

# Multi-Agent Oriented Programming

## – Agent-Oriented Programming –

### The Jason Agent Programming Language

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Fundamentals Features Use in MAS Perspectives Beliefs Goals Events Plans Reasoning Comparison

## Agent Oriented Programming

- ▶ Use of *mentalistic* notions and a *societal* view of computation
- ▶ Various sophisticated abstractions
  - ▶ Agent: Belief, Goal, Intention, Plan (*this course*)
  - ▶ Organisation: Group, Role, Norm (*see next course*)
  - ▶ Interaction: Speech Acts, Interaction protocols (*this course*)
  - ▶ Environment: Artifacts, Percepts, Actions (*see next course*)



## Outline

- 1 Origins and Fundamentals
- 2 Features
- 3 Use of Jason within a Multi-Agent System
- 4 Current Shortfalls and Future Trends

Fundamentals Features Use in MAS Perspectives Beliefs Goals Events Plans Reasoning Comparison

## Agent Oriented Programming

### Features

- ▶ *Reacting* to events  $\times$  *long-term* goals
- ▶ Course of *actions* depends on *circumstance*
- ▶ *Plan failure* (dynamic environments)
- ▶ *Rational* behaviour
- ▶ *Social* ability
- ▶ Combination of *theoretical* and *practical* reasoning



## Languages and Platforms

Jason (Hbner, Bordini, ...); 3APL and 2APL (Dastani, van Riemsdijk, Meyer, Hindriks, ...); Jadex (Braubach, Pokahr); MetateM (Fisher, Guidini, Hirsch, ...); ConGoLog (Lesperance, Levesque, ... / Boutilier – DTGolog); Teamcore/ MTDP (Milind Tambe, ...); IMPACT (Subrahmanian, Kraus, Dix, Eiter); CLAIM (Amal El Fallah-Seghrouchni, ...); SemantiCore (Blois, ...); GOAL (Hindriks); BRAHMS (Sierhuis, ...); STAPLE (Kumar, Cohen, Huber); Go! (Clark, McCabe); Bach (John Lloyd, ...); MINERVA (Leite, ...); SOCS (Torroni, Stathis, Toni, ...); FLUX (Thielscher); JIAC (Hirsch, ...); JADE (Agostino Poggi, ...); JACK (AOS); Agentis (Agentis Software); Jackdaw (Calico Jack); ...



## Jason

a practical implementation of AgentSpeak

- ▶ *Jason* implements the *operational semantics* of a variant of AgentSpeak
- ▶ Has various extensions aimed at a more *practical* programming language (e.g. definition of the MAS, communication, ...)
- ▶ Highly customised to simplify *extension* and *experimentation*
- ▶ Developed by *Rafael H. Bordini* and *Jomi F. Hübner*



## AgentSpeak

the foundational language for Jason

- ▶ Originally proposed by Rao (1996)
- ▶ Programming language for BDI agents
- ▶ Elegant notation, based on *logic programming*
- ▶ Inspired by PRS (Georgeff & Lansky), dMARS (Kinny), and BDI Logics (Rao & Georgeff)
- ▶ Abstract programming language aimed at theoretical results



## Basics

- ▶ As in Prolog, any symbol (i.e. a sequence of characters) starting with a lowercase letter is called an *atom*
- ▶ An atom is used to represent particular individuals or objects
- ▶ A symbol starting with an uppercase letter is interpreted as a *logical variable*
- ▶ Initially variables are *free* or *uninstantiated* and once *instantiated* or *bound* to a particular value, they maintain that value throughout their *scope* (*plan*).
- ▶ Variables are bound to values by *unification* ; a formula is called *ground* when it has no more uninstantiated variables.



## Main Language Constructs and Runtime Structures

- ▶ **Beliefs**: represent the information available to an agent (e.g. about the environment or other agents)
- ▶ **Goals**: represent states of affairs the agent wants to bring about
- ▶ **Plans**: are recipes for action, representing the agent's know-how
- ▶ **Events**: happen as a consequence to changes in the agent's beliefs or goals
- ▶ **Intentions**: plans instantiated to achieve some goal



## Jason basic reasoning cycle

- ▶ perceives the environment and update belief base
- ▶ processes new messages
- ▶ selects event
- ▶ selects *relevant* plans
- ▶ selects *applicable* plans
- ▶ creates/updates intention
- ▶ selects intention to execute



## Main Architectural Components

- ▶ **Belief base**: where beliefs are stored
- ▶ **Set of events**: to keep track of events the agent will have to handle
- ▶ **Plan library**: stores all the plans currently known by the agent
- ▶ **Set of Intentions**: each intention keeps track of the goals the agent is committed to and the courses of action it chose in order to achieve the goals for one of various foci of attention the agent might have



## Beliefs – Representation

### Syntax

Beliefs are represented by annotated literals of first order logic

```
functor(term1, ..., termn) [annot1, ..., annotm]
```

### Example (belief base of agent Tom)

```
red(box1) [source(percept)].
friend(bob,alice) [source(bob)].
lier(alice) [source(self),source(bob)].
~lier(bob) [source(self)].
```



## Beliefs – Dynamics I

### by perception

beliefs annotated with `source(percept)` are automatically updated accordingly to the perception of the agent

### by intention

the operators `+` and `-` can be used to add and remove beliefs annotated with `source(self)`

```
+lier(alice); // adds lier(alice)[source(self)]
-lier(john); // removes lier(john)[source(self)]
++lier(john); // updates lier(john)[source(self)]
```



## Beliefs – Dynamics II

### by communication

when an agent receives a *tell* message, the content is a new belief annotated with the sender of the message

```
.send(tom,tell,lier(alice)); // sent by bob
// adds lier(alice)[source(bob)] in Tom's BB
...
.send(tom,untell,lier(alice)); // sent by bob
// removes lier(alice)[source(bob)] from Tom's BB
```



## Goals – Representation

### Types of goals

- ▶ Achievement goal: goal *to do*
- ▶ Test goal: goal *to know*

### Syntax

Goals have the same syntax as beliefs, but are prefixed by  
`!` (achievement goal)  
`?` (test goal)

### Example (initial goal of agent Tom)

```
!write(book).
```



## Goals – Dynamics I

### by intention

the operators `!` and `?` can be used to add a new goal annotated with `source(self)`

```
...
// adds new achievement goal !write(book)[source(self)]
!write(book);

// adds new test goal ?publisher(P)[source(self)]
?publisher(P);
...
```



## Goals – Dynamics II

### by communication – achievement goal

when an agent receives an *achieve* message, the content is a new achievement goal annotated with the sender of the message

```
.send(tom,achieve,write(book)); // sent by Bob
// adds new goal write(book)[source(bob)] for Tom
...
.send(tom,unachieve,write(book)); // sent by Bob
// removes goal write(book)[source(bob)] for Tom
```



## Goals – Dynamics III

### by communication – test goal

when an agent receives an *askOne* or *askAll* message, the content is a new test goal annotated with the sender of the message

```
.send(tom,askOne,published(P),Answer); // sent by Bob
// adds new goal ?publisher(P)[source(bob)] for Tom
// the response of Tom will unify with Answer
```



## Events – Representation

- ▶ Events happen as a consequence to changes in the agent's beliefs or goals
- ▶ An agent reacts to events by executing plans
- ▶ Types of plan triggering events
  - +b (belief addition)
  - b (belief deletion)
  - +!g (achievement-goal addition)
  - !g (achievement-goal deletion)
  - +?g (test-goal addition)
  - ?g (test-goal deletion)



## Plans – Representation

An AgentSpeak plan has the following general structure:

**triggering\_event** : **context** <- **body**.

where:

- ▶ the *triggering event* denotes the events that the plan is meant to handle (cf. events description)
- ▶ the *context* represents the circumstances in which the plan can be used
- ▶ the *body* is the course of action to be used to handle the event if the context is believed to be true at the time a plan is being chosen to handle the event



## Plans – Operators for Plan Context

### Boolean operators

& (and)  
 | (or)  
 not (not)  
 = (unification)  
 >, >= (relational)  
 <, <= (relational)  
 == (equals)  
 \ == (different)

### Arithmetic operators

+ (sum)  
 - (subtraction)  
 \* (multiply)  
 / (divide)  
 div (divide – integer)  
 mod (remainder)  
 \*\* (power)



## Plans – Operators for Plan Body

A plan body may contain:

- ▶ Belief operators (+, -, --)
- ▶ Goal operators (!, ?, !!)
- ▶ Actions (internal/external) and Constraints

### Example (plan's body)

```

+beer : time_to_leave(T) & clock.now(H) & H >= T
  <- !g1;           // new sub-goal suspending plan execution
      !!g2;         // new goal not suspending plan execution
      +b1(T-H);     // adds new belief
      -+b2(T*H);    // updates belief
      ?b(X);        // new test goal
      X > 10;       // constraint to carry on
      close(door). // external action
  
```



## Plans – Example

```

+green_patch(Rock) [source(percept)]
: not battery_charge(low)
<- ?location(Rock,Coordinates);
    !at(Coordinates);
    !examine(Rock).

+!at(Coords)
: not at(Coords) & safe_path(Coords)
<- move_towards(Coords);
    !at(Coords).

+!at(Coords)
: not at(Coords) & not safe_path(Coords)
<- ...

+!at(Coords) : at(Coords).
  
```



## Plans – Dynamics

The plans that form the *plan library* of the agent comes from:

- ▶ initial plans defined by the programmer
- ▶ plans added dynamically and intentionally by
  - ▶ .add\_plan
  - ▶ .remove\_plan
- ▶ plans received from messages of type:
  - ▶ tellHow
  - ▶ untellHow
 messages

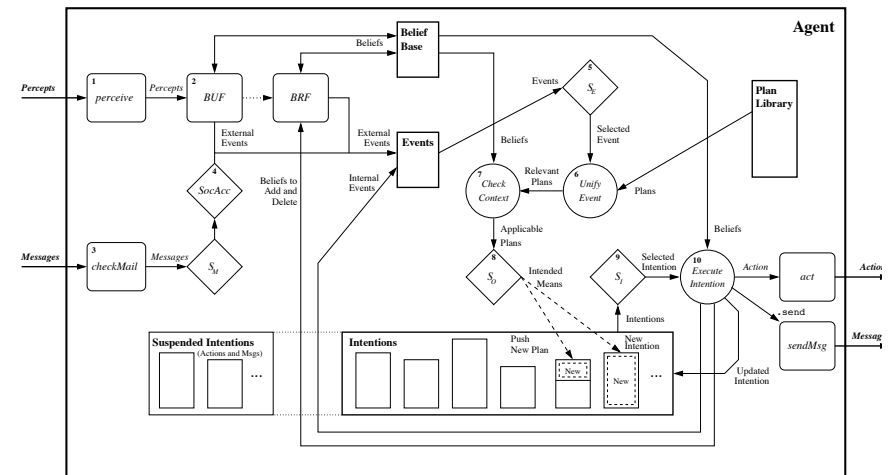


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## Jason reasoning cycle



## Jason vs Java I

Consider a very simple robot with two goals:

- ▶ when a piece of gold is seen, go to it
- ▶ when battery is low, charge



## Jason vs Java II

### Example (Java code – go to gold)

```
public class Robot extends Thread {
    boolean seeGold, lowBattery;
    public void run() {
        while (true) {
            while (! seeGold) {
            }
            while (seeGold) {
                a = selectDirection();

                doAction(go(a));
            }
        }
    }
}
```

(how to code the charge battery behaviour?)



## Jason vs Java III

### Example (Java code – charge battery)

```
public class Robot extends Thread {
    boolean seeGold, lowBattery;
    public void run() {
        while (true) {
            while (! seeGold)
                if (lowBattery) charge();
            while (seeGold) {
                a = selectDirection ();
                if (lowBattery) charge();
                doAction(go(a));
                if (lowBattery) charge();
            }
        }
    }
}
```

(note where the test for low battery have to be done)



## Jason vs Java IV

### Example (Jason code)

```
+see(gold)
  <- !goto(gold).
+!goto(gold) : see(gold)           // long term goal
  <- !select_direction(A);
    go(A);
    !goto(gold).
+battery(low)                     // reactivity
  <- .suspend(goto(gold));
    !charge;
    .resume(goto(gold)).
```



## Jason vs Prolog

- ▶ With the *Jason* extensions, nice separation of theoretical and practical reasoning
- ▶ BDI architecture allows
  - ▶ long-term goals (goal-based behaviour)
  - ▶ reacting to changes in a dynamic environment
  - ▶ handling multiple foci of attention (concurrency)
- ▶ Acting on an environment and a higher-level conception of a distributed system



### 1 Origins and Fundamentals

### 2 Features

- Negation
- Rules
- Plan Annotations
- Failure Handling
- Internal Actions
- Customisations

### 3 Use of Jason within a Multi-Agent System

### 4 Current Shortfalls and Future Trends

## Negation

### Negation as failure

- ▶ **not**: formula is true if the interpreter fails to derive it
- ▶ *Closed world assumption*: anything that is neither known to be true, nor derivable from the known facts using the rules in the program, is assumed to be false.

### Strong negation

- ▶ **~**: used to express that an agent *explicitly* believes something to be false.



## Prolog-like Rules in the Belief Base

### Rules

Rules can be used to simplify certain tasks, i.e. making certain conditions used in plans more succinct.  
Their syntax is *similar* to the one used for plans.

### Example

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



## Plan Annotations

- ▶ Like beliefs, plans can also have *annotations*, which go in the plan *label*
- ▶ Annotations contain meta-level information for the plan, which selection functions can take into consideration
- ▶ The annotations in an intended plan instance can be changed *dynamically* (e.g. to change intention priorities)
- ▶ There are some pre-defined plan annotations, e.g. to force a breakpoint at that plan or to make the whole plan execute atomically

### Example (an annotated plan)

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



## Failure handling

### Example (an agent blindly committed to g)

```
#!g : g.
```

```
#!g : ... <- ... ?g.
```

```
#!g : true <- !g.
```



## Internal Actions

- ▶ Unlike actions, internal actions do not change the environment
- ▶ Code to be executed as part of the agent reasoning cycle
- ▶ AgentSpeak is meant as a high-level language for the agent's practical reasoning and internal actions can be used for invoking legacy code elegantly
- ▶ Internal actions can be defined by the user in Java

```
libname.action_name(...)
```



## Meta Programming

### Example (an agent that asks for plans on demand)

```
#!G[error(no_relevant)] : teacher(T)
  <- .send(T, askHow, { +!G }, Plans);
  .add_plan(Plans);
  !G.
```

*in the event of a failure to achieve **any** goal *G* due to no relevant plan, asks a teacher for plans to achieve *G* and then try *G* again*

- ▶ The failure event is annotated with the error type, line, source, ... `error(no_relevant)` means no plan in the agent's plan library to achieve *G*
- ▶ `{ +!G }` is the syntax to enclose triggers/plans as terms



## Standard Internal Actions

- ▶ Standard (pre-defined) internal actions have an empty library name
  - ▶ `.print(term1, term2, ...)`
  - ▶ `.union(list1, list2, list3)`
  - ▶ `.my_name(var)`
  - ▶ `.send(ag, perf, literal)`
  - ▶ `.intend(literal)`
  - ▶ `.drop_intention(literal)`
- ▶ Many others available for: printing, sorting, list/string operations, manipulating the beliefs/annotations/plan library, creating agents, waiting/generating events, etc.



## Jason Customisations

- ▶ *Agent* class customisation:  
selectMessage, selectEvent, selectOption, selectIntetion, buf, brf, ...
- ▶ Agent *architecture* customisation:  
perceive, act, sendMsg, checkMail, ...
- ▶ *Belief base* customisation:  
add, remove, contains, ...
  - ▶ Example: persistent belief base  
(in text files, in data bases, ....)



## Execution & Communication Platform

Different execution and communication platforms can be used with *Jason*:

- Centralised**: all agents in the same machine,  
one thread by agent, very fast
- Centralised (pool)**: all agents in the same machine,  
fixed number of thread,  
allows thousands of agents
- Jade**: distributed agents, FIPA-ACL
- Saci**: distributed agents, KQML
- .... others defined by the user (e.g. AgentScape)



### 1 Origins and Fundamentals

### 2 Features

### 3 Use of Jason within a Multi-Agent System

- Platforms
- Definition of a Simulated Environment
- MAS project
- Tools

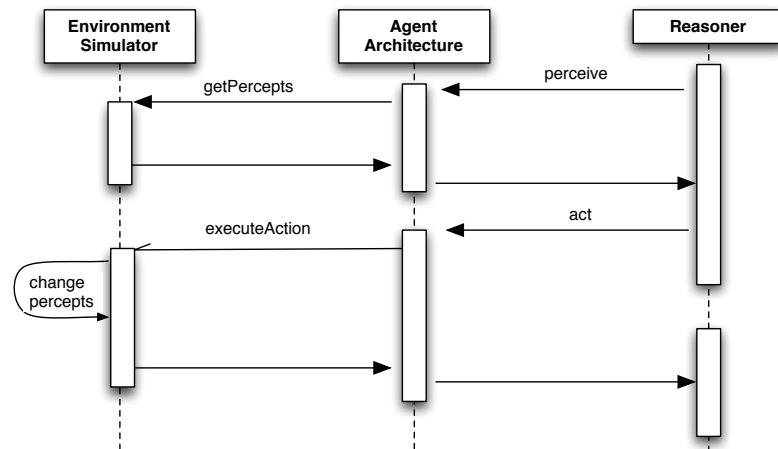
### 4 Current Shortfalls and Future Trends

## Definition of a Simulated Environment

- ▶ There will normally be an environment where the agents are situated
- ▶ The agent architecture needs to be customised to get perceptions and to act on such environment
- ▶ We often want a simulated environment (e.g. to test a MAS application)
- ▶ This is done in Java by extending *Jason's* Environment class



## Interaction with the Environment Simulator



## Example of an Environment Class

```

1 import jason.*;
2 import ...;
3 public class robotEnv extends Environment {
4     ....
5     public robotEnv() {
6         Literal gp =
7             Literal.parseLiteral("green_patch(souffle)");
8         addPercept(gp);
9     }
10
11     public boolean executeAction(String ag, Structure action) {
12         if (action.equals(...)) {
13             addPercept(ag,
14                 Literal.parseLiteral("location(souffle,c(3,4))");
15         }
16         ...
17         return true;
18     }
19 }
  
```

## MAS Configuration Language I

- Simple way of defining a multi-agent system

### Example (MAS that uses JADE as infrastructure)

```

MAS my_system {
    infrastructure: Jade
    environment: robotEnv
    agents:
        c3po;
        r2d2 at jason.sourceforge.net;
        bob #10; // 10 instances of bob
    classpath: "../lib/graph.jar";
}
  
```

## MAS Configuration Language II

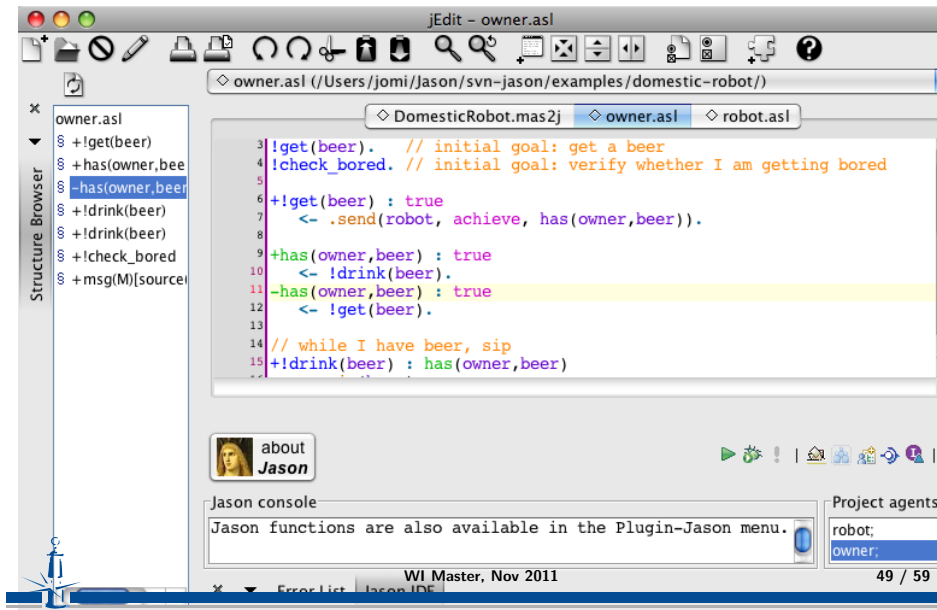
- Configuration of event handling, frequency of perception, user-defined settings, customisations, etc.

### Example (MAS with customised agent)

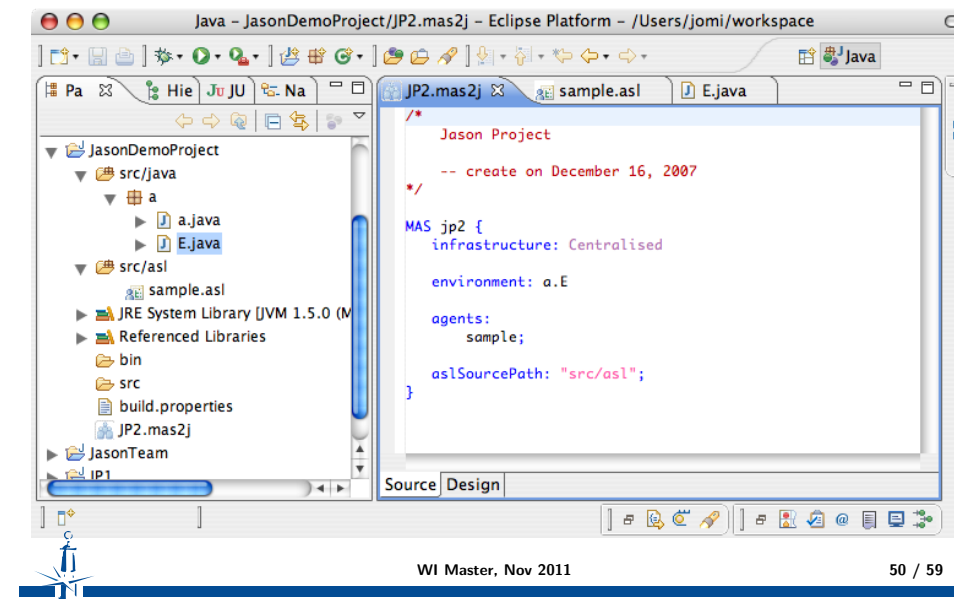
```

MAS custom {
    agents: bob [verbose=2,paramters="sys.properties"]
        agentClass MyAg
        agentArchClass MyAgArch
        beliefBaseClass jason.bb.JDBCPersistentBB(
            "org.hsqldb.jdbcDriver",
            "jdbc:hsqldb:bookstore",
            ...
        )
}
  
```

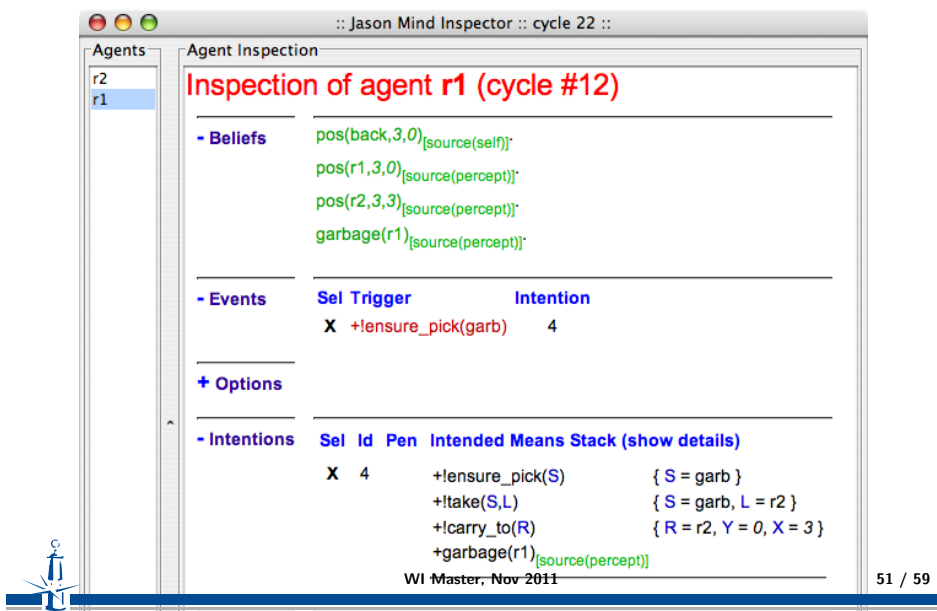
## jEdit plugin



## Eclipse plugin



## Mind inspector



- 1 Origins and Fundamentals
- 2 Features
- 3 Use of Jason within a Multi-Agent System
- 4 Current Shortfalls and Future Trends
  - Perspectives: Some Past and Future Projects
  - Summary

## Some Related Projects I

- ▶ *Speech-act* based communication  
Joint work with Renata Vieira, Álvaro Moreira, and Mike Wooldridge
- ▶ *Cooperative* plan exchange  
Joint work with Viviana Mascardi, Davide Ancona
- ▶ *Plan Patterns* for Declarative Goals  
Joint work with M.Wooldridge
- ▶ *Planning* (Felipe Meneguzzi and Colleagues)
- ▶ *Web and Mobile Applications* (Alessandro Ricci and Colleagues)
- ▶ *Belief Revision*  
Joint work with Natasha Alechina, Brian Logan, Mark Jago



## Some Related Projects II

- ▶ *Ontological* Reasoning
  - ▶ Joint work with Renata Vieira, Álvaro Moreira
  - ▶ *JASDL*: joint work with Tom Klapiscak
- ▶ Goal-Plan Tree Problem (Thangarajah et al.)  
Joint work with Tricia Shaw
- ▶ Trust reasoning (ForTrust project)
- ▶ Agent verification and model checking  
Joint project with M.Fisher, M.Wooldridge, W.Visser, L.Dennis, B.Farwer



## Some Related Projects III

- ▶ Environments, Organisation and Norms
  - ▶ Normative environments  
Join work with A.C.Rocha Costa and F.Okuyama
  - ▶ MADeM integration (Francisco Grimaldo Moreno)
  - ▶ Normative integration (Felipe Meneguzzi)
  - ▶ *CARTAgO* integration
  - ▶ *MOISE<sup>+</sup>* integration
- ▶ More on [jason.sourceforge.net](http://jason.sourceforge.net), related projects



## Some Trends for Jason I

- ▶ Modularity and encapsulation
  - ▶ Capabilities (JACK, Jadex, ...)
  - ▶ Roles (Dastani et al.)
  - ▶ Mini-agents (?)
- ▶ Recently done: *meta-events*
- ▶ To appear soon: annotations for *declarative goals*, improvement in plan failure handling, etc.
- ▶ *Debugging* is hard, despite mind inspector, etc.
- ▶ Further work on combining with environments and organisations

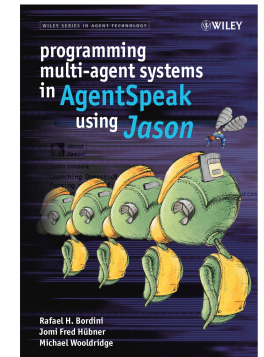


## Summary


- ▶ AgentSpeak
  - ▶ Logic + BDI
  - ▶ Agent programming
- ▶ Jason
  - ▶ AgentSpeak interpreter
  - ▶ implements the operational semantics of AgentSpeak
  - ▶ speech act based
  - ▶ highly customisable
  - ▶ useful tools
  - ▶ open source
  - ▶ open issues

## More information

- ▶ <http://jason.sourceforge.net>
- ▶ Bordini, R. H., Hübner, J. F., and Wooldridge, M.  
*Programming Multi-Agent Systems in AgentSpeak using Jason*  
 John Wiley & Sons, 2007.



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 Agentspeak(l): Bdi agents speak out in a logical computable language.  
 In de Velde, W. V. and Perram, J. W., editors, *MAAMAW*, volume 1038 of  
*Lecture Notes in Computer Science*, pages 42–55. Springer.