Delegation as a communicative act: a logical analysis

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Abstract. Delegation is one of the main determinants of coordination, joint activity and collaboration within the context of organizations. In particular, delegation is the fundamental aspect for the redistribution and for the transfer of tasks within the context of an organization, and it is responsible for making organizations dynamic. We present in this paper a conceptual and formal analysis of delegation. In our approach, delegation is intrinsically a communicative act of directive type, that is a communicative act whose essential condition is to induce the hearer to perform a certain action. The concept of delegation and its essential condition will then be formalized by a logic which combines the expressiveness of dynamic logic and Standard Deontic Logic (SDL) with that of a logic of belief and choice.

1 Introduction

When looking at social interaction within the context of organizations, social scientists have been mostly interested in individuating the antecedents of collective behavior and collective action between interacting individuals. A central concern of the field has been to identify the determinants and constituents of coordination, joint activity and collaboration. Among the different determinants, trust and delegation have been recognized as ones of the most important [20, 3, 23, 8]. Suppose that agent i has a general goal to achieve. Agent i might decide to exploit other agents in order to achieve his goal thereby forming a complex plan involving the actions of other agents. In this situation, agent i will delegate some elements in his multi-agent plan to other agents in the organization. In this perspective, delegation is the fundamental aspect for the redistribution and for the transfer of tasks, roles, powers, and obligations, within the context of an organization. In this sense, delegation is responsible for making organizations dynamics. Delegation is tightly related with trust. Indeed, an agent i's decision to delegate some task to another agent j is often based on i's trust in j, that is, in many situations trust is a necessary precondition for delegation.

In some previous works [17] we have been more interested in the formal characterization of trust and in the analysis of the role of trust within agent organizations. In this work we provide a formal cognitive analysis of delegation. We describe agents in terms of their mental attitudes (beliefs, goals, intentions) and we provide a logical characterization of the essential cognitive constituents of delegation, that is, those mental attitudes which characterize the cognitive state of an agent *delegating* the performance of a certain action (or task) to another agent. Note that it has long been argued that multi-agent systems should have a social semantics, that is a semantics about externally observable states of affairs (such as commitment, permissions, obligations, *etc.*) rather than the internals to the agents (such as belief, choices, intentions, *etc.*). Our claim here is that observable social concepts are nothing else than public expression of internal states of affairs. Thus, it seems to us that a characterization of delegation by the way of mental attitudes is the necessary first step for studying such a concept.

The major claim we defend in this work is that delegation is intrinsically a communicative act of directive type [22], that is a communicative act whose *essential condition* (or *illocutionary goal*) is to induce the hearer to perform a certain action. We show that this communicative act has *additional conditions* with respect to other directive acts like request and order. These conditions lead us to distinguish two kind of delegation: the first one with an option of refusal (and closed to a request), and the second one without any option of refusal (closed to an order).

The sequel of the article is organized as follows. In Section 2 we provide an analysis of delegation trying to individuate its essential constituents. This part of the work provides the conceptual backbone of all the work. In Section 3, we present a formalism which is sufficiently expressive to capture the concept of delegation discussed in Section 2. It is a BDI-like modal logic which supports reasoning about agents' actions, powers, abilities, and mental attitudes (beliefs, goals and intentions). In Section 4, the concept of delegation is formalized and its logical properties are studied. Section 5 is devoted to compare our approach with some approaches of delegation that have been proposed in the multi-agent system field.

2 Delegation: an informal view

We conceive delegation as a specific kind of communicative act of a delegant towards a delegated agent. Thus, the essential cognitive constituents of delegation we aim at specifying in this work should be conceived as the *conditions of success* of the communicative act *delegation* in the sense of Speech Act theory. According to this theory [22], the conditions of success of a communicative act (or speech act) [1] are the conditions that must be obtained in a possible context of utterance in order that the speaker successfully performs that act in that context. More precisely, the conditions of success of a speech act are the mental attitudes that are necessarily expressed by a speaker when the speaker is successfully performing this speech act. For example, a condition of a promise to perform a certain action in a certain context is that the speaker intends to perform this action in this context (sincerity condition). If the speaker does not intend to perform this action in this context, then he cannot make a (non-defective) promise to perform this action in this context.[2]

[1] Roughly speaking, 'speech acts' and 'communicative acts' are the same thing for us. Speech Act theory is indeed sufficiently general to speak about communication in general (verbal communication, communication by gestures, by facial expressions, *etc.*). The main objective of Speech Act theory is indeed the specification of different *types* of acts with different illocutionary forces (request, order, promise, *etc.*), independently from how every instance of speech act is effectively realized and performed.

[2] Technically in Speech Act theory, if this condition is *expressed* through the performance of this act, this performance will be successful. But if the speaker is here insincere the performance

Let us now explain what are the different conditions that must be satisfied for achieving delegation with an option of refusal. Suppose that agent i has a goal φ to achieve and that i decides to exploit an action α of another agent j in order to achieve such a goal. In this case, agent i *relies* on the execution of action α by agent j for the achievement of φ, what is exactly described by the following Condition A:

(A) agent i intends that agent j will perform action α so that φ will be achieved.

This aspect of *reliance* is for us the first necessary constituent of delegation, where reliance means an agent's decision to exploit the actions of other agents in order to achieve his goals.

Rational intentions must be realist [6], that is, a rational agent i cannot intend something to be true unless i thinks it to be possible. Thus, delegation has the additional condition:

(B) agent i thinks it is possible that agent j will perform action α.

As our concept of intention is based on rational choice (that is: if agent i prefers that φ be true, then i envisages at least one possible world where φ is true), Condition A entails Condition B.

Delegation and reliance are not synonymous and although *reliance* is a fundamental dimension of delegation, it is not sufficient to define it. Delegation is indeed a specific kind of speech (or communicative) act and involves a communicative aspect which is not necessarily involved in reliance. As such, performance conditions of this act should at least include all performance conditions of the primary directive act. This is the case because conditions A and B are nothing else that the sincerity condition and the preparatory condition of the primary directive act respectively. As emphasized by Vanderveken [25] these conditions are necessarily expressed by the speaker when an act of directive type is performed. Thus, if an agent i (the speaker) wants to delegate to an agent j (the hearer) the performance of a certain action α for the achievement of a certain goal φ then, necessarily:

(C) i has the intention to communicate to j that i is currently relying on j's execution of the action α.

Furthermore, when delegating a certain action α to agent j, agent i manifests to j that he is granting to him the permission to do action α. Thus, delegation has the additional preparatory condition:

(D) i has the intention to communicate to j that j has the permission to perform action α.

Finally, when delegating to agent j the performance of α,

(E) agent i has the power and the authority to grant to agent j the permission to perform action α.

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of this act will be defective. (That is, it conveys nothing.) See [25, p. 130] for more details. Here, we do not distinguish between success conditions and non-defective conditions.

Note that i's power of granting a permission to j as well as i's power of obliging j to do something (see Condition E$'$ below) should be conceived as specific forms of institutional power based on so-called constitutive rules shared by the agents of the form 'an act of i of a certain type *counts as* i's act of ensuring that j has that permission (resp. obligation)'. The relationship between constitutive rules and an agent's power to grant a permission will not be analyzed here (on this issue see, e.g., [19, 15, 11]).

These last two conditions D and E are also components of the speech act *permit*, *allow*, *authorize*, *etc.* (and, for a stronger form of delegation, a component of order). Thus, what distinction can be made between these acts and delegation? It is the fact that these acts are not of directive type: if agent i permits/allows/authorizes agent j to do action α, it does not necessarily mean that i requests j to do α.

The distinction between the *request* act and delegation is that, differently from the latter, the former does not necessarily imply the creation of a norm. [3] More exactly, delegation conveys a *transfer of prerogative* from the speaker to the addressee, that is, just before the delegation act the hearer does not have the permission to do the action that the speaker wants to delegate. In other words, before delegating to agent j the execution of action α:

(F) it is forbidden for agent j to do action α.

Note that j will acquire the permission to do action α after the completion of the delegation act. (Thanks to Condition D.)

From this perspective, delegation can be conceived as a particular speech act of directive type which is a more specific form of request. We illustrate this idea by the both following examples.

Scenario 1. *Suppose that agent i is the editor-in-chief of a scientific journal. Agent i decides to delegate to agent j, a member of his editorial board, the task of reviewing an article submitted to the journal. This means that i **relies on** j's action of reviewing the article, i.e. i intends that j will review the article. Furthermore, i **intends to ask** j to review the article and i **intends to communicate** j **that he is granting him the permission** to review the article. In this situation, i,* qua *editor-in-chief of the journal, he is in the position to grant a permission to a member of the editorial board to review an article. By delegating the task of reviewing the article, i also creates the permission for j (and maybe here, the obligation) to review the article.*

Scenario 2. *Agent i believes that his car is damaged and wants it to be repaired. Thus, he decides to delegate to a mechanic the task of repairing the car. This means that i **relies on** the mechanic's action of repairing the car, i.e. i intends that the mechanic will repair the car. Agent i's act of delegating to the mechanic the task of repairing the car also involves i's **intention to ask** the mechanic to repair the car and i's **intention to communicate the mechanic that he is granting him the permission** to repair the car (in his shoes). In this situation i,* qua *owner of the car, he is in the position to grant a permission to the mechanic to repair his car. By delegating the task of repairing the car, i also creates the permission for the mechanic to repair the car.*

[3] By 'norm', we mean an obligation or a permission.

In both scenarios, the conditions associated to Conditions D–F are the most characteristic/important conditions of delegation because they distinguish delegation from other kinds of directive speech act. For instance, suppose that in the first scenario another agent z is not the editor-in-chief of the journal, but he is simply a colleague of agent j. Suppose also that z is in charge to review the article but has not the authority to permit j to review the article. In this case, agent z cannot delegate to j the task of reviewing the article. At the most z can just ask j to do that (which is a simple request).

It is to be noted that there are stronger forms of delegation which are based on an order of the delegant to the delegated agent, and in which there is no option of refusal. In these situations, i (the delegant) does not simply intend to communicate to j (the delegated agent) that j has now the permission to perform a certain action α, but rather i intends to communicate to j that j is now obliged to perform action α. Thus, the speaker does not give any choice of refusal to the speaker. More precisely, delegation based on order is defined by the conditions A–C given above plus the following three clauses which substitute the previous three clauses D–F.

(D′) agent i has the intention to communicate to agent j that j has now the obligation to perform action α.

(E′) agent i has the power and authority to oblige agent j to do action α.

(F′) agent j does not have the obligation to do action α and he will have this obligation after the completion of the delegation act.

The following variant of the previous scenario illustrates the fundamental constituents of delegation based on order.

Scenario 3. *Suppose that agent i is the president of a company and suppose that this company must be represented at a journalist meeting. Suppose now that agent i delegates to agent j, an employee of the company, the task of participating to this meeting. In this case, the employee does have any refusal option (this is an order).*

Note that before delegation, the employee did not have either obligation or permission to go to the meeting. It is only after the performance of the delegation act by i that j is obliged to go to the meeting (which illustrates the creation of an obligation through the delegation act).

3 A logic for delegation

This section presents the multimodal logic $\mathcal{L}$ exploited to formalize the fundamental concepts involved in our model of delegation. $\mathcal{L}$ combines the expressiveness of dynamic logic [14] and temporal logic with that of a logic of belief and choice that can be used to define intention (and may be called BDI-like, see [7] for instance).

3.1 Syntax

The syntactic primitives of the logic $\mathcal{L}$ are the following: a nonempty finite set of individual agents $AGT = \{i, j, \ldots\}$; a nonempty finite set of atomic actions $ACT = \{\alpha, \beta, \ldots\}$; a nonempty set of atomic formulas $ATM = \{p, q, \ldots\}$. The language of $\mathcal{L}$

is the set of formulas defined by the following BNF:

$$\varphi ::= p \mid \neg\varphi \mid \varphi \vee \varphi \mid \mathtt{Do}_{i:\alpha}\varphi \mid \mathtt{After}_{i:\alpha}\varphi \mid \mathtt{Bel}_i\varphi \mid \mathtt{Choice}_i\varphi \mid \mathtt{Oblig}\,\varphi$$

where p ranges over ATM, α ranges over ACT and i ranges over AGT.

The operators of our logic have the following reading. $\mathtt{After}_{i:\alpha}\varphi$ means 'immediately after agent i does α, it is the case that φ' (therefore $\mathtt{After}_{i:\alpha}\bot$ is read 'agent i cannot do action α'). $\mathtt{Do}_{i:\alpha}\varphi$ means 'agent i is going to do α and φ will be true afterwards' (therefore $\mathtt{Do}_{i:\alpha}\top$ is read: 'agent i is going to do α'). $\mathtt{Bel}_i\varphi$ means 'agent i believes that φ'. $\mathtt{Choice}_i\varphi$ means 'agent i has the chosen goal that φ' (which can be shortened to 'agent i wants φ to be true'). $\mathtt{Oblig}\,\varphi$ means 'φ is obligatory'.

Operators $\mathtt{Choice}_i$ are used to denote an agent's chosen goals, that is, the goals that the agent has decided to pursue. We do not consider how an agent's chosen goals originate through deliberation from more primitive motivational attitudes called desires. The operator $\mathtt{Oblig}$ is the modality for obligation of Standard Deontic Logic (SDL) [2]. The following abbreviations will be convenient:

$$\mathtt{Poss}_i\varphi \stackrel{\text{def}}{=} \neg\mathtt{Bel}_i\neg\varphi$$

$$\mathtt{Capable}_i(\alpha) \stackrel{\text{def}}{=} \neg\mathtt{After}_{i:\alpha}\bot$$

$$\mathtt{Int}(i,\varphi,\alpha) \stackrel{\text{def}}{=} \mathtt{Choice}_i\mathtt{Do}_{i:\alpha}\varphi$$

$$\mathtt{Power}_i(\varphi,\alpha) \stackrel{\text{def}}{=} \mathtt{Capable}_i(\alpha) \wedge \mathtt{After}_{i:\alpha}\varphi$$

$$\mathtt{Oblig}_i(\alpha) \stackrel{\text{def}}{=} \mathtt{Oblig}\,\mathtt{Do}_{i:\alpha}\top$$

$$\mathtt{Forbid}_i(\alpha) \stackrel{\text{def}}{=} \mathtt{Oblig}\,\neg\mathtt{Do}_{i:\alpha}\top$$

$$\mathtt{Perm}_i(\alpha) \stackrel{\text{def}}{=} \neg\mathtt{Oblig}\,\neg\mathtt{Do}_{i:\alpha}\top$$

$\mathtt{Poss}_i\varphi$ stands for 'i thinks that φ is possible'. $\mathtt{Capable}_i(\alpha)$ stands for 'i has the capability to do α' (which can be shortened to 'agent i can do action α'). $\mathtt{Int}(i,\varphi,\alpha)$ stands for 'agent i intends to do action α and intends that φ will be true after the occurrence of action α'. We shorten this to 'agent i intends to do action α in order to ensure φ'. $\mathtt{Power}_i(\varphi,\alpha)$ stands for 'agent i has the power to ensure φ by doing α'. $\mathtt{Oblig}_i(\alpha)$ stands for 'agent i is obliged to do action α'. $\mathtt{Forbid}_i(\alpha)$ stands for 'it is forbidden for agent i to do action α'. $\mathtt{Perm}_i(\alpha)$ stands for 'agent i has the permission to do action α'.

3.2 Semantics

We first define Kripke frames, and then models and truth conditions for the logical connectives.

Frames. Frames of the logic $\mathcal{L}$ ($\mathcal{L}$-frames) are tuples $F = \langle W, B, C, O, A, D\rangle$ defined as follows.

- W is a nonempty set of possible worlds or states.
- $B : AGT \longrightarrow W \times W$ maps every agent i to a serial, transitive and Euclidean[4] relation B_i between possible worlds in W.

[4] A relation B_i on W is Euclidean if and only if, if $(w, w') \in B_i$ and $(w, w'') \in B_i$ then $(w', w'') \in B_i$.

– $C : AGT \longrightarrow W \times W$ maps every agent i to a serial relation C_i between possible worlds in W.
– O is a serial relation between possible worlds in W.
– $A : AGT \times ACT \longrightarrow W \times W$ maps every agent i and action α to a relation $A_{i:\alpha}$ between possible worlds in W.
– $D : AGT \times ACT \longrightarrow W \times W$ maps every agent i and action α to a deterministic relation $D_{i:\alpha}$ between possible worlds in W.[5]

It is convenient to view relations on W as functions from W to 2^W; therefore we write $A_{i:\alpha}(w)$ for the set $\{w' : (w, w') \in A_{i:\alpha}\}$, etc. $B_i(w)$ is the set of worlds that are compatible with agent i's beliefs at w; $O(w)$ is the set of worlds that are ideals at w; and $C_i(w)$ is the set of worlds that are compatible with agent i's choices at w. $A_{i:\alpha}(w)$ is the set of worlds w' that can be reached from w through the occurrence of agent i's action α. If $(w, w') \in D_{i:\alpha}$ then w' is the unique actual *successor* world of w, that will be reached from w through the occurrence of agent i's action α at w. (We might also say that $D_{i:\alpha}$ is a partial function.) We therefore have two kinds of relations for specifying the dynamic dimension of frames:

– when $D_{i:\alpha}(w) = \{w'\}$ then at w agent i performs an action α resulting in the next state w';
– when $w' \in A_{i:\alpha}(w)$ but $w' \notin D_{i:\alpha}(w)$ then if at w agent i would do something different from what it actually does it might have produced another outcome world w'.

If $D_{i:\alpha}(w) \neq \emptyset$ (resp. $A_{i:\alpha}(w) \neq \emptyset$) then, we say that $D_{i:\alpha}$ (resp. $A_{i:\alpha}$) is defined at w.

Frames will have to satisfy some constraints in order to be legal $\mathcal{L}$-frames. For every $i, j \in AGT$, $\alpha, \beta \in ACT$ and $w \in W$ we suppose:

S1 if $D_{i:\alpha}$ and $D_{j:\beta}$ are defined at w then $D_{i:\alpha}(w) = D_{j:\beta}(w)$.

Constraint $S1$ says that if w' is the *next* world of w which is reachable from w through the occurrence of agent i's action α and w'' is also the *next* world of w which is reachable from w through the occurrence of agent j's action β, then w' and w'' denote the same world. Indeed, we suppose that every world can only have one *next* world. Note that $S1$ implies determinism of every $D_{i:\alpha}$.

Moreover, for every $i \in AGT$, $\alpha \in ACT$ we suppose:

S2 $D_{i:\alpha} \subseteq A_{i:\alpha}$.

The constraint $S2$ says that if w' is the *next* world of w which is reachable from w through the occurrence of agent i's action α, then w' must be a world which is *possibly* reachable from w through the occurrence of agent i's action α.

Moreover, we suppose that for every $w \in W$:

S3 there exists $i \in AGT$ and $\alpha \in ACT$ such that $D_{i:\alpha}$ is defined at w.

[5] A relation $D_{i:\alpha}$ is deterministic iff, if $(w, w') \in D_{i:\alpha}$ and $(w, w'') \in D_{i:\alpha}$ then $w' = w''$.

The constraint $S3$ says that there is always some agent who does something.

The following semantic constraints $S4$ and $S5$ are about the relationship between an agent i's choices (i.e., chosen worlds) and the actions performed by i. For every $i \in AGT$, $\alpha \in ACT$ and $w \in W$, we suppose that:

S4 if $A_{i:\alpha}$ is defined at w and $D_{i:\alpha}$ is defined at w' for all $w' \in C_i(w)$ then $D_{i:\alpha}$ is defined at w;

S5 if $w' \in C_i(w)$ and $D_{i:\alpha}$ is defined at w, then $D_{i:\alpha}$ is defined at w'.

The next constraint relates worlds that are compatible with agent i's beliefs and worlds that are compatible with i's chosen goals: as motivated in the beginning of Section 3.1, they should not be disjoint. For every $i \in AGT$ and $w \in W$:

S6 $C_i(w) \cap B_i(w) \neq \emptyset$.

The following constraint on $\mathcal{L}$-frames is one of introspection w.r.t. choices. For every $i \in AGT$ and $w \in W$:

S7 if $w' \in B_i(w)$ then $C_i(w) = C_i(w')$.

Models and truth conditions. Models of the logic $\mathcal{L}$ ($\mathcal{L}$-models) are tuples $M = \langle F, V \rangle$ defined as follows.

- F is a $\mathcal{L}$-frame.
- $V : W \longrightarrow 2^{ATM}$ is a truth assignment which associates each world w with the set $V(w)$ of atomic propositions true in w.

Given a model M, a world w and a formula φ, we write $M, w \models \varphi$ to mean that φ is true at world w in M. The rules defining the truth conditions of formulas are just standard for atomic formulas, negation and disjunction. The following are the remaining truth conditions for $\texttt{Oblig}\,\varphi$, $\texttt{After}_{i:\alpha}\varphi$, $\texttt{Do}_{i:\alpha}\varphi$, $\texttt{Bel}_i\varphi$ and $\texttt{Choice}_i\varphi$.

- $M, w \models \texttt{After}_{i:\alpha}\varphi$ iff $M, w' \models \varphi$ for all w' such that $(w, w') \in A_{i:\alpha}$.
- $M, w \models \texttt{Do}_{i:\alpha}\varphi$ iff there is $w' \in D_{i:\alpha}(w)$ such that $M, w' \models \varphi$.
- $M, w \models \texttt{Bel}_i\varphi$ iff $M, w' \models \varphi$ for all w' such that $(w, w') \in B_i$.
- $M, w \models \texttt{Choice}_i\varphi$ iff $M, w' \models \varphi$ for all w' such that $(w, w') \in C_i$.
- $M, w \models \texttt{Oblig}\,\varphi$ iff $M, w' \models \varphi$ for all w' such that $(w, w') \in O$.

Observe that the modal operator $\texttt{Do}_{i:\alpha}$ is of type possibility, and that all other modal operators are of type necessity.

We write $\models_{\mathcal{L}} \varphi$ if φ is *valid* in all $\mathcal{L}$-models, i.e. $M, w \models \varphi$ for every $\mathcal{L}$-model M and world w in M. Finally, we say that φ is *satisfiable* if there exists a $\mathcal{L}$-model M and world w in M such that $M, w \models \varphi$.

3.3 Axiomatization

Table 1 contains the axiomatization of the logic $\mathcal{L}$. Principle $\mathbf{KD45}_{\texttt{Bel}}$ is for the belief operator: its logic is KD45. Principle $\mathbf{KD}_{\texttt{Choice}}$ is for the choice operators, whose logic is KD. These operators are similar to Cohen & Levesque's goal operators [7]. Thus, we suppose positive and negative introspection for beliefs, and we assume that an agent cannot have inconsistent beliefs and conflicting choices. We have a standard KD logic for obligation modalities (Principle $\mathbf{KD}_{\mathtt{Oblig}}$) as in Standard Deontic Logic (SDL). Therefore, obligations are always consistent. Principle $\mathbf{K}_{\mathtt{After}}$ says that every modal operator $\mathtt{After}_{i:\alpha}$ obeys the principles of the basic normal modal logic K, Principle $\mathbf{K}_{\mathtt{Do}}$ says the same for every $\mathtt{Do}_{i:\alpha}$. Axiom $\mathbf{Alt}_{\mathtt{Do}}$ says that if i is going to do α and φ will be true afterward, then it cannot be the case that j is going to do β and $\neg\varphi$ will be true afterward. Axiom **Active** expresses the world is never passive, i.e. there exists always some agent who does something. Axiom **Active** ensures that for every world w there is a next world of w which is reachable from w by the occurrence of some action of some agent. This is the reason why the operator $\mathtt{X}$ for next of LTL (linear temporal logic) can be defined as follows:

$$\mathtt{X}\,\varphi \stackrel{\text{def}}{=} \bigvee_{i\in AGT,\alpha\in ACT} \mathtt{Do}_{i:\alpha}\top.$$

Note that $\mathtt{X}$ satisfies the standard property $\mathtt{X}\,\varphi \leftrightarrow \neg\mathtt{X}\,\neg\varphi$.

The other axioms are about more complex interactions between the modal operators, and are going to be discussed in detail in the rest of the section.

(**PC**)	All theorems of propositional calculus
($\mathbf{KD45}_{\mathtt{Bel}}$)	All principles of modal logic KD45 for every $\mathtt{Bel}_i$
($\mathbf{KD}_{\mathtt{Choice}}$)	All principles of modal logic KD for every $\mathtt{Choice}_i$
($\mathbf{KD}_{\mathtt{Oblig}}$)	All principles of modal logic KD for $\mathtt{Oblig}$
($\mathbf{K}_{\mathtt{After}}$)	All principles of modal logic K for every $\mathtt{After}_{i:\alpha}$
($\mathbf{K}_{\mathtt{Do}}$)	All principles of modal logic K for every $\mathtt{Do}_{i:\alpha}$
($\mathbf{Alt}_{\mathtt{Do}}$)	$\mathtt{Do}_{i:\alpha}\varphi \rightarrow \neg\mathtt{Do}_{j:\beta}\neg\varphi$
(**Active**)	$\bigvee_{i\in AGT,\alpha\in ACT} \mathtt{Do}_{i:\alpha}\top$
($\mathbf{Inc}_{\mathtt{After},\mathtt{Do}}$)	$\mathtt{Do}_{i:\alpha}\varphi \rightarrow \neg\mathtt{After}_{i:\alpha}\neg\varphi$
(**IntAct1**)	$(\mathtt{Choice}_i\mathtt{Do}_{i:\alpha}\top \wedge \mathtt{Capable}_i(\alpha)) \rightarrow \mathtt{Do}_{i:\alpha}\top$
(**IntAct2**)	$\mathtt{Do}_{i:\alpha}\top \rightarrow \mathtt{Choice}_i\mathtt{Do}_{i:\alpha}\top$
(**WR**)	$\mathtt{Bel}_i\varphi \rightarrow \neg\mathtt{Choice}_i\neg\varphi$
($\mathbf{PIntr}_{\mathtt{Choice}}$)	$\mathtt{Choice}_i\varphi \rightarrow \mathtt{Bel}_i\mathtt{Choice}_i\varphi$
($\mathbf{NIntr}_{\mathtt{Choice}}$)	$\neg\mathtt{Choice}_i\varphi \rightarrow \mathtt{Bel}_i\neg\mathtt{Choice}_i\varphi$

Table 1. Axiomatization of $\mathcal{L}$

Axiom $\mathbf{Inc}_{\mathtt{After},\mathtt{Do}}$ says that if i is going to do α and φ will be true afterward, then it is not the case that φ will be false after i does α. Axioms **IntAct1** and **IntAct2** relate intentions with actions. According to **IntAct1**, if i has the intention to do action α (i.e. i has the chosen goal to perform action α) and has the capacity to do α, then i is going to do α. According to **IntAct2**, an agent is going to do action α only if it has the intention to do α. In this sense we suppose that an agent's *doing* is by definition intentional.

Given $\textbf{Inc}_{\texttt{After},\texttt{Do}}$, **IntAct1** and **IntAct2** could be replaced by the single axiom:

(**IntAct**) $$\texttt{Do}_{i:\alpha}\top \leftrightarrow (\texttt{Choice}_i\texttt{Do}_{i:\alpha}\top \wedge \neg\texttt{After}_{i:\alpha}\bot)$$

Similar axioms have been studied in [18] in which a logical model of the relationships between intention and action performance is proposed.

As far as beliefs and chosen goals (choices) are concerned, we suppose that the two kinds of mental attitudes must be compatible, that is, if an agent has the goal that φ, then it cannot believe that $\neg\varphi$. This is the so-called assumption of *weak realism* [6]. According to this hypothesis, a rational agent cannot choose φ if it believes that φ is an impossible state of affairs. The principle of weak realism is expressed by Axiom **WR**.

We also assume positive and negative introspection over chosen goals, as expressed by axioms $\textbf{PIntr}_{\texttt{Choice}}$ and $\textbf{NIntr}_{\texttt{Choice}}$. Together with Axiom D for $\texttt{Choice}_i$ they imply the equivalences $\texttt{Choice}_i\varphi \leftrightarrow \texttt{Bel}_i\texttt{Choice}_i\varphi$ and $\neg\texttt{Choice}_i\varphi \leftrightarrow \texttt{Bel}_i\neg\texttt{Choice}_i\varphi$.

3.4 Soundness and completeness

We call $\mathcal{L}$ the logic axiomatized by the axioms and rules of inference presented above. We write $\vdash_{\mathcal{L}} \varphi$ if formula φ is a theorem of $\mathcal{L}$ (i.e. φ is the derivable from the axioms and rules of inference of the logic $\mathcal{L}$).

We can prove that the logic $\mathcal{L}$ is *sound* and *complete* with respect to the class of $\mathcal{L}$-frames. Namely:

Theorem 1. *$\mathcal{L}$ is determined by the class of $\mathcal{L}$-frames.*

Proof. It is a routine task to check that the axioms of the logic $\mathcal{L}$ correspond one-to-one to their semantic counterparts on the frames. In particular, $\textbf{KD45}_{\texttt{Bel}}$ correspond to the seriality, transitivity and Euclideanity of every relation B_i. $\textbf{KD}_{\texttt{Choice}}$ corresponds to the seriality of every relation C_i. Axiom $\textbf{KD}_{\texttt{Oblig}}$ corresponds to the seriality of the relation O. Axiom $\textbf{Alt}_{\texttt{Do}}$ corresponds to the semantic constraint $S1$. Axiom $\textbf{Inc}_{\texttt{After},\texttt{Do}}$ corresponds to the semantic constraint $S2$. Axiom **Active** corresponds to the semantic constraint $S3$. Axioms **IntAct1** and **IntAct2**, correspond to the constraints $S4$ and $S5$. Axiom **WR** corresponds to the constraint $S6$. Finally, Axioms $\textbf{PIntr}_{\texttt{Choice}}$ and $\textbf{NIntr}_{\texttt{Choice}}$ correspond together to the constraint $S7$.

It is routine, too, to check that all of our axioms are in the Sahlqvist class. This means that the axioms are all expressible as first-order conditions on frames and that they are complete with respect to the defined frames classes, cf. [4, Th. 2.42]. □

4 Delegation: a formalization

Before providing a logical characterization of the concept of delegation, we need to define the concept of communicative intention. We consider the classical Gricean view of linguistic communication in which a communicative intention of the speaker has an intrinsic reflexive character [12], i.e. a communicative intention of the speaker is aimed at the recognition by the hearer of the speaker's goal of informing the hearer about something.[6] In particular, we say that agent i has the intention to communicate φ to

[6] For a more complex logical account of communicative intention see [1], in which the authors provide a fix-point characterization of this concept.

agent j by doing action α (noted $\mathtt{CommInt}(i, j, \varphi, \alpha)$) if and only if, agent i intends to perform some action α so that j will believe that i wants that j believes φ. Formally:

$$(\text{Def}_{\mathtt{CommInt}}) \qquad \mathtt{CommInt}(i, j, \varphi, \alpha) \stackrel{\text{def}}{=} \mathtt{Int}(i, \mathtt{Bel}_j \mathtt{Choice}_i \mathtt{Bel}_j \varphi, \alpha)$$

For example, $\mathtt{CommInt}(\mathit{Bill}, \mathit{John}, \mathit{Bill\text{-}grateful\text{-}John}, \mathit{say\text{-}Thank's!})$ means that Bill has the intention to communicate to John that Bill is grateful to John for John's help by uttering the sentence "John, thank you very much for your help!". We are now in the position to define formally the concept of reliance, delegation based on request, and delegation based on order.

We start with the concept of reliance as an agent i's goal that another agent j will perform a certain action α.

$$(\text{Def}_{\mathtt{Rely}}) \qquad \mathtt{Rely}(i, j, \alpha) \stackrel{\text{def}}{=} \mathtt{Choice}_i \mathtt{X}\, \mathtt{Do}_{j:\alpha} \top$$

$\mathtt{Rely}(i, j, \alpha)$ has to be read 'i relies on the execution of action α by agent j'.

Now, we can formally define the concept of request-based delegation by translating into the logic $\mathcal{L}$ the informal conditions A-F given in Section 2:

$$(\text{Def}_{\mathtt{ReqDel}}) \quad \mathtt{ReqDel}(i, j, \alpha, \beta) \stackrel{\text{def}}{=} \mathtt{Do}_{i:\beta} \top \wedge \mathtt{Rely}(i, j, \alpha) \wedge \mathtt{CommInt}(i, j, \mathtt{Rely}(i, j, \alpha) \wedge \mathtt{Perm}_j(\alpha), \beta) \wedge \mathtt{Power}_i(\mathtt{Perm}_j(\alpha), \beta) \wedge \mathtt{Forbid}_j(\alpha)$$

$\mathtt{ReqDel}(i, j, \alpha, \beta)$ has to be read 'agent i, by doing action β, performs a request-based delegation of action α to agent j'. The clause $\mathtt{Do}_{i:\beta} \top$ just expresses that i performs action β by means of which he performs the action of delegating action α to agent j. The clause $\mathtt{Rely}(i, j, \alpha)$ ('i intends that j will perform action α') corresponds to the Condition A given in Section 2, the clause $\mathtt{CommInt}(i, j, \beta, \mathtt{Rely}(i, j, \alpha) \wedge \mathtt{Perm}_j(\alpha))$ corresponds to the Conditions C and D ('i intends to communicate to j that i relies on j's execution of the action α' and 'i intends to communicate to j that j has now the permission to do the action α'). Indeed, $\mathtt{CommInt}(i, j, \mathtt{Rely}(i, j, \alpha) \wedge \mathtt{Perm}_j(\alpha), \beta)$ is logically equivalent to $\mathtt{CommInt}(i, j, \beta, \mathtt{Rely}(i, j, \alpha), \beta) \wedge \mathtt{CommInt}(i, j, \mathtt{Perm}_j(\alpha), \beta)$. The clause $\mathtt{Power}_i(\mathtt{Perm}_j(\alpha), \beta)$ corresponds to the Condition E ('i has the power to grant to j the permission to do α') and the clause $\mathtt{Forbid}_j(\alpha)$ to the Condition F ('j does not have the permission to do α'). Note that it is not necessary to include Condition B explicitly in the formal definition of request-based delegation. Indeed, it is implied by $\mathtt{ReqDel}(i, j, \alpha, \beta)$:

$$\vdash \mathtt{ReqDel}(i, j, \alpha, \beta) \rightarrow \mathtt{Poss}_i \mathtt{X}\, \mathtt{Do}_{j:\alpha} \top.$$

That is, if agent i, by doing action β, performs a request-based delegation of action α to agent j then, i thinks it possible that j will perform action α. The formula $\mathtt{ReqDel}(i, \mathit{mechanic}, \mathit{repairCar}, \mathit{say\text{-}can\text{-}you\text{-}repair\text{-}my\text{-}car?})$ captures the second scenario of request-based delegation given in Section 2: agent i, by telling to the mechanic 'can you repair my car, please?', performs a request-based delegation of the action of repairing the car to the mechanic.

We can also define the concept of order-based delegation by translating into the logic $\mathcal{L}$ the informal conditions A-C and D′-F′ given in Section 2:

$$(\text{Def}_{\texttt{OrdDel}}) \quad \texttt{OrdDel}(i,j,\alpha,\beta) \stackrel{\text{def}}{=} \texttt{Do}_{i:\beta}\top \wedge \texttt{Rely}(i,j,\alpha) \wedge \texttt{CommInt}(i,j,\texttt{Rely}(i,j,\alpha) \wedge \texttt{Oblig}_j(\alpha),\beta) \wedge \texttt{Power}_i(\texttt{Oblig}_j(\alpha),\beta) \wedge \neg\texttt{Oblig}_j(\alpha)$$

$\texttt{OrdDel}(i,j,\alpha,\beta)$ has to be read 'i, by doing action β, performs a order-based delegation of action α to agent j'.

Note that order-based delegation does not necessarily imply request-based delegation (and vice versa), i.e. $\texttt{OrdDel}(i,j,\alpha,\beta)$ does not necessarily imply $\texttt{ReqDel}(i,j,\alpha,\beta)$ (and vice versa). This just means that request-based delegation and order-based delegation should be conceived as distinct communicative acts.

5 Related works

Falcone & Castelfranchi [9, 10] have proposed a model of delegation that has some similarities with the approach proposed in this work. They are also interested in a specification of the cognitive constituents of delegation as a particular cognitive state (defined in terms of beliefs, goals, intentions) of the delegating agent. Castelfranchi & Falcone individuate several kinds of delegation. They introduce a first type of delegation called *weak delegation*, that is, the delegation based on exploitation, on the passive achievement by an agent i of a certain task. In weak delegation, an agent i just exploits in his plan a fully autonomous action of another agent j. In fact, i has only to recognize the possibility that j will realize a certain action and that this action ensures that the goal of i will be satisfied. In this case agent i 'passively' awaits the satisfaction of his goals given his expectation that j will ensure it. Then, they have a second type of delegation called *mild delegation*, the delegation based on the active indirect achievement by i of the task. Agent i not only exploits agent j's action for the achievement of his goals since he sees agent j's intervention as fundamental for this, but also acts in order to induce j to perform the right course of action. Finally, they have a third type of delegation called *strong delegation* based on goal adoption. In strong delegation, agent i has a certain goal φ and decides to act in order to induce j to adopt his goal φ. Although Castelfranchi & Falcone recognize that strong delegation might be based on a request/order of the delegant to the delegated agent, they leave implicit the communicative aspect of delegation and they miss a crucial point in the theory of delegation, namely the fact that delegation *is* a kind of communicative (or speech) act. They do not consider the relationship between delegation and other more elementary speech acts of directive type like permit/allow/authorize (delegation based on request), and order/command/require (delegation based on order). Finally, Castelfranchi & Falcone's definition does not capture another essential element of the concept of delegation, namely the delegant's complex configuration of presuppositions: the delegant's presupposition that he has the power to permit the delegated agent to accomplish the delegated task and that at present the delegated agent does not have this permission (delegation based on request), or the delegant's presupposition that he has the power to oblige the delegated agent to accomplish the delegated task and that at present the delegated agent does not have this obligation (delegation based on order).

Recently other researchers have developed formal systems for reasoning about delegation. Many of these approaches try to express the concept of delegation without referring to mental states. Norman & Reed [21] analyze those forms of delegation where by issuing an imperative an agent i creates an obligation for another agent j to accomplish a given task. They exploit a logic of agentive action by using a *see to it that* modal operator S_i similar to [16] and a deontic operator $O\varphi$. According to them a formula such as $S_iOS_j\varphi$ reading "agent i sees to it that the state of affairs holds in which it is obligatory for j to see to it that φ" corresponds to i's action of issuing an imperative to j and expresses delegation. A similar approach to delegation is proposed by Grossi et al. [13] in which delegation is taken as primitive action without being analyzed in terms of cognitive states of the delegant, and what delegation does is just creating directed obligations, given that certain necessary preconditions for the creation of the obligation hold.

Van der Hoek & Wooldridge [24] develop a logic for reasoning about cooperation in which the powers of agents and coalitions of agents stem from a distribution of atomic Boolean variables to individual agents, where the choices available to coalitions correspond to the possible truth assignments to the propositions they control. They have formulae $\Diamond_i\varphi$ reading "agent i has the power to bring about φ" and specific dynamic programs $i \rightsquigarrow_p j$ reading "agent i transfers the control on p to agent j". After defining the notion of *agent i's control on a variable* p as agent i's power to choose p to be either true or false,

$$Control(i,p) \overset{\text{def}}{=} \Diamond_i p \wedge \Diamond_i \neg p,$$

they take the following as an axiom:

$$Control(i,p) \rightarrow \langle i \rightsquigarrow_p j\rangle Control(j,p).$$

This means that after the occurrence of the program $i \rightsquigarrow_p j$, j acquires the control on variable p (j gets the power to choose p to be either true or false). Van der Hoek & Wooldridge define delegation on the basis of this primitive notion of empowerment.

In our view the previous approaches are too poor in expressive power and their definitions are too broad to really clarify the concept of delegation in many cases.

On one side, it is not reasonable in our view to collapse the concept of delegation into the general concept of empowerment as Van der Hoek & Wooldridge do. Indeed the connection between empowerment and delegation of a task is not a necessary one.[7]

Suppose agent i pays 6.000 Euro to agent j to buy j's car. After the purchase j has 6.000 Euro more in his budget. He has acquired the power to buy a new motorbike. Indeed by paying 6.000 Euro to j, i has transfered to j the power to buy a new motorbike (supposing that before the purchase j's budget was 0 Euro): $\langle i \rightsquigarrow_{BuyMotorbike} j\rangle\top$. According to Van der Hoek & Wooldridge's logic after this transfer of power i has the power to buy a motorbike. Indeed $\langle i \rightsquigarrow_{BuyMotorbike} j\rangle(\Diamond_i BuyMotorbike \wedge \Diamond_i \neg BuyMotorbike)$ holds. Anyway it seems to us very counterintuitive to say that in the example there is some delegation involved (i is not delegating to j the task of

[7] In [5] an analysis of the relation between institutional empowerment and task/goal delegation is provided.

"buying a motorbike"). Indeed no form of delegation is involved when an agent simply pays a certain amount of money to another agent.

Although we agree with Norman & Reed [21] and Grossi et al. [13] that some forms of delegation are responsible for the creation of obligation (see the notion of delegation based on order in Section 4), it is too simplistic to reduce delegation to something like "agent i sees to it that the state of affairs holds in which it is obligatory for j to see to it that φ" as Norman & Reed do. The main problem with this approach is that it is not able to exclude from the definition of delegation all those situations where by performing a certain action, an agent i accidentally (non intentionally) sees to it that agent j is subject to a certain obligation. For example, by passing through the security gate at the airport with a suspicious hand luggage, a terrorist named Oscar sees to it that the state of affairs holds in which it is obligatory for the security service to search Oscar's hand luggage (suppose that there is a general rule saying that "security service must search all suspicious hand luggage"):

$$S_{Oscar} O S_{Security} SearchOscarLuggage.$$

It seems quite odd to say that Oscar delegates the security service to search his hand luggage. Indeed, Oscar neither wants nor intends that security service search his hand luggage. It is rather the institutional authority of the airport that having the intention to prevent terrorist attacks (intentionally) delegates to the security service the general task of searching all suspicious hand luggage and the more specific task of searching Oscar's luggage.

In our view in order to provide a formal characterization of the notion of delegation, we cannot avoid to have mental states such as goals and intentions in the framework. Indeed delegation is intrinsically an intentional notion. An agent i delegates another agent j to accomplish tasks that according to i are important, that is, an agent i delegates to agent j a certain task/action α only if agent i wants that j will do action α (we have called reliance this fundamental dimension of delegation).

6 Conclusion

We have presented in this work a conceptual and formal analysis of delegation. The major claim we have defended is that delegation is intrinsically a communicative act of directive type. We have distinguished delegation from other kinds of speech act of directive type like request and order.

Directions of future work are manifold. The present work has been mainly focused on the characterization of the cognitive state of the delegant. In the future, we will consider the normative effects of the delegation act on the delegated agent. For example, we intend to show how an act of order-based delegation of i towards j about a certain action α will create the obligation for j to perform action α. Another aspect that we intend to investigate in the future is the logical relationship between trust and delegation (is trust a sufficient condition for delegation? Does delegation necessarily require trust?). To this aim we will integrate the analysis presented here with our previous works on trust [17].

Acknowledgements

This research is supported by the project ForTrust "Social trust analysis and formalization" ANR-06-SETI-006 financed by the French "Agence Nationale de la Recherche".

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