

Multi-Agent Oriented Programming

The JaCaMo Platform

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Tutorial Organisation

- ▶ Introduction to Multi-Agent Oriented Programming
- ▶ Programming Agents
- ▶ Programming Agents' Environment
- ▶ Programming Agents' Interaction
- ▶ Programming Agents' Organisations
- ▶ Programming Applications
- ▶ Conclusion & Perspectives

Multi-Agent Oriented Programming
Introduction

Outline

Introduction

Motivation

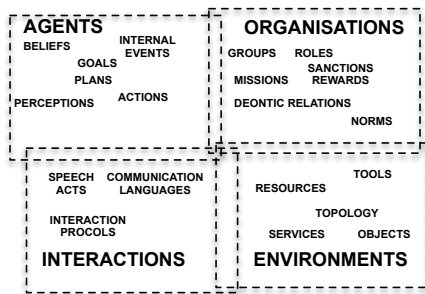
Multi-Agent Oriented Programming (MAOP)

MAOP Perspective in the JaCaMo Platform

Current Landscape of Multi-Agent Programming

- ▶ Many AOSE **methodology** (Prometheus, Gaia, Tropos, ...) exist!
- ↪ Use at least one of these methodologies for analysing and designing your MAS application
- ▶ Many agent languages have efficient and stable interpreters — used extensively in teaching
- ▶ All have some programming tools (IDE, tracing of agents' mental attitudes, tracing of messages exchanged, etc.)
- ▶ Some are integrating **social** aspects of MAS
- ▶ However, there are not yet proper tools to program multi-agent systems!
- ↪ some reasons and motivations follow!

MAS Conceptual framework / Dimensions

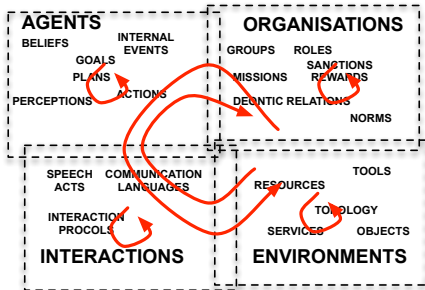


cf. VOWELS [Demazeau, 1995, Demazeau, 1997]

- ▶ **A**gents: abstractions for the definition of the decision/reasoning entities architectures
- ▶ **E**nvironment: abstractions for structuring resources, processing entities shared among the agents
- ▶ **I**nteraction: abstractions for structuring interactions among entities
- ▶ **O**rganisation: abstractions for structuring and ruling the sets of entities within the MAS

↪ A rich set of abstractions for capturing applications complexity!

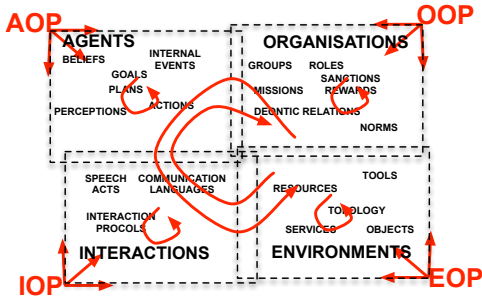
MAS Conceptual framework / Dynamics



- ▶ Each dimension has its own dynamics
- ▶ Dynamics may be interlaced into bottom-up / top-down global cycles
- ▶ Coordination of these dynamics may be programmed into one or several dimensions [Boissier, 2003]

↪ A rich palette of possible dynamics & coordination!!

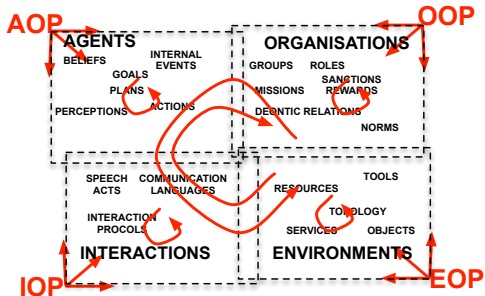
MAS Programming



- ▶ Agent Oriented Programming [Shoham, 1993]
- ▶ Environment Oriented Programming [Ricci et al., 2010b]
- ▶ Interaction Oriented Programming [Huhns, 2001]
- ▶ Organisation Oriented Programming [Pynadath et al., 1999]

- ▶ In these approaches, some dimensions lose their control & visibility!
- ▶ Integrating the dimensions into one programming platform is not so easy!
 - ▶ Examples of Multi-Agent Oriented Programming Platforms: Volcano platform [Ricordel and Demazeau, 2002], MASK platform [Ocelllo et al., 2004], MASQ [Stratulat et al., 2009], extending AGRE and AGREEN, Situated E-Institutions [Campos et al., 2009], ...

MAS Programming



- ▶ Agent Oriented Programming [Shoham, 1993]
- ▶ Environment Oriented Programming [Ricci et al., 2010b]
- ▶ Interaction Oriented Programming [Huhns, 2001]
- ▶ Organisation Oriented Programming [Pynadath et al., 1999]

Challenge

Shifting from an A/E/I/O oriented approaches to a **Multi-Agent** Oriented approach

- ▶ **keeping alive** the concepts, dynamics and coordinations of the A, E, I and O dimensions

Outline

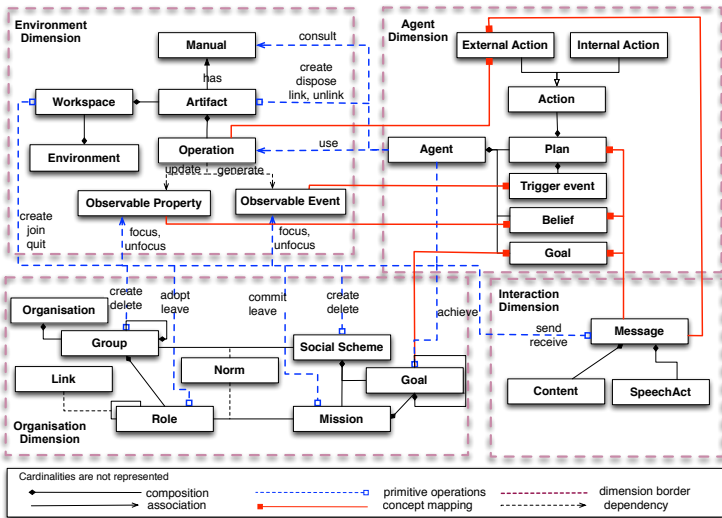
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Multi-Agent Oriented Programming (MAOP)

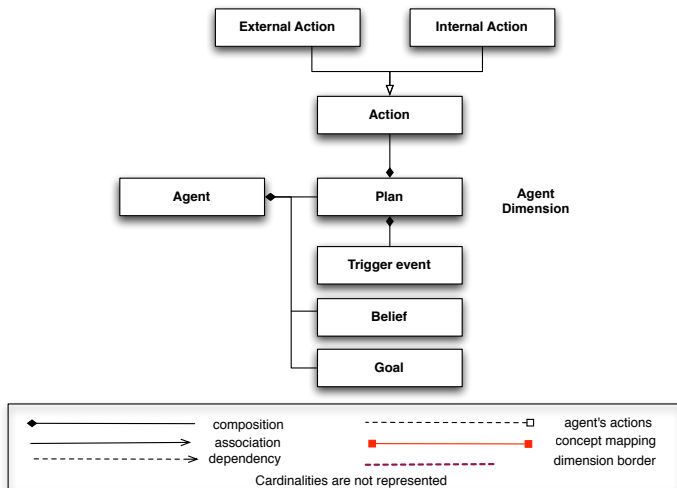
MAOP Perspective in the JaCaMo Platform

Seamless Integration of A & E & I & O



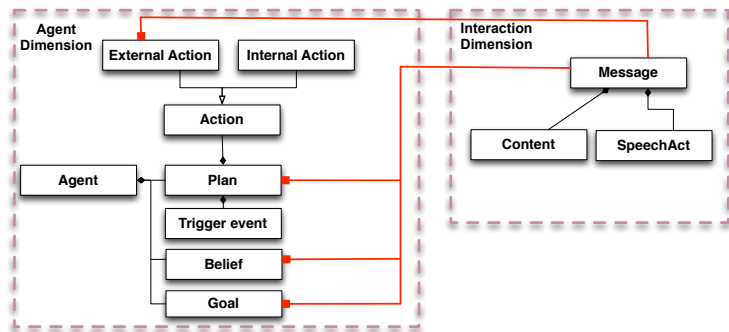
JaCaMo Meta-model [Boissier et al., 2011], based on Cartago [Ricci et al., 2009b], Jason [Bordini et al., 2007], Moise [Hübner et al., 2009a] meta-models

Agent meta-model

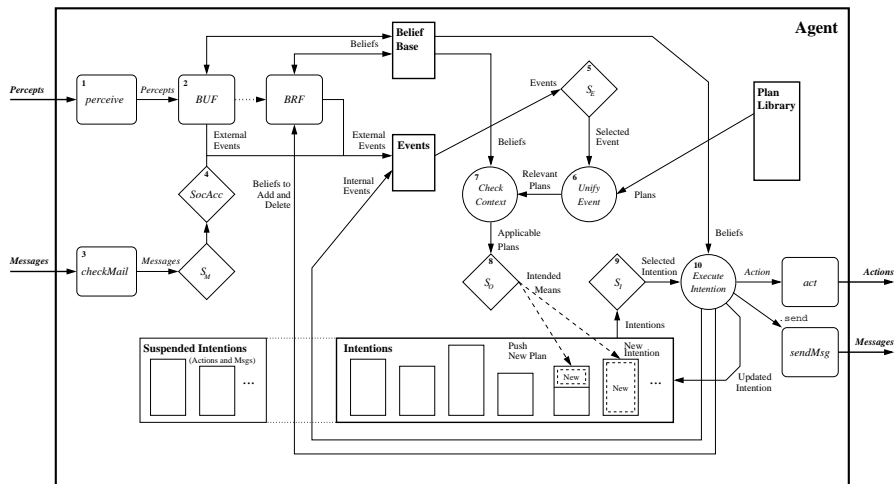


Based on Jason meta-models [Bordini et al., 2007]

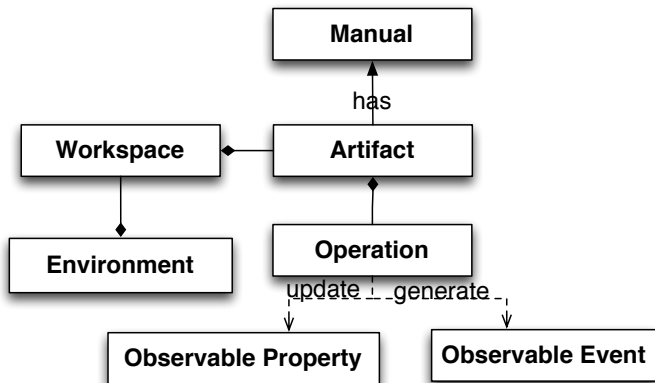
Agent & Agent Interaction meta-model



Agent's dynamics

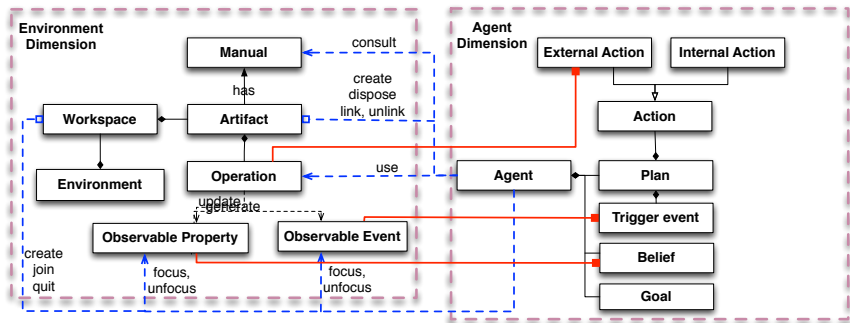


Environment meta-model



Based on A&A meta-model [Omicini et al., 2008]

A & E Interaction meta-model



Environment's dynamics

Artifact life-cycle

- ▶ Creation/Deletion
- ▶ Activation/Execution/Fail or Success/Deactivation of an Operation
- ▶ Linking / Unlinking

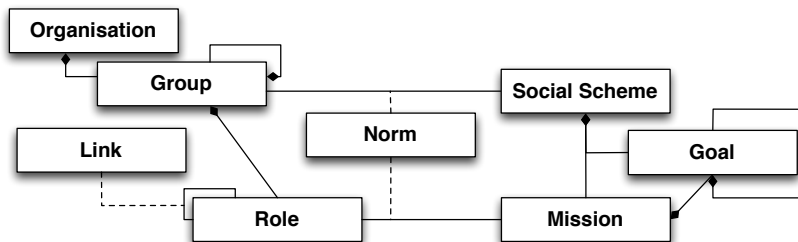
Workspace life-cycle

- ▶ Creation/Deletion of a workspace
- ▶ Creation/Deletion of Artifacts
- ▶ Creation/Deletion & Entry/Exit of Agents

Outcomes of A & E Integration

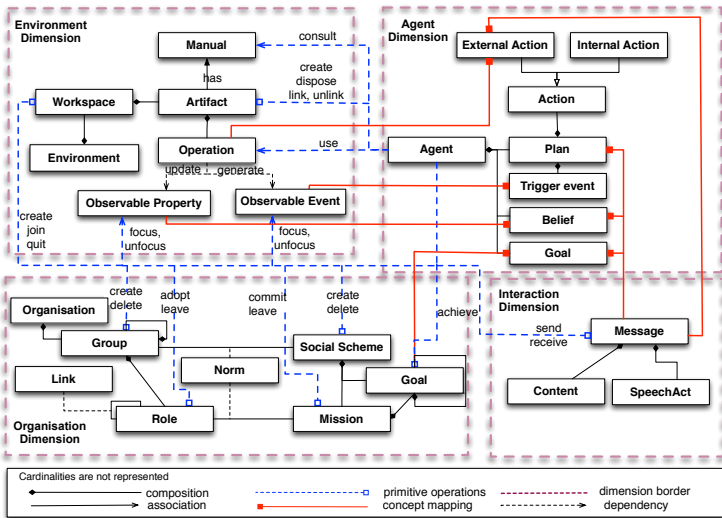
- ▶ Agents with dynamic action repertoire, extended/reshaped by agents themselves
- ▶ Uniform implementation of any mechanisms (e.g. coordination mechanism) in terms of actions/percepts
 - ▶ No need to extend agents with special purpose primitives
- ▶ Exploiting a new type of agent modularity, based on externalization [Ricci et al., 2009a]

Organisation meta-model



Simplified *Moise* meta-model [Hübner et al., 2009a]

A & E & O Interaction meta-model



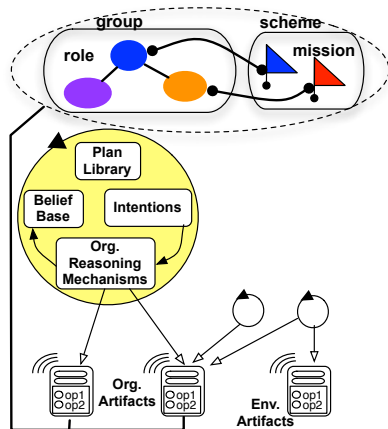
Based on Cartago [Ricci et al., 2009b], Jason [Bordini et al., 2007],
Moise [Hübner et al., 2009a] meta-models

A & O Integration

- ▶ Definition of organisational beliefs, organisational actions mediating the perception and actions on the organisation entity
- ▶ Done by instrumenting the organisation management by dedicated **Organisational Artifacts**
 - ▶ Mapping of the **organisational state** onto artifacts computational state
 - ▶ Encapsulation of organisational functionalities by suitably designed artifacts providing **organisational operations**
- ↪ Reification of organisation management actions/perceptions by actions/percepts on the artifacts

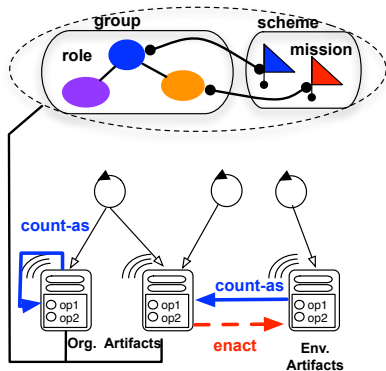
- ▶ Extensible set of organisational artifacts:
 - ▶ Openness Management Artifact [Kitio, 2011]
 - ▶ Reorganisation Artifact [Sorici, 2011]
 - ▶ Evaluation Artifact (kind-of reputation artifact) [Hübner et al., 2009b]
 - ▶ Communication management Artifact [Ciortea, 2011]

A & O Integration (2)



- ▶ Exploit the uniform access to artifacts
- ~> Agents may be aware of the Organisation by the way of:
 - ▶ organisational events
 - ▶ organisational actions
- ~> Agents can reason on the organisation:
 - ▶ to achieve organisational goals
 - ▶ by developing organisational plans

E & O Integration



- ▶ Env. Artifacts provide operations on shared resources
- ▶ Org. Artifacts provide organisational operations
- ▶ Both artifacts bound by count-as, enact constitutive rules [Piunti et al., 2009, de Brito et al., 2012]
- ~> Org-agnostic agents may indirectly act on the organisation
- ~> Environment can act on the organisation
- ~> Organisation is embodied, situated in the environment

Organisation's dynamics (triggered by Agents, Environment)

Organisation life-cycle

- ▶ Entrance/Exit of an agent
- ▶ Creation/Deletion of an Organisation entity
- ▶ Change of Organisation specification

Structural Organisation life-cycle

- ▶ Creation/Deletion of a group
- ▶ Adoption/Release of a role

Functional Organisation life-cycle

- ▶ Creation/End of a schema
- ▶ Commitment/Release of a mission
- ▶ Change of a global goal state

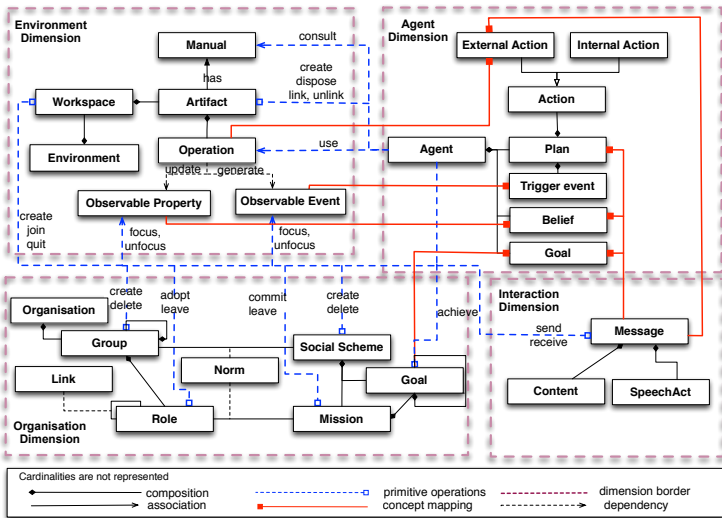
Normative Organisation life-cycle

- ▶ Activation/De-activation of obligation
- ▶ Fulfilment/Violation/Sanction

Outcomes of A & E & O Integration

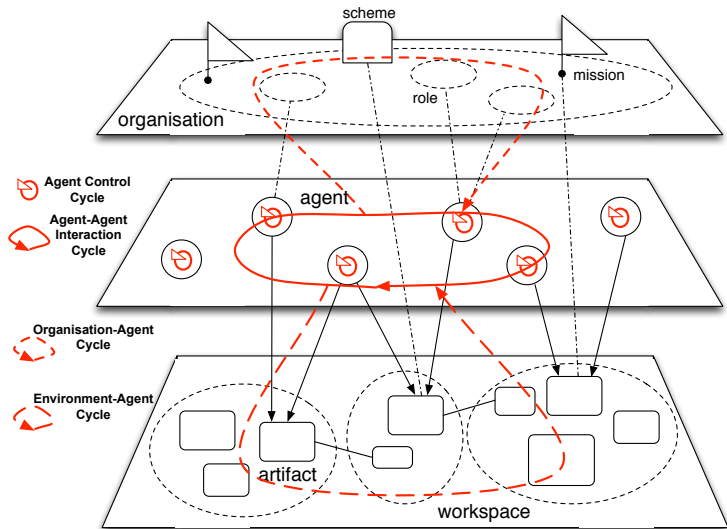
- ▶ Normative deliberative agents
 - ▶ possibility to define mechanisms for agents to evolve within an organisation/several organisations
 - ▶ possibility to define proper mechanisms for deliberating on the internalisation/adoption/violation of norms
- ▶ Reorganisation, adaptation of the organisation
 - ▶ possibility to define proper mechanisms for diagnosing/evaluating/refining/defining organisations
- ▶ “Deliberative” Organisations
 - ▶ possibility to define dedicated organisational strategies for the regulation/adaptation of the organisation behaviour (organisational agents)
- ▶ “Embodied” Organisation / Organisation Aware Environment
 - ▶ possibility to connect organisation to environment

Synthesis: MAOP meta-model



JaCaMo Meta-model [Boissier et al., 2011], based on Cartago [Ricci et al., 2009b], Jason [Bordini et al., 2007], Moise [Hübner et al., 2009a] meta-models

Synthesis: MAO Dynamics



Outline

Introduction

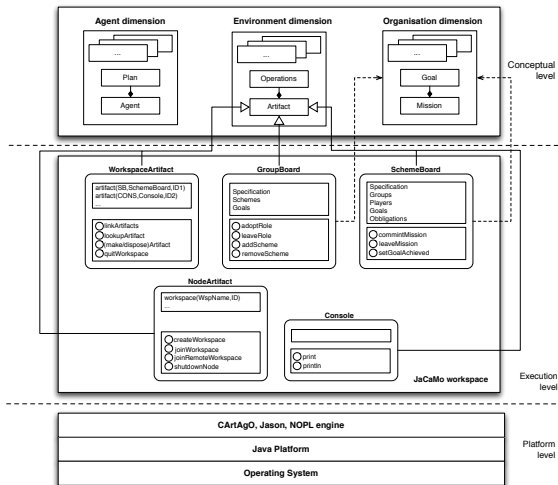
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Multi-Agent Oriented Programming (MAOP)

MAOP Perspective in the JaCaMo Platform

JaCaMo Platform

<http://jacamo.sourceforge.net>



Execution Platform

Agent execution and communication management infrastructures can be:

Centralised: all agents in the same machine,
one thread by agent, very fast

Centralised (pool): all agents in the same machine,
fixed number of threads,
allows thousands of agents

Distributed (jade): distributed agents, FIPA-ACL communication using
Jade

.... others defined by the user (e.g. AgentScape)

Environment execution can be:

Centralised: one centralised environment shared by the agents, is
automatically included in case of no other specification

Distributed: multiple environments shared by the agents – specified by
cartago("infrastructure")

MAS Configuration & Deployment Language

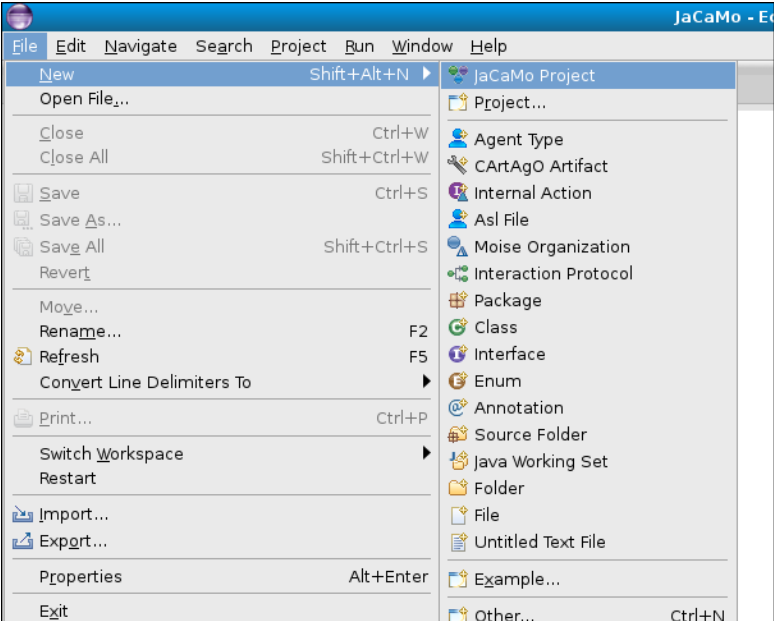
- ▶ Simple way of defining a multi-agent system within the JaCaMo Platform

Example (Building House Definition)

```
mas house_building {
  agent giacomo      // the agent that wants to build a house
  agent companyA    // builder agents (see their code for details)
  agent companyB
  agent companyC {
    instances: 5
  }
  agent companyD {
    instances: 13
  }
  agent companyE

  asl-path:  src/agt, src/agt/inc
}
```

Eclipse JaCaMo plugin



Agent's Mind **inspector**

The screenshot shows the Mind Inspector application window. The title bar reads "...: Mind Inspector ...". On the left, there is a sidebar titled "Agents" with a list containing "majordomo" and "orgmajordomo", where "orgmajordomo" is selected. The main area is titled "Agent Inspection" and displays the "Inspection of agent orgmajordomo". Under the "Beliefs" section, the following list of beliefs is shown:

- commitment(italian,mItaly,"jacamoPlan")[-]
- commitment(french,mFrench,"jacamoPlan")[-]
- commitment(brazilian1,mBrazil,"jacamoPlan")[-]
- commitment(brazilian2,mBrazil,"jacamoPlan")[-]
- current_wsp(cob_1,"server","427dd8d5-408e-431a-a702-7b11ce574e09")[-]
- formationStatus(ok)[-]
- goalState("jacamoPlan",greetings,[french],[french],satisfied)[-]
- goalState("jacamoPlan",greetings_uk_done,[italian],[italian],satisfied)[-]
- goalState("jacamoPlan",greetings_italy_done,[italian],[italian],satisfied)[-]
- goalState("jacamoPlan",greetings_brazil_done,[brazilian1,brazilian2],[brazilian1,brazilian2],satisfied)[-]
- goalState("jacamoPlan",greetings_france_done,[french],[french],satisfied)[-]
- groups(["jacamoTeam"])[-]
- my_group("jacamoTeam")[-]
- my_group_id(cob_2)[-]
- my_ssch("jacamoPlan")[-]
- my_ssch_id(cob_3)[-]

At the bottom of the window, there is an "Agent History" section showing "Cycle 0". Below that is a control bar with a "Run" button, a field for "1" cycle(s) for, a dropdown menu set to "all agents", and a "view as:" dropdown menu set to "html".

Organization Structure inspector

The screenshot shows a window titled "Organisation Inspector" with a subtitle "Group Board jacamoTeam (jacamoGr)". The window has a tabbed interface with the following tabs: "organisation entity", "normative state", "normative facts", "normative program", and "specification". The "specification" tab is active.

Structural Specification

Roles

- [greeter](#) extends [soc](#).
- [greeterc](#) extends [greeter](#).
- [greeterb](#) extends [greeter](#).
- [greeteri](#) extends [greeter](#).
- [greeterf](#) extends [greeter](#).

Group jacamoGr

Possible roles: [greeterb](#), [greeteri](#), [greeterf](#).

Local links:

- [greeter](#) has a *communication* link to [greeter](#) (intra-group, does not extend to subgroups)

Constraint Formation

- Cardinalities
 - cardinality of [greeterb](#) is (2,2)
 - cardinality of [greeteri](#) is (1,1)
 - cardinality of [greeterf](#) is (1,1)

History

The window also features a vertical sidebar on the left with the text "jacamoPlan" and "jacamoTeam". At the bottom left of the slide, there is a Creative Commons BY license icon.

Organization Structure **inspector**

The screenshot shows a window titled "Organisation Inspector" with a sub-header "Group Board jacamoTeam (jacamoGr)". A navigation bar at the top contains tabs for "organisation entity", "normative state", "normative facts", "normative program", and "specification". The main content area displays the following information:

- jacamoTeam (group)**
- created from specification [jacamoGr](#) (root group) - owner is [orgmajordomo](#)
- Formation:**
 - ok
- Players**
 - [brazilian1](#) plays [greeterb](#)
 - [brazilian2](#) plays [greeterb](#)
 - [french](#) plays [greeterf](#)
 - [italian](#) plays [greeteri](#)
- Responsible for the following schemes:**
 - [jacamoPlan](#)

A vertical sidebar on the left contains a button labeled "jacamoPlan". At the bottom of the window, there is a section titled "History" which is currently empty.

Organization Functioning **inspector**

...: Organisation Inspector ...

... Scheme Board jacamoPlan (jacamoSch) ...

organisation entity normative state normative facts normative program **specification**

Functional Specification

Scheme *jacamoSch*

goal	mission	type	# agents that should satisfy	tff	description	arguments	plan
greetings	mFrench	achievement	all				greetings_fra greetings_bra greetings_italy greetings_uk_done
greetings_france_done	mFrench	achievement	all		Greetings from France		
greetings_brazil_done	mBrazil	achievement	all		Greetings from Brazil		
greetings_italy_done	mItaly	achievement	all		Greetings from France		
greetings_uk_done	mItaly	achievement	all		Greetings from UK		

History

```
created: obligation(french,n1,committed(french,mFrench,"jacamoPlan"),1411504910034){c
created: obligation(brazilian1,n2,committed(brazilian1,mBrazil,"jacamoPlan"),14115049
created: obligation(brazilian2,n2,committed(brazilian2,mBrazil,"jacamoPlan"),14115049
created: obligation(italian,n3,committed(italian,mItaly,"jacamoPlan"),1411504910098){
created: obligation(french,ngoal("jacamoPlan",mFrench,greetings_france_done),achieved
created: obligation(brazilian1,ngoal("jacamoPlan",mBrazil,greetings_brazil_done),achi
created: obligation(brazilian2,ngoal("jacamoPlan",mBrazil,greetings_brazil_done),achi
created: obligation(italian,ngoal("jacamoPlan",mItaly,greetings_italy_done),achieved
created: obligation(italian,ngoal("jacamoPlan",mItaly,greetings_uk_done),achieved("ja
```

Organization Functioning **inspector**

... Organisation Inspector ...

... Scheme Board jacamoPlan (jacamoSch) ...

organisation.entity | normative state | normative facts | normative program | specification

jacamoPlan (scheme instance)

created from specification [jacamoSch](#)

Formation:
ok

Responsible groups: [jacamoTeam](#).

Players

- [brazilian1](#) committed to [mBrazil](#)
- [brazilian2](#) committed to [mBrazil](#)
- [french](#) committed to [mFrench](#)
- [italian](#) committed to [mItaly](#)

goal	state	committed/achieved by	arguments	plan
greetings	satisfied	[french]/[french]		= greetings_france greetings_brazil reetings_italy_done reetings_uk_done
greetings_france_done	satisfied	[french]/[french]		
greetings_brazil_done	satisfied	[brazilian1,brazilian2]/[brazilian1,brazilian2]		
greetings_italy_done	satisfied	[italian]/[italian]		
greetings_uk_done	satisfied	[italian]/[italian]		

History

```
created: obligation(french,n1,committed(french,mFrench,"jacamoPlan"),1411504910034){c
created: obligation(brazilian1,n2,committed(brazilian1,mBrazil,"jacamoPlan"),14115049
created: obligation(brazilian2,n2,committed(brazilian2,mBrazil,"jacamoPlan"),14115049
created: obligation(italian,n3,committed(italian,mItaly,"jacamoPlan"),1411504910098){
created: obligation(french,ngoal("jacamoPlan",mFrench,greetings_france_done),achieved
created: obligation(brazilian1,ngoal("jacamoPlan",mBrazil,greetings_brazil_done),achi
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created: obligation(italian,ngoal("jacamoPlan",mItaly,greetings_uk_done),achieved("ja
```

Integration of Multi-Agent technologies

- ▶ **A**gent: *Jason* agents [Bordini et al., 2007]
- ▶ **E**nvironment: CArtAgO platform [Ricci et al., 2009b]
- ▶ **O**rganisation: *Moise* framework with the extended/refactored version of the *Moise* OMI: ORA4MAS [Hübner et al., 2009a]
- ▶ **I**nteraction: based on tight integration between *Jason* and KQML or ACL/FIPA

Dimensions are integrated with dedicated bridges:

- ▶ **A-E** (c4Jason, c4Jadex [Ricci et al., 2009b])
- ▶ **E-O** (count-as/enact rules [Piunti et al., 2009, de Brito et al., 2015])
- ▶ **A-O** is for free (thanks to ORA4MAS). Strategies and reasoning capabilities from \mathcal{J} -*Moise*⁺ [Hübner et al., 2007] can be reused.

Open to integrate other Multi-Agent Technologies

Integration with other technologies

- ▶ Web 2.0
 - ▶ implementing Web 2.0 applications
 - ▶ <http://jaca-web.sourceforge.net>
- ▶ Android Platforms (JaCa-Android)
 - ▶ implementing mobile computing applications on top of the Android platform [Santi et al., 2011]
 - ▶ <http://jaca-android.sourceforge.net>
- ▶ Web Services
 - ▶ building SOA/Web Services applications [Ricci et al., 2010a]
 - ▶ <http://cartagows.sourceforge.net>
- ▶ Arduino Platforms
 - ▶ building “Web of Things” Applications
 - ▶ <http://jacamo.sourceforge.net>
- ▶ Semantic Technologies
 - ▶ JaSA: Semantically Aware Agents
 - ▶ <http://cartago.sourceforge.net>

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