Programming Intentional Agents in AgentSpeak(L) & Jason

Autonomous Systems
Sistemi Autonomi

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Academic Year 2013/2014
1. Implementing BDI Architectures

2. AgentSpeak(L)
   - Syntax
   - Semantics

3. Jason
   - Reasoning Cycle
   - Jason Programming Language
   - Advanced BDI aspects

4. Conclusions and References
Outline

1. Implementing BDI Architectures

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4. Conclusions and References
BDI Abstract Control Loop [Rao and Georgeff, 1995]

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
Implementing BDI Architectures

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 [Wooldridge, 2002]
Procedural Reasoning System (PRS) [Georgeff and Lansky, 1987]

- PRS is one of the first BDI architectures (developed by M.P. Georgeff and A.L. Lansky)
- PRS is a goal directed and reactive planning system
- Goal directedness allows reasoning about and performing complex tasks
- Reactiveness allows handling real-time behaviour in dynamic environments
- PRS is applied for high-level reasoning of robot, airport traffic control systems etc.
PRS Architecture

System Interface

Environment

Agent

Data Input

Monitor

Sensors

Data Base (Beliefs)

KAS (Plans)

Goals (Desires)

Stack (Intentions)

Effectors

Data Output

Interpreter (Reasoner)

Command Generator

Environment

System Interface

Agent

Data Input

Monitor

Sensors

Data Base (Beliefs)

KAS (Plans)

Goals (Desires)

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AgentSpeak(L) is an abstract language used for describing and programming BDI agents.

Inspired by PRS, dMARS (Kinny), and BDI Logics (Rao and Georgeff)

Originally proposed by Anand S. Rao [Rao, 1996]

AgentSpeak(L) is extended to make it a practical agent programming language [Bordini and Hübner, 2006]

AgentSpeak(L) programs can be executed by the Jason platform [Bordini et al., 2007]

Operational semantics for extensions of AgentSpeak(L) which provides a computational semantics for BDI concepts
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**

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

- Ground belief atoms are *base beliefs*
- If \( \Phi \) is a belief atom, \( \Phi \) and \( \neg \Phi \) are belief literals
Beliefs and Goals

Goals

If $g$ is a predicate symbol, and $t_1, \ldots, t_n$ are terms, $!g(t_1, \ldots, t_n)$ and $?g(t_1, \ldots, t_n)$ are goals.

1. ‘!’ means Achievement Goals (Goal to do)
2. ‘?’ means Test Goals (Goal to know)
Events

- Events are signalled 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

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...

- ... are recipes for achieving goals
- ... declaratively define a workflow of actions
- ... 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)
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Plans

If $e$ is a triggering event, $b_1, ..., b_n$ are belief literals (plan context), and $h_1, ..., h_n$ are goals or actions (plan body), then

$$e : b_1 \land ... \land b_n \leftarrow h_1; ...; h_n$$

is a plan (where $e : c$ is called the plan’s head)
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

An AgentSpeak plan has the following general structure:

\[ \text{triggering_event} : \text{context} \leftarrow \text{body}. \]

where:

- 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).
AgentSpeak(L) Semantics

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

The selection functions

- $S_e$ selects an events 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

- $tr : ct \leftarrow +\varphi; ... \Rightarrow$ Generates event $+\varphi$ and updates beliefs. If no applicable plan for $+\varphi$, discard the event.
- $tr : ct \leftarrow -\varphi; ... \Rightarrow$ Generates event $-\varphi$ and updates beliefs. If no applicable plan for $-\varphi$, discard the event.
- $tr : ct \leftarrow !\varphi; ... \Rightarrow$ Generates event $+!\varphi$. If no applicable plan for $+!\varphi$, remove plan and generate $-!\psi$ if $tr = +!\psi$ (or $-?\psi$ if $tr = +?\psi$).
- $tr : ct \leftarrow ?\varphi; ... \Rightarrow$ Generates event $+?\varphi$ If no applicable plan for $+?\varphi$, remove plan and generate $-!\psi$ if $tr = +!\psi$ (or $-?\psi$ if $tr = +?\psi$).
- $tr : ct \leftarrow \varphi; ... \Rightarrow$ If the action fails, remove plan and generate $-!\psi$ if $tr = +!\psi$ (or $-?\psi$ if $tr = +?\psi$).
- $tr : ct \leftarrow .\varphi; ... \Rightarrow$ 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 \textit{program} consisting of a set of beliefs and plans
- \(C = \langle I, E, A\rangle\) is the \textit{agent circumstance}
- \(M = \langle In, Out, SI\rangle\) is the \textit{communication component}
- \(T = \langle R, Ap, \iota, \varepsilon, \rho\rangle\) is the \textit{temporary information component}
- \(s\) is the current step within an agent’s \textit{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 \( \{ i, i', ... \} \); each intention \( i \) is a stack of partially instantiated plans
- \( E \) is a set of events \( \{(tr, i), (tr', i'), ...\} \); 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

\[ \langle ag, C, M, T, s \rangle \]

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
- **RelPl**: retrieving all relevant plans
- **ApplPl**: checking which of those are applicable
- **SelAppl**: 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 [Bordini et al., 2007]

- Developed by Jomi F. Hübner and Rafael H. Bordini
- Jason implements the operational semantics of a variant of AgentSpeak [Bordini and Hübner, 2006]
- 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 realize mechanisms (i.e. agent internal functions) and customize the architecture
- Comes with a framework for developing multi-agent systems

\(^1\text{http://jason.sourceforge.net/}\)
Jason Architecture

Reasoning Cycle

1. Percepts
   - 1. perceive
   - 2. BUF
   - 3. checkMail

2. Belief Base
   - Events
     - External Events
     - Internal Events
     - Beliefs

3. Plan Library

4. SocAcc
   - Beliefs to Add and Delete

5. Selected Event
   - Relevant Plans
   - New Plan
   - Push New Plan

6. Unified Event
   - Selected Intention
   - Intended Means

7. Check Context
   - Applicable Plans
   - New Intention

8. Executable Intention
   - Action
   - send
   - Messages

Suspended Intentions
   - (Actions and Msgs)

Intentions
   - ...

Messages
   - ...

Percepts
   - ...

Actions
   - ...

Updated Intention
   - ...

SendMsg
   - ...

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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

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public void reasoningCycle() {
    try {
        C.reset(); // C is actual Circumstance
        if (nrcslbr >= setts.nrcbp()) {
            nrcslbr = 0;
            ag.buf(agArch.perceive());
            agArch.checkMail();
        }
        nrcslbr++; // 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
    }
}
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
- For instance: let Φ be a literal, then a Jason PlanBody can include the following additional elements:
  - !!Φ To launch a given plan Φ 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).
  - − + Φ To update a Belief Φ in an atomic fashion (atomic deletion and update)
Belief Annotations

Jason introduces the notion of *annotated predicates*:

\[ p_s(t_1, ..., t_n)[a_1, ..., a_m] \]

where \( a_i \) are first order terms

- All predicates in the belief base have a special annotation \( source(s_i) \)
  where \( s_i \in \{self, percept\} \cup AgId \)

  - `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)].`
  - `lier(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**

\[
+\text{!pit\_stop}(\text{fuel}(T), \text{tires}_{\sim}(\_)) \\
: \text{not raining} \land \text{not} \sim\text{raining} \quad /* \text{Lack of knowledge:} \\
\quad \text{there is no belief indicating} \ \text{raining} \\
\quad \text{neither belief indicating} \ \sim\text{raining} */
\]

\[
\leftarrow \quad +\text{tires}(\text{intermediate}); \quad /* \text{Atomic Belief Update} */
\]

\[
\quad +\text{!fuel}(T+2);
\]

\[
\ldots
\]

\[
+\text{!pit\_stop}(\text{fuel}(T), \text{tires}_{\sim}(\_)) \\
: \text{raining} \quad /* \text{There is a belief indicating} \ \text{raining} */
\]

\[
\leftarrow \quad +\text{tires}(\text{rain}); \quad /* \text{Atomic Belief Update} */
\]

\[
\quad +\text{!fuel}(T+5);
\]

\[
\ldots
\]

\[
+\text{!pit\_stop}(\text{fuel}(T), \text{tires}_{\sim}(\_)) \\
: \sim\text{raining} \quad /* \text{There is a belief indicating} \ \sim\text{raining} */
\]

\[
\leftarrow \quad +\text{tires}(\text{slick}); \quad /* \text{Atomic Belief Update} */
\]

\[
\quad +\text{!fuel}(T);
\]

\[
\ldots
\]
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 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 \(g\):

\[
+!g(X) : \text{goalstate}
\quad \leftarrow \text{true.}
\]
\[
+!g(X) : \text{not goalstate}
\quad \leftarrow \ldots
\quad \text{?g.}
\]
\[
\ldots
\]
\[
-!g : \text{true} \quad /* \text{Goal deletion event} */
\quad \leftarrow !g.
\]
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).
```

- \((\text{chance of success} \times \text{usual payoff})\) 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`.

```java
package myLib;

import jason.JasonException;
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 JasonException("check arguments");
        try {
            int R = random.nextInt( ((numberTerm)args[0]).solve() );
            return un.unifies(args[1], new NumberTermImpl(R));
        } catch (Exception e) {
            throw new JasonException("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).
- $ilf \in \{ \text{tell}, \text{untell}, \text{achieve}, \text{unachieve}, \text{askOne}, \text{askAll}, \text{askHow}, \text{tellHow}, \text{untellHow} \}$
- $m(X)$ the content of the message

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

- Handles it by customizing a reaction:

  $$+m(X)[\text{source}(A)] : \text{true}$$
  $$\leftarrow \text{dosomething};...$$
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 specializing 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

```java
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 Plannig

- 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.
Hierarchical Planning (II)

- 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.

- Differently from traditional planning systems, which mainly make an offline planning, Intentional Systems need to plan in dynamic environments and need to cope with changing contexts and situations [Sardina et al., 2006]

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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Academic Year 2013/2014