables X, beliefs B, desires D, and goals G are all finite disjoint sets. We write $RA \cup SA \cup RO = A$ for the set of all agents and $M = D \cup G$ for their motivations.

- An agent description $AD : A \rightarrow 2^{A \cup X \cup B \cup D \cup G}$ is a complete function that maps each agent to other agents that exist in its profile, sets of variables (its decision variables), and its beliefs, desires and goals. For each agent $a \in A$, we write A_a for $A \cap AD(a)$, and B_a for $B \cap AD(a)$, et cetera. We write parameters $P = X \cup_{a \in A} X_a$.

- The mental description $MD : B \cup D \cup G \rightarrow Rul(X)$ is a complete function from the sets of beliefs, desires and goals to the set of rules built from X. We write $m\ x \rightarrow y$ for: m such that $MD(m) = x \rightarrow y$.

- A priority relation is used to resolve conflicts among motivational attitudes: $\geq : A \rightarrow 2^M \times 2^M$ is a function from agents to a transitive and reflexive relation on the powerset of the motivations containing at least the subset relation. We write $\geq_a$ for $\geq (a)$.

- The institutional facts $I \subseteq P$ are parameters.

- The role playing function $PL : RO \rightarrow A$ associates a role to its player.

The set of variables whose truth value is determined by an agent (decision variables representing actions) are distinguished from those which are not directly determined by the agent (P, the parameters). Only real agents act in the world, while social institutions act only through the agents playing roles in them. For this reason, social institutions are not associated with decision variables ($\cup_{\{a \in S\ A \cup RO\}} X_a = \emptyset$).

Besides, "institutional facts" I are states of affairs which exist only inside normative systems and organizations. As discussed in Section 3.2 (Searle 1995) suggests that money, properties, and marriages exist only as part of social reality; since we model social reality by means of the attribution of mental attitudes to social entities, institutional facts are just in the beliefs of these agents.

EXAMPLE 1. $MAS = \langle RA, SA, RO, X, B, D, G, AD, MD, \geq, I, PL \rangle$ with $RA = \{\mathbf{A}\}$, $SA = \{\mathbf{O}\}$, $RO = \{\mathbf{B}\}$, $P = \{p, q, r, s\}$, and X, P, B, D, G, AD, MD, PL and $\geq$ are implicitly given by the following table:

	A		**O**		**B**	
A	$\mathbf{O}$		$\mathbf{B}$		——	
B			b_1	$x_2 \rightarrow p$		
D	d_1	$\top \rightarrow \neg p$				
G	g_1	$\top \rightarrow x_1$	g_2	$\top \rightarrow p$	g_3	$\top \rightarrow x_2$
X	x_1, x_2		——		——	
$\geq$	$d_1 > g_1 > g_2 > g_3$		$g_2 > g_3 > d_1 > g_1$		$g_3 > g_2 > d_1 = g_1$	
PL	$\mathbf{B}$		——			

This table should be read as follows. There are three agents, one real agent **A**, a social institution **O** and a role **B** of the institution, played by **A**. The A row specifies which profiles are attributed by each agent: agent **A** attributes profile **O** to the institution, and the institution in turn defines role **B** by attributing to it the mental attitudes specified in the last column. The long dashes in a cell represent that the field cannot have a value.

Agent **A** has, amongst others, a desire d_1 ($MD(d_1) = \top \rightarrow \neg p$), and the institution has a goal g_2 which can be realized by an action x_2 of agent **A** since $MD(b_1) = x_2 \rightarrow p$.

Finally, only a fragment of the priority relation is given, because it is only given for singleton motivations, whereas it is defined over sets of motivations. It says that each agent gives highest priority to its own motivations. The table can be extended to deal with more detailed motivations in the obvious way.

OBSERVATION 1. Roles are definitionally dependent on the institutions they belong to. An institution a, since it is modelled as an agent, is defined by the agent description function $AD{:}A \rightarrow 2^{A \cup X \cup B \cup D \cup G}$. This function describes also the agents' profiles associated to the institution (the set A_a), in particular, it describes the set of roles associated to the institution $RO_a = RO \cap A_a$. Thus, the roles RO_a are defined by the definition of the institution $a \in SA$.

OBSERVATION 2. A role can play a role as required in Section 3.3. The PL relation associate a role in RO to its player in A: since $RO \subseteq A$, then a role a can play a role b ($PL(b, a)$).

Social institutions like normative systems and organizations are able to change themselves. For example, they specify how their norms can be modified. Since social institutions depend on the attribution of mental attitudes which define both the regulative and constitutive norms, we represent their modification by means of the modification of their mental attitudes expressed as rules.

We adopt here a relatively simple solution for adding, revising and removing rules from a rule base; it is based on the assumption that all relevant beliefs, desires and goals are already present in the system, such that we only have to adapt the agent description AD. An advantage of this construction is that the priorities of the desires and goals are also already defined in the multi-agent system, and we do not have to introduce an update mechanism.

Additions (also known as expansions) to the agent description are defined as $+ : A \times (B \cup D \cup G) \rightarrow I$, i.e. as for each agent mappings from mental attitudes to institutional facts. Since institutional facts I like the additions exist only in the beliefs of a normative system or an organization, we need a way to express how these beliefs can be made true. The relations among

propositional variables are expressed as belief rules. Rules concerning beliefs about institutional facts are called constitutive rules and represent the "counts-as" relations introduced by (Searle 1995).

DEFINITION 2 (Counts-as). Given
$MAS = \langle RA, SA, RO, X, B, D, G, AD, MD, \geq, I, PL \rangle$
Counts-as conditionals $CA \subseteq B_o$ of constitutive norms are beliefs of a social institution or a role $o \in SA \cup RO$, such that constitutive rules $CR = MD(CA)$ are the set of rules whose heads are elements of literals built out of institutional facts $Lit(I)$. We write counts-as$_o$(Y, p) where $Y \subseteq Lit(X)$ and $p \in I$ if $\exists\, m \in CA$ such that $MD(m) = Y \to p$.

In Boella and van der Torre (2006a) we discuss the properties of constitutive rules seen as goals of the agents.

EXAMPLE 2 (continued). Given $I = \{r, s\}$.

	A		**O**		**B**	
A	O		B		——	
B			b_1	$x_s \to p$	b_3	$x_2 \to s$
			b_2	$x_1 \to r$		
D	d_1	$\top \to \neg p$				
G	g_1	$\top \to x_1$	g_2	$\top \to p$	g_3	$\top \to x_2$
X	x_1, x_2		——		——	
$\geq$	$d_1 > g_1 > g_2 > g_3$		$g_2 > g_3 > d_1 > g_1$		$g_3 > g_2 > d_1 = g_1$	
PL	B		——			

Belief rules b_2 and b_3 are constitutive rules establishing institutional facts r and s via action x_1 and x_2 of agent **A**. Note that b_3 is a constitutive rule of the role: action x_2 of the player of the role makes it true.

The following definition introduces multi-agent systems which can modify themselves:

DEFINITION 3 (*SMAS*). A self modifying *MAS* is defined as
$\langle RA, SA, RO, X, B, D, G, AD, MD, \geq, I, PL, +, CA \rangle$ with additions $+ : A \times (B \cup D \cup G) \to I$. We write $+_a(m)$ for $+(a, m)$. The update of a SMAS by a set of literals $L \subseteq Lit(I)$ is $AD'_a = AD_a \cup \{m \mid +_a(m) \in L\}$.

EXAMPLE 3 (continued). We introduce additions:

	A		**O**		**B**	
A	**O**		**B**			——
B			b_1	$x_2 \rightarrow p$	b_3	$x_2 \rightarrow s$
			b_2	$x_1 \rightarrow r$	b_6	$s \rightarrow +_{\mathbf{B}}(g_4)$
			b_4	$r \rightarrow +_{\mathbf{O}}(b_5)$		
D	d_1	$\top \rightarrow \neg p$				
G	g_1	$\top \rightarrow x_1$	g_2	$\top \rightarrow p$	g_3	$\top \rightarrow x_2$
X	x_1, x_2			——		——
$\geq$	$d_1 > g_1 > g_2$		$g_1 > d_1 > g_2$		$g_2 > d_1 = g_1$	
PL	**B**			——		

The institutional fact *r* (performed via **A**'s x_1) "counts as" (b_4) adding b_5 of the beliefs of the institution: this means that the agent **A** has the power to express the opinion of the institution it belongs to. Moreover, the institutional fact *s* (performed via **A**'s x_2) "counts as" (b_6) the introduction of a goal g_4 in the state of the role **B**: **A** has the power to commit the role **B** to a certain goal by means of its actions.

The consequences of belief rules are incorporated via a logic of rules called *out*. It takes the transitive closure of a set of rules, which can be extended in the process, and it is an extension of reusable throughput in input/output logic (Makinson and van der Torre 2000) with generator revision.

DEFINITION 4 (Consequences). $U = 2^{Lit(X)} \rightarrow 2^{Rul(X)}$ are the possible add lists of sets of rules in situations. *out* is a function from set of rules, sets of formulas and add lists to new sets of rules and sets of formulas: *out*: $2^{Rul(X)} \times 2^{Lit(X)} \times 2^U \rightarrow 2^{Lit(X)}$. Let *out*(E,S,R) be the closure of S under the rules E updated by added rules R, defined as follows.

- $outE^0(E, S, R) = E$
- $out^0(E, S, R) = S$
- $outE^{i+1}(E, S, R) = outE^i \cup U(out^i(E, S, R))$
- $out^{i+1}(E, S, R) = out^i(E, S, R) \cup \{l | L \rightarrow l \in outE^i(E,S,R), L \subseteq out^i(E,S,R)\}$
- $out(E, S, R) = \cup_o^\infty out^i(E, S, R)$

Here we are interested in the closure of a decision under a set of belief rules. The new belief rules of an agent *a* in situation *S* is R_a^+, defined by $R_a^+(S) = \{MD(b) \mid b \in B, +_a(b) \in S\}$.

We finally introduce decisions of agents; they must be consistent with the consequences of beliefs according to the agents **A** ($out(B_\mathbf{A}, \delta, R_\mathbf{A}^+)$). The set of decisions Δ is the set of sets $\delta_\mathbf{A} \subseteq Lit(X)$ such that their closures under the beliefs $out(B_\mathbf{A}, \delta, R_\mathbf{A}^+)$ do not contain a variable and its negation.

EXAMPLE 4 (Continued). $out(B_{\mathbf{B}},\{x_1,x_2\},R_{\mathbf{B}}^+) = \{x_1,x_2,s,\,+_{\mathbf{B}}(g_4)\}$. According to role **B**, $A's$ decision x_2 leads to s and adds goal b_4.

Finally, we relate our formalization to the last property of roles: the powers they have in the institution.

OBSERVATION 3. Roles have powers if there is some institutional fact (and, thus, also additions) which is influenced by an action of the role. For example, given a role $b \in RO$: $\exists x \in X_b$ such that the action x is included in the input of some constitutive rule $\exists m \ C \rightarrow p$ where $m \in CA$ and $x \in C$.

5. Related work

The meaning of the term social role in MAS only partially overlaps with the notion of social roles in social theory.

The functionalist approach in social theory considers a role as the set of expectations that a society places on individuals. Such expectations can be ascribed, like in the schoolchild role, or achieved, like in the university student role. In this paper we model only the latter type of roles. For this theory, collectively, a group of interlocking roles creates a social institution. Also in this paper, roles are associated with institutions.

Social theory considers also roles like friend, competitor, and paterfamilias which are not apparently connected with a formal institution, but we can cover some of these cases by means of informal institutions like friendship, the market, a family, etc.

A role, in the interactionalist social theory, is not fixed or prescribed, but something that is constantly negotiated between individuals in a tentative, creative way. These aspects go beyond the scope of this paper.

Turner (1968) delineates four types of roles: first, basic roles – such as gender and age roles – that are located in society rather than particular organizations; second, structural status roles – such as occupational, family, minister, nun – that are attached to office or status in particular organizations; third, functional group roles – such as mediator, leader, challenger – that are not formally designated or attached to group positions or offices but are recognized in the group culture; and, last, value roles – such as hero, traitor, heretic, saint - that embody values of the group. Clearly we focus on the second type of roles. Finally, social roles must be distinguished also from biological roles like young, adult, father, etc.

Social theory associates powers with roles too. However, powers in our context is a synonym of institutional power, while social theory considers also the case of power of influencing other people due to the associated status.

The relation between roles and power has been also noticed in the AI and Law field, among others by Demolombe and Louis (2005) and (Viganò and Colombetti 2006). For example, Demolombe and Louis (2005) define roles as a tuple composed of role name, conditions necessary to play the role, the obligations associated to it and its institutional powers. Roles are associated only informally to an institution. However, in our model we do not only connect roles and powers, but we identify powers as one of the defining features of roles in ontologies and we relate their possibility to the property of definitional dependence.

Finally, Breuker (2004) in his LRI-Core ontology distiguishes various kinds of roles (function, case role, etc.) and among them social roles. Social roles have a mental nature as in our model, however, in LRI-Core roles, and their definitions, are not explicitly bounded to an institution.

6. Summary

In this paper, we analyse the properties of social roles in MAS and OO, we identify new properties as distinguishing properties of roles in an ontology of MAS, and we provide a simple formal model of social institutions with roles. We attribute three main properties to roles First their definitional dependence: social roles exist only as they are defined by some social institution; second, besides rights and permissions, social roles are associated to powers in the institution they belong to. Finally, roles can play roles as any other agent, since in our model social roles should be considered as an agent.

In Figures 3 and 4, we reconsider the properties attributed in Section 3 to roles by, respectively, AO and OO, and we show how they are dealt with in

5 Roles define expected behavior and obligations: a role's goals are its responsibilities.

6 Roles define sets of rights: since institutions are modelled as normative systems they can associate not only obligations but also rights and authorizations to roles.

7 Roles embed behavior specific to a context; roles exist only and because of the institution they belong to: the institution is the context of a role defining its specific behavior.

8 Define common interactions: constitutive rules define also how an action of a player of a role affects the beliefs and goals of another role, thus allowing communication.

9 Promote an organizational view of the system: roles compose the organizational structure of an institution and the institution gives them the power to exogenously coordinate its own behavior.

Figure 3. Some properties of roles in AO.

1. Roles have properties, for example, each role has its own beliefs and goals. Moreover, roles have behavior in the sense that they can execute institutional actions via the actions of their players.

2. Dependence of roles from relationships is implied by the stronger notion of definitional dependence: the relation they depend on is the relation between the role and the social institution which defines it.

3. An agent may play different roles simultaneously: the role playing function is not surjective.

4. An agent may play the same role several times: a role is not defined by its beliefs and goals only, but also by the institution attributing them to the role. The same roles in two different institutions are different roles and nothing prevents to play both.

5. An agent may acquire and abandon roles dynamically: to play a role it is sufficient to know which beliefs and to adopt which goals the player is expected to have. The model can be extended with constitutive rules which affect the role playing relation.

6. The sequence in which roles may be acquired and relinquished is subject to restrictions which are specified in the constitutive rules of the social institution.

7. Objects of unrelated types can play the same role: to play a role it is necessary to be able to perform the actions which "count as" actions of the institution. A different issue is if the agent is suited to play a role, i.e., which are its beliefs and motivations.

8. Roles can play roles since roles are defined as agents and agents can play roles.

9. A role can be transferred from one agent to another: the new player is expected to behave as if it has the current beliefs and goals attributed to the role.

10. The state of an agent is role-specific: the agent's powers change with the role it is playing.

11. Features of an agent can be role-specific: according to its role, the agent has to act as if it has the beliefs and goals of the role.

12. Roles restrict access. Roles are accessed only via powers.

13. Different roles may share structure and behavior: role definitions can be organized in a hierarchical way.

14. An agent and its roles share identity. Roles are not real agents, but only descriptions of agents. So they have no identity as agents.

15. An agent and its roles have different identities and role are instances.

Figure 4. The properties of roles in OO revisited.

our model. Since the two lists of properties overlap, in Figure 3 we focus only on the properties which require the autonomy of the agent playing the role.

We propose a formalization of our model of roles using Input/Output logics. Goals and beliefs of agents are modelled as conditionals. Roles, as description of expected behaviour, are modelled as descriptions of agents and thus they are attributed mental attitudes too.

As stated in the introduction, the term social role refers to the sense it is used in ontologies and multi-agent systems. This meaning seems to correspond quite closely to the sense the term role is used by some authors in object oriented programming.

In this paper we describe the ontological properties of roles using our model of normative multi-agent systems. In Boella and van der Torre (2006b) we propose a logical model of roles with the same properties using an extension of Masolo et al. (2004)'s approach, rather than in MAS. Finally, our model of roles is being used as the basis to introduce roles in Object Oriented programming languages like Java (Baldoni et al. 2007).

In this way we offer a unified notion of roles in both Agent Oriented systems and Object Oriented ones. The integration between agent systems and more traditional OO systems can be fostered, e.g. agents can be used to play roles in OO systems. Moreover, agent systems implemented using OO architectures and languages already have roles at their disposal.

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