

# A BDI Architecture for High Level Robot Deliberation

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## ABSTRACT

In this work we present a BDI agent architecture used for high level reasoning agents that control mobile robots that play soccer. This architecture is build on top of layered system, where each of these layers is associated with a different level of abstraction. The proposed approach allows the specification of declarative goal driven robot behavior, that uses sophisticated high level reasoning and reactivity when needed. The elements of mental components are studied with their interaction and their syntaxis and semantics are defined.

## 1 INTRODUCTION

The development and implementation of any type of computational system requires an adequate analysis of requirements that allows the definition of the system that will be modeled, restrictions imposed (be them on requirements or on the specification), and performance parameters by which the behavior of the system can be evaluated.

Robotic soccer is a way of putting different developments in intelligent agents into practice. This includes developments in autonomous, cooperative, competitive, reasoning, learning, and revision systems [15, 9]. Furthermore, it is useful in identifying problems related to aspects concerned with vision and communication. This type of problems cannot be all taken into account beforehand, and therefore demand that the system be designed in to be robust enough to recover from eventualities of this type. Robotic soccer is a complex domain, and it is necessary to take into account several aspects related to the robots. Each robot has sensors and effectors which are prone to failure. The environment is dynamic so there is no chance of knowing in advance the situations that can arise in a game. Therefore, it is necessary to be able to recover from adverse situations like sensorial or effectorial failure, and the decisions needed to carry out the recovery process have to be taken quickly.

As mentioned above, mobile robots involved in complex environments, such as robotic soccer, require high degree of intelligence integrated with lower level capabilities. Robots

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should be able to react quickly in a highly dynamic environment and also to reason about strategies and robot behavior at a high level. Therefore, a robot may need to decide which action (move forward, rotate, etc.) to execute next, in order to progress in the desired direction. For example, it may decide to move forward if it is facing the desired location, or it may decide to rotate in order to end looking the goal (desired location). However, it may also need to decide among different strategies or possible high level behaviors. As an example, a robot may need to decide whether to try to go after the ball or to stay in a defensive position, among other possibilities.

The system designed and implemented for controlling the robots need to take into account the characteristics of the environment, and also reaction capabilities and robot behavior requirements. Therefore, the system controlling the robots need to be able to combine reactive response with high level behavior.

In this work, we present the design used as the basis for a Multi-Agent System implemented for the control of a team of robots for the VI Argentine Championship of Robot Soccer (CAFR 2008 [1]). The implementation of the system was carried out following a layered design; the objective is to have a set of Service Layers, each of which is associated with a different level of abstraction. Each layer solves a different set of problems by means of the services that it offers; these services can then be used by the upper layers.

In particular will present and formally define a BDI architecture for high level control the mobile robots. This architecture will represent the higher level of layered system. The proposed architecture will use logic-based model of the knowledge representation and reasoning. The Logic language selected provides a useful tool for the implementation of reasoning systems that offer the possibility of rapid prototyping of agents and declarative design. The desire model of this approach allows a declarative way to express high level strategies, and to select between them in an elegant way. Intention rules and its application complete the agent architecture. The intention model will allow the developer to specify the situations where a plan is applicable in a declarative manner. Moreover this model will allow the agent to use its internal state as part of the reasoning process, and to handle history. The approach will also contain reactive rules that allow the agent to work correctly in critical situations were fast computation is needed and a fast reflexive action is needed.

## 2 BACKGROUND

Mobile robots involved in complex environments require high degree of intelligence or high level capabilities (such as reasoning, knowledge representation, planning, agent communication) integrated with lower level primitives (such as sensor management, basic movements, obstacle avoidance, navigation, etc.). Since 2004 we have been working in mobile robotics, specially in robotic soccer. Our previous research was focused on those high and lower level areas. In particular, we have developed an obstacle avoiding system [13], research on sensorial information and basic movements [11], and a multi-agent architecture to control the robots [8]. We also have developed a robotic soccer team that participated in the E-League held in Robocup 2004.

We designed a new Multi-Agent System for implementing the control of the team. We developed the system following a three-layer architecture. The main goal of the design and implementation of this architecture was to encapsulate all the low level developments,

including the ones mentioned above, in the lower layers of the architecture and allow an easier implementation of high level capabilities in the upper layer. Therefore, AI theories developed on reasoning, knowledge representation, planning, agent communication, among others, can be tested in this real scenario. In particular, we developed a team controlled by a BDI architecture to participate in the VI Argentine Championship of Robot Soccer (CAFR 2008 [1]). The main goal of the leagues we participated in is to provide an environment where researchers, practitioners and students interact sharing knowledge and expertise while enjoying the games. The leagues provide common basic services to all of the participants, such as vision and communication. Teams can use low cost kits such as and concentrate on the development and study of Artificial Intelligence techniques, as the ones mentioned above. The most important feature of these leagues is its simple and modular structure. There are only three basic components that must be available to obtain a functional team: a vision module that works as the robot's perception component, a communication module that allows actions to be communicated to the robots, and a control module that is implemented by agents that control the robots on the field of play.

Each team has one or more auxiliary computers in which the agents are executed. These agents communicate with the vision component in order to obtain information about what happens on the field, and send messages to the robots by means of a communication module. Even though the league does not define a standard platform for the construction of the robots, it does impose restrictions over the processing and memory capacity. This allows the use of low cost robotic kits, many of which fall under these restrictions. The system we developed was implemented using Lego Mindstorms kits, which are within the rules of the league. Each team is composed of three or four robots, one of the robots acting as a goalkeeper. There are restrictions over the size of the robots, their shape, and the components used in their construction. Even though the robots do not communicate amongst themselves, the processes that control them can do so.

In the following section we will describe a multi-agent system designed to cope with these requirements, also trying to facilitate the testing of new theories developed on reasoning, knowledge representation, planning, agent communication, among others AI techniques.

### 3 DESIGN OF THE AGENT SYSTEM

The proposed design considers the construction of the system based on an hybrid architecture combining reaction with deliberation [14]. The most popular hybrid architectures is the three layer architecture (see Figure 1), which consists of a *reactive layer*, an *executive layer* and a *deliberative layer*, each of which covers different levels of abstraction of the problem to be solved. The *reactive layer* provides low-level control of the robot. The *executive layer* serves as the glue between the *reactive* and the *deliberative layer*. It accepts directives by the *deliberative layer*, and sequences them for the *reactive layer*. The *deliberative layer* is responsible for controlling the robot behavior by taking high level decisions.

As will be explain next, each layer provides services to the upper layer, which are implemented using those provided by the lower layer. Therefore, this layered design allows local modifications. Thus, the implementation of some services can be modified without provoking many changes in other layers using these services.

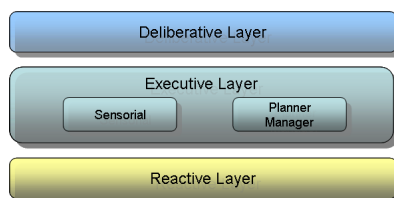


Figure 1: architecture used for the implementation of the Matebots team.

### 3.1 Reactive layer

We associate with this layer the program running inside the robots and implementing the basic actions they need to be able to act in a dynamic environment such as robotic soccer. This layer also includes the basic hardware and software support that is provided by the league. This involves physical support, such as infrared transmitters, video camera, communication network, and common software. The software that is provided by the league includes video and command communication servers.

This layer provides basic actions to the executive layer in order to allow the construction of specific sequences of actions with a determined goal, such as going to the ball. The basic actions implemented inside the robots include three generic movements: moving forward and backward, rotating clockwise or counterclockwise and describing different kinds of arcs. These actions may also vary in the velocity of the wheels, allowing the robots to execute movements with different speeds and precision.

The video server, called *Doraemon* [3], is part of the software support provided by the league. A video camera covers the field of play and this server processes the images that it obtains, generating information packets that are then made available to be used by the agents that control both teams' robots. The packets that are generated by the video server provide information about the objects that are on the field of play. Information about the position, orientation, and speed of these objects (the robots and the ball) is transmitted. This information will be captured and processed by the executive layer, as we will explain in the following subsection.

The league also provides a command communication software called *Command Server* (abbreviated CS from now on), which allows the agents, who control the robots, to send messages to the field. As we have mentioned, the processing and memory capabilities of the robots is limited, and the control software must therefore reside and execute on auxiliary computers. In this way, the decision processes are carried out by these agents in the upper layers, and the decisions are then communicated to the robots through the CS. The decisions communicated to the robots are the actions to execute, which, as we mentioned above, are implemented in the program running inside the robots. The frequency by which an agent can send actions to the robots through the CS is limited by the physical characteristics of the transmission method used by the robots, in our case Lego Mindstorms kits using IR.

### 3.2 Executive Layer

This layer is divided in two sub-layers, the *sensorial sub-layer* and the *planner manager sub-layer*. In the former sub-layer, the visual information is processed and translated

into information that express states of the world. This information is divided in basic information and inferred information. The latter sub-layer provides a set of implemented schematic plans allowing the *deliberate layer* to control the robot behavior without worrying about low level details.

The entire layer is implemented as an interface between the *reactive layer* and the *deliberate layer*, and has been developed in the C programming language providing PROLOG predicates for the *deliberate layer*. This decision has several advantages. As we mentioned before, the environment is highly dynamic, which causes the states of the world to change quickly. Therefore, it is necessary for the robots to be able to react accordingly to this dynamism. Moreover, the information obtained by the robots can be wrong due to sensorial failure; after recovering from such a failure, the current situation could be completely different from the one previously perceived. In this type of cases, the system has to be able to analyze new situations, and quickly decide which actions should be taken by the robots.

The *sensorial sub-layer* provides basic information (such as the coordinates and speeds of the robots and the ball), and also inferred information (elements obtained using inference rules that contain the basic information), such as: The robots' and the ball's locations relative to the field, player and/or team that is closest to the ball, distances between different objects on the field (between players, rival players, etc). This information is provided to the *deliberate layer* as PROLOG predicates, and they are implemented by querying and analyzing the information from the video server. Then, the situations modeled through these predicates are used in the *deliberate layer* to model and implement the team's game strategy.

The *planner manager sub-layer* is responsible for the execution of schematic plans. A schematic plan represents a plan in a highly dynamic environment, in which the sequence of actions needed to achieve the desired goal may vary at the moment of executing the plan. Therefore, these schematic plans are divided in several atomic actions, such as rotation and forward and backward movements, and each of these actions depend on the state of the field at the moment immediate before of been executed. The schematic plans implemented are: go to a given object (such as another robot or the ball), pass the ball to a teammate, go to a zone in the field, kick the ball, dribble to a given location, and clear the ball out of the defensive zone.

The existence of this layer allow us to disregard the physical structure of the environment in which the team of robots is embedded. For example, it is possible to implement the services of this layer based on a simulated environment like the *FIRA SimuroSot*. If the interface of the services offered by this layer remain unchanged, then the rest of the *deliberate layer* can also remain unchanged.

### 3.3 Deliberative Layer

This layer is responsible for the design and implementation of the agents that control the robots behavior. The lower layers allows this layer to obtain high level processed information, use it to decide the behavior of the robots, and finally control the robots. In the deliberative layer, as in any other agent system, the agents will have a deliberative cycle in which they perceive information about the environment and reason/decide about the *schematic plans* to take. The implementation of the *executive layer* allows to specify

the elements of the cognitive layer using different knowledge representation and reasoning systems. One alternative is to use the Belief-Desires-Intentions (BDI) model [5] to implement the agents controlling the robots. In particular, we developed a team controlled by using this architecture in order to participate in the VI Argentine Championship of Robot Soccer (CAFR 2008 [1]).

In this work will focus on that alternative, using BDI as the agent architecture used to specify the agents that control the robots. Next, in the following section we will present a detailed explanation of how the BDI architecture is used in our approach.

#### 4 ARCHITECTURE DESCRIPTION FOR HIGH LEVEL REASONING

One of the most promising agent architecture for developing intelligent agents is BDI. It is one of the most recognized and studied agent architectures in the literature [7]. The BDI framework involves two aspects in the area of intelligent agents: it is an agent theory and it is a practical agent architecture. The former is a well known agent logic based the theory of practical reasoning presented [6]. The latter is an architecture [5],[12], based on the agent logics of [6], for building agents that are able to reason about their environment and deliberate about their actions. A BDI agent is specified using mentalistic attributes Belief, Desires and Intentions, and uses these components to determine the agent state. Thus the agent will have a belief set containing information about the environment in which it is involved, a desire set containing all the possible goal that the agent have and a set of intentions containing a all the possibilities that the agent has to achieve its desires.

In this section we will show how to integrate the concepts of the BDI architecture with the lower level layers. Next we will show how the role of each mental components in our approach and introduce the syntaxis and semantics of their elements and their respective interactions. In order to do so, we will introduce the following working example, which describes a particular situation in the match.

**Example 1** Consider an agent belonging to the blue team is playing against the yellow team (see figure 2). Its team is loosing the match 0 - 2. Currently the agent (labelled “me”) is moving towards the opponent area and is located in the left part of middle field, its teammate “b1” is carrying the ball and its located in the right part of the middle field, one of its opponents “y1” is located in the right part of the middle field and the other opponent “y2” is located in the center of the yellow team penalty area.

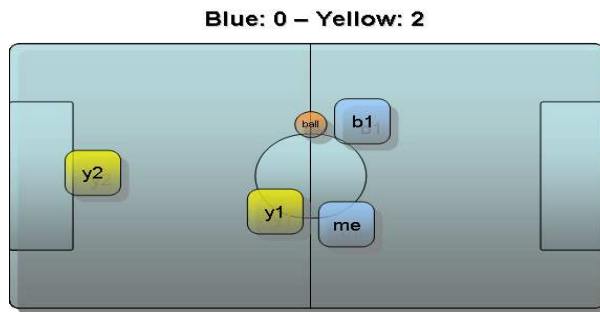


Figure 2: Situation of example 1

## 4.1 Beliefs

The beliefs of the agent in the BDI Architecture are used to represent situation of the world that the agent is in. In this approach beliefs represent are all the information that the agent obtains from the field each deliberative cycle. As explained in previous subsections it is divided in basic information (elements directly perceived from the field like X,Y coordinates) and inferred information (elements obtained using inference rules that contain the basic information, like the best place to attack).

A mobile robot should be able to work in dynamic environments with incomplete knowledge of their environment. This involves information about the objects of the world and a degree of uncertainty of the effects of their actions. Therefore, the robots will need a formalism to reason about this incomplete, uncertain, and changing information. In order to address those issues, we will use a logic formalism to obtain the elements that the agent believes in the deliberative cycles. In particular will be used PROLOG as the knowledge representation language and as belief inference mechanism. This introduces interesting advantages for the agent developer such as declarativity in the belief program specification and non-monotonic reasoning for the agent inferences.

The beliefs of our agent will be represented by a PROLOG program. The belief base of an agent can contain sensed information such as field (X,Y) coordinates of an object, distances between objects, direction that a robot is facing, or if a robot has the ball; strict information such as which robots are teammates, or which robots are opponents; and inference rules to obtain inferred information such as the empty spots in the field or the best places to dribble. Next we will define the belief base of an agent considering these information categories.

**Definition 1 (belief base)** *The belief base of an agent will be a PROLOG program  $\mathcal{P}_b=(\phi, \pi,\delta)$ , where  $\phi$  is a set of PROLOG facts used to represent sensed information,  $\pi$  is a set of PROLOG facts used to represent strict information and  $\delta$  is a set of PROLOG rules used to obtain inferred information.*

**Example 2** *Consider the situation depicted in figure 2, there the agent from example 1 will have the following set of sensed information  $\phi_1=\{hasBall(b1), pos(middle, right, b1), pos(middle, left, me), pos(middle, left, y1),pos(opPenBox, center, y2), loosing\}$ , as strict information will will have the following set  $\pi_1=\{teammate(b1),opponent(y1),opponent(y2)\}$ , and suppose that has the following inference rules (sketch)  $\delta_1=\{$*

*offensiveZone(opPenBox, Opdir) :  $\neg$ teamMate(X), pos(Zone, Dir, X), opositeDir(Dir, ODir)*

*defensiveZone(Zone, Opdir) :  $\neg$ teamMate(X), pos(Zone, Dir, X), opositeDir(Dir, ODir)*

*blocked(X) :  $\neg$ pos(Zone, Dir, me), pos(Zone, Dir, X), opponent(X)*

*\}. Thus its belief base will be  $\mathcal{P}_b = (\phi_1, \pi_1, \delta_1)$*

The facts of the set  $\phi$  are updated every deliberative cycle by the sub-sensorial layer. Since this sensorial information surely will be used by the inference rules the inferred information can also change every deliberative cycle. In order to be useable by the other mental components, next, we will define which elements are obtained from the  $\mathcal{P}_b$ .

**Definition 2 (actual belief)** *Let  $\mathcal{P}_b=(\phi, \pi,\delta)$  be a belief base of a agent, The PROLOG atom  $h$  is an actual belief from  $\mathcal{P}_b$  (noted  $\mathcal{P}_b \vdash h$ ) iff  $h \in \phi \cup \pi$  or  $h$  can be obtained via a PROLOG derivation using the rules of  $\delta$  and the PROLOG inference mechanism. If it is the case that an atom  $h$  is not a actual belief from  $\mathcal{P}_b$  it will be noted  $\mathcal{P}_b \not\vdash h$*

**Example 3** *The agent with a belief base presented in the example 2, will have the following actual beliefs:  $offensiveZone(opPenBox, right)$ ,  $defensiveZone(middle, right)$ ,  $blocked(me)$  and the elements of  $\phi$  and  $\pi$ .*

The belief base will provide the other mental components with the *actual beliefs* to do their computations and decide how to act based in the situation in which the agent is in. The computation of an actual belief will be made by demand of the requesting component. Thus the agent will be able to reason using a non-monotonic approach and act reactively in a efficient way because the belief elements will be only calculated when needed without adding overhead to the overall deliberative cycles.

## 4.2 Desires

The desires in the BDI architecture represent what the agent wants to do. In this work desires will represent high level attitudes that the agent will try to achieve during the match, for instance attack, defend or score a goal. The agent will have a number of desires that it will be continuously trying to achieve. However, depending on the situation in which it is involved, there are desires can be justified or not. For instance, if the agent has the ball and is loosing the match, then, the desire defend is not quite adequate, whereas attack is a plausible option. Therefore, agents should reason about their desires to select the ones that could be actually justified or selectable. In order to specify this desire behavior, next, we will introduce the desire rules, which are used to determine when a desire is justified.

**Definition 3 (desire rule)** *A desire rule is a triplet  $DR=(d, Just, Imp)$ , where  $d$  is an atom representing a desire, and  $Just=\{p_1, \dots, p_n, not\ c_1, \dots, not\ c_m\}$  ( $n \geq 0$  and  $m \geq 0$ ) is formed by a set of atoms  $\{p_1, \dots, p_n\}$  representing belief preconditions and a set of extended atoms  $\{not\ c_1, \dots, not\ c_m\}$  representing belief restrictions, and  $Imp$  is a number denoting the importance value of the rule desire.*

Since desire rules involve belief and desires and both of them are atoms we will assume that beliefs and desires are represented with separate names. Hence, a desire cannot be perceived or derived as a belief. All the specified desire rules determine the agent *desire base* noted  $\mathcal{P}_d$ . Note that the set  $D = \{\bigcup d \mid (d, Just, Imp) \in goalbase\}$  contains all the possible desires that the agent have.

**Example 4** *The agent desire base(sketch) is*

$$\begin{aligned} \mathcal{P}_d = \{ & (attack, \{hasBall(me), loosing\}, 20) \\ & (attack, \{hasBall(X), teamMate(X), loosing\}, 15) \\ & (defend, \{hasBall(X), teamMate(X)\}, 5) \\ & (defend, \{hasBall(X), opponent(X)\}, 20) \} \end{aligned}$$

Using these rules agent will be able to determine which of its desires are justified in each deliberative cycle. Next we will define who justified desires are computed.

**Definition 4 (justified desire)** *Let  $\mathcal{P}_b$  be a belief base, a desire rule  $DR = (d, Just, Imp)$ , and  $Just=\{p_1, \dots, p_n, not\ c_1, \dots, not\ c_m\}$  with  $n \geq 0$  and  $m \geq 0$ . Then  $d$  will be a justified desire with an importance value of  $Imp$  (noted  $[d, Imp]$ ) iff  $\forall i = 1..n \mathcal{P}_b \vdash p_i$  and  $\forall j = 1..m \mathcal{P}_b \not\vdash c_j$*



**Example 5** Suppose that an agent is in the situation described in figure 2, the belief base of example 2 and has the desires rules of example 4 then it will have the following justified desires:  $[attack,15]$  and  $[defend,5]$ .

The set  $JD$  of justified desires will contain all the desires that are justified. Notice that a desire  $d$  might be justified by several rules, if its the case the agent will only use the justified desire with higher importance value. This means that the  $JD$  will have one occurrence of each justified desire. The set  $JD$  is calculated every deliberative cycle and will allow the agent to determine whether intentions it can commit to.

This desire oriented approach allows a declarative way to express high level strategies, and to select between them in an elegant way. Moreover it allows developing agents that behave depending the match attitudes which will be based in the high level information provided by the belief base.

### 4.3 Intentions

The intentions in the BDI architecture determine what the agent can do to achieve its desires. In this work the intentions will represent the plans that the agent can execute to reach its desires, for instance if the agent desires to attack, it can have intentions to plan a dribble to the opponent area, plan a shoot to make a goal or just plan a move to the opponent area. Thus the developer will be able to specify different alternatives or intentions to achieve a desire. However, depending on the situation in which the agent is involved, there are intentions that can be applicable or not. For instance when the agent does not has the ball its not possible to dribble or to shoot. Once that the agent determine which of the intentions are applicable it should commit to one of them and execute its plan. The intentional model of the agent should contemplate that there will an executing intention. Thus, the elements that affect the intention applicability are beliefs, the running plan and the justified desires. In order to specify this intentional behavior next, we will introduce the intention rules next.

**Definition 5 (intention rule)** A intention rule  $IR$  is an ordered tuple  $IR=(\kappa, \beta, cp, \pi)$ , where:  $\kappa$  (header goal) is a conjunction of atoms representing the desire to be achieved,  $cp$  is an atom representing the running plan preconditions,  $\pi$  is a plan to be executed, and  $\beta=\{p_1, \dots, p_n, not\ c_1, \dots, not\ c_m\}$  ( $n \geq 0$  and  $m \geq 0$ ) is a guard formed by a set of atoms  $\{p_1, \dots, p_n\}$  representing belief preconditions and a set of extended atoms  $\{not\ c_1, \dots, not\ c_m\}$  representing restrictions for  $IR$ . An intention-rule  $(\kappa, \beta, cp, \pi)$  is also denoted  $\kappa \leftarrow \beta [cp] \mid \{\pi\}$ . All the specified intention rules determine the agent intention base noted  $\mathcal{P}_i$ .

**Example 6** The agent intention base(sketch) is

$$\begin{aligned} \mathcal{P}_d = \{ & attack \leftarrow hasBall(me), position(opPenBox, Dir, me) \mid \{shoot\} \\ & attack \leftarrow hasBall(me) \mid \{dribbleTo(opPenBox, Dir)\} \\ & attack \leftarrow offensiveZone(Zone, Dir) \mid \{goto(Zone, Dir)\} \\ & defend \leftarrow defensiveZone(Zone, Dir) \mid \{goto(Zone, Dir)\} \\ & \leftarrow pos(myPenArea, X, me), hasBall(me) \mid \{clear\} \} \end{aligned}$$

For instance the first rule specifies if that if the agent wants to attack and it has the ball, and is near the opponent penalty area, it will be adequate to shoot to the goal.

Note that the plans of the *IR* of the previous example are those described in section 3.2. Using these rules agent will be able to determine which intentions are applicable each deliberative cycle. Next we will how to determine which intentions are applicable.

**Definition 6 (applicable intention)** *Let  $\mathcal{P}_b$  be a belief base,  $JD$  the set of justified desires, and  $IR$  is an intention rule  $\kappa \leftarrow \beta [cp] \mid \{\pi\}$  where  $\beta = \{p_1, \dots, p_n, \text{not } c_1, \dots, \text{not } c_m\}$  with  $n \geq 0$  and  $m \geq 0$ . Then  $IR$  will be an applicable iff  $\forall i = 1..n \mathcal{P}_b \vdash p_i$  and  $\forall j = 1..m \mathcal{P}_b \not\vdash c_j$ ,  $\exists[\kappa, Imp] \in JD$ , and  $cp$  is the running plan. From an applicable intention rule, the applicable intention will be a pair  $(\pi, Imp)$*

**Example 7** *Suppose that an agent is in the situation described in figure 2, the belief base of example 2 and has the justified desires of example 5 then it will have the following applicable intentions:  $(\text{goto}(\text{opPenArea}, \text{right}), 15)$  and  $(\text{goto}(\text{middle}, \text{left}), 5)$  because the third and the fourth intention rule are applicable.*

The test if  $cp$  is the plan that the agent is currently executing, is made by an interaction with the executive layer. Note that a rule can have an empty  $cp$ , this means that the rule does not has a running plan precondition, and in this case the condition over the running plan is always met. Also an intention rule can have an empty  $\kappa$  (a reactive rule), this means that the rule does not have a desire to achieve, and will be used to represent reactive reasoning. In this case the justified desire condition is always met. The intention reactive rules will be treated differently from the other intention rules in the deliberative cycle in order to benefit agent reactivity. The set of all applicable intentions obtained from non reactive rules will be called *AI*.

Since only one intention from *AI* should be selected to execute, next we will introduce one possible criterion to select one: Let  $[IR1, \dots, IRn]$  be the sequence of the applicable intention rules of the agent, the order of this sequence is determined the rule order in the agent specification. First, select those elements of *AI* with higher value of *Imp*. If there more than one element that meet the first condition, select element obtained from first intention rule appearing in  $[IR1, \dots, IRn]$  between those elements that meet the first condition. For instance, from the example 7 the selected intention will be  $(\text{goto}(\text{opPenArea}, \text{right}), 15)$

Once an intention is selected its plan will be sent to the executive layer to be executed. However, if the sent plan of is the same as running plan the executive layer will ignore the sent one, and continue the execution of the running one.

As said above intention reactive rules will be treated differently. The applicability of the reactive rules will be computed a the start of the deliberative cycle and the first applicable (using the specification of the agent as order) will sent its plan to execution.

Intention rules and its application complete the agent architecture. These rules allow to developer to specify the situations where a plan is applicable in a declarative manner. Using the running plan as part of the conditions to determine that an intention rule is applicable, allows the agent to use its internal state as part of the reasoning process, to handle history and to establish the commitment to new alternatives for the selected strategy. The reactive rules will allow the agent to work correctly in critical situations were fast computation is needed and a fast reflexive action is needed.

## 4.4 Deliberative Cycle

In this section we will show how the mental components described previously interact each other. Next in figure 3 the component interaction and the connection with the executive layer is shown.

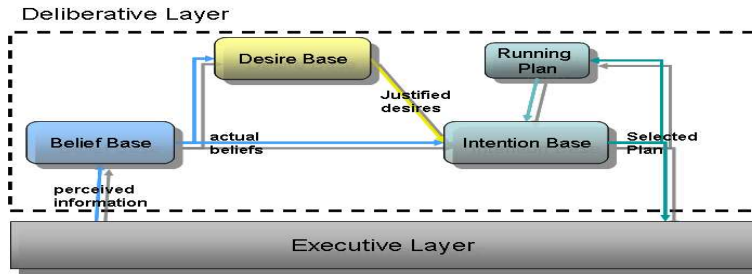


Figure 3: Mental components and Layer interaction

Next we will show a the deliberative cycle of the BDI architecture proposed in this work. The main difference with the basic BDI deliberative cycle is that in our approach the intention revision is handled inside the intention selection semantics.

1. update the perceive elements  $\phi$  in the  $\mathcal{P}_b$
2. if a reactive intention rule is applicable using only the *actual beliefs* and the *running plan*, and goto step X
3. obtain the *justified desires* from  $\mathcal{P}_a$  using the *actual beliefs*
4. obtain the applicable intentions using the *justified desires*, the *actual beliefs* and the *running plan*.
5. select one intention from the previous step using a intention selection criterion.
6. send the selected intention plan to the executive layer and set it as the running intention.

This deliberative cycle ensures a sophisticated goal oriented reasoning using the justified desires to determine the best strategies or game attitudes. The intention rules give different alternatives to achieve one of the justified desires. The definition of those elements and the deliberative cycle are combined in order to allow the agent developer to abstract of the reasoning mechanisms and concentrate in the on the match situation that trigger a game attitude and its respective plan. Furthermore the combination of the reactive intention rules, its selection policy and that the actual beliefs are computed “by demand” means allow the agent to act reactively when needed, which is very important in robotics.

## 5 CONCLUSIONS AND FUTURE WORK

In this work we have presented and formally defined a BDI architecture for high level control of mobile robots. This architecture is built on top a layered system. This layered system gives the architecture the necessary level of abstraction to do cognitive reasoning. This design allows the abstraction and modularization of the different aspects of the complex domain that robotic soccer represents.

The design of the knowledge representation and reasoning mechanisms was carried out using a logic-based model. Logic programming is a useful tool for the implementation of reasoning systems that offer the possibility of rapid prototyping of agents and declarative design. This desire oriented approach allows a declarative way to express high level strategies, and to select between them in an elegant way. Intention rules and its application complete the agent architecture. The intention rules allow the developer to specify the situations where a plan is applicable in a declarative manner. Using the running plan as part of the conditions to determine that an intention rule is applicable, allows the agent to use its internal state as part of the reasoning process, and to handle history. The reactive rules will allow the agent to work correctly in critical situations where fast computation is needed and a fast reflexive action is needed.

Having built a functional team of agents using this model to participate in the CAFR 2008 competition, we are currently working on the development of more complex agents that incorporate a wide range of AI techniques developed within LIDIA from the fields of planning, argumentation, learning, belief revision, among others.

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