An operational model for the FIPA-ACL semantics

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Abstract. Despite the effort made to standardize agent communication languages, almost no tool has been developed to implement agents' conformance to their semantics. In this paper, we review the formal principles supporting the FIPA-ACL semantics and propose an operational model facilitating their implementation. This model is being implemented in the JADE platform, resulting in more flexible agents, avoiding intensive use of rigid protocols.

1 Introduction

Many research and industrial actors in the field of multi-agent systems have identified the need for a shared agent communication language (ACL) long ago. The most enthusiastic ones consider such a language as the counterpart of human natural languages for agents. In particular, ACLs should make it possible to convey meanings instead of "simple" objects with no semantics like in classical object middlewares [1]. At least, ACLs should let heterogeneous agents communicate and interact with each other [2]. This trend resulted in late nineties in mainly two initiatives to come to a standard language: KQML (Knowledge Query and Manipulation Language) from the ARPA knowledge sharing project [3] and FIPA-ACL from the Foundation for Physical Intelligent Agents consortium [4, 5]. Although the usefulness of such languages has been widely acknowledged, they have also often been criticized because of their formal semantics, which make them generally difficult to implement and hence seldom implemented. The underlying models indeed specify agents through their mental states (involving concepts such as beliefs and intentions) whereas agents are almost never programmed using these notions [6]. This matter of fact is not only pointed out at a theoretical level but also at a concrete development level [7]. As a resulting drawback, the massive use of rigid interaction protocols as "stopgaps" that avoid explicitly interpreting the ACL semantics often results in decreasing the flexibility and therefore the autonomy of agents.

Beyond the difficulty in handling mental states, one should also consider it is even more difficult from a developer perspective to master the theories of agency that support ACLs semantics, and therefore to consistently implement the formal meaning of communicative acts. Although the availability of proper tools could probably encompass these difficulties, little work, to our knowledge, has investigated this area. For example, in the FIPA community, most of the existing platforms that claim to be FIPA-compliant (among the most famous, JADE [8], FIPA-OS [9], Zeus [10]) implement the middleware-related specifications but provide no concrete support regarding the ACL semantics-related specifications.

In order to promote such tools, this paper proposes an operational model for implementing the theory of agency that underlies the FIPA-ACL semantics. This model, which is obviously missing today, aims at both helping developers to soundly conform to the FIPA-ACL semantics and leading to the development of proper tools to be integrated into FIPA-compliant platforms. Actually, this model provides a design framework that ensures consistency with the theory principles. Interestingly, it is flexible enough to customize agents' behaviors, while the built agents also benefit from generic capabilities for interpreting and generating communicative acts. This paper only focuses on the interpretation part.

The next section reviews some formal principles of the theory of agency underlying the FIPA-ACL semantics, which are relevant to the interpretation of communicative acts. Section 3 describes the main concepts and mechanisms of the model from which these principles can be implemented. Section 4 illustrates the resulting model with a simple example. Finally, section 5 concludes and discusses some perspectives.

2 Reviewing FIPA-ACL semantics

The FIPA Agent Communication Language is defined through a set of communicative acts [5]. Their precise meaning results from their interpretation as particular actions within a more general theory of agency, namely the theory of rational interaction proposed by Sadek [11]. Thus, the semantics of FIPA communicative acts is formally defined by the generic principles of Sadek's theory that apply to actions. Although the FIPA specifications list most of these principles [5, Informative Annex A], some significant ones are unfortunately missing. This section reviews the essential principles formalizing the interpretation of FIPA-ACL communicative acts and identifies a general template in the perspective of implementing them.

All formal properties described in this paper are written in FIPA-SL [12], which is the modal logic language that sustains the theory of agency defining the FIPA-ACL semantics.

2.1 Mental attitudes and actions

First of all, the underlying theory formally specifies agents' behaviors through mental state notions describing internal agents' features that must be interpreted subjectively, i.e. from their point of view. Mental states are classically described using beliefs and intentions (according to the widely acknowledged Belief-Desire-Intention paradigm [13]). Beliefs are formalized by two logical modal operators: $(\mathtt{B}\ \underline{\mathtt{i}}\ \underline{\mathtt{p}})$[1]

[1] In this paper, the underlined terms in logical formulas denote schematic variables. Here, $\underline{\mathtt{i}}$ and $\underline{\mathtt{p}}$ may be respectively replaced with references to agents and formulas.

expresses that agent `i` believes that `p` holds and `(U i p)` expresses that agent `i` is uncertain about `p`, that is, s/he does not believe that `p` holds but s/he believes that `p` is more probably true than `(not p)`. The `B` operator satisfies a KD45 model and is semantically defined by a Kripke possible world structure, whereas the semantics of the `U` operator is defined in probabilistic terms upon the accessible possible worlds supporting the `B` operator.[2] Intentions are mainly formalized by one logical operator, `(I i p)`, which expresses that agent `i` intends that `p` holds. Sadek's theory actually provides several degrees of intention (similar, to some extent, to Cohen and Levesque's approach [15]), including choice, achievement goal (agent `i` does not believe that `p` holds), persistent goal (agent `i` will drop her/his goal `p` until it is satisfied or s/he comes to believe it is unachievable) and intention itself (agent `i` commits to perform, individually or collectively with other cooperative agents, any action s/he believes that can reach the goal `p`), each one being defined upon a more primitive choice concept [16]. Within the scope of the FIPA specifications, the intention operator is considered to be primitive.

A property of agents' mental attitudes, which is worth mentioning, is that they must be consistent with their beliefs: agents always believe the mental attitudes they actually have. Formally, the following property is valid within the theory, for both primitive (expressed with the previous operators of belief, uncertainty and intention) and composite mental attitudes (expressed by combining these operators with logical connectors):

`(equiv (B i PHI(i)) PHI(i))`
where `i` denotes an agent and `PHI(i)` a mental attitude of `i` **(1)**

Consequently, agents' internal states (including all their mental attitudes) can be exclusively described by their beliefs. An important corollary is that agents cannot be uncertain (with the meaning of the `U` operator) of any of their mental attitudes (since they fully believe it). The following property is valid within the theory:

`(not (U i PHI(i)))` **(2)**
where `i` denotes an agent and `PHI(i)` a mental attitude of `i`

In order to describe temporal facts, the theory supports two other modalities: `(done a p)` expresses that action `a` has just occurred and that `p` held just before its occurrence (past-oriented), and `(feasible a p)` expresses that action `a` may possibly occur and that `p` will hold just after its occurrence, if it actually occurs (future-oriented). Both these operators are possible normal modal operators that satisfy a K model and are semantically defined by a Kripke possible world structure. Their accessibility relations classically define a branching future (several different actions may occur in a given possible world) and a linear past (exactly one action has just occurred in a given possible world).

The resulting framework is a homogeneous multimodal logic powerful enough to account for very subtle nuances. For example, `(exists ?X (B i (feasible ?X p)))` expresses that agent `i` knows an action `?X` (which is not explicit) that may

[2] Sadek originally proposed a set of logical properties satisfied by the `U` operator. More recent work investigates an axiomatic system for this operator, but without proving its completeness with respect to the semantic model [14].

bring about `p` (e.g. “Mary knows a recipe to cook a cake”), whereas `(B i (exists ?X (feasible ?X p)))` expresses that agent `i` believes that there are some ways of reaching `p`, without necessarily knowing how to reach it (e.g. “Mary knows cakes can be cooked”).

2.2 Formally interpreting incoming communicative acts

FIPA-ACL defines four primitive (Inform, Confirm, Disconfirm and Request) and eighteen composite communicative acts [5]. Each of them (primitive or composite) is defined by two semantic features, namely its feasibility precondition and its rational effect. We now review the formal principles embedded in the theory of agency that specify how agents should interpret received communicative acts based on their semantic features.

Feasibility precondition

The feasibility precondition of a communicative act states the condition that must necessarily hold for this act to be sent. This classical notion of action precondition is formalized by the following axiom within the theory[3]. It means that any agent observing a communicative act performance (left part of the implication) necessarily believes that its feasibility precondition held just before its performance (right part, in the scope of the `done` operator):

```
(B i (implies (done a true)  (done a FP(a))))
```

where `a`, `FP(a)` and `i` respectively denote a communicative act, its feasibility precondition and an agent (**3**)

This principle is particularly useful to check the consistency of incoming communicative acts. For example, agents should reject received Inform acts about one of their own mental attitudes (e.g. when they are told “you intend to jump out the window”) because applying property (**2**) to the corresponding propositional content makes the feasibility precondition inconsistent. Actually, the informative annex of [5] mentions no property that formally deals with feasibility precondition interpretation, so that a specification of inconsistent communicative acts is clearly missing.

Rational effect

The rational effect of a communicative act states what the result expected by agents performing this act is. It underlies a unique classical actual postcondition of the communicative act, namely its “intentional effect”, which is formalized by the following axiom within the theory. It means that agents observing an act performance (left part of the implication) believe that the sender intends each receiver believes the sender intends the rational effect of this act (right part):

```
(B i (implies (done a true)
              (I j (B k (I j RE(a))))
```

(**4**)

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[3] This axiom, which was actually proposed by Louis [14], generalizes Sadek’s original formalization: `(B i (implies (feasible a true) FP(a)))`.

))

where $\underline{a}$, $\underline{RE}(\underline{a})$, $\underline{i}$, $\underline{j}$ and $\underline{k}$ respectively denote a communicative act, its rational effect, an agent, the author of $\underline{a}$ and a receiver of $\underline{a}$

Actually, [5, Property 4] only considers the following weaker principle:

```
(B i (implies (done a true)
              (I j RE(a))))))
```

where $\underline{a}$, $\underline{RE}(\underline{a})$, $\underline{i}$ and $\underline{j}$ respectively denote a communicative act, its rational effect, any agent and the author of $\underline{a}$ (**5**)

The consequent is simplified, assuming that most agents receiving a message (whether they be cooperative or not with the sender) adopt the primary intention expressed by the intentional effect, that is, believe the sender intends the rational effect. Anyway, the important feature of both of these expressions is the surrounding B operator, which makes the intentional effect relative to each observing agent. It means the intentional effect is not an absolute effect, but rather a subjective one that has to be interpreted individually (and possibly differently) by each agent. Thus, it is up to the receiver of a communicative act to satisfy the author's intention (recognized through the principles (**4**) or (**5**)), depending on her/his specified behavior.

Cooperation principles

Since interpreting the intentional effect of a received message should be specific to each agent (resulting in customized behaviors), the informative annex of [5] gives no recommendation about this process. However, the underlying theory provides some formal principles that should be made explicit. For instance, we accommodate two principles of Sadek's theory that guide the agents' behaviors in the perspective of implementing FIPA agents.

The belief transfer principle states the condition under which an agent comes to believe what another agent intends s/he believes. It is formally expressed by the following axiom schema:

$$\texttt{(implies (and (B } \underline{i} \texttt{ (I } \underline{j} \texttt{ (B } \underline{i} \ \underline{p}\texttt{))) (B } \underline{i} \ \underline{\texttt{COND}_B\texttt{(j,p)}}\texttt{))} \quad \texttt{(B } \underline{i} \ \underline{p}\texttt{))} \tag{6}$$

where $\underline{i}$, $\underline{j}$ and $\underline{p}$ respectively denote two agents and a formula

Sadek's original principle only applies to facts $\underline{p}$ denoting a mental attitude of agent $\underline{j}$. We have extended it to any kind of facts by adding a condition $\underline{\texttt{COND}_B\texttt{(j,p)}}$ that has to be customized depending on the expected behavior of agent $\underline{i}$. Note that this condition appears under the scope of an $\underline{i}$'s belief operator, so that it can be differently specified (i.e. customized) for each agent. For example, if agent i_0 does not trust agent i_1 at all, the i_0-related condition can simply be specified to be false for $\underline{j}=i_1$ and any $\underline{p}$.

Similarly, the intention transfer principle states the condition under which agents adopt intentions of other agents. In other words, it sets the extent to which agents are cooperative with other agents. It can be formally expressed by an axiom schema of the following form:

$$\texttt{(implies (and (B } \underline{\texttt{i}} \texttt{ (I } \underline{\texttt{j}} \ \underline{\texttt{p}}\texttt{)) (B } \underline{\texttt{i}} \ \underline{\texttt{COND}_\texttt{I}\texttt{(j,p)}}\texttt{))} \quad \texttt{(I } \underline{\texttt{i}} \ \underline{\texttt{p}}\texttt{))} \tag{7}$$

where $\underline{\texttt{i}}$, $\underline{\texttt{j}}$ and $\underline{\texttt{p}}$ respectively denote two agents and a formula that is not a mental attitude of $\underline{\texttt{i}}$

Here, the agents' cooperative inclination can be customized by specifying the condition $\underline{\texttt{COND}_\texttt{I}\texttt{(j,p)}}$ (which, as above, is specific to each agent $\underline{\texttt{i}}$). Note that the schematic variable $\underline{\texttt{p}}$ is constrained not to denote a mental attitude of $\underline{\texttt{i}}$, so that the application of (**6**) and (**7**) is mutually exclusive. Actually, we only provide an example of what could be an intention transfer principle in the perspective of implementing FIPA agents and we do not claim giving a complete set of axioms in the scope of this paper. For further interest, [11] and [17] propose extended cooperation principles that could easily be adapted to this framework in order to get more specific agents' behaviors.

Identifying a general template for formal principles

As `(B` $\underline{\texttt{i}}$ `(implies` $\underline{\texttt{p}}$ $\underline{\texttt{q}}$`))` logically entails `(implies (B` $\underline{\texttt{i}}$ $\underline{\texttt{p}}$`) (B` $\underline{\texttt{i}}$ $\underline{\texttt{q}}$`))` within the modal logic supporting the theory of agency, the following template can be easily identified as matching the reviewed principles that formally characterize the semantic interpretation of communicative acts:

$$\texttt{(implies (and } \underline{\texttt{A}} \ \underline{\texttt{COND}}\texttt{) } \underline{\texttt{C}}\texttt{)} \tag{8}$$

$\underline{\texttt{A}}$ denotes the antecedent to recognize for applying the corresponding principle, $\underline{\texttt{COND}}$ denotes a condition that must be checked before applying it and $\underline{\texttt{C}}$ denotes the consequent resulting from its application. For example, instantiating $\underline{\texttt{A}}$ with `(B` $\underline{\texttt{i}}$ `(done` $\underline{\texttt{a}}$ `true))`, $\underline{\texttt{COND}}$ with `true` (i.e. no additional condition to check) and $\underline{\texttt{C}}$ with `(B` $\underline{\texttt{i}}$ `(done` $\underline{\texttt{a}}$ `FP(`$\underline{\texttt{a}}$`)))` soundly represents the feasibility precondition principle (**3**).

Casting all formal principles of the theory into this template provides a sound but not necessarily complete set of axioms with respect to this theory. In the perspective of implementing agents, the soundness ensures the consistency of their behaviors; the completeness loss is not a problem provided the inferences that are relevant to their behaviors are preserved. Anyway, as the underlying theory of agency is intrinsically not decidable, a trade-off must be found in order to implement it.

The next section develops an operational model for implementing a set of such templates and therefore a significant part of the FIPA-ACL semantics.

3 Operationalizing the FIPA-ACL semantics

As previously argued, implementing agents that comply with and thus take full advantage of the FIPA-ACL semantics requires a suitable mechanism. This section describes the main constituents of a FIPA-ACL operational model that can lead to the implementation of such a mechanism. These elements can be refined into two main categories: the first one includes classical constituents BDI-style agents must hold, whereas the second one introduces new specific elements in order to reify the general template identified in the previous section for the formal principles defining the FIPA-ACL semantics. As a prerequisite, we first expose three major constraints a FIPA-ACL implementation has to deal with.

Firstly, agents conforming to FIPA-ACL are supposed to receive and send communicative acts according to their mental states (i.e., their beliefs). As a direct consequence, the aimed mechanism should make it possible to program agents through these mental states. For example, in order to inform another agent about the value of a property, an agent is required to have this value among her/his beliefs, as well as the fact that the receiver does not already believe this value.

Secondly, the aimed mechanism should efficiently handle FIPA-SL expressions, since the semantics of FIPA-ACL is defined using the terms of this language. For example, the feasibility precondition and the rational effect of communicative acts are specified by SL formulas.

Lastly, parts of agents' behaviors, such as their cooperation abilities, are not imposed by the FIPA-ACL semantics and should be customizable. Thus, that the aimed mechanism should provide flexibility hooks. For example, extending these hooks should make it possible to setup which requested actions an agent should perform.

3.1 Classical agent constituents

Two basic concepts at least are needed to handle the FIPA-ACL semantics: activities and beliefs.

Activities

By activity, we mean an agent's performing some course of action, such as issuing a communicative act, sending an email, switching on a light, … Most of the time, interpreting incoming messages results in adding one or several activities to the receiving agent. For example, handling Query-if communicative acts typically results in an activity consisting in issuing an Inform act, and handling Request acts typically results in an activity consisting in performing the requested action. Activities are generally either primitive or compound, resulting from a planner computation. In an implementation perspective, the JADE platform provides a "Behaviour" mechanism that could support the concept of activity.

Beliefs

Agents need to perform some reflexive operations both to access and update their own beliefs. Interpreting or sending communicative acts indeed intensively refers to the author's and receiver's beliefs, according to their semantic features. For example, in order to inform another agent about a fact, agents should select the proper act (Inform, Confirm or Disconfirm) depending on their beliefs about the receiver's beliefs regarding this fact. Moreover, after issuing this act, they should come to believe the other agent henceforth believes this fact. Typically, the `COND` part of the template `(implies (and A COND) C)` refers to agents' beliefs.

Such reflexive operations should at least support an Assert operation to add new believed facts, a Query-if operation to query believed facts, and a Query-ref operation to query the believed values of identifying expressions. Here are some examples of invocation of such operations:

1. `Assert("(temperature 20)");`
2. `Query-if("(temperature 21)");`
3. `Query-if("(temperature-greater-than 10)");`
4. `Query-ref("(any ?x (temperature ?x))");`

The first invocation asserts the agent believes the temperature is 20. The second one queries whether the agent believes the temperature is 21. The third one queries whether the agent believes the temperature is greater than 10. The last one queries for a temperature value believed by the agent.

Considering this example, several issues may generally influence the whole mechanism implementation. The first issue is the need for a mechanism that ensures the consistency of the stored beliefs. For example, assuming a classical semantics for the `temperature` predicate (i.e., it satisfies exactly one value), an agent should not believe at the same time `(temperature 20)` and `(temperature 21)`. The second issue is the practical need for inference capabilities. In this example, an agent that believes `(temperature 20)` should also believe `(temperature-greater-than 10)`. Finally, the real semantics of the Query operations is worth highlighting. Query-if returns true for a given fact if the agent believes this fact (whether the truth value of this fact actually be). It returns false if this fact does not belong to her/his beliefs (s/he does not necessarily believe it is false). This characterizes the agent subjectivity.

3.2 Additional constituents

Beyond the two basic concepts of activity and belief, we introduce two key additional concepts to build our operational model: semantic representations (SRs) and semantic interpretation principles (SIPs).

Semantic representation (SR)
A semantic representation is a FIPA-SL formula representing a part of the meaning of an event perceived by the agent, for instance, an incoming message. As SRs refer to *perceived* events, they are necessarily expressed as beliefs of the corresponding agent, ranging from simple beliefs (about the state of the world, her/his own intentions, other agents' beliefs, …) to combined ones.

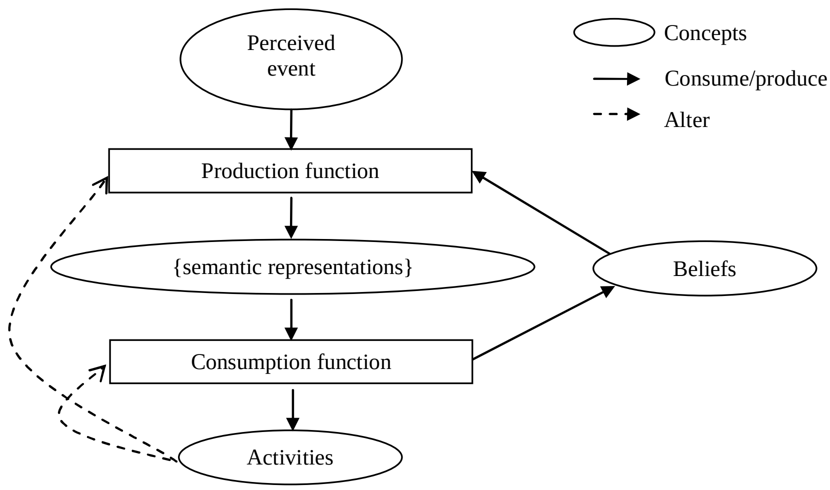

Fig. 1. Interpretation abstract process

SR is the central concept supporting the general process for interpreting incoming messages (and more generally perceived events). This process is refined into two main functions, which can take place simultaneously: the first one consists in producing SRs while the second one consumes them (see Fig. 1):

1. The production function computes from an input perceived event an output consisting of all SRs expressing the agent understanding of this event. For example, assuming agent `j` perceives the following communicative act:

   ```
   (Inform
        :sender i
        :receiver j
        :content "((p))")
   ```

   The production function implemented by `j` generates the following SRs:
   – `(B j (done (action i (Inform …)`: this SR means `j` believes that `i` has just issued the Inform act, it is the direct representation of the perceived event;
   – `(B j (B i p))`: this SR means `j` believes that `i` believes the content of the Inform act is true. It represents the interpretation of part of the feasibility precondition of this act (namely, the fact that the sender should believe the informed content) and can be formally derived using the formal principle (**3**) applied to the Inform act;
   – Other SRs may represent the interpretation of the intentional effect of the Inform act, the intentions derived applying cooperation principles, and so on.
2. The consumption function computes from the previously produced SRs new activities and beliefs within the perceiving agent. In the previous example, the consumption function implemented by `j` adds `(B i p)` to `j`'s beliefs from the second produced SR. The global interpretation process ends when all SRs are consumed.

In this general interpretation process, the formal principles defining the FIPA-ACL semantics can be directly connected to the production function. This connection is detailed in the next subsection about "SIPs". Another point worth mentioning is the requirement for a normal form mechanism to ensure that two logically equivalent FIPA-SL formulas lead to the same SR, resulting in the same understanding of the agent. Finally, this model provides a natural support to proactive behaviors: internally generated events (sensor events, activity-triggered events, …) viewed as particular perceived events are interpreted through the same process.

Semantic interpretation principle (SIP)
Semantic interpretation principles provide the basic means to produce and consume SRs (see Fig. 2). A SIP is closely related to a particular instantiation of the general template `(implies (and A COND) C)` corresponding to one formal principle of the theory:

- It accepts as input the SR representing the `A` part of the formal principle,
- If the `COND` part is satisfied (this generally requires accessing the agent's beliefs), then:
  - It produces as output a set of SRs, representing the `C` part,
  - It consumes the input SR,
  - It may add new activities to the agent,
  - It may update the agent's beliefs.

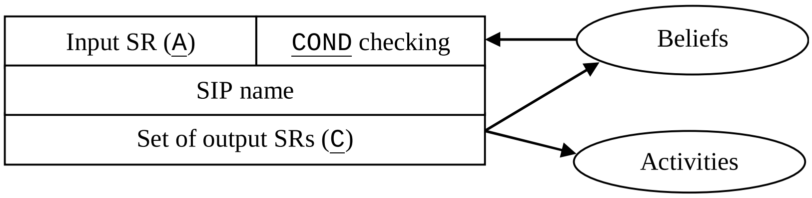

Fig. 2. Representation of a SIP

Finally, implementing the FIPA-ACL semantics using our operational model generally consists in:

- Reusing SIPs that implement generic formal principles of the underlying theory, such as the intentional effect interpretation (**5**) or the feasibility precondition checking (**3**),
- Customizing SIPs that implement customizable cooperation principles of the theory, such as the belief transfer (**6**) or the intention transfer (**7**) principle,
- Defining agent- or application-specific SIPs, providing our model with flexibility hooks.

4 Example

Fig. 3 partially shows the interpretation process applied by an agent `j` to two almost equivalent incoming messages from agent `i`. The first one is an Inform act stating that `i` intends `j` to perform action `a`. The second one is a Request act requiring `j` to perform `a`.

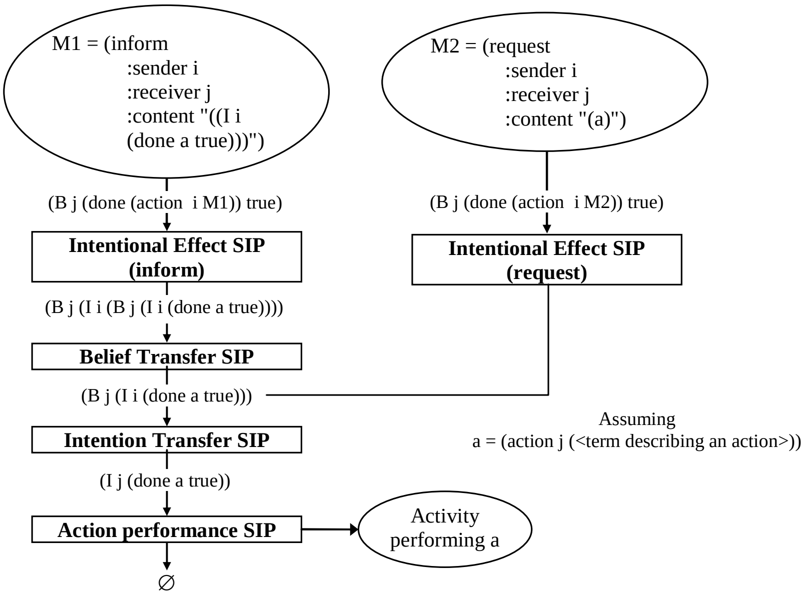

Fig. 3. Interpreting Inform and Request messages

The Inform act is interpreted by applying four SIPs:

1. The first SIP produces an SR representing the intentional effect of the act, which states `j` believes `i` intends the rational effect of the Inform act to hold,
2. The second SIP produces an SR stating `j` believes `i` intends `a` to be done, by applying a belief transfer principle,
3. The third SIP produces an SR stating `j` intends `a` to be done, by applying an intention transfer principle,
4. Then the last SIP creates the activity to perform `a`.

The Request act is interpreted by applying three SIPs:

1. The first SIP is the same one as the previous 1., except that it applies to a Request instead of an Inform act,
2. The second and the third SIPs are respectively the same as the previous 3. and 4., resulting in the same behavior of `j`.

This simple example illustrates how agents can react to incoming messages in respect to their meaning rather than their syntax.

5 Concluding remarks

We have identified a recurrent template for the formal principles of the theory of agency that defines the FIPA-ACL semantics. Considered as a general primitive inference rule, this template can be thought of as the basis of a global interpretation process. We define the concepts of “semantic interpretation principle” (SIP) and “semantic representation” (SR) to implement such a template. These notions, together with proper mechanisms and classical agent-related notions like beliefs and activities, result in an operational model that makes it possible to implement the FIPA-ACL semantics.

Agents built upon this operational model, which relies on the identified template, comply with the formal principles defining the semantics of FIPA-ACL. For example, these agents reject inconsistent incoming messages, such as Inform messages about their own mental states. Moreover, they naturally interpret incoming messages according to their semantic meaning and not to their syntactic form (see the example in section 4). Finally, the operational model provides enough flexibility to support specific behaviors by customizing or specifying additional SIPs.

Considering the effective implementation of our proposed model, we see at least three solutions: the first one consists in using a dedicated inference engine for the modal logic theory of agency supporting the FIPA-ACL semantics. In this case, each instance of SIP is implemented as a particular axiom schema within this engine. For example, the ARTIMIS technology, which currently supports the deployment of real agent-based dialogue applications [18, 19], relies on this approach. However, it requires a complex inference engine, which is not available on the market, to our knowledge. The second solution consists in using a rule engine, each instance of SIP being a rule itself. The anticipated difficulty is to setup the proper data structures to handle logical formulas and their normal forms. Finally, we actually consider a direct ad-hoc implementation of our operational model into the JADE FIPA compliant platform, a first release of which is publicly expected around mid-2005.

In any case, our operational model is expected to give rise to new reliable software tools that will make it possible to develop “semantic” agents. Such challenging agents, which intrinsically work on the meaning of the messages, would no longer explicitly need interaction protocols. The flexibility and therefore the autonomy of these agents would thus be significantly improved. For example, an agent expecting an answer to her/his query from another agent could perfectly deal with an unplanned sub-query from this other agent before getting the actual answer, which is currently not possible by implementing protocols like FIPA-Query with finite state machines.

Finally, our operational model provides novel perspectives regarding the often criticized problem of FIPA compliance testing. Obviously, it remains not possible to externally check agents’ conformance to the FIPA-ACL semantics because there is no means to access their private mental states. Anyway, we argue that future complex systems (disappearing computing, ambient intelligence and so on) will mix both artificial and human agents and so make illusory any usual conformance test. In this spirit, our operational model provides a kind of “weak” compliance framework that ensures that the designed agents at least conform to a subset of a standardized formal semantics by directly implementing some principles of the corresponding theory.

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