BDI Agents and AgentSpeak(L)

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BDI/AgentSpeak(L)

References

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A. Rao, M. Georgeff, An abstract architecture for rational agents, Proceedings of the 3rd International Conference on Principles of Knowledge Representation and Reasoning, KRR92, Boston, 1992

R. Bordini et al, Programming MAS in AgentSpeak using Jason, Wiley, 2007

BDI/AgentSpeak(L)

Motivations:

- BDI agents are “traditionally” specified in a modal logic with modal operators to represent BDI (Beliefs, Desires and Intentions).
- Their implementations (e.g. PRS, dMARS,jason), however, have typically simplified their specifications and used non-logical procedural approaches.
- AgentSpeak is a programming language based on restricted FOL (First-Order-Logic), similar to prolog.
- AgentSpeak attempts to provide operational and proof theoretic semantics for existing implementations (and thus by a roundabout way for BDI agents)

BDI/AgentSpeak(L)

Further Motivations:

- To incorporate some practical reasoning:
  - Means ends reasoning, deciding how to achieve goals
  - Reaction to events, for example when something unexpected happens
  - Choice deliberation, deciding what we want to achieve (our intention) from amongst our desires

BDI Agents

- Systems that are situated in a changing environment
- Receive continuous perceptual input
- Take actions to affect their environment

From the various options and alternatives available to it at a certain moment in time, the agent needs to select the appropriate actions or procedures to execute.

The ***selection function*** should enable the system to achieve its objectives, given

- the computational resources available to the system
- the characteristics of the environment in which the system is situated.

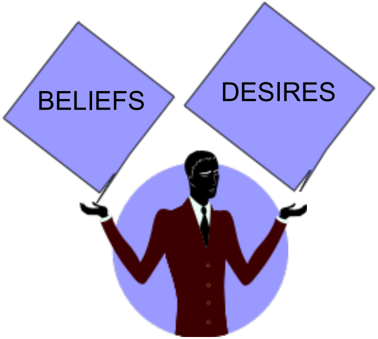
BDI Agents

- two types of input data required for the selection function:
- **Beliefs:**
  - represent the characteristics of the environment
  - are updated appropriately after each sensing action.
  - can be viewed as the ***informative*** component of the system.
- **Desires**
  - contain the information about the objectives to be accomplished, the priorities and payoffs associated with the various objectives
  - can be thought as representing the ***motivational*** state of the system.

BDI Agents

- **Intentions**
  - represent the currently chosen course of action (the output of the most recent call to the selection function)
  - capture the *deliberative* component of the system.

BDI Agents



SELECTION
FUNCTION

AgentSpeak(L)

- attempt to bridge the gap between theory and practice
- a model that shows a one-to-one correspondence between the model theory, proof theory and the abstract interpreter.

  - natural extension of logic programming for the BDI agent architecture
  - provides an elegant abstract framework for programming BDI agents.
  - based on a restricted first-order language with events and actions.
  - the behavior of the agent (i.e., its interaction with the environment) is dictated by the programs written in AgentSpeak(L).

AgentSpeak(L) and B-D-Is

SRITTI IN PROLOG

- An agent's ***belief state*** is the current state of the agent, which is a model of itself, its environment, and other agents.
- The agent's ***desires*** are the states that the agent wants to bring about based on its external or internal stimuli.
- When an agent commits to a particular set of plans to achieve some goal, these partially instantiated plans are referred to as an ***intention*** associated with that goal. Thus, ***intentions*** are active plans that the agent adopts in an attempt to achieve its goals.

AgentSpeak(L) - Basic Notions

- The specification of an agent in AgentSpeak(L) consists of:
  - a set of base ***beliefs***
    - Facts and rules in the logic programming sense
  - a set of ***plans***.
    - context-sensitive, event-invoked recipes that allow hierarchical decomposition of goals as well as the execution of actions with the purpose of accomplishing a goal.

BDI/AgentSpeak(L) Internal (Mental) State

L'EVENTO PUÒ DIRE:
- ADD A BELIVES
- REMOVE " "
- SEGUI IL GOAL

- A set of *beliefs*
- A set of current *desires* (or goals)
  - typically of the form !b where b is belief
  - interpreted as desire for state of the world in which b holds.
- A set of pending *events*
  - typically perceptions of messages interpreted as belief updates: +b, -b or as goals to be achieved: +!b
  - including request messages from other agents usually recorded as new belief events, perhaps as a new belief that the request has been made.
- A set of *intentions*
- A *plan library*. A plan has a triggering condition (an event), a mental state applicability condition, and a collection of sub-goals and actions (similar to ECA rules).

Agent nigga (L) Beliefs nigga Terms

- No modal operators
- Beliefs: a conjunction of ground literals
- adjacent(room1, room2) & loc(room1) & ¬empty(room1)
- Events: If b is an atomic belief then the following are event terms:
  - !b represents an achievement goal, e.g. !loc(room2)
  - ?b represents a test goal, e.g. ?empty(room1)
  - +b, -b representing events of adding or deleting beliefs (events generated by messages)
  - +!b, -!b
  - +?b, -?b
- Agent can have explicit goals, given by events

AgentSpeak(L) - Basic Notions

- ***belief atom***
  - is a first-order predicate in the usual notation
  - belief atoms or their negations are termed ***belief literals***.

AgentSpeak(L) - Basic Notions

- ***goal***
  - is a state of the system, which the agent wants to achieve.
- two types of goals:
  - ***achievement goals***: ground prolog-like atoms
    - predicates prefixed with the operator “!”
    - state that the agent wants to achieve a state of the world where the associated predicate is true.
    - in practice, these initiate the execution of *subplans*.
  - ***test goals****: prolog-like atoms (possibly non-ground)*
    - predicates prefixed with the operator‘?’
    - returns a unification for the variables occurring in the atom with one of the agent’s beliefs; it fails if no unification is found.

AgentSpeak(L) - Basic Notions

- ***triggering event***
  - defines which events may initiate the execution of a plan.
  - an *event* can be
    - internal, when a subgoal needs to be achieved
    - external, when generated from belief updates as a result of perceiving the environment.
  - two types of triggering events:
    - related to the *addition* (‘+’) and *deletion* (‘-’) of attitudes (beliefs or goals).

AgentSpeak(L) - Basic Notions

- ***Plans***
  - refer to the *basic actions* that an agent is able to perform on its environment.

```
p ::= te : ct <- h
```

Where:

- **`te`** *- triggering event (denoting the purpose for that plan)*
- **`ct`** *- a conjunction of belief literals representing a context.*
  - *The context must be a logical consequence of that agent's current beliefs for the plan to be applicable.*
- **`h`** *- a sequence of basic actions or (sub)goals that the agent has to achieve (or test) when the plan, if applicable, is chosen for execution.*

Triggering event

Context

```
+concert (A,V) : likes(A) <-
     !book_tickets(A,V).

+!book_tickets(A, V) :
        ¬busy(phone)
        <- call(V);
           …;
              !choose
  seats(A,V).
```

Achievement goal added

Basic action

AgentSpeak(L) - Basic Notions

- ***Intentions***
  - plans the agent has chosen for execution.
  - Intentions are executed one step at a time.
  - A step can
    - query or change the beliefs
    - perform actions on the external world
    - suspend the execution until a certain condition is met
    - submit new goals.
  - The operations performed by a step may generate new events, which, in turn, may start new intentions.
  - An intention succeeds when all its steps have been completed. It fails when certain conditions are not met or actions being performed report errors.

AgentSpeak Plans

- Each agent has its own repertoire of (primitive) actions and plan library.

Plans are ECA(Event-Condition-Action) rules of the form:

e:b1,…,bm <- h1;..;hk

e is an event term

the bi are belief terms – b1, …, bm is called context

the hi are goals or (primitive) actions

Plans are used to respond to belief update events and new goal events

AgentSpeak Plan Example

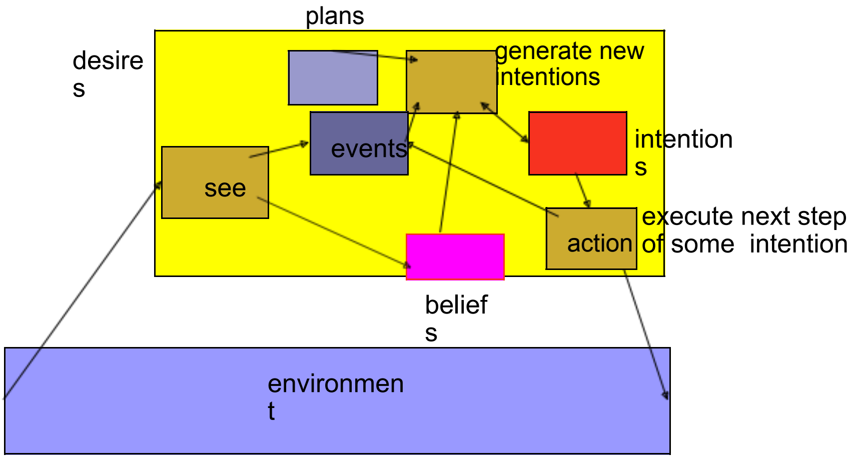
```
                              CONTESTO
+!quench_thirst:have_glass <-
         !have_soft_drink; → sotto goal
          fill_glass, drink  → azioni

+!have_soft_drink:soft_drink_in_fridge
          <- open_fridge;
             get_soft_drink
```

AgentSpeak Plan Example (cunt'd)

```
+!have_soft_drink:not soft_drink_in_fridge
            <- go_to_shop;
               buy_soft_drink
+!have_soft_drink:not soft_drink_in_fridge
            <- go_to_neighborough;
               ask_soft_drink
```

AgentSpeak Agent Cycle



AgentSpeak Agent Cycle

1. Notice external/internal changes
2. Update belief and record as events in event stores

   e.g. +!location(robot, b), +location(waste, a)
3. Choose event (from event store) or desire (from desire store for which there is at least one plan)
4. Select plan – this becomes new intention
5. Drop intentions no longer believed viable
6. Resume intention
   - Execute an action, or
   - Post subgoal as a new goal event
7. Repeat cycle

AgentSpeak(L) Syntax

```
ag   ::=  bs  ps
bs   ::=  at1. … atn.                          (n□0)
at   ::=  P(t1, … tn)                          (n□0)
ps   ::=  p1 … pn                          (n□1)
p    ::=  te : ct <- h.
te   ::=  +at | -at | +g | -g
ct   ::=  true | l1 & … & ln                  (n□1)
h    ::=  true | f1 ; … ; fn                  (n□1)
l    ::=  at | not (at)
f    ::=  A(t1, … tn) | g | u                  (n□0)
g    ::=  !at | ?at
u    ::=  +at | -at
```

AgentSpeak(L)- Informal Semantic

- The interpreter for AgentSpeak(L) manages
  - a set of *events*
  - a set of *intentions*
  - three *selection functions*.

AgentSpeak(L)- Informal Semantic Events

- ***Events***, which may start off the execution of plans that have relevant triggering events, can be:
    - ***external***, when originating from perception of the agent's environment (i.e., addition and deletion of beliefs based on perception are external events). External events may create new intentions**.**
    - ***internal***, when generated from the agent's own execution of a plan (i.e., a subgoal in a plan generates an event of type "addition of achievement goal").

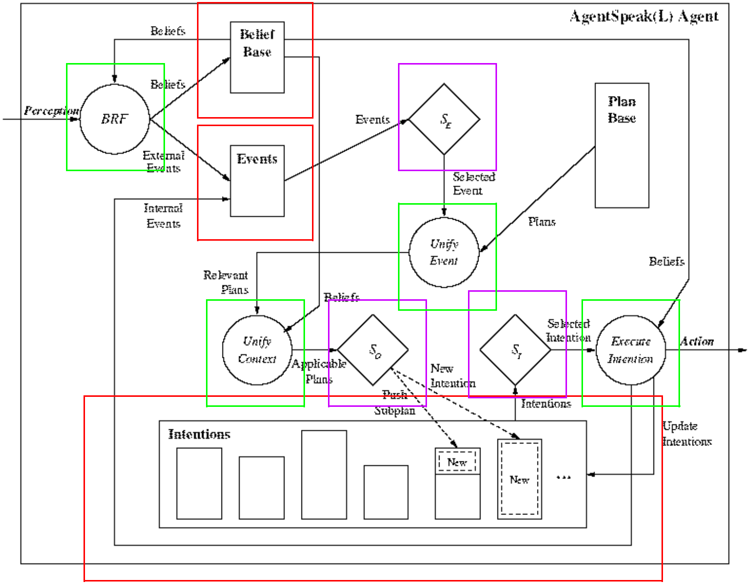
AgentSpeak(L)- Informal Semantic Intentions

- ***Intentions*** are particular courses of actions to which an agent has committed in order to handle certain events. Each intention is a stack of partially instantiated plans

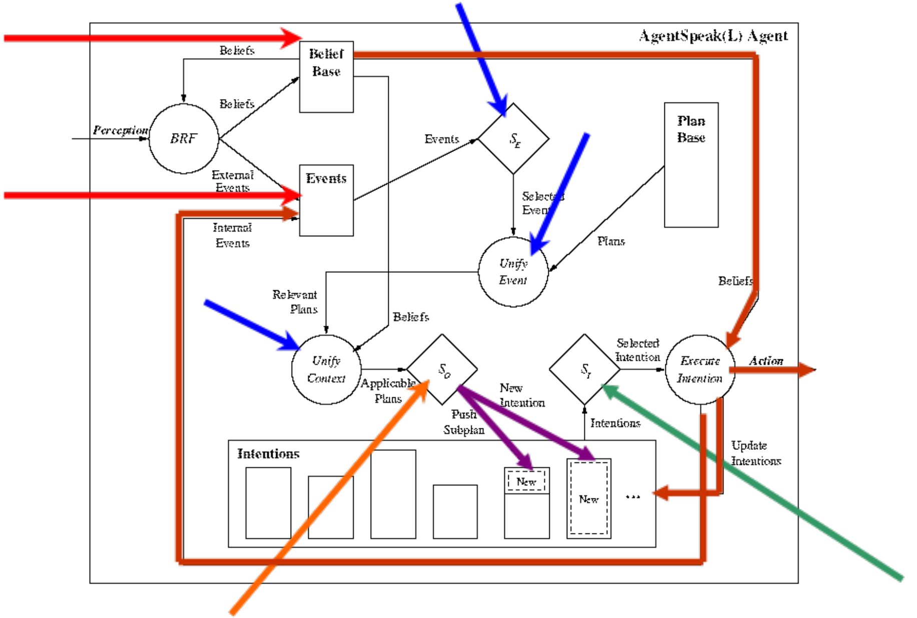
AgentSpeak(L)- Informal Semantic Selection Functions

- **SE** (the event selection function)
  - selects a single event from the set of events
- **SO**
  - selects an “option” (i.e., an applicable plan) from a set of applicable plans
- **SI**
  - selects one particular intention from the set of intentions.
- *The selection functions are agent-specific, in the sense that they should make selections based on an agent’s characteristics.*

AgentSpeak(L)- Informal Semantic



AgentSpeak(L)- Informal Semantic



AgentSpeak(L) Example

ALICE

- During lunch time, forward all calls to Carla.
- When I am busy, incoming calls from colleagues should be forwarded to Denise.

AgentSpeak(L) Example Beliefs

```
user(alice).
user(bob).
user(carla).
user(denise).
~status(alice, idle).
status(bob, idle).
colleague(bob).
lunch_time("11:30").
```

AgentSpeak(L) Example Plans

```
user(alice).
user(bob).
user(carla).
user(denise).
~status(alice, idle).
status(bob, idle).
colleague(bob).
lunch_time("11:30").
```

"During lunch time, forward all calls to Carla".

```
+invite(X, alice) : lunch_time(t)   []
  !call_forward(alice, X, carla). (p1)
```

"When I am busy, incoming calls from colleagues should be forwarded to Denise".

```
+invite(X, alice) :

   colleague(X)  []
  !call_forward_busy(alice,X,denise).
                               (p2)
```

```
+invite(X, Y): true   []  connect(X,Y).

                                (p3)
```

AgentSpeak(L) Example Plans

```
user(alice).
user(bob).
user(carla).
user(denise).
~status(alice, idle).
status(bob, idle).
colleague(bob).
lunch_time("11:30").
+invite(X, alice) : lunch_time(t)   □   !call_forward(alice, X, carla).   (p1)
+invite(X, alice) :     colleague(X)  □ call_forward_busy(alice,X,denise).(p2)
+invite(X, Y): true   □  connect(X,Y).                         (p3)
```

```
+!call_forward(X, From, To) : invite(From, X)
   □ +invite(From, To), - invite(From,X)
  (p4)
```

```
+!call_forvard_busy(Y, From, To) : invite(From, Y)&
  not(status(Y, idle)))
       □ +invite(From, To), - invite(From,Y).     (p5)
```

AgentSpeak(L) Example

```
user(alice).
user(bob).
user(carla).
user(denise).
~status(alice, idle).
status(bob, idle).
colleague(bob).
lunch_time("11:30").

+invite(X, alice) : lunch_time(t)
          □ !call_forward(alice, X, carla).          (p1)
+invite(X, alice) :    colleague(X)
          □ call_forward_busy(alice,X,denise).       (p2)
+invite(X, Y): true   □  connect(X,Y).                 (p3)
+!call_forward(X, From, To) : invite(From, X)
   □ +invite(From, To), - invite(From,X)
    (p4)
+!call_forvard_busy(Y, From, To) : invite(From, Y)&
  not(status(Y, idle)))
       □ +invite(From, To), - invite(From,Y).           (p5)
```

Execution - 1

- a new event is sensed from the environment, **`+invite(bob, alice)`** (there is a call for Alice from Bob).
- There are three *relevant* plans for this event (p1, p2 and p3)
  - the event matches the triggering event of those three plans.

Relevant Plans	**Unifier**

`p1: +invite(X, alice) : lunch_time(now)`
`□!call_forward(alice, X, carla)`	

`p2: +invite(X, alice) : colleague(X)`
`□ !call_forward_busy(alice, X, denise).`
	{X=bob}

`p3 : +invite(X, Y): true □ connect(X,Y).`	{Y=alice, X=bob}

Execution - 2

- only the context of plan p2 is satisfied - **`colleague(bob)`** => p2 is *applicable*.
- a new intention based on this plan is created in the set of intentions, because the event was external, generated from the perception of the environment.
- The plan starts to be executed. It adds a new event, this time an internal event: **`!call_forward_busy(alice,bob,denise).`**

Intention ID	**Intension Stack**	**Unifier**

1	**`+invite(X,alice):colleague(X)`**
	 `<- !call_forward_busy(alice,X,denise)`
		{X=bob}

Execution - 3

- a plan relevant to this new event is found (p5):

Relevant Plans	Unifier
`p5: +!call_forward_busy(Y, From, To) : invite(From, Y) & not(status(Y, idle)) ▯ +invite(From, To), - invite(From,Y).`	{From=bob, Y=alice, To=denise}

- p5 has the context condition true, so it becomes an *applicable* plan and it is pushed on top of *intention 1 (*it was generated by an internal event)

Intention ID	Intension Stack	Unifier
1	`+!call_forward_busy(Y,From,To) : invite(From,Y) & not status(Y,idle) <- +invite(From,To); -invite(From,Y)`	{From=bob, Y=alice, To=denise}
	`+invite(X,alice) : colleague(X) <- !call_forward_busy(alice,X,denise)`	{X=bob}

Execution - 4

- A new internal event is created, **`+invite(bob, denise).`**
- three relevant plans for this event are found, p1, p2 and p3.
- However, only plan p3 is applicable in this case, since the others don't have the context condition true.
- The plan is pushed on top of the existing intention.

Intention ID	Intension Stack	Unifier
1	**`+invite(X,Y) : <- connect(X,Y)`**	{Y=denise, X=bob}
	`+!call_forward_busy(Y,From,To) : invite(From,Y) & not status(Y,idle) <- +invite(From,To); -invite(From,Y)`	{From=bob, Y=alice, To=denise}
	`+invite(X,alice) : colleague(X) <- !call_forward_busy(alice,X,denise)`	{X=bob}

Execution - 5

- on top of the intention is a plan whose body contains an action.
- the action is executed, **`connect(bob, denise)`** and is removed from the intention.
- When all formulas in the body of a plan have been removed (i.e., have been executed), the whole plan is removed from the intention, and so is the achievement goal that generated it.

Intention ID	Intension Stack	Unifier
1	**`+!call_forward_busy(Y,From,To) : invite(From,Y) & not status(Y,idle) <- -invite(From,Y)`**	{From=bob, Y=alice, To=denise}
	`+invite(X,alice) : colleague(X) <- !call_forward_busy(alice,X,denise)`	{X=bob}

- The only thing that remains to be done is –invite(bob, alice) (this event is removed from the beliefs base).
- This ends a cycle of execution, and the process starts all over again, checking the state of the environment and reacting to events.

AgentSpeak Plans
Another Example: Cleaning Robot

```
+location(waste, X) :
      location(robot,X) & location(bin,Y) & X =\= Y <-
            pick(waste);                     !location(robot,Y);
            drop(waste).
+location(waste, X) :
      location(robot,X) & location(bin,X) <-
            pick(waste);                     drop(waste).
```

AgentSpeak Cleaning Robot

```
+location(waste, X) :
    location(robot,X) & location(bin,Y) <-
        pick(waste);
  !location(robot,Y); drop(waste).
```

Context

Triggering Event- Addition of a fact

Body of the plan

AgentSpeak Cleaning Robot

```
+location(waste, X) :
      location(robot,X) & location(bin,Y) <-
            pick(waste);
    !location(robot,Y); drop(waste).
```

The intended reading of this is very similar to event-condition-action rules (except that the action part is more sophisticated):

On event of noticing waste at X, if robot is at X and bin at Y, then (robot) pick waste, make its location Y and drop waste.

AgentSpeak Cleaning Robot

```
+!location(robot, X) :
       location(robot,X) <- true.

+!location(robot, X) :
   location(robot,Y) & not X=Y &
   adjacent(Y,Z) & not location(robot,Z) <-
         !move(robot,Y,Z);
         +!location(robot,X).
```

```
+!move(robot, X,Y) :
  location(robot,Y) & not X=Y &
  adjacent(Y,Z) <-
        -location(robot,Y),
        moveA(Y,Z),
        +location(robot,Z),
```

AgentSpeak Cleaning Robot

```
+!location(robot, X) :
   location(robot,Y) & not X=Y &
   adjacent(Y,Z) & not location(robot, Z) <-
         move(Y,Z); +!location(robot,X).
```

The intended reading of this is similar to goal reduction rules:

To achieve a goal location(robot,X) ….

Jason

- a fully-fledged interpreter for AgentSpeak(L)
- many extensions, providing a very expressive programming language for agents.
- allows configuration of a multi-agent system to run on various hosts.
- implemented in Java (thus it is multi-platform)
- available *Open Source* and is distributed under GNU LGPL.
- http://jason.sourceforge.net/

Jason characteristics

- support for developing Environments (Java)
- the possibility to run a multi-agent system distributed over a network
- fully customisable (in Java) selection functions, trust functions, and overall agent architecture (perception, belief-revision, inter-agent communication, and acting)
- a library of essential "internal actions"
- straightforward extensibility by user-defined internal actions, which are programmed in Java.

Conclusion

- AgentSpeak(L) has many similarities with traditional logic programming, which would favor its becoming a popular language
- it proves quite intuitive for those familiar with logic programming.
- it has a neat notation, thus providing quite elegant specifications of BDI agents.