F. Dignum and H. Weigand. Communication and deontic logic. In R. Wieringa and R. Feenstra, editors, *Information Systems, Correctness and Reusability*, pages 242--260. World Scientific, Singapore, 1995.

COMMUNICATION AND DEONTIC LOGIC

FRANK DIGNUM
Dept. of Mathematics and Computer Science, Eindhoven University of Technology
P.O.Box 513, 5600 MB Eindhoven, The Netherlands
email: dignum@win.tue.nl

and

HANS WEIGAND
Infolab, Tilburg University
P.O.box 90153, 5000 LE Tilburg, The Netherlands
email: h.weigand@kub.nl

ABSTRACT

In a normative system many of the obligations, prohibitions and permissions exist as a result of communication with users and/or other systems. In this paper we will discuss the role of illocutionary logic and deontic logic in modelling these communication processes and the resulting norms. The combination of illocutionary and deontic logic can be used to reason about communication structures. The use of deontic logic also makes it possible to describe the course of action in the cases that the communication protocol fails. This is of particular interest for the specification of flexible transactions in the context of interoperable systems.

1. Introduction

In recent years there appears to be a growing interest in the behaviour of normative systems (see e.g. Meyer & Wieringa (1993)[7]). However, little has been said about how the norms that govern these systems are established. Many of the obligations, prohibitions and permissions in normative systems exist as a result of communication with users and/or other systems. For instance, an accepted order for a certain product results in the obligation to deliver that product.

We consider a normative system to be a set of interacting *agents*. Each agent has certain capabilities, actions that it can perform. These actions can be material, such as opening a window, or communicative, such as providing some piece of information. Each agent also has an agenda containing the actions to be performed by the agent, instantly or at some designated time. We assume that the agenda is not fixed but can be manipulated by the agent. This is typically done on the request of another agent. The life cycle of the agent consists of processing incoming messages, checking the agenda, and performing the actions due at that time.

Agents communicate by means of messages. According to speech act theory (Searle (1969)[9]), a message consists of an illocution operator and a propositional content. We make a rough distinction between directive messages, that deal with the agendas of the agents, and assertive messages, that act upon the agent's database. This distinction will be refined below.

When reasoning about agents it is convenient to use *deontic* operators like *should* and *may* for the description of what is on an agent's agenda - its own agenda or the one of another agent. The fundamental reason for the use of deontic concepts is that coordination of behaviour always requires some form of agreement and mutual commitment. If, for whatever reason, an agent does not execute an action it has itself committed to, this causes a violation of the agreement. Since the action is in the future, it can never be guaranteed, so the interpretation "it will happen in all future courses of events" is too strong, but the interpretation "it will happen in some course of events" is too weak. Interpreting the formula "α is obligatory" as: "not doing α violates a commitment", we get a more precise meaning of what it is that something is on an agent's agenda.

Coordination of behavior is relatively easy when there exists a hierarchical ordering between the agents. When agent A is superior to agent B, then a request of A will always lead to an obligation for B. However, especially when these systems belong to different organizational units, or in CSCW applications, where the agents are humans standing in a peer relationship, the coordination requires more effort. Let us suppose that A does send a request to B. In general, this can lead to an obligation on the part of B for three fundamentally different reasons:

- Charity
- Power
- Authorization

Charity means that B does answer A's request without being forced to do so. We take it for granted that systems that include humans, or are closely intertwined with human affairs, can never be formalised completely. Such systems should leave open the possibility of open requests. The request itself does not create an obligation; an obligation arises only when B replies with positive commitment. *Power* means that B does answer A's request because of some dominance relationship between A and B external to the communication network. This is the case in the hierarchical system mentioned above. By "external" we mean that the dominance relationship is not rooted in the communication process, by mutual consent. A power relationship can be restricted to a certain domain or to specific roles of the agents. *Authorization* means that the request is authorized by previous agreement. So, when B has committed itself to a certain service (possibly in return to some other service), a request of A leads to an obligation when the conditions are met. A refusal would lead to a violation of the agreement, which makes this case different from both the first one and the second. See also Dietz and Wiederhoven [4] for the distinction between power claims and authorization claims in CSCW tools such as the Coordinator (Flores et.al.[5]).

In this paper we will discuss the role of illocutionary logic and deontic logic in modelling the communication processes described above and their resulting norms. Illocutionary logic (Searle & Vanderveken (1985)[8]) is a logical formalisation of the theory of speech acts (Searle (1969)[9]) and is used to formally describe the communication structure itself. In section 2 we will give a short introduction to illocutionary logic and we will show which of the elements of illocutionary logic are important for modelling communication between agents in a formal normative system.

In section 3 we present a logical formalism that incorporates the speech acts into the dynamic deontic logic described in Meyer(1988) [6]. This language can be used to model the norms that result from the communications between agents in a normative system. The language also contains speech acts for authorization and derogation. In this way, it is possible to adapt the communication protocol dynamically. The combination of illocutionary logic and deontic logic can be used to build communication protocols or contracts, that define the subsequent steps in the communication and how these steps are related (see Weigand (1993)[10] for more details).

Because the whole protocol has been described using a logical formalism it is possible to reason about properties of the protocols. For instance, one might prove that, given certain preconditions, after the order protocol has been followed one party has the obligation to deliver a product while the other party has the obligation to pay for it. The use of deontic logic within the protocol also makes it easy to describe the course of action in the cases that the communication protocol fails.

2. Communication between formal systems

In this section we will discuss the logical formalization of the communication between formal systems. As said in the introduction the basis for this formalization will be illocutionary logic. Illocutionary logic is a logical formalization of the theory of speech acts as developed by Searle, which we take as the basic description of the communication between two systems.

The illocution (= illocutionary force) of a speech act is what the contents of that speech act indicates that the speaker intends the hearer to recognize him to be doing in uttering the speech act. E.g. the speaker might be asserting, denying, predicting, confirming, requesting, greeting, baptizing etc. Illocution should be distinguished from utterance type, e.g. imperative or declarative.

Before presenting our logical formalization of the communications we will give an overview of the main concepts of illocutionary logic. For each concept we will indicate its relevance for the communication between formal systems.

2.1. Illocutionary logic

The basic concept in illocutionary logic is the *illocutionary act*. The illocutionary act consists of three parts:

(1) illocutionary context

(2) illocutionary force

(3) propositional contents

The *propositional contents* of the illocutionary act is the part that expresses what the speech act is about. For instance, the propositional content of the illocutionary act "I promise that I will go to the meeting" is "I will go to the meeting".

The *illocutionary context* indicates the relevant knowledge about the situation in which the speech act is made. This can be factual knowledge about the place where the speech act is performed, but also epistemic knowledge about the intentions and believes of the participants in the speech act. It also includes the speaker and addressee of the speech act themselves. Formally, the context of an illocutionary act consists of five elements:

(a) speaker

(b) addressee

(c) time

(d) location

(e) circumstances (world knowledge)

In formal network-based communication, location and circumstances seem to be less relevant. Time is relevant, but is not treated in this paper for the sake of comprehensibility. The speaker and addressee will be incorporated in the speech act.

The *illocutionary force* determines for a large part the reasons and the goal of the communication. The central element of the illocutionary force is the illocutionary point. The other elements of the illocutionary force are all dependent on the illocutionary point. They either indicate the strength of it or the effect of it in some way. The illocutionary point of an illocutionary act indicates the type of effect for which the act is performed. Five different illocutionary points are distinguished:

- assertives
- directives
- commisives
- declarations
- expressives

This distinction is directly related to the "direction of fit" of speech acts (Austin (1962)[1]): word-to-world or world-to-word.

An assertive speech act has a word-to-world fit. Such an act simply makes a statement about the state of affairs in the world. Therefore the propositional contents should conform with the state of affairs in the world. E.g. "The cat is on the mat".

Both directive speech acts and commisive speech acts have a world-to-word fit. They try to change the situation in which they are uttered to fit the propositional content of the speech act. The directives lay the responsibility of this fit with the addressee. E.g. "Open the window, please.". The commisives lay the responsibility of the fit with the speaker. E.g. "I promise to finish this today".

Declarations have a double direction of fit. By making a declaration the world is changed according to the declaration. E.g. "Hereby you are fired". If performed by the correct person this speech act causes the addressee to be fired.

An expressive speech act has the empty direction of fit. It expresses the speaker's attitude about the state of affairs. E.g. "You should not have done that". In our formalization we have left out expressives as we do not see any use of them in this context.

Besides the illocutionary point, the illocutionary force contains six more elements.

- degree of strength of the illocutionary point
- mode of achievement
- propositional content conditions
- preparatory conditions
- sincerity conditions
- degree of strength of sincerity conditions

The *degree of strength* of the illocutionary force indicates how strong the direction of fit is made. For instance, one can say: "open the window" or "could you please open the window". The first speech act has a stronger illocutionary force than the second one.

The *mode of achievement* indicates that some conditions must hold for the illocutionary act to be performed in that way. For instance, a directive can be given through a command or an order. A command makes use of a position of authority of the speaker while an order does not. The distinctions in normative grounding (see above) can be viewed as different modes of achievement.

In many cases the illocutionary point forces some *conditions on the propositional content* of the speech act. For instance, if a speaker makes a promise the propositional content must be that the speaker will cause some condition to hold in the future. One cannot promise to have done something in the past or that someone else will do something.

There are basically two types of *preparatory conditions*. There are preparatory conditions that are dependent of the illocutionary point. For instance, if the speaker promises something it is presupposed that the thing he promises is beneficial for the addressee and also that the speaker can in some way fulfil the promise. There are also preparatory conditions that depend on the propositional content of the speech act. For instance, if I order someone to open the window I presuppose that the window is closed. Both types of presuppositions are included in the preparatory conditions of the illocutionary force.

Every illocutionary act expresses a certain psychological state. If the propositional content of the speech act conforms with the actual psychological state of the speaker then we say that the illocutionary force is sincere. Sincerity conditions can be given in different forms. That an assertion expresses a belief, can also be described by saying that the effect of the assertion is that the hearer assumes that the speaker believes such and such. This effect is independent from the "sincerity" of the speaker.

We have added one component to the illocutionary acts, the *intended effect*. The intended effect of an illocutionary act is only effectuated if all the conditions of the act are fulfilled. For instance, the intended effect of ordering a product is the obligation of the addressee to deliver the product. However, there may be all kinds of circumstances that prevent this obligation to arise. For instance, when someone can only order a product if one paid all previous deliveries (a preparatory condition) and the speaker did not comply to this rule. In this case there is still an effect of the speech act, e.g. the addressee now knows that the speaker wants to order a product again. But this effect is not equal to the intended effect. The definition of a successfull illocutionary act is an illocutionary act for which the intended effects are also actual effects of the speech act.

3. Speech acts and deontic logic

In this section we will show how the different elements of speech acts, that are recognized in formal communication between normative agents,can be formalised using an extended type of deontic logic.

3.1. The language

We start with a language based on the Dynamic Deontic Logic Language given in Meyer (1988) [6]. We will only give a short overview.

We start by defining a language of parameterized actions L_{act}

Definition 1 The language L_{act} of actions is given by the following BNF:

$$\alpha ::- \ \underline{a}|\alpha_1 \cup \alpha_2|\alpha_1 \& \alpha_2|\overline{\alpha}|\mathbf{any}|\mathbf{fail}$$

The $\underline{a}$ stands for the atomic actions in the system, like "order(i,j,p)", which states that agent i orders p from agent j. The first parameter indicates the subject of the action. The meaning of $\alpha_1 \cup \alpha_2$ is a choice between α_1 and α_2. $\alpha_1 \& \alpha_2$ stands for the parallel execution of α_1 and α_2. The expression $\overline{\alpha}$ stands for the non-performance of the action α. The **any** action is a universal or "don't care which" action. Finally the **fail** action is the action that always fails (deadlock). This action does not lead to a next state.

The language L_{act} can be used to describe actions within dynamic deontic logic. The language of dynamic deontic logic (L_{dd}) is given in the following definition.

Definition 2 The language L_{dd} of dynamic deontic logic is given by the following BNF:

$$\Phi ::- \ \phi|\Phi \vee \Psi|\Phi \wedge \Psi|\neg\Phi|[\alpha]\Phi|\alpha_1 \succ \alpha_2|B(i,\Phi)|I(i,\alpha)|I(i,\phi)$$

Where ϕ is a first order logic formula and α, α_1 and α_2 are elements of L_{act}.

To give a formal semantics of all constructions would involve giving a complete semantics for the actions. Because this would take to much space and is not very relevant for the paper we will not do this. Instead we will give the intuitive meaning of the constructions and give some useful axioms.
The intuitive meaning of $[\alpha]\Phi$ is that after the execution of α, Φ necessarily holds. We use the following axioms concerning the use of this construction:

Axiom 3

1. $[\alpha](\phi_1 \rightarrow \phi_2) \rightarrow ([\alpha]\phi_1 \rightarrow [\alpha]\phi_2)$
2. $[\alpha_1 \cup \alpha_2]\phi \leftrightarrow [\alpha_1]\phi \wedge [\alpha_2]\phi$
3. $[\overline{(\alpha_1 \cup \alpha_2)}]\phi \leftrightarrow [\overline{\alpha_1}\&\overline{\alpha_2}]\phi$
4. $[\overline{(\alpha_1\&\alpha_2)}]\phi \leftrightarrow [\overline{\alpha_1} \cup \overline{\alpha_2}]\phi$
5. $[\mathbf{fail}]\phi \leftrightarrow \mathbf{true}$

The meaning of $\alpha_1 \succ \alpha_2$ is that the performance of α_1 involves the performance of α_2. For instance, "drinking coffee" involves "drinking" and "washing and singing" involves "singing". It is a kind of implication between actions. Of course this relation is reflexive and transitive. We have the following axioms:

Axiom 4

1. $\alpha \succ \alpha$
2. $\alpha_1 \succ \alpha_2 \wedge \alpha_2 \succ \alpha_3 \rightarrow \alpha_1 \succ \alpha_3$
3. $\alpha_1 \succ \alpha_2 \rightarrow ([\alpha_1]\phi \rightarrow [\alpha_2]\phi)$

We also use the following abbreviation:

Definition 5
$\alpha_1 = \alpha_2$ **iff** $\alpha_1 \succ \alpha_2 \wedge \alpha_2 \succ \alpha_1$

The meaning of $B(i, \Phi)$ is that agent i believes Φ. We use the "standard" axioms for believes:

Axiom 6

1. $B(i, (\phi_1 \rightarrow \phi_2)) \rightarrow (B(i, \phi_1) \rightarrow B(i, \phi_2))$
2. $\neg(B(i, \phi) \wedge B(i, \neg\phi))$
3. $B(i, \phi) \rightarrow B(i, B(i, \phi))$
4. $\neg B(i, \phi) \rightarrow B(i, \neg B(i, \phi))$

$I(i, \alpha)$ means that agent I intends to perform α and $I(i, \phi)$ means that agent i intends to bring ϕ about. These are very weak notions for which only the following axioms hold:

Axiom 7

1. $\alpha_1 \succ \alpha_2 \rightarrow (I(i, \alpha_1) \rightarrow I(i, \alpha_2))$

1'. $\phi_1 \rightarrow \phi_2 \rightarrow (I(i, \phi_1) \rightarrow I(i, \phi_2))$

2. $\neg(I(i, \alpha) \wedge I(i, \overline{\alpha}))$

2'. $\neg(I(i, \phi) \wedge I(i, \neg\phi))$

Due to a lack of space we did not include temporal aspects in the logical language. One way to do this in a simple way is described in Wieringa et al (1989)[11].

The deontic operators are defined by the following abbreviations (cf. Meyer (1988)[6];Wieringa et al (1989)[11]):

Definition 8

$$\begin{aligned} O_{ij}(\alpha(i)) &= [\overline{\alpha(i)}]Violation_{ij} \\ F_{ij}(\alpha(i)) &= [\alpha(i)]Violation_{ij} \\ &= O_{ij}(\overline{\alpha(i)}) \\ P_{ij}(\alpha(i)) &= \neg[\alpha(i)]Violation_{ij} \\ &= \neg F_{ij}(\alpha(i)) \end{aligned}$$

Where $Violation_{ij}$ are special predicates indicating the violation of an agreement between i and j. So, the agent i is obliged to agent j to perform the action $\alpha(i)$ if not doing $\alpha(i)$ by i leads to a violation of i with respect to j, i is forbidden to do $\alpha(i)$ by j if doing $\alpha(i)$ leads to a violation of i with respect to j. i is permitted to do $\alpha(i)$ by j if i is not forbidden to do $\alpha(i)$ by j. Due to the lack of temporal operators, all the obligations are immediate. This is not very realistic but can be easily overcome, as shown in Wieringa et al (1989)[11], once temporal aspects are introduced in the language.

In order to model the communication between agents in a normative system the language L_{dd} has to be extended to incorporate speech acts as described in illocutionary logic. Before we introduce the speech acts, first we introduce two special relations involving agents. One relation implements a power relation between two agents and the other one implements an authorization of an agent to perform some action.
The power relation is the most primitive relation of the two. There exists a power relation between the agent i and the agent j with respect to action α, if i has the power to order j to perform the action α. For instance, the boss can order his secretary to type a letter for him. Note that he might not have the power to order his secretary to make coffee for him! We assume that the power relation is persistent and is only changed in special occasions, like when a manager is appointed.
As the example shows the power relation usually indicates a legal relation between the agents, although it could also indicate a practical power relation in less formal settings. Most important property of this relation is that it provides a basis to create obligations from one agent to another.
The power relation can also be defined with respect to a proposition. This means so much as that i has the power to convince j of the truth of ϕ. For instance, a student will (usually) consider the statements (assertions) of a teacher to be true.
This power relation has no legal connotation, because it will not be connected to obligations but to believes of another agent. The power relation defines a partial ordering on the class of agents for every action α. This ordering is reflexive (self-power) and transitive but not necessarily total.
Notation: if i has power over j with respect to α we write: $j <_\alpha i$. If i has power over j with respect to the truth of ϕ we write $j <_\phi i$.

The above properties are made formal in the following definition and axiom:

Definition 9 We use $PC_1(\alpha) \dots PC_n(\alpha)$ to indicate the actions that can change the power relation between two agents with respect to α. $PC_1(\phi) \dots PC_n(\phi)$ indicate the actions that can change the power relation between two agents with respect to ϕ.

The following axioms hold for the power relation:

Axiom 10

1 $i <_\alpha i$

1' $i <_\phi i$

2 $i <_\alpha j \wedge j <_\alpha k \rightarrow i <_\alpha k$

2' $i <_\phi j \wedge j <_\phi k \rightarrow i <_\phi k$

3 $i <_\alpha j \rightarrow [\overline{PC_1(\alpha) \cup \ldots \cup PC_n(\alpha)}] i <_\alpha j$

3' $i <_\phi j \rightarrow [\overline{PC_1(\phi) \cup \ldots \cup PC_n(\phi)}] i <_\phi j$

4 $\alpha_1 \succ \alpha_2 \wedge i <_{\alpha_1} j \rightarrow i <_{\alpha_2} j$

4' $\phi_1 \rightarrow \phi_2 \wedge i <_{\phi_1} j \rightarrow i <_{\phi_2} j$

The second relation is the authorization relation. This relation can be established for a certain time with mutual agreement (under certain restrictions). For instance, I can agree that a company can order me to pay a certain amount of money after they delivered a product. This relation ends after I pay the money. The authorization relation is modelled using a special predicate.
Notation: if i is authorized to do α we write: auth(i,α).

We will now continue by extending the language of actions to include the speech acts. A speech act is formalised as an illocutionary point (indicating the goal of the speech act) with three parameters: the Speaker, the Addressee, and the content. We distinguish the following basic speech acts:

Definition 11
DIR(i,j,α) – i does a request to j for α
COM(i,j,α) – i commits himself to j to do α
ASS(i,j,ϕ) – i asserts to j proposition ϕ
DECL(i,j,ϕ) – i declares and informs j that ϕ holds from now on

From these basic speech acts we can construct other basic speech acts by e.g. using the logical negation of actions.

Definition 12
FOR(i,j,α) = DIR(i,j,$\overline{\alpha}$) – i forbids j to do α
PER(i,j,α) = DECL(i,j,$P_{j,i}(\alpha(j))$) – i permits j to do α

The basic speech act types correspond to the ones given in section 2. There might be some dispute over the question whether the declarative DECL has an Addressee parameter, since if it succeeds, the effect will be a change of the world and not of the knowledge of the Addressee only. Depending on the preparatory conditions, it is not necessary that there is an Addressee at all. However, in general it makes little sense to do a declarative speech act and not inform anybody. Hence the Addressee should be understood here as the agent (or set of agents) that is informed.

As explained in section 2, declaratives can only be used for specific institutionalized speech acts, so the propositional content is usually rather restricted. In practice, a limited number of specific declaratives will be distinguished, such as the "authorization" action that we will introduce in section 3.2.

As argued in the introduction, speech acts can be grounded in three different ways: charity, power and authorization. For instance, a directive (DIR) can be made on the basis of charity, which means it is a request, or on the basis of a power relation or authorization (in which cases it is an order). Hence for each basic speech act we distinguish three variants, indicated by a subscript c,p or a. So, DIR_a stands for an authorized request, whereas DIR_p stands for an order based on power. Similarly for assertives and declaratives. For commissives, the distinction seems to be not very relevant and we ignore it here. Likewise, when the distinction of the powerbase of a speech act is not important, we will ignore the subscript.

The language of all acts is now defined in two steps. First we define the set of all speech acts L_{Sact}.

Definition 13

1. All basic speech acts are elements of L_{Sact}.
2. If $\alpha \in L_{Sact}$ then also $IP(i, j, \alpha) \in L_{Sact}$ and $IP(i, j, \overline{\alpha}) \in L_{Sact}$ where $IP \in \{DIR, COM\}$

Note that this is a recursive definition. So, we can have speech acts about speech acts, etc.
The language of actions L_{ACT} can now be defined as:

Definition 14

$$L_{ACT} \ = \ L_{act} \cup L_{Sact}$$

The following axioms hold for speech acts:

Axiom 15
for IP∈{DIR,COM}:

$$\mathrm{IP}(i, j, \alpha_1)\&\mathrm{IP}(i, j, \alpha_2) = \mathrm{IP}(i, j, \alpha_1\&\alpha_2)$$
$$\mathrm{IP}(i, j, \alpha_1) \cup \mathrm{IP}(i, j, \alpha_2) \succ \mathrm{IP}(i, j, \alpha_1 \cup \alpha_2)$$

for IP∈{DECL,ASS}:

$$\mathrm{IP}(i, j, \phi_1)\&\mathrm{IP}(i, j, \phi_2) = \mathrm{IP}(i, j, \phi_1 \wedge \phi_2)$$
$$\mathrm{IP}(i, j, \phi_1) \cup \mathrm{IP}(i, j, \phi_2) \succ \mathrm{IP}(i, j, \phi_1 \vee \phi_2)$$

The speech acts of L_{Sact} as defined above do not contain all elements of speech acts that are identified in illocutionary logic as introduced in section 2.
The propositional content conditions are not modelled at this moment. They can be modelled through a refinement of the language L_{Sact} which renders only those speech acts syntactically correct that comply to the propositional content conditions. In an Information System environment, the propositional content conditions are contained in the data model.

The preparatory conditions (ϕ) and the intended effects (ψ) of a speech act (α) can be modelled through the following schema:

$$\phi \rightarrow [\alpha]\psi$$

Which means that if ϕ is true then ψ will hold after α has been performed. The intended effects of the speech acts are described by means of deontic and epistemic operators, while the preparatory conditions refer to either the authorization relation or the power relation. We have the following general preparatory conditions and intended effects for the basic speech acts. Of course, for speech acts mentioning specific actions there might be more conditions and effects.

Axiom 16
1. $([DIR_p$ (i,j, $\alpha)]$ $O_{ji}(\alpha)) \leftarrow$ j $<_\alpha$ i
2. $([DIR_a$ (i,j, $\alpha)]$ $O_{ji}(\alpha)) \leftarrow$ auth(i,DIR(i,j,α))
3. [COM(i,j,α)] $O_{ij}(\alpha)$
4. $[DECL_a$ (i,j,ϕ)] $\phi \leftarrow$ auth(i,DECL(i,j,ϕ))
5. $[DECL_p$ (i,j,ϕ)] $\phi \leftarrow$ j $<_\phi$ i
6. $([ASS_a$ (i,j,ϕ)] B(j,ϕ)) $\leftarrow$ auth(i,ASS(i,j,ϕ))
7. $([ASS_p$ (i,j,ϕ)] B(j,ϕ)) $\leftarrow$ j $<_\phi$ i

The last two of the above properties express the fact that a person can be authorized to assert some facts. If this person asserts such a fact the effect is that the Addressee(s) will believe that fact (which is not the same as making the fact true, which happens with a declaration!). This is especially useful to create a set of common believes between several parties, which in the end may trigger some common action of the agents. For instance, if a bank and a company both believe that it is profitable to invest money in a new venture, this may result in the actual investment being financed by the bank.

The axioms describe the effects of power and authorization speech acts, but not of those based on charity. This is correct, although we might add some politeness rules that say that a message is always replied. For example, a request based on charity would be replied by either a commissive or an assertion of the effect that the agent does not commit himself:

$$[DIR_c \text{ (i,j, } \alpha)]\ O_{ji}(COM(j,i,\alpha) \cup ASS(j,i,\neg O_{ji}(\alpha)))$$

In a formal context we assume that an agent is always sincere and thus we have:

Axiom 17

$[DIR(i,j,\alpha)]I(i,\alpha)$ −− any DIR speech acts expresses that i intends α to happen
$[DECL(i,j,\phi)]I(i,\phi)$ −− any DECL speech acts expresses that i intends to bring
−− about ϕ (by the speech act)
$[ASS(i,j,\phi)]B(i,\phi)$ −− any ASS speech act expresses that i believes ϕ

So the effect of a DIR_c is at least that the agent knows about the subjects intention, and this can trigger him to commit himself.

To illustrate how the speech acts work, we specify how obligations can arise for an agent in several ways:

1 by means of an authorized speech act:

$$\text{auth(i,DIR(i,j,}\alpha\text{))} \rightarrow [DIR_a\ (\text{i,j, }\alpha)]O_{ji}(\alpha)$$

2 by means of a DIR_c , followed by a COM from the other party:

$$[DIR_c(\text{i,j,}\alpha)][\text{COM(j,i,}\alpha)]O_{ji}(\alpha)$$

No authorization is needed, the other party commits himself.

3 by means of a DIR_p and an existing power frame:

$$\text{j} <_\alpha \text{i} \rightarrow [DIR_p\ (\text{i,j, }\alpha)]O_{ji}(\alpha)$$

In that case, the obligation arises independent of the commitment of the other party.

4 by means of a $DECL$ and an existing power frame:

$$\text{j} <_{O_{ji}(\alpha)} \text{i} \rightarrow [DECL_p\ (\text{i,j, }O_{ji}(\alpha))]O_{ji}(\alpha)$$
$$\text{auth(i,DECL(i,j,}O_{ji}(\alpha))) \rightarrow [DECL_a\ (\text{i,j, }O_{ji}(\alpha))]O_{ji}(\alpha)$$

3.2. The dynamics of authorization

If the subject is not authorized, it can not issue a DIR_a speech act sucessfully. In that case, it can try to attain an authorization first. This can be done by means of a $DIR_c(i,j,$DECL$(j,i,$auth$(i,$DIR(..)))), that is, a request for authorization of the other party. If the other party complies to the request and grants the authorization, the subject gets authorized from that time on. This example shows that a normative system should not only formalize authorized behavior itself, but also the creation of authorizations, and, for that matter, the deletion. The crux of our formalization is that authorizations can only be made and retracted by an act of the other party. Because the establishment of authorizations is an important and frequently occurring speech act we introduce the following notation:

$$\mathrm{AUT}(i,j,\alpha) == DECL_a(i,j,\mathrm{auth}(\mathrm{j},\alpha))$$

So, AUT(i,j,α) means that i gives authorization to j to do α. Of course, this speech act is only successful if i is authorized to give this authorization. For that reason, we have to presuppose the following axiom:

Axiom 18

1. $auth(i,AUT(i,j,DIR_a(j,i,\alpha(i))))$
2. $auth(i,AUT(i,j,ASS_a(j,i,p)))$

that says that each agent is authorized to authorize other parties as far as actions and beliefs of the agent himself are concerned. This is irrespective of whether the granting of authorizations is forbidden by for example a higher power. If that would be the case, the authorization would still be succesfull, although the agent might be punished for it.

Authorizations may refer to any action: material actions, communicative actions, and also to deontic speech acts. An example of such an "indirect" authorization is the following:

$$\mathrm{auth}(i,DIR_a(i,j,\mathrm{AUT}(j,i,\alpha)))$$

which says that i is authorized to direct j to authorize him action α. So i might be not authorized yet, but he has the possibility to attain an authorization if he wants. From this example it is clear that quite precise agreements can be made. Such agreements may also concern the retracting of authorizations.

The ability to retract an authorization should be left to the subject of the authorization. If i has granted j an authorization, it is only j who can retract the authorization. For this purpose, we introduce a new declarative RTR:

$$\mathrm{RTR}(i,j,\alpha) == DECL_a(i,j,\neg\mathrm{auth}(i,\alpha))$$

The preparatory condition of RTR is that the authorization does exist. By axiom, every agent is authorized to retract authorizations given to him. If an agent has first granted an authorization, and then wants to retract it, he must ask the other party to do so. Of course, the agents may have made appointments. For example, the agent who grants the authorization may ensure himself of the authorization to request the retracting. The effect is that he can have the authorization retracted whenever he wants.

$$\mathrm{auth}(j,\alpha) \wedge \mathrm{auth}(i,DIR_a\ (i,j,\mathrm{RTR}(j,i,\alpha)))$$

An important question with respect to authorization is whether an authorization can be passed on. In the axiomatization above, this is possible but not dynamically. New authorizations can be created by means of the AUT action only, and this action can only be performed by the object of the authorization (the one who becomes obliged). What is possible, dynamically, is that agent i gives agent j the authorization to request from him to give authorizations to some agent k. In this way, j can pass the authorization on, but only via i. That is, j issues the following directive to i:

$$DIR_a(j,i,\mathrm{AUT}(i,k,DIR_a(k,i,\alpha)))$$

thus creating for i an obligation to do AUT(i,k,..). Before that, j must be authorized by i in the following way:

$$\mathrm{AUT}(i,j,DIR_a(j,i,\mathrm{AUT}(i,k,DIR_a(k,i,\alpha)))$$

This speech act succeeds because every agent is, by axiom, authorized to grant authorizations concerning its own behaviour. If j had issued a DIR_c instead of a DIR_a, he would not have needed the latter authorization, but then it would depend on i's charity whether he would commit himself or not.

In the specification language itself it is possible to stipulate much more general authorizations. For example, that j is authorized to grant authorizations about i's behaviour independently. However, the question is how such a specification becomes valid in the normative system. In terms of justification, this can only be done by means of power. An adequate treatment of the question will lead us to a formal definition of inheritance (cf. Bertino & Weigand (1994)[2]) and delegation. We do not work this out here.

3.3. Speech acts and deontic logic

We will now take a look at some traditional deontic axioms and discuss how they are interpreted in the context of speech acts.

$$(1)\ \mathrm{P}(\alpha) == \neg\mathrm{O}(\overline{\alpha})$$

This axiom (sometimes also seen as an abbreviation) stipulates that everything which is not forbidden, is permitted. If permitted is interpreted as "authorized", this axiom is too strong, since authorizations only make sense for actions that affect the behavior of others, such as DIR speech acts. In a network of autonomous agents, most of the agent's capabilities will be private actions, actions that affect the inner state of the agent only. For those actions, authorizations make no sense. In the weak sense of P as given in Dynamic Deontic Logic, the axiom is valid by definition (definition 3).

$$(2)\ \mathrm{O}(\alpha) \Rightarrow \mathrm{P}(\alpha)$$

This axiom from the system of Von Wright is not valid in deontic dynamic logic. As argued in Weigand (1993)[10] it is acceptable when it is given a speech act interpretation: a rational agent can not request an action that is not permitted by himself. In the illocutionary logic, this constraint has different interpretations. One interpretation is that requesting something implies giving permission. Formally,

$$(1)\ \mathrm{DIR}(\alpha) \supset \mathrm{PER}(\alpha)$$

or, equivalent,

$$(2)\ [\mathrm{DIR}(\mathrm{i.j},\alpha)]P_{ij}(\alpha) \leftarrow \mathrm{auth}(\mathrm{j,i},\alpha)$$

Such an axiom makes sense for actions that require authorization, such as directives, and can be formulated in our system independently.

Another way to formulate the above axiom in deontic logic is :

$$\neg(O(\alpha) \wedge F(\alpha))$$

which can be interpreted in the context of illocutionary acts to the fact that one can not request an action and forbid it at the same time. Using the axioms for illocutionary acts we have that:

$$\mathrm{DIR}(\alpha)\ \&\ \mathrm{FOR}(\alpha) = \mathrm{DIR}(\alpha\&\overline{\alpha}) = \mathrm{DIR}(\mathbf{fail})$$

If the speaker is authorized to let the hearer do both α and $\overline{\alpha}$ the following holds:

$$[\mathrm{DIR}(\mathrm{i,j},\mathbf{fail})]O_{ji}(\mathbf{fail}) =$$
$$[\mathrm{DIR}(\mathrm{i,j},\mathbf{fail})][\mathbf{any}]\mathrm{Violation}$$

This means that the speech act can be successful, but that in the resulting state all actions lead to "Violation", i.e. are not deontically acceptable. In Weigand (1993)[10], the speech act itself was not legitimate, i.e., DIR(i,j,**fail**) is made equivalent to **fail**. This is reasonable when prescribing rational communication, but too strong in a descriptive system.

Requesting and afterwards forbidding makes sense if we take the second action as overruling the first one. In that case, the inconsistency would be solved by an appropriate formulation of the frame axioms, that is, the axioms that define the persistence of obligations (and other knowledge) from one state to another.

4. Conclusions

Although deontic logic has been applied in the field of Information Systems before, the dynamics of normative systems have received almost no attention. In this paper we have explored the way how deontic statements are created and adapted in communication processes, and the role they play in the regulation of communication itself. We have distinguished three different perspectives, corresponding with three validity claims that communicative agents can make: charity, authorization, power. As in human social systems, these perspectives can complement each other in the organization of interoperable computer systems.

We have shown how authorizations for specific acts can be requested, granted and also delegated, thereby creating a dynamic environment for establishing and derogation of authorized norms.

Several open issues are left for further research. One is the use of conditions. In the deontic/illocutionary logic given in section 3, all deontic statements were unconditional. In practice, a certain obligation or authorization only obtains under certain conditions: a specific event, a specific time or time slot etc. In the directive that creates a certain deontic statement, an extra parameter "condition" should be added.

References

1. J.L. Austin, *How to do things with words* Oxford: Clarendon Press, 1962.
2. E. Bertino, H. Weigand, *An approach to authorization modelling in object-oriented database systems* Data & Knowledge Engineering 12(1994) pp.1-29.
3. S.D. Dewitz, *Contracting on a performative network: using information technology as a legal intermediary* Collaborative Work, Social Communications and Information Systems (R. Stamper et al (eds)) Elsevier Science Publ, 1991.
4. J.L.G. Dietz and G.A.M. Wiederhoven, *A comparison of the linguistic theories of Searle and Habermas as a basis for communication supporting systems* Linguistic Instruments in Knowledge Engineering (Riet, R.P van de, and R.A. Meersman (eds) North-Holland, 1992.
5. F. Flores, M. Graves,B. Hartfield,T. Winograd, *Computer Systems and the Design of Organizational Interaction* ACM Trans. on Information Systems Vol.6, No.2, 1988.
6. J.-J.Ch. Meyer, *A different approach to deontic logic: deontic logic viewed as a variant of dynamic logic,* Notre Dame Journal of Formal Logic 29(1), 1988, pp.109-136.
7. J.-J.Ch. Meyer and R. Wieringa (eds.), *Deontic Logic in Computer Science* Wiley Professional Computing, 1993.
8. J.R. Searle and D. Vanderveken, *Foundations of illocutionary logic* Cambridge University Press. 1985.
9. J.R. Searle, *Speech Acts* Cambridge University Press. 1969.
10. H. Weigand, *Deontic aspects of communication* Deontic Logic in Computer Science (Meyer,Wieringa eds) Wiley Professional Computing, 1993.
11. R.J. Wieringa, J.-J.Ch. Meyer and H. Weigand, *Specifying dynamic and deontic integrity constraints* Data & Knowledge Engineering Vol.4, 1989, pp.157-189.
12. R.J.Wieringa, H.Weigand,J.-J.Ch.Meyer,F.P.M.Dignum, *The inheritance of dynamic and deontic integrity constraints* Annals Math. Artificial Intelligence, Vol 3 (1991) 393-428.