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Modelling Planning and Interaction in the Framework of Human Cooperative Problem Solving

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Abstract

This article deals with a human model of cooperative problem solving based on a psychological experimentation. Our main goal is to improve the design of open multi-agent systems able to interact with human beings. We aim at analyzing, modelling and simulating human capabilities of planning and interacting in a cooperative problem solving context. Our planning model uses the BDI concepts extended with the notions of phases, states of mind, strategies and tactics. Our interaction model is twofold: 1) it is based on the Speech Act theory to represent the utterances; 2) it uses a discourse model, represented by timed automata, to describe the dynamics of human conversations. This paper goes on to present an original architecture called BDIggy *where interaction and planning are linked homogeneously.*

Keywords: *Cognitive modelling, cooperative problem solving, human planning, human interaction, BDI agents.*

1. Introduction

In this paper we argue that the study of human reasoning and interaction is useful to build systems able to well interact with human beings. In fact we share the idea that computers should be adapted to human communication and reasoning processes. Thus, our research is at the confluence of Multi-Agents Systems (MAS) and cognitive modelling fields. Cognitive modelling is necessary to understand the way human beings solve problems (particularly in a cooperative context) whereas MAS provide a framework to formalize interaction between human and/or artificial agents. Our long term goal is twofold: on the one hand, build a complete model of human planning with coordination between agents; on the other hand, design an interaction language that allows artificial and human agents to communicate.

The study presented here is narrowed to a particular application: human subjects have to solve a planning problem where information is incomplete and thus they have to interact with the others to obtain the missing information. Consequently, we are interested in a cooperative planning problem where the interaction is made thanks to written dialogs dealing with information search.

We have set up a psychological experimentation to obtain experimental protocols (record of the performed actions and the verbal utterances) which have been analyzed from the point of view of human planning [6] and human interactions [7].

This article summarizes the results of our analysis. It shows how these two components, namely planning and interaction, can be integrated in an homogeneous agent architecture.

Among existing models of agent, the BDI (Belief, Desire, Intention) ones offer an interesting framework to design cognitive (*i.e* deliberative) agents able to plan and interact according to their mental states. The BDIggy architecture we propose is a merging of our Iggy system which performs an individual problem solving and the BDI architecture extended to a cooperative problem solving.

This article is organized as follows: Section 2 describes the application we chose and the psychological experimentation we have set up. Section 3 emphasizes our model of human planning. Section 4 details our model of human interaction. Section 5 sketches the BDIggy architecture including planning and interaction. Section 6 discusses related work while Section 7 concludes this paper.

2. The Experimental Framework

2.1. The Problem to be Solved

To study human mechanisms of planning and communication, it is necessary to observe how the subjects reason and interact to solve a problem. We have set up a psychological experimentation related to a travel-agency application. Three salesmen work in a travel agency and have different skills: the first one is specialized in planes, the second in railways and the last one in taxis and coaches. Each of them has to organize a journey for his client. These journeys are characterized by a departure and an arrival point in France, a date and a time of departure, a date and a time of arrival, a number of travellers to be booked and a budget. None of the journeys can be arranged using a single means of transport. Each agent has, therefore, an individual problem to solve but they all participate in solving the other two problems. To communicate, the subjects use e-mails written in natural language. Consequently, each human subject has to act:

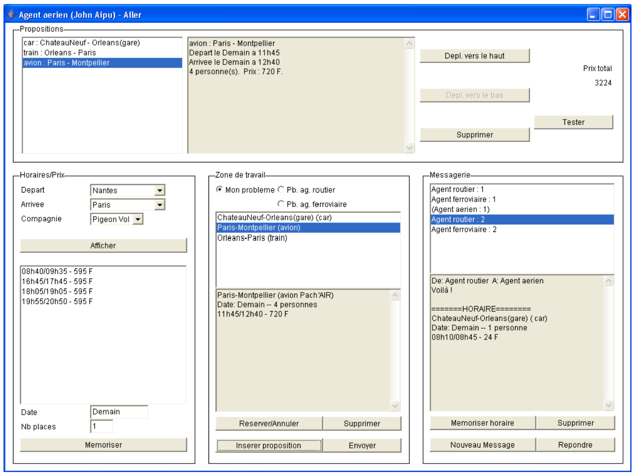
- **individually**, each subject solves his own problem:
  - the subject is used to the problem environment so that he can concentrate on how to solve it,
  - the information is incomplete in order to force the subject to plan and to search the information,
  - the subject must comply with the problem constraints.
- **collectively**, the subjects must cooperate if they want to solve their problem:
  - the subjects have complementary skills,
  - the subjects can interact thanks to a written communication (e-mail) in natural language.

2.2. The Experimentation

The subjects are isolated in different rooms and the three problems have to be solved simultaneously. They are provided with a user-interface (see figure 1) we designed to be as convenient as possible.

This user-interface is divided into four areas to help the subjects during problem solving: a panel to consult the timetable and price databases, a working panel to arrange journeys, a solution panel to propose and test a solution and a communication panel to send and receive e-mails.

All the subjects' actions are recorded by the simulation program and written in text files. The subjects were asked to solve their problem by thinking aloud and these simultaneous verbal utterances called *verbalizations* are recorded by an experimenter. The text files and the verbalizations are called *experimental protocols*. Our cognitive model is based on the analysis of these protocols.



car : ChateauNeuf - Orleans(gare)
train : Orleans - Paris
avion : Paris - Montpellier

avion : Paris - Montpellier
Depart le Demain a 11h45
Arrivee le Demain a 12h40
4 personne(s). Prix : 720 F.

Prix total 3224

Depart: Nantes
Arrivee: Paris
Compagnie: Pigeon Vol

08h40/09h35 - 595 F
16h45/17h45 - 595 F
18h05/19h05 - 595 F
19h55/20h50 - 595 F

Date: Demain
Nb places: 1

● Mon probleme ○ Pb. ag. routier

ChateauNeuf-Orleans(gare) (car)
Paris-Montpellier (avion)
Orleans-Paris (train)

Paris-Montpellier (avion Pach'AIR)
Date: Demain -- 4 personnes
11h45/12h40 - 720 F

Agent routier : 1
Agent ferroviaire : 1
(Agent aerien : 1)
Agent routier : 2
Agent ferroviaire : 2

De: Agent routier A: Agent aerien
Voilà !

=======HORAIRE========
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Date: Demain -- 1 personne
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Figure 1. The workspace

To reduce the difficulties caused by interface and problem particularities, the subjects started with a simple test problem to get used to the environment.

This experimentation was carried out with twelve groups of three students. These thirty-six protocols were then split into two classes: the first one (eight groups of three) was analyzed to build the model and the second one (four groups of three) for the validation of the cognitive model.

3. A Model of Human Planning Implemented by the Iggy System

This section presents the model resulting from the analysis of the protocols. This analysis focuses on planning.

3.1. The Cognitive Model

Our first model is the individual human planning model implemented by the IGGY system [8]. It was validated in [9] and extended in [6] to suit our current planning problem in a cooperative context.

3.1.1. The Phases The *phases* differentiate the normal and the abnormal situations. The problem-solving process does not develop smoothly and "obstacles" can appear. Two kinds of obstacles are distinguished: some need minor corrections and others constitute a deadlock to be removed.

Each protocol can be divided into phases that are:

- a planning phase to build plans,
- a correction phase to partly correct a plan,
- a deadlock solving phase to replan the current solution,
- a checking phase to check the plans built,
- a test phase to propose a complete solution,
- and a cooperation phase where the subjects help the others solve their problem.

3.1.2. The States of Mind The decision to perform any particular action depends on the attention paid to the different constraints. Moreover, the subjects act according to criteria linked to the constraints. Thus, we defined five criteria related to the five problem constraints:

- price criterion, the subjects paid attention to the pricing of the different stages of the journey,
- timetable compatibility criterion, the timing of two contiguous stages had to be compatible,
- transfer criterion, the focus is on the transfers that had to be undertaken between two contiguous stages,
- time criterion, the subjects checked that the departure and the arrival times were respected,
- reservation criterion, the subjects wanted to book the stages of their circuit as soon as possible.

The subjects did not take all these criteria into account at the same time but only a subset of them. This subset, called *state of mind*, evolves according to the problem-solving situation (acquired information) and its changes triggered modifications in the subject's behavior.

3.1.3. The Strategies The subjects actually used planning to solve their problem and this planning was done in a sequential way or in a parallel way. Two approach strategies have been observed:

- parallel planning
- sequential planning

Moreover, the order in which plans were built varied according to the subjects. There are four planning strategies:

- prospective planning: from the departure point to the arrival point
- retrospective planning: from the arrival point to the departure point
- centrifugal planning: by beginning with the stages in the middle of the journey
- centripetal planning: by beginning with the stages at the extremities of the journey

3.1.4. The Tactics The same strategy can be instantiated through different atomic actions. In order to differentiate between these different choices, our model introduces the notion of tactics which concerns the planning strategies.

There exists tactics for choosing the different stages of the journey (journeys via the largest towns, the most direct journeys, ...), tactics for choosing the means of transport (the cheapest means of transport, the fastest means of transport, ...).

3.1.5. The Observations During the solving process, any change in each of the ingredients (phase, state of mind, strategy or tactic) corresponds to a new episode. We assume that these changes, called *observations*, are triggered by the evaluation from the subjects of the current situation of the problem (the journey is too expensive, there exists a railway station in Saint-Martin, the time of this plane does not work with the current solution, ...). These observations are represented by first order predicates.

3.1.6. The Personality (or Profile) of the Subject The personality represents the individual differences between subjects. Six features are directly related to our problem:

- careful, according to the frequency of careless mistakes made by the subject;
- thrifty, according to the importance attached by the subject to the price of the configuration;
- opportunistic, according to the subject's ability to use information flexibly;
- systematic, according to the subject's ability to perform action in the same order;
- good estimator, according to the subject's aptitude to estimate a situation correctly;
- cooperative, according to the subject's aptitude to cooperate with the others.

All of these features can take the values poorly, fairly or greatly.

3.2. The Iggy System

To implement the individual human planning model, we built the system called IGGY [8] written in Common Lisp. It is a generator of protocols that takes as input a problem and a personality and gives as output a simulated protocol. The model we set up has been validated thanks to a Turing test [9].

4. A Model of Human Interaction

The experimental protocols have been analyzed from the interaction point of view. Our focus is the sending and receiving of messages, without taking into account internal actions such as data query or reservation.

4.1. The Utterance Level

The first results obtained were presented in [7], where a list of primitive performatives was proposed. These performatives were selected among either KQML [13, 16] or FIPA-ACL [14] performatives before being adapted to remain faithful to the experimental protocols.

If we refer to Searle's classification [21][1], the performatives observed come from the three following classes: the *descriptives* (also called *assertives* or *representatives*), the *directives* and the *commissives.* There are no *declaratives*, which is not surprising according to the studied problem: All the exchanged messages contain information but the world does not change when they are uttered. Moreover, we consider that the *expressives* are not necessary, because an expressive is no more than a particular descriptive: the description of one agent's feelings is the description of one part of the world, even if it is an introspection.

All the performatives listed here are issued from real conversations:

- **Descriptives:**
  - *inform*: A gives a piece of information to B.
  - *reply*: A answers B,
  - *reply-achieved*: A confirms to B that the requested action has been carried out,
  - *error*: A does not understand one of B's previous messages.
- **Directives:**
  - *achieve*: A requests B to carry out an action,
  - *query*: A asks B for a piece of information,
  - *refuse-information*: A tells B that he does not accept his information proposal,
  - *refuse-action*: A tells B that he does not accept his action proposal,
  - *cancel*: A tells B not to take into account a previous message.
- **Commissives:**
  - *propose-information*: A proposes to give information to B,
  - *propose-action*: A proposes to perform an action for B,
  - *reply-later*: A warns B that he will answer later.

This list is exhaustive in sofar as we are interested only in information-search dialogs.

One can note that the illocutionary force and its proposition (noted $F(P)$ in the Speech Act theory) are closely linked, so are the performative and its contents. In our model, a message content is represented by a mental state applied to a predicate and consequently an utterance is represented by a performative applied to a mental state the scope of which is a predicate:

- A *descriptive* is applied to a *believe*: it describes the way the speaker perceives the world. It corresponds to its *beliefs* which fits the world if the descriptive is satisfied. For example, if agent A wants to inform agent B that there is a train at 9 from Angers to Paris, he can send the following message: inform(A, B, Bel(A, step(train, Angers, Paris, 9h))).
- A *directive* is applied to a *desire*: it is used when the speaker wants the hearer to do something. He has the *desire* that the world turns into a particular state and he transmits this desire as a partial plan. For instance, if agent A wants agent B to send him timetables about trains from Angers to Paris, he can write the following message: query(A, B, Des(A, step(train, Angers, Paris, ?X))).
- A *commissive* is applied to an *intention*: A speaker uses a commissive to tell the hearer that he intends to carry out an action. For example, if agent A proposes to agent B to send him train timetables for Angers-Paris trains, he can send the following message: propose-information(A, B, Int(A, step(train, Angers, Paris, ?X))).

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[1] This classification comes from the Speech Acts theory introduced by Austin [3] and formalized by Searle [21]. A detailed presentation of this theory is written by Moeschler [17].

These propositions are not sufficient to model human utterances. A complete semantics of the selected performatives in terms of beliefs, desires and intentions has to be provided.

4.2. The Discourse Level

Interactions could not be considered as a simple series of queries and answers following a rigid scheme. Indeed, each locution conducts to a huge variety of behavior from the interlocutor. In this section, we are interested in modelling this dynamics of conversations.

Our discourse analysis is based on Vanderveken's works [23] which extends the Speech Act theory to discourse. He still splits conversations into *illocutionary acts*, introduces *mental states* as basic reasoning units and call *intervention* a series of messages.

We divided the agent dialogs into interventions. Each of these interventions is guided by the discourse intention of the initiator subject, according to the first performative he sent. We classified the interventions into the five following categories: *information query*, *action query*, *information proposal*, *action proposal* and *spontaneous sending of information.* The discourse intention is directive for the first two, commissive for the two following ones and descriptive for the last one.

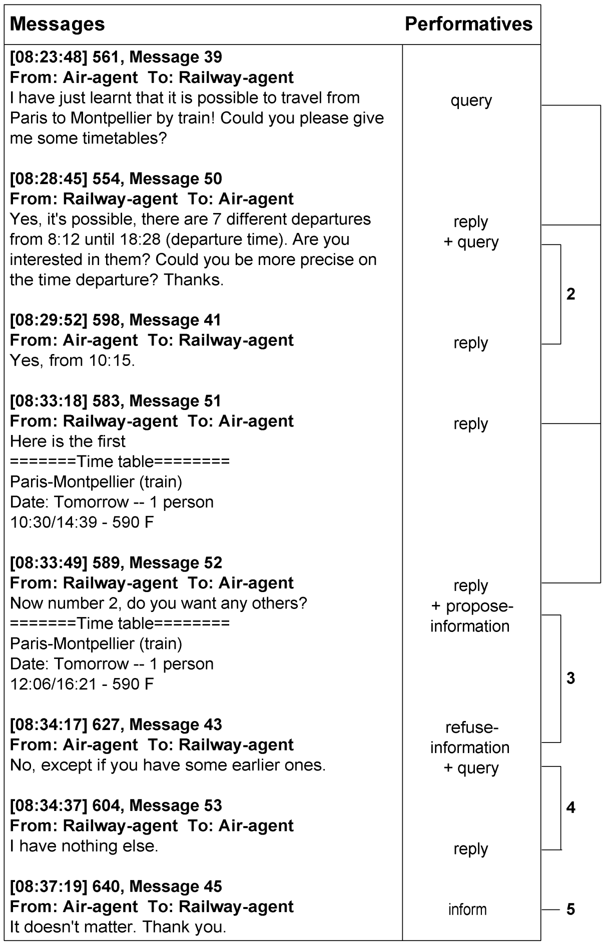
The way interventions are terminated defines their satisfaction. An intervention can be either *satisfied* (the interlocutor's goal happens) or not (the contrary of the interlocutor's goal happens or the interlocutor's goal still does not happen).

The starting performative enables us to classify the intervention and the ending performative, if it exists, defines the intervention satisfaction. Nevertheless, an intervention can be considered as terminated by the interlocutors even without explicit emission of an ending performative. In this case, we consider that the intervention has failed and so cannot be satisfied. Spontaneous sending of information needs only one main act: the starting performative.

To sum up, the next chart contains the various observed intervention types, their corresponding discourse intention, starting performative and ending performative:

Intervention type	**Discourse intention**	**Starting performative**	**Ending performative**
information query	directive	query	reply
action query	directive	achieve	reply-achieved
information proposal	commissive	propose-information	inform
action proposal	commissive	propose-action	reply-achieved
spontaneous sending of information	descriptive	inform	-

An example of a sequence of interventions is given in figure 2. The interactions between the two protagonists are written on the left part whereas the corresponding performatives can be found on the right part. The performatives are grouped into interventions thanks to the numbered brackets on the right.



Messages	**Performatives**
[08:23:48] 561, Message 39 **From: Air-agent To: Railway-agent** I have just learnt that it is possible to travel from Paris to Montpellier by train! Could you please give me some timetables?	query
[08:28:45] 554, Message 50 **From: Railway-agent To: Air-agent** Yes, it's possible, there are 7 different departures from 8:12 until 18:28 (departure time). Are you interested in them? Could you be more precise on the time departure? Thanks.	reply + query
[08:29:52] 598, Message 41 **From: Air-agent To: Railway-agent** Yes, from 10:15.	reply
[08:33:18] 583, Message 51 **From: Railway-agent To: Air-agent** Here is the first =======Time table======== Paris-Montpellier (train) Date: Tomorrow -- 1 person 10:30/14:39 - 590 F	reply
[08:33:49] 589, Message 52 **From: Railway-agent To: Air-agent** Now number 2, do you want any others? =======Time table======== Paris-Montpellier (train) Date: Tomorrow -- 1 person 12:06/16:21 - 590 F	reply + propose-information
[08:34:17] 627, Message 43 **From: Air-agent To: Railway-agent** No, except if you have some earlier ones.	refuse-information + query
[08:34:37] 604, Message 53 **From: Railway-agent To: Air-agent** I have nothing else.	reply
[08:37:19] 640, Message 45 **From: Air-agent To: Railway-agent** It doesn't matter. Thank you.	inform

Figure 2. Example of an intervention sequence

From our point of view, when the interlocutors do not meet any interpretation problem for an utterance (a non-expected event), they conduct the current intervention as a governing dialog. Otherwise, they initiate an incidental dialog to solve the problem, looking for a common interpretation. When this common interpretation appears, they reactivate the suspended governing dialog.

In the example, intervention 1 is a governing intervention. It can be classified as an information query because of its starting performative (a query). Its ending performative (a reply containing the requested information) indicates that the intervention is satisfied. Intervention 2 is an incidental information-query dialog. Intervention 3 is an information proposal, intervention 4 is an information query and finally intervention 5 is a spontaneous send of information.

In the particular case of our application, where messages are e-mails, time is primordial to take into account re-queries and to terminate an intervention. For example, when an agent needs a piece of information or an action from another agent, if he still has not received any answer after a certain time, he will re-ask for his action or information. Similarly, intervention without any explicit ending speech act should be considered as terminated after a certain time. We model these exchanges of messages and the temporality as well, thanks to timed automata [2] which helps the agent

- to generate a message: they are produced following an automaton. When there is a choice, the decision is made according to the current step and the subject's personality.
- to interpret a message: an automaton describes the expected messages depending on the interlocutors' states of mind. Two interlocutors can manage many interventions simultaneously so this expected event helps to know if a message belongs to an intervention or another.

We have constructed a pair of automata (an automaton for each interlocutor) for each type of intervention. In this article, due to the lack of place, we present only the case of information query. The next figure (see fig. 3) describes all the possible interactions we have observed in our experimental protocols which follow an information query.

The first automaton (called A_1) describes the behavior of the intervention initiator (A) whereas the second one (called A_2) represents his interlocutor (B). To manage with time, A_1 respectively A_2 contains a clock t respectively h and a deadline $tsync$ respectively $hsync$ before A respectively B considers the intervention is terminated. A_1 also contains a counter m to count how many times A has to re-ask for a piece of information before perhaps receiving an answer from B.

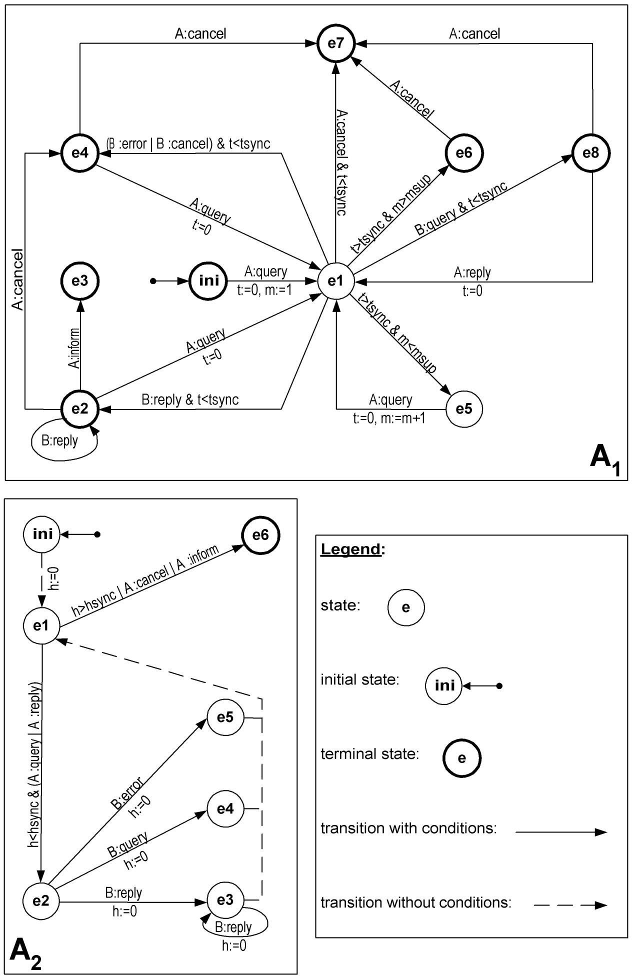


Figure 3. The two automata describing an information query

In A_1, A sends an information query (state e1). If A receives an answer in one or more messages (state e2), if this answer is satisfactory, he can either do nothing or thanks B (state e3). The current intervention is therefore satisfied, even without any explicit end message. On the other hand, if B's answer is incomplete or inappropriate, he can either leave the intervention explicitly (state e4) or not, or he can re-formulate his query (state e1). If A waits during $tsync$ without any answer from B (state e5), he increments m and re-asks B for information. If it happens too frequently (state e6), he can leave the intervention telling B (state e1) or not. If A does not need anymore for the information, he can send a cancelling message (state e7). If B asks A for more information about his query (state e8), an incidental dialog of information query is created, which is similar to the current one but B becomes A and *vice-versa*. The incidental dialog can be satisfied and the governing intervention is re-activated (state e1), or it can failed and A cancels his query explicitly (state e7) or not. B can also tell A either that he cannot satisfy his query, or that he should not be concerned by the message, or that the information query should be stopped (state e4). This last case only happens if the current intervention is an incidental dialog. The intervention is therefore leaved explicitly or not and it failed.

In A_2, B is working (state e1) when he receives a question from A (state e2). If he can understand it, he answers it with as many messages as necessary (state e3). If the question is incomplete, he asks for more information (state e4) and starts the incidental dialog of information query previously presented. If he cannot answer A, he sends A an error message (state e5). Whatever the answer he sent, he waits for a confirmation from A that he had well interpreted A's query. If he receives a cancel message, an information message or if he receives no answer (state e6), he considers the intervention as terminated.

Thus, timed automata are a powerful formalism to take into account the interleaving of the dialogs (state e8 in A_1) and time management in the conversation representation.

5. The BDIggy Architecture

Our goal is to design a system which simulates the experimental protocols we obtained. The agent architecture we propose to compute our planning model and our interaction models is based both on our Iggy system presented in Section 3 and on a BDI architecture extended in a multi-agents framework.

The BDI agents were introduced by Bratman [5], but there exists many other BDI systems such as Rao and Georgeff's one [19]. Further references to BDI model are based on dMARS [12][2].

A BDI agent includes a *queue of events* which buffers internal and external events occurring in the system, some *beliefs* (the agent's knowledge), a library of plans (the know-how of the agent), some stacks of *desires* (the agent's goals) and some stacks of *intentions* (instanced plans to reach the goals). The BDI-interpreter cycle runs as follows: first of all, events are updated generating new beliefs. Then, new desires are calculated matching plans of the library with the beliefs. One of these plans is selected for execution and put into the intention stacks. Finally, an intention is selected and its plan whose internal actions add and/or delete new events, is performed and so on.

Our BDI architecture (see figure 4) called BDIggy includes:

- a perception module as interface between the Iggy system and the environment that generates a set of observations,
- an Iggy model which generates an episode described by some observations, a phase, a state of mind, some strategies and some tactics,
- a desire generator which interprets an episode as desires (goals as abstract plans); this module embodies a representation of the current plans,
- an intention generator which refines a desire into intentions,
- an execution module which carries out necessary actions of an intention,
- and a communication module allowing the agent to interact; this module is used by the perception module to interpret received messages and by the execution module to write messages; it contains our utterance model and our dialog model.

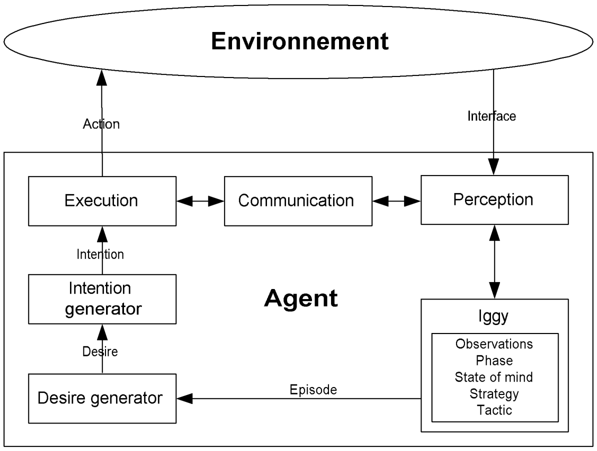


Figure 4. Architecture BDIggy

In comparison with a classical BDI architecture such as JACK [19] based on the dMARS model, we added a communication module and we proposed some changes:

- the queue of events is replaced by the perception module that synthesizes the changes of the environment,
- the observations issued from the Iggy module are similar to beliefs which would have been filtrated according to the situation.
- plans are here dynamically constructed by Iggy: the strategies and the tactics are an abstract description of a plan class.

The main advantages of our architecture are that on the one hand it includes a communication module to cooperate with other agents and on the second hand plans are not fixed *a priori* but are dynamically generated according to the environment changes: it simulates

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[2] see [15] for more information or references on BDI agents.

how humans construct plans in an opportunistic manner. Moreover, communication and planning are represented in a homogeneous way (*i.e* BDI) in the same system.

6. Related Work

Our study deals with three main issues: cognitive modelling, human cooperative planning and human interaction. To our knowledge, there is no work integrating all these three aspects.

Allen, Blaylock and Ferguson propose in [1] a model for collaborative agents which integrates an individual problem-solving model, a collaborative problem-solving model and an interaction model in natural language. Even if it does not include explicitly a BDI model, the notions used (*situations*, *objectives* and *recipes*) are very similar. The main drawback of this model is that, it is based on authors' intuitions about human planing and human communication and not on a real experimentation.

The Bouzouba and Moulin's point of view adopted in [4] is similar to ours but they are only concerned with a communication model. They propose to extend KQML to KQML+ in order to suit better to the Speech Act theory. They are inspired by human conversations to design their performatives but without using a real corpus.

From the computational point of view and as far as communications are concerned, there are many sorts of formalism to represent a conversation. KQML [13, 16] and FIPA-ACL [14] propose some communication protocols which cannot take into account the dynamics of human communications. The Dooley Graphs presented by Van Dyke Parunak in [18] also contain information about the situation and the protagonists of a conversation. But they neither take into account the time dimension for the conversational dynamics. Our modelling by means of timed automata has been motivated by the need to represent duration associated with communicative actions and to be able to synchronize interactions inside interventions.

7. Conclusion and Perspectives

The models we have proposed in this article are based on the analysis of the protocols issued from a psychological experimentation. They describe human planning and human interaction as faithfully to the protocols as possible.

These models represented homogeneously are integrated in a same architecture called BDIggy.

Moreover, it improves classical BDI architecture by including a communication module to generate and interpret the messages and is able to construct dynamically plans.

Work in progress aims at providing a complete semantics in terms of beliefs, desires and intentions for the performatives we have selected. We can rely on the existing works of Cohen and Levesque [10], Dignum [11], Singh [22], Sadek [20] and Guerra-Hernndez [15].

We use timed automata which are a powerful formalism to introduce recursiveness and time management in the conversation representation. We work to parameterize these automata to keep only three for the information-query dialogs.

Moreover, once BDIggy would be implemented, our cognitive models have to be validated by comparing the experimental protocols and the artificial protocols generated by simulation.

At a longer term, we are interested in interpreting and generating messages in natural languages and in taking into account the linguistic phenomenon of indirect speech acts.

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