

# Programming Intentional Agents in AgentSpeak(L) & Jason

Autonomous Systems  
Sistemi Autonomi

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- 1 Implementing BDI Architectures
- 2 AgentSpeak(L)
- 3 *Jason*
- 4 Conclusions



# Outline

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# BDI Abstract Control Loop

[RG95]

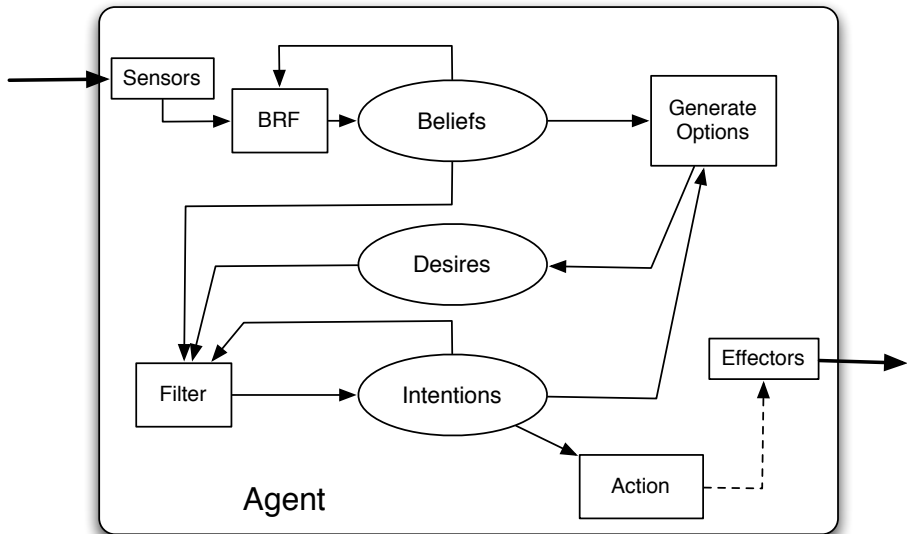
```
1. initialize-state();
2. while true do
3.     options := option-generator(event-queue);
4.     selected-options := deliberate(options);
5.     update-intentions(selected-options);
6.     execute();
7.     get-new-external-events();
8.     drop-successful-attitudes();
9.     drop-impossible-attitudes();
10. end-while
```

# Structure of BDI Systems

BDI architectures are based on the following constructs

- ① a set of *beliefs*
- ② a set of *desires* (or *goals*)
- ③ a set of *intentions*
  - or better, a subset of the goals with an associated stack of plans for achieving them; these are the intended actions
- ④ a set of *internal events*
  - elicited by a belief change (i.e., updates, addition, deletion) or by goal events (i.e. a goal achievement, or a new goal adoption)
- ⑤ a set of *external events*
  - perceptive events coming from the interaction with external entities (i.e. message arrival, signals, etc.)
- ⑥ a *plan library* (repertoire of actions) as a further (static) component

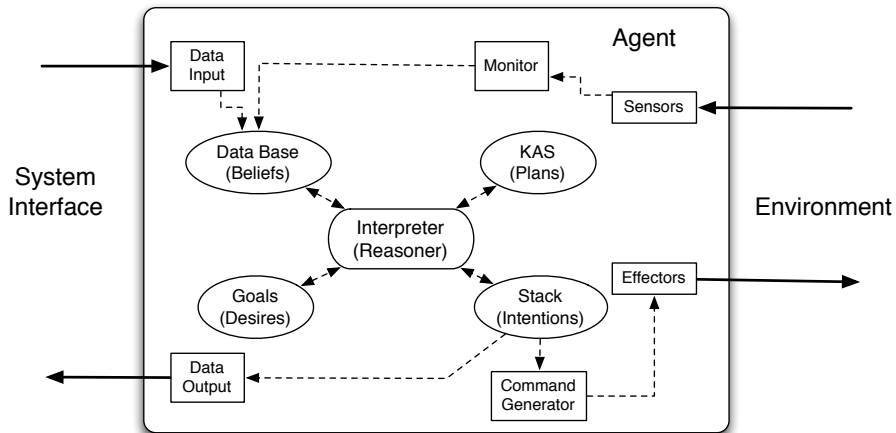
# Basic Architecture of a BDI Agent [Woo02]



# Procedural Reasoning System (PRS)

- PRS is one of the first BDI architectures [GL87]
- PRS is a *goal-directed* and *reactive* planning system
  - goal-directedness allows reasoning about / performing complex tasks
  - reactivity allows handling real-time behaviour in dynamic environments
- PRS is applied for high-level reasoning of robot, airport traffic control systems etc.

# PRS Architecture





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# AgentSpeak(L)

AgentSpeak(L)...

- is an *abstract language* used for describing and programming BDI agents
- inspired by PRS, dMARS [dKLW98], and BDI Logics [RG95]
- originally proposed by Anand S. Rao [Rao96]
- extended so as to make it a practical agent programming language [BH06]
- programs can be executed by the *Jason* platform [BHW07]
- has an operational semantics for extensions of AgentSpeak(L) providing a computational semantics for BDI concepts

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## 1 Implementing BDI Architectures

## 2 AgentSpeak(L)

- **Syntax**
- Semantics

## 3 *Jason*

- Reasoning Cycle
- *Jason* Programming Language
- Advanced BDI aspects

## 4 Conclusions



# Syntax of AgentSpeak(L)

- The main language constructs of AgentSpeak are
  - Beliefs** — current state of the agent, information about environment, and other agents
  - Goals** — state the agent desire to achieve and about which he brings about (Practical Reasoning) based on internal and external stimuli
  - Plans** — recipes of procedural means the agent has to change the world and achieve his goals
- The architecture of an AgentSpeak agent has four main components
  - 1 Belief Base
  - 2 Plan Library
  - 3 Set of Events
  - 4 Set of Intentions

# Beliefs and Goals

## Beliefs

**Beliefs** If  $b$  is a predicate symbol, and  $t_1, \dots, t_n$  are (first-order) terms,  $b(t_1, \dots, t_n)$  is a *belief atom*

- ground belief atoms are *base beliefs*
- if  $\Phi$  is a belief atom,  $\Phi$  and  $\neg\Phi$  are belief literals

## Goals

**Goals** If  $g$  is a predicate symbol, and  $t_1, \dots, t_n$  are terms,  $!g(t_1, \dots, t_n)$  and  $?g(t_1, \dots, t_n)$  are goals

- 1 '!' means Achievement Goals (*Goal to do*)
- 2 '?' means Test Goals (*Goal to know*)

# Events I

- Events occur as a consequence of changes in the agent's belief base or goal states
- Events may signal to the agent that some situation is requiring servicing (*triggering events*)
- The agent indeed is supposed to react to such events by finding a suitable plan(s)
- Due to events and goal processing, AgentSpeak(L) architectures are both
  - reactive
  - proactive

# Events II

## Events

**Events** If  $b(t)$  is a belief atom,  $!g(t)$  and  $?g(t)$  are goals, then  $+b(t)$ ,  $-b(t)$ ,  $+!g(t)$ ,  $+?g(t)$ ,  $-!g(t)$ , and  $-?g(t)$  are *triggering events*

- Let  $\phi$  be a literal, then the AgentSpeak triggering events are the following
  - $+\phi$  Belief addition
  - $-\phi$  Belief deletion
  - $+!\phi$  Achievement-goal addition
  - $-!\phi$  Achievement-goal deletion
  - $+?\phi$  Test-goal addition
  - $-?\phi$  Test-goal deletion

# Plans I

- Plans are recipes for achieving goals
- Plans declaratively define a workflow of actions
- Plans come along with the triggering and the context conditions that must hold in order to initiate the execution
- Plans represent agent's means to achieve goals (their know-how)

## Plans

**Plans** If  $e$  is a triggering event,  $b_1, \dots, b_n$  are belief literals (plan context), and  $h_1, \dots, h_n$  are goals or actions (plan body), then  $e : b_1 \wedge \dots \wedge b_n \leftarrow h_1; \dots; h_n$  is a *plan* (where  $e : c$  is called the plan's head)



## Plans II

### PlanBody

Let  $\Phi$  be a literal, then the PlanBody (i.e., intentions in AgentSpeak) can include the following elements:

- ! $\Phi$  Achievement goals
- ? $\Phi$  Test goals
- + $\Phi$  Belief addition
- $\Phi$  Belief deletion
- $\Phi$  Actions
- . $\Phi$  Internal Actions (*not actually here, this is Jason...*)

## Plans III

### General structure of an AgentSpeak plan

```
triggering_event: context ← body.
```

- the **triggering\_event** denotes the events that the plan is meant to handle
- the **context** represents the circumstances in which the plan can be used
  - logical expression, typically a conjunction of literals to be checked whether they follow from the current state of the belief base (Belief Formulae)
- the **body** is the course of action to be used to handle the event if the context is believed true at the time a plan is being chosen to handle the event
  - a sequence of actions and (sub) goals to achieve that goal

# AgentSpeak(L) Examples

```
/* Initial Beliefs */
likes(radiohead).
phone_number(covo,"05112345")

/* Belief addition */
+concert(Artist, Date, Venue)
  : likes(Artist)
  <- !book_tickets(Artist, Date, Venue).

/* Plan to book tickets */
+!book_tickets(A,D,V)
  : not busy(phone)
  <- ?phone_number(V,N); /* Test Goal to Retrieve a Belief */
     !call(N);
     . . .;
     !choose_seats(A,D,V).
```

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- Syntax
- **Semantics**

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# AgentSpeak(L) Semantics I

AgentSpeak(L) has an operational semantics defined in terms of agent configuration  $\langle B, P, E, A, I, S_e, S_o, S_I \rangle$ , where

- $B$  is a set of beliefs
- $P$  is a set of plans
- $E$  is a set of events (external and internal)
- $A$  is a set of actions that can be performed in the environment
- $I$  is a set of intentions each of which is a stack of partially instantiated plans
- $S_e, S_o, S_I$  are selection functions for events, options, and intentions

# AgentSpeak(L) Semantics II

The selection functions

- $S_e$  selects an *event* from  $E$ . The set of events is generated either by requests from users, from observing the environment, or by executing an intention
- $S_o$  selects an *option* from  $P$  for a given event. An option is an *applicable plan* for an event, i.e. a plan whose triggering event is unifiable with event and whose condition is derivable from the belief base
- $S_I$  selects an *intention* from  $I$  to execute

# Semantics of Intention Execution

## Semantics of intention execution

- $tr : ct \leftarrow +\varphi; \dots \Rightarrow$  generates event  $+\varphi$  and updates beliefs. If there is no applicable plan for  $+\varphi$ , discard the event.
- $tr : ct \leftarrow -\varphi; \dots \Rightarrow$  generates event  $-\varphi$  and updates beliefs. If there is no applicable plan for  $-\varphi$ , discard the event.
- $tr : ct \leftarrow !\varphi; \dots \Rightarrow$  generates event  $+\varphi$ . If there is no applicable plan for  $+\varphi$ , remove plan and generate  $-\psi$  if  $tr = +\psi$  (or  $-\psi$  if  $tr = +\psi$ ).
- $tr : ct \leftarrow ?\varphi; \dots \Rightarrow$  generates event  $+\varphi$ . If there is no applicable plan for  $+\varphi$ , remove plan and generate  $-\psi$  if  $tr = +\psi$  (or  $-\psi$  if  $tr = +\psi$ ).
- $tr : ct \leftarrow \varphi; \dots \Rightarrow$  if the action fails, remove plan and generate  $-\psi$  if  $tr = +\psi$  (or  $-\psi$  if  $tr = +\psi$ ).
- $tr : ct \leftarrow .\varphi; \dots \Rightarrow$  if the internal action fails, remove plan and generate  $-\psi$  if  $tr = +\psi$  (or  $-\psi$  if  $tr = +\psi$ ).

If no plan is applicable for a generated  $-\psi$  or  $-\psi$ , then the whole intention is disregarded and an error message is printed

# Agent Configuration

## Configuration of an AgentSpeak agent

$$\langle ag, C, M, T, s \rangle$$

- $ag$  is an AgentSpeak *program* consisting of a set of beliefs and plans
- $C = \langle I, E, A \rangle$  is the *agent circumstance*
- $M = \langle In, Out, SI \rangle$  is the *communication component*
- $T = \langle R, Ap, \iota, \varepsilon, \rho \rangle$  is the *temporary information component*
- $s$  is the current step within an agent's *reasoning cycle*



# Circumstance Component

$$\langle ag, C, M, T, s \rangle$$

## Agent's circumstance

$$C = \langle I, E, A \rangle$$

- $I$  is a set of intentions  $\{i, i', \dots\}$ ; each intention  $i$  is a stack of partially instantiated plans
- $E$  is a set of events  $\{(tr, i), (tr', i'), \dots\}$ ; each event is a pair  $(tr, i)$ , where  $tr$  is a triggering event and  $i$  is an intention (a stack of plans in case of an internal event or  $T$  representing an external event)
- $A$  is a set of actions to be performed in the environment; an action expression included in this set tells other architecture components to actually perform the respective action on the environment, thus changing it.

# Communication Component

$$\langle ag, C, M, T, s \rangle$$

## Agent's communication

$$M = \langle In, Out, SI \rangle$$

- *In* is the mail inbox: the system includes all messages addressed to this agent in this set
- *Out* is where the agent posts all messages it wishes to send to other agents
- *SI* is used to keep track of intentions that were suspended due to the processing of communication messages

# Communication Component

$$\langle ag, C, M, T, s \rangle$$

## Agent's communication

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## Message

$$\langle messageid, agentid, ilf, content \rangle$$

# Temporary Information Component

$$\langle ag, C, M, T, s \rangle$$

## Temporary information

$$T = \langle R, Ap, \iota, \varepsilon, \rho \rangle$$

- $R$  for the set of relevant plans (for the event being handled)
- $Ap$  for the set of applicable plans (the relevant plans whose context are true)
- $\iota, \varepsilon$  and  $\rho$  keep record of a particular intention, event and applicable plan (respectively) being considered along the execution of an agent

# Deliberation Steps

The current step  $s$  within an agent's reasoning cycle is one of the following elements:

- ProcMsg** processing a message from the agent's mail inbox
- SelEv** selecting an event from the set of events
- RelPI** retrieving all relevant plans
- AppPI** checking which of those are applicable
- SelAppI** selecting one particular applicable plan (the intended means)
- AddIM** adding the new intended means to the set of intentions
- SelInt** selecting an intention
- ExecInt** executing the select intention
- ClrInt** clearing an intention or intended means that may have finished in the previous step

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# Jason [BHW07]

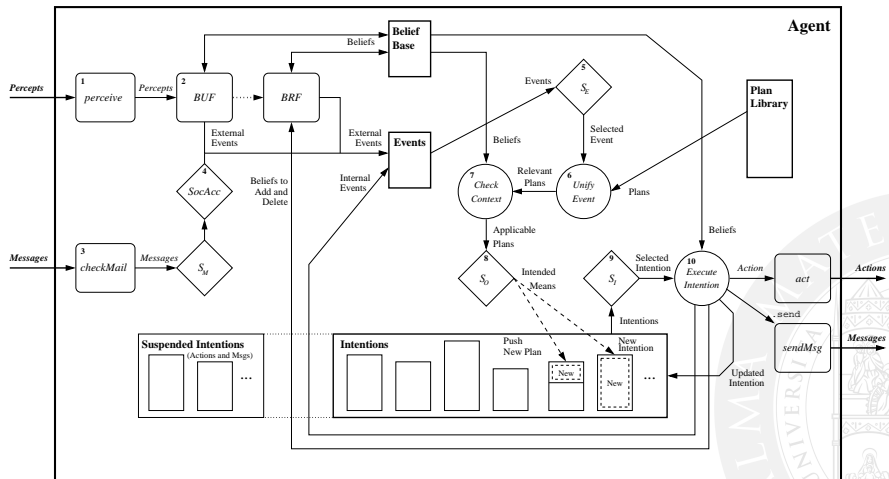
- Developed by Jomi F. Hübner and Rafael H. Bordini
- *Jason* implements the operational semantics of a variant of AgentSpeak [BH06]
- Extends AgentSpeak, which is meant to be the language for defining agents
- Adds a set of powerful mechanism to improve agent abilities
- Extensions aimed at a more practical programming language
  - High level language to define agents (goal oriented) behaviour
  - Java as low level language to realise mechanisms (i.e. agent internal functions) and customise the architecture
- Comes with a framework for developing multi-agent systems<sup>1</sup>

---

<sup>1</sup><http://jason.sourceforge.net/>



# Jason Architecture



# Jason Reasoning Cycle

- 1 perceiving the environment
- 2 updating the belief base
- 3 receiving communication from other agents
- 4 selecting 'socially acceptable' messages
- 5 selecting an event
- 6 retrieving all relevant plans
- 7 determining the applicable plans
- 8 selecting one applicable plan
- 9 selecting an intention for further execution
- 10 executing one step of an intention

# jason.asSemantics.TransitionSystem

```

public void reasoningCycle() {
    try {
        C.reset();    //C is actual Circumstance
        if (nrctlbr >= setts.nrcbp()) {
            nrctlbr = 0;
            ag.buf(agArch.perceive());
            agArch.checkMail();
        }
        nrctlbr++;    // counting number of cycles
        if (canSleep()) {
            if (ag.pl.getIdlePlans() != null) {
                logger.fine("generating idle event");
                C.addExternalEv(PlanLibrary.TE_IDLE);
            } else {
                agArch.sleep();
                return;
            }
        }
        step = State.StartRC;
        do {
            if (!agArch.isRunning()) return;
            applySemanticRule();
        } while (step != State.StartRC);
        ActionExec action = C.getAction();
        if (action != null) {
            C.getPendingActions().put(action.getIntention().getId(), action);
            agArch.act(action, C.getFeedbackActions());
        }
    } catch (Exception e) {
        conf.C.create(); //ERROR in the transition system, creating a new C
    }
}

```

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# Jason as an Agent Programming Language

- *Jason* include all the syntax and the semantics already defined for AgentSpeak
- boolean operators
  - `==, <, <=, >, >=, &, |, \==, not`
- arithmetic
  - `+, -, /, *, **, mod, div`
- then, *Jason* includes several extesions
- e.g.: let  $\Phi$  be a literal, then a *Jason* PlanBody can include the following additional elements:
  - `!! $\Phi$`  to launch a given plan  $\Phi$  as a new intention (the new intention will not be related to the current one, its execution will be *as if* it is in a new thread)
  - `- +  $\Phi$`  to update a Belief  $\Phi$  in an atomic fashion (atomic deletion and update)

# Belief Annotations

Jason introduces the notion of *annotated predicates*:

$$p_s(t_1, \dots, t_n)[a_1, \dots, a_m]$$

where  $a_i$  are first order terms

- All predicates in the belief base have a special annotation  $source(s_i)$  where  $s_i \in \{self, percept\} \cup Agld$ 
  - `myLocation(6,5) [source(self)]`.
  - `red(box1) [source(percept)]`.
  - `blue(box1) [source(ag1)]`.
- Agent developer can define customised predicates (i.e. grade of certainty on that belief)
  - `colourblind(ag1) [source(self), doc(0.7)]`.
  - `liar(ag1) [source(self), doc(0.2)]`.

# Strong Negation

- Strong negation (operator  $\sim$ ) is another *Jason* extension to AgentSpeak
- To allow both closed-world and open-world assumptions

```

+!pit_stop(fuel(T), tires(_))
  : not raining & not ~raining    /* Lack of knowledge:
                                   there is no belief indicating raining
                                   neither belief indicating ~raining */
  <- --+tires(intermediate);      /* Atomic Belief Update */
    !fuel(T+2);
    ...
+!pit_stop(fuel(T), tires(_))
  : raining /* There is a belief indicating raining */
  <- --+tires(rain); /* Atomic Belief Update */
    !fuel(T+5);
    ...
+!pit_stop(fuel(T), tires(_))
  : ~raining /* There is a belief indicating ~raining */
  <- --+tires(slick); /* Atomic Belief Update */
    !fuel(T);
    ...

```

# Belief Rules

In *Jason*, beliefs (and their annotations) can be pre-processed with Prolog-like rules:

```
likely_color(Obj,C)
:- colour(Obj,C)[degOfCert(D1)]
  & not (
    colour(Obj,_) [degOfCert(D2)]
    & D2 > D1 )
  & not ~colour(Obj,B).
```





# Handling Plan Failures

Handling plan failures is very important when agents are situated in dynamic and non-deterministic environments

- Goal-deletion events are another *Jason* extension to AgentSpeak
- `-!g`
- To create an agent that is blindly committed to goal `g`:

```
+!g(X) : goalstate
  <- true.
+!g(X) : not goalstate
  <- ...
  ?g.
...
-!g : true /* Goal deletion event */
  <- !g.
```

# Plan Annotations

Plan can have annotations too (e.g., to specify meta-level information)

- Selection functions (Java) can use such information in plan/intention selection
- Possible to change those annotations dynamically (e.g., to update priorities)
- Annotations go in the plan label

```
@aPlan[ chance_of_success(0.3), usual_payoff(0.9),  
        any_other_property]  
+!g(X) : c(t)  
  <- a(X).
```

- (`chance_of_success * usual_payoff`) is the expected utility for that plan

# Internal Actions

- In *Jason* plans can contain an additional structure: *internal action*  $\Phi$
- Self-Contained actions which code is packed and atomically executed as part of the agent reasoning cycle
- Internal actions can be used for special purpose activities
  - to interact with Java objects
  - to invoke legacy systems elegantly
  - as we will see in the rest of the course, to use *artifacts* in A&A systems
- Example of user defined internal action:

```
userLibrary.userAction(X,Y,R)
```

can be used to manipulate parameters  $X$ ,  $Y$  and unify the result of that manipulation in  $R$

# Defining New Internal Actions

Internal action: `myLib.randomInt(M, N)` unifies `N` with a random int between 0 and `M`.

```
package myLib;

import jason.JsonException;
import jason.asSemantics.*;
import jason.asSyntax.*;

public class randomInt extends DefaultInternalAction {

    private java.util.Random random = new java.util.Random();

    @Override
    public Object execute(TransitionSystem ts, Unifier un, Term[] args) throws Exception {
        if (!args[0].isNumeric() || !args[1].isVar())
            throw new JsonException("check arguments");
        try {
            int R = random.nextInt( ((numberTerm)args[0]).solve() );
            return
                un.unifies(args[1], new NumberTermImpl(R));
        } catch (Exception e) {
            throw new JsonException("Error in internal action 'randomInt'", e);
        }
    }
}
```

# Predefined Internal Actions

- Many internal actions are available for: printing, sorting, list/string operations, manipulating the beliefs/annotations/plan library, waiting/generating events, etc. (see *jason.stdlib*)
- Predefined internal actions have an empty library name
  - `.print(1,X,"bla")` prints out to the console the concatenation of the string representations of the number 1, of the value of variable *X*, and the string "bla"
  - `.union(S1,S2,S3)` *S3* is the union of the sets *S1* and *S2* (represented by lists). The result set is sorted
  - `.desire(D)` checks whether *D* is a desire: *D* is a desire either if there is an event with  $+!D$  as triggering event or it is a goal in one of the agent's intentions
  - `.intend(I)` checks if *I* is an intention: *I* is an intention if there is a triggering event  $+!I$  in any plan within an intention; just note that intentions can be suspended and appear in *E*, *PA*, and *PI* as well
  - `.drop_desire(I)` removes events that are goal additions with a literal that unifies with the one given as parameter
  - `.drop_intention(I)` drops all intentions which would make *.intend* true

# Internal Actions used for Message Passing

**Sender** Agent *A* sends a message to agent *B* using a special internal action:

```
.send(B, ilf, m(X))  
.broadcast(ilf, m(X))
```

- *B* is the unique name of the agent that will receive the message (or a list of names)
- *ilf*  $\in$  {*tell*, *untell*, *achieve*, *unachieve*, *askOne*, *askAll*, *askHow*, *tellHow*, *untellHow*}
- *m(X)* the content of the message

**Receiver** Agent *B* receives the message from *A* as a triggering event

- Handles it by customizing a reaction:

```
+m(X) [source(A)] : true  
<- dosomething;...
```

# Environments

- To build and deploy a MAS you need to rely on some sort of environment where the agents are situated
- The environment has to be designed (and implemented as well)
- There are two ways to do this:
  - 1 defining perceptions and actions so to operate on specific environments
    - this is done defining in Java lower-level mechanisms, and by specialising the Agent Architecture and Agent classes (see later)
  - 2 creating a 'simulated' environment
    - this is done in Java by extending *Jason's* Environment class and using methods such as `addPercept(String Agent, Literal Percept)`

## Example of an Environment Class

```
import jason.*;
import ...;
public class myEnv extends Environment{
....
    public myEnv() {
        Literal loc = Literal.parseLiteral("location(3,5)");
        addPercept(pos1);
    }

    public boolean executeAction(String ag, Term action) {
        if (action.equals(...)) {
            addPercept(ag,
                Literal.parseLiteral("location(souffle,c(3,4))");
        }
        ...
        return true;
    }
}
```



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# Hierarchical Planning I

- hierarchical abstraction is a well-known principle
- exhibits a great effectiveness in planning
- used to reduce a composite intention – or a given task – to a greater number of independent sub-intentions – or sub-tasks – placed at a lower level of abstraction
- an agent can manage at runtime an alternating hierarchy of (meta)goals and plans, which emerge from top-level goals over plans to subgoals and so forth
  - this highly simplifies the structure of plans
  - allow the plans to be conceived around self-contained actions (the leafs of the goal hierarchy) which can be reused with different purposes too
- defined having in mind the problem domain (the goal to be achieved) and trying to imagine those fine grained actions which in turn are supposed to accomplish the required activities

# Hierarchical Planning II

- differently from traditional planning systems, which mainly make an *offline* planning, Intentional Systems need to plan in dynamic environments and need to cope changing contexts and situations [SdSP06]

**Planning Systems** is offline — can create plans to achieve goals by composing actions in repertoire

**BDI planning** hybrid approach — the plans are defined at design time and at the language level *but* their execution is ruled by the architecture (means ends reasoning) according to context conditions (i.e., *Jason*, *Jadex*) or planning rules (i.e., 2APL).

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# Conclusions

## AgentSpeak

- goal-oriented notion of agency
- mentalistic notions as building blocks
- agent programming
- logic + BDI
- operational semantics

## Jason

- AgentSpeak interpreter
- implements the operational semantics
- support for Agent Communication Language
- highly customisable, open source

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