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A Semantics for Speech Acts*

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Abstract

Speech act theory is important not only in Linguistics, but also in Computer Science. It has applications in Distributed Computing, Distributed Artificial Intelligence, Natural Language Processing, and Electronic Data Interchange protocols. While much research into speech acts has been done, one aspect of them that has largely been ignored is their semantics, i.e., their conditions of satisfaction. A formal semantics for speech acts is motivated and presented here that relates their satisfaction to the intentions, know-how, and actions of the participating agents. This makes it possible to state several potentially useful constraints on communication and provides a basis for checking their consistency.

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1 Introduction

One of the most significant developments in the study of language was the formulation of speech act theory by Austin, Grice, Searle, and others. Austin's main contribution was in pointing out that the major role of language, communication, is a kind of action *par excellence* [3]. This idea has inspired much work in the Philosophy of Language, Linguistics, and Artificial Intelligence. Unfortunately, research in each of these three areas has been concentrated on what are, from the point of view of semantics, somewhat peripheral matters. Typically, the issues addressed in the study of speech acts concern such things as the heuristics that may be used to determine when what sort of a speech act may be said to have occurred, or the syntactic forms that different kinds of utterances might take. Occasionally, one may see a paper on the definitions of speech acts in terms of how the cognitive states of the participants are updated as a consequence of a speech act. However, the crucial matter of the *semantics* of speech acts *per se* is never addressed. In other words, extant theories tell us when a specific kind of speech act occurred and what should happen as a result of it in ordinary or ideal circumstances, but they do not tell us when it is, in fact, satisfied.

A semantics for speech acts is direly needed to provide a rigorous foundation for our understanding of languages, both artificial and natural, and to further advance the many applications of speech act theory. These applications are in a number of areas of Computer Science, including the following.

1. *Distributed Computing.* The initial specifications of distributed systems and protocols that human designers and ultimate users come up with often are in terms of the speech acts performed by the processes in a system [24]. A semantics would make precise notions such as permission and promise that are commonly used—though used only informally. Having precise definitions would help in designing reliable systems and would facilitate the debugging of their specifications relative to the desires of their ultimate users.

2. *Distributed Artificial Intelligence.* The messages exchanged by intelligent agents may usefully be considered to be speech acts [6, 14]. A semantics of speech acts would be useful in setting down the objective criteria for the evaluation of the communications and other actions of agents. Such criteria could be used by the designers of multiagent systems and by the agents who compose such systems.

3. *Natural Language Understanding and Generation.* This application is perhaps the easiest to identify, since ultimately all of natural language involves speech acts. In particular, it helps to consider speech acts as first-rate actions that discourse participants plan, and then perform [2]. A formal semantics would provide clear criteria for success and failure that can be used in better integrating the natural components of an intelligent system with other parts of it. It may also be used in planning and replanning speech acts and in clearing up misunderstandings between participants.

4. *Electronic Data Interchange protocols.* The documents exchanged among organizations may fruitfully be seen as speech acts performed by them [8, 16]. A semantics for speech acts would provide a uniform basis for standardization and formal specification of such protocols that is critically needed.

Thus a semantics for speech acts is needed to fully develop each of the above applications. Further, a semantics for speech acts is also needed in classical linguistics. This is because most languages have verbs such as "obey" (as in "obey a command"), "follow" (as in "follow an instruction"), "keep" (as in "keep a promise"), and so on. The semantics of each of these verbs and their derived forms depends crucially on what it means to, respectively, obey a command, follow an instruction, or keep a promise. But this is a component of the semantics of speech acts as motivated and defined here.

I present a formal theory that gives the semantics of several different kinds of speech acts. This theory uses the concepts of know-how and intentions as primitives. The technical framework of this paper follows the ones developed previously to formalize know-how and intentions [25, 26]. This connection to other theories is reason to be reassured that the primitives can in fact be formalized and that this theory will fit into a bigger picture. It also helps us capture many of the intuitive properties of speech acts. The original contributions of this paper include the following.

1. This paper argues that there is a level of formal semantics of speech acts that is distinct from both (a) what is traditionally considered their semantics, namely, the conditions under which they may be said to have occurred; and (b) their pragmatics, namely, the effects they may or ought to have on the speaker's and hearer's cognitive states. That is, it proposes a novel semantics that differs from both the illocutionary and the perlocutionary aspects of speech acts.

2. This paper argues that the semantics of speech acts roughly corresponds to the conditions under which we would affirm that the given speech act had been satisfied, e.g., a command is satisfied if it is obeyed and a promise is satisfied when it is kept. That is, this paper extracts a component of our pretheoretic intuitions concerning the satisfaction of speech acts that has been largely ignored in past work.

3. This paper proposes that this suggested notion of semantics be captured in the usual model-theoretic framework by introducing a modal operator that distinguishes the satisfaction of a speech act from its mere occurrence.

4. This paper argues that the actual definitions of the semantics be given in terms of the intentions and know-how of the agents participating in the given speech act, as well as the state of the world (at some salient time or times).

The ideas developed in this paper can be used to motivate a taxonomy of speech acts on semantic grounds, rather than on syntactic or pragmatic ones alone. This is the first such attempt known to me—existing taxonomies fall into the latter two categories. The formalization is presented in the simple and fairly well-known framework of modal and temporal logics. This formalization can be used to provide a model-theoretic basis for normative constraints on communication among agents, and for felicity conditions for different kinds of speech acts.

In §2, I give a brief overview of speech act theory. In §3, I motivate the semantics presented in this paper. In §4, I give the technical framework of this paper and describe the formal language and the formal model used. In §5, which is the core of this paper, I give the actual satisfaction conditions. In §6, I outline a novel application of this theory to the semantics of the verbs of fulfillment and in §7, I present some example constraints that make communication felicitous in various respects. In §8, I compare the approach of this paper with some recent work on speech acts.

2 Speech Acts and Their Semantics

When speech act theory first arose as a research area, the doctrine of *verificationism* was still quite powerful in Philosophy and Logic. This doctrine held that only those sentences of a language (natural or artificial) were meaningful that could be verified, at least in principle. That is, all sentences that, even in principle were neither true nor false were deemed to be nonsense. The standard logical notion of semantics, e.g., as captured by the Tarskian $\models$, reflects this doctrine. Unfortunately, the above doctrine is unduly restrictive: most utterances are neither true nor false. Sentences such as "I declare you man and wife" and "I plead not guilty" are perfectly meaningful, but their meaning is not captured by the fact of their truth or falsity. Furthermore, sentences such as "Please shut the door," which are also perfectly meaningful, cannot be assigned a truth value at all. Thus, from its very roots, speech act theory has been against the standard logical notion of semantics.

It is useful to see speech act theory as arising in reaction to this doctrine. Speech act theory concerns itself primarily with the role of language as action, and this view forces the rejection of verificationism. This is presented as a sort of a historical explanation of the tendency of speech act theory to shun standard semantics. But, as I hope to show, there is no real technical reason why this should be so—one can retain the key ideas of speech act theory and still give a formal semantics.

Austin, in his early work, made a distinction between what he termed *constative* and *performative* sentences. The former included most ordinary sentences in language; the latter were those like "I declare you man and wife" whose utterance constitutes an action being done. Later this distinction was collapsed when it was realized that all sentences could be put in the form of performatives, by using appropriate performative verbs. For example, the sentence "Shut the door" could be seen as a variant of "I ask you to shut the door," which is an explicit performative. This observation is usually taken as the starting point for speech act theory.

There has been much work done in speech act theory from various angles, in particular, those of Syntax, Pragmatics, and Artificial Intelligence. I briefly discuss each of these below.

2.1 Syntax

Syntactic work on speech act theory has drawn inspiration from the fact that there is a close relationship between the surface form of a sentence and the kind of performative it represents. For example, it is easy to see that the proposition "the door is shut" underlies both the indicative "The door is shut" and the imperative "Shut the door." Different performative verbs can be combined with a given proposition, appropriately linguistically represented, to yield different kinds of speech acts. For example, the above indicative and imperative may be recast as "I tell you that the door is shut" and "I order you to shut the door," respectively. This sort of syntactic regularity has driven much work in generative grammar, e.g., that of J. R. Ross [18]. The performative form of a sentence is taken to be the deep structure from which the appropriate surface structure is derived. This approach nicely explains some other data involving performatives, e.g., about the so-called dangling clauses of the form "Since you ask me, buy new tires," where the subordinate clause really makes sense with the missing performative verb inserted, e.g., as "..., I *tell* you to buy new tires." In other syntactic work, Vendler classified the so-called performative verbs, such as "order" and "entreat," on various dimensions, e.g., of the kinds of objects they take [29]. This data explains certain facts about performatives and their differences from, and similarities with, attitudinal verbs.

2.2 Pragmatics

Much of the work on speech acts in pragmatics has been about identifying the illocutionary force of a speech act. Speech acts with the same locutions can have different illocutionary forces depending on the speaker's intentions and beliefs. For example, "It is cold in here" might serve as both an assertion, namely, that it is cold, and as a request, namely, to turn up the heater. Research in pragmatics has mostly concerned itself with giving the felicity conditions for speech acts. A possible condition stated, and debated, here would be that a speech act succeeds when it is the true cause of the appropriate effect on the cognitive states of the speaker and the hearer. The appropriate effect would include the instantiation of various mutual beliefs, perhaps with further restrictions enforced on them [10, 20].

2.3 Artificial Intelligence

Work in Computational Linguistics on speech acts has borrowed heavily from the tradition in Pragmatics. It too is primarily concerned with the linguistic or discourse-related aspects of this problem, e.g., for identifying the illocutionary force of indirect speech acts [1], or for defining their effects on the mutual beliefs of agents [7]. Speech acts are defined in terms of the effects of the cognitive state of the hearer that are intended by the speaker. They are seen as parts of plans that the participants find and execute [2]. This idea helps explain the true illocutionary force of a speech act and also sheds some light on the phenomena of presuppositions and implicature. Thus it is useful for many aspects of natural language understanding.

Most other Artificial Intelligence (AI) work on speech acts is in the area of Distributed AI. Here the classification of speech acts is used to motivate different sets of message types for communications among different intelligent agents [6, 14]. Different heuristics are studied that shed light on how agents ought to generate and process different kinds of speech acts. No formal semantics for these message types has been available.

2.4 Logic

Classical logic is concerned only with statements that are true or false or which, at least in principle, can be found to be either. Thus it applies only to assertives. Even other work in logic is different in spirit from the research reported in this paper. For example, deontic logics are about the nature of what an agent is permitted or obliged to do. They would validate inferences of the form: if an agent is permitted A, then he is also permitted B, for appropriate actions or propositions, A and B. This issue is orthogonal to the matter of when a speech act that issues a permission is satisfied. Logics of commands are similar to deontic logics in this respect. In any case, the approach proposed here is model-theoretic rather than proof-theoretic. However, some of the ideas of these logics are useful when adapted to the framework of this paper. In particular, work on the semantics of questions can be used to motivate the definition of satisfaction for interrogatives, which are treated as special kinds of directives here.

3 Intuitive Motivation for Semantics

While much useful work has been done on various aspects of speech acts, one obvious facet of them has never been studied properly. This is the facet of their semantics, in the mundane sense of success. The satisfaction of a speech act is very different from its being understood—most work related to semantics has addressed the latter, and not the former, problem. The problem of formally describing the conditions of satisfaction for the different kinds of speech acts is of interest here. The reduction of all speech acts to performatives makes a performative verb, e.g., "tell" or "request," the main verb of a sentence. Thereby a lot is gained in the understanding of speech acts. Unfortunately, it also has tended to restrict the attention of semanticists to the performative verb itself. The verb of the nested clause, which is likely to be the verb of the sentence in its usual surface form, is not paid sufficient attention to. The sentence "I request you to open the door" is thus true, if I succeed in so requesting you, i.e., if I can in an appropriate manner convince you of my intention to communicate that request (e.g., see [19, p. 43]). What I requested, and whether that request was satisfied, are two factors that are simply left out of the picture. These factors are central to the picture of this paper.

A problem not addressed here concerns the effects a speech act has on the hearer. These depend on issues such as the social relationship of the agents or on matters of performance—these are not easy to describe, and are connected to processes of deliberation and belief revision [17], rather than to the semantics of speech acts *per se*. Similarly, how an agent ought to respond to a speech act is a matter of pragmatics. In any case, a semantics such as the one presented here would help clarify our intuitions even about the pragmatic aspects of speech acts. Indeed, in §7 I discuss some possible normative constraints on communications: when such constraints apply, they restrict the communications and other actions of agents in response to different speech acts. As a clarification of my goals, note that the role of the proposed semantics is akin to that of classical semantics for assertives. Classical semantics only tells us when an assertive is objectively satisfied—it makes no claims about when a given assertive should actually be uttered or believed.

3.1 Illocutionary Force and Propositional Content

Traditionally, speech act theory classifies speech acts into several kinds of *illocutionary acts* [19, 21]. In this paper, I consider the classes of *assertives, directives, commissives, permissives, prohibitives,* and *declaratives*. Briefly, assertives are statements of fact; directives are commands, requests or suggestions; commissives, e.g., promises, commit the speaker to a course of action; permissives issue permissions; and prohibitives take them away. Declaratives entail the occurrence of an action in themselves. For example, the declarative "I plead not guilty" differs from the mere assertive "I pleaded not guilty yesterday." The former speech act, which succeeds only in certain situations, not only reports the fact of the speaker pleading not guilty, but also constitutes the occurrence of the reported action.

The classification of speech acts given above is necessarily coarse. Speech acts of varying strengths, and of differing pragmatic effects are lumped together here. For example, assertives include statements, tellings, claims, and so on; directives include commands, entreaties, requests, suggestions, and so on. This should not be taken to mean that the proposed theory cannot accommodate different kinds of speech acts, or that it cannot capture the distinctions between, e.g., requests and commands. It just means that the distinctions between them are not seen to be *semantic*. The conditions of the satisfaction of different speech acts in the same class are identical; their differences lie in pragmatic factors, e.g., cultural conventions and the social stature of the participants. For example, a command can be successfully issued only to subordinates; however, one can request almost anyone. Further constraints on when requests and commands are satisfied may be stated that capture their non-semantic aspects properly.

In speech act theory, an *illocution* or speech act is usually seen to have two parts: an *illocutionary force* and a *proposition* [19]. The illocutionary force distinguishes, e.g., a command from a promise; the proposition describes the state of the world that is, respectively, commanded or promised. This suggests a simple syntax for our formal language—an illocution or *message*, m, is a pair $\langle i, p \rangle$, where i identifies the illocutionary force, and p the proposition. Here i is an atomic symbol from the set {assertive, directive, commissive, permissive, prohibitive, declarative}, and p a logical formula. The propositional part of an illocution specifies the state of the world that it is, in some sense, about. For example, an assertive asserts of that state that it holds currently (though the proposition could be temporally indexed); a directive asks the hearer to bring that state about; a commissive commits the

Force	**Example**
Assertive	The door is shut
Directive	Shut the door
Commissive	I will shut the door
Permissive	You may shut the door
Prohibitive	You may not shut the door
Declarative	I name this door the Golden Gate

Table 1: Classification of Speech Acts

speaker to bringing it about, and so on. Paradigmatic examples of speech acts of different illocutionary forces are given in Table 1. Thus the satisfaction of a speech act depends both on its illocutionary force and on its proposition.

3.2 Whole-Hearted Satisfaction

I now present the definition of satisfaction intuitively, so as to motivate the formal framework of §4. In the context of imperatives, Hamblin distinguishes between what he calls *extensional* and *whole-hearted* satisfaction [12, pp. 153–157]. Briefly, the former notion admits accidental or contingent success, while the latter does not. Here I consider only the latter, though I extend it to other important kinds of speech acts. Also, my aim is to obtain a semantics of speech acts. Hamblin's aim was simply to be able state prescriptive conditions on when what kind of imperatives ought to be issued, and the philosophical problems that arise when one is in a quandary. That is, his focus was largely pragmatic.

As motivation, I informally discuss the case of directives in this section. The *whole-hearted* satisfaction of a directive requires not only that the specified proposition be made true, but be made true in a surefire manner. The concerned agent should not only bring about the right state of the world, but know how to bring it about and intend to bring it about. We know that the proposed condition is correct because, and only because, it matches our pretheoretic sense of when a directive is satisfied. We know, as language users ourselves, that our requests are whole-heartedly satisfied when the person requested goes about making the appropriate conditions occur. This is the only kind of justification we could have for a semantics. Indeed, this methodology is common in all of logic, e.g., that of belief. Furthermore whole-hearted satisfaction allows us to capture other intuitions as well. For example, we can normatively require that an agent not issue two commands that cannot both be whole-heartedly satisfied, even if they can both be extensionally satisfied. This is a useful constraint for communication to be felicitous.

The definition of the satisfaction of speech acts as proposed here depends on the definitions of know-how and intentions. These concepts have been formalized in models of branching time (that allow the possible actions of agents to be considered) [26, 22, 25]. I use essentially the same framework here as in the cited work, extending it only to accommodate speech acts.

Briefly, an agent knows how to achieve A, if he can achieve A if he so intends. Intuitively, an agent knows how to achieve A, iff he possesses the skills required to act in such a way as to achieve A. For example, I know how to open a door in a certain variety of circumstances in which I can perform actions, such as opening a bolt and pulling at the handle, that would result in the door being open. I would not know how to open a door, if a stronger person than I were to hold the door from the other side, or if the door were locked. The key idea is that the given agent forces the appropriate condition to come to hold. An agent's intentions can be taken as primitives of his cognitive state, or derived from an abstract characterization of the extended actions he is currently engaged in. Their important properties are that they are "pro-attitudes" of agents, agents usually act for them and tend to persist with them. Intentions are also usually associated with agents' rationality in that they are supposed to be mutually consistent and consistent with the beliefs of the agent holding them.

An important intuitive property to keep in mind is that neither an intention nor some know-how is by itself sufficient for the agent to achieve something: one can intend things beyond one's capacities, or not intend things within one's capacities. But if an agent intends something and persists with it and acts on his intention and knows how to achieve it, then he will eventually succeed. The above properties are not used in the technical development of this paper, though they are an important part of our understanding of these concepts.

The ideas of this paper are modular with respect to the exact underlying theory of intentions and know-how that one might choose. This is a good thing for the following reasons. Several applications of this theory were discussed in §1. The particular formalization that one chooses depends on the application at hand. For example, the closure of intentions, as of knowledge, under logical consequence is problematic for humans [26], but is acceptable for processes in distributed computing [5]. Secondly, I do not wish to debate the relative merits of different theories here: my claim is that no matter how one understands the primitives involved, the satisfaction of a speech act requires that certain conditions hold among them. These primitives are an important layer of abstraction because our pretheoretic intuitions are most natural in their terms. Using these primitives thus boosts our confidence that we are capturing our intuitions properly.

4 The Formal Framework

The formal model of this paper posits a set of possible *times*, each of which is intuitively associated with a state of the world. I describe it informally before coming to the formal definitions. As diagramed in Figure 1, from each possible time the world may develop in any of several ways depending on the agents' actions and other events. That is, there is a partial order on the times that may branch into the future but, for simplicity, is taken to be linear in the past.

Two agents are considered in Figure 1, whose actions label the branches out of t_0. At time t_0, if the first agent does action a, the state of the world may change to t_1, or to t_2,

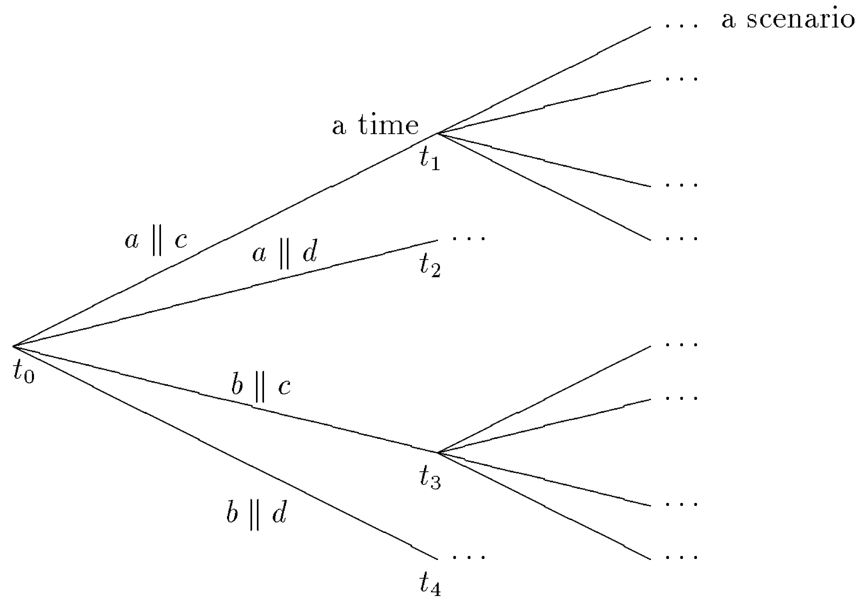

Figure 1: The Formal Model

depending on what the other agent does then. Each of the agents influences the future by acting, but the outcome also depends on other events. For example, in Figure 1, the first agent can constrain the future to some extent by choosing to do action a or action b—if he does action a, then the world progresses along one of the top two branches out of t_0; if he does action b, then it progresses along one of the bottom two branches. However, the agent cannot control what exactly transpires, since that also depends on the other agent's actions.

Each of the different branches of time that begins at a point in the model is called a *scenario* (at that time) and is equivalent to a possible course of events. That is, a *scenario* at a time is any branch of the future beginning there—this corresponds to a particular run or trace of the given system. A *subscenario* is a triple, $\langle S, t, t' \rangle$, which denotes a section of scenario S from time t to t'.

4.1 The Formal Language

The formal language of this paper, $\mathcal{L}$, is based on CTL* (a propositional branching time logic [9]) augmented with a predicate for intention, 'intends' and two predicates for know-how, 'K_{how}' and 'K_{prev}.' Each of these applies to an agent and a formula. The predicate for communication, 'comm,' is as defined above, as is the operator WSAT.

Now I formally define the syntax of $\mathcal{L}$. $\mathcal{L}$ is the minimal set closed under the following rules. Here Φ is a set of atomic propositions symbols, $\mathcal{B}$ a set of actions, and $\mathcal{B}'$ a set of basic action symbols. $\mathcal{F} = \{$assertive, directive, commissive, permissive, prohibitive, declarative$\}$ is the set of illocutionary forces. $\mathcal{A}$ is the set of agent symbols. $\mathcal{M}$ is the set of *messages* as defined below. $\mathcal{L}_s$ is the set of *scenario-formulae* that is used as an auxiliary definition. It contains formulae that are evaluated relative to scenarios in the model, rather than relative to times.

1. $\psi \in \mathcal{L}$, where $\psi \in \Phi$
2. $p, q \in \mathcal{L}$ implies $p \wedge q \in \mathcal{L}$
3. $p \in \mathcal{L}$ implies $\neg p \in \mathcal{L}$
4. $p \in \mathcal{L}_s$ implies $\mathsf{WSAT}p \in \mathcal{L}_s$
5. $p \in \mathcal{L}_s$ implies $\mathsf{A}p \in \mathcal{L}$, where A is the universal scenario-quantifier
6. $p \in \mathcal{L}$ and $x \in \mathcal{A}$ implies $K_{how}(x,p), K_{prev}(x,p), \text{intends}(x,p) \in \mathcal{L}$
7. $\mathcal{L} \subseteq \mathcal{L}_s$
8. $p, q \in \mathcal{L}_s$ implies $p \wedge q \in \mathcal{L}_s$
9. $p \in \mathcal{L}_s$ implies $\neg p \in \mathcal{L}_s$
10. $p, q \in \mathcal{L}_s$ implies $p\mathsf{U}q \in \mathcal{L}_s$
11. $p \in \mathcal{L}$ implies $\mathsf{P}p \in \mathcal{L}$, where P is the past operator
12. $p \in \mathcal{L}$ and $i \in \mathcal{F}$ implies $\langle i, p \rangle \in \mathcal{M}$
13. $x, y \in \mathcal{A}$ and $m \in \mathcal{M}$ implies 'comm(x, y, m)' $\in \mathcal{L}_s$
14. $\mathcal{B}' \subseteq \mathcal{B}$
15. $x, y \in \mathcal{A}$ and $m \in \mathcal{M}$ implies 'says-to(x, y, m)' $\in \mathcal{B}$
16. $p \in \mathcal{L}$ and $a \in \mathcal{B}$ implies $[a]p \in \mathcal{L}_s$

Throughout this paper, the agent is elided over when obvious from the context. A denotes "in *all* scenarios at the present time." A useful abbreviation is E, which denotes "in *some* scenario at the present time"—i.e., $\mathsf{E}p \equiv \neg\mathsf{A}\neg p$. $p\mathsf{U}q$ means that q sometimes on the future on the given scenario and p holds from now to then. $\mathsf{F}p$ denotes "p holds sometimes in the future on this scenario" and abbreviates "$\mathsf{true}\mathsf{U}p$." $\mathsf{G}p$ denotes "p always holds in the future on this scenario" and abbreviates "$\neg\mathsf{F}\neg p$." $\mathsf{P}p$ denotes "p held at some point in the past." Implications $(p \rightarrow q)$ and disjunctions $(p \vee q)$ of formulae are defined as the usual abbreviations. For an action a, an agent x, and a formula p, $x[a]p$ denotes that on the given scenario, if a is ever done by x starting now, then p holds at some time during the period when a is being done. Let $x\langle a \rangle p$ abbreviate $\neg x[a]\neg p$. Thus $\mathsf{A}[a]p$ denotes that on all scenarios at the present moment, if a is ever done then p holds at a time during the period over which a is done.

4.2 The Formal Model

Let $M = \langle F, [\![\,]\!] \rangle$ be an intensional model for the language $\mathcal{L}$, where $F = \langle \mathbf{T}, <, \mathbf{A} \rangle$ is a frame and $[\![\,]\!]$ is an interpretation. Here $\mathbf{T}$ is a set of possible times ordered by $<$; $\mathbf{A}$ assigns agents to different times; i.e., $\mathbf{A} : \mathbf{T} \mapsto \mathcal{A}$. As described below, $[\![\,]\!]$ assigns intensions to atomic propositions and to pairs of agent symbols and actions.

A scenario at a time is any single branch of the relation $<$ that begins at the given time, and contains *all* times in some linear subrelation of $<$. Different scenarios correspond to different ways in which the world may develop in the future, as a result of the actions of agents and events in the environment. Formally, a scenario at time t is a set $S \subseteq \mathbf{T}$ of which the following conditions hold.

- *Root*: $t \in S$
- *Linearity:* $(\forall t', t'' \in S : (t' = t'') \vee (t' < t'') \vee (t'' < t'))$
- *Density:* $(\forall t', t'' \in S, t''' \in \mathbf{T} : (t' < t''' < t'') \rightarrow t''' \in S)$
- *Maximality:* $(\forall t' \in S, t'' \in \mathbf{T} : (t' < t'') \rightarrow (\exists t''' \in S : (t' < t''') \wedge (t''' \not< t'')))$

  Intuitively, this property means that if it is possible to extend the scenario S (here to t''), then it is extended, either to t'' (when $t''' = t''$), or along some other branch.

$\mathbf{S}_t$ is the class of all scenarios at time t. The classes of scenarios at different times are disjoint, i.e., $t \neq t' \Rightarrow \mathbf{S}_t \cap \mathbf{S}_{t'} = \emptyset$. The tuple $\langle S, t, t' \rangle$ denotes a subscenario of S from t to t', inclusive. Whenever $\langle S, t, t' \rangle$ is written, it may be assumed that $t, t' \in S$ and $t \leq t'$. This captures the essential intuition behind subscenarios, namely that they are periods of time, and helps simplify the formalism somewhat.

The intension, $[\![\,]\!]$, of an atomic proposition is the set of times where it is true. The intension of an action is, for each agent x, the set of subscenarios in the model in which an instance of it is done by x. Thus $[\![\,]\!]$ is the union of two functions of types $\Phi \mapsto \mathcal{P}(\mathbf{T})$ and $\mathcal{A} \times \mathcal{B} \mapsto \mathcal{P}(\mathcal{P}(\mathbf{T}) \times \mathbf{T} \times \mathbf{T})$, respectively. $t \in [\![p]\!]$ means that p is true at time t and $\langle S, t, t' \rangle \in [\![a]\!]^x$ means that agent x does action a in the subscenario of S from time t to t'. I require that all actions in $\mathcal{B}$ take time; i.e., $t < t'$ holds in the above. The superscript is deleted when it can be understood from the context.

The following coherence conditions on models are imposed to make them intuitively reasonable and to preserve certain technical properties [25]: (1) if begun at a particular time on a scenario, an action can end at most once on that scenario; (2) subscenarios are uniquely identified by the times over which they stretch; i.e., the scenario used to refer to them is not important; (3) there is always a future time available in the model; (4) something must be *done* by each agent along each scenario in the model, even if it is a dummy action; (5) for any time in the future of a given time, there is a finite sequence of actions that would reach it; and (6) if an action is performed from t to t', it may be taken to be performed from any time in the middle to t'.

4.3 Formalizing Speech Acts

Speech acts are, first of all, actions. I take them to be the actions of just their speakers, and as occurring over subscenarios. Let 'says-to' be a parametrized speech act, to be used as in 'says-to(y, m).' This action will be seen as an action done by agent x. $\langle S, t_b, t_e \rangle \in [\![\text{says-to}(y, m)]\!]^x$ means that, on scenario S, agent x performed the speech act of saying m to agent y in the time from t_b (the time of beginning) to t_e (the time of ending). This just means that the illocution was successfully made. There is no commitment at this stage as to whether it was satisfied or not. I require that $t_b < t_e$; i.e., the above action, like all actions, takes time.

The semantics of speech acts is captured in the theory of this paper by means of a new modal operator. The operator WSAT captures the *whole-hearted satisfaction* of speech acts, which is described in §5. It is convenient to have a special predicate in the language that allows us to talk of the performance of a speech act. This allows us to apply our modal operator to formulae that denote propositions, rather than to those that denote actions. Besides allowing us to follow the usual way of defining a modal operator, the definition of 'comm' also allows speech acts to be nested as in "I tell you that he pleaded guilty."

Let the new predicate be 'comm' that applies to two agents, and an illocution. Since actions take place over scenarios, it is most convenient to evaluate 'comm(x, y, m)' at scenarios and times. 'Comm(x, y, m)' is true at S, t just if y said (or started to say) m to x then. A performed illocution may, of course, not be satisfiable—e.g., some commands may be issued that are impossible to obey. WSAT, then, applies on formulas of the form 'comm(x, y, m)' and denotes the satisfaction of the associated speech act.

4.4 Semantics of the Formal Language

The semantics of sentences, i.e., formulae, in the formal language is given relative to a model a time in it. $M \models_t p$ expresses "M satisfies p at t." This is the main notion of satisfaction in this paper. For formulae in $\mathcal{L}_s$, it is useful to define an auxiliary notion of satisfaction, $M \models_{S,t} p$, which expresses "M satisfies p at time t on scenario S." This presupposes that $t \in S$; however, t may not be the root of S. The satisfaction conditions for the temporal operators are adapted from those in [9]. Formally, we have the following definitions.

1. $M \models_t \psi$ iff $\langle t \rangle \in [\![\psi]\!]$
2. $M \models_t p \wedge q$ iff $M \models_t p$ and $M \models_t q$
3. $M \models_t \neg p$ iff $M \not\models_t p$
4. $M \models_t \mathsf{A}p$ iff $(\forall S : S \in \mathbf{S}_t \rightarrow M \models_{S,t} p)$
5. $M \models_t \mathsf{P}p$ iff $(\exists t' : t' < t \wedge M \models_{t'} p)$
6. $M \models_{S,t} p\mathsf{U}q$ iff $(\exists t' : t \leq t' \wedge M \models_{S,t'} q \wedge (\forall t'' : t \leq t'' \leq t' \rightarrow M \models_{S,t''} p))$
7. $M \models_{S,t} [a]p$ iff $(\exists t' : \langle S, t, t' \rangle \in [\![a]\!]) \rightarrow (\exists t' : \langle S, t, t' \rangle \in [\![a]\!] \wedge (\exists t'' : t \leq t'' \leq t' \wedge M \models_{S,t''} p))$

8. $M \models_{S,t} p \wedge q$ iff $M \models_{S,t} p$ and $M \models_{S,t} q$

9. $M \models_{S,t} \neg p$ iff $M \not\models_{S,t} p$

10. $M \models_{S,t} \text{comm}(x, y, m)$ iff $(\exists t' : t' \in S \wedge \langle S, t, t' \rangle \in [\![\text{says-to}(y, m)]\!]^x)$

11. $M \models_{S,t} p$ iff $M \models_t p$, if $p \in \mathcal{L}$, and t is the unique time such that $S \in \mathbf{S}_t$

The semantic conditions for the rest of the language are motivated and presented below.

5 Whole-Hearted Satisfaction Formalized

Whole-Hearted satisfaction is defined relative to a scenario and a time. A performative is taken to be in force as soon as it is completed, but not sooner. This is done to allow the possibility of a communication being aborted midway. That is, a speaker's failed attempts to say something, i.e., to get his point across, do not count as communications.

As I have already argued, the primary considerations in this paper are semantic, rather than syntactic or pragmatic. As we shall see, this justifies the particular taxonomy of speech acts considered here. The advantages of not partitioning the space of speech acts in terms of their syntax are that (1) intuitively disparate speech acts like permissions and requests are kept apart in the theory; and (2) the phenomenon of indirect speech acts can be accounted for with ease (of course, the problem of determining, given an utterance, what speech act really has occurred is not addressed here). The advantage of not considering the pragmatics directly is that the semantics can be more systematically and rigorously defined, whereas the pragmatics, which relies on performance issues would be hard to pin down exactly. In the following, the satisfaction of a speech act requires that it have actually been performed on the given scenario. While we could possibly have stated conditions about scenarios that would tell us whether a given speech act, if performed on them, would be satisfied, this would not be intuitive. It would also leave open the possibility of a speech act being satisfied on scenarios on which it could not have occurred given the physics of the world, or the communicative conventions in force.

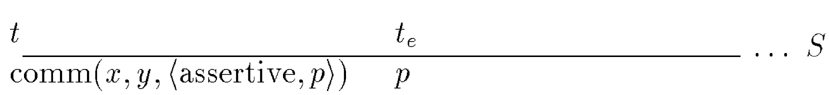

Figure 2: The Satisfaction Condition for Assertives

1. $M \models_{S,t} \mathsf{WSAT}(\text{comm}(x, y, \langle \text{assertive}, p \rangle))$ iff
$(\exists t_e : \langle S, t, t_e \rangle \in [\![\text{says-to}(x, y, \langle \text{assertive}, p \rangle)]\!]^x \wedge M \models_{S,t_e} p)$

An assertive is satisfied simply if its proposition is true at the time the utterance is made. Thus the assertive, "The door is shut," is satisfied on all scenarios where the door is, in fact, shut. The satisfaction conditions for the other kinds of speech acts are more interesting than this.

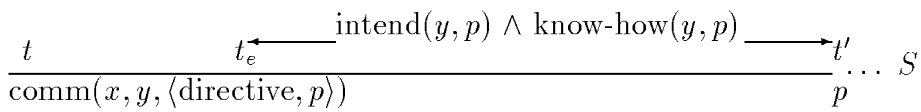

Figure 3: The Satisfaction Condition for Directives

2. $M \models_{S,t}$ $\mathsf{WSAT}(\text{comm}(x, y, \langle\text{directive}, p\rangle))$ iff
$(\exists t_e : \langle S, t, t_e\rangle \in [\![\text{says-to}(x, y, \langle\text{directive}, p\rangle)]\!]^x \wedge (\exists t' \in S : t' \geq t_e \wedge M \models_{S,t'} p \wedge (\forall t'' : t_e \leq t'' < t' \rightarrow M \models_{S,t''} K_{how}(y, p) \wedge \text{intends}(y, p))))$

A directive is satisfied just if (1) its proposition, p, becomes true at a point in the future of its being said, and (2) all along the scenario from now to then, the hearer has the know-how, as well as the intention to achieve it. For example, a directive to open the door is satisfied if the door ends up open (within some salient period of time, perhaps), and furthermore the hearer continuously planned to open the door and was in a position to be able to execute the plan to open it. Note that this definition does not finally require that the door open because of the hearer's actions. This would not be an important requirement to impose in my view, and would only cause action-theoretic complications about the matter of when an agent can be said to have performed a certain action, especially when that action is not a single-step basic action.

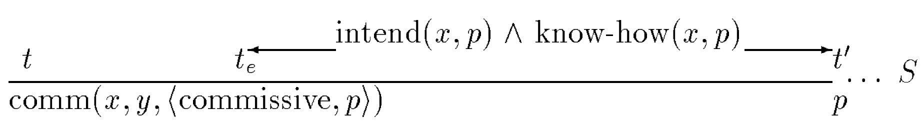

Figure 4: The Satisfaction Condition for Commissives

3. $M \models_{S,t}$ $\mathsf{WSAT}(\text{comm}(x, y, \langle\text{commissive}, p\rangle))$ iff
$(\exists t_e : \langle S, t, t_e\rangle \in [\![\text{says-to}(x, y, \langle\text{commissive}, p\rangle)]\!]^x \wedge (\exists t' \in S : t' \geq t_e \wedge M \models_{S,t'} p \wedge (\forall t'' : t_e \leq t'' < t' \rightarrow M \models_{S,t''} K_{how}(x, p) \wedge \text{intends}(x, p))))$

Similarly, a commissive is satisfied just if (1) its proposition becomes true at a point in the future of its being said, and (2) all along the scenario from now to then, the *speaker* has the know-how, as well as the intention to achieve it. Technically, a commissive is just like a directive except that the role of the hearer is taken over by the speaker. For example, the commissive, "I promise to shut the door," is satisfied on all scenarios on which the door eventually gets shut and until it does, the speaker intends and knows how to shut it.

A difference between commissives and directives that is of significance in some applications is that the satisfaction condition of a commissive depends on the actions, intentions, and know-how of just one agent. This can make the satisfaction of commissives easier to enforce in artificial systems. A related observation that is also interesting is that there seem to be fewer forms of commissives in natural languages than directives. This seems to be related to the fact that the satisfaction of directives involves actions by agents other than the speaker, and so different kinds of social considerations come into play—one may request or command or beseech or advise someone to do something, but one can simply do it on one's own (one can, of course, issue commissives on the basis of others' actions, and even issue a commissive to do something if another agent acts in a certain way).

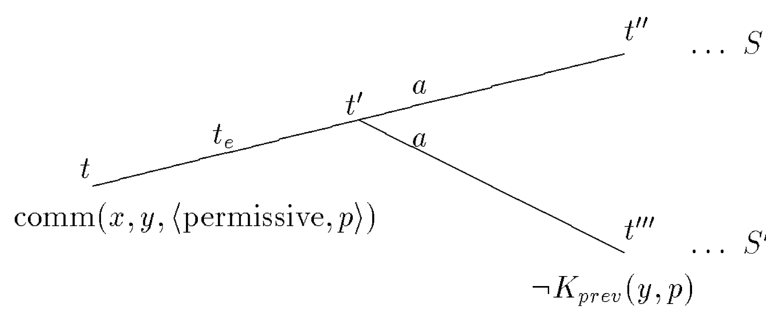

Figure 5: The Satisfaction Condition for Permissives

4. $M \models_{S,t} \mathsf{WSAT}(\text{comm}(x, y, \langle\text{permissive}, p\rangle))$ iff $(\exists t_e : \langle S, t, t_e\rangle \in [\![\text{says-to}(x, y, \langle\text{permissive, } p\rangle)]\!]^x \wedge (\exists t' \in S : t' \geq t_e \wedge (\forall a : (\exists t'' : \langle S, t', t''\rangle \in [\![a]\!]^y) \rightarrow (\exists S', t''' : \langle S', t', t'''\rangle \in [\![a]\!]^y \wedge M \not\models_{S',t'''} K_{prev}(y, p)))))$

A permissive is satisfied at a scenario and a time just if it is taken advantage of by the hearer at a future point on that scenario. But when a permissive is taken advantage of, it allows the hearer to do actions at certain times that he could not have done before, because those actions might possibly have led to the condition becoming true. Thus a permissive is satisfied on a scenario on which the hearer does at least one action whose performance can lead to a situation where he is unable to prevent that condition from occurring. That is, the hearer can now risk letting that condition hold. For example, a permissive allowing a hearer to let the door be open is satisfied on a scenario, if (as a result of the given permissive, as it were), the hearer can, e.g., risk opening the window, even though the breeze may open the door. Without this permissive, the hearer would have to take some precaution, e.g., latch the door, before opening the window. The satisfaction of a permissive tends to increase the know-how of the hearer by giving him more options. Unfortunately, no closed-form characterization of this increase in know-how is available at present.

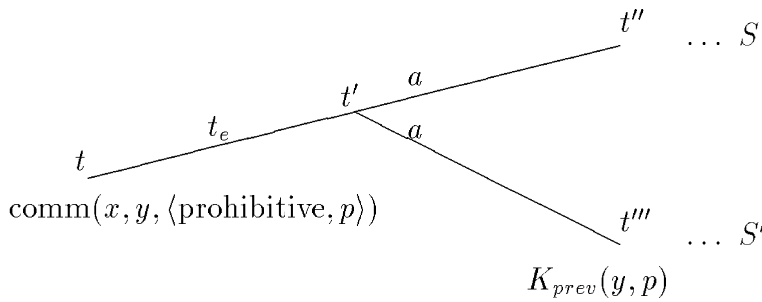

Figure 6: The Satisfaction Condition for Prohibitives

5. $M \models_{S,t} \mathsf{WSAT}(\text{comm}(x, y, \langle\text{prohibitive}, p\rangle))$ iff
$(\exists t_e : \langle S, t, t_e\rangle \in [\![\text{says-to}(x, y, \langle\text{prohibitive}, p\rangle)]\!]^x \wedge (\forall t' \in S : t' > t_e \rightarrow (\forall a : (\exists t'' : \langle S, t', t''\rangle \in [\![a]\!]^y) \rightarrow (\forall S', t''' : \langle S', t', t'''\rangle \in [\![a]\!]^y \rightarrow M \models_{S',t'''} K_{prev}(y, p)))))$

A prohibitive is satisfied at a scenario and time just if none of the actions done by the hearer on that scenario (in the future), can lead to a situation where the hearer would be unable to prevent the condition from occurring. That is, the hearer cannot risk violating the prohibition. For example, a prohibitive to not let the door be open can be satisfied only if the hearer does not let the window be open, where the opening of the window may lead to the door being opened.

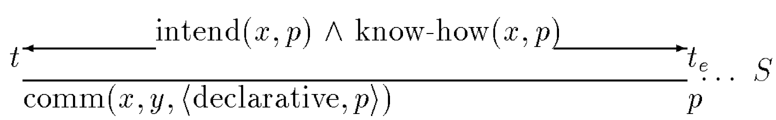

Figure 7: The Satisfaction Condition for Declaratives

6. $M \models_{S,t} \mathsf{WSAT}(\text{comm}(x, y, \langle\text{declarative}, p\rangle))$ iff
$(\exists t_e : \langle S, t, t_e\rangle \in [\![\text{says-to}(x, y, \langle\text{declarative}, p\rangle)]\!]^x \wedge (\exists t' \in S : t' \geq t_e \wedge M \models_{S,t'} p \wedge (\forall t'' : t_e \leq t'' < t' \rightarrow M \models_{S,t''} K_{how}(x, p) \wedge \text{intends}(x, p))))$

A declarative is satisfied just if (1) its proposition, p, becomes true at the time that it is said, and (2) all along while the speaker is saying it, he intends that condition to occur and knows how to make it occur. For example, a declarative to name a certain door the Golden Gate is satisfied if the door ends up named thus, and the speaker intended it to be so named and knew how to name it. The door has its new name as soon as the declarative is completed. The condition about the know-how is included to ensure that the speaker at each point is able to force the completion of the declarative and thereby force the occurrence of the appropriate condition. This helps eliminate cases where the speaker has the intention, but is not in the right social or conventional position to make the declarative succeed—the naming should succeed, but not because of some contingent features of the given scenario. According to some traditional theories, e.g., that of Vanderveken [27], the occurrence of declaratives merely coincides with their success. This seems too weak since it allows a declarative to succeed even if the speaker did not have full control over its occurrence, i.e., even if the speaker could not have forced the given condition to occur.

Since declarative epitomize doing things by saying, they occur exactly when they are satisfied. In other words, we have the following condition:

- $\text{comm}(x, y, \langle\text{declarative}, p\rangle) \equiv \mathsf{WSAT}(\text{comm}(x, y, \langle\text{declarative}, p\rangle))$

That is, a declarative can be successfully uttered only when it is satisfied. As a consequence, the appropriate intentions and know-how are presupposed for a declarative to even be uttered.

An interesting observation can be made about the relationship between declaratives and other speech acts. All speech acts can be expressed as declaratives. In fact, this is the core claim of the account of performatives as given by Austin. It would seem, then, that if we reduce, say, a promise to a declarative, we would have to say that it was satisfied precisely when it was uttered. Thus the intuitions captured by WSAT would be lost. However, this is not really the case in the theory of this paper. I used the performative account to motivate the syntax of the formal language used here. If a speech act that is not naturally a declarative is interpreted as a declarative, we have to wrap an extra illocution around it, i.e., we obtain something like $\text{comm}(x, y, \langle\text{declarative}, \text{comm}(x, y, \langle\text{commissive}, p\rangle)\rangle)$. The satisfaction of this does indeed coincide with the successful issuing of the appropriate promise; however, it is not the same as the promise nested within it. Of course, this leaves the question open of how to distinguish different speech acts in natural language but, as explained in §1, I am not addressing the problem of determining the appropriate illocutionary force of natural language utterances. I should note, though, that the proposed formal framework is rich enough to capture the relevant distinctions. Also, when the above complex speech act is considered, we can see that the act of issuing a promise involves at least intending to issue it, and knowing how to do so.

Interrogatives are semantically quite like directives; e.g., see Searle & Vanderveken [21, p. 199] and Harrah [13, p. 740, 747]. However, they need special treatment to allow for answers to be defined and received. An interrogative is treated as a directive to perform an assertive speech act (back to the speaker of the question) that provides the answer to the question posed in the original interrogative. Thus it is satisfied when a true answer to it is given, i.e., the assertive containing the answer is itself satisfied. This derives from an intuition about treating interrogatives as imperatives of the form 'Tell me Truly' [13, pp. 747–748].

We need to introduce 'interrogative' as a new force in $\mathcal{F}$. This is a subcategory of directives. Questions can be thought of as lambda expressions of the form $(\lambda\vec{a}p)$. An interrogative is then a directive to assert the correct answer to the given question, i.e., the set of substitutions for which the above expression evaluates to true. This corresponds to the semantics of questions, e.g., as proposed by Groenendijk & Stokhof [11]. Let $\mathcal{R}$ be a set of tuples. Let 'answer-to$((\lambda\vec{a}p),\ \mathcal{R})$' hold iff $(\forall\vec{b} : \vec{b} \in \mathcal{R} \leftrightarrow (\lambda\vec{a}p)[\vec{b}])$; i.e., $\mathcal{R}$ is the answer to $(\lambda\vec{a}p)$. $\mathcal{R}$ must be finite if it is to be explicitly communicated, but could be infinite if it is communicated by reference, e.g., as "the set of all even numbers." For simplicity, let $\mathcal{R}$ denote a representation of itself in the formal language. It is useful to have the following abbreviations: m_q stands for $\langle$interrogative, $(\lambda\vec{a}p)\rangle$, m_r stands for $\langle$assertive, answer-to$((\lambda\vec{a}p), \mathcal{R})\rangle$, and c_r stands for comm(y, x, m_r).

7. $M \models_{S,t} \mathsf{WSAT}(\text{comm}(x, y, m_q))$ iff $(\exists t_e : \langle S, t, t_e\rangle \in [\![\text{says-to}(x, y, m_q)]\!]^x \wedge (\exists \mathcal{R}, t' : t_e \leq t' \wedge M \models_{S,t'} \mathsf{WSAT}(c_r) \wedge (\forall t'' : t_e \leq t'' < t' : M \models_{S,t'} \text{intends}(x, \mathsf{WSAT}(c_r)) \wedge K_{how}(x, \mathsf{WSAT}(c_r)))) \wedge (\forall \mathcal{R}, t''' : t_e \leq t''' \rightarrow [M \models_{S,t'''} c_r \rightarrow M \models_{S,t'''} \mathsf{WSAT}(c_r)]))$

The last conjunct is included to capture the restriction that all answers asserted by the hearer of the interrogative must be WSAT. That is, only correct answers may be produced. This takes care of interrogatives that contain the so-called Wh-questions; those that contain yes-no questions are analogous. A yes-no question for q is of the form $(\lambda v(q \equiv v))$, where v is of the sort *truth-value*; thus this lambda expression evaluates to true iff v is the boolean value of q.

6 Verbs of Fulfillment

Force	Example
Directive	He acceded to my request to shut the door
Commissive	I kept my promise to shut the door
Permissive	He enjoyed the permission to let the door be shut
Prohibitive	He upheld the prohibition against shutting the door
Declarative	He named this door the Golden Gate

Table 2: Some Verbs of Fulfillment

One of the applications of the theory developed in this paper is to systematically give a rigorous semantics to what I call the *verbs of fulfillment*. These are verbs such as "obey," "follow," "keep," "enjoy," and "uphold." The connotations of them that are of interest here are the ones used in, e.g., "obey an order," "follow a suggestion," "keep a promise," "enjoy some privileges," and "uphold the law (which corresponded to a prohibition)." There are no special such verbs for declaratives; however, the verbs used for declaratives can themselves be used in the appropriate sense to indicate fulfillment, e.g., as in "He named the door the Golden Gate." These verbs correspond to the different kinds of speech acts, and denote their fulfillment. It is perhaps no accident that there are no verbs of fulfillment for assertives. The truth of assertives can be referred to in various ways, but there are no special conditions of fulfillment for them. This is because their conditions of satisfaction are themselves trivial, and they call for no further action or inaction. Assertives describe their own conditions of satisfaction; these conditions can also be referred to with predicates such as "is true." However, there is no explicit fulfillment of assertives, as I have defined the term here.

Work on the semantics of speech acts is usually taken to be about the performative verbs. By contrast, it is suggested here how the corresponding fulfillment verbs may be given a semantics. The idea is really quite simple. The semantic content of a fulfillment verb is the set of scenarios where the corresponding speech act is WSAT. Different fulfillment verbs correspond to different kinds of speech acts. For each, the appropriate definition may be invoked, and plugged into whatever kind of a natural language semantics one cares to employ.

In a way, the exercise of giving a semantics to different verbs of fulfillment is no different from the exercise of giving special semantics to verbs such as "believes," "knows," and "intends." Such verbs have been carefully considered for decades. I believe that verbs of fulfillment are on par with attitudinal verbs, at least insofar as they cannot be given a reasonable extensional semantics.

7 Normative Constraints for Felicitous Communication

The conditions of the satisfaction of speech acts can be used to motivate some normative constraints on communication among agents. The particular constraints stated below are given primarily as examples; some entail the others, and not all would make sense simultaneously. However, if some of these constraints or others like them are satisfied, the scenarios that are actualized are "good"—i.e., those where maxims akin to the Gricean maxims may be said to hold, and where communication is not only successful, but also cooperative and felicitous. In other words, these constraints restrict the possible models to those that have some properties of felicitous communication.

1. **Intending One's Directives:**

   The proposition of a directive should be intended by its issuer. If the speaker does not intend that something occur, he should not go about directing others to achieve it.

   $\mathrm{comm}(x, y, \langle \mathrm{directive}, p\rangle) \rightarrow \mathrm{intends}(x, p)$

2. **Weak Consistency for Directives:**

   A directive issued by an agent should not clash with the agent's own intentions; i.e., at least in some scenarios, the speaker's intentions and his directives should be compatible. This differs significantly from constraint 1, which says that the issuer intends the given directive; this constraint says that all of the issuer's intentions are consistent with the directive.

   $\text{intends}(x, q) \wedge \text{comm}(x, y, \langle \text{directive}, p \rangle) \rightarrow \mathsf{E}[\mathsf{WSAT}\text{comm}(x, y, \langle \text{directive}, p \rangle) \wedge \mathsf{F}q]$

3. **Consistency with Intentions:**

   All speech acts must be WSAT over all scenarios compatible with the speaker's current intentions.

   $\text{intends}(x, q) \wedge \text{comm}(x, y, m) \rightarrow \mathsf{A}[\mathsf{F}q \rightarrow \mathsf{WSAT}\text{comm}(x, y, m)]$

4. **No Loss of Know-how for Issuers of Directives:**

   A speech act made by an agent should not clash with his own intentions. Its satisfaction should not reduce his ability to achieve his intentions. That is, on all scenarios on which the given speech act is satisfied, the speaker should, in the future of making the speech act, know how to achieve the intentions he had at the time he issued it. In other words, speech acts should not backfire on their issuers.

   $\text{intends}(x, q) \wedge \text{comm}(x, y, m) \rightarrow$
   $\mathsf{A}[\mathsf{WSAT}\text{comm}(x, y, m) \rightarrow [\text{says-to}(x, y, m)]\mathsf{F}K_{how}(x, q)]$

5. **Weak Consistency for Prohibitives:**

   A prohibitive is issued by an agent only if the agent himself does not intend that it be violated. That is, the agent who prohibits another from letting a certain condition occur should not himself try to make it happen. This is a minimal level of cooperation or rationality one would expect from the issuers of prohibitions.

   $\text{comm}(x, y, \langle \text{prohibitive}, p \rangle) \rightarrow \neg\text{intends}(x, p)$

6. **Intending to Uphold the Law:**

   An agent must never intend to violate a prohibitive issued to him. That is, not only must the agent never violate a prohibitive in practice, he should not even intend its violation on any scenario.

   $\text{comm}(x, y, \langle \text{prohibitive}, p \rangle) \rightarrow \neg\mathsf{EF}[\text{intends}(x, \mathsf{WSAT}\text{comm}(x, y, \langle \text{prohibitive}, p \rangle))]$

7. **Mutual Consistency of Speech Acts:**

   All the speech acts performed by one speaker on any single scenario must be mutually consistent in the sense of being jointly satisfiable on at least some scenario in the future of the world and time at which they have both been uttered. This prevents many unacceptable situations. It also requires in practice that the agents be able to check the consistency of their speech acts, which can be a difficult task if their speech acts involve complex propositions.

$\mathsf{P}\mathrm{comm}(x, y, m_1) \wedge \mathrm{comm}(x, y, m_2) \rightarrow \mathsf{E}[\mathsf{WSAT}\mathrm{comm}(x, y, m_1) \wedge \mathsf{WSAT}\mathrm{comm}(x, y, m_2)]$

8 Comparisons

The taxonomy of speech acts of this paper is motivated by the semantic definitions given above, which are different for permissives, prohibitives, and directives. This distinguishes the taxonomy of this paper from other classifications of speech acts. Since syntactically, permissives, prohibitives, and directives are all imperatives, they are usually classified together, e.g., by Bach & Harnish [4, pp. 39–54] and Searle & Vanderveken [21, ch. 9]. This is surprising in the case of Searle & Vanderveken, since their focus is pragmatic, rather than syntactic.

I have argued at many places in this paper that traditional approaches to formalizing speech acts ignore the aspects of them focused on here. In this section, I compare this paper to some semantics of speech acts that others have proposed. One important work is that of Searle & Vanderveken [21]. However, they do not relate the satisfaction conditions of different sorts of speech acts with the intentions and know-how of the speaker or the hearer. Their greater aim seems to be to derive the possible illocutionary forces from a set of core features, e.g., what they call the illocutionary point and the direction of fit.

Searle & Vanderveken's approach has been challenged by Cohen & Levesque who argue that the illocutionary point is theoretically redundant and can be derived from the inferences that a speech act sanctions [7]. These inferences involve the updating of the beliefs, intentions, and mutual beliefs of the speaker and the hearer—for this reason, Cohen & Levesque's approach is largely of pragmatic interest. Perrault has argued that, despite Cohen & Levesque's attempts, how the participants' cognitive states ought to be updated cannot be monotonically specified [17]. He proposes that a default mechanism, in his paper Reiter's default logic, be used to characterize the effects of speech acts and, hence, their pragmatic content.

In more recent work, Vanderveken has independently addressed the problems of the "success and satisfaction" of speech acts [27, 28]. Vanderveken's goal is a general illocutionary logic, and a large part of his theory is focused on the conditions of when a performative succeeds, i.e., when a speech act of a particular illocutionary force is made. His goal is to give the semantics of performative verbs in an extension of Montague grammar. He also considers the degree of strength of different speech acts explicitly, and classifies a variety of speech act verbs, as special as the declaratives, "homologate" and "ratify," which differ primarily on their pragmatic aspects. The particular definitions given by Vanderveken are extensional in that no reference is made to the intentions or the know-how of the agents. For example, for him a directive is satisfied if the appropriate condition comes to hold, and a prohibitive, merely a special kind of directive for him, is satisfied if the appropriate condition does not occur. He lumps permissives and prohibitives with directives [27, pp. 189–198], which I have argued should not be done. Vanderveken also does not consider the temporal aspect of speech acts explicitly. In sum, while the results of the theory of this paper are more refined than the corresponding results of his theory, they could fruitfully be combined with the pragmatic and other aspects of speech acts that he has studied in much greater detail.

9 Conclusions

I have presented a formal semantics of speech acts that is not only quite intuitive, but also has many applications. A question may be raised about its relationship with the traditional work on speech acts, especially in AI. The relationship is essentially one of complementarity. As already mentioned, traditional theories have addressed the problem of determining when what kind of a speech act occurs. Those theories can thus be used to feed into the theory of this paper: One simply has to use those theories under appropriate assumptions to determine the truth of different instances of '$\text{comm}(x, y, m)$' and then apply the present theory to determine the satisfaction conditions of those instances.

This way of looking at things places the semantics presented here at the natural boundary of deciding what to say, on the one hand, and deciding how to say it, on the other. That is, on the one hand, we have the concerns of deciding what speech act to make, and on the other, the concerns of how to get a point across. This is a useful way to organize an AI system that is designed to also communicate with humans—the first aspect mentioned above is a part of Distributed AI, the second aspect a part of Computational Linguistics.

An important contribution of this paper is that it brings the satisfaction conditions for speech acts into the fold of logic. Using definitions of the intentions and know-how of an agent, I was able to systematically give rigorous and accurate definitions of the conditions of satisfaction for speech acts of different of illocutionary forces. The theory presented here can yield some well-motivated normative constraints on communication among agents. An advantage of the model-theoretic approach is that it allows our intuitions to be expressed directly and formally and thus can be used in clarifying and debugging them.

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