Organizational Structure and Responsibility

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Abstract. We analyze the organizational structure of multi-agent systems and explain the precise added value and the effects of such organizational structure on the involved agents. To pursue this aim, contributions from social and organization theory are considered which provide a solid theoretical foundation to this analysis. We argue that organizational structures should be seen along at least three dimensions, instead of just one: power, coordination, and control. In order to systematize the approach, formal tools are used to describe the organizational structure as well as the effect of such structures on the activities in multi-agent systems, and especially the responsibilities within organizations of agents. The main aim of the research is to provide a formal analysis of the connections between collective obligations to individual responsibilities. Which individual agent in a group should be held responsible if an obligation directed to the whole group is not fulfilled? We will show how the three dimensions of an organizational structure together with a specific task decomposition determine the responsibilities within a (norm-governed) organization.

1 Introduction

The concept of responsibility is a central concept to all legal systems and norm-governed organizations. Analyzing this concept is therefore fundamental if we aim at improving the behavior of these systems or organizations. Obtaining a formal representation of responsibility, however, is quite complex because of the very different meanings of this concept can take. Our concept of responsibility is restricted to the analysis of organizational performance. Therefore, we clarify and classify some meanings of responsibility and we relate them to the three relevant dimensions of an organizational structure we isolated in [1]. These three relevant dimensions are power, coordination and control, with their matching actions 'to delegate', 'to inform' and 'to monitor'. The coordination actions are actually only one type of meta actions that should be considered. Besides the plan to achieve the content of the obligation the group should create that plan, allocate agents to parts of the plan, create a plan for what to do when the original plan fails, etc. These meta actions should also be coordinated again creating in the end an infinite regression of meta actions. In this paper we will not take all these layers into account, but will limit us to the coordination actions that are necessary to indicate the several notions of responsibility.

In this article we will import some of the studies in organizations and social theory to describe a more rigorous foundation of organizational structures in MAS, which will

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be informally and formally exposed in Section 2. In order to describe organizational structures we have to first describe exactly what the meaning is of the relations that form the structure. E.g. what is the meaning of an "power" relation and, maybe even more importantly, what are the consequences of the existence of such a relation between two agents? We will introduce a modal logic for this characterization. Several notions of responsibility (given a plan) will be discussed formally in Section 3. How the individual responsibilities relate to the underlying structure of an organization will be discussed in Section 4. In the last section, we will draw some conclusions and give directions for future research.

2 Organizational Structure and its Logic

The thesis we hold in this paper, which is inspired by foundational work on social and organization theory like [2–5], is that organizations do not exhibit one single structural dimension, but that they are instead multi-structured objects. In particular, we view organizational structure as hiding at least three relevant dimensions which we call: power, information and control. We will analyze **power** in relation with the delegation activity, **coordination** in relation with the knowledge and information issues, and **control** in relation with the monitoring and recovery issues. As a result of this analysis, organizations will be represented as explicitly displaying a triple structure constrained on the basis of the interplay between the three notions of power, coordination, and control. It is the structure based on goal or task decomposition and related to power and delegation capabilities between the roles. Although we do not pretend to give full definitions of these relations (see [6, 7] for some more elaborate definitions of the delegation and power relations) we will characterize these relations in terms of some of their consequences for the agents, enacting the roles, between which these relations are defined.

To describe an organization and its structure we will use a (typed) multi-modal propositional logic. The organizational structures are denoted through the special propositions $Power(r, s)$ to indicate that 'the agent enacting role r has the agent enacting role s in its power' (i.e. the agent playing role r can delegate goals to the agent playing role s), $Coordination(r, s)$ to indicate that 'the agent enacting role s has access to the information that is accessible to the agent enacting role r', and $Control(r, s)$ to indicate that 'the agent enacting role r controls the agent enacting role s' (i.e. the agent playing role r is responsible for the agent playing role s). Note that these relations are defined on roles. We denote the fact that agent i enacts role r, i.e., is a *role enacting agent* ([8]), by the special proposition $rea(i, r)$. Furthermore we use a modal operator K_i for knowledge accessible to an agent i. For the characterization of the organization structures we build on dynamic logic ([9]). Dynamic formulas such as $[\xi]\phi$, meaning that after each execution of ξ formula ϕ holds, where ξ is a parameterized construct of the type $i : \alpha$ denoting the performance of action α by agent or role i, or a composed construct such as: $i : \alpha_1; j : \alpha_2$ (subsequent performance), $i : \alpha_1 \& j : \alpha_2$ (parallel performance), $\overline{i : \alpha}$ (i refrains from performing α). The formal semantics is given by means of a Kripke structure where there are accessibility relations $R_{i:\alpha}$ associated with each parameterized action $i : \alpha$.

We can now give a full formal definition of the syntax of our description language Org:

Definition 1. (Syntax of Org)
Given a finite set AR of role names, a finite set Ag of agent names, a countable set P_0 of atomic propositions, a finite set of parameterized actions $\mathcal{A}$ (in general the elements of $\mathcal{A}$ are denoted by $i : \alpha$ with i in Ag the performing agent of α) containing at least $i : achieve(\phi)$, $i : delegate(j, \phi)$, $i : inform(j, \phi)$ and $i : monitor(\phi)$, the propositional language L_p that is built up from atoms P_0, the countable set $P = L_p \cup \{Power(r, s)$, $Coordination(r, s)$, $Control(r, s)$, $rea(i, r) \mid r, s \in AR, i \in Ag, \phi \in L_p\}$, the admissible formulas are recursively defined as follows:

- $P \subseteq Org$
- *If ϕ and $\psi \in Org$, then $\phi \wedge \psi$, $\neg\phi \in Org$*
- *If $\phi \in Org$ and $i \in A$, then $K_i(\phi) \in Org$*
- *If $\phi \in Org$ and $i : \alpha \in \mathcal{A}$, then $[i : \alpha]\phi \in Org$*
- *If $i : \alpha \in \mathcal{A}$, then $DONE(i : \alpha), DO(i : \alpha), O(i : \alpha)$ and $Can(i : \alpha) \in Org$*

Binary connectives $\rightarrow$ and $\vee$, and nullary connective $\perp$ can be defined as usual. For the knowledge operators (K_i) we assume the axiomatization characterizing $\mathbf{S5}$. The assertions DONE($i : \alpha$) stands for "α has just been performed by agent i", DO($i : \alpha$) stands for "α is going to be the next action performed by agent i", and $CAN_i(\alpha)$) stands for "α lies in the capabilities of agent i". $O(i : \alpha)$ is the deontic assertion to the effect that agent i ought to perform action α.

The semantics of Org will be given in two steps. First we define the semantics of the special relations $Power$, $Coordination$ and $Control$ through a multi-digraph defined on the set of roles. This defines a tuple OS which will be part of the Kripke model given after. We will only introduce some basic elements which are strictly of use for the development of this article.

Definition 2. (Organizational structures)
OS is characterized by the following:

$$\langle Roles \cup Agents, \{R_{Power}, R_{Coordination}, R_{Control}, Rea\}\rangle$$

where $Roles \cup Agents$ is the finite set of roles and agents;
and $\{R_{Power}, R_{Coordination}, R_{Control}\}$ are three irreflexive binary relations on $Roles$ characterizing the Power, Coordination and Control structures. Rea indicates which agents play which roles.

The semantics of Org is defined in terms of Kripke models (cf. [1]).

3 A Formal Analysis

3.1 Task Allocation

In order for organizations to fulfill their objectives, subtasks are isolated via a form of organizational planning and distributed in a way which defines the roles agents can play

in contributing to the performance of the organization. We call this designing process of the activity of an organization *task-allocation*. Roles can then be seen as sort of placeholders in a rationally designed activity of an organizations: an agent taking part to the organization will occupy one of these places, that is, will play a role. In this work, agents playing a role in an organization are called, following [8], *role enacting agents* or *rea*'s.

The distribution of the sub-tasks in an organization in order to achieve a certain goal or collective task τ depends on a plan of the organization, i.e., a concrete manner to achieve the goal (collective task). We can define a plan to achieve a certain goal τ as a decomposition of the complex action $achieve(\tau)$ by a sequence of (possible simultaneous) individual actions. Besides task division, task allocation is needed, which indicates which role of the organization has to achieve which sub-task of the complex task. We use the following definition for task allocation:

Definition 3. (Task allocation)
A task allocation for a task τ within the set of roles AR is defined as follows:

$$\langle r_1 : achieve(\tau_1) \bullet r_2 : achieve(\tau_2) \bullet \ldots \bullet r_n : achieve(\tau_n)\rangle$$

such that $r_1 : achieve(\tau_1) \bullet r_2 : achieve(\tau_2) \bullet \ldots \bullet r_n : achieve(\tau_n)]\tau$. We refer to the task allocation of τ within AR as $Plan(AR, \tau)$. To indicate that task $achieve(\tau_j)$ has been allocated to role r_j in $Plan(AR, \tau)$ (for $j = 1, 2, \ldots, n$), we use the following notation: $\langle r_j : \tau_j\rangle \in Plan(AR, \tau)$[3].

where $\bullet$ stands for either the simultaneous operator '$\&$' or the sequential operator '$;$'. $r_1 : achieve(\tau_1) \& r_2 : achieve(\tau_2)$ stands for the simultaneous performance of $achieve(\tau_1)$ by an agent enacting role r_1 and $achieve(\tau_2)$ by an agent enacting role r_2, and $r_1 : achieve(\tau_1); r_2 : achieve(\tau_2)$ stands for the sequential composition of $r_1 : achieve(\tau_1)$ and $r_2 : achieve(\tau_2)$.

We need the simultaneous operator, since some actions have to be performed at the same time. The sequential operator is needed because some actions might depend on other ones: a certain action can only be performed if an other action is done. So, the plan must at least determine the *order* of sub-actions. For example, the notification of acceptance of a certain paper by an Editorial Board can only be done if it is reviewed by some members of the Editorial Board.

We will use the concept of task allocation as a starting point for framing the various notions we are interested in. In particular, as we will see in the coming section, it plays an essential role for the definition of the notion of task-based responsibility. Besides, we will analyze the notion of "failure" in the accomplishment of a task understanding it as an organizational variant of the notion of social harm described in [10]. In our context, we define the *untoward event* $D\tau_r$ as the impossibility, or the reduction of the possibility to achieve the goal τ allocated to role r. The performance of an action α by an agent i enacting role r determining social harm can then be represented as $[i : \alpha]D\tau_r$, that means, after each execution of action α by agent i the social harm represented by $D\tau_r$ is the case.

[3] Note that the function of the numeric index j consists in denoting the position within the task allocation sequence.

3.2 Responsibilities in Form

So far we have dealt with organizations at their role level, where the task-allocation and the organizational structure range. Responsibilities concern agents and arise in relation with task-allocation and structure once there are agents enacting the roles of a given organization.

Given a task-allocation allocating a specific subtask to a role, and given that an agent is enacting that role, the agent is then said to be responsible for that task or *task-based responsible*. In other words, the allocation of subtasks to roles determines a distribution of what we call *task-based responsibilities* over the set of agents enacting the roles of the organization. Being autonomous, agents can independently decide whether to perform the subtasks to which they are allocated or not, and whether to perform them in the expected way. In this case the fulfillment of the organizational objectives is put in jeopardy by the conduct of some agent that is said then to be *causally responsible* for the failure occurred.

In organizations an agent can happen to be causally responsible of some failure without actually being blamed by the organization. This can happen if an agent i which is task-based responsible for performing a task, *delegates* the performance to a subordinate agent j which fails or jeopardizes the execution of the delegated task. This observation reveals an interplay between the notions of responsibility isolated above, and dimensions of social structure such as the possibility to delegate allocated tasks, i.e., what we called *power relation* in the previous section. Social structure in relation with responsibility will be discussed in detail in Section 4. Here it suffices to notice that the presence of a power structure within an organization causes a difference between the two notions of task-based and causal responsibility: 'I may have not performed the task you delegated to me, but you were the one appointed to it'. Therefore, if an organizational task is not performed, the one being *socially responsible* in front of the organization, the one who gets the blame for the failure, is not necessarily the one causally responsible for it, but it is the one to which that task was appointed. The acknowledgment of such a gap calls for the distinction of yet another meaning of the notion of responsibility which we call *failure-based responsibility*: who should control the performance of an agent to check whether a failure occurs and take countermeasures if that is the case?

We can now provide an action logic representation of the notions of responsibility.

Causal responsibility.
An agent is said to be *causally responsible* when it does something (or fails to do something) that causes the untoward event D_τ. We formalize causal responsibility as follows:

Definition 4. (Causal responsibility)
For all $i \in Ag$: $R_i^c(D\tau) := [i:\alpha]D\tau \wedge DO(i:\alpha) \wedge \neg D\tau$

meaning that agent i is causally responsible for the untoward event if and only if agent i performs an action which necessarily determines the occurrence of the untoward event and, finally, the untoward event is not the case before the agent performs the action.

Causal responsibility can also be attributed to nonhuman events, for example, that a house is severely damaged in a storm. In this article, we restrict ourselves to agents

in an organizational context. Notice that an agent which is causally responsible, may not be considered *blameworthy*. For example, if the chairman of the Editorial Board has forgotten to inform a member i to review some papers in one week, and agent i did not review the papers in one week, then the achievement of the goal of the Editorial Board to notify of the results of the reviews within the deadline will be reduced. The member i would be considered responsible in the sense of having *caused the situation*, but he would not be responsible in the sense of *blameworthy*. An agent does something blameworthy, if he knows (or could have known) that the action he performs leads to the impossibility or the reduction of the possibility to achieve a goal τ:

Definition 5. (Causal blameworthiness)
For all $i \in Ag$: $Bl_i^c(D\tau) := [i:\alpha]D\tau \wedge DO(i:\alpha) \wedge \neg D\tau \wedge K_i([i:\alpha]D\tau)$

The importance of the knowledge component in the dynamics of responsibilities within organizations is analyzed in detail in Section 4.

Task-based responsibility.
The notion of *task-based responsibility* is somehow interchangeable with duty and refers to what individuals are expected to do in virtue of their social roles. We assume that task-based responsibility is a consequence of role adoption: an agent who accepts to play a given role in an organization takes a responsibility with regard to the accomplishment of that role, i.e., with the tasks associated to it [10]. In this article, this notion of responsibility completely depends on the position an agent occupies in the performance of the organization.

Definition 6. (Task-based responsibility)
For all $i \in Ag$ *and a task allocation* $Plan(AR, \tau)$*:*

$$R_i^{tb}(\tau_j) := rea(i, r_j) \wedge \langle r_j : \tau_j \rangle \in Plan(AR, \tau)$$

Intuitively, we want that the following property holds:

Property 1. For all $i, j \in Ag$ and a task allocation $Plan(AR, \tau)$:

$$R_i^{tb}(\tau_j) \rightarrow O(i : achieve(\tau_j)) \wedge [\overline{i : achieve(\tau_j)}]D\tau_j$$

The obligation $O(i : achieve(\tau_j))$ expresses that the organization entrusts agent i with his task τ_j ($rea(i, r_j) \wedge \langle r_j : \tau_j \rangle \in Plan(AR, \tau)$), and $[i : achieve(\neg\tau_j)]D\tau_j$ expresses the empowerment of i to prevent the reduction of the possibility or the impossibility to achieve goal τ_j. So, an agent i fails to fulfill his task-based responsibility $R_i^{tb}(\tau_j)$ if he violates the norm $O(i : achieve(\tau_j))$ which leads to the untoward event $D\tau_j$. However, the agent is considered blameworthy when he actually knows (or could have known) that he has this obligation and that he can perform the action to achieve his task. For example, he has not received the information needed for the performance of his task, or the achievement of his task depends on an earlier task in the task allocation which is not performed. This notion of blameworthy can formally be described as follows:

Definition 7. (Task-based blameworthiness)
For all $i \in Ag$ and a task allocation $Plan(AR, \tau)$:

$$Bl_i^{tb}(\tau_j) := R_i^{tb}(\tau_j) \wedge K_i(R_i^{tb}(\tau_j)) \wedge CAN_i(achieve(\tau_j))$$

Social responsibility.
The notion of social responsibility builds on the notion of task-based responsibility, and it is somehow analogous to a notion of violation in standard deontic logic.

Definition 8. (Social responsibility)
For all $i \in Ag$ and a task allocation $Plan(AR, \tau)$: $R_i^s(\tau_j) := R_i^{tb}(\tau_j) \wedge D_{\tau_j}$

that is to say, agent i has the responsibility to achieve τ_j and the achievement of τ_j is impossible or jeopardized. Notice that this notion of responsibility is very simple and is independent from the notion of causal responsibility.

4 Responsibilities and Organization Structure

We cannot hope to provide a full account of all interactions between responsibilities and organizational structures. However, in the rest of this section we aim to capture some essential traits of those interconnections. We understand those relations essentially as guaranteeing some effects to the basic actions of *delegate*, *inform* and *monitor*, which play an essential role with respect to responsibilities and their development in organizations.

The following definitions characterize the influence of the organization relations on the actions above. Through these basic properties we can also formally analyze some consequences of them on the notions of responsibilities studied in the previous section.

Definition 9. (Power)
For all $i, j \in Ag$ s.t. $i \neq j$ and $r, s \in AR$:

$$(Power(r, s) \wedge rea(i, r) \wedge rea(j, s)) \rightarrow [i : delegate(j, \phi)]O(j : achieve(\phi))$$

If a power relation exists between roles that are enacted by two agents then a *delegate* action will have as effect an obligation for the recipient, that is, a form of "your wish is my command" principle. Intuitively, if a power relation holds between roles r and s, all delegation acts performed by an agent i enacting role r on agents enacting role s succeed in creating an obligation for these agents.

Task-based responsibility cannot be delegated. If Agent i has, according the task allocation, to achieve task ϕ and has a power relation with agent j, he can delegate his task to j, but he remains task-based responsible for the achievement of ϕ. Since ϕ is not the original task of agent j according to the given task allocation (see definition 6). Agent j, however, can be causally responsible if he fails to fulfill his delegated obligation.

A difference between an individual task and a collective task is that in an individual task all information is readily available and can be reasoned about. However, when a collective task is divided over the individuals of that collective, they might not know the whole plan, typically do not have information about actions that are performed, etc. Therefore, we need a coordination structure.

Definition 10. (Coordination)
For all $i, j \in Ag$ *s.t.* $i \neq j$, $r, s \in AR$*:*

$$((Coordination(r, s) \wedge rea(i, r) \wedge rea(j, s)) \wedge DONE(i : monitor(\phi))) \rightarrow$$

$$((K_i\phi \rightarrow O(i : inform(j, \phi))) \wedge [i : inform(j, \phi)]K_j\phi)$$

If a coordination relation holds between roles r and s, all information acts performed by agents enacting role r to agents enacting role s are successful in the sense that they create, in these last agents, the knowledge they acquired via monitoring the occurrence of a certain fact: the *inform* action will automatically lead to the corresponding epistemic state in the recipient. Further, there is a normative aspect: agent i *should* inform another agent j about ϕ if they are connected through a coordination link and if agent i has monitored (checked) ϕ.

On this basis, a coordination-related type of responsibility can be defined.

Definition 11. (Coordinational responsibility)
For all $i, j \in Ag$ *and a task allocation* $Plan(AR, \tau)$*:*

$$R_i^{coor}(inform(j, \phi)) := K_i([\overline{i : achieve(K_j\phi)}]D\tau_l) \wedge R_j^{tb}(\tau_l)$$

On the basis of the coordination structure, there is a specific allocation of the information actions, which is needed for the achievement of the individual tasks in the task allocation. Given this definition, we can say agent i is responsible to inform agent j, when the knowledge of ϕ is a necessary means to the achievement of τ_l and that agent j does not have that knowledge.

We state the if someone is coordinationally responsible to inform an agent about ϕ, he is also obliged that the agent will be informed about ϕ. This can be expressed as follows:

Property 2. For all $i, j \in Ag$ and a task allocation $Plan(AR, \tau)$:

$$R_i^{coor}(inform(j, \phi)) \rightarrow O(i : achieve(K_j, \phi))$$

The responsibility of an agent i to inform some agent j about a certain aspect ϕ can follow from the coordination link between these agents if the knowledge of ϕ is necessary for the achievement of the task of agent j according the task allocation and i can monitor or check ϕ. This shows, in particular, how a given task allocation needs to be integrated with a suitable allocation of coordinational responsibilities in order to guarantee the information necessary for the correct functioning of the organization. This property can be formalized as follows:

Property 3. For all $i, j \in Ag$ s.t. $i \neq j$, $r_k, r_l \in AR$ and task allocation $Plan(AR, \tau)$:

$$Coordination(r_k, r_l) \wedge rea(i, r_k) \wedge rea(j, r_l) \wedge \langle r_l : \tau_l \rangle \in Plan(AR, \tau) \wedge$$
$$(\neg K_j\phi \rightarrow \neg CAN(j : achieve(\tau_l))) \wedge CAN(i : monitor(\phi)) \rightarrow R_i^{coor}(inform(j, \phi))$$

So, agent i is responsible to inform agent j about ϕ if there is a coordination link between the roles r_l and r_k they respectively enact, and without the information about ϕ agent j cannot perform his task according to the task allocation. If agent i does not inform agent j, it follows that agent j cannot perform his task, which can lead to $D\tau_l$. So, agent i can be causally responsible if he does not inform agent j about ϕ (see definition 4). Note, that agent j is still task-based responsible with respect to τ_l, but not blameworthy, when he does not get the information necessary for the achievement of τ_l (see definition 7).

Finally, we get to a characterization of the dimension of control in organizational structure:

Definition 12. (Control)
For all $i, j \in Ag$ s.t. $i \neq j$ and $r_k, r_l \in AR$:

$$(Control(r_k, r_l) \wedge rea(i, r_k) \wedge rea(j, r_l)) \rightarrow$$

$$[i : monitor(DONE(j : achieve(\phi))](D\tau_l \rightarrow O(i : achieve(\tau_l))$$

If a control relation exists then the *monitor* action will have as further consequence the generation of an obligation for the controller in case the controlled actor did not achieve the relevant state causing the untoward event. On this basis, the notion of *failure-based responsibility* can be defined.

Definition 13. (Failure-based responsibility)
For all $i, j \in Ag$ s.t. $i \neq j$ and $r, s \in AR$:

$$R_i^{control}(monitor(j, \phi)) := Control(r, s) \wedge rea(i, r) \wedge rea(j, s)$$

This type of responsibility depends completely on the control relation.

The control responsibility has another normative aspect: if an agent has control over another agent he is obliged to monitor the controlled agent whenever he knows the controlled agent has an obligation. Formally,

Property 4. For all $i, j \in Ag$ and a task allocation $Plan(AR, \tau)$:

$$(R_i^{control}(monitor(j, \phi)) \wedge K_i(O(j : achieve(\phi))) \rightarrow$$

$$O(i : monitor(DONE(j : achieve(\phi))))$$

We can imagine that an agent who has delegated his task to agent j, has the obligation to monitor whether the delegated agent has done the task, since he might be responsible to monitor agent j and he knows that the delegated agent j has the obligation.

5 Conclusions

We have provided some elementary notions of responsibility in its interconnection with the structure of an organization. We argued that organizations are defined through several structural relations. Although people refer to these structures they still lack a precise formal definition. In this article these relations have been given a solid foundation. This

allows us to check desirable properties of the structures and how they (should) interact. Now we have a characterization and can proof properties given some structural properties of these relations. In future work we will look at more elaborate definitions of the power, coordination and control relations.

Responsibilities are closely related to the specific task allocation within an organization. Although the task allocation can be determined dynamically through the process of delegation, some of it is predetermined through the role structure of the organization which assigns typical tasks to certain roles. The organizational structure plays an even greater role in the monitoring and control of execution of the tasks for which the agents are responsible. The logical framework we presented offers a semantics for the notions of responsibility that is necessary for determining at least some interconnections between organizational structure and responsibilities. It gives some insides into when an agent can really be held responsible for when tasks are not (or wrongly) performed. These observations might lead to guidelines for the design of an organizational structure given that one wants some responsibilities to be covered at all times. In this article we just offered a glance of these observations through the example. However, we hope to extend this area in future work, e.g., to combine our work with the work done in [11] about the representation of organized interaction with action concepts.

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