

## Normative autonomy and normative co-ordination: Declarative power, representation, and mandate

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**Abstract.** In this paper we provide a formal analysis of the idea of normative co-ordination. We argue that this idea is based on the assumption that agents can achieve flexible co-ordination by conferring normative positions to other agents. These positions include duties, permissions, and powers. In particular, we explain the idea of declarative power, which consists in the capacity of the power-holder of creating normative positions, involving other agents, simply by “proclaiming” such positions. In addition, we account also for the concepts of representation, namely the representative’s capacity of acting in the name of his principal, and of mandate, which is the mandatee’s duty to act as the mandator has requested. Finally, we show how the framework can be applied to represent the contract-net protocol. Some brief remarks on future research and applications conclude this contribution.

**Key words:** institutionalized power, multi-agent systems, normative co-ordination

### 1. Motivation and scope of this article

A paradigm shift is happening in Artificial Intelligence as well as in mainstream computer science with the advent of agents and agent-oriented approaches to developing systems, both on a theoretical and practical level. As pointed out in Broersen et al. (2001), at least three general models for autonomous agents are developed in the literature. A first approach includes a number of systems that roughly focus on goal-based planning or on qualitative decision theory (see Boutilier 1994). A second line of research is mainly aimed to provide a cognitive account of agents by specifying their mental states and motivational attitudes, such as the BDI model (see Rao Georgeff 1991). The third option is specifically oriented to model societies of agents by means of normative concepts such as obligation, permission, power and so on (see Conte and Dellarocas 2001; Lomuscio and Nute 2004; Pitt 2004).

In this paper we will focus on the third of the above mentioned approaches to multi-agent systems. This research assumes that as in human societies, also in artificial societies normative concepts may play a decisive role, allowing for the flexible co-ordination of intelligent autonomous agents. It has been argued, in addition, that the adoption of a normative perspective would allow a substantial progress in the creation of agent societies, a progress that would be even more important for societies where humans and agents interact (see Pitt 2004).

Of course, there is a number of ways according to which the issue of the role of normative concepts in MAS can be approached. Among them, a formal-theoretical investigation seems to be of great interest. In particular, a logic-oriented approach is useful insofar as it allows to make more rigorous normative notions as those analyzed by philosophers and sociologists and potentially relevant for modelling MAS. In this perspective, a precise logical analysis of normative notions such as obligations, institutions, responsibilities, delegation, powers, etc., is one precondition for the development of norm-governed societies. As recently pointed out regarding the design of computerized multi-agent systems, this logical analysis “[is] a means of supplying an intermediate level of description, falling somewhere between [...] ordinary-language account of what a system [...] is supposed to be able to do and [...] the level of implementation” (Jones 2003). In fact, describing and modelling norm-governed organizations and societies of agents means manipulating and making inferences over the normative concepts that are required to account for such organizations. In its turn, this presupposes to have an accurate and suitable formal representation of those concepts.

In the spirit of this extensive line of research, the current paper will not address explicitly the problem of practical implementations of multi-agent systems. Rather, it will be supplying some hints on how to articulate the just mentioned intermediate level of description. In particular, our aim is to provide a formal analysis of some conceptual preconditions that, we believe, any normative-based approach to agents’ co-ordination should take into account. The idea of normative co-ordination is based on the assumption that (human and artificial) agents can achieve flexible co-ordination by conferring normative positions to other agents. Those positions can include not only duties and permissions, but also powers, as for instance powers of creating further normative positions on the head of other agents. In particular we will characterize three ideas. First, the idea of declarative power, which consists in the capacity of the power-holder of creating normative positions, involving other agents, simply by “proclaiming” such positions. Secondly, the idea of representation, which is the representative’s capacity of acting in the name of his principal. Thirdly, the idea of mandate, which corresponds to the mandatee’s duty to act as the mandator has requested. These notions do not exhaust the idea of normative co-ordination.

However, we believe that they belong to the basic building blocks for such an approach to be specified. They may indeed be useful both for determining the relations and interactions between a user and its agents, or between autonomous agents.

We shall proceed as follows. In Section 2 we will informally discuss these notions. After presenting the logical framework used in this paper (Section 3), in Sections 4 and 5 we will provide a formal analysis of declarative power, representation and mandate. In Section 6 such a framework will be used to account for the scenario of the contract-net protocol. Section 7 reports future developments of our work. In Section 8 we sum the related work. Finally, in Section 9 we make our concluding remarks.

## **2. The legal framework: Declarative power, representation and mandate**

The notions we want to investigate originate from a legal background. Power, representation and mandate are indeed notions we can find in every legal system, though they may be differently regulated. We will focus on their general aspects, which are common to most legal systems.

### 2.1. DECLARATIVE POWER AND CONTRACTUAL LIBERTY

The idea of declarative power provides a general facility through which autonomous agents can shape their own normative environment. If agents are to be really autonomous (in the sense in which one legally speaks of “private autonomy”) they must go beyond the possibility of activating institutional connections between pre-determined actions and pre-determined results: they must be empowered to state what normative relations they want to hold between them, and to achieve those effects by doing so. This is performed by what is usually called a declaration of will or intention: the interested agents state the results they want to achieve, in the appropriate form, and the institution within which they are operating makes so that exactly those results are achieved (usually assuming that certain conditions are satisfied).

Such an empowerment of autonomous agents also corresponds to the needs of a complex self-organizing society, where it is not possible to establish in advance all normative relations between agents. In such a society it must be left to agents themselves to decide what normative relations are appropriate to their needs, or required for the fulfillment of their tasks. In the law, this normative self-organization typically happens through contracts (a contract is a declarative act jointly performed also by all parties whose status

is going to be changed by the declaration they are performing). For example, the Italian Civil Code art. 1321 establishes that “the contract is the agreement between two or more parties to create, regulate, or extinguish any legal relationship between them”. This means that, through a contract, the parties can create new legal positions (duties, powers or rights), they can extinguish them, and they can transfer them (for example, property rights) from one party to another. Note that the law does not establish what changes a contract will make to the legal positions of the parties: it is up to the latter to establish those changes, and the law will in principle recognize their will, i.e., it will produce exactly those results which the parties state in the contractual terms (the law can integrate and modify some of those results though). This also explains why single contracts usually cannot be exhaustively classified as of the types of acts which theories of institutional acts usually distinguish (commissive, commands, etc.): a single contract usually, at once, establishes new duties (for example, the obligation to pay the price), creates new rights (for example, the right to receive the price, or to be delivered the goods), transfers existing rights (for example, the property of the goods), and so forth.

In fact contracts put into focus a new dimension of autonomy: private autonomy, or contractual autonomy, by which one means the possibility of realizing the legal effects the parties wish, just by stating those effects. In this regard, we must consider that contracts are similar to legislation (as, for example, observed in Kelsen 1967): the legal effects of an act of Parliament are those effects which are stated in that act: to determine what rules and legal positions have been brought into existence by an act of Parliament, one should not look at a pre-existing convention, since the effects of the act are not established by conventions, but by the act itself. One should rather look at the content of the act, i.e., one should look at what the Parliament declared (there may be interpretative conventions, but these connect the words used in the act to certain meanings, not directly to certain institutional results).

## 2.2. REPRESENTATION AND MANDATE

An agent that has the power of making the type of statements we described above, may however not be in condition of directly exercising this power (he may lack the time, the opportunity, etc.). However also in this regard, there is no need to impose a regulation from above: an autonomous agent must rather be able to delegate to other agents the exercise of his own powers. So autonomy is further enhanced by instrument of representation, which basically concerns the situation “where a principal is held to declarations, especially contracts, made on his behalf” (Zweigert and Kötz 1992). As it is

argued, the essential aspect of representation is the grant of an authority or of a power: the representative's declarations can directly bind the principal, since they count as if they were the principal's declarations (contrary to the fact that one person's declaration normally can only bind that person).

In most cases, one subject confers representation to another, by accompanying it with a mandate, that is with the obligation of exercising (and of exercising in a certain way) the power of representation. So, in general terms, the idea of mandate concerns instead the situation where one agent (the mandator) has commanded another agent (the mandatee) to do something on his account. Usually a mandate presupposes that the mandator has authority over the mandatee (for example, being his employer), or that a contract has been signed between them for the execution of a specific business. Therefore, the mandator's requests generate the mandatee's duty to act in such a way as the mandator has requested, in order to satisfy the interests (or to achieve the goals) of the mandator. It is interesting to remark that while in common law the ideas of representation and mandate tend to conflate into the idea of agency (intended in general as the situation when one is acting in the interest of another), in the civil law tradition the distinction has become a commonplace since the XIX century (Zweigert and Kötz 1992, p. 461 ff.), when German legal doctrine introduced it. The distinction, however, is also clear within the common law, though not being reflected in a precise terminology. So, (Salmond and Williams 1945) say: "We are here concerned with agency not in its aspect as a relationship or contract between principal and agent imposing and conferring rights and obligations between the parties, but in its aspect as a grant by the principal to his agent of authority to represent him in the exercise of his power of making contracts with third persons".

### 2.3. CONNECTIONS AMONG DECLARATIVE POWER, REPRESENTATION AND MANDATE

Before moving into the formal analysis, let us spend a few words on the connection among the three concepts we have sketched so far.

The notion of declarative power is the basic one. Representation is usually created by an exercise of such a power, and so is a mandate. Additionally, it is not uncommon that representation and mandate go together with each other: whenever a principal confers an agent the power to represent her, usually the principal also binds the agent so that the agent acts in certain specific ways, or there is a legal relation which provides the background for the exercise of the representation. Consider, for example, the case when an employee in a shop represents his employer, and makes in his name contracts

with the clients. In such a case, the authority of the representative is linked to his duties as an employee, and he is bound to exercise his authority according to such duties. However, it is possible that there is representation without mandate (that the agent has the power to act in the name of the principal, without the obligation to do so). As the American Restatement of the law of torts affirms: “It is not essential to the existence of authority, that there be a contract between the principal and the agent and that the agent promise or otherwise undertake to act as an agent”. Consider for example the situation when one person confers to a relative the power of representing her in the sale of her house. The relative may not be obliged towards his principal to exercise this power (assume that he tells her: “If I have enough time I will go to the notary and sell the house in your name, but I undertake no obligation to do that”). He may just be permitted to do that (she relies on his goodwill for accomplishing this task).

What usually accompanies representation, besides the power of the representative, is his duty to exercise this power (if he decides to do so) in such a way as to satisfy the interest of his principal (see for example, art. 1388 of the Italian Civil Code, which explicitly requires that the representative acts “nell’interesse”, that is in the interest, of the principal). However, representation still exists when the representative violates this duty, acting against the interest of the principal. Though there is an “abuse of representation”, the contract concluded by the representative still binds the principal (the contract is only voidable if the counterparty knew, or should have known, that the representative was acting against the duty assigned by the principal). However, the representative may be obliged to compensate the principal for the losses incurred because of his abuse. The situation where the representative acts against any duties he may have towards the principal, but does an act which is within his power, must be distinguished from the situation where the representative lacks the power of representation or acts beyond such power. In this case the contract will generally not be effective at all in regard to the person in the name of which the representative affirmed he was acting.

In our discussion of representation, we should finally consider one aspect where common law and civil law systems diverge. In civil law systems, the representative only binds the principal towards the third party, when he acts “in the name” of the principal, that is when he makes known to the third party that he is representing the principal (for example, the Italian code explicitly says that, in representation, the representative acts in the name of the principal). Only in this case the civil law sees a real instance of representation, which implies that the principal acquires the legal positions arising from the act of the middleman, so that the third party can directly sue the principal. If the middleman transacts in his own name, he alone acquires rights and duties under the contract even if, just as in the case of “true” representations, he was acting on the principal’s business and account

without having any personal interest in the transactions at all. According to the common law, on the contrary, representation exists also when the agent does not disclose the name of the principal, though he is acting under the instruction of the principal. The third party can also in this case directly sue the principal, once he has discovered her identity. However, even civil law systems consider the hypothesis when one contract is concluded for whom it may concern, that is when the middleman makes known that he is representing somebody, but does not mention the specific person on whose behalf he is acting. In such a case, according to the Italian law, when the middleman indicates the name of the person who is going to take over the contract, and this person accepts, then the contract directly binds this person, as if the middleman was representing this person from the start. If the person is not named or refuses to take over the contract, then the contract binds the middleman.

One important aspect of representation, which makes it interesting when used for intelligent agents, is that the representative does not limit his contribution to the transmission of a declaration which was prepared by the principal in advance. Usually, on the contrary, the principal elects a representative, exactly because she does not know how she should best handle the business she has entrusted to the representative, in the circumstance where this business will take place (since she does not know what this circumstance will be). When the representative decides to perform a transaction in the name of his principal, this is the representative's own decision, so that his contractual declaration expresses his own intention, as determined by his goals and beliefs. In other words, beyond those specific conditions that were predetermined by the principal, the transaction is willed and decided upon by the representative. This is relevant, in particular, for the so-called defects of the will, i.e., those mental states of the parties that may impair the validity of a contract, determining its voidableness (as in cases of mistake, duress, misrepresentation or deception). To establish whether one such state holds, one has to consider the mind of the representative, rather than the mind of the principal (the states of mind of the principal are only relevant in relation to those aspects of the contract which were predetermined by the principal). So, for example, for deciding whether the contract is voidable because it was based upon a mistake, one must consider whether the representative was mistaken (Sartor 2003).

Moreover, it is interesting to remark that usually, the legal capacity for the act to be performed by the representative is required in the principal and not in the representative: one person may ask her underage child to perform some business for her (e.g., buy a bottle of milk), and the act performed by the child in her name will be valid, though the child could not perform that act for himself.

### 3. The logical framework

Our approach falls within the Kanger-Lindahl-Pörn (Kanger 1972; Lindhal 1977; Pörn 1977) theory of organized interaction.

Firstly, we will use the well-known action operator  $E_j$ , employed in expressions like “ $E_jA$ ” to mean that “agent  $j$  brings it about that  $A$ ”. In addition to this classical reading, we extend the formalism to cover also collective actions. <sup>1</sup> As suggested in Lindhal (1977), for the purpose of this paper it is sufficient to index  $E$  by sets of agents (Carmo and Pacheco 2001). So,  $E_{\{i,j,k\}}A$  means that  $i, j, k$  collectively bring it about that  $A$ . Investigating the nature of collective agency is outside the scope of this paper. Thus we refer to the basic properties of  $E$  as described in Santos and Carmo (1996) and Santos et al. (1997). In fact, different axiomatizations have been provided for  $E$  but almost all are closed under logical equivalence and include

$$E_iA \rightarrow A \quad (1)$$

i.e., successfulness, and also

$$\neg E_i\top \quad (2)$$

$$(E_iA \wedge E_iB) \rightarrow E_i(A \wedge B) \quad (3)$$

If these are some general properties for  $E$ , a specific axiom advanced in Santos et al. (1997) to characterize specifically this operator is

$$E_iE_jA \rightarrow \neg E_iA \quad (4)$$

It corresponds to the idea that the brings-it-about operator expresses actions performed directly and personally. These properties are simply extended here to the case of sets of agents. For example, the axiom stating that  $E$  is a successful operator is reformulated as  $E_XA \rightarrow A$ , for any set of agents  $X$ . When the set of agents is a singleton, the logical meaning of  $E_{\{j\}}$  collapses into that of the usual expression  $E_j$ . For cases with more than one agent, such as  $E_{\{i,j,k\}}A$ , we assume that neither  $E_{\{i,j,k\}}A$  implies that each agent in  $\{i, j, k\}$  brings it about that  $A$ , nor the converse: a collective action to achieve a goal is qualitatively different from a sum of actions performed to achieve the same goal by the single agents belonging to the group (See, e.g., Conte and Castelfranchi 1995; Dunin-Keplicz and Verbrugge 1996; Royakkers and Dignum 1999.). Moreover, when the content  $A$  of the operator  $E_{\{i\}}$  is a specific action (represented as an action predicate) we also use it to express that agent  $i$  executes by itself the action  $A$ . So, for example, we may use the expression  $E_{\{j\}}sell(o)$  to mean that agent  $j$  sells the object  $o$ .

Secondly, we will also make provision for directed deontic operators for obligation and permission. For the sake of uniformity, we may index the deontic operators  $O$  and  $P$  as well by set of agents. However, for the purposes



of our analysis, this is not necessary, thus avoiding to enter into a critical discussion such as that about collective obligations (for an overview, see, for instance, Krogh and Herrestad 1996; Royakkers 1998; Royakkers and Dignum 1998). Accordingly, we simply write  $O_j E_{\{k\}} A$  to mean that agent  $k$  has, towards agent  $j$ , the obligation of realizing  $A$ . One might also say that agent  $k$  has the obligation of realizing  $A$  in the interest of agent  $j$ . Similarly, we write  $P_j E_{\{k\}} A$  to mean that agent  $k$  has, toward  $j$ , the permission of realizing  $A$  (on the concept of directed obligation, see Herrestad and Krogh 1995; Krogh and Herrestad 1996, though a different formalization is provided). Let us thus sketch a suitable logic for directed obligations. It may be argued that Standard Deontic Logic (SDL) is not adequate for combining deontic and action operators. For example, in SDL  $O_j E_i A$  implies that  $O_j A$ , which we feel unacceptable: the fact that  $i$  is obliged towards  $j$  to bring it about that  $A$  should not entail that  $A$  is in general obligatory. For similar reasons,  $O_k E_i E_j A \rightarrow O_k E_j A$  is a theorem of SDL. However, also this principle cannot be accepted because the personal obligation on  $i$  should not imply a personal obligation on  $j$  (Royakkers 1998). For obvious reasons, we will not enter here into a discussion about which axiomatization is suitable for modelling deontic concepts. To avoid the just mentioned problems, it suffices to assume that the logic for deontic concepts is closed under logical equivalence and contains only the following axioms

$$(O_j A \wedge O_j B) \rightarrow O_j (A \wedge B) \quad (5)$$

$$O_j A \rightarrow \neg O_j \neg A \quad (6)$$

We also accept the interdefinability between obligation and permission:

$$O_j A =_{df} \neg P_j \neg A \quad (7)$$

Thirdly, we need a way of expressing connections holding in the context of an institution. A typical example of this connection is the “counts as” relation, according to which we may say that a certain piece of paper with certain characteristics counts as a five euros bill. As argued in (Gelati et al. 2002a), we basically follow the seminal idea developed by Jones and Sergot (1996), where it is introduced a specific conditional connective ‘ $\Rightarrow_s$ ’ to express the ‘counts as’ connection in an institution  $s$ . Jones and Sergot’s logic for  $\Rightarrow_s$  is of type *CE* and contains the schemata *CC*, *CS* and *S* (transitivity) (see Chellas 1980). Their analysis is integrated by introducing the normal **KD** modality  $D_s$  such that  $D_s A$  means that  $A$  is “recognized by the institution  $s$ ” (Santos et al. 1997). Accordingly, the schemata  $(A \Rightarrow_s B) \rightarrow D_s (A \rightarrow B)$  and  $(A \Rightarrow_s B) \rightarrow (A \rightarrow D_s A)$  are accepted, which permit to obtain  $D_s B$  from  $A \Rightarrow_s B$  and  $A$ .

Jones and Sergot’s approach is of great interest but does not suit well with our specific purposes. Our general intuition is that the “counts as”

connection basically corresponds to a general type of normative conditionality, but in which institutional facts (Searle 1995; MacCormick and Weinberger 1986) occur in the rules. We argue that any institution can only state what normative situation holds for itself, given certain conditions, and according to this general type of conditionality. In this regard, we thus adopt a different formalization. We represent the “counts as” link as follows (for further details, see also Gelati et al. 2002a; Artosi et al. 2004):

$$(A \Rightarrow_s B) =_{def} (A \Rightarrow D_s B) \wedge (D_s A \Rightarrow D_s B) \quad (8)$$

where

- ‘ $\Rightarrow$ ’ corresponds to a general normative (non-monotonic) connection with a restricted form of detachment;
- $D_s$  strictly denotes the domain of institutional facts of a given institution and so it is a non-normal modality.

More precisely, our logic for  $\Rightarrow$  corresponds at least to cumulative reasoning (Artosi et al. 2002): it is closed under the rules *RCEA* and *RCK* (Chellas 1980), contains the schemata

$$A \Rightarrow A \quad (9)$$

$$(A \Rightarrow B) \wedge (A \wedge B \Rightarrow C) \rightarrow (A \Rightarrow C) \quad (10)$$

$$(A \Rightarrow B) \wedge (A \Rightarrow C) \rightarrow (A \wedge B) \Rightarrow C \quad (11)$$

and, in addition, is characterized by a restricted form of detachment that allows to infer the consequent  $X$  of a “counts as” rule only when no other, and more specific, rule in the system (which is assumed to be finite) is applicable and permits to obtain  $\neg X$  (Gelati et al. 2002a).

The logic for the “counts as” link, thus, enjoys a restricted form of Reflexivity, which seems to characterize any non-monotonic classificatory relation (Kraus et al. 1990). In addition, it does not have full transitivity, which does not hold in general: from “ $x$ ’s digital signature *counts as*  $x$ ’s autograph signature” and “ $x$ ’s autograph signature *counts as* evidence of  $x$ ’s handwriting” we cannot obtain “ $x$ ’s digital signature *counts as* evidence of  $x$ ’s handwriting” (see also Artosi et al. 2004).

In its turn, the logic for the modality  $D_s$  is not in general closed under the logical consequence. In our perspective, it should be closed under logical equivalence and contain

$$D_s A \rightarrow \neg D_s \neg A \quad (12)$$

and

$$(D_s A \wedge D_s B) \rightarrow D_s(A \wedge B) \quad (13)$$

If  $D_s$  is intended to express the domain of institutional facts relative to  $s$ , this choice is justified because we want to drop some counterintuitive conclusions that can be drawn by weakening the content in the scope of such a modality. In other words, inferences like the following should be avoided:  $(\textit{raising\_one\_hand}) \Rightarrow_s (\textit{bidding}) \vdash D_s((\textit{raising\_one\_hand}) \rightarrow ((\textit{bidding}) \vee (\textit{drinking\_water})))$  (see Gelati et al. 2002a; Artosi et al. 2004). For similar reasons, we do not accept the necessitation rule. Since the intended meaning of this modality is to express the domain of the institutional facts holding in a given institution, the lack of necessitation is reasonable: it sounds strange that  $\top$  is an institutional fact for any institution  $s$ . However, some restricted form of closure is permitted. In particular, it is reasonable to accept a schema like

$$D_s E_X A \rightarrow D_s A \quad (14)$$

to preserve successfulness of actions performed within institutions. Notice that our combination of the logics for  $\Rightarrow$  and  $D_s$  captures the defeasible character of the “counts as” link, while in Jones and Sergot’s original approach it is possible to have  $A \Rightarrow_s B \vdash D_s(A \wedge C \rightarrow B)$ .

Let us also recall the main idea behind the idea of “counts as” as defined in (8). In fact, this notion occurs in the law mainly in two contexts: when the law specifies that a certain brute fact (destroying the receipt) counts as a certain type of legal act (freeing the debtor from his obligation) and when the law wants to specify that a certain legal act (a contract made by person  $j$  in the name of person  $k$ ) has the same legal effects of another legal act (a contract made by  $k$ ) (see also Gelati et al. 2002a). Let us also remark, that though the  $A \Rightarrow B$  connection and the modality  $D$  are usually relative to a certain institution (Jones and Sergot 1996), we do not need to specify this since we are considering just one institution (the legal system).

The last notion we need is the idea of proclaiming. It is used to deal with all those acts by which a subject makes a statement expressing a certain proposition, and this statement has the function (purpose, point or objective) of making this proposition true. Such a notion is formalized by the modal operator *proc* Gelati et al. (2002a). In short, *proc* is a non-normal modal operator whose logic is closed under the logical equivalence. In addition to what is said in Gelati et al. (2002a), *proc*, as for  $E$ , will be indexed by sets of agents. In this way,  $\textit{proc}_X A$  means that the members of  $X$  jointly proclaim  $A$ <sup>2</sup>. In this perspective, it is plausible to assume that, when a set of agents  $X$  makes a joint proclamation that  $A$ , then each agent  $j \in X$  makes such a proclamation<sup>3</sup> for all  $j \in X$

$$\textit{proc}_X A \rightarrow \textit{proc}_{\{j\}} A \quad (15)$$

The converse is not generally valid, since it may be argued that a joint declaration is more than a couple of parallel declarations having the same content. Also, as in Gelati et al. (2002a), *proc* is characterized by the following axiom:

$$(proc_X A \wedge proc_X B \equiv proc_X(A \wedge B)) \quad (16)$$

In fact, it may seem that by proclaiming a conjunction a group also proclaims each conjunct and that by proclaiming two propositions it proclaims their conjunction.

As we argued in Gelati et al. (2002a), *proc* is neutral in regard to intention-based (Grice 1989) and non intention-based theories of speech acts (Jones 1990). By saying that *j*'s statement has the function to achieve *A* we do not specify how the notion of function is to be characterized: it may be determined by the intention of the speaker, by the intention attributed to the speaker by its interlocutor, by a shared convention, by a communication protocol, and so forth. However, given an expression like  $proc_{\{j\}}A$ , if one wants to identify the mental precondition of a sincere use of  $proc_{\{j\}}A$ , one may consider that (a) *j* must believe that *A* is not the case before performing the proclamation, and (b) *j* must believe that through the proclamation one will produce *A*.

Let us also remark that a proclamation is not necessarily effective (it does not necessarily produce *A*). When the notion of function is interpreted with reference to the intention of the speaker it necessarily involves an attempt to achieve *A*, but this attempt may not be successful. Whether it is successful or not, within a certain institutional context, depends on whether that institution makes it effective. For example, in legal systems children cannot validly undertake obligations. If *j* is a child and she proclaims that she assumes an obligation (e.g., the obligation to pay a certain price for a good), no obligation for *j* will be created according to the law. In designing a society of autonomous agents a very important task is allocating declarative powers to agents, that is in establishing what proclamations of theirs will be effective.

Finally, note that the idea of proclaiming is neutral in regard to what is proclaimed. So a proclamation can play the function usually vested by different speech acts. In particular, the combination of *proc* with directed deontic operators allows to account, e.g., for the following cases:

$$proc_{\{j\}}(O_k E_{\{j\}}A) \quad (17)$$

where the proclamation is *j*'s attempt to commit itself towards *k*; on the other hand, a proclamation is *j*'s attempt to command *k*, when it has the form:

$$proc_{\{j\}}(O_j E_{\{k\}}A) \quad (19)$$

with *k* different from *j*. It is *j*'s attempt to free itself from an obligation towards *k*, when it has the form:

$$proc_{\{j\}}(\neg O_k E_{\{j\}} A) \quad (19)$$

#### 4. Declarative power

##### 4.1. BASIC NOTIONS

As we have observed, proclamations are not necessarily effective. When an agent  $j$  proclaims that  $A$ ,  $j$  brings it about that  $A$  only if the concerned institution provides for this result. This means that within the concerned institution a rule must hold having the following content:

$$proc_{\{j\}} A \Rightarrow E_{\{j\}} A \quad (20)$$

In other words, for the institution,  $j$ 's proclamation that  $A$  counts as  $j$ 's action producing  $A$ . Note that according to the action logic we have presented,  $E_{\{j\}} A$  implies  $A$ . Therefore when  $proc_{\{j\}}(A)$  is effective,  $A$  follows within the given institution in virtue of (14). Rules stating that a proclamation is effective can be seen as a particular type of power-conferring rules. By a power-conferring rule, we mean any rule stating that doing an action  $A$  counts as (in the concerned institution) the performance of an action  $B$  (Jones and Sergot 1996), that is any rule having the form  $E_{\{j\}} A \Rightarrow E_{\{j\}} B$ .

Not every power is exercised through a proclamation. It may also be the case in which an institution links a specific outcome to a specific action: consider for example the connection between raising one's hand in an auction and making an offer. The peculiarity of the *proc* operator consists in its generality: it may produce any state of affairs which is the object of the proclamation.

When an institution provides for the effectiveness of a proclamation that  $A$ , we say that the subject of the proclamation has a declarative power:

$$DeclPow_{\{j\}} A =_{def} proc_{\{j\}} A \Rightarrow E_{\{j\}} A \quad (21)$$

Therefore, that an agent  $j$  has the declarative power of producing  $A$  means that if  $j$  proclaims that  $A$  then  $j$  produces  $A$ .

##### 4.2. EMPOWERING AUTONOMOUS AGENTS

A fundamental aspect of a norm-governed society consists in the allotment of permissions and obligations to its members. This is the way in which such a society restrains and organizes the actions of its members. However, in an autonomous society (autonomous means establishing laws for one-self) the agents themselves must be able of creating those permissions and obligations. The decisive aspect of an autonomous social organization consists therefore in the empowerment of its agents, that is in establishing how agents may

create what normative relations. In our model agents are empowered by attributing them appropriate declarative powers. This should enable agents to create the normative relations they need, and in this way to co-ordinate their behaviors. The failure to provide a viable allocation of such powers may threaten the survival of society. For example, if each self interested agents were given an unlimited power to unilaterally create obligation on the head of other agents, society would soon collapse, since everybody would soon be covered with an unsustainable workload, obligations would no longer be fulfilled, conflicts would explode, and trust would fade away. In the following we will sketch some features of a viable allocation of powers, which gives each agent the maximum of power consistent with the attribution of the same power to other agents.

#### 4.2.1. Multi-lateral proclaims (Contracts)

A declarative power may be jointly exercised by more than one party. If so, the proclamation will be an action performed by a set of agents. In very general terms, we may call such an action a contract. For example the making of a contract through which  $j$  takes the obligation towards  $k$  to provide a piece of music  $m$  and  $k$  undertakes the obligation toward  $j$  to pay the price  $p$ , can be represented by the following proclamation:<sup>4</sup>

$$proc_{\{j,k\}}(O_k E_{\{j\}}(deliver(m)) \wedge O_j E_{\{k\}}(pay(p))) \quad (22)$$

Such joint proclaims are usually performed by two acts, the first of which is called offer, and the second acceptance. This combination is considered as a joint declaration (even when there is a delay between offer and acceptance). So we may want to say that the combination of an offer and an acceptance counts as making a contract. In cases where contracts are limited to the creation of reciprocal obligations we can express this as follows:

$$offer_{\{j\},\{k\}}(A, B) \wedge accept_{\{j\},\{k\}}(A, B) \Rightarrow proc_{\{j,k\}}(O_k E_{\{j\}}A \wedge O_j E_{\{k\}}B) \quad (23)$$

If  $j$  offers to  $k$  to make a contract with reciprocal obligations having content  $A$  and  $B$ , and  $k$  accepts, this counts as making the contract. If the parties have the power to make an effective contract, the joint declaration generates within the institution the obligations for the parties involved in the contract. The operators *offer* and *accept* are two committing declarative acts, that can be defined using the non committing declarative acts *proposal* and *agree*:

$$proposal_{\{j\},\{k\}}(A, B) = proc_{\{j\}}(O_k E_{\{j\}}A \wedge O_j E_{\{k\}}B) \quad (24)$$

$proposal_{\{j\},\{k\}}$  is a declaration of  $j$  where she proposes to ascribe to herself the obligation towards  $k$  to do  $A$ , and to  $k$  the obligation towards herself to do  $B$ .

On the other hand, agreeing means to make a proclamation when the other party has already made a proclamation in which it is proposed a specific contractual content:

$$agree_{\{k\},\{j\}}(A, B) = proposal_{\{j\},\{k\}}(A, B) \wedge proc_{\{k\}}(O_j E_{\{k\}} B) \quad (25)$$

(25) means that  $k$  recognizes  $j$ 's proposal and agrees with its content. More precisely, given  $j$ 's proposal,  $k$  agrees with binding herself to the obligation towards  $j$  to do  $B$ .

We are now able to introduce *offer* and *accept* formally. We have an offer when

$$\begin{aligned} offer_{\{j\},\{k\}}(A, B) &= proposal_{\{j\},\{k\}}(A, B) \wedge \\ (agree_{\{k\},\{j\}}(A, B) \Rightarrow proc_{\{j,k\}}(O_k E_{\{j\}} A \wedge O_j E_{\{k\}} B)) \end{aligned} \quad (26)$$

i.e.,  $j$  proposes the content of the contract to  $k$  and she is in a context where the acceptance of it by  $k$  will create the respective obligations. Accordingly,  $k$ 's acceptance is formalized as follows:

$$accept_{\{k\},\{j\}}(A, B) = offer_{\{j\},\{k\}}(A, B) \wedge proc_{\{k\}}(O_j E_{\{k\}} B) \quad (27)$$

In other words, *accept* indicates that  $k$  accepts the legally binding offer of  $j$ . Since  $k$ 's proclamation is done in presence of  $j$ 's proposal (see (26)), such a proclamation determines  $k$ 's agreement with the content  $(A, B)$ . In addition, the second conjunct of (26) ensures that the offer and the acceptance are binding within the underlying institution.

#### 4.2.2. Empowerment to commit oneself

We may consider giving every agent the power of creating obligations for itself, i.e., the power of making effective promises, or of committing itself. If our agents are autonomous, this power should be equally given to each of them. However, this may seem too liberal:  $j$ 's obligation, towards  $k$  to perform  $A$  implies the permission toward  $k$  to perform that action. So,  $k$ 's consent seems to be required. We can propose a general rule attributing the agents the power of committing themselves to other agents through a contract:

$$DeclPow_{\{j,k\}}(O_k E_{\{j\}} A) \quad (28)$$

which means that every couple of agents has the power of establishing any obligation between them, simply by proclaiming it. In other words, we empower all our agents to make effective promises (with the consent of the promisee).

#### 4.2.3. Empowerment to remit obligations and give permissions

It is reasonable to assign every agent  $j$  the power of freeing any other agent  $k$  from obligations toward  $j$ , even without  $k$ 's consent. For example, if  $j$  is no

longer interested in  $k$ 's performance,  $j$  should be allowed to free  $k$  from that performance. In fact, if  $j$  is able to look after itself and an obligation on  $k$  was originally created to promote  $j$ 's interest, then  $j$  should be empowered to choose whether to cancel that obligation or not:

$$DeclPow_{\{j\}}(\neg O_j E_{\{k\}} A) \wedge DeclPow_{\{j\}}(\neg O_j \neg E_{\{k\}} A) \quad (29)$$

Accordingly, this formula also enables an agent to give any permission towards itself:

$$DeclPow_{\{j\}}(P_j E_{\{k\}} A) \quad (30)$$

So, for example, if agent  $j$  has the obligation towards  $k$  not to access a certain piece of information,  $k$  has the power of permitting that  $j$  accesses the information, according to 30. This is a very libertarian approach, but is appropriate for autonomous agents, e.g., in the commercial domain.

#### 4.2.4. Empowerment to command

It would be unreasonable to give all agents the power of commanding whatever action to any other agent. The power of commanding needs to be restricted only to specific cases, such as when one agent is hierarchically superior to another. A power of commanding held by superiors over inferiors would be conferred by the following rule:<sup>5</sup>

$$j \prec k \Rightarrow DeclPow_{\{j\}}(O_j E_{\{k\}} A) \quad (31)$$

where  $\prec$  corresponds to a hierarchical relation between agents. Notice that ' $\Rightarrow$ ' stands for the generic normative connection we have alluded to. In many types of societies, further restriction would be opportune, if the boss is not be a total dictator over its subordinates. A total power of commanding may be, however, the right empowerment for a human user over its agents.

#### 4.2.5. Empowerment to renounce to power

It may seem reasonable to give agents also the power to renounce to their powers. In general terms this would be expressed by the following general empowerment:

$$DeclPow_{\{j\}}(\neg DeclPow_{\{j\}} A) \quad (32)$$

#### 4.2.6. Empowerment to empower

We give our agents a further chance to develop their societal relationships if we give them the power of conferring a power. For example, the formula below expresses the idea that  $j$  has the power of creating  $l$ 's power of creating the obligation that  $k$  realizes  $A$ .

$$DeclPow_{\{j\}}(DeclPow_{\{l\}}(O_x E_{\{k\}} A)) \quad (33)$$



What kinds of empowerment to empower can be allocated to our agents, according to a general rule? A very liberal choice would consist in stating that each agent has the power of giving other agents the powers he has for itself.

$$DeclPow_{\{j\}}A \Rightarrow DeclPow_{\{j\}}(DeclPow_{\{k\}}A) \quad (34)$$

So, for example, since each agent  $j$  has the power of committing itself according to (28), according to (34),  $j$  also has the power of submitting itself to another agent  $k$ , giving  $k$  the power to commanding  $j$ . This will be done via the following proclamation:

$$proc_{\{j\}}(DeclPow_{\{k\}}O_kE_{\{j\}}A) \quad (35)$$

Note that according to the definition above, when  $j$  gives to  $k$  a power which was previously possessed by  $j$ ,  $j$  does not lose its power: both  $j$  and  $k$  can now exercise it. Obviously, empowerment may lead to cycles. Agent  $j_1$  empowers  $j_2$  to  $A$ , . . . , agent  $j_n$  empowers  $j_1$  to  $A$ . However, this is no problem: the latter empowerment simply is redundant, since  $j$  already possessed that power (unless it has renounced its power when conferring that power to another agent).

#### 4.2.7. Recursive empowerment

Finally, it is possible to confer our agents a further kind of power, which includes both the power of conferring a power to create a normative position and also the power of transferring to others a similar power. We define this type a recursive declarative power:

$$RecDeclPow_{\{j\}}(O_jE_{\{k\}}A) = DeclPow_{\{j\}}(O_jE_{\{k\}}A) \wedge \quad (36)$$

$$DeclPow_{\{j\}}(RecDeclPow_{\{l\}}(O_jE_{\{k\}}A))$$

The above formula means that the holder  $j$  of the recursive declarative power is enabled to exercise his power in two ways. The first capacity,

$$DeclPow_{\{j\}}(O_jE_{\{k\}}A) \quad (37)$$

enables  $j$  to make so that  $k$  is obliged to realize  $A$ . The second capacity enables  $j$  to transfer to another agent  $l$  the same recursive declarative power which  $j$  possesses. This latter notion is useful in those cases where an organization is developed in multiple levels, and the top level wants to delegate not only the performance of the action, but also the command to perform it. The exercise of this power may lead to cycles, but again, this is no problem (the agent who started the cycle may consider having another try), or better it is a problem that it is up to the concerned agents to solve, according to their view of their own interest.

#### 4.2.8. *Specific limitations to empowerment*

In the previous pages, we have sketched the constitution of a liberal, or better a libertarian society, where every agent is considered to be fully able to look after its interest, and where any normative relation can be created via the consent of the interested parties. In many real life contexts, and in particular in legal institutions, various limitations to individual freedom are provided, for a number of reasons: preventing frauds, protecting the weaker party, preventing the parties from making mistakes. Unfortunately, there is not much that we may say in general in regard to such limitations. It depends on the particular institutional what exceptions are made to the libertarian framework we sketched above. Consider, for example, the regulations which require a proclamation to a certain effects to be performed in certain specific ways (e.g., contracts concerning real estates have to be made in writing, or through deeds, unilateral promises are binding only if they serve an interest of the promisor, testaments have to be signed, etc.). We will not investigate here those special conditions, nor the way in which our formalism need to be extended to cope with them. This will be a matter of future research.

### 5. Representation and mandate

On the basis of the notions previously introduced, we will now provide a formalization of the notions of representation and mandate (which we informally introduces in Section 2).

#### 5.1. REPRESENTATION

Representation is a notion which is very important in all modern legal systems, and it can be used for modelling an important aspect of the relation between a user and her agent, or of the relations between agents: representation enables an agent to act in the name of its user or in the name of other agents. Obviously this notion is very important to achieve flexible and decentralized decision-making. In the following, we always use the index  $j$  to refer to the principal and  $k$  to refer to  $j$ 's representative. First we may characterize representation itself as consisting in the possession of a declarative power. The representative has the declarative power of proclaiming that the represented person performs a certain proclamation: if he proclaims that the represented person is performing a certain proclamation, then this counts as this person's doing this proclamation:

$$proc_{\{k\}}(proc_{\{j\}}A) \Rightarrow E_{\{k\}}(proc_{\{j\}}A) \quad (39)$$

that is, when  $k$  proclaims that  $j$  proclaims that  $A$ , this counts as  $k$ 's making so that  $j$  proclaims that  $A$ . Using the *DeclPow* abbreviation, this connection can be expressed as:

$$DeclPow_{\{k\}}(proc_{\{j\}}A) \quad (40)$$

that is,  $k$  has the declarative power of making so that  $j$  proclaims that  $A$ .

For example, let us assume that  $k$  represents  $j$  with respect to permitting any other agent  $l$  (towards  $j$ ) to access  $j$ 's database *db1*. We represent this as

$$DeclPow_{\{k\}}(proc_{\{j\}}(P_j E_{\{l\}} access(db1))) \quad (41)$$

which is to be read as  $k$  has the declarative power of making so that  $j$  gives permission to any agent  $l$  to access. Then, when  $k$  says that  $j$  proclaims that  $l$  is permitted to access the database *db1*, this counts as  $j$ 's proclaiming that  $l$  is permitted.

Let us now consider what allocation of representative powers will be appropriate to the type of libertarian society we have been so far defining. The most appropriate choice seems to be to give any agent the power of conferring to any other agent  $k$  the power of representing itself (everybody has the power of making so that another person represents herself), in regard to any type of act  $A$ . This is expressed by the following rule:

$$DeclPow_{\{j\}}(DeclPow_{\{k\}}(proc_{\{j\}}A)) \quad (42)$$

Each  $j$  and each  $k$  are such that  $j$  has the power of conferring to  $k$  the power of representing  $j$ , in regard to any proclamation. Representation does not need to be conferred in relation to a specific proclamation. It may concern any proclamation concerning a certain type of proposition. For example,  $j$  can confer  $k$  the power of representing  $j$  in all proclamations which concern permitting access  $j$ 's database *db1*. This will be achieved via the following proclamation:

$$proc_{\{j\}}(\forall l(DeclPow_{\{k\}}(proc_{\{j\}}(P_j E_{\{l\}} access(db1)))))) \quad (43)$$

We have so far considered representation as the situation where  $k$ 's proclamation counts as  $j$ 's proclamation:

$$proc_{\{k\}}(proc_{\{j\}}A) \Rightarrow proc_{\{j\}}A \quad (44)$$

which we have simplified into:

$$DeclPow_{\{k\}}(proc_{\{j\}}A) \quad (45)$$

Another type of representation is also possible:  $k$ 's proclaiming that  $A$  counts as  $j$  making so that  $A$ :

$$proc_{\{k\}}(E_{\{j\}}A) \Rightarrow E_{\{k\}}(E_{\{j\}}A) \quad (46)$$

This can be simplified in:  $DeclPow_{\{k\}}(E_{\{j\}}A)$ . The second type of representation is necessary when the representative substitutes a principal which would not be able to perform directly the activity which is delegated to the

representative. Consider, for example, the situation where only certain agents are empowered of making certain transactions (for example, trading on line). Agent  $j$ , which has not the power of performing those transactions, can still confer a power of representation to agent  $k$ , but this should not mean that  $k$ 's proclamations count as  $j$ 's proclamation, since  $j$ 's proclamations would be ineffective. It should rather mean that  $k$ 's proclamations count as  $j$ 's realization of the proclaimed result. A further aspect normally involved in  $j$ 's representation, but which we cannot approach here, is  $k$ 's duty of acting for the interest of  $j$ , that is of adopting  $j$ 's interests or goals as his own goal in the exercise of representation. In fact, being a representative includes having the power of making certain declarations in the name of the principal, but also the constraint to exercise such a power in the interest of the principal (on goal adoption, see Castelfranchi and Falcone 1998).

## 5.2. MANDATE

We may say that a mandate is a proclamation intended to create the obligation of exercising a declarative power, or the obligation to exercise this power in a specific way. The author of the proclamation is called the mandator, and the bearer of the obligation is called the mandatee. So, a mandate has the form:

$$proc_{\{j\}}(O_j E_{\{k\}} A) \quad (47)$$

where  $A$  consists of, or is related to, the exercise of a declarative power. Usually, the conferral of a power of representation is accompanied by a mandate, which obliges the representative to exercise the power of representation in certain ways. For example, besides giving his agent the general power of representing him in buying musical recordings, a user may command the agent to buy a specific recording, from a retailer included in a list of agreed retailers, below a certain maximum price, and so on.

In such a case, the representation can be conferred through the following proclamation:

$$proc_{\{j\}}(DeclPow_{\{k\}} proc_{\{j,l\}}(P_l(E_{\{j\}} DownloadRecord(r) \wedge O_l E_{\{j\}} PayPrice(p)))) \quad (48)$$

This formula says that  $j$  proclaimed that his representative  $k$  can (in the name of  $j$ ) acquire for  $j$  the permission to download records, and put  $j$  under the obligation to pay to the vendor  $l$  the corresponding price.

The mandate to buy a record (the collection Revolver, but the Beatles) would take the form of the following proclamation (using a very rough formulation):

$$\begin{aligned} & \text{proc}_{\{j\}}(O_j E_{\{k\}} \text{DownloadRecord}(\text{Revolver}) \\ & \wedge O_j E_{\{k\}} \text{PayLowPriceFor}(\text{Revolver})) \end{aligned} \quad (49)$$

Since the mandate puts the mandatee under an obligation, according to the principles we sketched above, an effective mandate presupposes that either the mandator has the power of commanding the mandatee (as expressed in (48) and (49)), or that a contract between the mandatee and the mandator is concluded. The first hypothesis may concern, in particular, the relationship between a user and his personal digital assistant, the second hypothesis the relation between a user and an agent the user has hired for a specific business. The legal notion of mandate includes further refinements: in particular,  $k$  being the mandatee of mandator  $j$  in regard to an action usually implies also that  $k$  should perform that action in the interest of  $j$ . It seems that this may require both the obligation to perform this activity (for instance buying a certain house), and also the obligation to act in such a way that this power satisfies  $j$ 's interests (buy the house at the lowest price, with the best conditions, from a reliable seller, and so forth). It is not easy to specify what it means to make so that  $j$ 's interest in  $A$  is satisfied. Note that, it is unwarranted to require that  $k$ 's way of achieving  $A$  is really optimal, in regard to  $j$ 's interest. However,  $k$  must make his best, within the costs that are justified by the importance of the affair, to achieve the optimum. One may wonder to what extent those refinements should be included in a notion of mandate appropriate for interactions with and between electronic agents. Whether such refinements are necessary, and how they can be formalized this is something we will consider in our future work.

## 6. The framework applied to the contract net protocol

In this section, we show how the framework can formalize a well-known trading scenario, the contract-net protocol. As informal specification of the contract-net protocol we assume that proposed in (Pitt et al. 2001). For short, a contractor sends a call for proposal to a set of prospective workers. In general, some workers answer to the proposal, by offering to do the job, some do not. Among the answers received by the timeout, there be refusals and offers. At this stage, the contractor chooses the best offer according to some parameters. Then, it accepts the offer of the winner and rejects the others. The winner must perform the contracted task and inform the contractor after the execution.

There are some constraints which govern the process of contracting. First, a worker can only offer to accomplish a task which it is able to accomplish. Second, a worker can only offer to accomplish a task which has been

proposed to him. Third, a contractor can only accept an offer when he has the resources for paying for the price.

We may view these constraints in two ways. One perspective is to consider them to introduce conditions for the validity (effectiveness) of contracts stipulated between a contractor and a worker. This would mean that if the contractor has no money, or the worker is unable, or the contract was not preceded by a proposal, then the contract would be invalid. This would be an exception to our definition of multi-lateral proclaims, namely that the joint declaration of the interested parties is sufficient for the effectiveness of the contract.

In this representation we adopt a different approach. Those constraints express obligations on the parties, which they may violate at their risk (incurring in possible sanctions) but which do not imply the ineffectiveness of their contracts. Note that this is what happens in the law: the fact that a party is unable to execute a contract determines the liability of that party (for failure to perform its contractual duties), rather than the invalidity of the contract.

First, observe that the content of the contract (which is proposed, offered and accepted) is always  $O_c E_{\{w\}} performed(t) \wedge O_w E_{\{c\}} paid(p)$ , which means that the worker  $w$  undertakes, toward the contractor, the obligation to perform the task  $t$ , while the contractor  $c$  undertakes, towards the worker  $w$ , the obligation of paying the price  $p$ .

We write  $cfp_c^W(X)$  to mean that contractor  $c$  calls for proposals (of making a contract) having content  $X$  from any worker  $w \in W$ . Note that a call for proposals is a special case of ‘*proposal*’, as previously described, and corresponds to  $proposal_{\{c\},\{w\}}(X)$  for any  $w \in W$ . We write  $offer_{\{w\},\{c\}}(X)$  to mean that worker  $w$  offers contractor  $c$  to conclude a contract with content  $X$ . Similarly, we write  $accept_{\{c,w\}}(X)$  to mean that contractor  $c$  accepts to conclude a contract with worker  $w$  having content  $X$ .

Here is how we represent those constraints:

1. If a worker agent cannot perform a task, then it is not permitted to offer to perform it<sup>6</sup>

$$(worker(w) \wedge \neg can_{\{w\}}(performed(t))) \Rightarrow quad \neg P(offer_{\{w\},\{c\}}(E_{\{w\}}performed(t), E_{\{c\}}paid(p))) \quad (50)$$

2. If a task has not been proposed, a worker agent is not permitted to offer for it:

$$worker(w) \wedge \neg cfp_c^W(X) \Rightarrow \neg P(offer_{\{w\},\{c\}}(X)) \quad (51)$$

3. If a contractor agent cannot pay the price for which a worker has offered to perform the task than it is not permitted to accept the offer:

$$\begin{aligned} & \text{contractor}(c) \wedge \neg \text{can}_{\{c\}}(\text{paid}(p)) \Rightarrow \\ & \neg P_w(\text{accept}_{\{c\},\{w\}}(E_{\{w\}}\text{performed}(t), E_{\{c\}}\text{paid}(p))) \end{aligned} \quad (52)$$

We can now move to show a typical sequence of messages (in our framework, proclamations) that compose the contract net protocol. First the contractor issues a proposal of a contract the terms of which state that the worker has the obligation to print a copy of the book *War and Peace* ( $t$ ) and the contractor has the obligation to pay 20 Euros ( $p$ ) for it.

$$\text{cfp}_c^W(E_{\{w\}}\text{performed}(t), E_{\{c\}}\text{paid}(p)) \quad (53)$$

As a consequence, now, workers, who are able to print the book are allowed to make offers. This assumes that what is not forbidden is allowed. Let us assume that worker  $w$  returns an offer, intended as a (possibly committing) counter-proposal to (53):

$$\text{offer}_{\{w\},\{c\}}(E_{\{w\}}\text{performed}(t), E_{\{c\}}\text{paid}(p')) \quad (54)$$

where  $p' = 15$  Euros. Let us now assume that this is the best offer  $c$  has received, so that it accepts it (this implies  $c$ 's agreement; see Section 4.2).

$$\text{accept}_{\{c\},\{w\}}(E_{\{w\}}\text{performed}(t), E_{\{c\}}\text{paid}(p')) \quad (55)$$

From (54) and (55) the following is obtained (within the institution):

$$D(\text{proc}_{\{c,w\}}(O_c E_{\{w\}}\text{performed}(t) \wedge O_w E_{\{c\}}\text{paid}(p'))) \quad (56)$$

This means that the parties have made a contract. The contract is effective according to the general principles. In fact, according to the logical properties of proclamation, (56) implies the following

$$D(\text{proc}_{\{c,w\}}(O_c E_{\{w\}}\text{performed}(t)) \wedge \text{proc}_{\{c,w\}}(O_w E_{\{c\}}\text{paid}(p'))) \quad (57)$$

Finally, according to axioms (28) and (14) we obtain (within the institution) that  $w$  is obliged to do the job and  $c$  is obliged to pay for it:

$$D(O_c E_{\{w\}}\text{performed}(t) \wedge O_w E_{\{c\}}\text{paid}(p')) \quad (58)$$

Once the contractor agent has decided which offer fits its needs the most, he has also to communicate his refusals to the losers  $w'$ :<sup>7</sup>

$$\begin{aligned} & \text{proposal}_{\{w'},\{c\}}(E_{\{w'}\}\text{performed}(t), E_{\{c\}}\text{paid}(p'')) \\ & \wedge \text{proc}_{\{c\}}(\neg O_{w'} E_{\{c\}}\text{paid}(p'')) \end{aligned} \quad (59)$$

## 7. Future developments: Applications and computational issues

As we have alluded to, this paper is mainly theoretical. In this section we will briefly indicate two developments and applications of the framework we have previously defined.

A first aspect regards a possible and concrete application of the framework in the area of Digital Rights Management (DRM), a field that has drawn attention from both the scientific community and industry in the last few years. DRM is intended as a pool of technologies for data security and protection, copyright protection and access control. DRM addresses the management of digital resources, including their publishing, manipulation and transferring. DRM is ultimately one key enabling technology for marketing intellectual products, such as music, images and e-books, on the Internet (Kamyab et al. 2001). As a first approach, we have already looked at the eXtensible rights Markup Language (*XrML*), an XML-based grammar for specifying rights related to digital resources (Contentguard 2001): *XrML* is in fact an *XML* grammar intended for terming licenses related to digital resources. Licenses establish which rights are granted to which parties and the conditions by which digital resources can be operated. We have already provided a simple extension of the set of elements of *XrML* language to cover some types of normative positions required by our logical framework (Gelati et al. 2003; Gelati and Riveret 2004). Subsequently, a prototype, based on this extension, has been built using the *JADE* multi-agent system platform (Bellifemine et al. 2003a, b; see Gelati and Riveret 2004). The result is a system that can be used to make agents negotiate the exchange of goods. Although the system seems to be a good test bed for some virtual marketplace scenarios, limitations of the system are due to the nature of *XrML*: every concept contained in a license must be understood by the counterparts in the negotiation and this implies that every *XrML* tag must be *explicitly* dealt with the parser. The future work will thus focus on devising a suitable inference engine, so that agents can reason about rules reaching a more flexible behavior. This should also permit to embed into the language and express more complex normative concepts than those already added to standard *XrML*.

A second line of research consists in developing a computational framework, based on the logical intuitions we have described here, and which should be able to treat the basic mechanisms of institutional agency and normative co-ordination. Also in this regard we have some first, but interesting, results. We have already proposed a computationally oriented model based on Defeasible Logic. Defeasible logic has been developed by Nute (1987) with a particular concern about computational efficiency and developed over the years by Maher and Governatori (1999) and Antoniou et al. 2000. The reason being ease of implementation (Maher et al. 2001),



flexibility (Antoniou et al. 2000) – it has a constructively defined and easy to use proof theory which allows us to capture a number of different intuitions of non-monotonicity – and it is efficient: it is possible to compute the complete set of consequences of a given theory in linear time (Maher 2001). At the moment, we have provided two extensions of standard Defeasible Logic. The first incorporates the notions of “counts as” and agency, as described in this paper (Governatori and Rotolo 2003; Governatori et al. 2004). The second combines agency, BDI concepts and obligations (Governatori and Rotolo 2004). Our future work will be devoted to developing a unique framework which is able to deal with the cognitive component (BDI concepts), agency, and normative notions (“counts as” and deontic operators). In addition, thanks to the nice computational features of the logic, we plan to investigate how the framework can lead to real implementations.

## 8. Related Work

This paper originates from two lines of research. The first concerns research into legal positions, and particularly into the notion of power. The second line of research concerns how normative positions are generated through speech acts. In the first regard, we are particularly indebted to Jones and Sergot (1996). The idea of power has been formalized also by Allen and Saxon (1991) along similar lines. In regard to the link between speech acts and normative positions, we refer to Jones (1990), Castelfranchi and Falcone (1998), Singh (1999), Castelfranchi et al. (2000), and Colombetti (2000) for informal characterization of delegation (1998). The peculiarity of our work, however, lies in the attempt of substituting a unique speech act (proclaiming) to model all speech acts which are characterized by a world to word direction of fit, that is all speech acts which are intended to modify the normative (institutional) world. In most approaches, what we modelled as proclamations is represented through different types of speech acts (commissives, permissives, agreements, etc.), each one characterized by its own specific semantics. On the contrary, we are able to view all those performatives as instances of just one speech act, since their differences, from our perspective, only pertain to the content which is proclaimed. This provides a simpler and more flexible framework for institutional performatives. The framework is simple since the logic of all institutional performatives is exhausted by the simple logic of the *proc* operator. The framework is flexible since proclamations can have whatever content, and, by distinguishing their possible contents, we can provide a precise account of many nuances characterizing institutional performatives. Of course, a number of works have been put forward to give a formal account of speech acts theory in MAS. Let us mention two of the most popular

approaches to agent communication, that is FIPA ACL (FIPA 2001) and KQLM (Finin et al. 1997). Even if some intuitions about well-known paths like propose/accept-proposal have been provided here, a full comparison of our analysis to what is developed in those settings is outside the scope of this paper. Such a work will be the object of future investigations.

One important issue, which we could not address here, is how to deal with conflicting normative positions arising from the exercise of declarative powers (such conflicts are even implicit in certain types of acts, such as when an agent cancels an obligation or renounces a powers). Various approaches are suitable, such as that of making use of defeasible reasoning techniques (Prakken and Sartor 1996), or also of Event Calculus as recently done by (Artikis et al. 2002). Also this crucial question will be a matter of future research.

## 9. Conclusions

We are aware that this paper raises many issues, rather than providing definitive solutions. This is due to the complexity of the legal aspects we have tried to analyze. We believe however, that the notions we have presented may provide a very general model for normative interactions between autonomous agents. In our future work we aim at providing a more refined characterization, and at studying how the building blocks we have here sketched can be used in building effective coordination.

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## Notes

<sup>1</sup> The issue of collective action and cooperation is greatly discussed in the recent literature. For a recent extension of the *E* logic to cover collective agency, see (Carmo and Pacheco 2001).

<sup>2</sup> Also in this case, when *X* has only one element *i*,  $proc_X^A$  means that *A* is proclaimed personally by *i*.

<sup>3</sup> We are aware that this is a debatable assumption. It might be argued that such an implication holds only if the proclamation of a set of agents consists of a set of parallel utterances performed in the presence and with the awareness of the others.

<sup>4</sup> Notice that our reading is different from that proposed, e.g., by Herrestad and Krogh (Herrestad and Krogh 1995). They view a contract relation as follows:  $O^i E_i B \wedge O_j E_j B$ . The first conjunct is an ought-to-do statement expressing that *i* has the obligation to do *B*; the second

corresponds to an ought-to-be statement saying that  $j$  requires  $i$  to perform  $B$ . We think this approach is intuitively unsatisfactory since it lacks to make explicit a strong logical relation between the two conjuncts. We solve this problem by saying that the conjunction of directed obligations is proclaimed jointly by both parties. For a criticism of Herrestad and Krogh's approach, see (Tan and Thoen 1999).

<sup>5</sup> For a formal treatment of hierarchies among agents in the current setting, see (Gelati et al. 2002a).

<sup>6</sup> The expression '*can*' may be viewed as the operator *Ability* described in (Elgesem 1997).

<sup>7</sup> Formula (59) expresses  $c$ 's disagreement. Its definition can be intuitively formulated from the formula (25).

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