# *Interpreting communicative acts and building a conversation model*

DANIEL ROUSSEAU

*Knowledge Systems Laboratory*, *Gates Computer Science Bldg 2A*, *Stanford*, *CA 94305–9020*, *USA*
*e-mail*: rousseau@hpp.stanford.edu

BERNARD MOULIN

*Département d'Informatique*, *Université Laval*, *Sainte-Foy*, *G1K 7P4*, *Canada*
*e-mail*: moulin@ift.ulaval.ca

GUY LAPALME

*Département d'Informatique et de Recherche Opérationnelle*, *Université de Montréal*, *CP 6128*, *succ. Centre-Ville*, *Montréal*, *H3C 3J7*, *Canada*
*e-mail*: lapalme@iro.umontreal.ca

(*Received 1 November 1995; Revised 23 September 1996*)

**Abstract**

Researchers and industry are actively developing Software Agents (SAs), autonomous software that will assist users in achieving various tasks, collaborate with them, or even act on their behalf. To explore new interaction modes for SAs which need to be more sophisticated than simple exchanges of messages, we have analysed human conversations and elaborated an interaction approach for SAs based on a conversation model. Using this approach, we have developed a multi-agent system that simulates conversations involving SAs. We assume that SAs perform communicative acts to negotiate about mental states, such as beliefs and goals, turn-taking and special conversational sequences. We also assume that SAs respect communication protocols when they negotiate. In this paper, we describe the conceptual structure of communicative acts, the knowledge structures used to model a conversation, and the communication protocols. We show how an inference engine using 'conversation-managing rules' can be integrated in a conversational agent responsible for interpreting communicative acts, and we discuss the different kinds of rules that we propose. The prototype PSICO was implemented to simulate conversations on a computer platform.

## 1 Introduction

The Internet and World Wide Web open a new planetary interaction space in which the public and companies are able to offer and access information and services. This new connectivity is dramatically changing the way people use computing resources, and ultimately their way of living. So, applications are needed to assist people in accessing the huge number of resources made available on these so-called information highways. Researchers and industry are actively developing Software Agents (SAs),

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

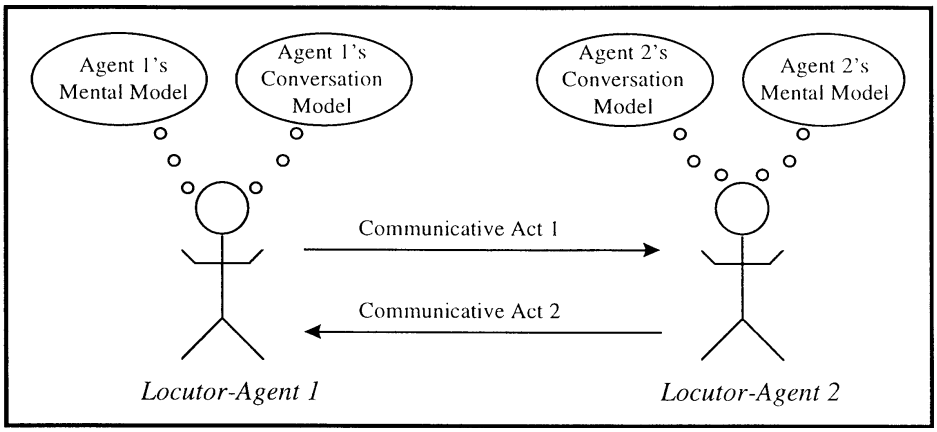



Fig. 1. Symbolic representation of a conversation.

autonomous software that will assist users in achieving various tasks, collaborate with them to solve problems, or even act on their behalf (ACM, 1994; IEEE, 1995). Currently, most software agents interact with other SAs by asking them to perform various kinds of commands or by reacting to their demands (Finin *et al.*, 1994). However, we anticipate that such a simple communication language will not be sufficient to support more sophisticated interactions that will take place between SAs and users collaborating in order to achieve complex tasks. SAs and users will need to interact in a way that is closer to human conversations than to simple exchanges of commands. It will be especially important that SAs be capable of reasoning on the information that is communicated during an interaction. To explore new interaction modes for SAs, we launched a research project which aimed at analysing human conversations, elaborating an interaction approach for SAs based on a conversation model and developing a multi-agent system that simulates conversations between SAs.

A human conversation is a cooperative activity which results from interlocutors' coordinated interactions (Gibbs and Mueller, 1990) through the performance of communicative acts composed of speech acts (Searle and Vanderveken, 1985) and gestures (Moulin and Rousseau, 1996). Speech acts, such as affirming or requesting, are linguistic actions. Gestures, such as pointing or nodding, are non-verbal. Both types of actions are used for communication purposes and are performed during conversations in which several speakers have the collective intention of achieving some common discourse goals (Vanderveken, 1994). However, communicative acts are planned by individuals to achieve different goals such as communicating certain information or requesting the addressee to achieve a given task. A conversation is mainly a reactive process: the speaker performs a communicative act to react to what she perceives as the conversational 'demand' placed upon her at that stage of the conversation (Dascal, 1992; Trognon and Brassac, 1993).

In our work, we assume that software agents' reasoning mechanisms apply to *mental models* (Johnson-Laird, 1983; Gentner and Stevens, 1983) that gather information directly perceived from the environment, obtained from the interpret-

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Julia and Mary are roommates. On Thursday night, Julia decides to invite a friend, Sylvia, to have dinner at home for Friday night. She talks to Mary about it.

(1) Julia: *Mary! Would you mind if I invite Sylvia for dinner tomorrow night?*

(2) Mary: *Good idea!*

(3) Julia: *I will call Sylvia and invite her.*

(4) Mary: *OK!*

Fig. 2. One conversation between locutor-agents.

ation of other agents' communicative acts, or inferred from reasoning activities. Following a common practice in artificial intelligence, we represent the content of mental models in terms of *mental states* which are typed knowledge structures such as beliefs, intentions, expectations and desires (Cohen and Levesque, 1990b; Shoham, 1993; Rao and Georgeff, 1995). These mental states are used by reasoning mechanisms that simulate an agent's cognitive activities such as decision making, deduction and planning. When conversing, locutor-agents[1] perform communicative acts to transfer mental states to other agents, and interpret such acts in terms of mental states (Gibbs and Mueller, 1990).

As shown in Figure 1, a conversation can be viewed from three points of view:

- a sophisticated *communication process*, which enables locutor-agents to perform communicative acts in a structured and coordinated way;
- a *conceptual model*, which is jointly built by locutor-agents, and composed of the different mental states and the related agents' positionings contributed during the communication process;
- a *linguistic product*, which is the result of a conversation composed of the surface form of the different communicative acts performed by locutor-agents.

Figure 2 shows the *linguistic product* of a conversation involving two locutor agents Julia and Mary. The *conceptual model* of the conversation jointly built by Julia and Mary specifies that Julia has the goal of inviting Sylvia for dinner on Friday night and that Mary accepts that goal. During the *communication process*, Julia and Mary use several protocols of communication concerning turn-taking, adjacent pairs of speech acts (for example, Mary has to accept or refuse the goal proposed by Julia) and conversational states (such as Julia beginning the conversation by saying 'Mary!' before proposing her goal to Mary) in order to perform their communicative acts.

To reach our research goals, we developed a conceptual framework for modelling and simulating conversations which integrates several techniques found in conversation analysis, speech act theory, computational linguistics, artificial intelligence, multi-agent systems, planning and cognitive psychology. This framework, presented in section 2, is plausible according to socio-linguistic analyses of conversations and is adequate for simulating sophisticated interactions which take place between software agents. In sections 3 and 4 we present the conceptual structures used in a computer system for modelling communicative acts and conversation models. In

[1] Locutor-agents are SAs participating in a conversation.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

section 5 we describe the core component of a system managing conversations: an inference engine that uses specific rules for interpreting communicative acts and building the conversation model. In section 6 we give an example illustrating this approach and provide some information about the prototype PSICO that implements it. In section 7 we compare our approach with other research works dealing with conversation modelling and the interpretation of communicative acts.

## 2 A multi-agent system for simulating conversations

We think of a conversation as a language game (Wittgenstein, 1958) in which locutor-agents negotiate about the mental states they transfer to their interlocutors. An agent proposes certain mental states (beliefs, intentions, emotions, etc.) and other locutors react to these proposals, accepting or rejecting the proposed mental objects, asking for further information or justifications, etc. We say that they *position* themselves with respect to the transferred mental states. In addition, a locutor-agent is able to differentiate the conceptual objects that have been proposed during a conversation from the mental states that populate its own mental model. In our approach, we view locutor-agents' interactions at the conceptual level as exchanges of what we call *Conversational Objects* (COs). A CO corresponds to a mental state (belief, goal, capability, preference, commitment, interpersonal relationship, emotion) transferred by one agent to one or more other agents during a conversation. A 'positioning' relation is established between a locutor-agent and a given CO when the locutor-agent positions itself with respect to the mental state corresponding to the CO.

Software agents interacting in a conversation can be thought of as composing a multi-agent system that can be represented using distributed artificial intelligence (Moulin and Chaib-draa, 1996). Figure 3 shows the architecture that we propose for simulating conversations involving software agents. Our system is composed of several agents: a *conversational agent* which interprets communicative acts and builds conversation models; the *locutor-agents* involved in a conversation; and an *environmental agent* that simulates the environment in which locutor-agents operate. Such a system can be extended for simulating group conversations by the addition of other locutor-agents.

When a locutor-agent starts a conversation with other agents, a *conversational agent* is activated and instantiates a conversation model. The conversational agent analyses the information contained in a communicative act performed by a locutor-agent in the context of a conversation, and updates the corresponding knowledge structures in the conversation model. A conversation model is shared by all the locutor-agents participating in a conversation.[2]

*Locutor-agents* reason about their own mental states as well as about what they know of other agents. To reach their goals, they build plans containing non-linguistic

[2] Indeed, this is a simplification with respect to real conversations, since such a system supposes that all locutor-agents interpret communicative acts in the same way. Such a vision is relevant when modelling and simulating conversations in which software agents communicate together by transferring COs (see section 4) at a conceptual level where the problem of differential interpretation does not arise. It can be generalized and applied by associating a *conversational manager* with each locutor-agent to enable them to interpret communicative acts differently. Consequently, each locutor-agent would have its own conversation model.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

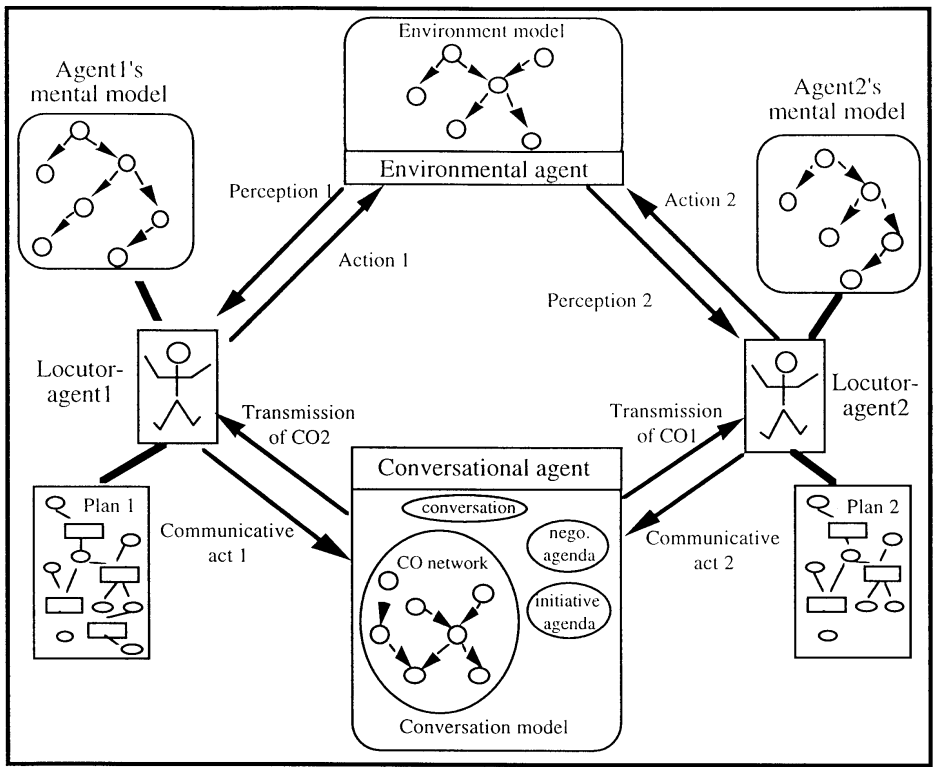



Fig. 3. A multi-agent system for simulating conversations.

actions and communicative acts. When performed, non-linguistic actions are transmitted to the environmental agent and communicative acts are transferred to the conversational agent.

Each locutor-agent possesses its own mental model: a conceptual network composed of mental objects (mental states, relations holding between mental states, temporal information, constraints, rules and stereotyped knowledge). An agent's mental states (beliefs, goals, capabilities, etc.) evolve over time. Some facts and actions can be directly perceived by an agent, bringing new mental states into its mental model. Agents obtain other mental objects transferred to them by communicative acts. An agent can also apply various kinds of rules to create new mental states. These rules model what an agent knows about the world in which it operates. Hence, several objects, such as goals and beliefs, can be created by an agent as the result of reasoning about the mental objects available in its mental model.

During a conversation, an agent can access COs representing the knowledge shared by locutor-agents through their interactions. When a conversation is finished, agents may keep the CO network in memory in order to access the details of the conversation later on: this is an historic memory of the conversation. They may also select some parts of the CO network that are deemed relevant to their purposes, and integrate them into their own mental models: this is a selective and integrative memory of a conversation.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

The *environmental agent* simulates the environment in which agents evolve: it records and propagates the effects of actions performed by locutor-agents in this world. The characteristics of the environment are described in the *environment model*, which is essentially composed of facts and rules. The environmental agent also simulates the perception capabilities of a locutor-agent, informing it about all the changes that occurred in the environment and are perceptible from its point of view. Since no agent is omniscient, the mental models of locutor-agents can differ from the environment model. So, locutor-agents may detect incompatibilities between their mental states and the environment, and try to correct or explain them.

In the following sections we concentrate on important characteristics that enable our system to build a conversational model: the structure of communicative acts (section 3), the structure of the conversation model (section 4), and the main features of the inference engine that is used to interpret communicative acts in terms of COs and other knowledge structures part of the conversation model (section 5). The architecture of a locutor-agent is not described in this paper, but is presented in Rousseau (1995).

## 3 Communicative acts

Most researchers have modelled communicative acts composed of speech acts only. They have characterized isolated speech acts in terms of their inner components corresponding to mental states (Searle, 1979; Cohen and Levesque, 1990a), or have used speech acts in planning systems (Allen, 1983; Litman and Allen, 1987). But ethnomethodologists, who study natural conversations from an observer's point of view (McLaughlin, 1984; Gibbs, 1985), have noted that communicative acts are not restricted to speech acts. In particular, Sinclair and Coulthard (1975) proposed a generic framework enriched by Francis and Hunston (1992) to hierarchically decompose conversations and communicative acts in terms of exchanges containing at least two moves. A move corresponds to what is said or done when an individual holds the turn.[3] Each move is composed of one or more elementary, verbal or non-verbal actions such as summons, greeting, or informing.

In our approach, a communicative act plays the same role as a move but is more general, because it may include time delays that separate utterances and gestures. Locutor-agents do not perform natural language utterances, but perform semantic representations of communicative acts. Table 1 shows the parameters associated with the knowledge structures we use to represent a communicative act. The term *id* denotes an identifier.

An *utterance* contains a symbolic representation of the linguistic information an agent transmits when performing a communicative act during a conversation. A gesture can be performed simultaneously with an utterance (such as pointing or illuminating an object on a screen) or it can play the same role as an utterance (such as nodding one's head or highlighting an icon on a screen).

An utterance is composed of one or more speech acts playing a specific role such as taking or releasing the initiative, or transmitting or complementing the main

[3] We say that an agent holds the turn when it takes the initiative in a conversation by performing a communicative act.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Table 1. *Knowledge structures of a communicative act*

| Structure | Predicate | Parameters |
|---|---|---|
| Communicative act | COMM-ACT (…) | Communicative act id, speaker, addressee, conversation id, list of utterance ids and delays, list of gesture ids and delays, list of temporal relations between utterances and gestures, time interval |
| Utterance | UTTERANCE (…) | Utterance id, communicative act id, list of speech act ids, time interval |
| Speech act | SPEECH-ACT (…) | Speech act id, utterance id, list of proposition ids and of rhetorical relations between propositions, time interval |
| Proposition | PROP (…) | Proposition id, speech act id, propositional content, type, tense, list of linguistic markers, prosody |
| Gesture | GESTURE (…) | Gesture id, communicative act id, description, time interval |

message conveyed by the utterance (Francis and Hunston, 1992). Researchers usually represent a speech act conceptually using predicates or similar formalisms (Cohen and Levesque, 1990a; Litman and Allen, 1987). But Beun (1993) proposed a more elaborate formalism describing a speech act in terms of linguistic and non-linguistic features which express a speaker's beliefs and intentions. We extend this representation so that propositions composing the speech act may be connected by rhetorical relations (Mann and Thompson, 1987), and are described using structures which record natural language features used to make it easier to interpret the message of the speech act. Here we describe the most important features of a communicative act. The *type* of a proposition is either declarative, interrogative, imperative or exclamatory. The *tense* indicates whether the proposition describes a situation past, present, or future relatively to the time of utterance. *Markers* are particles such as 'therefore' or 'so', or indexicals such as 'today' or 'tomorrow', that modify the proposition. The *prosody* parameter concerns intonation, accentuation and intensity of the speech act (Rousseau, 1995); it is used when such an information is available to software agents communicating with users.

As an illustration, consider the first communicative act performed by Julia (line 1 in Figure 2). This act is composed of an utterance itself composed of two speech acts. The first one, '*Mary!*', contains an exclamatory proposition. The second, '*Would you mind if I invite Sylvia for dinner tomorrow night?*', contains a speech act composed of an interrogative proposition. We represent Julia's communicative act using predicates as illustrated in Figure 4.

The *propositional content* of a communicative act is represented using a short literal expression (such as 'Mary' in *prop1*) or a formalism close to the linear form of

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

```
COMM-ACT (comm-act1,Julia,Mary,conv1,[utter1,[],[],[1,2])

UTTERANCE(utter1,comm-act1,[speech-act1,[BEFORE 0],speech act2],[1,2])

SPEECH-ACT(speech-act1,utter1,[prop1],[1,1])

SPEECH-ACT(speech-act2,utter1,[prop2],[2,2])

PROP(prop1,speech-act-act1,"Mary",exclamative,_,[],[rising,_,4])

PROP(prop2,speech-act2,
    Mind(AGT(#you),
        COND(Invite(AGT(#I),PAT(Sylvia),OBJ(dinner),TIME(tomorrow night))),
    interrogative,conditional,["tomorrow"],[rising,_,3]
```

Fig. 4. Conceptual representation of '*Mary! Would you mind if I invite Sylvia for dinner tomorrow night?*'

conceptual graphs (Sowa, 1984) as in *prop2*. A conceptual graph is a bipartite graph composed of conceptual relations and concepts that semantically characterize an object. *AGT*, *COND*, *PAT*, *OBJ* and *TIME* are conceptual relations. *Mind, Invite*, #*I*, #*you*, *Sylvia*, *dinner* and *Friday night* are concepts. *AGT* indicates that #*I* is the agent performing the action *Invite*, and #*you* is the agent of *Mind*. *PAT* shows that *Sylvia* is the agent who benefits from the invitation. *OBJ* expresses that the object of the invitation is a *dinner* and *TIME* refers to the time of the dinner. *COND* refers to a condition the action *Mind* applies to.

## 4 The conversation model

The *conversation model* contains the conceptual model of the conversation and information about the communication process modelled using the following knowledge structures:

- the *conversational object network*, which corresponds to the concepts conveyed by communicative acts as well as the relations holding between the concepts;
- the *conversation frame*, which records information related to conversational states and the communication maintenance;
- the *initiative agenda*, which records information concerning turn-taking;
- the *negotiation agenda*, used to manage macro-components such as topics in a conversation.

Several authors (Winograd and Flores, 1986; Reichman-Adar, 1984; De Vito, 1992) have observed that a conversation can go through different states. They have modelled the allowable transitions between these states using state transition diagrams. Transitions result from the performance of communicative acts. We use such diagrams, which we call *life cycles*, to specify the different states through which each structure in the conversational model can go during a conversation. We base the interpretation of a communicative act on the conversational context as well as on the

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

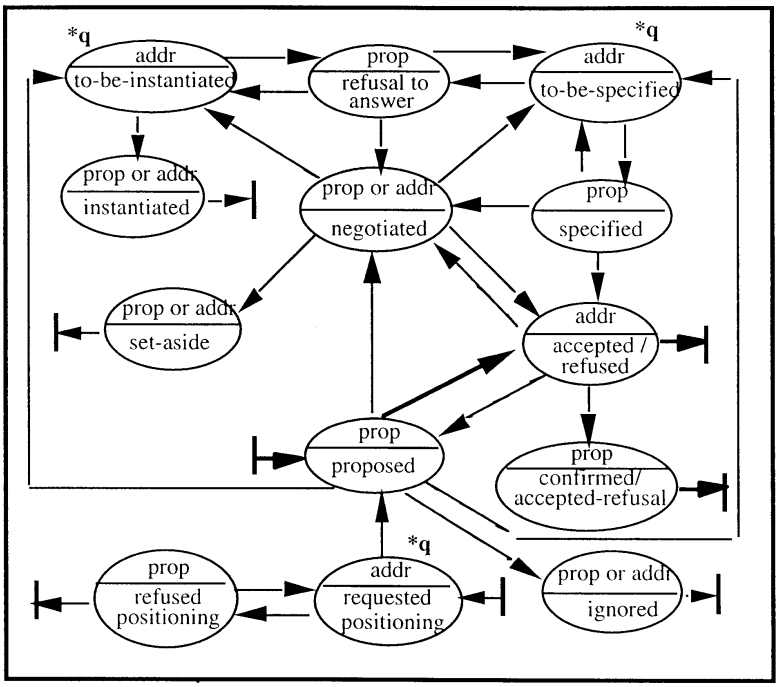



Fig. 5. The negotiation life cycle.

allowable states and transitions at different communication levels (exchange of COs, conversational states and turn-taking), assuming that each locutor-agent respects the same conventions. We determined the content of the life cycles empirically by studying conversations used by various researchers in their works.

In the remainder of this section, we detail each knowledge structure and describe its relevant life cycle.

### *4.1 The CO network*

We view locutor-agents' interactions at the conceptual level as exchanges of what we call *Conversational Objects* (COs). A CO corresponds to a mental state (belief, goal, capability, preference, commitment, interpersonal relationship, emotion) transferred by one agent to one or more other agents during a conversation. A CO goes through several negotiation states which correspond to locutor-agents' *positionings* (*proposed*, *negotiated*, *to-be-instantiated*, *to-be-specified*, *accepted*, *refused*) and express the evolution of the negotiation about this CO. Transitions that allow a CO to go from one state to another are modelled using the *negotiation life cycle* shown in Figure 5. In Rousseau (1995) we discuss these transitions in detail.

COs are linked together in a network. A conversation can dynamically unfold in directions allowed by the CO network with the addition or modification of COs contributed by locutor-agents performing their communicative acts. Sometimes, relations between COs are conveyed by communicative acts and locutor-agents can position themselves with respect to these relations as they do around COs. A relation connects at least two COs. It also connects locutors' mental states in their mental

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Table 2. *Knowledge structures of a CO network*

| Structure | Predicate | Parameters |
|---|---|---|
| CO | CONV-OBJ (…) | Type, CO id, description, temporal information |
| Agent's positionings about a CO | NEGO-POSIT (…) | CO id, conversation id, locutor-agent, list of positionings |
| Positioning | List | Negotiation state, degree of intensity, part of the communicative act conveying the positioning, time interval |
| Relation between COs | RELATION-CONV (…) | Type, involved COs |

model (see section 2). Examples of relations involving a goal and another CO include motivation, precondition, or postcondition. In Rousseau (1995) we have empirically identified a set of possible types of relations through the analysis of several conversations.

Table 2 shows the parameters of the conceptual structures used to represent a CO, a positioning and a relation between COs.

For example, Julia's communicative act shown in Figure 4 conveys Julia's proposal of CO *goal1* corresponding to the goal that '*Julia*, *Mary and Sylvia have dinner together at Julia's on Friday night*'. We represent this knowledge using the following knowledge structures in the conversation model:

```
CONV-OBJ(goal,goal1,
        Have-Dinner(AGT([Julia,Mary,Sylvia]),LOC(Julia's
                home)),TIME(Friday night))
NEGO-POSIT(goal1, conv1, Julia,[[proposed,1,prop2,[2,?t2]]])
```

### *4.2 The conversation frame*

A conversation frame records the states of a conversation and the names of the agents participating in the conversation. When a conversation starts, a conversation frame is created. The conversation goes through different states according to a life cycle described in Figure 6: it is *started* by a locutor-agent; then it goes into the *body* state; it can be *suspended* with the agreement of the participants, *resumed* later, *ended*, etc. A time interval is associated with each conversational state to indicate when a positioning is effective.

A conversation is divided into *periods*. A period is characterized by a stable group of locutor-agents in the conversation. A new period is created anytime an agent is added or removed from the conversation. The existence of periods is useful to model group conversations in which the number of participants varies.

Considering the example of Figure 4, the conversation *Starts* with Julia's first speech act and goes to the *Body* state with the second one. The conversation frame

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

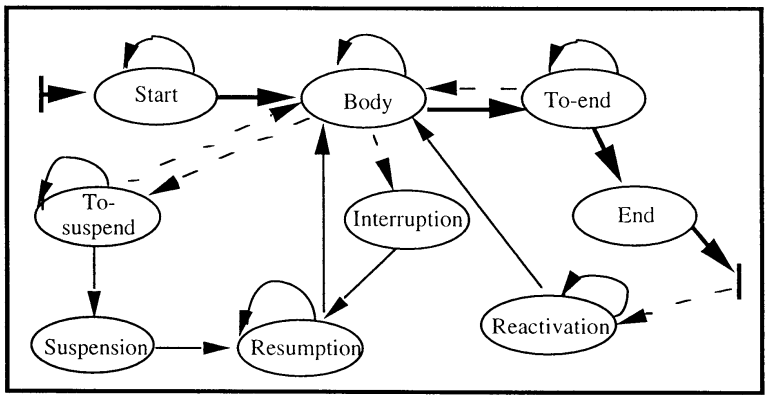



Fig. 6. The conversation life cycle.

also records that Julia and Mary participate in the conversation. The formal knowledge structures of the conversation frame are presented in Moulin and Rousseau (1996).

### *4.3 The initiative and negotiation agendas*

The initiative (or turn-taking) of a locutor-agent can go through different states: it can be *taken*, *released*, *kept*, *asked*, *refused*, etc. (Moulin and Rousseau, 1996). It is managed by a special object called the *initiative agenda*. For each locutor-agent there is an instance in the initiative agenda specifying the current state of that agent's initiative. The initiative agenda is updated each time at the beginning and at the end of the performance of a communicative act. For example, just after the communicative act of Figure 4, the initiative agenda specifies that Julia is offering the initiative and that Mary is still waiting for it.

The *negotiation agenda* is a special object that records the COs already proposed by locutor-agents and on which other agents normally position themselves in the current conversation. It is a kind of focus of attention mechanism that handles the management of topics in a conversation. There is a negotiation agenda for each conversational participant. When a locutor-agent positions itself on a CO which is not accepted or refused yet, the identifier of that CO is inserted in the addressee's negotiation agenda. The addressee is usually expected to react with respect to the COs contained in its negotiation agenda. So, after the performance of the communicative act of Figure 4, the CO denoting Julia's goal is inserted into Mary's negotiation aRgenda.

Formal representations of the agendas are presented in Moulin and Rousseau (1996).

## 5 An inference engine for interpreting communicative acts

The core component of a conversational agent is an inference engine which interprets communicative acts and builds a conversation model. This inference engine uses *conversation-managing rules* in which one can specify the various conditions characterizing the conversation model and the communication structure (such as a

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

communicative act or a gesture) that is being analysed. Those conditions refer to commonsense and linguistic knowledge as well as social conventions, including the communication protocols modelled using the life cycles shown in section 4. A conversation-managing rule also specifies the actions that must be performed by the inference engine to update the relevant knowledge structures in the conversation model.

The inference engine follows a technique proposed in Farreny and Ghallab (1987) where rules are grouped by the elements they interpret. So, when the inference engine has to interpret a communicative act (or part of it), it considers only conversation-managing rules of the relevant group. In a group, rules are ordered. So, the evaluation of the rules is performed in that order and ends as soon as the inference engine finds a rule it can apply in order to update the conversation model.

We associate a group with each kind of communication structure shown in Table 1. The main rule group deals with the communicative act, the proposition, the rhetorical relation and the gesture. It is not necessary to implement rules at the levels of utterance and speech act, because the inference engine analyses their components (propositions and rhetorical relations) to update the conversation model. Four rule sub-groups are specified for the four types of propositions that can be analysed: declarative, interrogative, imperative and exclamatory. There are other cases processed by specific rule sub-groups: positionings inferred from other positionings, cases where a conversation is suspended or ended, and events affecting a conversation. In Table 3, we specify the element each group analyses, the number of rules it

Table 3. *Groups of conversation-managing rules*

| Element | Number of rules | Conditions | Modified structures |
|---|---|---|---|
| Other communicative act | 2 | Simultaneous acts | Initiative agenda |
| Communicative act | 5 | Conversational state, participants | Conversation frame |
| Proposition | 9 | Expression, conversational state | Conversation frame |
| Proposition: | | Expression, performative verb, positioning, proposed COs | CO network |
| – declarative | 6 | | |
| – interrogative | 4 | | |
| – imperative | 2 | | |
| – exclamatory | 2 | | |
| Relation | 2 | Linked COs, proposed COs | CO network |
| Gesture | 6 | Meaning, proposed COs | CO network, conversation frame, initiative agenda |
| Inferred positioning | 5 | Positioning about COs, relation between COs | CO network |
| Conversation | 2 | No more communicative act | Conversation frame |
| Event | 1 | Interruption of a conversation | Conversation frame |

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

contains, the elements which are tested by the rules, and the knowledge structures they modify in the conversation model. Other groups and conversation-managing rules may be added in a future version of the system. We now examine the proposed groups.

- *Other communicative act*
  When a communicative act is performed by a locutor-agent, the inference engine checks whether no other communicative act is performed at once. A rule deals with the case of a locutor-agent interrupting another agent who owns the turn. Another rule applies if no interruption is detected.
- *Communicative act*
  After the previous group, the inference engine activates the group of rules for *updating the conversation frame* by considering the knowledge structure of the communicative act (see Table 1). Three rules deal with transitions between conversational states according to the conversation life cycle shown in Figure 6:

  – the conversation is considered in the *Start* state if there was no conversation frame instantiated for the current conversation before the performance of the communicative act;
  – it goes into the *Resumption* state if its current state is *Interruption* or *Suspension*;
  – it goes into the *Reactivation* state if its current state is *End* (the conversation is about the same topic and involves the same participants as before its end).

  In those three cases, the new conversational state is recorded in the conversation frame and a new period is created in order to record who the participants of this conversation are.

  Two other rules detect any new participant of a conversation as a speaker or an addressee. They compare the speaker or the addressee with the participants associated with the current period. A new period is created in the conversation model when a new participant is detected.
- *Proposition*
  Once the communicative act structure is analysed, the inference engine processes the utterances and the gestures of the act. The inference engine analyses an utterance by processing its speech acts. A speech act results in the processing of its propositions and rhetorical relations. Let us examine how a proposition is processed.

  Most of the managing rules that can update the conversational state in the conversation frame belong to the group of conversation-managing rules interpreting a *proposition*. Several rules check whether the analysed proposition is part of a *conversational sequence*. A conversational sequence comprises one or more stereotyped speech acts which put a conversation into a certain conversational state (*Start*, *To-be-suspended*, *To-be-ended*, *Resumption* or *Reactivation*) without conveying any CO. For example, a locutor-agent who says 'Hello!' starts a conversation but transmits no CO. It can go on by asking a

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

question requesting an answer from the addressee such as 'How are you?' or it can propose a CO. The other agent answers the question and can also ask a stereotyped question. The initiator agent can end the conversational sequence by answering the last question or it can follow up in the sequence by asking another stereotyped question. The general structure of a sequence specifies that an agent can ask a question after acknowledging another agent's answer.

Each conversational sequence has the same general structure. The speech acts used to realize a transition and the associated conversational context enable the system to distinguish different sequences characterized by specific conversational states. The possible propositional contents that can be used in a sequence are recorded in a lexical table that the inference engine consults when activating a conversation-managing rule referring to it. The current conversational state is also verified. Five rules (one for each kind of conversational sequence) check whether the current conversational state is already the one associated with the conversational sequence. Two other rules check whether a transition is performed from the *Body* state to the *To-be-ended* or *To-be-suspended* states.

According to an eighth conversation-managing rule, the inference engine puts the conversation in the *Body* state if none of the previous rules applies. Another rule is activated if the conversation is already in the *Body* state. In these two last cases, the inference engine interprets the proposition depending on its type (declarative, interrogative, imperative or exclamatory) in order to update the CO network.

- *Declarative proposition*

There are situations in which a positioning can be identified by considering the current negotiation state of the CO previously proposed. Usually, such a situation can be identified by special expressions recorded in a lexical table. For instance, 'It is not true' expresses the refusal of a CO that was proposed by the addressee. One managing rule deals with the case of a CO being *accepted* or *refused*, and another rule processes other kinds of positionings dealing with a CO that has been already proposed (such as *to-be-instantiated* and *to-be-specified*). Another rule is specific to declarative propositions that are used to ask for a positioning with respect to a CO.

Propositions containing a *performative* verb (such as to ask, to promise or to affirm) are special cases of declarative propositions. They are used with the personal pronoun 'I' and can be divided into two categories, each of them being processed by a different managing rule. Performative verbs of the first category specify the type of the analysed proposition. For example, 'I am asking you if P' is considered as an *interrogative* proposition because of the expression 'I am asking you if …'. Performative verbs of the second category indicate the type of the CO conveyed by the analysed proposition. For instance, a *promise* is considered as the *proposal* of a *commitment*. Each category of performative verbs is analysed using a different conversation-managing rule.

If none of the previous managing rules applies, the inference engine considers that the proposition conveys a proposal with respect to a CO. The relevant conversation-managing rule specifies that the type of the CO can be determined

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

by comparing the proposition and the elements of lexical tables. For instance, if the proposition has the form 'I want to P', P can be viewed as a goal. The CO is considered a belief by default if the proposition has no recognizable form.

Note that each conversation-managing rule that updates the CO network also modifies the negotiation agenda in the conversation model, no matter which group the rule is part of. An entry is added or updated in the relevant locutor-agent's negotiation agenda each time a CO or a relation holding between COs is not *accepted*, *refused* or *set aside*. Such an entry is removed from the negotiation agenda when one of those negotiation states is reached, according to the negotiation life cycle shown in Figure 5.

- *Interrogative proposition*
  *Interrogative* propositions express questions with respect to a CO when they are formulated in a direct way (i.e. interpreted literally). They correspond to three negotiation states: *requested-positioning*, *to-be-instantiated* and *to-be-specified*. Special expressions can be identified to determine the right positioning. For example, 'Is P?', 'Which P?' and 'Why P?' respectively express requests for a *positioning*, for an *instantiation* and for an *explanation* with respect to a CO. The inference engine uses one managing rule per negotiation state.

  An interrogative proposition can also be indirect (Searle, 1975). For instance, a question of the form 'Can you P?' is usually interpreted as the imperative 'Do P!', and not as a question about the addressee's capability of performing the action P. A managing rule deals with such a case by consulting a lexical table specifying the real type and the propositional content of the analysed proposition. For instance, in 'Can you P?', P would be considered the real description of an imperative proposition.
- *Imperative proposition*
  An *imperative* proposition is usually used to propose a goal to another agent. 'Close the door!' and 'Help me to carry a box!' are examples of such propositions. But, in indirect propositions, an imperative proposition contains an expression that specifies a type of question. For example, 'Tell me' is an expression that can be used in an imperative proposition in order to ask for a *positioning* ('Tell me if P'), an *instantiation* ('Tell me which P') or an *explanation* ('Tell me why P') with respect to a CO. A managing rule processes direct propositions and another interprets indirect propositions.
- *Exclamatory proposition*
  An *exclamatory* proposition can be used in order to *accept* or *refuse* a certain CO. Special expressions are then used (such as 'OK!' and 'Thank you!' for an acceptance, 'No!' and 'No way' for a refusal). An exclamatory proposition can also express an emotion ('I am so sad!') or a preference ('This food is excellent!'). A managing rule is used to process every exclamatory expression containing a special expression. Another rule interprets exclamatory propositions which do not contain key expressions and can be interpreted as *declarative* propositions with a stronger positioning degree. For example, 'I am the boss!' is considered stronger than 'I am the boss' because of the exclamatory type of the proposition.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

- *Relation*
  There are two types of situations involving a rhetorical relation between propositions in a speech act. The first type includes cases where all the COs involved in the relation are described in the same speech act. It is the usual case for speech acts that are composed of several propositions. Such a rhetorical relation is called *complete*. The second type comprises speech acts that do not describe all the COs linked by the relation. The rhetorical relation is said to be *partial*. In such a relation, the missing CO usually has previously been communicated by a locutor-agent in the current conversation.

  As an illustration, let us consider the following example:

  *A: I will not come and visit you on Friday because I must work.*
  *B: But you promised you would come.*

  The first speech act contains a complete rhetorical relation, in which the marker 'because' indicates that agent A's obligation about working motivates its intention not to come and visit B. The second speech act contains a partial rhetorical relation which is expressed by the connector 'But'. It means that there is a conflict between A's promise and its incapacity to come and visit B. We use two managing rules to interpret each category of rhetorical relations. Each rule has to find the COs involved in the relation.
- *Gesture*
  A managing rule specifies that a locutor-agent is removed from the participants of a conversation when it performs an action indicating that it leaves the conversation (such as leaving a meeting or hanging up the phone). A new period is created and that agent's initiative agenda is then deleted in the conversation model.

  Two other managing rules modify the initiative agenda. They are used to interpret gestures for asking for the initiative (such as raising a hand) or offering it (such as pointing towards someone).

  Three rules deal with gestures having an effect on the CO network. A first rule processes gestures that reinforce a message conveyed by an utterance. For example, a locutor-agent can nod his head and say 'I agree'. The two other rules deal with situations when an agent executes a gesture which conveys a message without saying a word. One rule detects gestures which are a reaction (acceptance, refusal) to what another agent has said. The other rule processes cases when the speaker positively or negatively proposes a CO after the request of a positioning by the addressee. The representation of every gesture can be interpreted using lexical tables manipulated by managing rules.
- *Inferred positioning*
  Indirect and cooperative answers are sometimes difficult to detect, because they depend on the context. When a locutor-agent A asks a question or gives an order to another agent B, A expects that B will react to the question or the order. Agent B's reaction may express an answer that is direct or indirect (Green and Carberry, 1992). If the answer is not direct, the inference engine tries to find a relevant indirect interpretation using managing rules that deal with inferred

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

positionings. A positioning with respect to a CO can be inferred from other positionings with respect to other COs in certain contexts. For example, an agent who answers 'I was in Montreal' to the question 'Did you go to Quebec City last weekend?' says indirectly that he was not in Quebec City.

A special group of managing rules deals with inferred positionings. Rules in this family specify potential situations when a CO can be indirectly *proposed*, *accepted*, *refused*, *instantiated*, or *specified* (see Figure 5) using a positioning relative to another CO. They are tested each time a CO is proposed by a locutor-agent to determine whether there is an indirect positioning relative to another CO already present in the CO network of the current conversation. An indirect positioning can be inferred from the relation holding between COs and from the current positionings relative to the COs.

- *Conversation*
  Two managing rules are used to detect when a conversation goes to the *End* or *Suspend* state (see Figure 6). The inference engine puts the conversation in the adequate state if no communicative act has been received after a time delay fixed by the designer of the managing rules, and if the conversation is already in the state *To-end* or *To-suspend*. The current period is then considered as being ended. The group of rules is activated when the conversation is already in one of those two states.
- *Event*
  A special rule is used to deal with cases when any event such as a phone connection breakdown interrupts a conversation.

## 6 Example of an application and the PSICO Prototype

To illustrate our approach, we explain how the first two communicative acts of Figure 2 can be interpreted using conversation-managing rules and how the relevant conversation model can be built. Remember that we work with communicative acts represented under a conceptual form presented in Figure 4.

In Table 4, we show how the first communicative act performed by Julia ('Mary! Would you mind if I invite Sylvia for dinner tomorrow night?') is interpreted by the inference engine and how the conversation model is modified. The first column indicates the level of knowledge structure that is analysed and the group of conversation-managing rules that is activated (see Table 3). The second column specifies the situation detected by the inference engine. The last column describes the modifications made to the conversation model.

Note that the inference engine changes the indirect proposition 'Would you mind if I invite Sylvia for dinner tomorrow night?' to the direct declarative proposition 'I want to invite Sylvia for dinner tomorrow night' before modifying the CO network. When all the communication structures of the first act are analysed, the inference engine modifies the initiative agenda in the conversation model to indicate that Julia offers Mary the initiative.

Table 5 shows the analysis of Mary's answer ('Good idea!'). The last two

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Table 4. *Analysis of* 'Mary! Would you mind if I invite Sylvia for dinner tomorrow night?'

| Level of analysis | Situation | Modification |
|---|---|---|
| Other communicative act | No other communicative act performed at once | The initiative agenda is created indicating that Julia is getting the initiative and Mary is waiting for it. |
| Communicative act | No conversation frame yet | The conversation frame is created. The conversation is put in the *Start* state and the current period includes Julia and Mary as conversational participants |
| Proposition: 'Mary!' | Used to start the conversation | No change |
| Proposition: 'Would you mind if…?' | Not part of a conversational sequence | The conversation is put in the *Body* state |
| Interrogative proposition: 'Would you mind if…?' | Indirect proposition | No change of structure, but transformation of the interrogative proposition into the following declarative one |
| Declarative proposition: 'I want to invite Sylvia for dinner…' | 'I want to' shows that Julia has the goal to have dinner with Sylvia | A relevant CO is created indicating that Julia proposes the goal to have dinner with Sylvia on Friday night |

communicative acts of the dialogue shown in Figure 2 are interpreted in the same way by the inference engine.

We used Quintus Prolog to implement a conversational agent and artificial locutor-agents in PSICO (Prototype for SImulating COnversations) to simulate conversations on a computer platform. Before beginning a session with PSICO, the content of each locutor-agent's mental model (especially its mental states) must be defined as well as conversation-managing rules and common sense knowledge used by the conversational agent implemented as an inference engine. PSICO can show a trace of the locutor-agents' interactions at two levels. The first level only shows the collection of communicative acts exchanged by locutor-agents as the conversation proceeds. The second level shows not only communicative acts, but also a trace of locutor-agents' reasoning about mental states that we describe in Rousseau (1995) as well as the interpretation of communicative acts in terms of COs and other knowledge structures inserted in a conversation model. The current version of PSICO is applied to dialogues, such as in the example previously discussed.

We applied PSICO to a corpus of dialogues rich enough to test most of the conversation-managing rules that we propose. In those dialogues, an agent asks another agent to perform a task or to accept a belief. The other agent accepts or rejects the proposed COs, after or without negotiating, depending on the dialogue. With our corpus, the conversational agent has to detect conversational states,

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Table 5. *Analysis of* 'Good idea!'

| Level of analysis | Situation | Modification |
|---|---|---|
| Other communicative act | No other communicative act is performed at once | Julia's initiative is put into the *Offering* state |
| Communicative act | The conversation is already in the *Body* state | No change |
| Proposition: 'Good idea' | Not part of a conversation sequence | No change (the conversation remains in the *Body* state) |
| Exclamatory proposition: 'Good idea!' | Expresses the acceptance of the CO proposed by Julia | Mary's acceptance of Julia's CO is recorded in the CO network |

including the suspension and the resumption of a conversation, as well as locutor-agents' positionings related to goals, beliefs and commitments figuring as COs. The detected positionings are not only direct, because some positionings must be inferred from others. Proposals of relations holding between COs are also part of the dialogues.

## 7 Related works

Ethnomethodologists who study natural conversations from an observer's point of view in order to analyse their coherence and explain how human locutors interact have noted conversational phenomena at different communication levels: turn-taking (Sacks *et al.*, 1978), interrelated utterance patterns about a same topic, including pair of actions (Linde, 1987; McLaughlin, 1984), special sequences like openings and closings of conversations (De Vito, 1992), hesitations and repairs in a speech act (Francis and Hunston, 1992). In our approach, we consider all these phenomena except hesitations and repairs to build a conversational model containing the relevant information concerning the current conversation, because we can assume that software agents do not need to hesitate or correct the content of their communicative acts while they perform them.

Researchers in artificial intelligence and in computational linguistics also assume that a conversation unfolds on many levels. They consider that locutor-agents perform actions of various levels during a conversation, or that a conversation can be modelled using interrelated components characterizing information related to various levels of communication. We mention some relevant works.

Traum and Hinkelman (1992) based their approach on multi-leveled communication in order to analyse a speaker's utterances in task-oriented spoken dialogues. Considering that speech acts are inherently multi-agent actions and each utterance encodes parts of several different acts, they suggest four levels of conversational acts for maintaining the coherence and content of a conversation: *turn-taking acts* (take, keep, release and assign turn); *grounding acts* (including backchannel responses, local repairs on utterances, requests for repairs or acknowledgments); *core speech acts* (corresponding to traditional speech acts such as

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

inform, request, promise) and *argumentation acts* (higher level speech acts supporting arguments, utterance sequences, etc.). Our approach supports all the types proposed by Traum and Hinkelman except the *grounding acts*, which concern the quality of the information that is transferred. Our communicative acts can play the same roles as conversational acts, and other roles as well. They may convey information relating to turn-taking, concepts (conversational objects) transfer, relations holding between conversational objects and conversational states.

Grau *et al*. (1993) propose a mechanism for analysing a dialog along three different communication levels: the intentions contained in the speech acts, the coherence of the topics that are discussed, and possible misunderstandings. Our approach considers the first two levels only, because we assume that there is no difference in interpretation among software agents participating in a conversation. Grau's approach does not take into account conversational states and turn-taking, as is the case for Litman and Allen's plan-oriented approach for modelling dialogues (Litman and Allen, 1987). Litman and Allen assume that conversational participants use domain plans and discourse plans when they are involved in a dialogue. Both types of plans are connected, as COs are connected to an agent's positionings in our approach, because COs are dependent of a domain. Note that our locutor-agents know stereotyped plans which are domain-dependent.

In a theoretical approach for analysing utterances, Grosz and Sidner (1986) claimed that the structure of a discourse is composed of three interrelated components: the *linguistic structure*, composed of discourse segments of naturally aggregating utterances; the *intentional structure*, containing the goals expressed in discourse segments as well as the relations linking the goals; and the *attentional state*, which dynamically records in *focus spaces* the most salient objects, properties and relations of each discourse segment. Grosz and Sidner (1990) enriched their previous model in order to enable locutors to recognize other agents' intentions by using and sharing plans viewed as mental states composed of intentions and beliefs (Pollack, 1990). Lochbaum (1995) developed an axiomatization of knowledge preconditions in such shared plans, assuming that an agent which does not possess the knowledge needed to perform an action may plan to get it by engaging in an information-seeking subdialogue.

In our approach, Grosz and Sidner's linguistic structure would correspond to the set of communicative acts that compose a conversation. Their intentional structure is a restricted version of our conceptual model, in which we can represent various types of mental states besides intentions. Our negotiation agenda plays the same role as their attentional state. COs and other relevant information conveyed by a communicative act can be recognized because of knowledge shared by the conversational participants: conversational protocols, the conversational model, linguistic and common sense knowledge. Our approach is general enough to allow locutor-agents to ask for information when they need it to reach a goal, as well as other kinds of information. Relations holding between COs can be modelled, including the preconditions communicated via communicative acts.

Our notion of CO network is similar to a model proposed by Steiner *et al*. (1993). These researchers consider that a speech act, called a *cooperation method*, involves a

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

transfer of information and that an intention underlies this transfer. A *cooperation method* is defined in terms of a *cooperation primitive* (such as propose, refine, modify, accept, reject) applied on a *cooperation object* which 'is either a goal, a plan, a task or some non-specific information such as results, parameters, or other knowledge'. Steiner's cooperation primitives correspond to locutor-agent's positionings with respect to a CO (which is close to the notion of cooperation object) in our approach. But COs can be related together using special relations creating a network of COs. Such relations between COs do not exist in Steiner's approach, and the positionings that we propose in our model are slightly different from the *cooperation primitives*, because we distinguish three different types of questions that a locutor-agent can ask about a CO.

Fischer *et al.* (1995) integrate the Conversational Roles model (Stein and Thiel, 1993) and the Rhetorical Structure Theory (Mann and Thompson, 1987) to model the structure of cooperative information-seeking dialogues in a multimedia environment. The Conversational Roles (COR) model corresponds to a state transition diagram which defines the possible interactions in a mixed-initiative dialogue. The COR model is quite different from our negotiation life cycle, because transitions denote various types of speech acts (request, offer, inform, and promise) that convey, retract or reject commitments. Our life cycle is based on positionings on COs corresponding to mental states. The Rhetorical Structure Theory (RST), originally designed for monologues, is used by Fischer to specify the semantic nature of the relation that connects pairs of speech acts in a dialogue, in order to add an additional level of coherence to the COR model. For instance, an informing act can be viewed as connected to a request by a *solutionhood* relationship if it is performed to satisfy the request. We do not believe that it is always necessary to identify such relationships in our approach. We assume that rhetorical relationships connecting the positionings about a same CO are implicit in the life cycle, but that relations connecting different COs must be expressed explicitly in the conversational model.

## 8 Conclusion

We have presented a multi-agent system for simulating conversations involving software agents based on a conversation model and communication protocols designed to take into account phenomena present in human conversations. Our approach can be very useful in applications where software agents and users interact in virtual worlds (Rousseau and Hayes-Roth, 1996; Reilly and Bates, 1995; Rhodes and Maes, 1995). In such systems, software agents' behaviors must be believable, including conversational behaviours. Recognizing the information conveyed by communicative acts, reasoning on this information, and selecting relevant behaviours are the three processes that are necessary to enable a software agent to interact in a coherent and believable way. The framework that we propose incorporates all of them (Rousseau, 1995).

We described in detail the conversational agent which is responsible for the interpretation of the communicative acts performed by the locutor-agents as well as for the construction of the conversation model as a conversation unfolds. We showed

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

how such an agent was implemented in the prototype PSICO using an inference engine and conversation-managing rules.

Using an inference engine and conversation-managing rules has several advantages: the conversation-managing rules can be easily extended; the conversational context can easily be defined in a conversation-managing rule; a communicative act, not reduced to a speech act but comprising gestures and pauses as well, is systematically interpreted in terms of knowledge structures concerning levels of communication and modifying the conversation model; the interpretation of a communicative act is based on communication protocols modelled using life cycles. In a more complete approach that could be applied to human-software agent interaction, we believe that conversation-managing rules could be used by locutor-agents in order to interpret communicative acts from their own perspective and to build their own conversation models. But, in such a case, conversation-managing rules would have to refer to locutor-agents' mental states and consider potential differences of interpretation of a same communicative act.

## Acknowledgements

This research is supported by the Natural Sciences and Engineering Council of Canada and FCAR (Fonds pour la Formation de Chercheurs et l'Aide à la Recherche) through grants and scholarships. We also thank Patrick Doyle and two anonymous reviewers who made many helpful suggestions.

## References

ACM (1994) *Communications of the ACM*. Special Issue on Intelligent Agents **37** (7) July.

Allen, J. F. (1983) Recognizing intentions form natural language utterances. In *Computational Models of Discourse*, M. Bradie and R. C. Berwick (eds.), MIT Press, Cambridge, pp. 108–166.

Beun, R. J. (1993) Mental state recognition and communicative effects. Technical report 865/III, Institute for Perception Research, Eindhoven, The Netherlands.

Cohen, P. R. and Levesque, H. J. (1990a) Rational interaction as the basis for communication. In *Intentions in Communication*, P. R. Cohen *et al*. (eds.), pp. 221–255.

Cohen, P. R. and Levesque, H. J. (1990b) Persistence, intention and commitment. In *Intentions in Communication*, P. R. Cohen *et al*. (eds.), pp. 33–69.

Cohen, P. R., Morgan, J. and Pollack, M. E. (eds.) (1990) *Intentions in Communication*. MIT Press.

Coulthard, M. (1992) *Advances in Spoken Discourse Analysis*. Routledge.

Dascal, M. (1992) On the pragmatic structure of conversation. In *On Searle on Conversations*, H. Parret and J. Verschueren (eds.), pp. 35–56.

De Vito, J. A. (1992) *The Interpersonal Book*. Harper Collins.

Farreny, H. and Ghallab, M. (1987) *Eléments d'intelligence artificielle*. Paris: Hermès.

Finin, T., Fritxon, R., McKay, D. and McEntire, R. (1994) KQML as an agent communication language. *Proc. Third Int. Conf. on Information and Knowledge Management*. ACM Press.

Fischer, M., Maier, E. and Stein, A. (1994) Generating cooperative system responses in information retrieval dialogues. *Proc. 7th International Workshop on Natural Language Generation*, Kennebunkport, Maine, June, pp. 207–216.

Francis, G. and Hunston, S. (1992) Analysing everyday conversation. In *Advances in Spoken Discourse Analysis*, M. Coulthard (ed.), pp. 123–161.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Gentner, D. and Stevens, A. L. (eds.) (1983) *Mental Models*. Hillsdale, N.J.: Lawrence Erlbaum.

Gibbs, R. W. (1985) Situational conventions and requests. In *Language and Social Situations*, J. P. Forgas (ed.). New York: Springer-Verlag.

Gibbs, R. W. and Mueller, R. A. G. (1990) Conversation as coordinated, cooperative interaction. In *Cognition, Computation and Cooperation*, W. W. Zachary and S. P. Robertson (eds.). Ablex.

Grau, B., Sabah, G. and Vilnat, A. (1993) Pragmatique et dialogue homme-machine. Technical Report, LIMSI-CNRS, Orsay, France.

Green, N. and Carberry, S. (1992) Conversational implicatures in indirect replies. *Proc. 30th Annual Meeting of the Association for Computational Linguistics*, University of Delaware, July, pp. 64–71.

Grosz, B. J. and Sidner, C. L. (1986) Attention, intentions, and the structure of discourse. *Computational Linguistics* **12**(3) July–September: 175–204.

Grosz, B. J. and Sidner, C. L. (1990) Plans for discourse. In *Intentions in Communication*, P. R. Cohen *et al.* (eds.), pp. 417–444.

IEEE (1995) *IEEE Expert*. Special issue on Intelligent Internet Services. **10** (4) August.

Johnson-Laird, P. H. (1983) *Mental Models*. Cambridge, MA: Harvard University Press.

Linde, C. (1987) The life story: discontinuous discourse type. In *Psycholinguistic Models of Production*, H. W. Dechert and M. Raupach (eds.). Kassel.

Litman, D. J. and Allen, J. F. (1987) A plan recognition model for subdialogues in conversations. *Cognitive Science* **11**: 163–200.

Lochbaum, K. E. (1995) The use of knowledge preconditions in language processing. *Proc. International Joint Conference on AI 95*, *Vol. 2*, Montreal, Canada, August, 1260–1265.

Mann, W. C. and Thompson, S. A. (1987) Rhetorical structure theory: description and construction of text structures. In *Natural Language Generation*, G. Kempen (ed.). Dordrecht: Martinus Nijhoff, pp. 85–95.

McLaughlin, M. L. (1984) *Conversation: How Talk is Organized*. Sage Publications.

Moeschler, J. (1993) Théorie des actes de langages et analyse des conversations. *Les Cahiers de Linguistique Française*, Université de Genève, No. 13.

Moulin, B. and Chaib-draa, B. (1996) Distributed artificial intelligence: an overview. In *Foundations of Distributed Artificial Intelligence*, N. Jennings and G. O'Hare (eds.). Wiley, pp. 3–55.

Moulin, B. and Rousseau, D. (1996) An approach for modeling and simulating conversations. To appear in *Essays in Speech Act Theory*, D. Vanderveken and S. Kubo (eds.). John Benjamins.

Parret, H. and Verschueren, J. (eds.) (1992) *On Searle on Conversation*. John Benjamins.

Pollack, M. E. (1990) Plans as complex mental attitudes. In *Intentions in Communication*, P. R. Cohen *et al.* (eds.), pp. 77–103.

Rao, A. S. and Georgeff, M. P. (1995) BDI agents: from theory to practice. *Proc. 1st International Conference on Multi-Agent Systems: ICMAS-95*, V. Lesser (ed.), MIT Press, pp. 312–319.

Reichman-Adar, R. (1984) Extended person-machine interface. *Artificial Intelligence* **22**: 157–218.

Reilly, W. S. and Bates, J. (1995) Natural Negotiation for Believable Agents. Technical Report CMU-CS-95–164, School of Computer Science, Carnegie Mellon University, Pittsburgh, PA.

Rhodes, B. and Maes, P. (1995) The stage as a character: automatic creation of acts of god for dramatic effect. *Workshop Notes of the AAAI 95 Spring Symposium on Interactive Story Systems: Plot and Character*, Stanford University, CA, March.

Rousseau, D. (1995) *Modélisation et simulation de conversations dans un univers multi-agent*. PhD dissertation, Université de Montréal, August.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press

Rousseau, D. and Hayes-Roth, B. (1996) Personality in Synthetic Agents. Technical Report KSL 96–21, Stanford University, CA.

Sacks, H., Schegloff, E. A. and Jefferson, G. (1978) A simplest systematics for the organization of turn taking for conversation. *Studies in the Organization of Conversational Interaction*, J. Schenkein (ed.), New York: Academic Press, pp. 7–55.

Searle, J. R. (1975) *Indirect Speech Acts*. Cambridge University Press.

Searle, J. R. (1979) *Expression and Meaning*. Cambridge University Press.

Searle, J. R. and Vanderveken, D. (1985) *Foundations of Illocutionary Logic*. Cambridge University Press.

Shoham, Y. (1993) Agent-oriented programming. *Artificial Intelligence* **60** (1): 151–92.

Sinclair, J. and Coulthard, M. (1975) *Towards an Analysis of Discourse*. Oxford University Press.

Sowa, J. F. (1984) *Conceptual Structures: Information Processing in Mind and Machine*. Addison-Wesley.

Stein, A. and Thiel, U. (1993) A conversational model of multimodal interaction in information systems. *Proc. 11th National Conference on AI* (*AAAI'93*), AAAI Press, Menlo Park, CA.

Steiner, D., Burt, A., Kolb, M. and Lerin, C. (1993) The conceptual framework of MAI²L. *Pre-Proceedings of the 5th European Workshop on Modeling Autonomous Agents in a Multi-Agent World*, *MAAMAW'93*, K. Ghedira and F. Sprumont (eds.) Institut D'Informatique et Intelligence Artificielle, Université de Neuchâtel, Cote #RI-93/8–1, pp. 1–11.

Traum, D. R. and Hinkelman, E. A. (1992) Conversation acts in task-oriented spoken language. *Computational Intelligence* **8** (3).

Trognon, A. and Brassac, C. (1993) L'enchaînement conversationnel. In *Les Cahiers de Linguistique Française*, J. Moeschler (ed.), pp. 76–107.

Vanderveken, D. (1994) *Principles of Speech Act Theory*. Tokyo.

Winograd, T. and Flores, F. (1986) *Understanding Computers and Cognition: A New Foundation for Design*. Norwood, NJ: Ablex.

Wittgenstein, L. (1958) *Philosophical Investigations*. Oxford: Blackwell.

https://doi.org/10.1017/S1351324997001411 Published online by Cambridge University Press