# Agent Communication Language: Towards a Semantics based on Success, Satisfaction, and Recursion

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**Abstract.** Searle and Vanderveken's model of speech acts is undoubtedly an adequate model for the design of communicating agents because it offers a rich theory which can give important properties of protocols that we can formalize properly. We examine this theory by focusing on the two fundamentals notions, *success* and *satisfaction*, which represent a systematic, unified account of both the truth and the success conditional aspects. Then, we propose an adequate formalism–the situation calculus–for representing these two notions (in a recursive way) in the context of agent communication language. The resulting framework is finally used for (1) the analysis and interpretation of speech acts; (2) the semantics and descriptions of agent communication languages.

## 1 Introduction

Speech act theory deals with natural language utterances. In fact, it was developed to deal with utterances like "I declare open the conference", that are not easy classified as being true or false, but rather are actions. Later it was extended to deal with all utterances, with the primary vision that all utterances are *actions* of some sort or the other [2,3,17]. In distributed AI and more specifically in multiagent systems, one of the most natural ways in which intelligent interaction may occur is through communication, especially communication about action. Agents may command, request, advise, report, or permit each other to do certain actions. They may also promise actions of their own, or prohibit those of others. Therefore, speech act theory can be considered as a foundation for communication among agents. In this paper, we present a new semantics for this kind of communication based on success and satisfaction; two notions which represent a systematic, unified account of both the truth and the success conditional aspects.

## 2 Theory of Speech Acts: An Unified Account of both the Truth and the Success Conditional Aspects

Linguists have long acknowledged the illocutionary aspects of sentence meaning in their analysis of the different syntactic types of sentences in natural language. Using speech act theory, one can reformulate as follows their analysis of the meaning of most current types of sentences [18,20,21]: *representatives* or *assertives* which represents a state of affairs, e.g. statements; *directives* which ask the hearer to do something, e.g. orders; *commissives* which lead the speaker to commit herself to doing something, e.g. promises; *expressives* which express a certain psychological state, e.g. congratulations; *declaratives* which bring something about in the world, e.g. an excommunication.

Most elementary illocutionary acts that are the meaning of sentences in a context of utterance consist of an illocutionary force $f$ together with a propositional content $p$ (an elementary act will be therefore represented by $\langle f, p \rangle$) [18]. For example, the two utterances "You will leave the party" and "Leave the party!" have the same propositional content, namely that you will leave the party; but the first of these has the illocutionary force of an assertion about the future and the second has the illocutionary force of an order.

In order to analyze the logical form of illocutionary acts, one must define recursively their conditions of success and of satisfaction, as well as the truth conditions of their propositional content. The *conditions of success* of an illocutionary act are the conditions that must be obtained in a possible context of utterance in order that the speaker succeed in performing that act in that context. For example, a condition of success of a promise is that the speaker commit himself in carrying out a future course of action. The *conditions of satisfaction* of an illocutionary act are the conditions that must be obtained in a possible context. For instance, a condition of satisfaction of a promise is that the speaker carries out in the world the future course of action represented by the propositional content.

In fact, in speech act theory the notion of satisfaction is a generalization of the notion of *truth* that is needed to cover all possible illocutionary forces. Just as an assertion is satisfied if and only if (iff) it is true, a promise is satisfied iff it is kept, a request is satisfied iff it is granted, a question is satisfied iff it is answered, etc. In case of satisfaction of an illocutionary act, there is a success of fit between language and the world. The propositional content is true in the sense that it represents an actual state of affairs in the world of utterance.

According to Searle and Vanderveken [18], each illocutionary force can be divided into: (1) an illocutionary point, (2) a mode of achievement of that point, (3) propositional content, (4) preparatory and (5) sincerity conditions and finally, (6) degree of strength. We will now explain the nature of these components.

1. The Illocutionary Point. Illocutionary point is the principal component of an illocutionary force $f$ because it determines the direction of fit of utterances with that force. More precisely, it determines how the propositional content is related in the speaker's mind to the world of utterance and in particular,

through which direction the success of fit must be achieved in order that the speech act can be satisfied. As pointed out elsewhere [18], there are four directions of fit and five and only five illocutionary points of utterances in language: the *assertive*, *commissive*, *directive declarative*, and the *expressive points*. The four direction of fit are as follows

(i) *The words-to-world direction of fit.* Here, when the illocutionary act $\langle f, p\rangle$ is satisfied, its propositional content fits a state of affairs existing in the world. Speech acts with the assertive point such as, for example, predictions, conjectures and objections have the words-to-world direction of fit. Their point is to represent how the things are in the world.

(ii) *The world-to-words direction of fit.* When the illocutionary act $\langle f, p\rangle$ is satisfied, the world is transformed to fit the propositional content. Speech acts with the commissive or directive point such as, promises, recommendations, supplications and demands have the world-to-words direction of fit. Their point is to get the world to be transformed by the future course of action of the speaker (commissives) or the hearer (directives) in order to match the propositional content of the utterance.

(iii) *The double direction of fit.* Here, when the illocutionary act $\langle f, p\rangle$ is satisfied, the world is transformed by an action of the speaker to fit the propositional content by the fact that the speaker represents it as being so transformed. Speech acts with the declarative illocutionary point such as for example, acts of appointing, nominating and endorsing, have the double direction of fit. Their point is to get the world to match the propositional content by saying that the propositional content matches the world.

(iv) *The empty direction of fit.* For some illocutionary acts, there is no question of success or failure of fit, and their propositional content is in general presupposed to be true. Speech acts with the expressive point such as for example, apologies, thanks, congratulations, etc., have the empty direction of fit. Their point is to express a propositional attitude of the speaker about the state of affairs represented by the propositional content. The point here is not to represent that state of affairs as actual or to try to get it to be actual in the world.

2. Mode of Achievement. Most purposes of our actions, and particularly illocutionary points, can be achieved in various ways or by different means. The mode of achievement of an illocutionary force determines how its point must be achieved on the propositional content in case of successful performance of an act with that force. For example, in a command the speaker must invoke a position of *authority* over the hearer and in a request he must give *option of refusal* to the addressee. The modes of achievement of illocutionary forces precisely state the conditions of achievement of their point. In English, they are expressed by adverbs such as for example "surely" and "whether you like it it or not" which modify the verb in sentences such as (a) "Surely, he is here" and (b) "Whether you like it or not, do it!". Special other modes of achievement include "humbly" and "politely" which modify the performative verbs.

3. Propositional Content Conditions. Many illocutionary forces impose conditions on the set of propositions that can be taken as propositional contents of acts with that force in a context of utterance. For example, the propositional content of a promise must represent a speaker's future course of action. The propositional content of a report must represent a state of affairs which is either past or present with respect to the moment of utterance, etc.
4. Preparatory Conditions. Whenever a speaker attempts to perform an illocutionary act, he *believes* that certain propositions hold in the context of his utterance. For example, a speaker who promises to do something presupposes that his future action promotes the hearer's utility. The preparatory conditions of an illocutionary force $f$ determine which propositions the speaker believes if he were performing an act with that force and a propositional content $p$ in a possible context of utterance.
5. Sincerity Conditions. Of course, by performing an illocutionary act, the speaker also *expresses* mental states of certain psychological modes about the state of affairs represented by the propositional content. For example, a speaker who promises something expresses an *intention* to do what he promises, and a speaker who requests a hearer to do something expresses a desire that he do it. As in the case of propositional content and preparatory conditions, some sincerity conditions are determined by the illocutionary point. For example, all assertive illocutionary forces have the sincerity condition that the speaker believes the propositional content.
6. Degree of Strength. Evidently, the mental states which enter into the sincerity conditions of speech acts are expressed with different degrees of strength depending on the illocutionary force. For example, the degree of strength of the sincerity conditions of a supplication is greater than that of request, because a speaker, who supplicates, expresses a stronger desire than a speaker who requests. Degree of strength is in general orally expressed by the intonation contour in English. Precisely, an increase in the degree of strength of the intonation contour serves in general to increase the degree of the sincerity conditions. Adverbs like "sincerely" also serves to strengthen the degree of strength of the sincerity condition in sentences such as "I sincerely advise you to do it".

## 3 The Situation Calculus: A Logical Formalism for Reasoning About Knowledge and Action

The situation calculus [10] seems to be an adequate formalism for reasoning about actions and their effects on the world. Axioms are used to specify the prerequisites of actions as well as their effects. Recently, Reiter [14] has given a set of conditions under which the explicit specification of frame axioms can be avoided. This solution is extended to the frame problem to cover *knowledge-producing actions*, that is, actions whose effects are to change a state of knowledge [15]. Notice that Reiter's approach does not, address the ramification problem, his approach fails in the presence of state constraints. To remedy this, Lin [9] proposed a

two step procedure for determining an axiomatization (using situation calculus) which monotonically solves some versions of the ramification and qualification problems.

With situation calculus, we can also encode messages which depend on the words and the *situation* in which the words are uttered. In this perspective, just as in situation calculus, the encoding and decoding functions take an extra argument representing the current situation.

For these reasons, we pursue the perspective of situation calculus for reasoning about actions in multiagent systems, and specially the reasoning about speech acts for the communication between agents. To achieve this, we incorporate semantics of intensional logic and illocutionary logic in the situation calculus. We will now present briefly the situation calculus, then we will show how we will use such calculus for reasoning about knowledge and action.

In situation calculus, terms are used to represent states of the world -i.e. *situations*. If $\alpha$ is an action and $s$ a situation, the result of performing a situation $\alpha$ in $s$ is represented by $do(\alpha, s)$. $Poss(\alpha, s)$ means that it is possible to perform the action $\alpha$ in the situation $s$. The constant $S_0$ is used to denote the initial situation; and there is also an ordering relation on situations $\succ$, where $s' \succ s$ stands for "$s'$ can be reached from $s$ by a sequence of one or more actions". A *fluent* $F$ is a function defined on situations. For instance, in the blocks world, the location of a given block $x$ is a fluent whose value are the possible locations of blocks. In the language of the situation calculus, the value of this fluent at $s$ for a block $x$ is denoted by $location(x, s)$. More generally, $F(do(\alpha, s))$ means that $F$ becomes true in the successor situation $do(\alpha, s)$; and $\neg F(do(\alpha, s))$ means that $F$ becomes false in the same successor situation.

Before we treat epistemic fluents, let us introduce an alternative formulation in order to facilitate the logical formalism for reasoning about knowledge and action. Rather than introduce a situational argument to all of the predicates in our domain, we can instead reify predicates like $loc$, making objects out of sentences such as $loc(b, l)$. More precisely, instead of writing $loc(b, l, s)$ to indicate that the location of $b$ is $l$ in situation $s$, we can write $loc(b, l)[s]$, where $loc(b, l)$ is now an object of our domain instead of a sentence. What $loc(b, l)[s]$ says is that the object $loc(b, l)$ holds in the situation $s$. One advantage of reification is that it allows us to quantify over sentences (now objects) being reified. For instance, if we want to say that *nothing* holds in some situation $s_1$, we could write this as:

$$\forall p \ \neg p[s_1]$$

If we have not adopted sentence reification in our domain, this axiom would involve quantification over predicates and would therefore not be a legitimate sentence of first-order logic.

However, some atomic formula like $Poss$ and $do$ are binary functions, whose arguments are an action and a situation and in this case it is important to use the reification appropriately. For instance, if we express by $move(x, y)$ the action of placing $x$ on top of $y$, we can describe the effect of this action by the following axiom: $Poss(move(x, y), s) \supset on(x, y)[do(move(x, y), s)]$

Now, we introduce some binary accessibility relations over situations, where a situation $s'$ is understood as being accessible for an agent $i$ from a situation $s$ if as far as $i$ believes (for example) in situation $s$, he might be in situation $s'$. Thus, something is believed in $s$ if it is true in every $s'$ accessible from $s$, and conversely something is not believed if it is false in some accessible situation. Therefore, the usual belief operator can be treated as an operator which reflects a mental state and which can hold or not in some situation $s$. To this end, we introduce a binary relation $B_i(s', s)$, read as "$s'$ is accessible for $i$ from $s$". Thus relation $B_i(s', s)$ holds in $s$ iff $s'$ is compatible with what $i$ believes in $s$. We can now introduce the object $bel(i, p)$ read as "agent $i$ believes $p$" and define it as:

$$bel(i, p)[s] \stackrel{\text{def}}{=} \forall s' \; B_i(s', s) \supset p[s'] \tag{1}$$

This is the usual "knowledge" operator and is considered here as primitive modal operator. Concerning this operator, we assume the usual axiom schemata corresponding to a "weak S5" modal logic.

We assume here that *goal* is not a primitive atomic predicate, as in Cohen and Levesque [5], because this predicate is based on the relation $G_i$, which is constrained by $B_i$. In fact, the relation $G_i$ can be defined as the intersection of $B_i$ and an accessibility relation expressing the fundamental notion of "interest", i.e., the set of situations that an agent *would wish were true*. We call such a relation $I_i$, and the corresponding predicate *wish*. In these conditions, $wish(i, p)$ means "agent $i$ has an interest that $p$ is true". This predicate is defined by the following:

$$wish(i, p)[s] \stackrel{\text{def}}{=} \forall s' \; I_i(s', s) \supset p[s'] \tag{2}$$

As $G_i = B_i \bigcap I_i$, this allows to us to introduce the "goal" predicate which is defined by:

$$goal(i, p)[s] \stackrel{\text{def}}{=} \forall s' \; G_i(s', s) \supset p[s'] \tag{3}$$

Now it is time to give our formalization of ability. In fact, we base this formalization on that of Moore [11], which in spite of its relative simplicity, does get at the essential connection between the ability of agents to achieve goals and the knowledge they have about relevant actions. To formalize this ability, we introduce firstly two operators for which situations will not be referred to explicitly: $res(a, p)$ and $agt(i, a)$. The first operator $res(a, p)$ will mean that it is possible for the event denoted by $a$ to occur and that, it it did, the formula $p$ would then be true. The semantics of this operator is similar to the operator RES of Moore [11]. The second operator $agt(i, a)$ says here that agent $i$ is the only agent for the action $a$.

In these conditions, the operator $can(i, a, p)$ read as "agent $i$ can achieve $p$ by performing action $a$" satisfies the following:

$$\forall i \, \exists x \; bel(i, (x = a) \wedge agt(i, x) \wedge res(a, p))[s] \supset can(i, a, p)[s] \tag{4}$$

This captures the fact that an agent $i$ can achieve $p$ by performing act $a$ if he knows what action $a$ is, and he knows that $p$ would be true as result of his

performing $a$. Notice that 4 is not bidirectional because it is impossible for an agent to know from the very beginning of this action, particularly if it is complex, "what" she is going to do every step.

We also need a formal definition of "commitment". For this purpose, we augment our formal system with a new accessibility relation $C_i$ which is Euclidean, transitive, serial and such as $C_i \subseteq I_i \bigcap B_i$. According to our intuition, $C_i$ accesses situations which the agent $i$ regards as both desirable and possible. The situations in $C_i$ are consequently those in which the agent does the action(s) that she has decided to do. Now we can define a predicate $cmt(i,p)$ read as "agent $i$ is committed to achieving $p$" and define it as:

$$cmt(i,p)[s] \stackrel{\text{def}}{=} \forall s' \; C_i(s',s) \supset p[s'] \tag{5}$$

Another mental state is the "intention" for which we need a weak notion of an agent *having* a plan [13]. We note this version of plan

$$has.plan(i,\pi,p)$$

This means that $i$ has the plan $\pi$ to achieve $p$. Notice that our weak notion of having a plan states: (1) $i$ believes that he can execute each act in $\pi$; (2) $i$ believes that executing the acts in $\pi$ will entail the performance of $p$ and, (3) $i$ believes that each act in $\pi$ plays a role.

Now, we can define a new predicate $int(i,p)$ read as "the agent $i$ intends to achieve $p$" as:

$$int(i,p)[s] \stackrel{\text{def}}{=} \exists \pi \; cmt(i,p)[s] \wedge has.plan(i,\pi,p)[s] \tag{6}$$

How should various feature of intentions follow from previous definitions?

1. *Intentions must be consistent.* This means that an agent cannot be committed to two simultaneous conflicting actions. This is the case since situations are internally consistent and according to the definition of *cmt*, the two actions must occur in all the situations in relation by $C_i$.
2. *Intentions are not closed under expected consequence.* This follows from the fact that we do not want *cmt* to be closed under (expected) implication. Particularly, $cmt(i,p) \; \wedge \; bel(i, p \supset q)$ does not imply $cmt(i,q)$.
3. *Intentions must be realistic.* An agent might believe that she will do some action without having a plan, that is, without having an idea on how to do it. Therefore, she can have a commitment, but not an intention.

Finally, we need to formalize "Obligations" as they are used, for instance, in the promises to reflect the mode of achievement. Obligations represent what an agent *should* do, according to some set of norms; its formal aspects are generally examined using Deontic Logic (e.g., [22]).

Obligations are generally different from and cannot be reduced to intentions and goals, Thus, although knowing that $p$ is not compatible with her goals, an agent may be obliged to make $p$ true for respecting norms or social laws. We

assume here that agents plan their actions to violate as few rules as possible. In the case of obligations, an agent chooses to violate her obligations or not depending on the price to pay. As a first approximation, we can expressed "i is obliged to $j$ to make $p$ true" by $oblig(i, j, p)$ which is defined by the following:

$$oblig(i, j, p)[s] \stackrel{\text{def}}{=} (\exists s_l \succ s) \wedge (\forall s'.s \succ s' \succ s_l)$$
$$\neg p[s_l] \wedge whish(i, p)[s'] \supset violating(i, j, p)[s_l] \quad (7)$$

Thus, if $p$ is not achieved by $i$ in some limit situation $s_l$, $i$ violates her agreement between $i$ and $j$ on $p$. Such a violation is represented by the predicate $violating(i, j, p)$. Evidently, between situations $s$ and $s_l$, agent $i$ has an interest that $p$ would be true. We state that by $whish(i, p)[s']$.

To sum up, the knowledge and action approach developped here is in fact a contribution to the belief, desire, intention (BDI) model. Nowadays, it is widely accepted that the bahavior of any agent is mainly governed by the specific way it handles the rational balance between its beliefs, desires, and intentions. Other papers in this book refer to the BDI model [7], [12], [16], [24].

## 4 Semantics of Speech Acts based on Success, Satisfaction and Recursion

The condition of success of an illocutionary act are the conditions that must be obtained in a possible situation (i.e. context) in order that the speaker succeed in performing that act in that situation. For instance, a condition of success of a request is that the speaker attempts to get the hearer to carry out the future course of action represented by $p$.

Moreover, communication between agents can fail even illocutionary acts are successfully performed. In this case, the illocutionary act(s) of this communication are not satisfied. For example, a request which is successfully performed by a speaker is satisfied, only if the hearer makes its propositional content true by carrying out in the multiagent environment the course of action that it represents. More generally, the conditions of satisfaction of a speech act corresponds to the conditions under which we would affirm that the given speech act has been satisfied.

In fact, conditions of success and of satisfaction are a part of semantics of speech acts. A formal semantics is important for MAS because we need a rigorous understanding of communication in order to design and analyze a multiagent systems. To this end, we propose in this section to capture conditions of success and satisfaction in the situation calculus, by using the different operators introduced in the previous section. To do this, we adopt the following Singh's notations [19]: (1) a message $m$ is a pair $\langle f, p\rangle$, where $f$ identifies the illocutionary force, and $p$ the proposition. In this notation, $f$ is an atomic symbol from the set {assertive, directive, commissive, declarative and expressive}; and $p$ is a logical formula; (2) a communication from $i$ to $j$ is represented by $comm(i, j, m)$. If we consider $says.to(i, j, m)$ as the only action that agent $i$ can perform to make $comm(i, j, m)$ true, then

$$Poss(says.to(i,j,m),s) \supset comm(i,j,m)[do(says.to(i,j,m),s)]$$

We need also to express the psychological states that enter into sincerity conditions which different degrees of strength depending on the illocutionary force (see Section 2). For this purpose, we use integers which serve to measure the degrees of strength of illocutionary forces. By convention we select zero (0) to represent the *neutral degree of strength* that is characteristic of the primitive illocutionary forces of utterances (such as assertion); +1 represents the next stronger degree of strength (e.g. testimony); +2 the next stronger degree of strength (e.g. solemn acts of swearing that something is the case). Similarly, -1 represents the greatest degree of strength smaller than 0 (e.g. conjecture), and so on. If $degree(\tau)$ represents the degree of strength of an act of type $\tau$, then $degree(\tau) = k$ means that if the act $\tau$ is performed in situation $s$, the speaker $S$ expresses psychological states with degree $k$. With such a degree of strength, we can order the speech acts for each illocutionary force. Thus, the following illustrates "some" degrees in the case of $\langle directive, p\rangle$:

$degree(order) = degree(command) = degree(require) = +1$
$degree(ask) = degree(tell.to) = degree(request) = 0$
$degree(suggest) = degree(advise) = degree(recommend) = -1$

We have similar orders for the assertives, commissives, declaratives and expressives (details are in [21]). A such order between speech acts has in fact many implications in cooperative systems communication. For instance, an act of *request* or *ask* type lets the Hearer $H$ know that the Speaker $S$ is either of the same rank or a lower rank. Thus, $H$ can grant or refuse the request by returning messages with either an assert or answer type. Roles have as function to reflect the position of each agent in the hierarchy of the multiagent system and to determine what reasoning strategies to use. To compare the ranking differences of agents, we can assign a number to every role as in COSMO [23]. For example, for two agents $i$ of $role_i$ and $j$ of $role_j$, agent $i$ ranks higher than $j$ iff $v(role_i) > v(role_j)$ where $v(role_x)$ denotes the role value of an agent $x$.

### 4.1 The Conditions of Success

As Searle and Vanderveken [18] pointed out, the conditions of success of elementary acts are uniquely determined by the components of their illocutionary force and by their propositional content.

> **Proposition 1:** An illocutionary act of the form $\langle f, p\rangle$ is *successfully performed* in the context of an utterance ($s$) iff the conditions of success of $\langle f, p\rangle$ hold in $s$. Formally, we state this by the following:
>
> $$success(comm(S,H,\langle f,p\rangle),s) \equiv cond.success(\langle f,p\rangle)[s] \qquad (8)$$
>
> In this formulation, $success(comm(S,H,\langle f,p\rangle),s)$ states if the act $\langle f,p\rangle$ between $S$ and $H$ is successfully performed, in situation

$s = do(says.to(S, H, \langle f, p\rangle), s_u)$, or not. Moreover, $cond.success(\langle f, p\rangle)$ expresses if the conditions of success of $\langle f, p\rangle$ hold or not in $s$. Finally, $s_u$ stands for the situation of utterance.

As specified in Section 2, the conditions of success (*cond.success*) for an illocutionary act of the form $\langle f, p\rangle$ with respect to $s$ are:

1. the speaker achieves the *illocutionary point* of the force $f$ on the proposition $p$;
2. the speaker achieves this illocutionary point with the *mode of achievement* of $f$;
3. $p$ satisfies the *propositional content conditions* of $f$ with respect to $s$;
4. the speaker presupposes the propositions determined by the *preparatory conditions* of $f$;
5. the speaker expresses, with the *degree of strength* of $f$, the psychological states of the modes determined by the *sincerity conditions* of $f$ about the state of affairs represented by $p$.

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These conditions can be formulated for any speech acts using the situation calculus and the different operators introduced in the previous section. For example, a speaker $S$ makes a **promise** for the hearer $H$ in a context of utterance ($s$) if and only if the following conditions (i.e. *cond.success*) hold in $s = do(says.to(S, H, \langle commissive, p\rangle), s_u)$:

1. $S$ commits herself to make $p$ true (illocutionary act). $cmt(S, p)[s]$
2. $S$ is obligated to $H$ to make $p$ true (mode of achievement). $oblig(S, H, p)[s]$
3. The propositional context of the utterance is that the speaker *will do* "something" to make $p$ true (propositional content conditions).
   $\exists a\, \exists s'\, (s' \succ s)\ bel(S, p)[do(a, s')]$
4. $S$ presupposes that he is capable of doing some action $a$ to make $p$ true and that $p$ is in the interest of $H$ (preparatory conditions);
   $\exists a\ can(S, a, p)[s] \wedge bel(S, goal(H, p))[s]$
5. $S$ expresses with the degree of strength of a promise, an intention to make $p$ true (Sincerity conditions with a degree of strength).
   $int(S, p)[s] \wedge degree(promise)[s]$

We can state similar conditions of success for $\langle assertive, p\rangle$, $\langle directive, p\rangle$, $\langle declarative, p\rangle$, and $\langle expressive, p\rangle$. For example, $S$ *requests* $H$ about $p$, in some context iff, in this context: (1) $S$ expresses a wish to get $H$ to carry out the future course of action represented by $p$ (illocutionary point); (2) in this whish, $S$ gives a (more or less total) option of refusal to $H$ (mode of achievement); (3) $p$ has the general propositional content condition that its content represents a future course of action of $H$ (condition on $p$); (4) $S$ presupposes that the hearer is capable of doing some action $a$ to achieve $p$ (preparatory condition); (5) and finally, $S$ expresses with a normal degree of strength a wish that $H$ do that act (sincerity condition).

Similar conditions of success can be formulated for the other illocutionary forces. Details about this formulation are given in [4].

Finally, it is important to note that a speech act can be *successful* though *defective*. Thus, a speaker $S$ might actually succeed in asserting or promising something even though he has not enough evidence for her assertion or her promise might be insincere. In fact, an ideal speech act is one which is both successful and nondefective. Evidently, nondefectiveness implies success, but not conversely. We generally assume that there are only two ways that an act can be successfully performed though still be defective. First, *some* of the preparatory conditions might not be the case in the real world and yet the act might still be performed. The sincerity conditions might not obtain, in other words, the act can be successfully performed even though it be insincere.

### 4.2 The Conditions of Satisfaction

The conditions of satisfaction of elementary illocutionary acts of the form $\langle f, p\rangle$ are a function of the truth-conditions of their propositional content and of the direction of fit of their illocutionary force [18,20,21]. Generally, the speaker expresses the proposition $p$ with the aim of achieving a success of fit between language and the world from a certain direction. On the basis of the previous considerations on direction of fit (see Section 2), we adopt the following proposition about the conditions of satisfaction of illocutionary acts in general semantics.

> **Proposition 2:** An illocutionary act $\langle assertive, p\rangle$ with the words-to-world direction of fit is satisfied in a situation $s$ of utterance iff $p$ holds in $s$. Formally, if we express the satisfaction with the words-to-world direction of fit by $satis^{wl}_{wd}$, then this proposition becomes:
>
> $$satis^{wl}_{wd}(comm(S, H, \langle assertive, p\rangle), s) \equiv p[s] \wedge p[s_u] \qquad (9)$$
>
> with $s = do(says.to(S, H, \langle assertive, p\rangle), s_u)$ and $s_u$ is the situation of utterance. •

Thus, the success of fit between words and things is achieved by the fact that the expressed propositional content matches a state of affairs existing in general, independently in the world.

In the case of the world-to-words or the double direction of fit, the conditions of success of commissives and directives are part of their conditions of satisfaction. Indeed, unlike assertive utterances, commissive and directive utterances have conditions of satisfactions that are not independent of these utterances. An assertion is "true" iff its propositional content corresponds to an existing state of affairs no matter how it got into existence. On the other hand, a promise is kept or an order is obeyed only if the speaker or hearer carries out in the world a future course of action because of the promise or the order. Similarly, a declaration is satisfied only if the speaker makes its propositional content true by saying that it is true in the performance of that declaration. Now, we can state the following proposition about the satisfaction.

An illocutionary act $\langle f, p\rangle$ with the world-to-words direction $\langle world, words\rangle$ of fit is satisfied ($satis$) in some situation $s$ iff $p$ holds in $s$ *because of* the performance of this illocutionary act.

As sincerity conditions of $\langle commissive, p\rangle$ and $\langle directive, p\rangle$ are $int(S, p)$ and $int(H, p)$ respectively, and that "intention" has been defined as a "commitment + having-plan" (see Definition 6) we can relate the performance of commissives and directives to the execution of plans by the speaker $S$ and hearer $H$. To do this, we assume that $\pi$ in $has.plan(i, \pi, p)$ represents the set of acts $[\pi_1, \ldots, \pi_n]$. In these conditions, $do(\pi_n, do(\pi_{n-1}, \ldots, do(\pi_1, s))\ldots)$ is a situation denoting the world history consisting of the sequence of actions $[\pi_1, \ldots, \pi_n]$. In light of these considerations, we consider firstly the satisfaction of $\langle commissive, p\rangle)$ and $\langle directive, p\rangle)$ by stating the two following propositions:

**Proposition 3:** An illocutionary act $\langle commissive, p\rangle$ with the world-to-words direction of fit is satisfied in some situation $s$ iff $p$ holds in $s$ *because of* the performance of this illocutionary act. Formally, if we express the satisfaction with the world-to-words direction of fit by $satis^{wd}_{wl}$, then this proposition is:

$$satis^{wd}_{wl}(comm(S, H, \langle commissive, p\rangle), s) \equiv$$
$$\exists s', s''\ (s \succeq s' \succeq s'')\ Poss(\pi_i, s') \ldots Poss(\pi_n, s') \wedge$$
$$success(comm(S, H, \langle commissive, p\rangle), s'') \supset$$
$$p[do(\pi_n, do(\pi_{n-1}, \ldots, do(\pi_1, s')))\ldots) \tag{10}$$

**Proposition 4:** An illocutionary act $\langle directive, p\rangle$ with the world-to-words direction of fit is satisfied in some situation $s$ iff $p$ holds in $s$ *because of* the performance of this illocutionary act. As the satisfaction with the world-to-words direction is expressed by $satis^{wd}_{wl}$, we can state:

$$satis^{wd}_{wl}(comm(S, H, \langle directive, p\rangle), s) \equiv$$
$$\exists s', s''\ (s \succeq s' \succeq s'')\ Poss(\pi_i, s') \ldots Poss(\pi_n, s') \wedge$$
$$success(comm(S, H, \langle directive, p\rangle), s'') \supset$$
$$p[do(\pi_n, do(\pi_{n-1}, \ldots, do(\pi_1, s')))\ldots) \tag{11}$$

Notice that in the case of $\langle commissive, p\rangle$ the agent which is in charge of the execution of the set of acts $[\pi_1, \ldots, \pi_n]$ is the speaker $S$, whereas in the case of $\langle directive, p\rangle$ it is the hearer $H$. Finally, the situation $s$ represents $do(\pi_n, do(\pi_{n-1}, \ldots, do(\pi_1, s')))\ldots)$ and $s'$ is the situation in which all preconditions of $[\pi_1, \ldots, \pi_n]$ hold, finally, $s''$ is the situation where $comm(S, H, \langle directive, p\rangle)$ is successfully performed.

As stated previously, a $\langle declarative, p\rangle$ is satisfied only if the speaker $S$ makes its propositional content true by saying that it is true in the performance of that declaration. This statement leads to the following proposition:

**Proposition 5:** An illocutionary act $\langle declarative, p\rangle$ with the double direction of fit is satisfied in some situation $s$ iff $p$ holds in $s$ *because of* the performance of this illocutionary act. If the satisfaction with the double direction of fit is expressed by $satis_{dble}$, then this proposition becomes:

$$satis_{dble}(comm(S, H, \langle declarative, p\rangle), s) \equiv$$

$$success(comm(S, H, \langle declarative, p\rangle), s) \supset p[do(says.to(S, H, \langle declarative, p\rangle), s_u)] \quad (12)$$

Finally, in the case of the empty or null direction of fit, there is no question of success or failure of fit, and the propositional content is in general presupposed to be true. Such are the expressives that have null or empty direction of fit. Their point is to express a mental attitude of the speaker $S$ about the state of affairs represented by $p$. Formally, we represent this by $m(S, p)$ where $m$ is a psychological mode which determines a particular direction of fit between mind and the world, and $p$ is the propositional content which represents the state of affairs to which they are directed. As we see, in the case of the empty direction of fit, it is not to represent that state of affairs as actual or to try to get it to be actual in the world.

**Proposition 6:** An illocutionary act $\langle expressive, p\rangle$ with the empty direction of fit is satisfied in some situation $s$ iff $m(S, p)$ holds in $s$ *because of* the performance of this illocutionary act. If the satisfaction with the empty direction of fit is expressed by $satis_{\emptyset}$, then this proposition becomes:

$$satis_{\emptyset}(comm(S, H, \langle expressive, p\rangle), s) \equiv$$

$$success(comm(S, H, \langle expressive, p\rangle), s) \supset m(S, p)[do(says.to(S, H, \langle expressive, p\rangle), s_u)] \quad (13)$$

Finally, it is important to note that *the set of illocutionary forces of possible utterances is recursive.* Consequently, there are five primitive illocutionary acts with an illocutionary act, no special mode of achievement of that point, a neutral degree of strength and only the propositional content, and the preparatory and sincerity conditions which are determined by their point. These primitive forces are : $\|assert\|$ for the assertives, $\|commit\|$ for the commissives, $\|direct\|$ for the directives, $\|declare\|$ for the declaratives and finally, the primitive expressive illocutionary force which is realized syntactically in the type of exclamatory sentences (there is no illocutionary verb or performative in English that names the primitive expressive). $\|\ \|$ is the function that assigns to each illocutionary verb the force or type of speech act that it names. Such a function can be associated to a propositional content as for instance $\|assert\|(p)$.

**Proposition 7:** Other illocutionary forces (than primitives) are obtained from the primitive illocutionary forces by a finite number of application of the following operations: i) adding propositional content conditions, ii) adding preparatory conditions, iii) adding sincerity conditions, iv) restricting the mode of achievement and finally, v) increasing the degree of strength.

These operations are Boolean operations (see [21] for details). Here are some examples of derived illocutionary forces. The illocutionary force $\|promise\|$ is obtained from the primitive commissive force $\|commit\|$ by imposing a special mode of achievement of the commissive point involving the undertaking of an obligation. $\|pledge\|$ is obtained from $\|commit\|$ by increasing the degree of strength of the sincerity conditions, etc.

## 5 Applications of our Approach

### 5.1 Contributions to the Analysis and Interpretation of Speech Acts

Our semantics, expressed into a tractable language (the situation calculus), is useful for several reasons. First, it enables us to analyze *illocutionary force markers* and to interpret a great number of speech acts. Second, it also enables us to make a reasoned dictionary of *illocutionary verbs* of actual natural language by way of a systematic breakdown of lexicalized forces into their components. Third, our theory is also useful to describe the various sorts of entailment and relative inconsistency that can exist between actual sentences expressed in the same contexts with related conditions of success and satisfaction. Such entailments and inconsistencies might be important in the context of Agent Communication Language (ACL). For example, a sentence $S_1$ such as "I ask you if you are busy" *illocutionarily entails* the sentence $S_2$ "Are you busy?". Thus a speaker could not perform $S_1$ without also performing $S_2$ in the same context. Similarly, the two sentences "How nice of you to finish the job $j_1$" and "I regret that you have done $j_1$" are *illocutionary incompatible* because they express in the same contexts speech acts that are not simultaneously performable. The formal model presented here can also generalize the traditional truth conditional notions of entailment and consistency and apply them to non-declarative sentences. For example, the imperative sentence $S_3$ "Please, touch me by email tomorrow morning!" can be said to entail *truth-conditionally* the sentence $S_4$ "you are able to touch me by email tomorrow morning". Thus, $S_3$ expresses in a given context a request which cannot be satisfied unless the assertion expressed by $S_4$ in the same context is true. Similarly, the imperative sentence $S_5$ "email piece of information $P_1$ ... and do not email $P_1$!" is truth-conditionally inconsistent since it expresses in all contexts a directive which is not satisfiable.

Thus, the approach presented here can be used to formally analyze illocutionary forces. Such an analysis is useful to formalize human interactions as well as the communications among software agents.

### 5.2 Agent Communication Language: Towards a Semantics of KQML performatives

The semantics developed by authors of KQML turns around the well known approach: speakers and hearers have *only* to recognize each other's intentions. This approach, which was initiated by [1] considers in fact that the only kinds of things that are *intrinsically*, as opposed to derivatively, meaningful are not linguistic acts like the act of asserting that something is the case, the act of requesting someone to make something the case, or the act of promising to make something the case, but rather *mental states* like the state of believing, desiring or intending. With a such approach, some aspects of the success are not considered (as for instance the "degree of strength" and some facets of the preparatory conditions) and cannot derive from the mental states of the intervening parties. In our point of view, the degree of strength and the preparatory conditions are very important for the interactions among agents as explained in Section 2. To remedy to this, we give here our semantics for some performatives used in KQML [8]: $\mathsf{achieve}(S, H, p)$, and $\mathsf{tell}(S, H, p)$.

Firstly, $\mathsf{achieve}(S, H, p)$ performative should be analyzed in our framework as a $\|request\|$ addressed by $S$ to $H$ in order to achieve $p$. Notice that request is a directive illocutionary act that allows for the possibility of refusal and consequently, it can be granted or refused by $H$. In these conditions, $\|request\|$ differs from the primitive directive $\|direct\|$ (see previous section) only by the fact that the mode of achievement allows $H$ the possibility of refusing to carry out the future course of action represented by $p$. In our framework, this can be expressed by:

$success(comm(S, H, \|request\|(p)), s) \equiv$
$success(comm(S, H, \|direct\|(p)), s) \wedge \forall s'(s' \succ s')\ \neg oblig(H, S, p)[s']$

The condition of satisfaction of $comm(S, H, \|request\|(p))$ is determined by **Proposition 5**.

Secondly, $\mathsf{tell}(S, H, p)$ performative should be analyzed here as an $\|assert\|$ that $p$. With our semantics, all other assertives of KQML (untell, sorry and error) should be analyzed in our framework according to the **Proposition 7**. Precisely, these assertives are obtained from the primitive illocutionary force $\|assert\|$ by a finite number of application of the following operations: i) adding propositional content conditions, ii) adding preparatory conditions, iii) adding sincerity conditions, iv) restricting the mode of achievement and finally, v) increasing the degree of strength. In fact, all KQML performatives should be expressed in our framework using recurrence. In this way, KQML "performatives" can be extended since developers have some guidance on how to formulate new performatives. Thus in the case of assertives for instance, developers have only to develop performatives which may differ from one another in respects such as their mode of achievement (the difference, for example, between arguing and testifying that $p$); their degree of strength (the difference, for example, between insisting that $p$ and conjecturing that $p$), their propositional content conditions (the difference, for example, between a prediction and a report), their preparatory conditions (the difference, for example, between reminding and informing

that $p$), or their sincerity conditions (the difference, for example, between asserting and complaining).

## 6 Conclusion

The model of speech acts presented in this paper represents a systematic, unified account of both the truth–and the success–conditional aspects. In this model, meaning and use are logically related and linguistic competence is not dissociated from performance. On the contrary, linguistic competence is constructed as the speaker's ability to understand which illocutionary acts can be performed by literal utterances in the various possible contexts of use of this language.

We have proposed an adequate formalism (the situation calculus) for representing this model in the context of agent communication language. Finally, we have explained how the resulting model allows us to (1) contribute to the analysis and interpretation of speech acts; (2) contribute to the semantics of agent communication language as KQML.

This work is only the beginning and we plan to extend it, in particulier to conversations taking into account social interactions of autonomous agents, and specially the private and global views on communication as developed by Dignum [6].

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