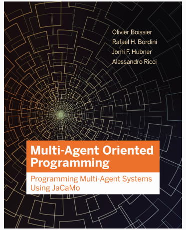


# Agent Dimension

PósAutomação — UFSC

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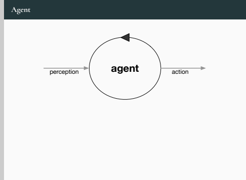
Agent Dimension

PósAutomação — UFSC

# Agent

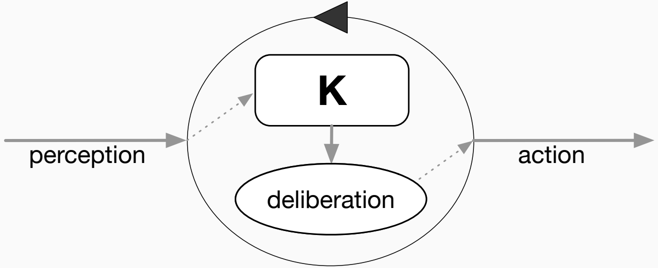





The goal of this part is to introduce agent oriented programming
So it is about **programming** and about **agent**
What is an agent?
- it is not like a conventional program (that starts and ends)
- it is continuously running (like a server)
- continuously **perceiving** ("inputs") the **environment** (sensors, messages, user commands, ...)
- the "output" is continuous **acting**
- output is not data (as a procedural program) neither knowledge (as an inference engine)
- **it changes a lot!**
- it is about how to program to act instead of programming to change data, or to infer something
- it is about **programming** an agent and not a computer or a "mind"!

# AI Agent





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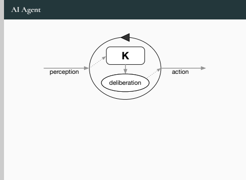
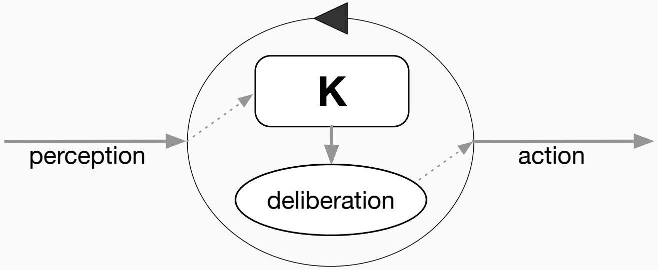
└AI Agent



- considering an AI context, we take a **symbolic** approach:
- the agent has **knowledge**
- its behaviour is based on knowledge — “The Knowledge Level” [**?**]
- the developer defines that K (it can be learnt, but not the focus today)
- what is K? information, rules, **plans**, **goals**, ...
- in our case (agents), the focus is on K elements directed to actions

# AI Agent




**while true do**

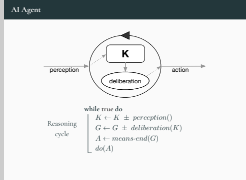
Reasoning cycle

$$
\begin{aligned}
& K \leftarrow K \pm perception() \\
& G \leftarrow G \pm deliberation(K) \\
& A \leftarrow means\text{-}end(G) \\
& do(A)
\end{aligned}
$$







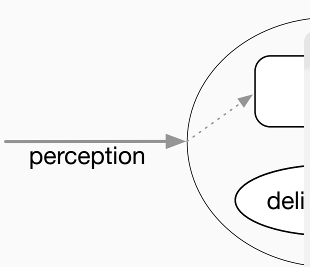


- what is the engine?
- it is a continuous process that
– perceives
– decides actions to achieve a goal
– does the actions

- the agent has **autonomy** the choose actions
- an agent decides what to do!
- part of the task that usually a programmer does (ordering the actions) is done by the agent.
- to program an agent is to define K (and not to write an algorithm)

Let's move to a more practical perspective to consolidate the basic concepts (we latter return to the conceptual background)

# AI Agent




**features**

- **pro-activity**: new (long-term) goals can be created and the agent is committed to them
- **reactivity**: prompt reaction even when pursuing goals

Reasoning cycle

**while true do**

$K \leftarrow K \pm perception()$
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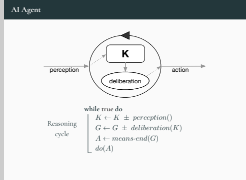
$do(A)$







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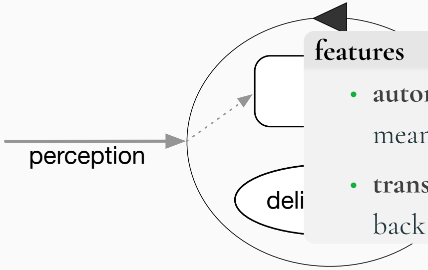


**features**

- **autonomy**: to find (good) means to achieve goals
- **transparency**: we can trace back the reasons for an action

**while true do**

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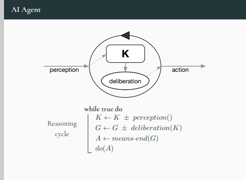


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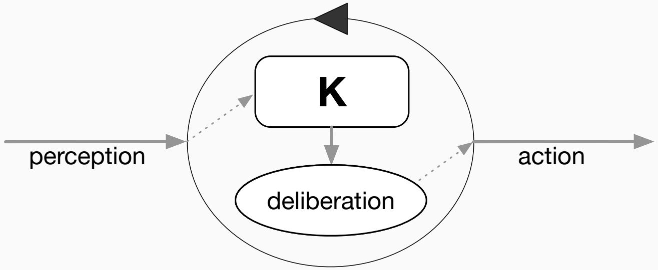


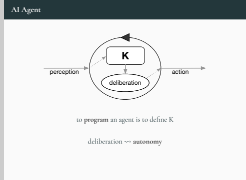

to **program** an agent is to define K

deliberation ⇝ **autonomy**







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# Agent Knowledge (in Jason)

**Beliefs** : information about the environment, other agents, itself, ...

```
temperature(20).
happy(bob).
```

**Goals** : the agent objectives

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!temperature(20).
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```

**Plans** :







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JaCaMo is a framework with languages that allows us to implement systems based on K agents and ...
so elements of agent knowledge in JaCaMo (beliefs quite usual, novelty are goals and plans, and how they are "interpreted")

- Syntax inspired by Prolog: predicate(arguments)
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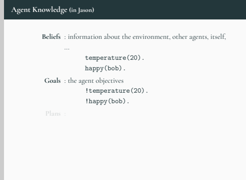


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specifies **reactions** to mental state changes

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└Agent Knowledge (in Jason) — $K = B + G + P$

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# Knowledge Sources

Beliefs, goals, and plans are provided by

- perception: in the case of beliefs
- developers: initial mental state of the agent
- other agents: by communication
- the agent itself: by reasoning or learning



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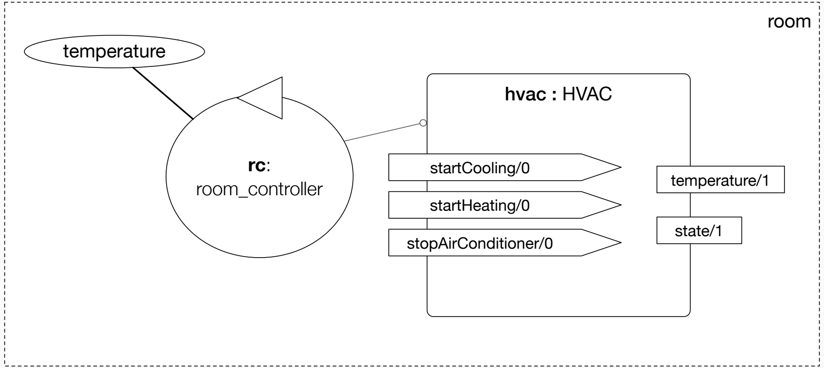
# Smart Room Scenario — initial implementation



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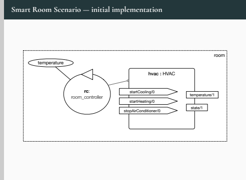
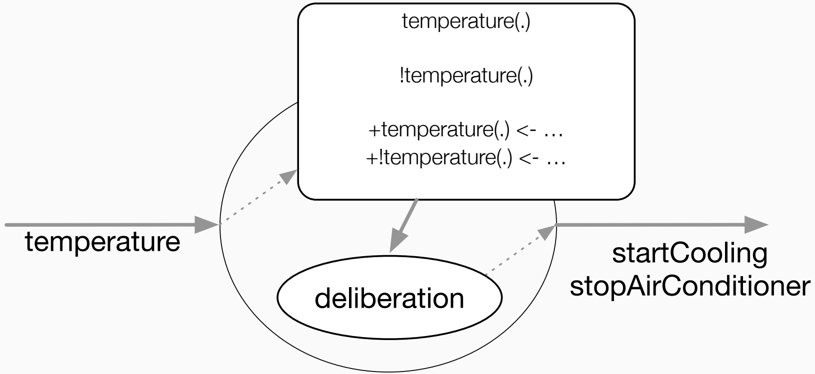


- HVAC provides perception of its state and the current temperature
- exposes 3 actions for the agent

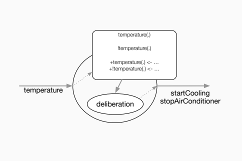
(details of how to program this artifact will be presented later)









Let's focus on programming that agent

- the perception of the current temperature is mapped to a belief like `temperature(30)`
- the objective to maintain some temperature is mapped to a belief like `!temperature(30)`
- the agent has plans to react to changes in the current temperature and the creation of new goals to maintain some temperature

```
+temperature(30)  <- !temperature(20).
+!temperature(20) <- startCooling.
```







Agent Programming (in JaCaMo)

Agent Programming (in JaCaMo)

+temperature(30) <- !temperature(20).
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(agents are programmed in JaCaMo using the **Jason** language)
- these 2 lines are a complete Jason program, a program with 2 plans
- beliefs are added by perception
- (read the plans): in the **event** of a new **belief** `temperature(30)`, **react** to it creating the **goal** `!temperature(20)`
- in the event of a new a goal `!temperature(20)`, react to it by **doing** `startCooling`
- the program has no begin/end, **declarative** approach (K is declared)
- set of reactive "rules" (implemented by the plans)

- which are the problems of this implementation?
(implement, run, and see!)

# Agent Programming (in JaCaMo)

```
+temperature(30)  <- !temperature(20).
+temperature(20)  <- stopAirConditioner.

+!temperature(20) <- startCooling.
```







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```


(improved version with stopAirConditioner, that stops)

(image the agent behaviour) - which are the problems of this implementation?

```
// initial belief, given by the developer
preference(20).

// reaction to changes in the temperature
+temperature(T)  : preference(P) & math.abs(P-T) > 2
   <- !temperature(P).
+temperature(T)  : preference(T)
   <- stopAirConditioner.

// plans to achieve some temperature
+!temperature(P) : temperature(T) & T >  P
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Agent Programming (in JaCaMo)

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What is new:

- new belief, not perceived, but defined in the inicial code of the agent
- **variable** with upper case first letter
- plans have **context**, used for the agent to select the most appropriated
- the evaluation of the context is like a **query** to the belief base, and it may assign values to variables

Agent behaviour:

- any change in temperature produces actions to start cooling, is it ok?
- what if the preference changes?

```
// initial belief, given by the developer
preference(20).

// initial goal, given by the developer
!keep_temperature.

// maintenance the goal pattern
+!keep_temperature
    : temperature(T) & preference(P) & T >  P
  <- startCooling;
     !keep_temperature.
+!keep_temperature
    : temperature(T) & preference(P) & T <= P
  <- stopAirConditioner;
     !keep_temperature.
```





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└Agent Programming (in JaCaMo)

**maintenance goal** — long term goals
agent is not reacting to changes in beliefs anymore, it has a "forever" goal that, based on the circumstances, select a proper plan of actions

- does it reacts to changes in the preference?

**pro-activity**

# Main Features

- **pro-activity**: new (long-term) goals can be created
- **reactivity**: even when pursuing some goals
- **autonomy**: to find (good) means to achieve goals
- **context awareness**: plans are selected based on the circumstances
- **transparency**: we can trace back the reasons for an action
- sound **theoretical background** for agent architectures:
  - practical reasoning [Bratman, 1987]
  - intentions [Cohen and Levesque, 1987]
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  - ...





Main Features
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  - ...

because:
- agents have a reasoning cycle
- based on knowledge
- reasoning about what **to do** (practical reasoning) (detailed later in the course)

Are usual languages (Java, Python, Prolog, ...) appropriate to implement agents?
Can we use them? Sure we can. But they will give us a lot of work to code agents.

# Wrap-up

- Knowledge Level

agents **know**

- Practical Reasoning

agents **act**





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└ Wrap-up

Wrap-up

- Knowledge Level

agents **know**

- Practical Reasoning

agents **act**

# Agent Interaction (communication)

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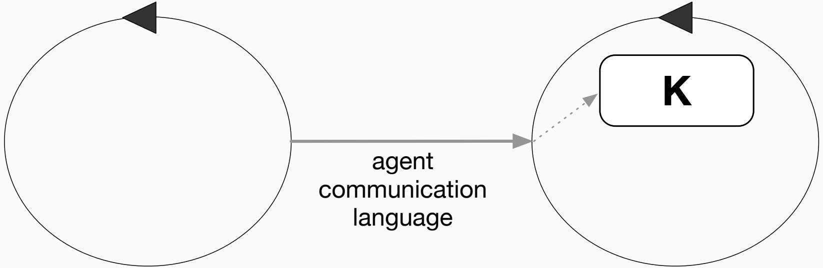
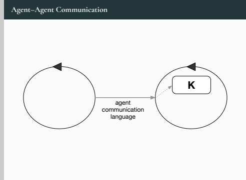
# Agent–Agent Communication





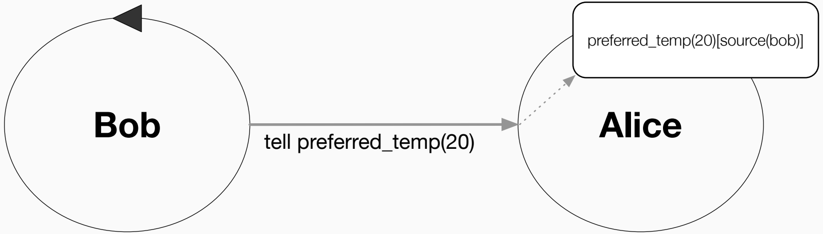





Agent Communication Language
- the language to communicate **is not** the same as the language to program agents, since they have different purposes
- works at the **Knowledge** level (again!)
- when sending a message, the sender **intends** to change the mind of receiver (mentalistic view)
- K is transmitted (thing I know that, know how to, I wish, ...)
so send beliefs, desires, plans, ...
- used to build negotiation, coordination, information share

# Semantic of messages




A message has:

- an intention (tell, ask, achieve, ...)
- a content (belief, goal, plan)





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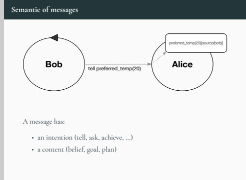
└─Semantic of messages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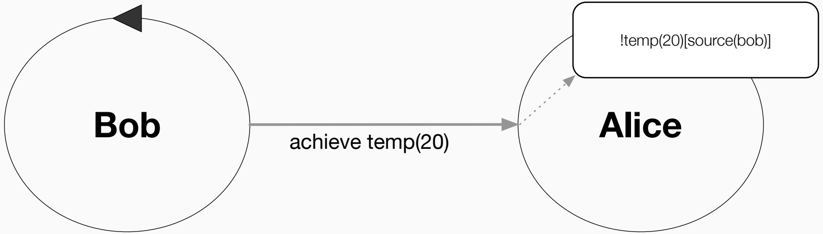


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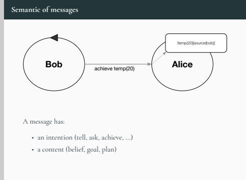

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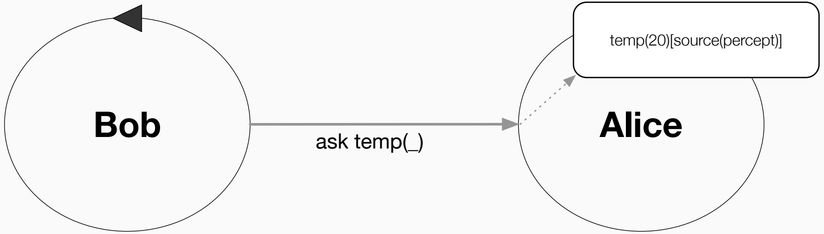


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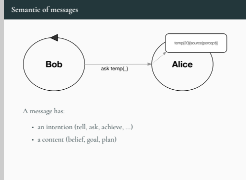

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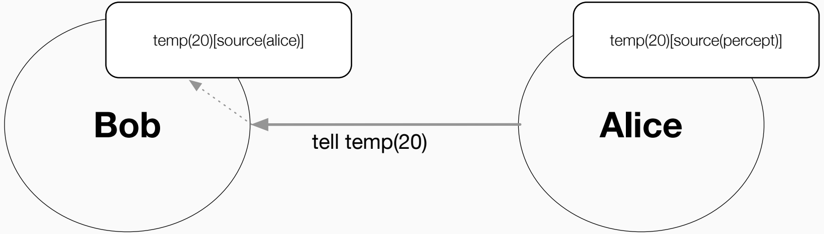


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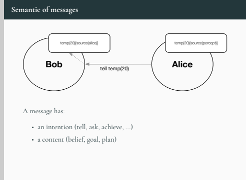

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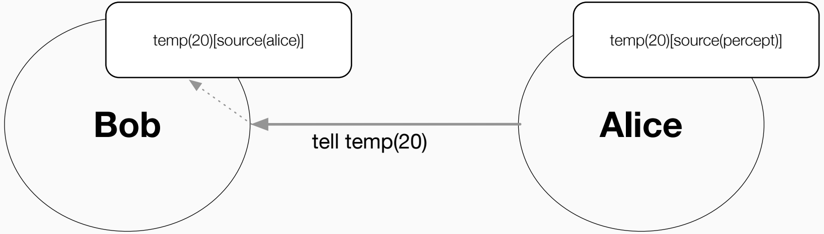


- we are not programming computers,
  we are programming agents, which are based on knowledge
- communication is not about data exchange, but
  knowledge sharing





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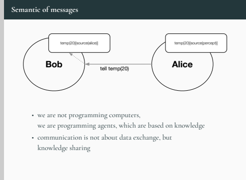
└Semantic of messages



# JaCaMo implementation

Sender: `.send(bob,tell,happy(alice))`

- receiver: agent unique name
- performative: tell, achieve, askOne, askHow, ...
- content: a literal

Receiver

- nothing is needed

Properties

- distributed & support for decentralized
- (usually) asynchronous
- KQML vs FIPA-ACL
- not reduced to method invocation







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- distributed & support for decentralized
- (usually) asynchronous
- KQML vs FIPA-ACL
- not reduced to method invocation

no code in the receiver, the semantics of the ACL is implemented on the interpreter!
distributed means several machines
decentralised means no central control

KQML and FIPA-ACL are initiatives to standardise ACL

KQML was the standard when Jason was first developed

# JaCaMo Performatives

- **tell** and untell: change beliefs of receiver
- **achieve** and unachieve: change goals of receiver
- **askOne** and askAll: ask for beliefs of the receiver
- **askHow**, tellHow, and untellHow: exchange plans with other agent
- **signal**: add an event in the receiver





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JaCaMo Performatives

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- **tell** and untell: change beliefs of receiver
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- **askOne** and askAll: ask for beliefs of the receiver
- **askHow**, tellHow, and untellHow: exchange plans with other agent
- **signal**: add an event in the receiver

Theoretical background is **speech acts** [**?**, **?**]: to say is to act; to power of word.

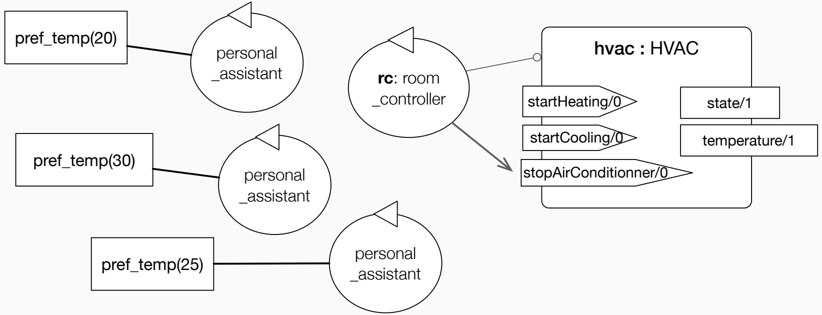
synchronous cases:
.send(a,askOne,v(X),A)
it blocks the intention until an answer is received, the answer is assigned to A

signal is quite recent in JaCaMo (Jason)
e.g. .send(bob,signal,hello)

# Smart Room Scenario

**many users**

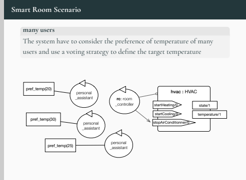
The system have to consider the preference of temperature of many users and use a voting strategy to define the target temperature





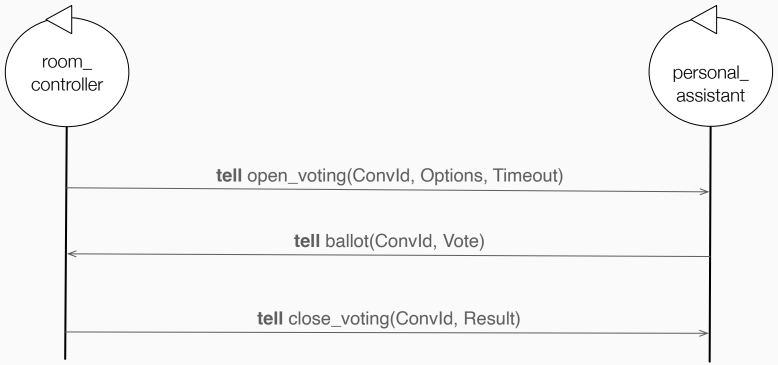




**decentralised** solution

we will solve it using agent communication





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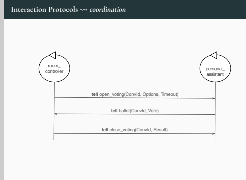
└Interaction Protocols ⇝ *coordination*



**decentralised** solution requires coordination (of actions)

coordination of actions, order actions

here, order of comunicative actions

# Protocol Implementation





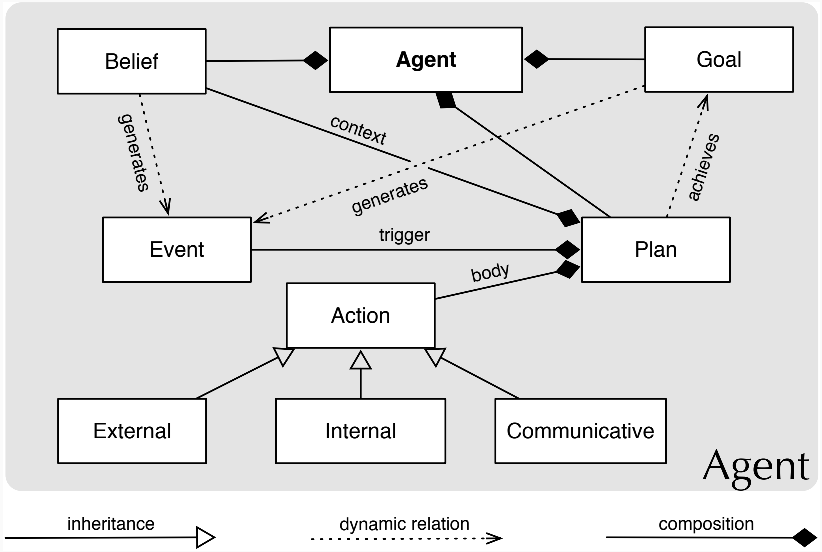


└─Protocol Implementation

Protocol Implementation

live coding

# Wrap-up: Agent Model



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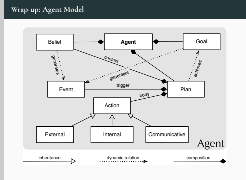
└─Wrap-up: Agent Model



# Wrap-up: Agent Programming

- **AgentSpeak**
  - Logic + BDI
  - Agent programming language
- ***Jason***
  - AgentSpeak interpreter
  - Implements the operational semantics of AgentSpeak
  - Speech-act based communicaiton
  - Highly customisable
  - Useful tools
  - Open source





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└Wrap-up: Agent Programming

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  - Logic + BDI
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  - Open source

# Fundamentals





I do not plan to present all the following slides, I will select them regarding the interests of the audience

# Literature

**Books:** [Bordini et al., 2005], [Bordini et al., 2009]

**Proceedings:** EMAS, ProMAS, DALT, LADS, AGERE, ...

**Surveys:** [Bordini et al., 2006], [Fisher et al., 2007] ...

**Languages of historical importance:** Agent0 [Shoham, 1993],
*AgentSpeak(L)* [Rao, 1996], MetateM [Fisher, 2005],
3APL [Hindriks et al., 1997],
Golog [Giacomo et al., 2000]

**Other prominent languages:**
*Jason* [Bordini et al., 2007], Jadex [Pokahr et al., 2005],
2APL [Dastani, 2008], GOAL [Hindriks, 2009],
JACK [Winikoff, 2005],
ASTRA, SARL

**But many others languages and platforms...**





Hard work have being done on this approach already.

# Some Languages and Platforms

Jason (Hübner, 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, ...); GOAL (Hindriks); BRAHMS (Sierhuis, ...); SemantiCore (Blois, ...); 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); ASTRA (Rem Collier); SARL (Stephane Galland, Sebastian Rodriguez); *simpAL*, *ALOO* (Ricci, ...);

...







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...

some proposals are libraries/packages for existing languages
others are new languages
many agent languages have efficient and stable interpreters

# Agent Oriented Programming — Inspiration

- Use of **mentalistic** notions and a **societal** view of computation [Shoham, 1993]
- Heavily influenced by the **BDI** architecture and reactive planning systems [Bratman et al., 1988]





Agent Oriented Programming — Inspiration
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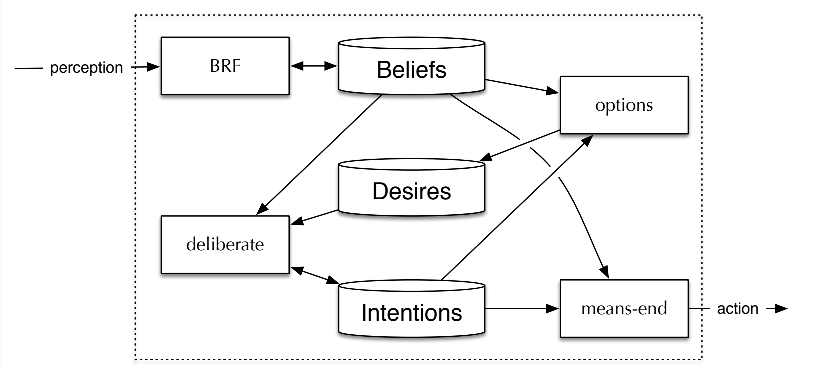
- Heavily influenced by the **BDI** architecture and reactive planning systems [Bratman et al., 1988]

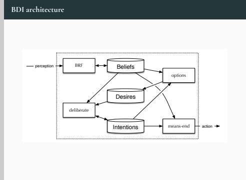
I do recommend to read foundational papers like these from a Philosopher (trying to solve the problem for humans)

# BDI architecture







mentalistic view (the behavior of the agent is explained in terms of its mental state: B, D, and I):
- B: beliefs (information) the agent has about its environment (updated by perception) - D: what the agent wishes - I: desires the agent has *committed* to (based on the current beliefs and other intentions)

Two main processes: deliberate: Desire -> Intention means-ends: Intention -> Actions

**BDI** explains the actions of the agent! (because the agent intents to, desires to, and believes it is feasible)

So next slides will highlight properties of the commitment (serious commitment but not too much)

# BDI reasoning cycle [Wooldridge, 2009]

**while** true **do**

$B \leftarrow brf(B, perception())$ `// belief revision`

$D \leftarrow options(B, I)$ `// desire revision`

$I \leftarrow deliberate(B, D, I)$ `// get intentions`

$\pi \leftarrow meansend(B, I, A)$ `// gets a plan`

**while** $\pi \neq \emptyset$ **do**

execute( $head(\pi)$ )

$\pi \leftarrow tail(\pi)$





intentions are desire + commitment.

types of commitments: over commitment, Singel-Minded, .... there are good bibliography on that.

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fine for pro-activity, but not for reactivity (over **commitment**)







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  - $B \leftarrow brf(B, perception())$
  - **if** $\neg sound(\pi, I, B)$ **then**
    - $\pi \leftarrow meansend(B, I, A)$

revise commitment to plan – re-planning for context adaptation







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- **while** $\pi \neq \emptyset$ **and** $\neg succeeded(I, B)$ **and** $\neg impossible(I, B)$ **do**
  - execute( $head(\pi)$ )
  - $\pi \leftarrow tail(\pi)$
  - $B \leftarrow brf(B, perception())$
  - **if** $\neg sound(\pi, I, B)$ **then**
    - $\pi \leftarrow meansend(B, I, A)$

revise commitment to intentions – Single-Minded Commitment







intentions are desire + commitment.

types of commitments: over commitment, Singel-Minded, .... there are good bibliography on that.

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  - $\pi \leftarrow tail(\pi)$
  - $B \leftarrow brf(B, perception())$
  - **if** $reconsider(I, B)$ **then**
    - $D \leftarrow options(B, I)$
    - $I \leftarrow deliberation(B, D, I)$
  - **if** $\neg sound(\pi, I, B)$ **then**
    - $\pi \leftarrow meansend(B, I, A)$

reconsider the intentions (not always!)







intentions are desire + commitment.

types of commitments: over commitment, Singel-Minded, .... there are good bibliography on that.

# Intentions

- Intentions pose problems for the agents: they need to determine a way to achieve them
  (planning and acting)
- Intentions provide a “screen of admissibility” for adopting new intentions
- Agents keep tracking their success of attempting to achieve their intentions
- Agents should not spend all their time revising intentions
  (losing pro-activity and reactivity)





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- Agents should not spend all their time revising intentions
  (losing pro-activity and reactivity)

# (BDI & Jason) Hello World – agent bob

```
friend(alice).              // B

!say(hello).                // D


+!say(M) <- .print(M).      // I
```







(BDI & Jason) Hello World – agent bob

```
friend(alice).              // B
!say(hello).                // D
+!say(M) <- .print(M).      // I
```


- how does it look like? (comparing with other languages like C, Java, ....)
- jason uses procedural goals (goals to do) and not declarative goals (goals to be), as 2APL. it comes from the orignal PRS inspiration where we are specifying behaviour instead of (env) states [?]
- **plans** are not prolog (theoretical reasoning), they are the for practical reasoning.
- the language gives constructors to program BDI with the required features shown in the Woodridge algorithm

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```

**beliefs**

- prolog like (FOL)







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```

**desires**

- prolog like
- with ! prefix





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# (BDI & Jason) Hello World – agent bob

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friend(alice).              // B

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+!say(M) <- .print(M).
```

**plans**

- define when a desire becomes an intention
  ⇝ **deliberate**
- how it is satisfied
- are used for practical reasoning
  ⇝ **means-end**







(BDI & Jason) Hello World – agent bob
friend(alice). // B
!say(hello). // D
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# BDI Hello World — desires from perception (*options*)

```
friend(alice).

+happy(A) <- !say(hi(A)).


+!say(M) <- .print(M).
```





BDI Hello World — desires from perception (*options*)

friend(alice).
+happy(A) <- !say(hi(A)).
+!say(M) <- .print(M).

desire via perception, the agent starts believing someone is happy and then creates a new desire

# BDI Hello World — plan selection

```
friend(alice).

+happy(A) : friend(A)     <- !say(hi(A)).
+happy(A) : not friend(A) <- !say(good_afternoon(A)).

+!say(M) <- .print(M).
```







BDI Hello World — plan selection

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+happy(A) : friend(A) <- !say(hi(A)).
+happy(A) : not friend(A) <- !say(good_afternoon(A)).

+!say(M) <- .print(M).

**the agent** selects the plan that is more suitable for the current circumstance. plan context is used for that.

whenever (trigger event)
- I start to believe that A is happy

and (context)
- I belief that A is a friend

then (body)
- create a new desire to say hi

whenever I have the desire to say something, **commit** to that desire and use the body of the plan to fullfil it.

# BDI Hello World — intention revision

```
friend(alice).

+happy(A) : friend(A)     <- !say(hi(A)).
+happy(A) : not friend(A) <- !say(good_afternoon(A)).

+!say(M) <- .print(M); .wait(1000); !say(M).

+busy(bob) <- .drop_intention(say(_)).
```







BDI Hello World — intention revision

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# BDI Hello World — intention revision

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friend(alice).

+happy(A) : friend(A)
+happy(A) : not friend(A)

+!say(M) <- .print(M); .wa

+busy(bob) <- .drop_intent
```

**features**

- we can have several intentions based on the same plans
  ⇝ running concurrently
- long term goals running
  ⇝ reaction meanwhile
  ⇝ not overcommitted
- plan selection based on circumstance
- sequence of actions (partially) computed by the interpreter
  ⇝ programmer **declares** plans







BDI Hello World — intention revision

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```

# Jason

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*Jason*

Jason

# AgentSpeak: The foundational language for *Jason*

- Programming language for BDI agents
- Originally proposed by Rao [Rao, 1996]
- 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



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└─*Jason*
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# *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**
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agent dimension in JaCaMo

# Main Language Constructs

**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





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Main Language Constructs

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**Goals:** represent states of affairs the agent wants to bring about
**Plans:** are recipes for action, representing the agent's know-how

### Syntax

Beliefs are represented by annotated literals of first order logic

$\texttt{functor}(term_1, \ldots, term_n)[annot_1, \ldots, annot_m]$

### 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 — Representation
Syntax
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functor(term1, ..., termn)[annot1, ..., annotm]
Example (belief base of agent Tom)
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lier(alice)[source(self),source(bob)].
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annotations is a set of terms with special unification — not available in Prolog

**by perception**

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

**by intention**

the **plan operators** + and - can be used to add and remove beliefs annotated with source(self) (**mental notes**)

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





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└ *Jason*

 └ Beliefs — Dynamics

Beliefs — Dynamics i

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

by intention
the plan operators + and - can be used to add and remove beliefs annotated with source(self) (mental notes)

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

**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
```







Beliefs — Dynamics ii

by communication

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# 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) or
**?** (test goal)

## Example (Initial goal of agent Tom)

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





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) or
? (test goal)
Example (Initial goal of agent Tom)
!write(book).

jason uses procedural goals (goals to do) and not declarative goals (goals to be, as in planning, 2APL, ...).
it comes from the orignal PRS inspiration where we are specifying behaviour instead of (env) states [**?**]

PRS also proposes maintenance goal, that is available in Jason(ER)

**by intention**

the **plan 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 i
by intention
the plan 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);
...

### 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 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 unifies with Answer
```





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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 unifies with Answer

# Triggering Events — Representation

- Events happen as 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) |







Triggering Events — Representation
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-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
- the context represent 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 true at the time a plan is being chosen to handle the event







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

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





2024-11-11

└─*Jason*
  └─Plans — Operators for Plan **Context**

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

```
+rain :  time_to_leave(T) & clock.now(H) & H >= T
   <- !g1;          // new sub-goal
      !!g2;         // new goal
      ?b(X);        // new test goal
      +b1(T-H);     // add mental note
      -b2(T-H);     // remove mental note
      -+b3(T*H);    // update mental note
      jia.get(X);   // internal action
      X > 10;       // constraint to carry on
      close(door);// external action
      !g3[hard_deadline(3000)].   // goal with deadline
```







Plans — Operators for Plan Body

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# Plans — Dynamics

The plans that form the plan library of the agent come from

- initial plans defined by the programmer
- plans added dynamically and intentionally by
  - .add_plan
  - .remove_plan
- plans received from
  - **tellHow** messages
  - **untellHow**







Plans — Dynamics

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  - **untellHow**

# A note about “Control”

Agents can control (manipulate) their own (and influence the others)

- beliefs
- goals
- plan

By doing so they control their behaviour

The developer provides initial values of these elements and thus also influence the behaviour of the agent





A note about “Control”

Agents can control (manipulate) their own (and influence the others)

- beliefs
- goals
- plan

By doing so they control their behaviour

The developer provides initial values of these elements and thus also influence the behaviour of the agent

Object Oriented encapsulates "beliefs" and "plans", but not "goals", no “thread of execution”

# Reasoning Cycle

2024-11-11

*Jason*

# Runtime Structures for the Reasoning Cycle

**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 consequence to changes in the agent's beliefs or goals

**Intentions:** plans instantiated to achieve some goal







Runtime Structures for the Reasoning Cycle

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

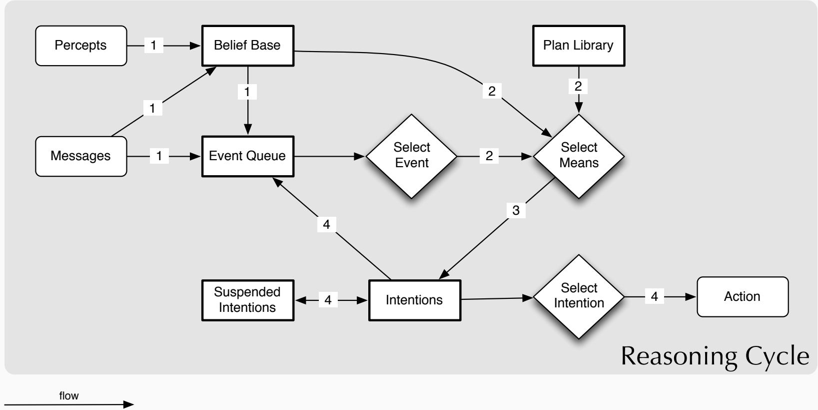
Plans: are recipes for action, representing the agent's know-how

Events: happen as consequence to changes in the agent's beliefs or goals

Intentions: plans instantiated to achieve some goal

The former three come from the agent program (syntax), the latter two exist at runtime to support the interpretation (semantics) of Jason

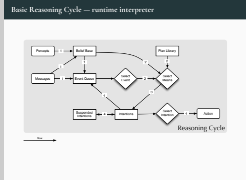
# Basic Reasoning Cycle — runtime interpreter









1 perceive the environment and update belief base

1 process new messages

1 select event

2 select **relevant** plans

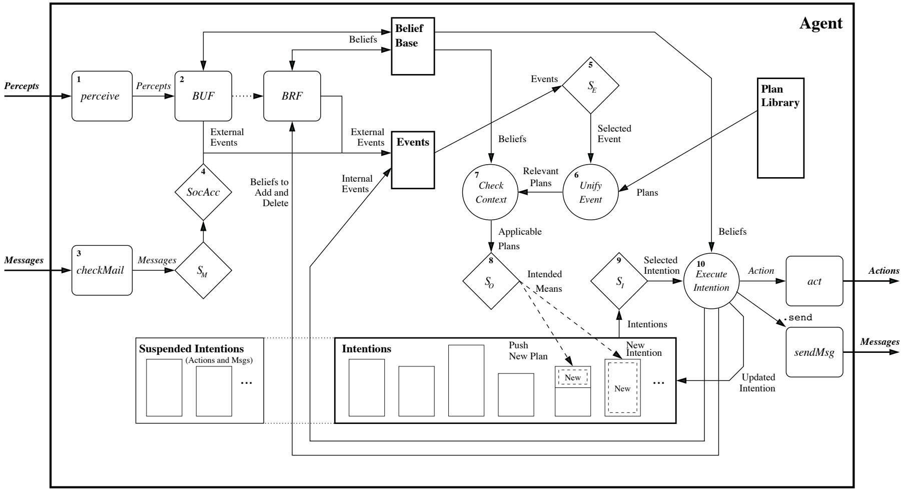
2 select **applicable** plans

3 create/update intention

4 select intention to execute

4 execute one step of the selected intention

# *Jason* Reasoning Cycle





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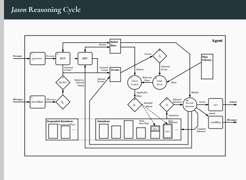
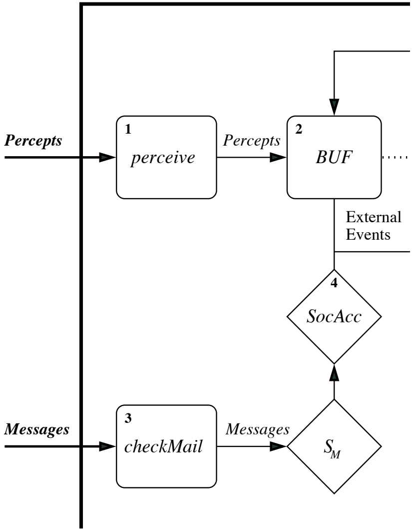
└*Jason*

└*Jason* Reasoning Cycle



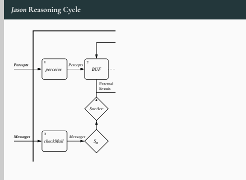



- machine perception
- belief revison
- knowledge representation
- communication, argumentation
- trust
- social power

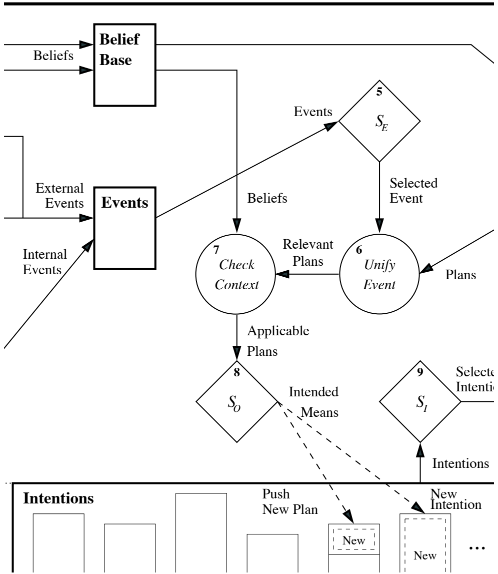








# *Jason* Reasoning Cycle




- planning
- reasoning
- decision theoretic techniques
- learning (reinforcement)



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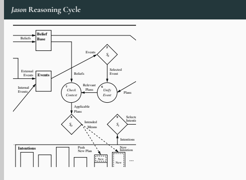
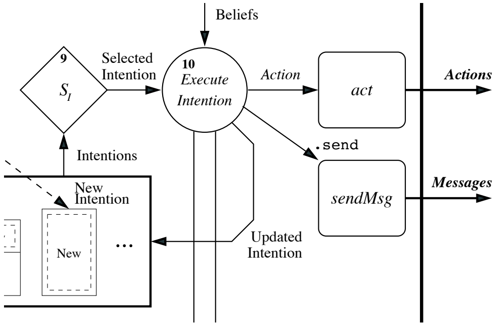


# *Jason* Reasoning Cycle

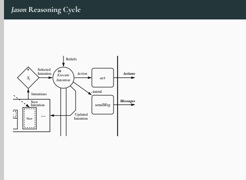



- intention reconsideration
- scheduling
- action theories









# Other Features

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*Jason*

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

```
+!g : g.    // g is a declarative goal

+!g : ... <- a1; ?g.
+!g : ... <- a2; ?g.
+!g : ... <- a3; ?g.

+!g <- !g. // keep trying
-!g <- !g. // in case of some failure

+g <-.succeed_goal(g).
```



2024-11-11

└*Jason*

  └Failure Handling: Contingency Plans

Failure Handling: Contingency Plans

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+g <-.succeed_goal(g).

# Failure Handling: Contingency Plans

**Example (single minded commitment)**

```
+!g : g.      // g is a declarative goal

+!g : ... <- a1; ?g.
+!g : ... <- a2; ?g.
+!g : ... <- a3; ?g.

+!g <- !g. // keep trying
-!g <- !g. // in case of some failure

+g <-.succeed_goal(g).

+f : .super_goal(g,SG) <-.fail_goal(SG).
```

$f$ is the drop condition for goal $g$



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└Jason
  └Failure Handling: Contingency Plans

Failure Handling: Contingency Plans

Example (single minded commitment)

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+g <-.succeed_goal(g).

+f : .super_goal(g,SG) <-.fail_goal(SG).

f is the drop condition for goal g

# Compiler pre-processing – directives

**Example (single minded commitment)**

```
{ begin smc(g,f) }
     +!g : ... <- a1.
     +!g : ... <- a2.
     +!g : ... <- a3.
{ end }
```





Compiler pre-processing – directives
Example (single minded commitment)
{ begin smc(g,f) }
+!g : ... <- a1.
+!g : ... <- a2.
+!g : ... <- a3.
{ end }

**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







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

# Other Language Features: Strong Negation

```
+!leave(home)
   :  ~raining
   <- open(curtains); ...

+!leave(home)
   :  not raining & not ~raining
   <- .send(mum,askOne,raining,Answer,3000); ...
```







Other Language Features: Strong Negation

```
+!leave(home)
   :  ~raining
   <- open(curtains); ...

+!leave(home)
   :  not raining & not ~raining
   <- .send(mum,askOne,raining,Answer,3000); ...
```

# Prolog-like Rules in the Belief Base

```
tall(X) :- woman(X) & height(X, H) & H > 1.70.
tall(X) :- man(X) & height(X, H) & H > 1.80.
```







Prolog-like Rules in the Belief Base
tall(X) :- woman(X) & height(X, H) & H > 1.70.
tall(X) :- man(X) & height(X, H) & H > 1.80.

# Internal Actions

- Unlike actions, internal actions do not change the environment
- They are 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(...)
```





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- Internal actions can be defined by the user in Java

libname.action_name(...)

# Standard Internal Actions

- Standard (pre-defined) internal actions have an empty library name
    - .print($term_1, term_2, \ldots$)
    - .union($list_1$, $list_2$, $list_3$)
    - .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.





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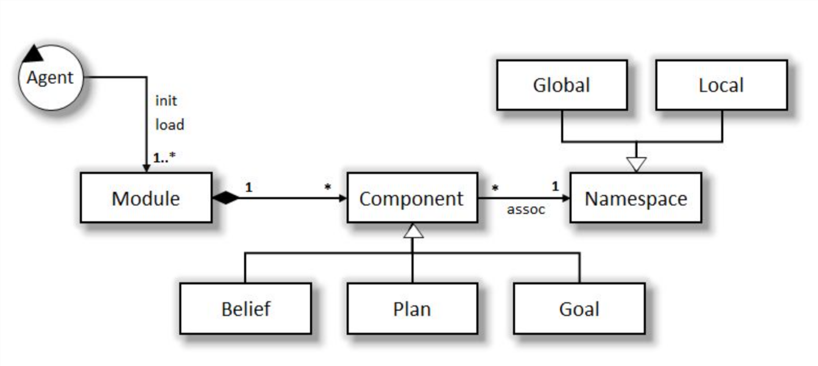
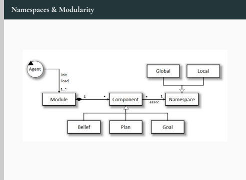
# Namespaces & Modularity







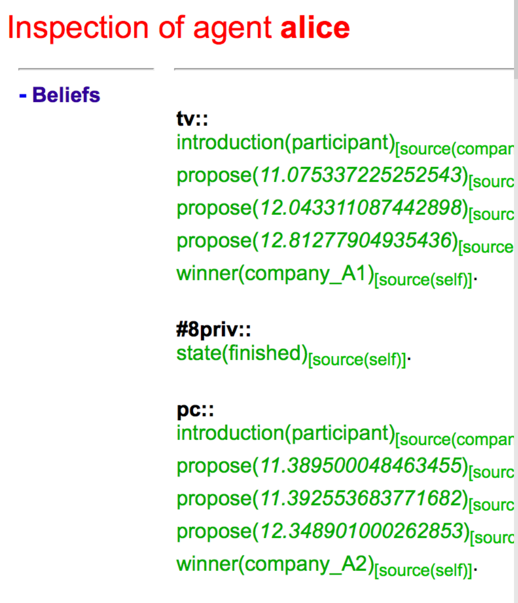


```
{include("initiator.asl", pc)}
{include("initiator.asl", tv)}

!pc::startCNP(fix(pc)).
!tv::startCNP(fix(tv)).

+pc::winner(X)
   <- .print(X).
```



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└ Jason
  └ Namespaces & Modularity

Namespaces & Modularity
{include("initiator.asl", pc)}
{include("initiator.asl", tv)}
!pc::startCNP(fix(pc)).
!tv::startCNP(fix(tv)).
+pc::winner(X)
<- .print(X).

# Concurrent Plans

```
+!ga <- ...; !gb; ...
+!gb <- ...; !g1 |&| !g2; a1; ...

+!ga <- ...; !gb; ...
+!gb <- ...; !g1 ||| !g2; a1; ...

+!g <- x; (a;b) |&| (c;d) ||| (e;f); y.
```





Concurrent Plans

+!ga <- ...; !gb; ...
+!gb <- ...; !g1 |&| !g2; a1; ...

+!ga <- ...; !gb; ...
+!gb <- ...; !g1 ||| !g2; a1; ...

+!g <- x; (a;b) |&| (c;d) ||| (e;f); y.

# Jason(ER) — motivation

```
+cfp(Id,Task)[source(A)] // answer to Call For Proposal
    : price(Task,Offer) & not my_offer(Task)
   <- +offered(Task);
      .send(A,tell,propose(Id,Offer)).
+cfp(Id,_)[source(A)]
   <- .send(A,tell,refuse(Id)).

+accept_proposal(Id) : my_offer(Task)
   <- !do(Task);
      -my_offer(Task).

+reject_proposal(Id) : my_offer(Task)
   <- -my_offer(Task).
```







Jason(ER) — motivation

+cfp(Id,Task)[source(A)] // answer to Call For Proposal
: price(Task,Offer) & not my_offer(Task)
<- +offered(Task);
.send(A,tell,propose(Id,Offer)).
+cfp(Id,_)[source(A)]
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+accept_proposal(Id) : my_offer(Task)
<- !do(Task);
-my_offer(Task).
+reject_proposal(Id) : my_offer(Task)
<- -my_offer(Task).

- what is the goal related to the action .send(A,tell,propose(Id,Offer))
- when executing actions for goal "do", if we ask "why" we can track back to accepted_ proposal, but not to the cfp or even some implicit goal that is "participate in CNP"

- some jason intentions have no explicit goal
- no explicit **causal** link among plans

# Scope & sub-plans & goal conditions

```
+!g(X) : c <: gc <- a1; !g1.
{

   +e : c1 <- a2(X).
   +!g1 ....
}
```







Scope & sub-plans & goal conditions

+!g(X) : c <: gc <- a1; !g1.
{
+e : c1 <- a2(X).
+!g1 ....
}

- main objective: **all behaviour is the result of an (explicit) goal**
(not a Jason intention, that can have no explicit goal)

- new syntax: goal condition after `<:` and sub-plans enclosed by { and }

- relevant event are defined by the current intentions
- event +e is relevant **only** the agent intends g
- relevant plans are defined by the scope of some goal
- plan for g1 is visible only in scope of g
- g is dropped **only** when gc is true: **maintenance goal**
- variables have a broader scope (X is visible in sub-plans

# Example of a participant in a CNP

```
+!participate_cnp <: false. {
   +cfp(Id,Task)[source(A)] // answer to Call For Proposal
       : price(Task,Offer) & not my_offer(Task,_)
      <: false
      <- +my_offer(Task, Offer); .send(A,tell,propose(Id,Of
      {
       +accept_proposal(Id) <- !do(Task); -my_offer(Task,_)

       +reject_proposal(Id) <- -my_offer(Task,_); .done.
      }
   +cfp(Id,_)[source(A)] <- .send(A,tell,refuse(Id)).

   +!do(T) <- ...
 }
```







- the intention for +participate_cfp never finishes
- e-plan for +cfp is triggered only if the agent has goal participate_cnp
- the progression of the intention due to +cfp is finished only by .done, since the goal condition ('false') will never hold
- the e-plans enclosed by { and } are relevant only while the progression for +cfp is "running"
- consider that some progress in the intention is created from cfp(10,"banana"), only events accept_proposal(10) and reject_proposal(10) are relevant to trigger the subplans.

- enforce that every behaviour is due to a goal

# *Jason* Customisations

- **Agent** class customisation:
  selectMessage, selectEvent, selectOption, selectIntention, buf, brf,
  ...

- Agent **architecture** customisation:
  perceive, act, sendMsg, checkMail, ...

- **Belief base** customisation:
  add, remove, contains, ...
  - Example available with *Jason*: persistent belief base (in text files, in data bases, ...)





*Jason* Customisations

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Consider a very simple robot with two goals:

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







*Jason* × Java

Consider a very simple robot with two goals:

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

```java
public class Robot extends Thread {
   boolean seeGold, lowBattery;
   public void run() {
      while (true) {
          while (!  seeGold) {
              a = randomDirection();
              doAction(go(a));

          }
          while (seeGold) {
              a = selectDirection();

              doAction(go(a));

} } } }
```





2024-11-11



Java code – go to gold

public class Robot extends Thread {
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public void run() {
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# Java code – charge battery

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







Java code – charge battery

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boolean seeGold, lowBattery;
public void run() {
while (true) {
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doAction(go(a));
if (lowBattery) charge();
}
while (seeGold) {
a = selectDirection();
if (lowBattery) charge();
doAction(go(a));
if (lowBattery) charge();

# *Jason* code

```
direction(gold)   :- see(gold).
direction(random) :- not see(gold).

+!find(gold)                    // long term goal
   <- ?direction(A);
      go(A);
      !find(gold).
+battery(low)                   // reactivity
   <- !charge.

^!charge[state(executing)]      // goal meta-events
   <- .suspend(find(gold)).
^!charge[state(finished)]
   <- .resume(find(gold)).
```





*Jason* code
direction(gold) :- see(gold).
direction(random) :- not see(gold).
+!find(gold) // long term goal
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^!charge[state(executing)] // goal meta-events
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- 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







*Jason* × Prolog

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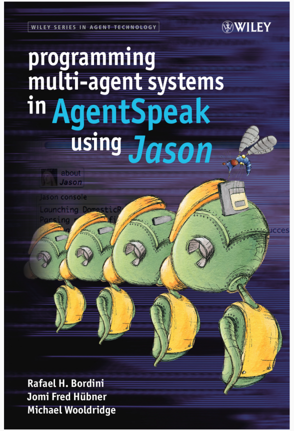
- BDI architecture allows
  - long-term goals (goal-based behaviour)
  - reacting to changes in a dynamic environment
  - handling multiple foci of attention (concurrency)
- Acting on an environment and a higher-level conception of a distributed system

# Further Resources

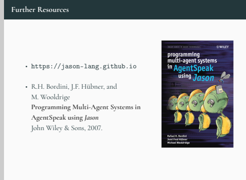
- https://jason-lang.github.io
- R.H. Bordini, J.F. Hübner, and M. Wooldrige
  **Programming Multi-Agent Systems in AgentSpeak using *Jason***
  John Wiley & Sons, 2007.









Besides the JaCaMo book (which has chapters dedicated to the agent dimension, the Jason book is all focused on this dimension

Bordini, R. H., Braubach, L., Dastani, M., Fallah-Seghrouchni, A. E., Gómez-Sanz, J. J., Leite, J., O'Hare, G. M. P., Pokahr, A., and Ricci, A. (2006).
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