A Modal Logic Framework for Organization Analysis and Design

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Abstract: This paper proposes a logic-oriented framework for organisation specification, analysis and design. Within this framework organizations are seen as a society of agents with responsibilities and capabilities, and that interact with each other according to some form of "institutionalised power relations". Organisations are analysed according to the properties of its agents' interactions, characterised by means of modal action and deontic logics of the type developed in the Philosophy area.

Although rather simple, the proposed framework supports some interesting aspects of the analyses of organizations, with potential applications in the scope of organisational design, e.g. analysis of task distribution and analysis of attribution of responsibilities. This later analysis is based on Reiter's diagnosis theory.

These aspects of analysis have been automated in a workbench capable of answering queries about what can and should be done, in a given organisation, to achieve particular goals. The workbench uses a tableaux theorem proving method extended with additional rules to deal with the proposed classical action and deontic modalities.

1. Introduction

This work explores some applications of modal logic to the formal characterisation and analysis of organisations. By *organisation* we mean a society of agents, comprising human or artificial agents, whose rule-governed interactions are aimed at some specified tasks or goals. We adopt the perspective proposed in [Normatics 1991], seeing organizations as instances of *normative systems*, and thus expressing the activity and interaction in terms of what agents are permitted and obliged to do (allowing also the possibility that their behaviour may deviate from the ideal), and in terms of other complex normative relations between them. One principal advantage of adopting this perspective is that it enables us to capitalise on a lot of the work that has been done on the application of formal-logical techniques to the analysis of law, legal systems and social systems (see, e.g., [Kanger 1971, 1972; Pörn 1970, 1971, 1977, 1989; Lindahl, 1977]). If we wish to model real societies of agents, or if we wish to design systems which automate some aspects of their activities, it is essential that such concepts as *right*, *permission*, *obligation*, *authority*, *authorisation*, *responsibility* and *delegation*, are precisely understood and defined, and not simply treated informally (see, e.g., [Jones & Sergot 1992, 1996]).

Organizations have, of course, some peculiarities that distinguish them from other kinds of normative systems. We are aware of the kinds of theoretical models that have been proposed in *Organisation Theory* (see, e.g., [Tosy 1994; Robbins 1987; Hodge & Anthony 1988]). Unfortunately, too little has so far been done in Organisation Theory to supply precise qualitative models of norm-governed interaction.

There had been a considerable amount of research in order to develop appropriate models to the automation of organisations. Contributions had appeared in different areas such *Information Systems*, *Distributed Artificial Intelligence* and *Computer-Supported Cooperative Work* (see, e.g., [Skarmeas 1995; Laudon & Laudon 1996]). Although it is recognised that the success of the automation of organisations depends on the adoption of explicit organisational models [Skarmeas 1995; Dobson & Strens 1994], there is a lack of approaches that consider such models. This is the reason why most of the applications in such context do not face up to organisational changes. This lack of explicit models has also impact in the current modelling techniques. Techniques such OMT [Rumbaugh *et al.* 1991] do not support concepts usually used in the characterisation of organisations. Other techniques specially proposed to the characterisation of organisations, e.g. ORDIT [Dobson & Strens 1994], adopt some organisational concepts (e.g., responsibility, right, delegation), but do not offer any clear description of their meaning. Consequently the interpretation of the organisational concepts mainly depends on the intuitions of the users of such techniques, with obvious impact to the automation of organisations. Moreover, this also obstruct any systematic analyse of organisations represented by such techniques.

We believe that organizations can fruitfully be analysed using a set of action, deontic and other relevant modalities as basic building blocks to be used in the characterization of organizational notions.

In a previous paper [Santos & Carmo 1996a] we stressed the need for a distinction between "direct" and "indirect" agency, and we have proposed a new operator to represent the latter. This new operator allows us to increase expressiveness in the characterization of agent's activities and interaction within organizations, by allowing an easy and abstract way of expressing the fundamental concept of responsibility (for some task). We have also shown how this indirect agency can be analysed only in terms of direct acts, by introducing the notion of a direct act of influence and a modal operator to capture it. In [Santos, Jones & Carmo 1997] we have proposed additional modalities in order to cope with further concepts relevant to the specification of organisations.

The main aim of this paper is to show that the previous ideas can interestingly be applied to systematic analysis of organizations. We propose a framework that supports some interesting aspects of the analyses of organizations, with potential applications in the scope of organisational design, e.g. analysis of task distribution and analysis of attribution of responsibilities. This later analysis is based on Reiter's diagnosis theory (see [Reiter 1987; Tan & Torre 1994; Ramos & Fiadeiro 1997, 1998]) specially adapted to the framework herein proposed. Some of the remaining analyses ideas where previously presented in [Santos & Carmo 1996b; Santos 1998].

An overview of the rest of the paper follows. In Section 2, we discuss our characterisation of organisational responsibilities. In Section 3, we discuss how we specify organizations and their models, and we illustrate how these models can be used to support some interesting aspects of the organization's activity and analysis, through some simple examples. In Section 4, we describe the automated theorem proving underlying the workbench that supports the previous analysis. Conclusions and directions for future work appear in Section 5.

2. Responsibility for action in organizations

All organisations, *formal* or *informal*, contain an underlying structure that stipulates the allocation of tasks to individuals, their interaction patterns and their coordination mechanisms. This structure is intended to provide the work distribution necessary to attain organisational goals. Work divided in this way is grouped into different operational or management/coordination positions that are allocated to individuals through the assignment of responsibilities. This organisational concept of responsibility usually involves obligations that members of the organisation must fulfil, in accordance with procedures, policies and strategies. On the one hand, agents in operational positions fulfil their obligations by acting according to their capabilities, and on the other hand, agents in management positions fulfil their obligations by ensuring that certain results are obtained via other agents, by using existing organisational procedures or by creating new ones, by delegating responsibilities, etc. Although the situation may vary according to the degree of formalization adopted in a given organisation, a common feature of these obligations is that they often refer to the specific results that must be achieved within the organisation, *without entering into details concerning the particular actions that the agents themselves must perform in order to achieve these results*. In fact, the concrete actions to be performed to fulfil those obligations depend on the underlying structure of the organisation (e.g., power structure, task decomposition), and on the specific circumstances (e.g. availability of specific agents and resources). It is commonly the case in organisations that an agent (a manager, say) is made responsible for securing the realisation of some state of affairs which he is either not capable of bringing about himself (he perhaps lacks the required skills), or is not permitted to bring about himself (the organisation perhaps does not consider it to be *his* job to perform the tasks concerned). Clearly, the manager's responsibility involves a requirement that he exercise power and influence over others in an effective way, getting them to perform the tasks necessary for reaching the goal that he (the manager) is obliged to secure. This indicates that, in order to characterise this notion of responsibility, it will be essential to define a notion of "indirect agency", to capture cases of agency in which an agent secures the production of some state of affairs A without necessarily bringing it about that A himself.

In what follows we propose to use the word *ensure* to represent the "indirect" action concept. On the other hand, we retain the expression "bring it about" (defined in [Kanger

1971, 1972; Pörn 1970, 1971, 1977, 1989; Lindahl, 1977; Elgesen 1993][1]) for an action concept which may be called "direct" in at least the following sense: an agent x brings it about that A only if he does not bring it about that some *other* agent y brings it about that A.

We use a monadic operator G_X to represent the "indirect" agency concept and E_X to stand for our notion of "direct" agency; we read expressions of the form G_XA as "agent x ensures that A" and expressions of the form E_XA as "agent x bring it about that A". Using this operator in combination with a suitable deontic obligation operator O, we now let expressions of the kind "agent x is responsible for A" be represented by OG_XA (i.e., responsibility for A amounts, on this view, to an obligation to ensure that A) [2]. Like the direct action modality, the indirect action modality is considered to be "successful". Thus we may consider that such expressions as $OG_XA \wedge G_XA$ and $OG_XA \wedge \neg G_XA$ represent an acceptable characterisation of "fulfilment" and "non-fulfilment" of responsibilities, respectively.

Starting from the logical properties of the "direct" action operator E_X, we propose the use of a propositional classical system of type ECT (according to the classification of Chellas [Chellas 1980]) including also the schema (No), i.e., a system based on classical propositional logic, and with the following axiom schemas:

(T) $E_XA \rightarrow A$

(C) $(E_XA \wedge E_XB) \rightarrow E_X(A \wedge B)$

(No) $\neg E_X True$

and the rule of inference:

(RE) If $\vdash A \leftrightarrow B$ then $\vdash E_XA \leftrightarrow E_XB$

The (T) schema captures the intuition that if agent x brings it about that A, then A is indeed the case; that is, E_X is a "success" operator. The (C) schema represents the idea that an agent brings it about all he brings it about separately. The (No) schema captures the idea that the truth-conditions of E_XA involve a negative component (*cf.* [Pörn 1977; Belnap 1991; Elgesen 1993]), requiring that if x had not acted as he did, A might have failed to obtain. Clearly, where A is a tautology, this condition is not met. (RE) is just closure under logical equivalence.

The same intuitions apply with respect to the formal properties of the operator G_X, i.e., we also adopt the axiom schemas:

(T) $G_XA \rightarrow A$

[1] For a brief overview of the action logics proposed by these authors, see [Santos & Carmo 1996a].

[2] The word "responsibility" may have very different meanings. Here we are thinking in terms of "responsibility for some task". See [Cholvy, Cuppens & Saurel 1997] for the formal characterization of other types of responsibility concept.

(C) $(G_x A \wedge G_x B) \rightarrow G_x(A \wedge B)$
(No) $\neg G_x True$

and the rule of inference:

(RE) If $\vdash A \leftrightarrow B$ then $\vdash G_x A \leftrightarrow G_x B$

The main difference between the operators E and G concerns interaction between different agents. We suggests the additional schema

(GGG) $G_x G_y A \rightarrow G_x A$

with the following intuitive reading: "whenever agent x ensures that agent j ensures that A, agent x also ensures that A" and marks the key difference between a "direct" and an "indirect" action concept. Since $G_x G_y A \rightarrow (G_x A \wedge G_y A)$ (by (T) and (GGG)), each agent involved in $G_x G_y A$ ensures that A.

On the other hand, we adopt the schema

(EE¬E) $E_x E_y A \rightarrow \neg E_x A$ (for $x \neq y$)

which makes explicit the idea that $E_x A$ implies that agent x brings it about that A *directly*, at least in the sense that his bringing it about that A is incompatible with his bringing it about that some other agent y brings it about that A.

With respect to the relationships between E and G, the following schema reflects the idea that "bringing it about is a particular case of ensuring":

(EG) $E_x A \rightarrow G_x A$

Furthermore, in [Santos & Carmo 1996a] we have also proposed a classical modality, ${}_x I_y$, to represent "direct" actions of "influence", where expressions of the form ${}_x I_y A$ are read "the agent x influences agent y to ensure A". Actions of this form are intended to represent any type of an "exercise of power", either informal like "convincing" and "committing", or "formal" (i.e. authorized exercise of influence) like "ordering" and "attributing responsibilities". Of course, the notion of influence proposed can be refined according to the specific applications one have in mind: e.g. a common institutionalised form of exercising influence within organizations is the *attribution of responsibilities* (herein represented by expressions of the form $E_x O G_y A$). In such applications, this specific form of influence can be introduced in the logic by adopting the axiom schemas:

(atrib.resp) $E_x O G_y A \rightarrow {}_x I_y A$

With respect to the operator ${}_{x}I_{y}$, we propose the use of a propositional classical system of type EC (according to the classification of Chellas [Chellas 1980]), i.e., a system containing the following axiom schema:

(C) $({}_{x}I_{y}A \wedge {}_{x}I_{y}A) \rightarrow {}_{x}I_{y}(A \wedge B)$

and the rule of inference:

(RE) If $\vdash A \leftrightarrow B$ then $\vdash {}_{x}I_{y}A \leftrightarrow {}_{x}I_{y}B$

Note that the absence of the (T) schema is justified by the fact that an act of influence is not necessarily successful. Consider, for instance, a situation in which a responsible agent has ordered his subordinate to perform a given task, but where the subordinate does not follow the order.

We further adopt the following principle of "transmission of agency" relating the actions of influence with the other actions within the "chain of successful influences" underlying an "indirect" action:

(TRANS) $({}_{x}I_{y}A \wedge G_{y}A) \rightarrow G_{x}A$

This principle represent the "transmission of agency" involved in most institutionalised organisations where influences are exercised by means of assignments of responsibilities. Note that schema (TRANS) together with (atrib.resp) entails $(E_{x}OG_{y}A \wedge G_{y}A) \rightarrow G_{x}A$.

With respect to the deontic operator O we simply adopt a propositional classical system of type E (according to the classification of Chellas [Chellas 1980]), i.e., a system containing the rule of inference:

(RE) If $\vdash A \leftrightarrow B$ then $\vdash OA \leftrightarrow OB$

This basic property is enough too the purposes of this paper. See, e.g., [Hilpinen 1971; Meyer & Wieringa 1993; Carmo & Jones 2001] for a detailed discussion of this concept.

We omit here the semantic details of the previous classical modalities. They are characterized in [Santos & Carmo 1996a; Santos, Jones & Carmo 1997] using Chellas' minimal models [Chellas 1980].

Let us illustrate the inference capabilities provided by these notions. Consider the following example of an organisation with four agents *a*, *b*, *c* and *d* , where the agents have just the capabilities indicated in Figure 1, where agent *a* has responsibility for $p1 \wedge p2 \wedge p3$. We also assume that agent *a* has effective control over agent *b* with respect to $p1 \wedge p2 \wedge p3$ and *b* has effective control over agents *c* and *d* with respect to *p1* and *p2*, respectively. We further assume that agents *b*, *c*, *d* have the capability to bring it about that *p1*, *p2*, *p3* respectively.

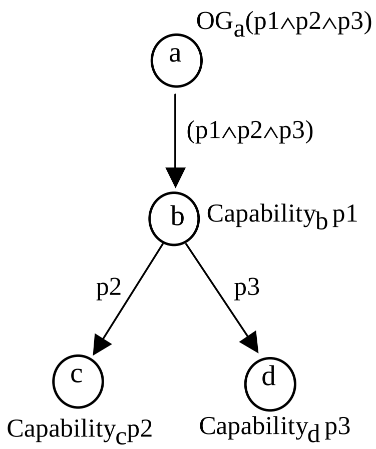

Figure 1

Within this example, there is just one possibility for *a* to fulfil his responsibility: each agent must act according to his capabilities. Thus, in order that *a* can ensure that $p1\wedge p2\wedge p3$, *a* must exercise an influence on agent *b* to ensure $p1\wedge p2\wedge p3$, agent *b* must himself do *p1* and exercise an influence on agents *c* and *d* to ensure *p2* and *p3*, respectively, and agents *c* and *d* must bring it about that *p2* and *p3*. And, in fact, our logical system yields the following deduction:

$$\Gamma \vdash OG_a(p1\wedge p2\wedge p3)\wedge G_a(p1\wedge p2\wedge p3)$$

where $\Gamma = \{OG_a(p1\wedge p2\wedge p3), {}_aI_b(p1\wedge p2\wedge p3), E_bp1, {}_bI_cp2, {}_bI_dp3, E_cp2, E_dp3\}$.

3. Organisation specification, analysis and design

For describing organizations we adopt a simple structure where we describe the agents and their capabilities, influence channels and responsibilities. The notion of “capability” is intended to represent formal abilities of the agents within the organization, i.e., the abilities that are expected according to the role the agent plays within the organization. The notion of “influence channel” is intended to capture effective powers (from an agent over another) that are recognised within the organisation. Each channel represents a directional link between two agents, represented e.g. by $x>_A y$, with the reading “there is an influence channel from x to y w.r.t. A”, and it is assumed that an agent x only can influence an agent y to ensure a task A, if there exists an influence channel from x to y w.r.t. A (similar remarks apply to the relations between “capability” and “bringing it about”). More formally (where PL denotes the set of propositional formulas used herein to represent the "tasks"):

Definition 1. An organisation is (represented by) a structure Org = (Ag, C, >, R) where:

(i) Ag $\neq \emptyset$ and finite;

(ii) C: Ag $\rightarrow 2^{PL}$, with C(x) finite for every x$\in$Ag;

(iii) >: AgxAg $\rightarrow 2^{PL}$, with >(x,y) finite for every x,y$\in$Ag;

(iv) R: Ag $\rightarrow 2^{PL}$, with R(x) finite for every x$\in$Ag.

Ag is the set of agents; C(x) represents the capabilities of agent x, and we write Cap_xA for A$\in$C(x); >(x,y) represents the influence channels that exist between x and y, and we write $x>_Ay$ for A$\in$>(x,y); R(x) represents the responsibilities of agent x, and we write OG_xA for A$\in$R(x).

As an illustration, consider a simple organisation with three agents *a*, *b*, *c*, where the agents have just the capabilities and responsibilities referred in the figure 2 and the influence channels represented by the labelled arrows:

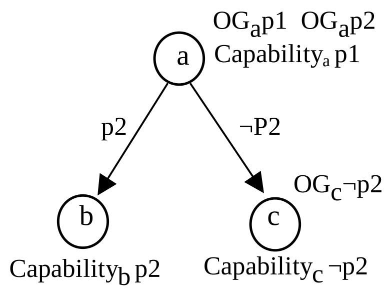

Figure 2

We represent it by org2 = ({a, b, c}, {Cap_ap1, Cap_bp2, $Cap_c\neg p2$}, {$a>_{p2}b$,$a>_{\neg p2}c$}, {OG_ap1, OG_ap2, $OG_c\neg p2$}).

The central idea for de analysis of organizations is to associate to each organisation *Org* the set B_{Org} of "possible behaviours" of the agents that constitutes the organisation, i.e. the set of different sets of "direct acts" (either of realisation of some task or of influence) that are possible according to the specified capabilities and influence channels. It is assumed that within an organization an agent *x* only may brings it about that *A* if *x* have such capability, and an agent *x* only may influence an agent *y* to ensure *A* if there is an influence channel from *x* to *y*, i.e. we follow the intuitive ideas "$E_xA \rightarrow Cap_xA$" and "${}_xI_yA \rightarrow x>_Ay$". Of course, each *possible behaviour* must be consistent with the logic proposed above for the action operators.

Definition 2. Given an organisation Org, B_{Org} = {Γ: consistent(Γ) and $\Gamma \subseteq \Delta_{Org}$}, where Δ_{Org}={E_xA: A$\in$C(x) and x$\in$Ag} $\cup$ {${}_xI_yA$: A$\in$>(x,y) and x,y$\in$Ag}.

For instance, for the organisation org2 above we get the following set of possible behaviours:

B_{org2} = {Ø, {E_ap1}, {E_bp2}, {E_c¬p2}, {$_aI_b$p2}, {$_aI_c$¬p2}, {E_ap1, E_bp2}, {E_ap1, E_c¬p2}, {E_ap1, $_aI_b$p2}, {E_ap1, $_aI_c$¬p2}, {E_bp2, $_aI_b$p2}, {E_bp2, $_aI_c$¬p2}, {E_c¬p2, $_aI_b$p2}, {E_c¬p2, $_aI_c$¬p2}, {$_aI_b$p2, $_aI_c$¬p2}, {E_ap1, E_bp2, $_aI_b$p2}, {E_ap1, E_bp2, $_aI_c$¬p2}, {E_ap1, E_c¬p2, $_aI_b$p2}, {E_ap1, E_c¬p2, $_aI_c$¬p2}, {E_ap1, $_aI_b$p2, $_aI_c$¬p2}, {E_bp2, $_aI_b$p2, $_aI_c$¬p2}, {E_c¬p2, $_aI_b$p2, $_aI_c$¬p2}, {E_ap1, E_bp2, $_aI_b$p2, $_aI_c$¬p2}, {E_ap1, E_c¬p2, $_aI_b$p2, $_aI_c$¬p2} }

Note that if Δ_{Org} is finite, B_{Org} is also finite, since $\#B_{Org} \leq 2^{\#\Delta Org}$ (the equality holds if Δ_{Org} is consistent, which is not the case in the previous example, since E_bp2 and E_c¬p2 are conflicting formulas due to the (T) schema for the “direct” action operator).

The model presented above can be used to support some aspects of the organization's analysis. The idea is to associate to each "relevant question" a particular formula, and to check if there exists a possible behaviour from which such formula can be derived. For instance, through this approach, we can answer to the following questions (w.r.t. a given organization):

(Q1) can agent x ensure A?;

(Q2) which agents can ensure A?;

(Q3) what must agent x (directly) do to ensure A?.

Although rather simple, these questions can be used to analyse interesting organisational problems. Questions of type (Q1) can be used to analyse problems related with the allocation of responsibility. It is well known that responsibilities should be assigned to agents within organizations with power/means enough to fulfil them. Thus the answer to the question “can agent x be responsible for task A?” can be interpreted as meaning “can x fulfil such responsibility for A, within the organization?”, i.e., “does the organization provides to x the means to ensure A?”. As an useful application of questions of type (Q2), we may think of expert systems that guide customers to the agents that are able to solve their problems, since the question “who should be addressed (within the organization) to obtain A?” can be interpreted as meaning “what agents can ensure A, within the organization?” (of course, in such applications possibly only a subset of such agents should be provided to the users: the ones that can ensure A and that are supposed to interact with the users). Finally, questions of type (Q3) can be used to guide task distribution within an organization or even to reason about the specification of fulfilment conditions for responsibilities. The answer to the question “what must agent x do to fulfil his responsibility for A?” can be interpreted as meaning “what are the possibilities provided to agent x for ensuring A, within the organization?”.

In order to answer to the questions (Q1), (Q2) and (Q3) we must analyse the behaviours in B_{Org} where G_xA holds. Let's first consider the following definition.

Definition 3. Given an organisation Org, the set of the behaviours that verifies A is defined by $B_{Org}(A) = \{\Gamma: \Gamma \in B_{Org}$ and $\Gamma \vdash A\}$, and the set of the x's actions within behaviours that verifies A is defined by $B^{x}_{Org}(A) = \{\Gamma \cap \Delta^{x}_{Org}: \Gamma \in B_{Org}(A)\}$, where $\Delta^{x}_{Org} = \{E_x A: A \in C(x)\} \cup \{{}_x I_y A: A \in >(x,y)$ and $y \in Ag\}$.

For instance, for the organisation org2 we get e.g.:

$B_{org2}(G_a(p2 \wedge \neg p2)) = \emptyset$;
$B_{org2}(G_a(p1 \wedge p2)) = \{\{E_a p1, E_b p2, {}_a I_b p2\}, \{E_a p1, E_b p2, {}_a I_b p2, {}_a I_c \neg p2\}\}$;
$B^{a}_{org2}(G_a(p1 \wedge p2)) = \{\{E_a p1, {}_a I_b p2\}, \{E_a p1, {}_a I_b p2, {}_a I_c \neg p2\}\}$.

Using this definition, within an organisation Org the previous questions of type (Q1) and (Q2) are answered by (A1) and (A2) respectively:

(A1) ***Yes***, if $B_{Org}(G_a A) \neq \emptyset$

(A2) ***X***, $X = \{x: x \in Ag$ and $B_{Org}(G_x A) \neq \emptyset\}$

With respect to questions of type (Q3), we can further distinguish between unavoidable and optional acts that should be (directly) done by agent x to ensure A. By unavoidable acts we mean those acts that there are no alternative for agent x in order to get A, and by optional acts we mean the sets of acts that represent the alternatives of agent x to obtain A. The former will be represented by the acts of agent x in the intersection of the behaviours in $B^{x}_{Org}(G_x A)$, and the later by the non-unavoidable acts of the agent x within each minimal behaviour in $(B^{x}_{Org}(G_x A), \subseteq)$. Note that each minimal set in $(B^{x}_{Org}(G_x A), \subseteq)$ represents a possible behaviour sufficient for x to ensure A.

(A3) unavoidable: ***U***, $U = \cap\Gamma$ s.t. $\Gamma \in B^{x}_{Org}(G_x A)$, if $B^{x}_{Org}(G_x A) \neq \emptyset$; $\emptyset$, otherwise

optional: ***O***, $O = \{Y - M: Y \in minimal((B^{x}_{Org}(G_x A), \subseteq))\}$

As an illustration of the organisation analysis supported by the previous formalisations, consider the following example of the organization pictured in figure 3, that can be represented as org3=({a, b, c, d}, $\{Cap_c p, Cap_d p\}$, $\{a >_p b, b >_p c, b >_p d\}$, $\{OG_a p\}$).

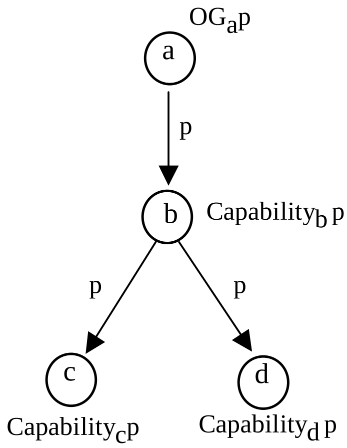

Figure 3

The answer to the question "can agent a ensure p?" is affirmative, since $B_{org3}(G_a p) \neq \emptyset$ (e.g. $\{{}_aI_b p, {}_bI_d p, E_d p\} \in B_{org3}(G_a p)$). On the other hand, by a similar reasoning, we obtain X={a, b, c, d} as an answer to the question "which agents can ensure p?". Finally, to answer the question "what must agent a do to ensure p?", we obtain $U = \{{}_aI_b p\}$ and $O = \{\emptyset\}$ for unavoidable and optional acts respectively; and for the answer to the question "what must agent b do to ensure p?", we obtain $U = \emptyset$ and $O = \{\{{}_bI_c p\}, \{{}_bI_d p\}\}$, as it is expected.

This framework also supports analysis of attribution of responsibilities to agents of an organisation. The main concern of this analysis is to detect what responsibilities are supported or not supported by a given organisation, i.e., to detect if the organisation provides to their responsible agents the means (power of influencing other agents with the convenient capabilities) enough to fulfil such responsibilities. Moreover, even in situation where responsibilities are not supported, we want also to detect what responsibilities should or should not be supported if we consider some changes in the organisation specification. An organisation designer may use this later information as a guide during the organisation design.

This kind of analysis is based on the adaptations of Reiter's diagnosis theory (see [Reiter 1987]) proposed in [Tan & Torre 1994; Ramos & Fiadeiro 1997, 1998] to the context of normative systems. We follow, in particular, Ramos & Fiadeiro diagnosis proposal as a form of detecting either obligations' violations or obligations' unfulfilment. Within our framework, responsibilities supported by a given organisation are obligations that can be fulfilled given an adequate possible behaviour of the agents of the organisation. Otherwise they are not supported. As we said before, not supported responsibilities may means that the described organisation do not provides to their responsible agents the sufficient means enough to accomplish their responsibilities. But this is not the only reason for an organisation not supporting responsibilities. Among several responsibilities there can be various responsibilities that may conflict with each other and therefore the fulfilment of a responsibility may imply the non-fulfilment of another. This means that all responsibilities should be analysed together and never analysed alone. That's why we do not support this kind of analysis with questions of type (Q1) presented behind.

The central idea of our diagnosis of responsibilities of an organisation Org is to analyse consistency of the different combinations of fulfilment and non-fulfilment of responsibilities over the set of possible behaviours B_{Org}. Let's consider the following definition:

Definition 4. Given an organisation Org and a behaviour $\Gamma\in B_{Org}$, the violation set is defined by $VS_{Org} = \{OG_xA\wedge\neg G_xA: A\in R(x) \text{ and } x\in Ag\}$, and the set of potential diagnosis for the behaviour Γ defined by $PD^{Org}_{\Gamma} = \{\Lambda: \Lambda\subseteq VS_{Org}$ and consistent$(\Gamma\cup\{OG_xA: A\in R(x) \text{ and } x\in Ag\} \cup\Lambda\cup\{\neg\delta:\delta\in VS_{Org} - \Lambda\})\}$.[3]

Each mentioned combination of fulfilment and non-fulfilment of responsibilities (i.e. $\Lambda\cup\{\neg\delta:\delta\in VS_{Org} - \Lambda\}$, for $\Lambda\subseteq VS_{Org}$) should be seen as an assumption that may or may not be plausible. Given a behaviour Γ that fulfils a responsibility OG_xA, it is, of course, not plausible to consider that such behaviour do not fulfils that responsibility, i.e. if $\Gamma \vdash G_xA$ then not consistent$(\Gamma\cup\{OG_xA\wedge\neg G_xA\})$. Thus $OG_xA\wedge\neg G_xA\notin\Lambda$, for every $\Lambda\in PD^{Org}_{\Gamma}$. Therefore PD^{Org}_{Γ} just refers responsibilities not fulfilled by behaviour Γ. On the other hand, if it is plausible to assume that a given behaviour Γ fulfils a responsibility OG_xA and do not fulfils the some responsibility, i.e. consistent$(\Gamma\cup\{OG_xA\wedge G_xA\})$ and consistent$(\Gamma\cup\{OG_xA\wedge\neg G_xA\})$, then we may conclude that such responsibility remains unfulfilled and it may be fulfilled if other additional acts are considered. In this case there exists $\Lambda1,\Lambda2\in PD^{Org}_{\Gamma}$ such that $OG_xA\wedge\neg G_xA\notin\Lambda1$ and $OG_xA\wedge\neg G_xA\in\Lambda2$. Finally, if it is plausible to assume that a given behaviour Γ do not fulfils a responsibility OG_xA, but it is not plausible to assume the fulfilment of the some responsibility, i.e. consistent$(\Gamma\cup\{OG_xA\wedge\neg G_xA\})$ and not consistent$(\Gamma\cup\{OG_xA\wedge G_xA\})$, then we may conclude that such responsibility remains unfulfilled even if other additional acts are considered. Thus $OG_xA\wedge\neg G_xA\in\Lambda$, for every $\Lambda\in PD^{Org}_{\Gamma}$.

As we said before, responsibilities should not be analysed alone. The main reason is due to the fact that conflicting responsibilities may not be fulfilled together. Consider, for instance, that the responsibilities OG_xA and OG_yB conflicts, i.e $G_xA\rightarrow \neg G_yB$. Within

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[3] This definition allows us to deal also with conditional obligations and other deontic properties, not explored in this paper. For the responsibility analysis presented herein it is sufficient to consider the following simpler definition of the violation set and potential diagnosis for the behaviour Γ: $VS_{Org} = \{\neg G_xA: A\in R(x) \text{ and } x\in Ag\}$; $PD^{Org}_{\Gamma} = \{\Lambda: \Lambda\subseteq VS_{Org}$ and consistent$(\Gamma \cup \Lambda \cup \{\neg\delta:\delta\in VS_{Org} - \Lambda\})\}$.

this diagnosis approach, given a behaviour Γ, we may get consistent($\Gamma\cup\{OG_xA\wedge\neg G_xA$, $OG_yB\wedge G_yB\}$), or consistent($\Gamma\cup\{OG_xA\wedge G_xA$, $OG_yB\wedge\neg G_yB\}$), or even consistent($\Gamma\cup\{OG_xA\wedge\neg G_xA$, $OG_yB\wedge\neg G_yB\}$), but never consistent($\Gamma\cup\{OG_xA\wedge G_xA$, $OG_yB\wedge G_yB\}$). Thus if $OG_xA\wedge\neg G_xA\notin\Lambda$ then $OG_yB\wedge\neg G_yB\in\Lambda$, for every $\Lambda\in PD^{Org}{}_{\Gamma}$.

As an illustration, consider the following example of the organisation pictured in figure 4, org4 = ({a, b, c}, {$Cap_b r$, $Cap_b p$, $Cap_c\neg p$}, {}, {$OG_b p$, $OG_c\neg p$, $OG_a r$}):

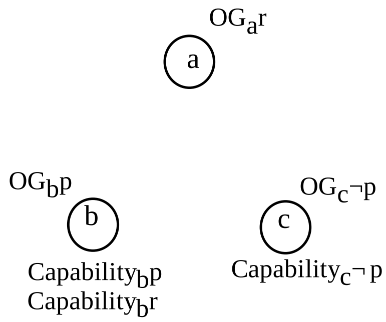

Figure 4

For the organisation org4 we get:

$PD^{org4}{}_{\emptyset}$ = $PD^{org4}{}_{\{Ebr\}}$ = { {$OG_ar\wedge\neg G_ar$, $OG_bp\wedge\neg G_bp$, $OG_c\neg p\wedge\neg G_c\neg p$}, {$OG_ar\wedge\neg G_ar$, $OG_bp\wedge\neg G_bp$}, {$OG_ar\wedge\neg G_ar$, $OG_c\neg p\wedge\neg G_c\neg p$}, {$OG_bp\wedge\neg G_bp$, $OG_c\neg p\wedge\neg G_c\neg p$}, {$OG_bp\wedge\neg G_bp$}, {$OG_c\neg p\wedge\neg G_c\neg p$} };

$PD^{org4}{}_{\{Ebp\}}$ = $PD^{org4}{}_{\{Ebp,Ebr\}}$ = {{$OG_ar\wedge\neg G_ar$, $OG_c\neg p\wedge\neg G_c\neg p$}, {$OG_c\neg p\wedge\neg G_c\neg p$} };

$PD^{org4}{}_{\{Ec\neg p\}}$= $PD^{org4}{}_{\{Ec\neg p,Ebr\}}$= {{$OG_ar\wedge\neg G_ar$,$OG_bp\wedge\neg G_bp$}, {$OG_bp\wedge\neg G_bp$}}.

Within behaviour Ø the responsibilities OG_bp, $OG_c\neg p$, OG_ar remains unfulfilled because $OG_bp\wedge\neg G_bp$, $OG_c\neg p\wedge\neg G_c\neg p$, $OG_ar\wedge\neg G_ar$ are referred in some potential diagnosis of $PD^{org4}{}_{\emptyset}$. We may also conclude that all of them may be fulfilled alone if other additional acts are considered since there are potential diagnosis of $PD^{org4}{}_{\emptyset}$ where they are not referred. In fact behaviour {E_bp} allows the fulfilment of OG_bp, since $OG_bp\wedge\neg G_bp$ is not referred in all potential diagnosis of $PD^{org4}{}_{\{Ebp\}}$. The same happens to the responsibility $OG_c\neg p$ with respect to the behaviour {$E_c\neg p$}. However, in the organisation org4 there are no behaviour that fulfils the responsibility OG_ar (for every $\Gamma\in B_{org4}$ it always referred in some potential diagnosis for the behaviour Γ). This means that the responsibility OG_ar is not supported by organisation org4. The previous conclusion that it may be fulfilled guide us to conclude that we may improve the design of org4 in order to support this responsibility. And in fact it would be supported if we consider the additional influence channel $a>_r b$ in the organisation org4.

Finally note that there is no behaviour that fulfils together the responsibilities $OG_b p$ and $OG_c\neg p$. In fact, there is no potential diagnosis where both responsibilities are not referred. Moreover, they are not supported together by the organisation org4, since these responsibilities will remains unfulfilled even if other additional acts are considered.

We may simplify the analysis presented before by considering the partial ordered set $(\{PD^{Org}_{\Gamma}: \Gamma\in B_{Org}\}, \subseteq)$. Note that minimal sets in $(\{PD^{Org}_{\Gamma}: \Gamma\in B_{Org}\}, \subseteq)$ represents the best sets of diagnosis for the organization Org in the sense that they refers less not fulfilled responsibilities. The union of this best diagnosis sets represents a diagnosis for an organisation Org. Formally:

Definition 5. Given an organisation Org, the set of potential diagnosis for the organisation Org is defined by $PD_{Org} = \cup minimal((\{PD^{Org}_{\Gamma}: \Gamma\in B_{Org}\}, \subseteq))$.

We may now interpret PD_{Org} and analyse supported and not supported responsibilities of an organisation Org using the some ideas proposed in [Ramos & Fiadeiro 1997, 1998]. Maximal sets in $(PD_{Org} , \subseteq)$ referrers alternatives of not yet supported (together) responsibilities in the organisation Org (the Ramos & Fiadeiro' *exigent diagnosis*). And minimal sets in $(PD_{Org} , \subseteq)$ referrers alternatives of responsibilities impossible to be supported together in the organisation Org (Reiter's diagnosis, also called *benevolent diagnosis* by Ramos & Fiadeiro). In summary, the responsibilities' diagnosis of the organisation Org are constituted by:

Alternatives sets of not yet supported responsibilities: $maximal((PD_{Org} , \subseteq))$

Alternatives sets of impossible to be supported responsibilities: $minimal((PD_{Org} , \subseteq))$

For instance, for organisation org4, $minimal((\{PD^{org4}_{\Gamma}: \Gamma\in B_{org4}\}, \subseteq)) = \{PD^{org4}_{\{Ebp\}}, PD^{org4}_{\{Ec\neg p\}}\}$. Thus $PD_{org4} = \{\{OG_a r\wedge\neg G_a r, OG_c\neg p\wedge\neg G_c\neg p\}, \{OG_c\neg p\wedge\neg G_c\neg p\}, \{OG_a r\wedge\neg G_a r, OG_b p\wedge\neg G_b p\}, \{OG_b p\wedge\neg G_b p\}\}$. Since $\{\{OG_a r\wedge\neg G_a r, OG_c\neg p\wedge\neg G_c\neg p\}, \{OG_a r\wedge\neg G_a r, OG_b p\wedge\neg G_b p\}\}$ are maximal in $(PD_{org4}, \subseteq)$, we may conclude that org4 don't supports yet (together) responsibilities $\{OG_a r , OG_c\neg p\}$ or alternatively don't supports yet (together) responsibilities $\{OG_a r , OG_b p\}$. On the other hand, since $\{\{OG_c\neg p\wedge\neg G_c\neg p\}, \{OG_b p\wedge\neg G_b p\}\}$ are minimal in $(PD_{org4}, \subseteq)$, we may conclude that responsibilities $OG_c\neg p$ and $OG_b p$ are impossible to be supported together in organisation org4.

For automating this analysis we face efficiency problems due to the dimension of B_{Org}. However, the following theorem helps us to get PD_{Org} in a more efficient way. It is based on the fact that the best sets of diagnosis are obtained in the maximal behaviours on (B_{Org}, ⊆).

Theorem 1. Given an organisation Org, $PD_{Org}=\cup\{PD^{Org}{}_{\Gamma}:\Gamma\in maximal((B_{Org},\subseteq))\}$.

Let us finishing this section by considering that a designer of the organisation org4 decides to include in it the influence channel $a>_r b$ based on the conclusion provided by PD_{org4} that $OG_a r$ is not supported but may be supported in organisation org4. The designer would conclude that the resulting organisation org4' = ({a, b, c}, {$Cap_b r$, $Cap_b p$, $Cap_c \neg p$}, {$a>_r b$}, {$OG_b p$, $OG_c \neg p$, $OG_a r$}) supports $OG_a r$ based on $PD_{org4'}$= {{$OG_c \neg p \wedge \neg G_c \neg p$}, {$OG_b p \wedge \neg G_b p$}}.

4. Automated theorem proving

The analysis presented above is actually supported by a workbench that supports the description of an organization Org and generates the model B_{Org}. The workbench uses an automated theorem proving based on propositional semantic tableaux (see, e.g. [Fitting 1990]), extended with the following additional rules to deal with the classical modal logics used to characterize the deontic and action operators and their relationships (where expression inside square brackets refers the conditions for the application of the rule):

(T-rule) $\dfrac{\Box A}{A}$

(C-rule) $\dfrac{\neg\Box\alpha}{\neg\Box\alpha_1 \mid \neg\Box\alpha_2}$, for α a conjunctive formula of the form $\alpha_1\wedge\alpha_2$

(No-rule) $\dfrac{\Box A}{False}$ [⊢ A]

(RE-rule) $\dfrac{\neg\Box A, \Box B}{False}$ [⊢ A↔B]

In order to apply (C-rule) during tableau construction, each time a formula of the form ¬□C is detected, C is converted to the clause form ($C_1\wedge\ldots\wedge C_n$). If n>1 then (C-rule) is applied considering $\alpha_1=(C_{i_1}\wedge\ldots\wedge C_{i_k})$ and $\alpha_2=(C_{i_{k+1}}\wedge\ldots\wedge C_{i_n})$, where $1\leq k<n$ and $\{i_1,\ldots,i_n\}$ a permutation of {1,…,n}.

We further consider the following rules related with the (EG) and (TRANS) schemes, (EG-rule) $\frac{E_x A}{G_x A}$

(TRANS-rule) $\frac{\neg G_x A,\ {}_x I_y B}{\neg G_y A}$ [$\vdash A \leftrightarrow B$]

It is easy to see that the previous rules yields a sound proof procedure, i.e., if B has a tableau proof then $\vdash$ B. However, The completeness of the previous tableaux method is not yet established. As a consequence, the possibility of including inconsistent behaviours in the generated model B_{Org} for Org must not be ignored. Nevertheless, the workbench supports a "behaviour checking" routine in order to avoid that possibility. The routine is based on the next theorem, where Lact denote the action logic discussed above.

Theorem 2. Given an organisation Org, let $\Gamma \subseteq \Delta_{Org}$ and $E^{-}(\Gamma)=\{A\colon E_x A \in \Gamma$ and $x \in Ag\}$. Then, $consistent_{Lact}(\Gamma)$ iff the following two conditions hold:

(1) $consistent_{PL}(E^{-}(\Gamma))$;

(2) not $\vdash_{PL}$ B, for every $B \in E^{-}(\Gamma)$.

That is, for the particular kind of sets of formulas used to describe the organization model, the previous theorem allows us to shift the calculus of consistency from Lact to PL. And since propositional tableaux is both sound and complete, we may ensure that the organization model generated by the workbench is correct.

5. Concluding remarks

We have proposed a framework for specification, analysis and design of organizations, based on a set of action concepts relevant for representing organisational responsibilities and relevant for analysing the conditions for their fulfilment within an organisation. Although rather simple, we have show that the proposed framework supports some interesting aspects of the analyses of organizations.

Organizations were described by a set of agents with responsibilities, capabilities and influence channels, and analysed according to the properties of the set of behaviours constrained by those capabilities and influence channels. An Adaptation of Reiter's diagnosis theory was applied in order to take conclusions about what responsibilities are supported or not supported by a given organisation.

We have also "described" a workbench that deals with the logic of the classical action modalities employed in the characterisation of such behaviours. The workbench supports answers to three types of useful questions that can be employed to analyse aspects concerned with *attribution of responsibilities*, *task distribution* and as a guide to address agents within organisations. It also supports the analysis of the *responsibilities supported* by each organisation.

We are fully aware that our work on specification and analysis of organisations is at this stage far from being applied to real organisations. Our short-term research is to explore more elaborated organisational structures in order to extend the analysis to other interesting organisational subjects. We foresee two ways of attaining this objective: 1. to extend our organisational structure with other primitive concepts important to enrich the description of an organisation; and 2. to extend our organisational structure with other non-primitive relevant concepts for allowing a quick description of organisations. With respect with the first one, we think that is urgent to develop a collective agent theory that allows the characterization of collective agency and institutionalised concepts like organs and roles. Some steps were done in this direction in [Carmo & Pacheco 2000, 2001]. With respect to the second one, we intend to develop languages for organisation specification supporting notions usually used by real organisations.

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