

FOUNDATION FOR INTELLIGENT PHYSICAL AGENTS

FIPA Communicative Act Library Specification

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17 **Foreword**

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19 industry of intelligent agents by openly developing specifications supporting interoperability among agents and agent-
20 based applications. This occurs through open collaboration among its member organizations, which are companies and
21 universities that are active in the field of agents. FIPA makes the results of its activities available to all interested parties
22 and intends to contribute its results to the appropriate formal standards bodies.

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27 participation in FIPA.

28 The FIPA specifications are developed through direct involvement of the FIPA membership. The status of a
29 specification can be either Preliminary, Experimental, Standard, Deprecated or Obsolete. More detail about the process
30 of specification may be found in the FIPA Procedures for Technical Work. A complete overview of the FIPA
31 specifications and their current status may be found in the FIPA List of Specifications. A list of terms and abbreviations
32 used in the FIPA specifications may be found in the FIPA Glossary.

33 FIPA is a non-profit association registered in Geneva, Switzerland. As of January 2000, the 56 members of FIPA
34 represented 17 countries worldwide. Further information about FIPA as an organization, membership information, FIPA
35 specifications and upcoming meetings may be found at <http://www.fipa.org/>.

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91 **1 Introduction**

92 This document contains specifications for structuring the FIPA Communicative Act Library (FIPA CAL) including: status
93 of a FIPA-compliant communicative act, maintenance of the library and inclusion criteria.

94
95 This document is primarily concerned with defining the structure of the FIPA CAL and the requirements for a proposed
96 communicative act to be included in the library. The elements of the library are listed in this document.

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98 This document also contains the formal basis of FIPA ACL semantics in the annex for the semantic characterization of
99 each FIPA communicative act.

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2 Overview

This document focuses on the organization, structure and status of the FIPA Communicative Act Library, FIPA CAL and discusses the main requirements that a communicative act must satisfy in order to be FIPA-compliant.

The objectives of standardizing and defining a library of FIPA compliant communicative acts are:

- To help ensure interoperability by providing a standard set of composite and macro communicative acts, derived from the FIPA primitive communicative acts,
- To facilitate the reuse of composite and macro communicative acts, and,
- To provide a well-defined process for maintaining a set of communicative acts and act labels for use in the FIPA ACL.

In the following, we present the basic principles of the FIPA CAL. These principles help to guarantee that the CAL is stable, that there are public rules for the inclusion and maintenance of the CAL and that developers seeking communicative acts for their applications can use the CAL.

2.1 Status of a FIPA-Compliant Communicative Act

The definition of a communicative act belonging to the FIPA CAL is normative. That is, if a given agent implements one of the acts in the FIPA CAL, then it must implement that act in accordance with the semantic definition in the FIPA CAL. However, FIPA-compliant agents are not required to implement any of the FIPA CAL languages, except the not-understood composite act.

By collecting communicative act definitions in a single, publicly accessible registry, the FIPA CAL facilitates the use of standardized Communicative Acts by agents developed in different contexts. It also provides a greater incentive to developers to make any privately developed communicative acts generally available.

The name assigned to a proposed communicative act must uniquely identify which communicative act is used within a FIPA ACL message. It must not conflict with any names currently in the library, and must be an English word or abbreviation that is suggestive of the semantics. The FIPA Agent Communication Technical Committee is the initial judge of the suitability of a name.

FIPA is responsible for maintaining a consistent list of approved and proposed communicative act names and for making this list publicly available to FIPA members and non-members. This list is derived from the FIPA Communicative Act Library.

In addition to the semantic characterization and descriptive information that is required, each Communicative Act in the FIPA CAL may specify additional information, such as stability information, versioning, contact information, different support levels, etc.

2.2 FIPA Communicative Act Library Maintenance

The most effective way of maintaining the FIPA Communicative Act Library is through the use of the communicative acts themselves by different agent developers. This is the most direct way of discovering possible bugs, errors, inconsistencies, weaknesses, possible improvements, as well as capabilities, strengths, efficiency etc. In order to collect feedback on the communicative acts in the library and to promote further research, FIPA encourages coordination between agent language designers, agent developers, and FIPA members.

FIPA will designate a Technical Committee to maintain the FIPA CAL. The FIPA CAL will be managed by this technical committee, which will be responsible for the following items:

- 152 • Collecting feedback and the comments about communicative acts in the FIPA CAL. Depending on interest, the
153 technical committee may organize more specific Working Groups. These groups would be responsible for
154 maintaining public lists referring to projects and people who are currently working on different communicative acts.
155
- 156 • Inviting contributions in various forms: e-mail comments, written reports, papers, technical documents, and so forth.
157 The current email address of the technical committee is specified on the first page of this document.
158
- 159 • All technical committee members will be notified about contributions, comments or proposed changes and should
160 be able to access them.
161
- 162 • The proposed updates to the FIPA CAL must be discussed and approved during an official FIPA meeting, in order
163 that the FIPA community may be involved with and informed of all of the FIPA approved communicative acts in the
164 library
165
- 166 • In the future, FIPA intends to supply templates (publicly accessible from the FIPA web site) in order to facilitate
167 submission of candidate communicative acts to the FIPA CAL, and to ensure that agent language developers
168 understand and can easily satisfy the requirements for the submission of a new communicative act to the FIPA
169 CAL.
170

171 **2.3 Inclusion Criteria**

172 In order to populate the FIPA CAL, it is necessary to set some fundamental guidelines for the selection of specific
173 communicative acts.

174
175 The minimal criteria that must be satisfied for a communicative act to be included in the FIPA CAL are:
176

- 177 • A summary of the candidate act's semantic force and content type are required.
178
- 179 • A detailed natural language description of the act and its consequences are required.
180
- 181 • A formal model, written in SL, of the act's semantics, its formal preconditions, and its rational effects is required.
182
- 183 • Examples of the usage of the new communicative act are required.
184
- 185 • Substantial and clear documentation must be provided. This means that the proposal must be already well
186 structured. FIPA members are in no way responsible for translating submitted communicative acts into an
187 acceptable form. See the form of the acts in the library for a sample.
188
- 189 • The utility of such a new communicative act should be made clear. In particular, it should be clear that the need it
190 solves is reasonably general, and that this need would be cumbersome to meet by combining existing
191 communicative acts.
192

193 FIPA does not enforce the use of any particular communicative act, except for the case of *not-understood*, and those
194 acts which are required to meet the agent management needs of the agent.
195

195 **3 FIPA Communicative Acts**196 **3.1 Accept Proposal**

Summary	The action of accepting a previously submitted proposal to perform an action.
Message Content	A tuple consisting of an action expression denoting the action to be done, and a proposition giving the conditions of the agreement.
Description	<p><i>Accept-proposal</i> is a general-purpose acceptance of a proposal that was previously submitted (typically through a <i>propose</i> act). The agent sending the acceptance informs the receiver that it intends that (at some point in the future) the receiving agent will perform the action, once the given precondition is, or becomes, true.</p> <p>The proposition given as part of the acceptance indicates the preconditions that the agent is attaching to the acceptance. A typical use of this is to finalize the details of a deal in some protocol. For example, a previous offer to "hold a meeting anytime on Tuesday" might be accepted with an additional condition that the time of the meeting is 11.00.</p> <p>Note for future extension: an agent may intend that an action become done without necessarily intending the precondition. For example, during negotiation about a given task, the negotiating parties may not unequivocally intend their opening bids: agent <i>a</i> may bid a price <i>p</i> as a precondition, but be prepared to accept price <i>p'</i>.</p>
Formal Model	$\langle i, \text{accept-proposal} (j, \langle j, \text{act} \rangle, \phi) \rangle \equiv$ $\langle i, \text{inform} (j, I_i \text{ Done} (\langle j, \text{act} \rangle, \phi)) \rangle$ $\text{FP: } B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ $\text{RE: } B_j \alpha$ <p>Where:</p> $\alpha = I_i \text{ Done} (\langle j, \text{act} \rangle, \phi)$
Example	<p>Agent <i>i</i> informs <i>j</i> that it accepts an offer from <i>j</i> to stream a given multimedia title to channel 19 when the customer is ready. Agent <i>i</i> will inform <i>j</i> of this fact when appropriate.</p> <pre>(accept-proposal :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :in-reply-to bid089 :content ((action (agent-identifier :name j) (stream-content movie1234 19)) (B (agent-identifier :name j) (ready customer78))) :language FIPA-SL)</pre>

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3.2 Agree

Summary	The action of agreeing to perform some action, possibly in the future.
Message Content	A tuple, consisting of an action expression denoting the action to be done, and a proposition giving the conditions of the agreement.
Description	<p><i>Agree</i> is a general-purpose agreement to a previously submitted <i>request</i> to perform some action. The agent sending the agreement informs the receiver that it does intend to perform the action, but not until the given precondition is true.</p> <p>The proposition given as part of the <i>agree</i> act indicates the qualifiers, if any, that the agent is attaching to the agreement. This might be used, for example, to inform the receiver when the agent will execute the action which it is agreeing to perform.</p> <p>Pragmatic note: The precondition on the action being agreed to can include the perlocutionary effect of some other CA, such as an <i>inform</i> act. When the recipient of the agreement (for example, a contract manager) wants the agreed action to be performed, it should then bring about the precondition by performing the necessary CA. This mechanism can be used to ensure that the contractor defers performing the action until the manager is ready for the action to be done.</p>
Formal Model	$\langle i, \text{agree}(j, \langle i, \text{act} \rangle, \phi) \rangle \equiv$ $\langle i, \text{inform}(j, I_i \text{ Done}(\langle i, \text{act} \rangle, \phi)) \rangle$ <p>FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = I_i \text{ Done}(\langle i, \text{act} \rangle, \phi)$ <p>Note that the formal difference between the semantics of <i>agree</i> and the semantics of <i>accept-proposal</i> rests on which agent is performing the action.</p>
Example	<p>Agent <i>i</i> (a job-shop scheduler) requests <i>j</i> (a robot) to deliver a box to a certain location. <i>J</i> answers that it agrees to the request but it has low priority.</p> <pre>(request :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (deliver box017 (loc 12 19)))) :protocol fipa-request :language FIPA-SL :reply-with order567) (agree :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((action (agent-identifier :name j) (deliver box017 (loc 12 19))) (priority order567 low)) :in-reply-to order567 :protocol fipa-request :language FIPA-SL)</pre>

3.3 Cancel

Summary	The action of one agent informing another agent that the first agent no longer has the intention that the second agent perform some action.
Message Content	An action expression denoting the action that is no longer intended.
Description	<i>Cancel</i> allows an agent <i>i</i> to inform another agent <i>j</i> that <i>i</i> no longer intends that <i>j</i> perform a previously requested action. This is not the same as <i>i</i> informing <i>j</i> that <i>i</i> intends that <i>j</i> not perform the action or stop performing an action. <i>Cancel</i> is simply used to let an agent know that another agent no longer has a particular intention. (In order for <i>i</i> to stop <i>j</i> from performing an action, <i>i</i> should <i>request</i> that <i>j</i> stop that action. Of course, nothing in the ACL semantics guarantees that <i>j</i> will actually stop performing the action; <i>j</i> is free to ignore <i>i</i> 's request.) Finally, note that the action that is the object of the act of cancellation should be believed by the sender to be ongoing or to be planned but not yet executed.
Formal Model	$\langle i, \text{cancel}(j, a) \rangle \equiv$ $\langle i, \text{disconfirm}(j, I_i \text{Done}(a)) \rangle$ $\text{FP: } \neg I_i \text{Done}(a) \wedge B_i (B_j I_i \text{Done}(a) \vee U_j I_i \text{Done}(a))$ $\text{RE: } B_j \neg I_i \text{Done}(a)$ <p><i>Cancel</i> applies to any form of <i>requested</i> action. Suppose an agent <i>i</i> has requested an agent <i>j</i> to perform some action <i>a</i>, possibly if some condition holds. This request has the effect of <i>i</i> informing <i>j</i> that <i>i</i> has an intention that <i>j</i> perform the action <i>a</i>. When <i>i</i> comes to drop its intention, it can inform <i>j</i> that it no longer has this intention with a <i>disconfirm</i>.</p>
Example	<p>Agent <i>j</i> asks <i>i</i> to cancel a previous <i>request-whenever</i> by quoting the action.</p> <pre>(cancel :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((action (agent-identifier :name j) (request-whenever :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content¹ ((action (agent-identifier :name i) (inform-ref :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content² \(((iota ?x (= (price widget) ?x))\)) (> (price widget) 50)) ...))) :langage FIPA-SL ...)</pre>

¹ The *request-whenever* message's `:content` parameter in the context of the *cancel* message is an embedded action expression. So, since this example uses SL as a content language, the content tuple of the *request-whenever* message must be converted into a Term of SL.

² The content of this *inform-ref* is further embedded in an embedded request-whenever message's content. So, because this example uses SL as a content language, the quote mark is itself escaped by `\`.

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3.4 Call for Proposal

Summary	The action of calling for proposals to perform a given action.
Message Content	A tuple containing an action expression denoting the action to be done, and a referential expression defining a single-parameter proposition which gives the preconditions on the action.
Description	<p><i>CFP</i> is a general-purpose action to initiate a negotiation process by making a call for proposals to perform the given action. The actual protocol under which the negotiation process is established is known either by prior agreement, or is explicitly stated in the <i>:protocol</i> parameter of the message.</p> <p>In normal usage, the agent responding to a <i>cfp</i> should answer with a proposition giving the value of the parameter in the original precondition expression (see the statement of <i>cfp</i>'s rational effect). For example, the <i>cfp</i> might seek proposals for a journey from Frankfurt to Munich, with a condition that the mode of travel is by train. A compatible proposal in reply would be for the 10.45 express train. An incompatible proposal would be to travel by airplane.</p> <p>Note that <i>cfp</i> can also be used to simply check the availability of an agent to perform some action. Also note that this formalization of <i>cfp</i> is restricted to the common case of proposals characterized by a single parameter (<i>x</i>) in the proposal expression. Other scenarios might involve multiple proposal parameters, demand curves, free-form responses, and so forth.</p>
Formal Model	$\langle i, \text{cfp} (j, \langle j, \text{act} \rangle, \text{Ref } x \phi(x)) \rangle \equiv$ $\langle i, \text{query-ref} (j, \text{Ref } x (I_i \text{ Done} (\langle j, \text{act} \rangle, \phi(x)) \Rightarrow$ $(I_j \text{ Done} (\langle j, \text{act} \rangle, \phi(x)))) \rangle$ $\text{FP: } \neg \text{Bref}_i(\text{Ref } x \alpha(x)) \wedge \neg \text{Uref}_i(\text{Ref } x \alpha(x)) \wedge$ $\neg \text{B}_i I_j \text{ Done} (\langle j, \text{inform-ref} (i, \text{Ref } x \alpha(x)) \rangle)$ $\text{RE: Done} (\langle j, \text{inform} (i, \text{Ref } x \alpha(x) = r_i) \rangle \mid \dots \mid$ $\langle j, \text{inform} (i, \text{Ref } x \alpha(x) = r_k) \rangle)$ <p>Where:</p> $\alpha(x) = I_i \text{ Done} (\langle j, \text{act} \rangle, \phi(x)) \Rightarrow I_j \text{ Done} (\langle j, \text{act} \rangle, \phi(x))$ <p>Agent <i>i</i> asks agent <i>j</i>: "What is the '<i>x</i>' such that you will perform action '<i>act</i>' when '$\phi(x)$' holds?"</p> <p>Note: <i>Ref x $\delta(x)$</i> is one of the referential expressions: $\iota x \delta(x)$, any $x \delta(x)$ or all $x \delta(x)$.</p> <p>Note: The RE of this is not a proposal by the recipient. Rather, it is the value of the proposal parameter. See the example in the definition of the <i>propose</i> act.</p>
Example	<p>Agent <i>j</i> asks <i>i</i> to submit its proposal to sell 50 boxes of plums.</p> <pre>(cfp :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((action (agent-identifier :name i) (sell plum 50)) (any ?x (and (= (price plum) ?x) (< ?x 10)))) :ontology fruit-market)</pre>

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3.5 Confirm

Summary	The sender informs the receiver that a given proposition is true, where the receiver is known to be uncertain about the proposition.
Message Content	A proposition.
Description	<p>The sending agent:</p> <ul style="list-style-type: none"> • believes that some proposition is true, • intends that the receiving agent also comes to believe that the proposition is true, and, • believes that the receiver is <i>uncertain</i> of the truth of the proposition. <p>The first two properties defined above are straightforward: the sending agent is sincere³, and has (somehow) generated the intention that the receiver should know the proposition (perhaps it has been asked). The last pre-condition determines when the agent should use <i>confirm</i> vs. <i>inform</i> vs. <i>disconfirm</i>: <i>confirm</i> is used precisely when the other agent is already known to be uncertain about the proposition (rather than <i>uncertain</i> about the negation of the proposition).</p> <p>From the receiver's viewpoint, receiving a <i>confirm</i> message entitles it to believe that:</p> <ul style="list-style-type: none"> • the sender believes the proposition that is the content of the message, and, • the sender wishes the receiver to believe that proposition also. <p>Whether or not the receiver does, indeed, change its mental attitude to one of belief in the proposition will be a function of the receiver's trust in the sincerity and reliability of the sender.</p>
Formal Model	$\langle i, \text{confirm}(j, \phi) \rangle$ FP: $B_i\phi \wedge B_iU_j\phi$ RE: $B_j\phi$
Examples	<p>Agent <i>i</i> confirms to agent <i>j</i> that it is, in fact, true that it is snowing today.</p> <pre>(confirm :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content "weather (today, snowing)" :language Prolog)</pre>

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³ Arguably there are situations where an agent might not want to be sincere, for example to protect confidential information. We consider these cases to be beyond the current scope of this specification.

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3.6 Disconfirm

Summary	The sender informs the receiver that a given proposition is false, where the receiver is known to believe, or believe it likely that, the proposition is true.
Message Content	A proposition.
Description	<p>The <i>disconfirm</i> act is used when the agent wishes to alter the known mental attitude of another agent.</p> <p>The sending agent:</p> <ul style="list-style-type: none"> • believes that some proposition is false, • intends that the receiving agent also comes to believe that the proposition is false, and, • believes that the receiver either believes the proposition, or is <i>uncertain</i> of the proposition. <p>The first two properties defined above are straightforward: the sending agent is sincere³, and has (somehow) generated the intention that the receiver should know the proposition (perhaps it has been asked). The last pre-condition determines when the agent should use <i>confirm</i> vs. <i>inform</i> vs. <i>disconfirm</i>: <i>disconfirm</i> is used precisely when the other agent is already known to believe the proposition or to be uncertain about it.</p> <p>From the receiver's viewpoint, receiving a <i>disconfirm</i> message entitles it to believe that:</p> <ul style="list-style-type: none"> • the sender believes that the proposition that is the content of the message is false, and, • the sender wishes the receiver to believe the negated proposition also. <p>Whether or not the receiver does, indeed, change its mental attitude to one of disbelief in the proposition will be a function of the receiver's trust in the sincerity and reliability of the sender.</p>
Formal Model	$\langle i, \text{disconfirm}(j, \phi) \rangle$ FP: $B_i \neg \phi \wedge B_i (U_j \phi \vee B_j \phi)$ RE: $B_j \neg \phi$
Example	<p>Agent <i>i</i>, believing that agent <i>j</i> thinks that a shark is a mammal, attempts to change <i>j</i>'s belief.</p> <pre>(disconfirm :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((mammal shark)) :language FIPA-SL)</pre>

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3.7 Failure

Summary	The action of telling another agent that an action was attempted but the attempt failed.
Message Content	A tuple, consisting of an action expression and a proposition giving the reason for the failure.
Description	<p>The <i>failure</i> act is an abbreviation for informing that an act was considered feasible by the sender, but was not completed for some given reason.</p> <p>The agent receiving a failure act is entitled to believe that:</p> <ul style="list-style-type: none"> • the action has not been done, and, • the action is (or, at the time the agent attempted to perform the action, was) feasible <p>The (causal) reason for the failure is represented by the proposition, which is the second element of the message content tuple. It may be the constant <i>true</i>. Often it is the case that there is little either agent can do to further the attempt to perform the action.</p>
Formal Model	$\langle i, \text{failure}(j, a, \phi) \rangle \equiv$ $\langle i, \text{inform}(j, (\exists e) \text{Single}(e) \wedge \text{Done}(e, \text{Feasible}(a) \wedge I_i \text{Done}(a)) \wedge \phi \wedge \neg \text{Done}(a) \wedge \neg I_i \text{Done}(a)) \rangle$ <p>FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = (\exists e) \text{Single}(e) \wedge \text{Done}(e, \text{Feasible}(a) \wedge I_i \text{Done}(a)) \wedge \phi \wedge \neg \text{Done}(a) \wedge \neg I_i \text{Done}(a)$ <p>Agent <i>i</i> informs agent <i>j</i> that, in the past, <i>i</i> had the intention to do action <i>a</i> and <i>a</i> was feasible. <i>i</i> performed the action of attempting to do <i>a</i> (that is, the action/event <i>e</i> is the attempt to do <i>a</i>), but now <i>a</i> has not been done and <i>i</i> no longer has the intention to do <i>a</i>, and ϕ is true.</p> <p>The informal implication is that ϕ is the reason that the action failed, though this causality is not expressed formally in the semantic model.</p>
Example	<p>Agent <i>j</i> informs <i>i</i> that it has failed to open a file.</p> <pre>(failure :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((action (agent-identifier :name j) (open "foo.txt")) (error-message "No such file: foo.txt")) :language FIPA-SL)</pre>

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3.8 Inform

Summary	The sender informs the receiver that a given proposition is true.
Message Content	A proposition.
Description	<p>The sending agent:</p> <ul style="list-style-type: none"> • holds that some proposition is true, • intends that the receiving agent also comes to believe that the proposition is true, and, • does not already believe that the receiver has any knowledge of the truth of the proposition. <p>The first two properties defined above are straightforward: the sending agent is sincere, and has (somehow) generated the intention that the receiver should know the proposition (perhaps it has been asked). The last property is concerned with the semantic soundness of the act. If an agent knows already that some state of the world holds (that the receiver knows proposition p), it cannot rationally adopt an intention to bring about that state of the world (<i>i.e.</i> that the receiver <i>comes to know</i> p as a result of the inform act). Note that the property is not as strong as it perhaps appears. The sender <i>is not</i> required to <i>establish</i> whether the receiver knows p. It is only the case that, in the case that the sender already happens to know about the state of the receiver's beliefs, it should not adopt an intention to tell the receiver something it already knows.</p> <p>From the receiver's viewpoint, receiving an inform message entitles it to believe that:</p> <ul style="list-style-type: none"> • the sender believes the proposition that is the content of the message, and, • the sender wishes the receiver to believe that proposition also. <p>Whether or not the receiver does, indeed, adopt belief in the proposition will be a function of the receiver's trust in the sincerity and reliability of the sender.</p>
Formal Model	$\langle i, \text{inform}(j, \phi) \rangle$ FP: $B_i\phi \wedge \neg B_i(Bif_j\phi \vee Uif_j\phi)$ RE: $B_j\phi$
Examples	<p>Agent i informs agent j that (it is true that) it is raining today.</p> <pre>(inform :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content "weather (today, raining)" :language Prolog)</pre>

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213 **3.9 Inform If**

Summary	A macro action for the agent of the action to inform the recipient whether or not a proposition is true.
Message Content	A proposition.
Description	<p>The <i>inform-if</i> macro act is an abbreviation for informing whether or not a given proposition is believed. The agent which enacts an <i>inform-if</i> macro-act will actually perform a standard <i>inform</i> act. The content of the inform act will depend on the informing agent's beliefs. To <i>inform-if</i> on some closed proposition ϕ:</p> <ul style="list-style-type: none"> • if the agent believes the proposition, it will inform the other agent that ϕ, and, • if it believes the negation of the proposition, it informs that ϕ is false, that is, $\neg\phi$. <p>Under other circumstances, it may not be possible for the agent to perform this plan. For example, if it has no knowledge of ϕ, or will not permit the other party to know (that it believes) ϕ, it will send a <i>refuse</i> message.</p>
Formal Model	$\langle i, \text{inform-if} (j, \phi) \rangle \equiv$ $\langle i, \text{inform} (j, \phi) \rangle \langle i, \text{inform} (j, \neg\phi) \rangle$ $\text{FP: } \text{Bif}_i \phi \wedge \neg \text{B}_i (\text{Bif}_j \phi \vee \text{Uif}_j \phi)$ $\text{RE: } \text{Bif}_j \phi$ <p><i>Inform-if</i> represents two possible courses of action: <i>i</i> informs <i>j</i> that ϕ, or <i>i</i> informs <i>j</i> that not ϕ.</p>
Examples	<p>Agent <i>i</i> requests <i>j</i> to inform it whether Lannion is in Normandy.</p> <pre>(request :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (inform-if :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content "in(lannion, normandy)" :language Prolog))) :language FIPA-SL)</pre> <p>Agent <i>j</i> replies that it is not:</p> <pre>(inform :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content "\+ in (lannion, normandy)" :language Prolog)</pre>

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3.10 Inform Ref

Summary	A macro action for sender to inform the receiver the object which corresponds to a descriptor, for example, a name.
Message Content	An object description (a referential expression).
Description	<p>The <i>inform-ref</i> macro action allows the sender to inform the receiver some object that the sender believes corresponds to a descriptor, such as a name or other identifying description.</p> <p><i>inform-ref</i> is a macro action, since it corresponds to a (possibly infinite) disjunction of <i>inform</i> acts, each of which informs the receiver that "the object corresponding to <i>name</i> is <i>x</i>" for some given <i>x</i>. For example, an agent can plan an <i>inform-ref</i> of the current time to agent <i>j</i>, and then perform the act "<i>inform j</i> that the time is 10.45".</p> <p>The agent performing the act should believe that the object or set of objects corresponding to the reference expression is the one supplied, and should not believe that the receiver of the act already knows which object or set of objects corresponds to the reference expression. The agent may elect to send a <i>refuse</i> message if it is unable to establish the preconditions of the act.</p>
Formal Model	$\langle i, \text{inform-ref} (j, \text{Ref } x \delta(x)) \rangle \equiv$ $\langle i, \text{inform} (j, \text{Ref } x \delta(x) = r_1) \rangle \mid \dots \mid$ $\langle i, \text{inform} (j, \text{Ref } x \delta(x) = r_k) \rangle$ <p>FP: $\text{Bref}_i \text{Ref } x \delta(x) \wedge \neg \text{B}_i (\text{Bref}_j \text{Ref } x \delta(x) \vee \text{Uref}_j \text{Ref } x \delta(x))$ RE: $\text{Bref}_j \text{Ref } x \delta(x)$</p> <p>Note: <i>Ref x δ(x)</i> is one of the referential expressions: $\iota x \delta(x)$, any $x \delta(x)$ or all $x \delta(x)$.</p> <p><i>Inform-ref</i> represents an unbounded, possibly infinite set of possible courses of action, in which <i>i</i> informs <i>j</i> of the referent of <i>x</i>.</p>
Example	<p>Agent <i>i</i> requests <i>j</i> to tell it the current Prime Minister of the United Kingdom:</p> <pre>(request :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (inform-ref :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content "((iota ?x (UKPrimeMinister ?x)))" :ontology world-politics :language FIPA-SL))) :reply-with query0 :language FIPA-SL)</pre> <p>Agent <i>j</i> replies:</p> <pre>(inform :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((= (iota ?x (UKPrimeMinister ?x)) "Tony Blair")) :ontology world-politics :in-reply-to query0)</pre> <p>Note that a standard abbreviation for the <i>request</i> of <i>inform-ref</i> used in this example is the act <i>query-ref</i>.</p>

3.11 Not Understood

Summary	The sender of the act (for example, <i>i</i>) informs the receiver (for example, <i>j</i>) that it perceived that <i>j</i> performed some action, but that <i>i</i> did not understand what <i>j</i> just did. A particular common case is that <i>i</i> tells <i>j</i> that <i>i</i> did not understand the message that <i>j</i> has just sent to <i>i</i> .
Message Content	A tuple consisting of an action or event, for example, a communicative act, and an explanatory reason.
Description	<p>The sender received a communicative act that it did not understand. There may be several reasons for this: the agent may not have been designed to process a certain act or class of acts, or it may have been expecting a different message. For example, it may have been strictly following a pre-defined protocol, in which the possible message sequences are predetermined. The <i>not-understood</i> message indicates to that the sender of the original, that is, misunderstood, action that nothing has been done as a result of the message. This act may also be used in the general case for <i>i</i> to inform <i>j</i> that it has not understood <i>j</i>'s action.</p> <p>The second element of the message content tuple is a proposition representing the reason for the failure to understand. There is no guarantee that the reason is represented in a way that the receiving agent will understand. However, a co-operative agent will attempt to explain the misunderstanding constructively.</p> <p>Note: It is not possible to fully capture the intended semantics of an action not being understood by another agent. The characterization below captures that an event happened and that the recipient of the not-understood message was the agent of that event.</p> <p>ϕ must be a well formed formula of the content language of the sender agent. If the sender uses the bare textual message, that is, 'String' in the syntax definition, as the reason ϕ, it must be a propositional assertive statement and (at least) the sender can understand that (natural language) message and calculate its truth value, that is, decide its assertion is true or false. So, for example, in the SL language, to use textual message for the convenience of humans, it must be encapsulated as the constant argument of a predicate defined in the ontology that the sender uses, for example:</p> <p>(error "message")</p>
Formal Model	$\langle i, \text{not-understood}(j, a, \phi) \rangle \equiv$ $\langle i, \text{inform}(j, \alpha) \rangle$ $\text{FP: } B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ $\text{RE: } B_j \alpha$ <p>Where:</p> $\alpha = \phi \wedge (\exists x) B_i ((\text{Done}(e) \wedge \text{Agent}(e, j) \wedge B_j(\text{Done}(e) \wedge \text{Agent}(e, j) \wedge (a = e))) = x)$

Examples	Agent <i>i</i> did not understand a <i>query-if</i> message because it did not recognize the ontology. <pre>(not-understood :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (query-if :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content "<fipa-ccl content expression>" :ontology www :language FIPA-CCL)) (unknown (ontology "www")))) :language FIPA-SL)</pre>
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3.12 Propagate

Summary	The sender intends that the receiver treat the embedded message as sent directly to the receiver, and wants the receiver to identify the agents denoted by the given descriptor and send the received <i>propagate</i> message to them.
Message Content	A tuple of a descriptor, that is, a referential expression, denoting an agent or agents to be forwarded the <i>propagate</i> message, an embedded ACL communicative act, that is, an ACL message, performed by the sender to the receiver of the <i>propagate</i> message and a constraint condition for propagation, for example, timeout.
Description	<p>This is a compound action of the following two actions. First, the sending agent requests the recipient to treat the embedded message in the received <i>propagate</i> message as if it is directly sent from the sender, that is, as if the sender performed the embedded communicative act directly to the receiver. Second, the sender wants the receiver to identify agents denoted by the given descriptor and to send a modified version of the received <i>propagate</i> message to them, as described below.</p> <p>On forwarding, the <code>:receiver</code> parameter of the forwarded <i>propagate</i> message is set to the denoted agent(s) and the <code>:sender</code> parameter is set to the receiver of the received <i>propagate</i> message. The sender and receiver of the embedded communicative act of the forwarded <i>propagate</i> message is also set to the same agent as the forwarded <i>propagate</i> message's sender and receiver, respectively.</p> <p>This communicative act is designed for delivering messages through federated agents by creating a chain (or tree) of <i>propagate</i> messages. An example of this is instantaneous brokerage requests using a <i>proxy</i> message, or persistent requests by a <i>request-when/request-when-ever</i> message embedding a <i>proxy</i> message.</p>
Formal Model	$\langle i, \text{propagate} (j, \text{Ref } x \delta(x), \langle i, \text{cact} \rangle, \phi) \rangle \equiv \langle i, \text{cact}(j) \rangle;$ $\langle i, \text{inform} (j, I_i((\exists y) (B_j (\text{Ref } x \delta(x) = y) \wedge \text{Done} (\langle j, \text{propagate} (y, \text{Ref } x \delta(x), \langle j, \text{cact} \rangle, \phi) \rangle, B_j \phi)))) \rangle$ $\text{FP: FP} (\text{cact}) \wedge B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ $\text{RE: Done} (\text{cact}) \wedge B_j \alpha$ <p>Where :</p> $\alpha = I_i((\exists y) (B_j (\text{Ref } x \delta(x) = y) \wedge \text{Done} (\langle j, \text{propagate} (y, \text{Ref } x \delta(x), \langle j, \text{cact} \rangle, \phi) \rangle, B_j \phi)))$ <p>Agent <i>i</i> performs the embedded <i>communicative act</i> to <i>j</i>: $\langle i, \text{cact}(j) \rangle$ and <i>i</i> wants <i>j</i> to send the <i>propagate</i> message to the denoted agent(s) by $\text{Ref } x \delta(x)$.</p> <p>Note that $\langle i, \text{cact} \rangle$ in the <i>propagate</i> message is the ACL communicative act without the <code>:receiver</code> parameter.</p> <p>Note: $\text{Ref } x \delta(x)$ is one of the referential expressions: $\iota x \delta(x)$, $\text{any } x \delta(x)$ or $\text{all } x \delta(x)$.</p>

<p>Example</p>	<p>Agent <i>i</i> requests agent <i>j</i> and its federating other brokerage agents to do brokering video-on-demand server agent to get "SF" programs.</p> <pre>(propagate :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((any ?x (registered (agent-description :name ?x :services (set (service-description :name agent-brokerage)))) (action (agent-identifier :name i) (proxy :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content "((all ?y (registered (agent-description :name ?y :services (set (service-description :name video-on-demand)))) (action (agent-identifier :name j) (request :sender (agent-identifier :name j) :content \"((action ?z⁴ (send-program (category \"SF\"))))\" :ontology vod-server-ontology :protocol fipa-request ...)) true)\" :ontology brokerage-agent-ontology :conversation-id vod-brokering-2 :protocol fipa-brokering ...)) (< (hop-count) 5)) :ontology brokerage-agent-ontology ...)</pre>
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⁴ We cannot specify the concrete actor name when agent *i* sends the *propagate* message because it is identified by the referential expression (all ?y ...). In the above example, a free variable ?z is used as the mandatory actor agent part of the action expression *send-program* in the content of embedded *request* message.

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3.13 Propose

Summary	The action of submitting a proposal to perform a certain action, given certain preconditions.
Message Content	A tuple containing an action description, representing the action that the sender is proposing to perform, and a proposition representing the preconditions on the performance of the action.
Description	<p><i>Propose</i> is a general-purpose action to make a proposal or respond to an existing proposal during a negotiation process by proposing to perform a given action subject to certain conditions being true. The actual protocol under which the negotiation process is being conducted is known either by prior agreement, or is explicitly stated in the <code>:protocol</code> parameter of the message.</p> <p>The proposer (the sender of the <i>propose</i>) informs the receiver that the proposer will adopt the intention to perform the action once the given precondition is met, and the receiver notifies the proposer of the receiver's intention that the proposer performs the action.</p> <p>A typical use of the condition attached to the proposal is to specify the price of a bid in an auctioning or negotiation protocol.</p>
Formal Model	$\langle i, \text{propose} (j, \langle i, \text{act} \rangle, \phi) \rangle \equiv$ $\langle i, \text{inform} (j, I_j \text{ Done} (\langle i, \text{act} \rangle, \phi) \Rightarrow I_i \text{ Done} (\langle i, \text{act} \rangle, \phi)) \rangle$ <p>FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = I_j \text{ Done} (\langle i, \text{act} \rangle, \phi) \Rightarrow I_i \text{ Done} (\langle i, \text{act} \rangle, \phi)$ <p>Agent <i>i</i> informs <i>j</i> that, once <i>j</i> informs <i>i</i> that <i>j</i> has adopted the intention for <i>i</i> to perform action <i>act</i>, and the preconditions for <i>i</i> performing <i>act</i> have been established, <i>i</i> will adopt the intention to perform <i>act</i>.</p>
Example	<p>Agent <i>j</i> proposes to <i>i</i> to sell 50 boxes of plums for \$5. This example continues the example of <i>cfp</i>.</p> <pre>(propose :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((action j (sell plum 50)) (= (any ?x (and (= (price plum) ?x) (< ?x 10))) 5) :ontology fruit-market :in-reply-to proposal2 :language FIPA-SL)</pre>

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3.14 Proxy

Summary	The sender wants the receiver to select target agents denoted by a given description and to send an embedded message to them.
Message Content	A tuple of a descriptor, that is, a referential expression, that denotes the target agents, an ACL communicative act, that is, an ACL message, to be performed to the agents, and a constraint condition for performing the embedded communicative act, for example, the maximum number of agents to be forwarded, etc.
Description	<p>The sending agent informs the recipient that the sender wants the receiver to identify agents that satisfy the given descriptor, and to perform the embedded communicative act to them, that is, the receiver sends the embedded message to them.</p> <p>On performing the embedded communicative act, the <code>:receiver</code> parameter is set to the denoted agent and the <code>:sender</code> is set to the receiver of the <i>proxy</i> message. If the embedded communicative act contains a <code>:reply-to</code> parameter (for example, in the <i>recruiting</i> case where the <code>:protocol</code> parameter is set to <i>fipa-recruiting</i>), it should be preserved in the performed message.</p> <p>In the case of a <i>brokering</i> request (that is, the <code>:protocol</code> parameter is set to <i>fipa-brokering</i>), the brokerage agent (the receiver of the <i>proxy</i> message) must record some parameters, for example, <code>:conversation-id</code>, <code>:reply-with</code>, <code>:sender</code>, etc.) of the received <i>proxy</i> message to forward back the reply message(s) from the target agents to the corresponding requester agent (the sender of the <i>proxy</i> message).</p>
Formal Model	$\langle i, \text{proxy}(j, \text{Ref } x \delta(x), \langle j, \text{cact} \rangle, \phi) \rangle \equiv$ $\langle i, \text{inform}(j, I_i((\exists y)(B_j(\text{Ref } x \delta(x) = y) \wedge \text{Done}(\langle j, \text{cact}(y) \rangle, B_j \phi))) \rangle$ <p style="margin-left: 40px;">FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$</p> <p style="margin-left: 40px;">RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = I_i((\exists y)(B_j(\text{Ref } x \delta(x) = y) \wedge \text{Done}(\langle j, \text{cact}(y) \rangle, B_j \phi)))$ <p>Agent i wants j to perform the embedded communicative act to the denoted agent(s) (y) by $\text{Ref } x \delta(x)$.</p> <p>Note that $\langle j, \text{cact} \rangle$ in the proxy message is the ACL communicative act without the <code>:receiver</code> parameter. Its receiver is denoted by the given $\text{Ref } x \delta(x)$ by the agent j.</p> <p>Note: $\text{Ref } x \delta(x)$ is one of the referential expressions: $\iota x \delta(x)$, $\text{any } x \delta(x)$ or $\text{all } x \delta(x)$.</p> <p>Two types of proxy can be distinguished. We will call the type of proxy defined above <i>strong</i>, because it is a feasibility precondition of j's communicative act to y that j satisfies the feasibility preconditions of the proxied communicative act. So, if i proxies an <i>inform</i> of the proposition ψ to y via j, j must believe ψ before it sends the proxied inform message to y.</p> <p>In addition, we could define <i>weak-proxy</i>, where we do not suppose that j is required to believe ψ. In this case, j cannot directly inform y of ψ, because j does not satisfy the feasibility preconditions of <i>inform</i>. In this case, j can only <i>inform</i> y that the original sender i has the intention that the <i>inform</i> of ψ should happen. More generally, <i>weak-proxy</i> can be expressed as an instance of proxy where the action $\langle j, \text{cact}(y) \rangle$ is replaced by $\langle j, \text{inform}(y, I_i \text{Done}(\langle i, \text{cact}(y) \rangle)) \rangle$.</p>

Example	<p>Agent <i>i</i> requests agent <i>j</i> to do recruiting and request a video-on-demand server to send "SF" programs.</p> <pre>(proxy :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((all ?x (registered(agent-description :name ?x :services (set (service-description :name video-on-demand)))))) (action (agent-identifier :name j) (request :sender (agent-identifier :name j) :content "((action ?y⁵ (send-program (category "SF"))))" :ontology vod-server-ontology :language FIPA-SL :protocol fipa-request :reply-to (set (agent-identifier :name i)) :conversation-id request-vod-1) true) :language FIPA-SL :ontology brokerage-agent :protocol fipa-recruiting :conversation-id vod-brokering-1 ...)</pre>
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⁵ We cannot specify the concrete actor name when agent *i* sends the *proxy* message because it is identified by the referential expression (all ?x ...). In the above example, a free variable ?x is used as the mandatory actor agent part of the action expression `send-program` in the content of embedded *request* message.

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3.15 Query If

Summary	The action of asking another agent whether or not a given proposition is true.
Message Content	A proposition.
Description	<p><i>Query-if</i> is the act of asking another agent whether (it believes that) a given proposition is true. The sending agent is requesting the receiver to <i>inform</i> it of the truth of the proposition.</p> <p>The agent performing the <i>query-if</i> act:</p> <ul style="list-style-type: none"> • has no knowledge of the truth value of the proposition, and, • believes that the other agent can inform the querying agent if it knows the truth of the proposition.
Formal Model	$\langle i, \text{query-if } (j, \phi) \rangle \equiv$ $\langle i, \text{request } (j, \langle j, \text{inform-if } (i, \phi) \rangle) \rangle$ FP: $\neg B_i \phi \wedge \neg U_i \phi \wedge \neg B_i I_j \text{Done}(\langle j, \text{inform-if } (i, \phi) \rangle)$ RE: $\text{Done}(\langle j, \text{inform}(i, \phi) \rangle \langle j, \text{inform}(i, \neg\phi) \rangle)$
Example	<p>Agent <i>i</i> asks agent <i>j</i> if <i>j</i> is registered with domain server d1:</p> <pre>(query-if :sender (agent-identifier :name i) :receiver (set (agent-identitfier :name j)) :content ((registered (server d1) (agent j))) :reply-with r09 ...)</pre> <p>Agent <i>j</i> replies that it is not:</p> <pre>(inform :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((not (registered (server d1) (agent j)))) :in-reply-to r09)</pre>

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3.16 Query Ref

Summary	The action of asking another agent for the object referred to by an referential expression.
Message Content	A descriptor (a referential expression).
Description	<p><i>Query-ref</i> is the act of asking another agent to inform the requester of the object identified by a descriptor. The sending agent is requesting the receiver to perform an <i>inform</i> act, containing the object that corresponds to the descriptor.</p> <p>The agent performing the <i>query-ref</i> act:</p> <ul style="list-style-type: none"> • does not know which object or set of objects corresponds to the descriptor, and, • believes that the other agent can inform the querying agent the object or set of objects that correspond to the descriptor.
Formal Model	$\langle i, \text{query-ref } (j, \text{Ref } x \delta(x)) \rangle \equiv$ $\langle i, \text{request } (j, \langle j, \text{inform-ref } (i, \text{Ref } x \delta(x)) \rangle) \rangle$ <p>FP: $\neg \text{Bref}_i(\text{Ref } x \delta(x)) \wedge \neg \text{Uref}_i(\text{Ref } x \delta(x)) \wedge$ $\neg \text{B}_i \text{I}_j \text{Done}(\langle j, \text{inform-ref } (i, \text{Ref } x \delta(x)) \rangle)$</p> <p>RE: $\text{Done}(\langle i, \text{inform } (j, \text{Ref } x \delta(x) = r_i) \rangle \dots$ $\langle i, \text{inform } (j, \text{Ref } x \delta(x) = r_k) \rangle)$</p> <p>Note: <i>Ref x δ(x)</i> is one of the referential expressions: $\iota x \delta(x)$, $\text{any } x \delta(x)$ or $\text{all } x \delta(x)$.</p>
Example	<p>Agent <i>i</i> asks agent <i>j</i> for its available services.</p> <pre>(query-ref :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((all ?x (available-service j ?x))) ...)</pre> <p>Agent <i>j</i> replies that it can reserve trains, planes and automobiles.</p> <pre>(inform :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((= (all ?x (available-service j ?x)) (set (reserve-ticket train) (reserve-ticket plane) (reserve automobile)))) ...)</pre>

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3.17 Refuse

Summary	The action of refusing to perform a given action, and explaining the reason for the refusal.
Message Content	A tuple, consisting of an action expression and a proposition giving the reason for the refusal.
Description	<p>The <i>refuse</i> act is an abbreviation for denying (strictly speaking, <i>disconfirming</i>) that an act is possible for the agent to perform, and stating the reason why that is so.</p> <p>The <i>refuse</i> act is performed when the agent cannot meet all of the preconditions for the action to be carried out, both implicit and explicit. For example, the agent may not know something it is being asked for, or another agent requested an action for which it has insufficient privilege.</p> <p>The agent receiving a <i>refuse</i> act is entitled to believe that:</p> <ul style="list-style-type: none"> • the action has not been done, • the action is not feasible (from the point of view of the sender of the refusal), and, • the (causal) reason for the refusal is represented by the a proposition which is the second element of the message content tuple, (which may be the constant true). There is no guarantee that the reason is represented in a way that the receiving agent will understand. However, a cooperative agent will attempt to explain the refusal constructively. See the description at <i>not-understood</i>.
Formal Model	$\langle i, \text{refuse}(j, \langle i, \text{act} \rangle, \phi) \rangle \equiv$ $\langle i, \text{disconfirm}(j, \text{Feasible}(\langle i, \text{act} \rangle)) \rangle;$ $\langle i, \text{inform}(j, \phi \wedge \neg \text{Done}(\langle i, \text{act} \rangle) \wedge \neg I_i \text{Done}(\langle i, \text{act} \rangle)) \rangle$ $\text{FP: } B_i \neg \text{Feasible}(\langle i, \text{act} \rangle) \wedge B_i (B_j \text{Feasible}(\langle i, \text{act} \rangle) \vee$ $U_j \text{Feasible}(\langle i, \text{act} \rangle)) \wedge B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ $\text{RE: } B_j \neg \text{Feasible}(\langle i, \text{act} \rangle) \wedge B_j \alpha$ <p>Where:</p> $\alpha = \phi \wedge \neg \text{Done}(\langle i, \text{act} \rangle) \wedge \neg I_i \text{Done}(\langle i, \text{act} \rangle)$ <p>Agent <i>i</i> informs <i>j</i> that action <i>act</i> is not feasible, and further that, because of proposition ϕ, <i>act</i> has not been done and <i>i</i> has no intention to do <i>act</i>.</p>
Example	<p>Agent <i>j</i> refuses to <i>i</i> reserve a ticket for <i>i</i>, since there are insufficient funds in <i>i</i>'s account.</p> <pre>(refuse :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content ((action (agent-identifier :name j) (reserve-ticket LHR MUC 27-sept-97)) (insufficient-funds ac12345)) :language FIPA-SL)</pre>

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3.18 Reject Proposal

Summary	The action of rejecting a proposal to perform some action during a negotiation.
Message Content	A tuple consisting of an action description and a proposition which formed the original proposal being rejected, and a further proposition which denotes the reason for the rejection.
Description	<p><i>Reject-proposal</i> is a general-purpose rejection to a previously submitted proposal. The agent sending the rejection informs the receiver that it has no intention that the recipient performs the given action under the given preconditions.</p> <p>The additional proposition represents a reason that the proposal was rejected. Since it is in general hard to relate cause to effect, the formal model below only notes that the reason proposition was believed true by the sender at the time of the rejection. Syntactically the reason should be treated as a causal explanation for the rejection, even though this is not established by the formal semantics.</p>
Formal Model	$\langle i, \text{reject-proposal} (j, \langle j, \text{act} \rangle, \phi, \psi) \rangle \equiv \langle i, \text{inform} (j, \neg I_i \text{ Done} (\langle j, \text{act} \rangle, \phi) \wedge \psi) \rangle$ <p>FP : $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ RE : $B_j \alpha$</p> <p>Where:</p> $\alpha = \neg I_i \text{ Done} (\langle j, \text{act} \rangle, \phi) \wedge \psi$ <p>Agent <i>i</i> informs <i>j</i> that, because of proposition ψ, <i>i</i> does not have the intention for <i>j</i> to perform action <i>act</i> with precondition ϕ.</p>
Example	<p>Agent <i>i</i> informs <i>j</i> that it rejects an offer from <i>j</i> to sell.</p> <pre>(reject-proposal :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (sell plum 50)) (cost 200) (price-too-high 50)) :in-reply-to proposal13)</pre>

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3.19 Request

Summary	The sender requests the receiver to perform some action. One important class of uses of the request act is to request the receiver to perform another communicative act.
Message Content	An action expression.
Description	The sender is requesting the receiver to perform some action. The content of the message is a description of the action to be performed, in some language the receiver understands. The action can be any action the receiver is capable of performing: pick up a box, book a plane flight, change a password, etc. An important use of the request act is to build composite conversations between agents, where the actions that are the object of the request act are themselves communicative acts such as <i>inform</i> .
Formal Model	$\langle i, \text{request}(j, a) \rangle$ FP: $\text{FP}(a) [i \setminus j] \wedge B_i \text{Agent}(j, a) \wedge \neg B_i I_j \text{Done}(a)$ RE: $\text{Done}(a)$ $\text{FP}(a) [i \setminus j]$ denotes the part of the FPs of a which are mental attitudes of i .
Examples	Agent i requests j to open a file. <pre>(request :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content "open \"db.txt\" for input" :language vb)</pre>

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3.20 Request When

Summary	The sender wants the receiver to perform some action when some given proposition becomes true.
Message Content	A tuple of an action description and a proposition.
Description	<p><i>Request-when</i> allows an agent to inform another agent that a certain action should be performed as soon as a given precondition, expressed as a proposition, becomes true.</p> <p>The agent receiving a <i>request-when</i> should either refuse to take on the commitment, or should arrange to ensure that the action will be performed when the condition becomes true. This commitment will persist until such time as it is discharged by the condition becoming true, the requesting agent <i>cancels</i> the <i>request-when</i>, or the agent decides that it can no longer honour the commitment, in which case it should send a <i>refuse</i> message to the originator.</p> <p>No specific commitment is implied by the specification as to how frequently the proposition is re-evaluated, nor what the lag will be between the proposition becoming true and the action being enacted. Agents that require such specific commitments should negotiate their own agreements prior to submitting the <i>request-when</i> act.</p>
Formal Model	$\langle i, \text{request-when} (j, \langle j, \text{act} \rangle, \phi) \rangle \equiv$ $\langle i, \text{inform} (j, (\exists e') \text{Done} (e') \wedge \text{Unique} (e') \wedge$ $I_i \text{Done} (\langle j, \text{act} \rangle, (\exists e) \text{Enables} (e, B_j \phi) \wedge$ $\text{Has-never-held-since} (e', B_j \phi)) \rangle$ <p>FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = (\exists e') \text{Done} (e') (\text{Unique} (e') \wedge$ $I_i \text{Done} (\langle j, \text{act} \rangle, (\exists e) \text{Enables} (e, B_j \phi) \wedge$ $\text{Has-never-held-since} (e', B_j \phi))$ <p>Agent <i>i</i> informs <i>j</i> that <i>i</i> intends for <i>j</i> to perform some <i>act</i> when <i>j</i> comes to believe ϕ.</p>
Examples	<p>Agent <i>i</i> tells agent <i>j</i> to notify it as soon as an alarm occurs.</p> <pre>(request-when :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (inform :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content "((alarm \"something alarming!\"))")) (Done(alarm))) ...)</pre>

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3.21 Request Whenever

Summary	The sender wants the receiver to perform some action as soon as some proposition becomes true and thereafter each time the proposition becomes true again.
Message Content	A tuple of an action description and a proposition.
Description	<p><i>Request-whenever</i> allows an agent to inform another agent that a certain action should be performed as soon as a given precondition, expressed as a proposition, becomes true, and that, furthermore, if the proposition should subsequently become false, the action will be repeated as soon as it once more becomes true.</p> <p><i>Request-whenever</i> represents a persistent commitment to re-evaluate the given proposition and take action when its value changes. The originating agent may subsequently remove this commitment by performing the <i>cancel</i> action.</p> <p>No specific commitment is implied by the specification as to how frequently the proposition is re-evaluated, nor what the lag will be between the proposition becoming true and the action being enacted. Agents who require such specific commitments should negotiate their own agreements prior to submitting the <i>request-when act</i>.</p>
Formal Model	$\langle i, \text{request-whenever } (j, \langle j, \text{act} \rangle, \phi) \rangle \equiv$ $\langle i, \text{inform } (j, I_i \text{ Done } (\langle j, \text{act} \rangle, (\exists e) \text{ Enables } (e, B_j \phi))) \rangle$ <p style="margin-left: 40px;">FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$</p> <p style="margin-left: 40px;">RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = I_i \text{ Done } (\langle j, \text{act} \rangle, (\exists e) \text{ Enables } (e, B_j \phi))$ <p>Agent <i>i</i> informs <i>j</i> that <i>i</i> intends that <i>j</i> will perform some <i>act</i> whenever some event causes <i>j</i> to believe ϕ.</p>
Examples	<p>Agent <i>i</i> tells agent <i>j</i> to notify it whenever the price of widgets rises from less than 50 to more than 50.</p> <pre>(request-whenever :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((action (agent-identifier :name j) (inform-ref :sender (agent-identifier :name j) :receiver (set (agent-identifier :name i)) :content "((iota ?x (= (price widget) ?x)))")) (> (price widget) 50)) ...)</pre>

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3.22 Subscribe

Summary	The act of requesting a persistent intention to notify the sender of the value of a reference, and to notify again whenever the object identified by the reference changes.
Message Content	A descriptor (a referential expression).
Description	<p>The <i>subscribe</i> act is a persistent version of <i>query-ref</i>, such that the agent receiving the <i>subscribe</i> will <i>inform</i> the sender of the value of the reference, and will continue to send further <i>informs</i> if the object denoted by the description changes.</p> <p>A subscription set up by a <i>subscribe</i> act is terminated by a <i>cancel</i> act.</p>
Formal Model	$\langle i, \text{subscribe} (j, \text{Ref } x \delta(x)) \rangle \equiv$ $\langle i, \text{request-whensoever} (j, \langle j, \text{inform-ref} (i, \text{Ref } x \delta(x)) \rangle, (\exists y) B_j ((\text{Ref } x \delta(x) = y))) \rangle$ <p>FP: $B_i \alpha \wedge \neg B_i (Bif_j \alpha \vee Uif_j \alpha)$ RE: $B_j \alpha$</p> <p>Where:</p> $\alpha = I_i \text{Done} (\langle j, \text{inform-ref} (i, \text{Ref } x \delta(x)) \rangle, (\exists e) \text{Enables} (e, (\exists y) B_j ((\text{Ref } x \delta(x) = y))))$ <p>Note: <i>Ref x δ(x)</i> is one of the referential expressions: $\iota x \delta(x)$, any $x \delta(x)$ or all $x \delta(x)$.</p>
Examples	<p>Agent <i>i</i> wishes to be updated on the exchange rate of Francs to Dollars, and makes a subscription agreement with <i>j</i> (an exchange rate server).</p> <pre>(subscribe :sender (agent-identifier :name i) :receiver (set (agent-identifier :name j)) :content ((iota ?x (= ?x (xch-rate FFR USD))))))</pre>

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5 Informative Annex A — Formal Basis of ACL Semantics

This section provides a formal definition of the communication language and its semantics. The intention here is to provide a clear, unambiguous reference point for the standardised meaning of the inter-agent communicative acts expressed through messages and protocols. This section of the specification is *normative*, in that agents which claim to conform to the FIPA specification ACL must behave in accordance with the definitions herein. However, this section may be treated as informative in the sense that no new information is introduced here that is not already expressed elsewhere in this document. The non mathematically-inclined reader may safely omit this section without sacrificing a full understanding of the specification.

Note also that *conformance testing*, that is, demonstrating in an unambiguous way that a given agent implementation is correct with respect to this formal model, is not a problem which has been solved in this FIPA specification. Conformance testing will be the subject of further work by FIPA.

5.1 Introduction to the Formal Model

This section presents, in an informal way, the model of communicative acts that underlies the semantics of the message language. This model is presented only in order to ground the stated meanings of communicative acts and protocols. It is **not a proposed architecture** or a structural model of the agent design.

Other than the special case of agents that operate singly and interact only with human users or other software interfaces, agents must communicate with each other to perform the tasks for which they are responsible. Consider the basic case shown in *Figure 1*.

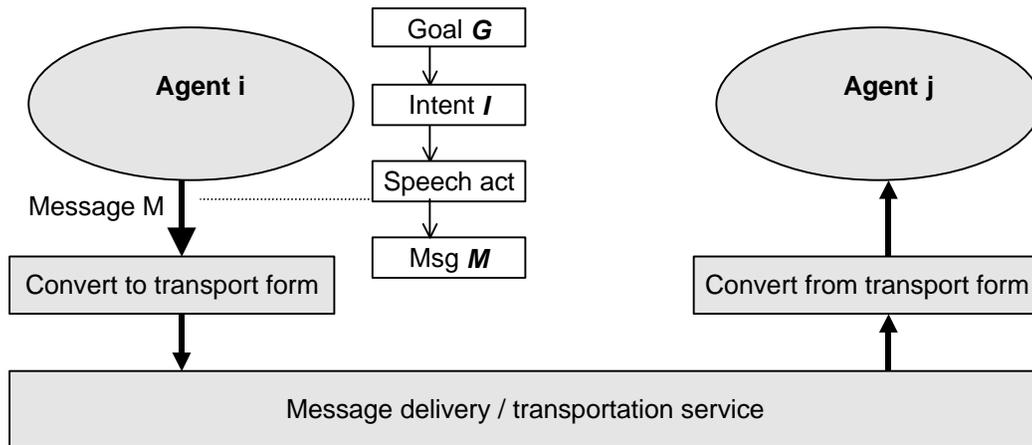


Figure 1: Message Passing Between Two Agents

Suppose that, in abstract terms, Agent i has amongst its *mental attitudes* the following: some goal or objective **G** and some intention **I**. Deciding to satisfy **G**, the agent adopts a specific intention, **I**. Note that neither of these statements entail a commitment on the design of Agent i: **G** and **I** could equivalently be encoded as explicit terms in the mental structures of a BDI agent, or implicitly in the call stack and programming assumptions of a simple Java or database agent.

Assuming that Agent i cannot carry out the intention by itself, the question then becomes which message or set of messages should be sent to another agent (**j** in *Figure 1*) to assist or cause intention **I** to be satisfied? If Agent i is behaving in some reasonable sense rationally, it will not send out a message whose effect will not satisfy the intention and hence achieve the goal. For example, if Harry wishes to have a barbecue (**G** = "have a barbecue"), and thus derives a goal to find out if the weather will be suitable (**G'** = "know if it is raining today"), and thus intends to find out the weather (**I** = "find out if it is raining"), he will be ill-advised to ask Sally "have you bought Acme stock today?" From Harry's perspective, whatever Sally says, it will not help him to determine whether it is raining today.

306

307 Continuing the example, if Harry, acting more rationally, asks Sally "can you tell me if it is raining today?", he has acted
 308 in a way he hopes will satisfy his intention and meet his goal (assuming that Harry thinks that Sally will know the
 309 answer). Harry can reason that the effect of asking Sally is that Sally would tell him, hence making the request fulfil his
 310 intention. Now, having asked the question, can Harry actually assume that, sooner or later, he will know whether it is
 311 raining? Harry *can* assume that Sally knows that he does not know, *and* that she knows that he is asking her to tell him.
 312 But, simply on the basis of having asked, Harry cannot assume that Sally will act to tell him the weather: she is
 313 independent, and may, for example, be busy elsewhere.

314

315 In summary: an agent plans, explicitly or implicitly (through the construction of its software) to meet its goals ultimately
 316 by communicating with other agents, that is, sending messages to them and receiving messages from them. The agent
 317 will select acts based on the relevance of the act's expected outcome or *rational effect* to its goals. However, it cannot
 318 assume that the rational effect will necessarily result from sending the messages.
 319

319

320 5.2 The Semantic Language

321 The Semantic Language (SL⁶) is the formal language used to define the semantics of the FIPA ACL. As such, SL itself
 322 has to be precisely defined. In this section, we present the SL language definition and the semantics of the primitive
 323 communicative acts.
 324

324

325 5.2.1 Basis of the Semantic Language Formalism

326 In SL, logical propositions are expressed in a logic of mental attitudes and actions, formalised in a first order modal
 327 language with identity⁷ (see [Sadek 91a] for details of this logic). The components of the formalism used in the following
 328 are as follows:
 329

329

- 330 • p, p_1, \dots are taken to be closed formulas denoting propositions,
- 331
- 332 • ϕ and ψ are formula schemas, which stand for any closed proposition,
- 333
- 334 • i and j are schematic variables which denote agents, and,
- 335
- 336 • $\models \phi$ means that ϕ is valid.

337

338 The mental model of an agent is based on the representation of three primitive attitudes: *belief*, *uncertainty* and *choice*
 339 (or, to some extent, *goal*). They are respectively formalised by the modal operators B , U , and C . Formulas using these
 340 operators can be read as:
 341

341

- 342 • B_p " i (implicitly) believes (that) p ",
- 343
- 344 • U_p " i is uncertain about p but thinks that p is more likely than $\neg p$ ", and,
- 345
- 346 • C_p " i desires that p currently holds".

347

348 The logical model for the operator B is a *KD45* possible-worlds-semantics Kripke structure (see, for example,
 349 [Halpern85]) with the fixed domain principle (see, for example, [Garson84]).
 350

350

351 To enable reasoning about action, the universe of discourse involves, in addition to individual objects and agents,
 352 sequences of events. A sequence may be formed with a single event. This event may be also the *void* event. The
 353 language involves terms (in particular a variable e) ranging over the set of event sequences.
 354

354

355 To talk about complex *plans*, events (or actions) can be combined to form *action expressions*:
 356

356

⁶ SL is also used for the content language of the FIPA ACL messages (see [FIPA00008]).

⁷ This logical framework is similar in many aspects to that of [Cohen90].

- 357 • $a_1 ; a_2$ is a *sequence* in which a_2 follows a_1
 358
 359 • $a_1 | a_2$ is a *nondeterministic choice*, in which either a_1 happens or a_2 , but not both.
 360

361 Action expressions will be noted as a .

362

363 The operators *Feasible*, *Done* and *Agent* are introduced to enable reasoning about actions, as follows:

364

- 365 • *Feasible* (a, p) means that a can take place and if it does p will be true just after that,
 366
 367 • *Done* (a, p) means that a has just taken place and p was true just before that,
 368
 369 • *Agent* (i, a) means that i denotes the only agent that ever performs (in the past, present or future) the actions which
 370 appear in action expression a ,
 371
 372 • *Single* (a) means that a denotes an action expression that is not a sequence. Any individual action is *Single*. The
 373 composite act $a ; b$ is not *Single*. The composite act $a | b$ is *Single* iff both a and b are *Single*.
 374

375

376 From belief, choice and events, the concept of *persistent goal* is defined. An agent i has p as a persistent goal, if i has p
 377 as a goal and is self-committed toward this goal until i comes to believe that the goal is achieved or to believe that it is
 378 unachievable. *Intention* is defined as a persistent goal imposing the agent to act. Formulas as $PG_i p$ and $I_i P$ are intended
 379 to mean that " i has p as a persistent goal" and " i has the intention to bring about p ", respectively. The definition of I
 380 entails that *intention generates a planning process*. See [Sadek92] for the details of a formal definition of intention.

381

382 Note that there is no restriction on the possibility of embedding mental attitude or action operators. For example,
 383 formula $U_i B_j I_j Done(a, Bp)$ informally means that agent i believes that, probably, agent j thinks that i has the intention
 384 that action a be done before which i has to believe p .

385

386 A fundamental property of the proposed logic is that the modelled agents are perfectly in agreement with their own
 387 mental attitudes. Formally, the following schema is valid:

388

$$\phi \Leftrightarrow B_i \phi$$

389

390 where ϕ is governed by a modal operator formalising a mental attitude of agent i .

391

392 5.2.2 Abbreviations

393

In the text below, the following abbreviations are used:

394

395 1. *Feasible* (a) \equiv *Feasible* ($a, True$)

396

397 2. *Done* (a) \equiv *Done* ($a, True$)

398

399 3. *Possible* (ϕ) \equiv ($\exists a$) *Feasible* (a, ϕ)

400

401 4. $Bif_i \phi \equiv B_i \phi \vee B_i \neg \phi$

402

$Bif_i \phi$ means that either agent i believes ϕ or that it believes $\neg \phi$.

403

404 5. $Bref_i \iota x \delta(x) \equiv (\exists y) B_i (\iota x \delta(x) = y)$

405

where ι is the operator for definite description and $\iota x \delta(x)$ is read "the (x which is) δ ". $Bref_i \iota x \delta(x)$ means that agent i
 406 believes that it knows the (x which is) δ .

407

408 6. $Uif_i \phi \equiv U_i \phi \vee U_i \neg \phi$

409

$Uif_i \phi$ means that either agent i is uncertain (in the sense defined above) about ϕ or that it is uncertain about $\neg \phi$.

410

411 7. $Uref_i \text{ } \text{ } \delta(x) \equiv (\exists y)U_i(\text{ } \text{ } \delta(x) = y)$
 412 $Uref_i \text{ } \text{ } \delta(x)$ has the same meaning as $Bref_i \text{ } \text{ } \delta(x)$, except that agent i has an uncertainty attitude with respect to $\delta(x)$
 413 instead of a belief attitude.

414
 415 8. $AB_{n,i,j} \phi \equiv B_i B_j B_i \dots \phi$
 416 introduces the concept of *alternate beliefs*, n is a positive integer representing the number of B operators alternating
 417 between i and j .

418
 419 In the text, the term "knowledge" is used as an abbreviation for "believes or is uncertain of".
 420

421 5.3 Underlying Semantic Model

422 The components of a communicative act (CA) model that are involved in a planning process characterise both the
 423 reasons for which the act is selected and the conditions that have to be satisfied for the act to be planned. For a given
 424 act, the former is referred to as the *rational effect* or RE^9 , and the latter as the *feasibility preconditions* or FPs , which are
 425 the qualifications of the act.
 426

427 5.3.1 Property 1

428 To give an agent the capability of planning an act whenever the agent intends to achieve its RE, the agent should
 429 adhere to the following property:

430
 431 Let a_k be an act such that:

- 432 1. $(\exists x) B_i a_k = x$
- 433 2. p is the RE of a_k and
- 434 3. $\neg C_i \neg \text{Possible}(\text{Done}(a_k))$;

435
 436
 437 then the following formula is valid:
 438

439
 440
 441 $I_i p \Rightarrow I_i \text{Done}(a_1 | \dots | a_n)$
 442

443 Where:

444
 445 a_1, \dots, a_n are *all* the acts of type a_k .
 446

447 This property says that an agent's intention to achieve a given goal generates an intention that one of the acts known to
 448 the agent be done. Further, the act is such that its rational effect corresponds to the agent's goal, and that the agent
 449 has no reason for not doing it.
 450

451 The set of feasibility preconditions for a CA can be split into two subsets: the *ability preconditions* and the *context-*
 452 *relevance preconditions*. The ability preconditions characterise the intrinsic ability of an agent to perform a given CA.
 453 For instance, to *sincerely assert* some proposition p , an agent has to believe that p . The context-relevance
 454 preconditions characterise the relevance of the act to the context in which it is performed. For instance, an agent can be
 455 intrinsically able to make a promise while believing that the promised action is not needed by the addressee. The
 456 context-relevance preconditions correspond to the Gricean quantity and relation maxims.
 457

⁹ Rational effect is also referred to as the *perlocutionary effect* in some of the work prior to this specification (see [Sadek90]).

458 5.3.2 Property 2

459 This property imposes on an agent an intention to seek the satisfiability of its FPs, whenever the agent elects to perform
460 an act by virtue of property 1⁹:

$$461 \models I_i \text{Done}(a) \Rightarrow B_j \text{Feasible}(a) \vee I_j B_j \text{Feasible}(a)$$

464 5.3.3 Property 3

465 If an agent has the intention that (the illocutionary component of) a communicative act be performed, it necessarily has
466 the intention to bring about the rational effect of the act. The following property formalises this idea:

$$467 \models I_i \text{Done}(a) \Rightarrow I_i \text{RE}(a)$$

469 Where:

471 $\text{RE}(a)$ denotes the rational effect of act a .

474 5.3.4 Property 4

475 Consider now the complementary aspect of CA planning: the consuming of CAs. When an agent observes a CA, it
476 should believe that the agent performing the act has the intention (to make public its intention) to achieve the rational
477 effect of the act. This is called the *intentional effect*. The following property captures this intuition:

$$478 \models B_i (\text{Done}(a) \wedge \text{Agent}(j, a) \Rightarrow I_j \text{RE}(a))$$

480 Note, for completeness only, that a strictly precise version of this property is as follows:

$$481 \models B_i (\text{Done}(a) \wedge \text{Agent}(j, a) \Rightarrow I_j B_j I_j \text{RE}(a))$$

485 5.3.5 Property 5

486 Some FPs persist after the corresponding act has been performed. For the particular case of CAs, the next property is
487 valid for all the FPs which do not refer to time. In such cases, when an agent observes a given CA, it is entitled to
488 believe that the persistent feasibility preconditions hold:

$$489 \models B_i (\text{Done}(a) \Rightarrow \text{FP}(a))$$

492 5.3.6 Notation

493 A communicative act model will be presented as follows:

494 $\langle i, \text{act}(j, C) \rangle$

495 FP: ϕ_1

496 RE: ϕ_2

497 where i is the agent of the act, j the recipient, act the name of the act, C stands for the semantic content or propositional
498 content¹⁰, and ϕ_1 and ϕ_2 are propositions. This notational form is used for brevity, only within this section on the formal
499 basis of ACL. The correspondence to the standard transport syntax (see [FIPA00070]) adopted above is illustrated by a
500 simple translation of the above example:

501 (act

⁹ See [Sadek91b] for a generalised version of this property.

¹⁰ See [Searle69] for the notions of *propositional content* (and *illocutionary force*) of an *illocutionary act*.

505 :sender *i*
 506 :receiver *j*
 507 :content
 508 *C*)
 509

510 Note that this also illustrates that some aspects of the operational use of the FIPA ACL fall outside the scope of this
 511 formal semantics but are still part of the specification. For example, the above example is actually incomplete without
 512 :language and :ontology parameters to given meaning to *C*, or some means of arranging for these to be known.
 513

514 **5.3.7 Note on the Use of Symbols in Formulae**

515 Note that variable symbols are used in the semantics description formulae of each communicative act as shown in
 516 *Table 1*.
 517

Symbol	Usage
<i>a</i>	Used to denote an action. Example: $a = \langle i, \text{inform}(j, p) \rangle$
<i>act</i>	Used to denote an action type. Example: $act = \text{inform}(j, p)$ Thus, if $a = \langle i, \text{inform}(j, p) \rangle$ and $act = \text{inform}(j, p)$ then $a = \langle i, act \rangle$.
<i>cact</i>	Used to denace only an ACL communicative act type.
ϕ	Used to denote any closed proposition (without any restriction).
<i>p</i>	Used to denote a given proposition. Thus ' ϕ ' is a formula schema, that is, a variable that denotes a formula, and ' <i>p</i> ' is a formula (not a variable).

518

Table 1: Meaning of Symbols in Formulae

519

520

521 Consider the following axiom examples:

522

523 $I_i \phi \Rightarrow \neg B_i \phi,$

524

525 Here, ϕ stands for any formula. It is a variable.

526

527 $B_i (\text{Feasible}(a) \Leftrightarrow p)$

528

529 Here, *p* stands for a given formula: the FP of act '*a*'.

530

531 **5.3.8 Supporting Definitions**

532 $\text{Enables}(e, \phi) = \text{Done}(e, \neg\phi) \wedge \phi$

533

534 $\text{Has-never-held-since}(e', \phi) = (\forall e_1) (\forall e_2) \text{Done}(e'; e_1; e_2) \Rightarrow \text{Done}(e_2, \neg\phi)$

535

536 **5.4 Primitive Communicative Acts**

537 **5.4.1 The Assertive Inform**

538 One of the most interesting assertives regarding the core of mental attitudes it encapsulates is the act of *informing*. An
 539 agent *i* is able to *inform* an agent *j* that some proposition *p* is true *only* if *i* believes *p* (that is, only if $B_i p$). This act is
 540 considered to be context-relevant only if *i* does not think that *j* already believes *p* or its negation, or that *j* is uncertain
 541 about *p* (recall that belief and uncertainty are mutually exclusive). If *i* is already aware that *j* does already believe *p*,
 542 there is no need for further action by *i*. If *i* believes that *j* believes *not p*, *i* should *disconfirm p*. If *j* is uncertain about *p*, *i*
 543 should *confirm p*.
 544

544

545 $\langle i, \text{INFORM}(j, \phi) \rangle$

545

546 FP: $B_i\phi \wedge \neg B_i(Bif_j\phi \vee Uif_j\phi)$
 547 RE: $B_j\phi$

548

549 The FPs for *inform* have been constructed to ensure mutual exclusiveness between CAs, when more than one CA might
 550 deliver the same rational effect.

551

552 Note, for completeness only, that the above version of the *inform* model is the operationalised version. The complete
 553 theoretical version (regarding the FPs) is the following:

554

555 $\langle i, \text{INFORM}(j, \phi) \rangle$
 556 FP: $B_i\phi \wedge \bigwedge_{n>1} \neg AB_{n,i,j} \neg B_i\phi \wedge \neg B_i B_j\phi \wedge \bigwedge_{n>2} \neg AB_{n,i,j} B_j\phi$
 557 RE: $B_j\phi$
 558

559 5.4.2 The Directive Request

560 The following model defines the directive *request*:

561

562 $\langle i, \text{REQUEST}(j, a) \rangle$
 563 FP: $FP(a) [i \setminus j] \wedge B_i \text{Agent}(j, a) \wedge B_i \neg PG_j \text{Done}(a)$
 564 RE: $\text{Done}(a)$
 565

566

566 Where:

567

- 568 • a is a schematic variable for which any action expression can be substituted,
- 569
- 570 • $FP(a)$ denotes the feasibility preconditions of a , and,
- 571
- 572 • $FP(a) [i \setminus j]$ denotes the part of the FPs of a which are mental attitudes of i .
- 573

574 5.4.3 Confirming an Uncertain Proposition: Confirm

575 The rational effect of the act *confirm* is identical to that of most of the assertives, *i.e.*, the addressee comes to believe
 576 the semantic content of the act. An agent i is able to *confirm* a property p to an agent j *only* if i believes p (that is, $B_i p$).
 577 This is the sincerity condition an assertive act imposes on the agent performing the act. The act *confirm* is context-
 578 relevant *only* if i believes that j is uncertain about p (that is, $B_i U_j p$). In addition, the analysis to determine the
 579 qualifications required for an agent to be entitled to perform an *Inform* act remains valid for the case of the act *confirm*.
 580 These qualifications are identical to those of an *inform* act for the part concerning the ability preconditions, but they are
 581 different for the part concerning the context relevance preconditions. Indeed, an act *confirm* is irrelevant if the agent
 582 performing it believes that the addressee is not uncertain of the proposition intended to be *confirmed*.

583

584 In view of this analysis, the following is the model for the act *confirm*:

585

586 $\langle i, \text{CONFIRM}(j, \phi) \rangle$
 587 FP: $B_i\phi \wedge B_i U_j\phi$
 588 RE: $B_j\phi$
 589

590 5.4.4 Contradicting Knowledge: Disconfirm

591 The *confirm* act has a negative counterpart: the *disconfirm* act. The characterisation of this act is similar to that of the
 592 *confirm* act and leads to the following model:

593

594 $\langle i, \text{DISCONFIRM}(j, \phi) \rangle$
 595 FP: $B_i \neg\phi \wedge B_i (U_j\phi \vee B_j\phi)$
 596 RE: $B_j \neg\phi$
 597

5.5 Composite Communicative Acts

An important distinction is made between acts that can be carried out directly, and those macro acts which can be planned (which includes requesting another agent to perform the act), but cannot be directly carried out. The distinction centres on whether it is possible to say that an act has been done, formally *Done (Action, p)*. An act which is composed of primitive communicative actions (inform, request, confirm), or which is composed from primitive messages by substitution or sequencing (via the ";" operator), can be performed directly and can be said afterwards to be done. For example, agent *i* can inform *j* that *p*; *Done (<i, inform(j, p)>)* is then true, and the meaning (that is, the rational effect) of this action can be precisely stated.

However, a large class of other useful acts is defined by composition using the disjunction operator (written "|"). By the meaning of the operator, only one of the disjunctive components of the act will be performed when the act is carried out. A good example of these macro-acts is the *inform-ref* act. *Inform-ref* is a macro act defined formally by:

$$\langle i, \text{INFORM-REF } (j, \text{I} \times \delta(x)) \rangle \equiv \langle i, \text{INFORM } (j, \text{I} \times \delta(x) = r_1) \rangle \mid \dots \mid \langle i, \text{INFORM } (j, \text{I} \times \delta(x) = r_n) \rangle$$

where *n* may be infinite. This act may be requested (for example, *j* may request *i* to perform it), or *i* may plan to perform the act in order to achieve the (rational) effect of *j* knowing the referent of $\delta(x)$. However, when the act is actually performed, what is sent, and what can be said to be *Done*, is an *inform* act.

Finally an inter-agent plan is a sequence of such communicative acts, using either composition operator, involving two or more agents. FIPA interaction protocols (see [FIPA00025]) are primary examples of pre-enumerated inter-agent plans.

5.5.1 The Closed Question Case

In terms of illocutionary acts, exactly what an agent *i* is *requesting* when uttering a sentence such as "Is *p*?" toward a recipient *j*, is that *j* performs the act of "*informing i that p*" or that *j* performs the act "*informing i that ¬p*". We know the model for both of these acts: $\langle j, \text{INFORM } (i, \phi) \rangle$. In addition, we know the relation "or" that holds between these two acts: it is the relation that allows for the building of action expressions which represent a *non-deterministic choice* between several (sequences of) events or actions.

In fact, as mentioned above, the semantic content of a directive refers to an *action expression*; so, this can be a *disjunction* between two or more acts. Hence, by using the utterance "Is *p*?", what an agent *i* *requests* an agent *j* to do is the following action expression:

$$\langle j, \text{INFORM } (i, p) \rangle \mid \langle j, \text{INFORM } (i, \neg p) \rangle$$

It seems clear that the semantic content of a directive realised by a yes/no-question can be viewed as an action expression characterising an indefinite choice between two CAs *inform*. In fact, it can also be shown that the binary character of this relation is only a special case: in general, any number of CAs *inform* can be handled. In this case, the addressee of a directive is allowed to choose one among several acts. This is not only a theoretical generalisation: it accounts for classical linguistic behaviour traditionally called *alternatives question*. An example of an utterance realising an alternative question is "Would you like to travel in first class, in business class, or in economy class?" In this case, the semantic content of the *request* realised by this utterance is the following action expression:

$$\langle j, \text{INFORM } (i, p_1) \rangle \mid \langle j, \text{INFORM } (i, p_2) \rangle \mid \langle j, \text{INFORM } (i, p_3) \rangle$$

Where p_1 , p_2 and p_3 are intended to mean respectively that *j* wants to travel in first class, in business class, or in economy class.

As it stands, the agent designer has to provide the plan-oriented model for this type of action expression. In fact, it would be interesting to have a model which is not specific to the action expressions characterising the non-deterministic choice between CAs of type *inform*, but a more general model where the actions referred to in the disjunctive relation remain unspecified. In other words, to describe the preconditions and effects of the expression $a_1 \mid a_2 \mid \dots \mid a_n$ where a_i ,

652 a_2, \dots, a_n are any action expressions. It is worth mentioning that the goal is to characterise this action expression as a
 653 *disjunctive macro-act* which is planned as such; we are not attempting to characterise the non-deterministic choice
 654 between acts which are planned separately. In both cases, the result is a branching plan but in the first case, the plan is
 655 branching in an *a priori* way while in the second case it is branching in an *a posteriori* way.

656

657 An agent will plan a macro-act of non-deterministic choice when it intends to achieve the rational effect of one of the
 658 acts composing the choice, *no matter which one it is*. To do that, one of the feasibility preconditions of the acts must be
 659 satisfied, *no matter which one it is*. This produces the following model for a disjunctive macro-act:

660

661 $a_1 \mid a_2 \mid \dots \mid a_n$
 662 FP: $FP(a_1) \vee FP(a_2) \vee \dots \vee FP(a_n)$
 663 RE: $RE(a_1) \vee RE(a_2) \vee \dots \vee RE(a_n)$

664

665 Where $FP(a_k)$ and $RE(a_k)$ represent the FPs and the RE of the action expression a_k respectively.

666

667 Because the yes/no-question, as shown, is a particular case of alternatives question, the above model can be
 668 specialised to the case of two acts *inform* having opposite semantic contents. Thus, we get the following model:

669

670 $\langle i, \text{INFORM}(j, \phi) \rangle \mid \langle i, \text{INFORM}(j, \neg\phi) \rangle$
 671 FP: $\text{Bif}_i\phi \wedge \neg\text{B}_i\text{Bif}_j\phi \vee \text{Uif}_j\phi$
 672 RE: $\text{Bif}_j\phi$

673

674 In the same way, we can derive the disjunctive macro-act model which gathers the acts *confirm* and *disconfirm*. We will
 675 use the abbreviation $\langle i, \text{CONFDISCONF}(j, \phi) \rangle$ to refer to the following model:

676

677 $\langle i, \text{CONFIRM}(j, \phi) \rangle \mid \langle i, \text{DISCONFIRM}(j, \phi) \rangle$
 678 FP: $\text{Bif}_i\phi \wedge \text{B}_i\text{U}_j\phi$
 679 RE: $\text{Bif}_j\phi$

680

681 5.5.2 The Query If Act

682 Starting from the act models $\langle j, \text{INFORM-IF}(i, \phi) \rangle$ and $\langle i, \text{REQUEST}(j, a) \rangle$, it is possible to derive the
 683 query-if act model (and not plan, as shown below). Unlike a confirm/disconfirm-question, which will be addressed
 684 below, a query-if act requires the agent performing it not to have any knowledge about the proposition whose truth
 685 value is asked for. To get this model, a transformation¹¹ has to be applied to the FPs of the act $\langle j, \text{INFORM-IF}(i,$
 686 $\phi) \rangle$ and leads to the following model for a *query-if* act:

687

688 $\langle i, \text{QUERY-IF}(j, \phi) \rangle \equiv$
 689 $\langle i, \text{REQUEST}(j, \langle j, \text{INFORM-IF}(i, \phi) \rangle) \rangle$
 690 FP: $\neg\text{Bif}_i\phi \wedge \neg\text{Uif}_i\phi \wedge \text{B}_i\neg\text{PG}_j\text{Done}(\langle j, \text{INFORM-IF}(i, \phi) \rangle)$
 691 RE: $\text{Done}(\langle j, \text{INFORM}(i, \phi) \rangle \mid \langle j, \text{INFORM}(i, \neg\phi) \rangle)$

692

693 5.5.3 The Confirm/Disconfirm Question Act

694 In the same way, it is possible to derive the following *confirm/disconfirm* question act model:

695

696 $\langle i, \text{REQUEST}(j, \langle j, \text{CONFDISCONF}(i, \phi) \rangle) \rangle$
 697 FP: $\text{U}_i\phi \wedge \text{B}_i\neg\text{PG}_j\text{Done}(\langle j, \text{CONFDISCONF}(i, \phi) \rangle)$
 698 RE: $\text{Done}(\langle j, \text{CONFIRM}(i, \phi) \rangle \mid \langle j, \text{DISCONFIRM}(i, \phi) \rangle)$

699

¹¹ For more details about this transformation, called the *double-mirror transformation*, see [Sadek91a] and [Sadek91b].

700 5.5.4 The Open Question Case

701 *Open question* is a question which does not suggest a choice and, in particular, which does not require a yes/no
 702 answer. A particular case of open questions are the questions which require referring expressions as an answer. They
 703 are generally called *wh-questions*. The "wh" refers to interrogative pronouns such as "what", "who", "where", or "when".
 704 Nevertheless, this must not be taken literally since the utterance "How did you travel?" can be considered as a wh-
 705 question.

706
 707 A formal plan-oriented model for the wh-questions is required. In the model below, *from the addressee's viewpoint*, this
 708 type of question can be viewed as a closed question where the suggested choice is not made explicit because it is *too*
 709 *wide*. Indeed, a question such as "What is your destination?" can be restated as "What is your destination: Paris,
 710 Rome,... ?".

711
 712 The problem is that, in general, the set of definite descriptions among which the addressee can (and must) choose is
 713 potentially an infinite set, not because, referring to the example above, there may be an infinite number of destinations,
 714 but because, theoretically, each destination can be referred to in potentially an infinite number of ways. For instance,
 715 Paris can be referred to as "the capital of France", "the city where the Eiffel Tower is located", "the capital of the country
 716 where the Man-Rights Chart was founded", *etc.* However, it must be noted that in the context of man-machine
 717 communication, the language used is finite and hence the number of descriptions acceptable as an answer to a *wh-*
 718 *question* is also finite.

719
 720 When asking a *wh-question*, an agent *j* intends to acquire from the addressee *i* an identifying referring expression (IRE)
 721 [Sadek90] for a definite description, in the general case. Therefore, agent *j* intends to make his interlocutor *i* perform a
 722 CA which is of the following form:

723 $\langle i, \text{INFORM} (j, \iota x \delta(x) = r) \rangle$

724
 725 Where *r* is an IRE, for example, a standard name or a definite description, and $\iota x \delta(x)$ is a definite description. Thus,
 726 the semantic content of the directive performed by a wh-question is a disjunctive macro-act composed with acts of the
 727 form of the act above. Here is the model of such a macro-act:

728
 729 $\langle i, \text{INFORM}(j, \iota x \delta(x) = r_1) \rangle \mid \dots \mid \langle i, \text{INFORM}(j, \iota x \delta(x) = r_k) \rangle$

730
 731 Where r_k are IREs. To deal with the case of closed questions, the generic plan-oriented model proposed for a
 732 disjunctive macro-act can be instantiated for the account of the macro-act above. Note that the following equivalence is
 733 valid:

734
 735 $(B_i \iota x \delta(x) = r_1 \vee B_i \iota x \delta(x) = r_2 \vee \dots) \Leftrightarrow (\exists y) B_i \iota x \delta(x) = y$

736
 737 This produces the following model, which is referred to as $\langle i, \text{INFORM-REF}(j, \iota x \delta(x)) \rangle$:

738
 739 $\langle i, \text{INFORM-REF}(j, \iota x \delta(x)) \rangle$
 740 FP: $Bref_i \iota x \delta(x) \wedge \neg B_i (Bref_j \iota x \delta(x) \vee Uref_j \iota x \delta(x))$
 741 RE: $Bref_j \iota x \delta(x)$

742
 743 Where $Bref_j \iota x \delta(x)$ and $Uref_j \iota x \delta(x)$ are abbreviations introduced above, and $\alpha ref_j \iota x \delta(x)$ is an abbreviation
 744 defined as:

745
 746 $\alpha ref_j \iota x \delta(x) \equiv Bref_j \iota x \delta(x) \vee Uref_j \iota x \delta(x)$

747
 748 Provided the act models $\langle j, \text{INFORM-REF}(i, \iota x \delta(x)) \rangle$ and $\langle i, \text{REQUEST}(j, a) \rangle$, the *wh-question* act
 749 model can be built up in the same way as for the yn-question act model. Applying the same transformation to the FPs of
 750 the act schema $\langle j, \text{INFORM-REF}(i, \iota x \delta(x)) \rangle$, and by virtue of property 3, the following model is derived:

751
 752 $\langle i, \text{QUERY-REF}(j, \phi) \rangle \equiv \langle i, \text{REQUEST}(j, \langle j, \text{INFORM-REF}(i, \iota x \delta(x)) \rangle) \rangle$
 753 FP: $\neg \alpha ref_i \iota x \delta(x) \wedge B_i \neg PG_j \text{Done}(\langle j, \text{INFORM-REF}(i, \iota x \delta(x)) \rangle)$

755 RE: Done ($\langle j, \text{INFORM}(i, \text{IxD}(x) = r_1) \rangle \mid \dots \mid \langle j, \text{INFORM}(i, \text{IxD}(x) = r_k) \rangle$)
 756

757 5.6 Inter-Agent Communication Plans

758 The properties of rational behaviour stated above in the definitions of the concepts of rational effect and of feasibility
 759 preconditions for CAs suggest an algorithm for CA planning. A plan is built up by this algorithm builds up through the
 760 inference of causal chain of intentions, resulting from the application of properties 1 and 2.

761 With this method, it can be shown that what are usually called "*dialogue acts*" and for which models are postulated, are,
 762 in fact, complex plans of interaction. These plans can be derived from primitive acts, by using the principles of rational
 763 behaviour. The following is an example of how such plans are derived.
 764

765 The interaction plan "hidden" behind a question act can be more or less complex depending on the agent mental state
 766 when the plan is generated.
 767

768 Let a *direct question* be a question underlain by a plan which is limited to the reaction strictly legitimised by the
 769 question. Suppose that the main content of *i*'s mental state is:
 770

771
 772 $B_i Bif_j \phi, I_i Bif_i \phi$
 773

774 By virtue of property 1, the intention is generated that the act $\langle j, \text{INFORM-IF}(i, \phi) \rangle$ be performed. Then,
 775 according to property 2, there follows the intention to bring about the feasibility of this act. Then, the problem is to know
 776 whether the following belief can be derived at that time from *i*'s mental state:
 777

778 $B_i(Bif_j \phi \wedge (\neg B_j Bif_i \phi \vee Uif_i \phi))$
 779

780 This is the case with *i*'s mental state. By virtue of properties 1 and 2, the intention that the act $\langle i, \text{REQUEST}(j, \langle j, \text{INFORM-IF}(i, \phi) \rangle) \rangle$
 781 be done and then the intention to achieve its feasibility, are inferred. The following belief is
 782 derivable:
 783

784 $B_i(\neg Bif_i \phi \wedge \neg Uif_i \phi)$
 785

786 Now, no intention can be inferred. This terminates the planning process. The performance of a direct strict-yn-question
 787 plan can be started by uttering a sentence such as "Has the flight from Paris arrived?", for example.
 788

789 Given the FPs and the RE of the plan above, the following model for a *direct strict-yn-question plan* can be established:
 790

791 $\langle i, \text{YNQUESTION}(j, \phi) \rangle$
 792 FP: $B_i Bif_j \phi \wedge \neg Bif_i \phi \wedge \neg Uif_i \phi \wedge B_i \neg B_j(Bif_i \phi \vee Uif_i \phi)$
 793 RE: $Bif_i \phi$