Task and Social Coordination in Agent Organizations

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Abstract

Support for new forms of organization and social interaction requires understanding the influence of structure on behavior. Goal dependencies indicate some relationship between roles, through which actions can be coordinated; and, social relationships determine power links between roles. Efficient coordination requires that goal dependency and power structure are well tuned to each other. In this paper, we will investigate what is the exact nature of this relationship between roles in an organization and what are the consequences of different structure forms. We will also see what is the difference if the relations are not hierarchical but organized through a market or network structure.

1 Introduction

One of the main issues in agent organizations is the specification of coordination mechanisms between agents playing roles in a regulated social environment. Coordination can be defined as the process of managing dependencies between activities [12]. One way to coordinate is to manage functional dependencies. In this sense, which is the most commonly used in Multi-Agent Systems (MAS) research, coordination refers to the allocations of tasks to agents, such that common goals are achieved. Coming forth from Organizational Theory, another way to manage dependencies, considers the supervision and collaboration relations between actors. In this sense, coordination refers to the specification of power and authority relations between agents. Although the two perspectives are interrelated, they are based on different concepts and views on organizations, and their differences are not explicitly accounted for in most MAS models.

Both in Organizational Theory as in MAS, the concept of *role* plays an important role in the specification of coordination. We present a role-based model for organizations that integrates both views. *Role hierarchies* define the links through which one role can exercise power over, or otherwise influence, other role. This means that a role can demand the realization of a goal from another role, or request goals from another roles. In organizational contexts this can also mean that the responsibility of some tasks lays with the role in top of the hierarchy. *Role dependencies* indicate how the goals of different roles depend on each other, and how interaction is to be achieved. Each role dependency indicates a need for coordination between those roles. The way interaction is to be organized between the roles, depends on the organizational power structures between the roles.

In this paper, we discuss the implications of the coordination type to the dependencies between roles. Given that one role depends on another to achieve a goal, the realization of that goal will depend on the social relationship between the roles, that is, whether the role has power over the other role. We distinguish between hierarchical, network and market social relationships between roles. Although role hierarchies can be thought of in terms of hierarchical organizations, we argue that the reason to call an organization hierarchical is not just because the roles are structured in some kind of a hierarchy (or tree), but has more bearing on the type of coordination used between roles that are related. A tree shaped organization usually also indicates that the roles coordinate in a hierarchical way (through commands), but this is not necessarily so. Even in such an organization, each role might offer a task to its "subordinates" (using something like contract net and a market mechanism) instead of delegating it.

The paper is organized as follows. In sections 2 and 3 we introduce both perspectives on coordination: from Organizational Theory as the representation of the social structure, and from MAS as the specification of task relationships. In section 4, we describe how the concept of role can integrate both views, by means of role dependencies and coordination types. Section 5 shows the consequences of this integration for the semantics of the role-based coordination model. Finally, we present our conclusions and directions for future research in section 6.

2 Social Structure

Social structures are the medium for human activities. Support for new forms of social interaction and organization requires understanding the influence of structure on behavior. Behavior and structure are interleaved; people go through a socialization process and become dependent of the existing social structures, but at the same time structures are modified by their activities. Giddens' *structuration theory* offers an account of social life in terms of structure and agency [10]. Giddens argues that order, or structure, is primarily created as a medium for practical activity. This instantiation of practical activity is not based on a even distribution of power and resources, but asymmetry and domination are, in fact, part of the natural order. Different power relations between actors and the utilization of different resources are at the basis of the development of particular structural principles. It is useful to consider groups and organizations from a structuration perspective because doing so: (a) helps one understand the relative balance of deterministic influences and willful choices that characterize groups; (b) suggests possibilities for how members may be able to exercise more influence than they otherwise think themselves capable of [4].

Organizational science and economics have since long researched these organizational structures [18, 15]. Drawing on disciplines such as sociology and psychology, research in organization theory focuses on how people coordinate their activities in formal organizations. Relationships between and within organizations are developed for the exchange of goods, resources, information and so on. Williamson argues that the transaction costs are determinant for the organizational model [18]. Transaction costs will rise when the unpredictability and uncertainty of events increases, and/or when transactions require very specific investments, and/or when the risk of opportunistic behavior of partners is high. When transaction costs are high, societies tend to choose a hierarchical model in order to control the transaction process. If transaction costs are low, that is, are straightforward, non- repetitive and require no transaction-specific investments, then the market is the optimal choice. Powell introduces networks as another possible coordination model [15]. Networks stress the interdependence between different organizational actors and pay a lot of attention to the development and maintenance of (communicative) relationships, and the definition of rules and norms of conduct within the network. At the same time, actors are independent, have their own interests, and can be allied to different networks. That is, transaction costs and interdependencies in organizational relationships determine different models for organizational coordination. The characteristics of the different forms of organization are summarized in table 1.

In human organizations and societies, norms and conventions are usually used to cope with the challenge of social order. Norms and conventions specify the behavior that society members are expected to conform to and are suitable means for decentralized control. Several researchers have recognized that the design of agent societies can benefit from abstractions analogous to those employed by our robust and relatively successful societies and organizations. There is a growing body of work that touches upon the concepts of norms and institutions in the context of multi-agent systems (cf. [5, 8]).

Role theory bridges social psychology, sociology, and anthropology [1], and recently has interested agent researchers. Its central concern has been with patterns of conduct, that is, expectations, identities, and social positions; and with context and social structure. Fox et al. introduce an organizational taxonomy which includes organizations, organizational goals, roles, and authority [9]. Agents can play roles, which potentially give them authority over other agents playing other roles. Empowerment and authority are recognized as critical aspects, since these identify

	Market	**Network**	**Hierarchy**
Coordination	Price mechanism	Collaboration	Supervision
Relation form	Competition	Mutual interest	Authority
Communication	Prices	Relationships	Routines
Climate	Precision-suspicion	Mutual benefits	Formal-bureaucratic
Cooperation	None expected	Negotiation of cooperation	Absolute expected
Conflict resolution	Haggling	Reciprocity-Reputation	Supervision

Table 1: Comparison of organizational forms

which roles (and hence which agents) are enabled to perform which actions.

3 Task Coordination

Multi-agent coordination, defined as managing interdependencies between activities, addresses the special issues arising from the dependency relationships between multiple agents tasks. The coordination structure must support the task-solving process using a generic mediation mechanism and should provide communication protocols to link the agents having common interests.

In Distributed Artificial Intelligence (DAI), coordination approaches are often based on contracting. The most famous example of these is the Contract Net Protocol (CNP) [17] for decentralized task allocation. CNP was designed to handle applications with a natural spatial distribution. It assumes a network of loosely coupled asynchronous nodes (agents), each containing a number of distinct knowledge sources. The agents are interconnected so that each agent can communicate with every other agent by sending messages. Agents can either execute tasks or have tasks that need to be executed. CNP provides a simple language to describe contracts for task execution in messages between agents.

By employing standard interaction mechanisms, the agents in the MAS can expect certain behavior. The behavior of each individual is determined to a great extent by the requirements of these interaction patterns. Roles provide both the building blocks for agent social systems and the requirements by which agents interact. Each agent is linked to other agents by the roles it plays by virtue of the applications functional requirements which are based on the expectations that the application has of the agent [13].

4 Roles and dependencies

Coordination in MAS, as shown above, is mainly taken care of by using standard interaction mechanisms, task allocation and planning. Global goals and requirements of users and stakeholders are completely implicit in the way task allocation is implemented, and there is no direct way to validate them. Organizational theory and social economics have devoted a great deal of research to the analysis of the motivations and implications of coordination structures, which can be of value for the improvement of coordination issues in MAS. An ongoing approach to this issue is to be found in attempts to model MAS as agent societies.

The idea of Agent Societies is that interactions occur not just by accident but aim at achieving some desired global goals. Global goals are external to each individual participant (or agent) but can only be reached by the interaction of those participants. The design of agent organizations must capture on the one hand, the structure and requirements of the society owners, and on the other hand, must assume that participating agents must be available that are able and interested in

enacting society roles. The OperA Model for agent societies [7] integrates a top-down specification of the society objectives and global structure, with a dynamic fulfillment of roles and interactions by independent participants. That is, the model separates the description of the structure and global behavior of the domain from the specification of the individual entities that populate the domain. Agents are actors that perform role(s) described by the society design. The agent's own capabilities and aims determine the specific way an agent enacts its role(s). An OperA model can be thought of as a kind of abstract protocol that governs how member agents should act according to social requirements. In this paper, we will only describe a few elements of the organizational model. In the next sections, we discuss how this model for agent coordination, based on organizational theory, can be used for social and task dependencies between roles.

4.1 Roles

Roles identify the activities and services necessary to achieve social objectives and enable to abstract from the specific individuals that will eventually perform them. From a society design perspective, roles provide the building blocks for agent systems that can perform the role, and from the agent design perspective, roles specify the expectations of the society with respect to the agent's activity in the society. Roles also define normative behavioral repertoires for agents [14]. That is, a role is the abstract representation of a policy, service or function.

In OperA, roles are described in terms of *objectives* and *sub-objectives* (that is, what is an actor of the role expected to achieve) and *norms* (that is, how is an actor expected to behave). Furthermore, role descriptions also specify the *rights* associated with the role and the *type* of enactment of the role, that is, whether it is an institutional role (which behavior is controlled by the society) or a external role.

The specification of objectives and sub-objectives can be more or less restrictive on the actor performance. The more the aspects that are fixed in the specification, the less the freedom an agent enacting the role has to decide on how to achieve the role objectives and interpret its norms. Following the ideas of [11], we call such expressions *landmarks*. Formally, landmarks are conjunctions of logical expressions that are true in a state. Intuitively, landmarks provide a description of a place or situation, which is enough to identify it but without prescribing any specific process. Several different specific actions can bring about the same state, and therefore, landmarks represent actually families of protocols. The use of landmarks to describe activity, enables the actors to choose the best applicable actions, according to their goals and capabilities. The level of specification of landmarks determines the degree of freedom the actors have about their performance.

Role objectives are thus states of affairs expected to be achieved in the environment. Once a society model is animated, the objectives of a role are expected to be executed by the agent(s) enacting that role, that is, role objectives should become part of the goals of the enacting agent. Intuitively, role objectives enable the 'link' between society objectives and agent goals. At this level of abstraction, role objectives do not have a fixed semantics since roles are not performative entities but mere 'placeholders' for actors. The actual semantics of objectives depend on the way objectives are treated and assumed by the agent acting the role and on the semantics of agent goals in the agent model.

Definition 1 (Role Objective) *A role objective, represented by ρ, is a predicate describing an ideal state (or set of states) for the role. P_r is the set of objectives of role r.* □

Roles are identified by their objectives, that is, different roles have different objectives and all roles must have at least one objective. Formally:

1. $\forall r_1, r_2 : r_1 = r_2 \Leftrightarrow P_{r_1} = P_{r_2}$
2. $\forall r : P_r \neq \{\}$

A role objective ρ can be further described by specifying a set of sub-objectives that must hold in order to achieve objective ρ. Sub-objectives give an indication of how an objective is to

be achieved, that is, describe the states that are part of any plan that an agent enacting the role can specify to achieve that objective. Sub-objectives abstract from any temporal issues that must be present in a plan, and as such must not be equated with plans. Intuitively, sub-objectives are objectives that contribute to the realization of another objective. That is, if $\Pi_\rho = \{\rho_1, ..., \rho_n\}$ is a set of sub-objectives for ρ, the realization of all sub-objectives in Π_ρ yields the realization of ρ. Furthermore, for each objective ρ, the trivial set of sub-objectives ρ is defined.

For example, in a Conference Organization, the objective of the PC-member role is to review papers submitted to the conference, that is, to be in a state in which there are review reports for all the papers assigned to her. Sub-objectives of that objective are (a) to have read the paper, (b) to have written the review report, and, (c) to have sent the report to the organizers. How an actor of the PC-member role is going to achieve this, and indeed if she herself will do it (e.g. she can ask a student to read the paper and make the review report) is not, in this situation, a concern of the society.

4.2 Coordination types

Different application contexts exhibit different needs with respect to coordination, and the choice of a coordination model will have great impact on the design of the agent society. The implications of the coordination type to the architecture and design of agent societies have usually not been considered. In this paper, we distinguish between three coordination types: hierarchies, markets and networks, which result in different frameworks for agent societies.

Global objectives of a society are domain dependent, but the way agents coordinate to achieve those objectives depends on the coordination requirements and socio-cultural characteristics of the society. Societies depend on a facilitation layer that provides the social backbone of the organization [3]. Facilitation activities deal with the functioning of the society itself and are related to the underlying coordination model.On top of this facilitation layer, an operational layer is needed that implements the objectives of the society. Operational activities are directly related to the objectives and aims of the society. The social coordination model is used to specify the facilitation framework for an agent society.

The chosen coordination model determines the facilitation style of the society. In **markets**, agents are self-interested (i.e. determine and follow their own goals) and value their freedom of association and own judgement above security and trust issues. Openness is thus a feature of markets. Facilitation in markets is, in the most extreme case, limited to identification and matchmaking activities, but usually also includes the specification of some trusted third party, such as a bank. Interaction in markets occurs through communication and negotiation. **Network** organizations are built around general patterns of interaction or contracts. Relationships are dependent on clear communication patterns and social norms. Agents in a network society are still self-interested but are willing to trade some of their freedom to obtain secure relations and trust. Therefore, agents need to enter a social contract with the network society in which they commit themselves to act within and according to the norms and rules of the society. The society is responsible to make its rules and norms known to potential members. Coordination is achieved by mutual interest, possibly using trusted third parties, and according to well-defined rules and sanctions. Finally, in a **hierarchy**, interaction lines are well defined and the facilitation level assumes the function of global control of the society and coordination of interaction with the outside world. In a hierarchy, agents are cooperative, not motivated by self interest and all contribute to a common global goal. Coordination is achieved through command and control lines.

The coordination model determines interaction patterns and functionality of the facilitation layer of the society, that is, the interaction primitives and agent roles necessary to implement the facilitation layer that are specific to each type of society (market, network or hierarchy). Moreover, coordination models provide a framework to express interaction between the activities of agents and the behavior of the system [2].

4.3 Dependencies between roles

The notion of role is closely related to those of cooperation and coordination. The way tasks, or objectives, are allocated to roles determines the dependencies between them. These dependencies describe how agents enacting the roles should interact and contribute to the realization of the objectives of each other. That is, an objective of a role can be delegated to, or requested from, other roles. The dependency relation between roles r_1 and r_2 for objective γ of r_1, represented by $r_1 \succeq_\rho r_2$, indicates that objective ρ can be passed to r_2, that is, that r_2 can realize objective ρ for r_1.

Definition 2 (Role dependency) *A dependency relation $r_1 \succeq_\rho r_2$ describes the fact that role r_1 depends on role r_2 to realize (sub)objective ρ. The relation $\succeq_\rho \in R \times R$ is reflexive and transitive. That is, for all $r_1, r_2, r_3 \in R$,*

1. $r_1 \succeq_\rho r_1$
2. $r_1 \succeq_\rho r_2$ *and* $r_2 \succeq_\rho r_3$ *implies* $r_1 \succeq_\rho r_3$. □

In OperA, roles are organized as a partially ordered set, represented as $\Re = (R, \succeq)$ that reflects role dependencies. A dependency graph represents the dependency relations between roles. Nodes in a dependency graph are roles in the agent society. Arcs are labelled with the objectives of the parent role for which realization the parent role depends on the child role. There can be more than one arc between two nodes, representing the fact that the parent role depends on the child role for more than one of its objectives. The root of the graph is the society itself, represented as a super-role, and contains the global objectives of the society, which are then decomposed into role objectives distributed along the role tree. The dependency graph for the Conference Organization is displayed in figure 1. For example, the arc labelled $paper{-}reviewed$, r, between nodes $PCchair$, C, and $PCmember$, M, represents the role dependency $C \succeq_r M$. Note that this graph does not have to be a tree. It should only be partially ordered (to avoid circular dependencies).

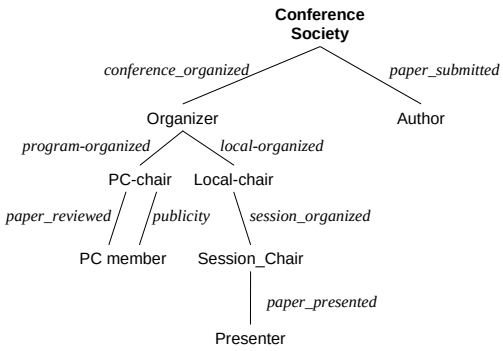

Figure 1: Role dependencies in the conference society.

Considering that dependencies require interaction between two actors in order to establish how to pass the objective from one actor to the other, it is necessary to describe how this interaction occurs. In OperA, this is determined by the three coordination types discussed in the previous section: hierarchy, market and network. The way the objective ρ in a dependency relation $r_1 \succeq_\rho r_2$ is actually passed between r_1 and r_2 depends on the coordination type of the society:

- In hierarchies, the parent role demands the realization of its sub-objectives from its children. In this case, the enactor of a children role can not decide which objectives it will get but must accept whichever objectives are delegated to it by its parent role. Hierarchical dependencies are represented by $r_1 \succeq_\rho^H r_2$.
- In markets, a child role can request the assignment of objectives from the parent role; the parent role will then decide whether allocation is desired and which instance of the child role

will get to realize the objective. In this case, the enactors of a child role can choose which objectives of its parent they will request, such that it best fits its own private goals. Market dependencies are represented by $r_1 \succeq_\rho^M r_2$.

- In a network, both situations can happen. That is, an objective can either be delegated by the parent role or requested by the child role, which defines an equivalence relation between related roles in a network. This can depend on prior agreements between the agents, or be negotiated for each specific situation. Network dependencies are represented by $r_1 \succeq_\rho^N r_2$.

Role dependencies illustrated in figure 1 are therefore interpreted in different ways depending on the coordination type holding in the society. For instance, in the case of an hierarchy, the relation $C \succeq_r M$, indicates that agents enacting the role $PCchair$, C, will delegate the objective $paper{-}reviewed$, r, to an enactor of role $PCmember$, M. In a market dependency relation, enactors of $PCmember$ can bid for objective review-paper to the enactor of $PCchair$, that is, a PC member can choose which papers they want to review and apply for those to the Program Chair. In a network, a dependency relation represents a request that can be initiated either by the parent or the child roles.

5 Coordination and dependency relations

In this section, we discuss in more detail what are consequences of the type of coordination mechanism to the interaction between roles, and how they influence the semantics of the communication between agents.

5.1 Implications of Dependencies

In organizational systems, it is usual to organize roles in a inheritance, or *is-a*, hierarchy. In such hierarchies, child roles inherit the characteristics (attributes, rights, norms) of its parent roles. However, other relationships can hold between roles. Dependency relations in OperA are not inheritance relations, but define the links through which objectives can be delegated to other roles. Coordination of behavior is relatively easy when in a hierarchical society, in which case when an agent i enacts a role that is superior to the role that agent j enacts, a request from i will result in an obligation for j. In networks and markets, however, coordination requires some more effort. Hierarchical organizations are thus very efficient, in that, task allocation occurs with no need for negotiation, given the power relations between agents. On the other hand, networks are more flexible, in that agents can negotiate task allocation between them so that they can attempt to obtain a most preferred assignment of objectives fitting with their own goals. In general, one can identify three different reasons for an agent to commit itself to a request from another agent [6]:

- **Power**: j accepts a request from i because of some domination relationship between i and j. This type of relation is standard in hierarchical societies, but can also be explicitly defined between two specific roles, in other types of societies. Power relations are represented by $power(i, j, \varphi)$, indicating that i has power over j for φ.

- **Authorization**: when j has committed itself to i for a certain service, a request from i leads to an obligation when the conditions are met. This relation is established by mutual agreement, e.g. in a (previous) interaction, for a certain time and under certain conditions. Although authorization relations can happen in any type of society, they are typical of networks (e.g. where participants can negotiate different approaches to goal realization in each situation). Authorization relations are represented by $auth(i, j, \varphi)$, meaning that i is authorized by j to do φ.

- **Charity**: j will answer a request from i without being obliged to do so. An obligation arises when the agent answers with a positive commitment.

The main difference between power and authorization relationships is that power is structurally determined and, for a great extent, static; that is, power relations are not influenced by the actions of the agents. On the other hand, authorization relations can be created by negotiation between agents; that is, an agent can decide to authorize another agent to request from it a certain action or resource. In the following, we describe the implications of power and authorization relations over the interaction behavior of the agents. For a complete description of the semantics, we refer the reader to [7]. Charity relations do not have a specific operator, since such relations are completely dependent on the 'personality' of the agent establishing such relation, and cannot thus be influenced or negotiated.

Definition 3 (Power relation) *$r_1 \succeq^H_\varphi r_2$, the hierarchical dependency relation between roles r_1 and r_2 gives rise to a power relation $power(i, j, \varphi)$ between agents i and j in all scenes s, such that rea(i, r_1, s) and rea(j, r_2, s). Where rea(i, r_1, s) means that agent i performs role r_1 in scene s.* □

The expression $power(i, j, \varphi)$ means informally that i has the power to force j to achieve φ. Power relations are *reflexive*, i.e. each agent has power over itself, and often, but not always, also *transitive*, that is, if $power(i, j, \varphi)$ and $power(i, k, \varphi)$ then $power(i, k, \varphi)$. Moreover, power to demand φ implies power to demand all what can be derived from φ. Formally, the following axiom holds for the power relation:

Definition 4 (Reflexivity of power relation) *Given expression φ and a role i, the following axiom holds:*

$\models \forall i : power(i, i, \varphi)$. □

Authorization relations describe situations when power can be (temporarily) effective. Informally, an authorization, $auth(i, j, \varphi)$ means that i is authorized by j to achieve φ. In fact, authorization establishes a agreed power relation of i over j for φ. Furthermore, authorization relations always hold in the case of a power relation. That is, if an agent i has the power to request φ from agent j, then agent i is also authorized to request j to achieve φ.

Definition 5 (Authorization relation) *Given expression φ and agents i and j, the following axiom holds:*

$\models \forall \varphi, i, j : power(i, j, \varphi) \rightarrow auth(i, j, \varphi)$. □

The different semantics of dependencies relations relative to the coordination structures, are defined over power and authorization relations between roles.

Definition 6 (Axioms for dependency relations) *Given two roles r_1 and r_2, the following axioms hold:*

1. $r_1 \succeq^H_\varphi r_2 \rightarrow power(r_1, r_2, \varphi)$
2. $r_1 \succeq^M_\varphi r_2 \rightarrow auth(r_2, r_1, request(r_2, r_1, \varphi))$
3. $r_1 \succeq^H_\varphi r_2 \rightarrow (auth(r_2, r_1, request(r_2, r_1, \varphi))$
   $\wedge\, auth(r_1, r_2, request(r_1, r_2, \varphi)))$. □

Note that the network relation defines the equivalence relation between r_1 and r_2 for objective φ, that is $r_1 \succeq^H_\varphi r_2 \leftrightarrow r_2 \succeq^H_\varphi r_1$. This is in accordance with the concept of network in OperA, which assumes peer relationships between roles. The relation is therefore symmetric. Consider again the role dependency, $C \succeq_r M$ in the example described above, representing the dependency between PC chair and PC member. Depending on the coordination type chosen to model this society, three interpretations of the relationship are possible: (1) if a hierarchy model is chosen, the dependency is interpreted as a power relation, i.e. the program chair will demand reviews from the PC members, which is the most common way of interaction in conference committees; (2) if a market model is chosen, the dependency is interpreted as a authorization, i.e. the PC members can request the papers they want to review from the program chair; and (3) if a network model is chosen, the dependency relation identifies an equivalence, i.e. there is no difference between program chair and PC members wrt the paper reviewing objective.

5.2 Realizing Coordination

We assume that all interaction is realized through communication. Communication between agents fulfilling roles can be described in terms of speech acts [16]. The illocution of a speech act is the content of the message that the speaker intends to be recognized by the hearer as what the speaker intends to be doing (informing, requesting, agreeing, etc.). The illocutionary force of a speech act is the combination of the illocutionary point of an utterance, and the particular presuppositions and attitudes that accompany that point, and therefore depends on the social relationship between the agents. Speech acts have different effects, depending on the type of social dependency between the agents. For example, a request to agent x has another force whether it is done by an agent with power over x, than by any other agent.

Definition 7 (Communicative Acts) *Given a domain language L_D and the basic communicative acts* `request`, `commit`, `inform` *and* `declare`, *the set of all communicative acts $Comm_D$, is defined as: (1) $Ill(i, j, \varphi) \in Comm_D$, where Ill is a basic communicative act, and (2) if $\iota \in Comm_D$ then also $Ill(i, j, \iota), Ill(i, j, \neg\iota) \in Comm_D$.*

The intended effects of communicative acts are described bellow by means of deontic and epistemic operators, and using the dependency relations between agents. For instance, a request uttered in the case that there is a power or authorization relation, will have a different meaning if such relation does not exist. In the following, we formally define the intended effects of communicative acts:

Definition 8 (Axioms for communicative acts) *The formal semantics of basic speech acts are:*

1. $\models commit(i, j, \varphi) \rightarrow O_{ij}\varphi$
2. $\models power(i, j, \varphi) \rightarrow auth(i, j, request(i, j, \varphi))$
3. $\models (request(i, j, \varphi) \wedge auth(i, j, request(i, j, \varphi))) \rightarrow O_{ji}\varphi$
4. $\models inform(i, j, \varphi) \rightarrow B_j(B_i\varphi)$
5. $\models (declare(i, j, \varphi) \wedge power(i, j, declare(i, j, \varphi))) \rightarrow \varphi$
6. $\models (declare(i, j, \varphi) \wedge auth(i, j, declare(i, j, \varphi))) \rightarrow \varphi$

These axioms describe how obligations can arise for an agent: by means of a request based on a power or authorization relation, or by committing itself. For simplicity sake, we do not consider any temporal issues in the semantics above. In reality, the semantics of OperA are based on the temporal logic, CTL*. Furthermore, in the axioms above, it is assumed that agents are sincere, and its intentions are reflected in the communicative act used (e.g. case 5, on beliefs). To illustrate the effect of communication between roles, we will use the example of the dependency for paper review, r between a Program Chair, C, and a PC member, M. Different social dependencies give rise to different attitudes concerning the communication:

- In a hierarchical relation, $C \succeq_r^H M$, the power relation $power(C, M, r)$ holds. Therefore, according to axiom 1 of definition 6 and axioms 2, 3 above, a request from C to M for paper-reviewed results in an obligation for M: $O_{MC}r$.
- In a market relation, $C \succeq_r^M M$, the authorization relation $auth(M, C, request(M, C, r))$ holds. Therefore, according to axiom 2 of definition 6 and axiom 3 above, a request from M to C for paper-reviewed results in an obligation for C: $OCMr$, which means that the C will have the paper reviewed by M.
- In a network relation, $C \succeq_r^N M$, both authorization relations $auth(C, M, request(C, M, r))$ and $auth(M, C, request(M, C, r))$ hold. Therefore, according to axiom 3 of definition 6 and axiom 3 above, a request from C to M for r results in a commitment for M to review the paper, and a request from M to C for r results in a commitment for C to have the paper reviewed by M.

6 Conclusion

In this paper we have argued that organizational structures are important for MAS. In line with other current research we think that these structures need to exist outside the individual agents in order to ensure the achievement of objectives of the organization that rise above the individual agent level. By having explicit organizational structures we also ensure the stability of the organization over a longer period of time.

We have shown that the organizational structure consists of several inter-related elements. We have concentrated mostly on the role dependencies that arise from the dependencies between the objectives of those roles. These dependencies seem to indicate the basic needs of coordination between the roles. Moreover we have shown that the basic coordination types from organizational theory (market, hierarchy and network) are also very useful for MAS design. Starting from the dependencies between roles that follow from their objectives, these coordination types determine how the interaction between the dependent roles is shaped. The coordination type of the organization also influences the type of facilitation roles that are needed in that organization, such as a matchmaker for a market and a gate keeper for a network organization.

In future research we hope to show how some characteristics of the coordination types and the environment determine the best structure to be used for a MAS in a particular environment. Although we will base our theory on the formal theory underlying the OperA model, we will use simulations to check for the organizational characteristics that will benefit the organization best in a certain environment.

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