Multi-Agent Oriented Programming

The JaCaMo Platform

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Tutorial Organisation

- Introduction to Multi-Agent Oriented Programming
- Programming Agents within JaCaMo
- Programming Agents' Environment within JaCaMo
- Programming Agents' Interaction within JaCaMo
- Programming Agents' Organisations within JaCaMo
- Conclusion & Perspectives

Acknowledgements

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  - #12342 (2012), #08361 (2008), #06261 (2006)
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  - USP-COFECUB 98-04
  - CMIRA Rhône-Alpes Region 2010
- French National Project:
  - FORTRUST Project ANR 06-10
  - ETHICAA Project ANR 14-18

Multi-Agent Oriented Programming
Introduction

Outline

Current Landscape of Multi-Agent Programming

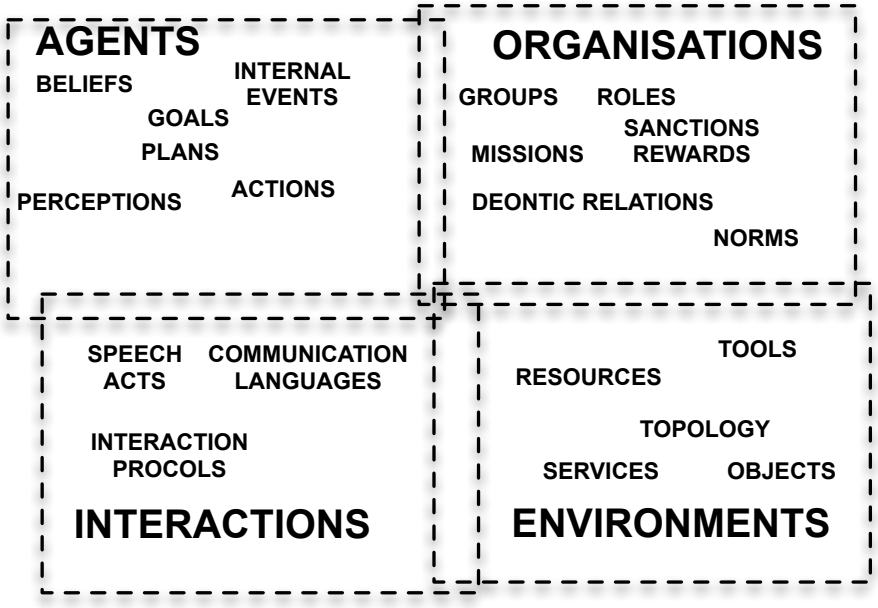
- Many AOSE methodology (Prometheus, Gaia, Tropos, ...) exist!

$\rightsquigarrow$ 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!

$\rightsquigarrow$ some reasons and motivations follow!

MAS Conceptual framework / Dimensions

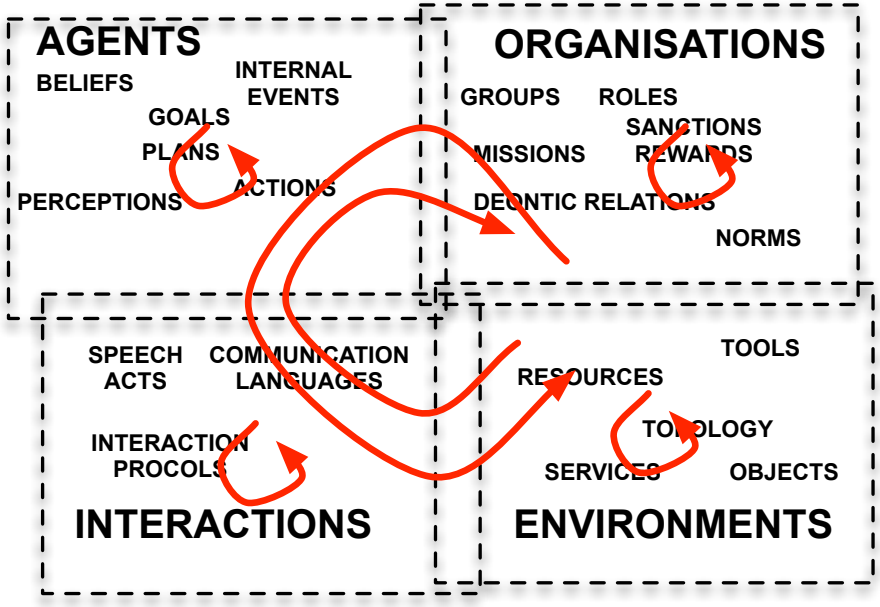


cf. VOWELS [Demazeau, 1995, Demazeau, 1997]

- Agents: abstractions for the definition of the decision/reasoning entities architectures
- Environment: abstractions for structuring resources, processing entities shared among the agents
- Interaction: abstractions for structuring interactions among entities
- Organisation: abstractions for structuring and ruling the sets of entities within the MAS

$\rightsquigarrow$ A rich set of abstractions for capturing applications complexity!

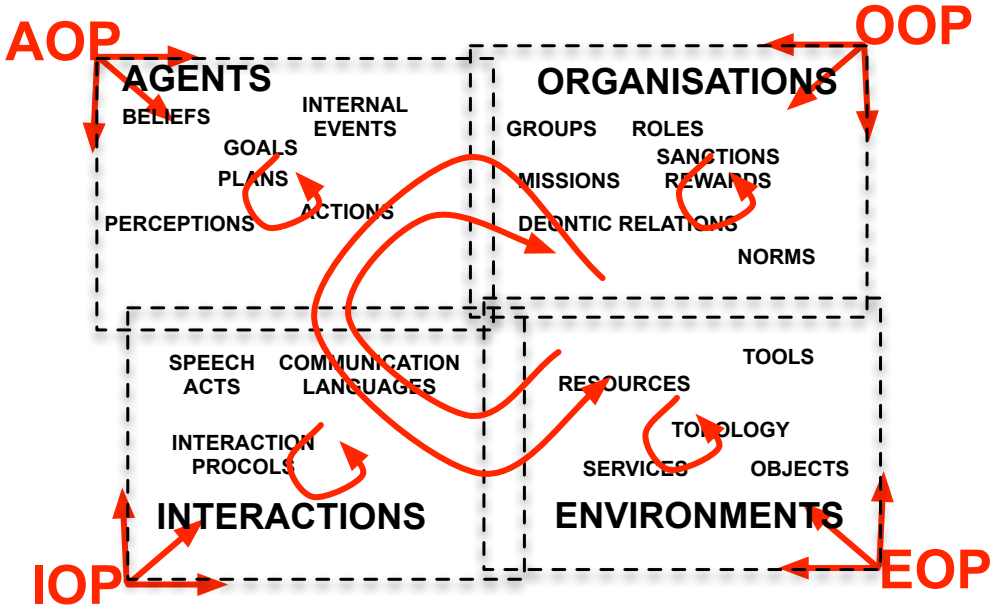
MAS Conceptual framework / Dynamics



- 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!!

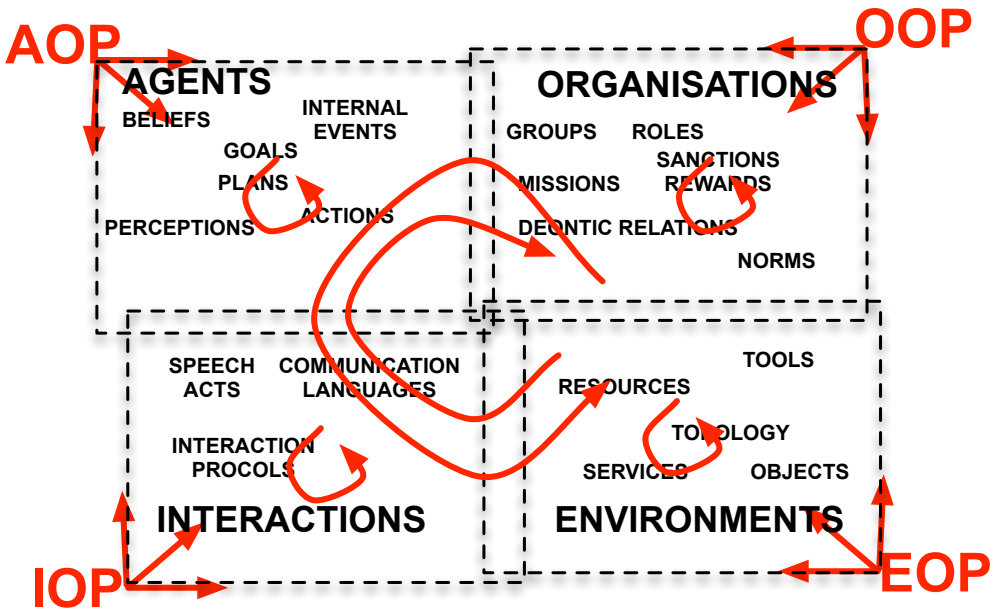
MAS Programming



- Agent Oriented Programming [Shoham, 1993]
- Environment Oriented Programming [Ricci et al., 2011]
- 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 [Occello 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]
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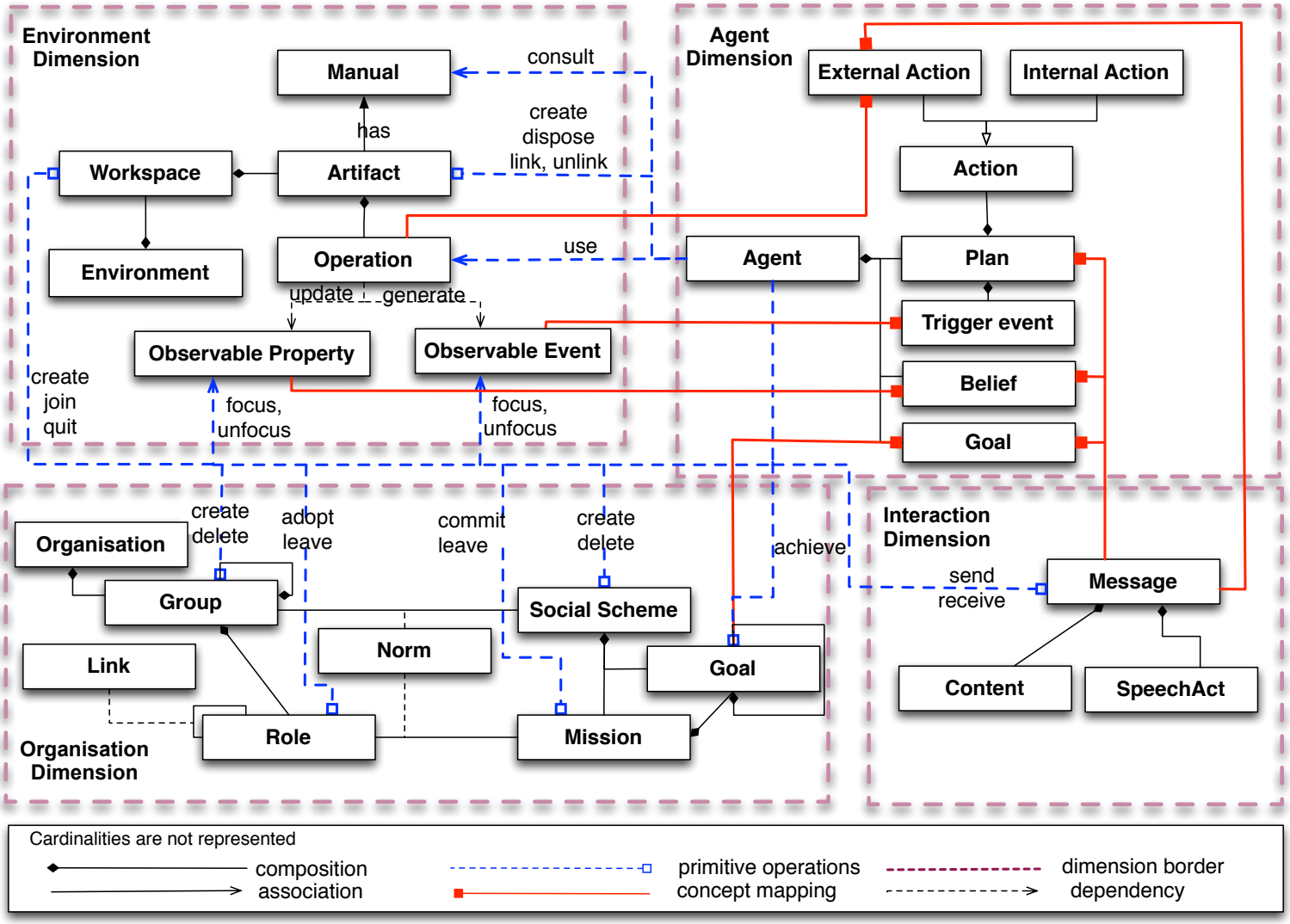
Challenge

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

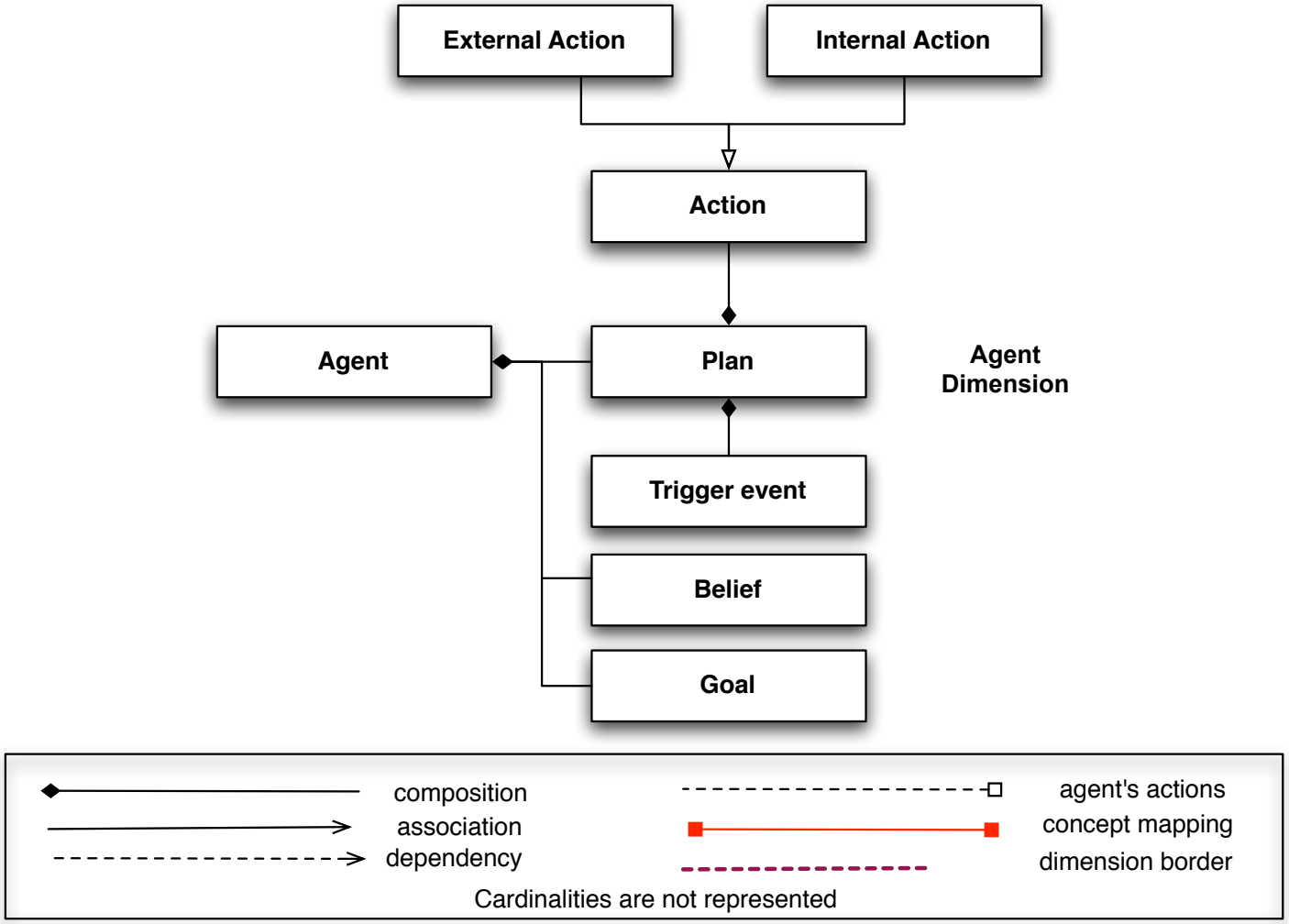
Outline

Seamless Integration of A & E & I & O



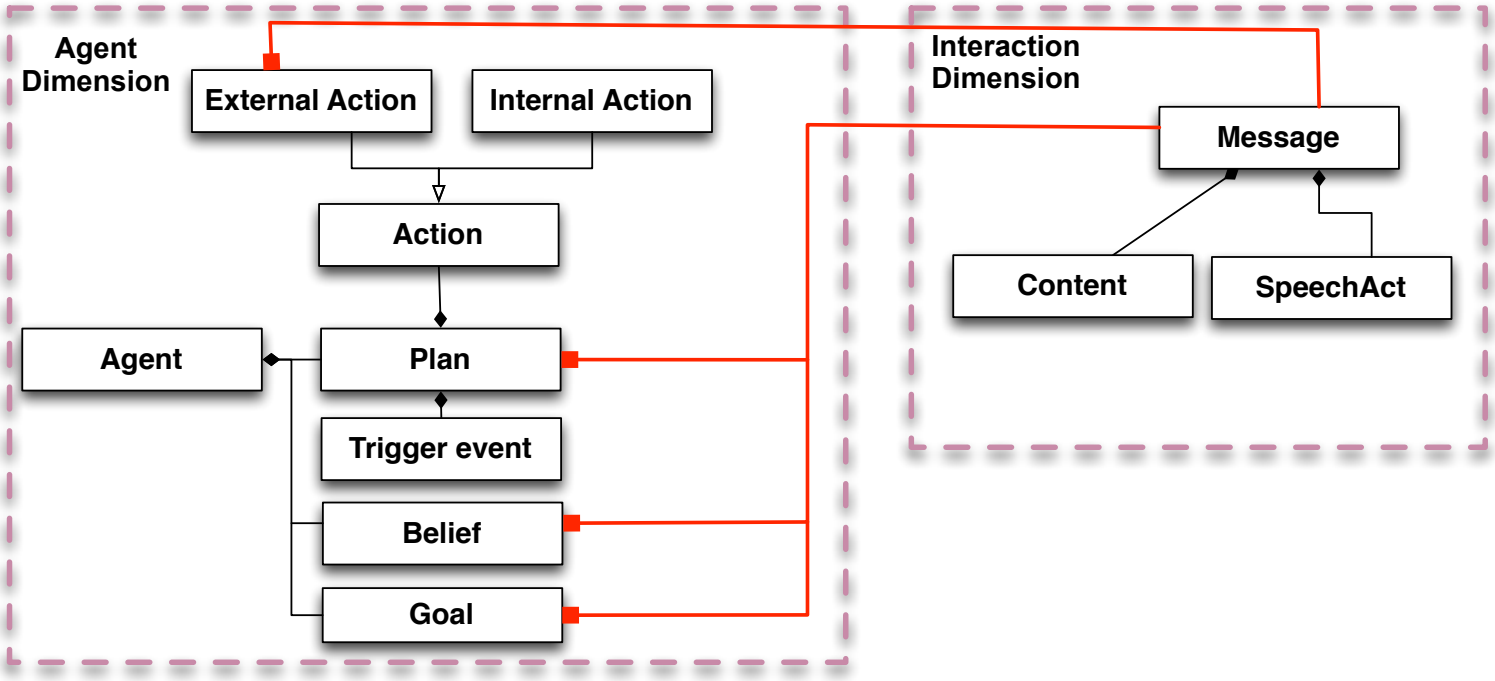
JaCaMo Meta-model [Boissier et al., 2011], based on Cartago [Ricci et al., 2009b], Jason [Bordini et al., 2007], $\mathcal{M}$oise [Hübner et al., 2009a] meta-models

Agent meta-model

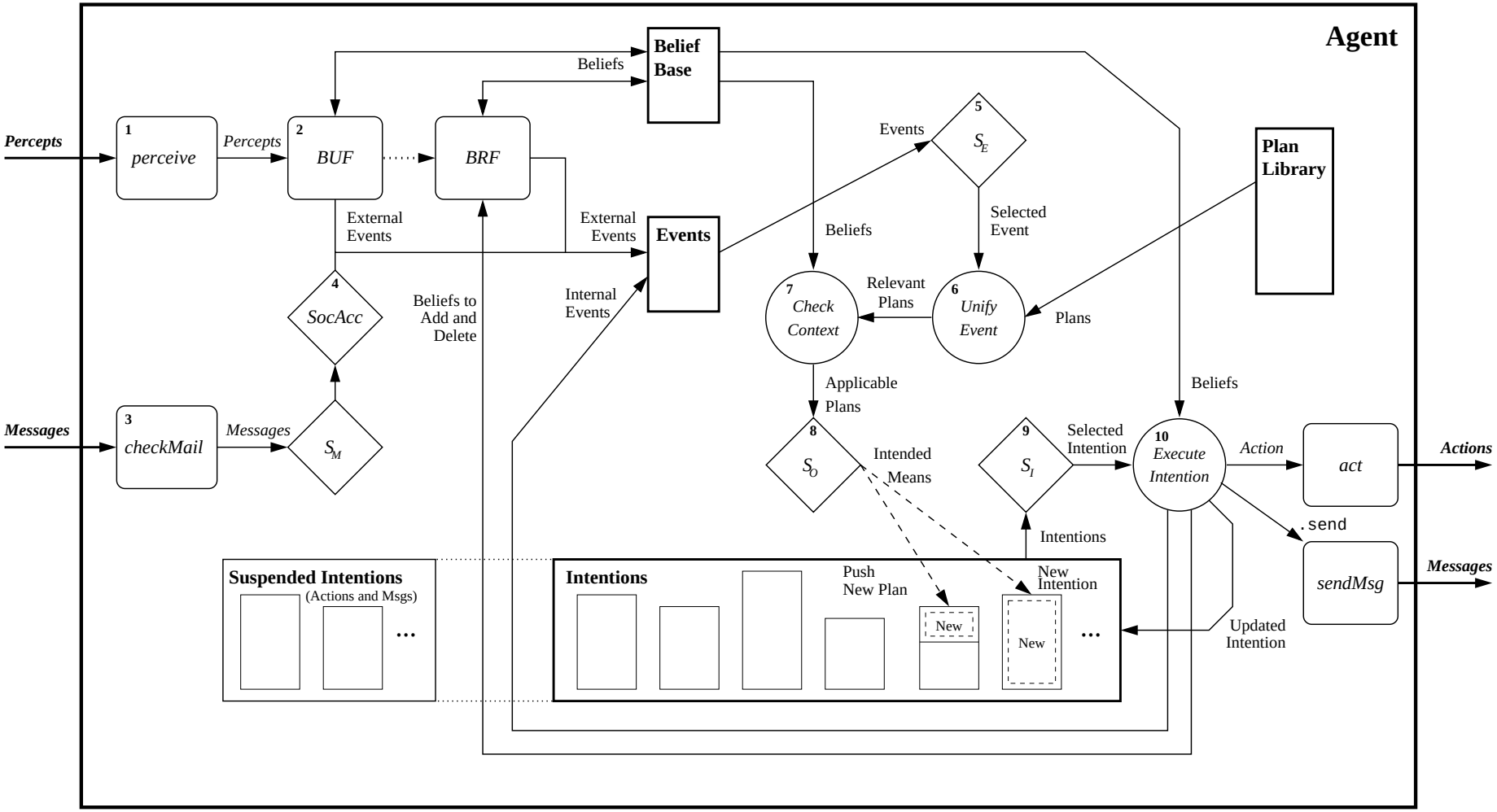


Based on Jason meta-models [Bordini et al., 2007]

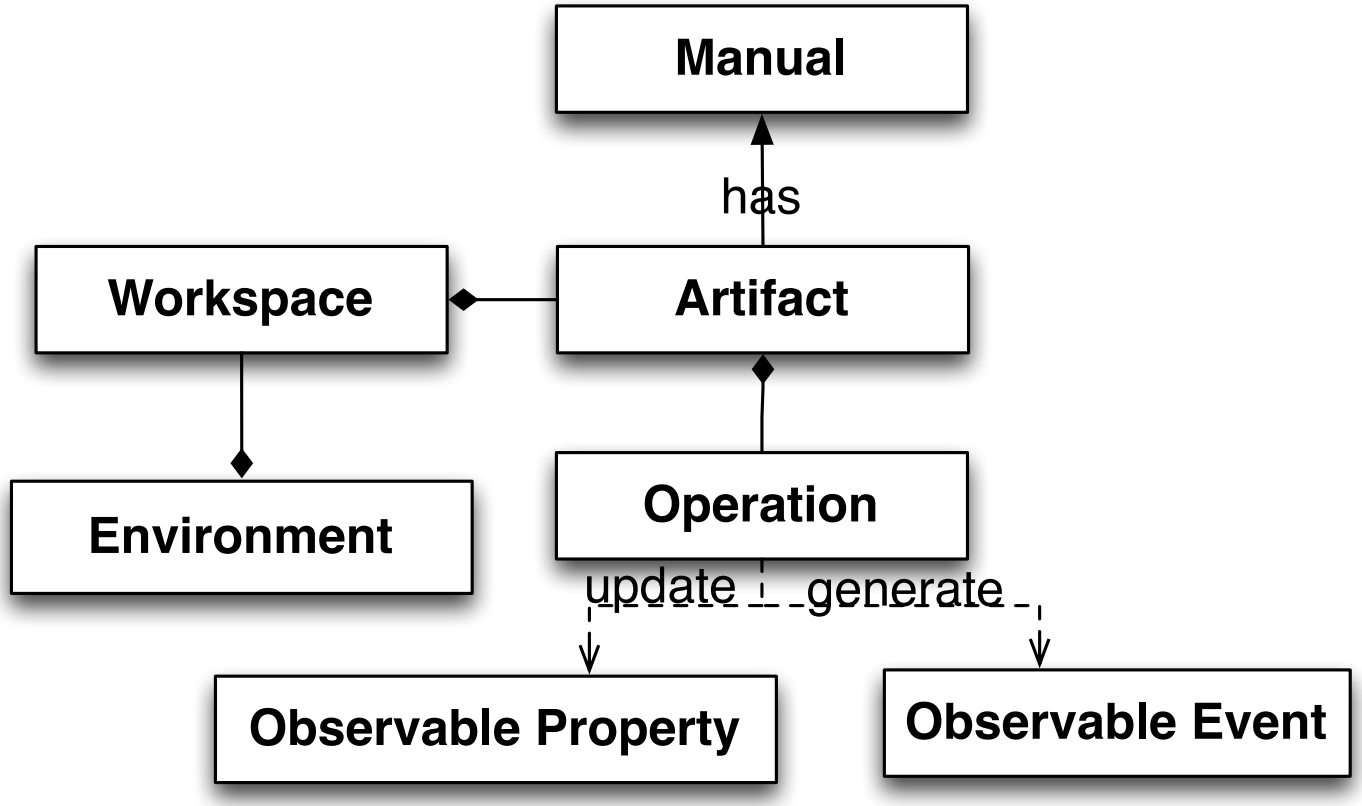
Agent & Agent Interaction meta-model



Agent's dynamics

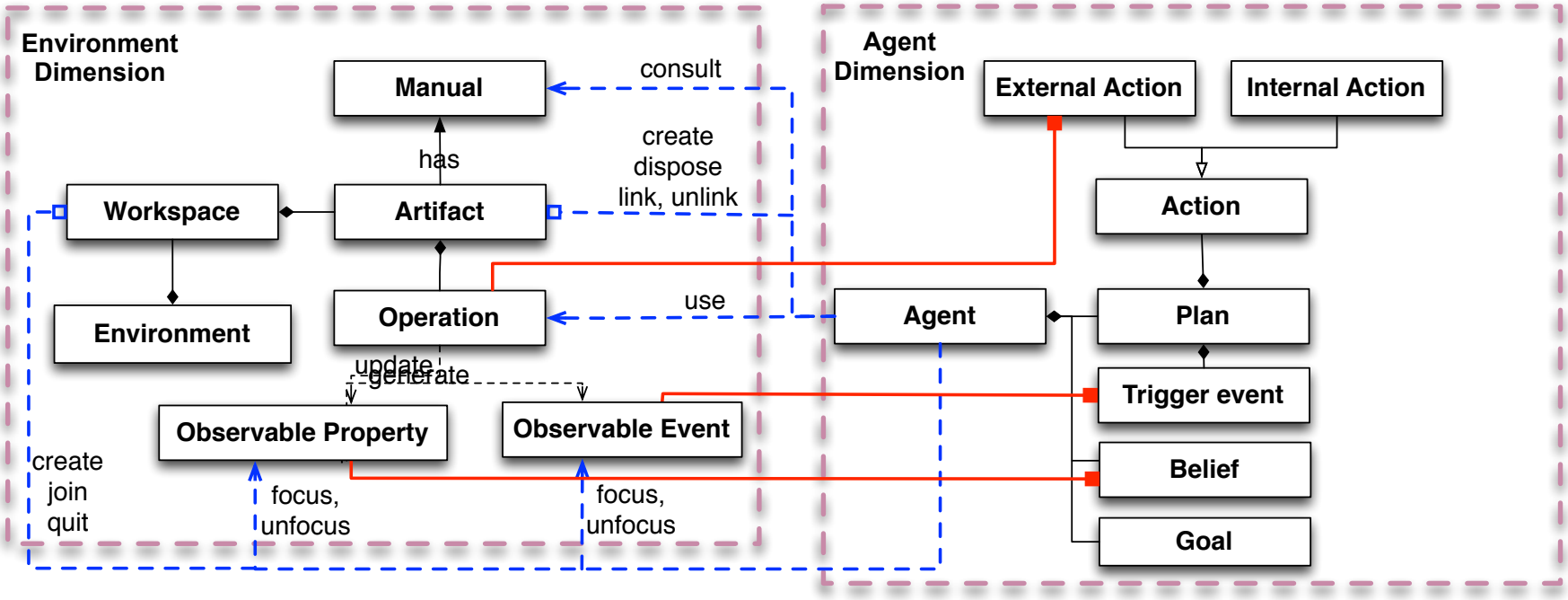


Environment meta-model



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

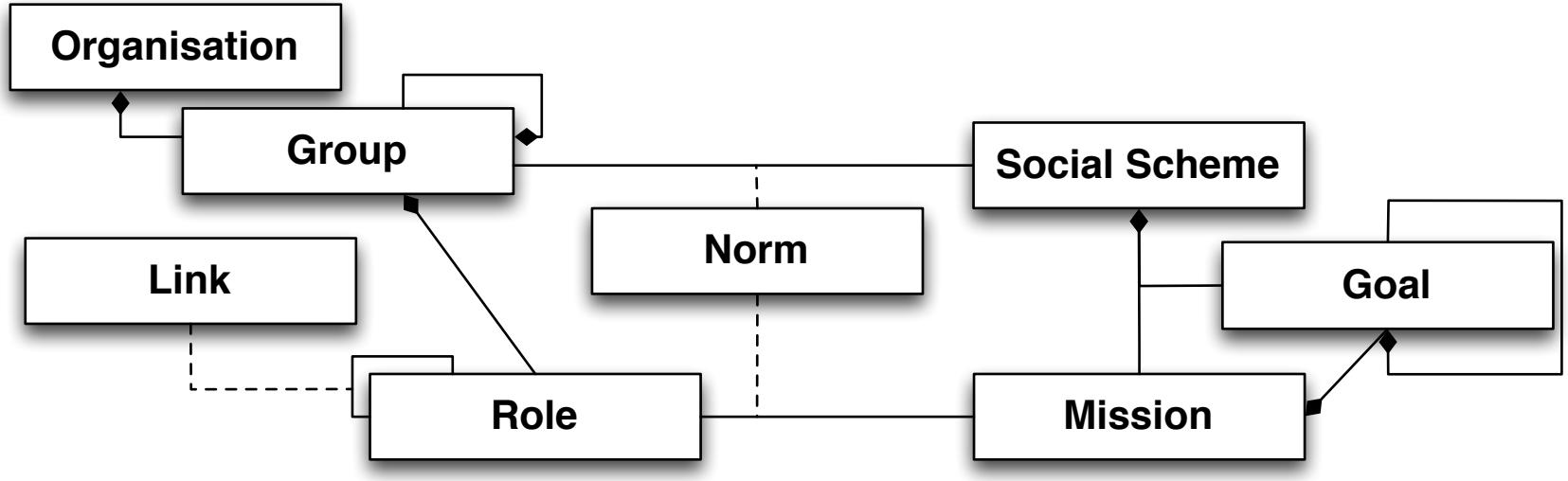
Workspace life-cycle

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

Outcomes of A & E Integration

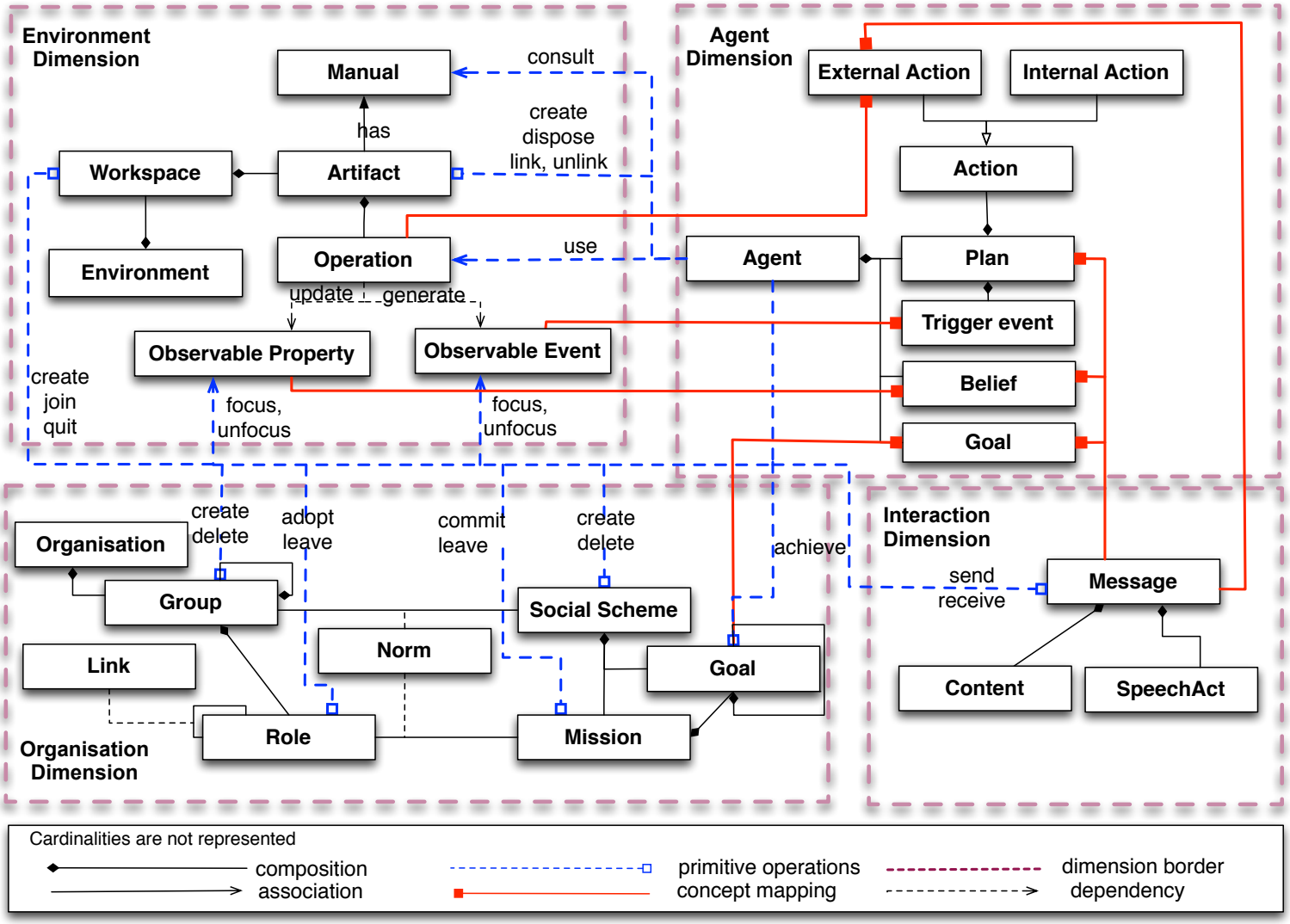
- Agents with dynamic action repertoire, extended/reshaped by agents themselves
- Uniform implementation of any mechanisms (e.g. coordination mechanism) in terms of actions/percepts
  - No need to extend agents with special purpose primitives
- Exploiting a new type of agent modularity, based on externalization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

Organisation meta-model



Simplified $\mathcal{M}$oise meta-model [Hübner et al., 2009a]

A & E & O Interaction meta-model



Based on Cartago [Ricci et al., 2009b], Jason [Bordini et al., 2007], $\mathcal{M}$oise [Hübner et al., 2009a] meta-models

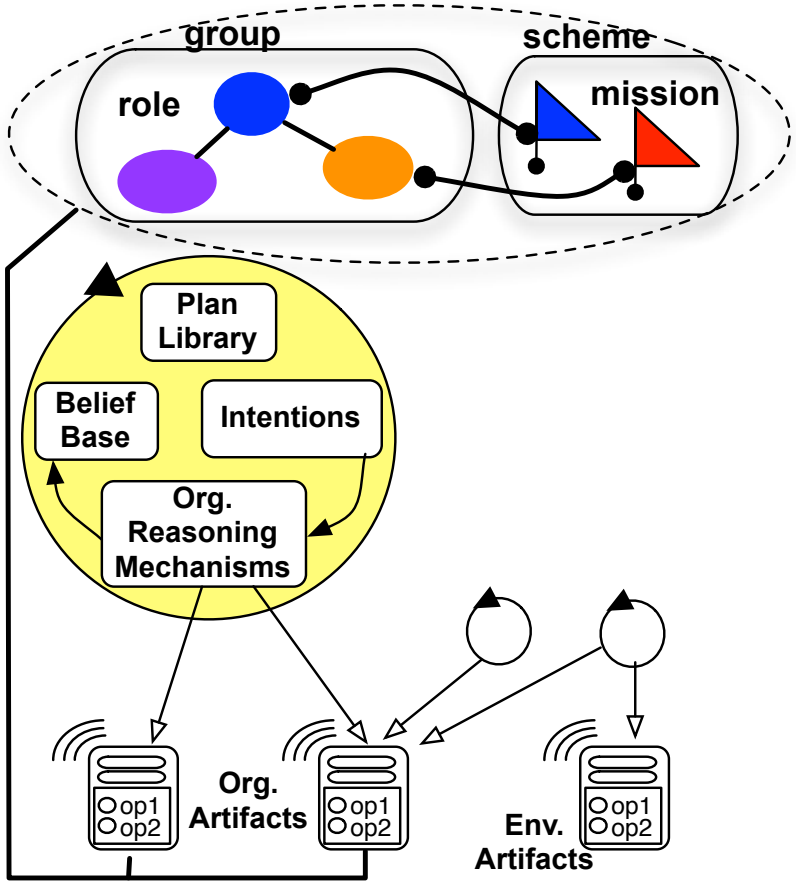
A & O Integration

- 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

$\rightsquigarrow$ 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

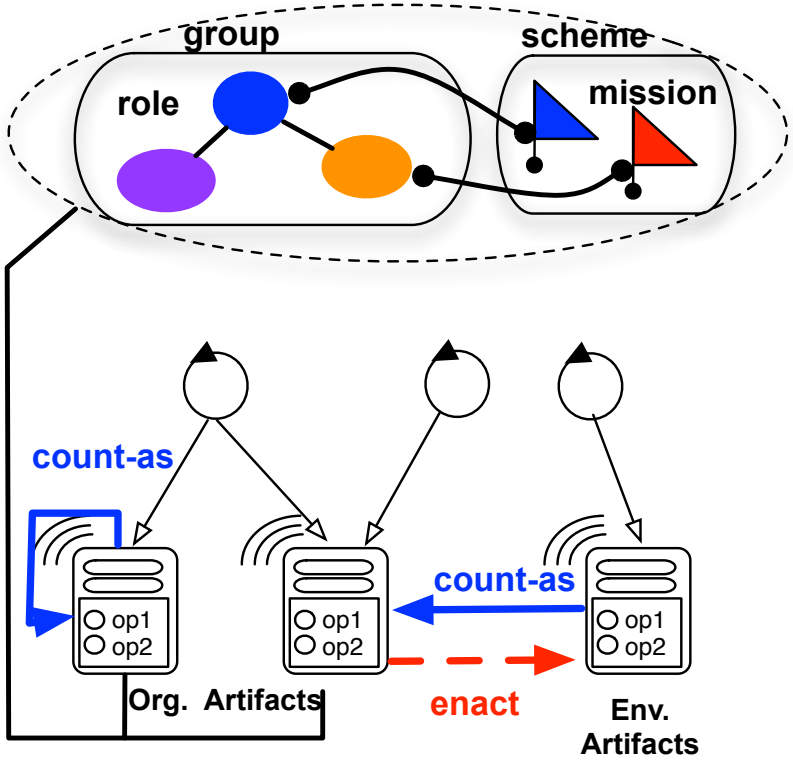
⇝ Agents may be aware of the Organisation by the way of:

  - 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

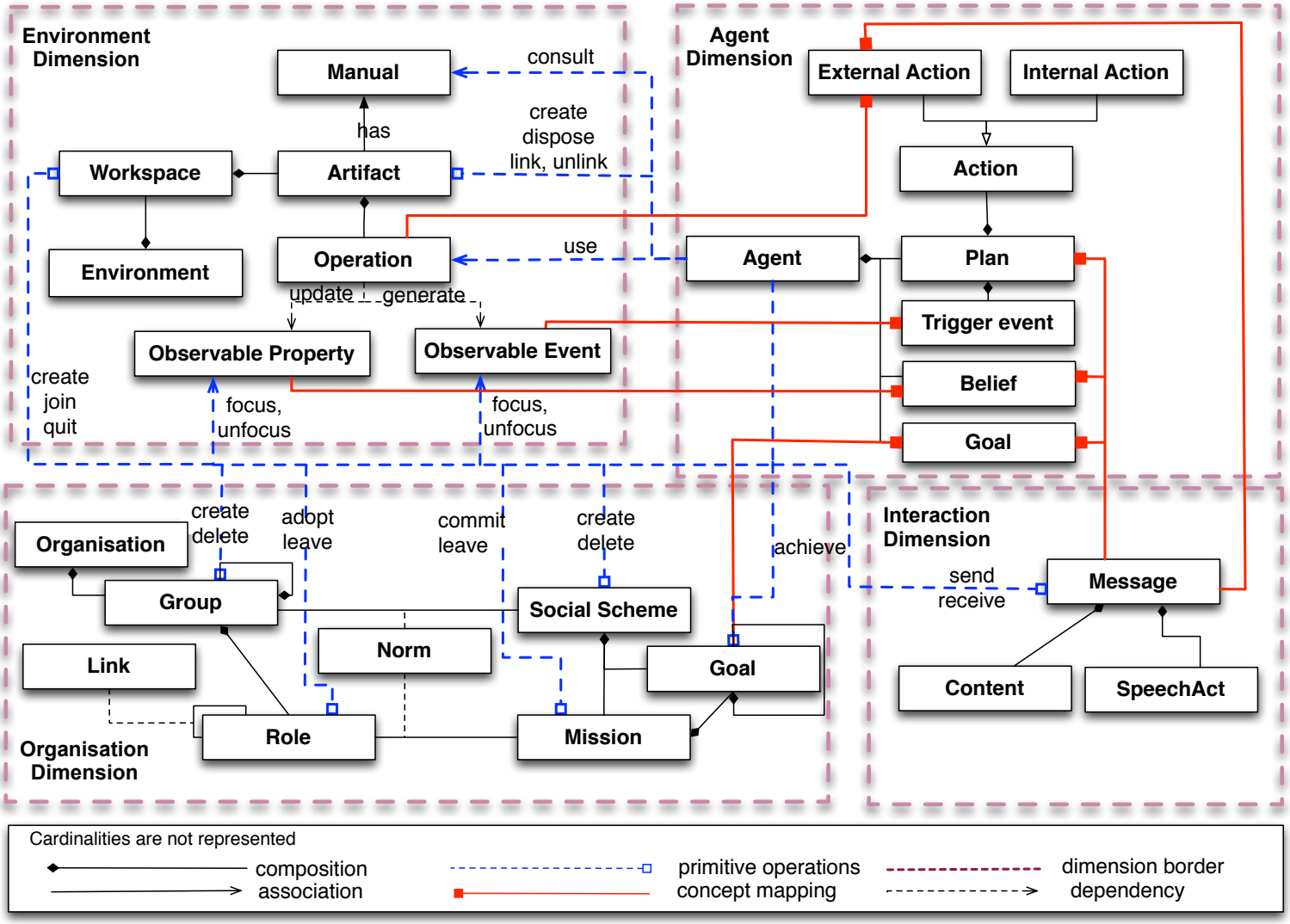
Normative Organisation life-cycle

- 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



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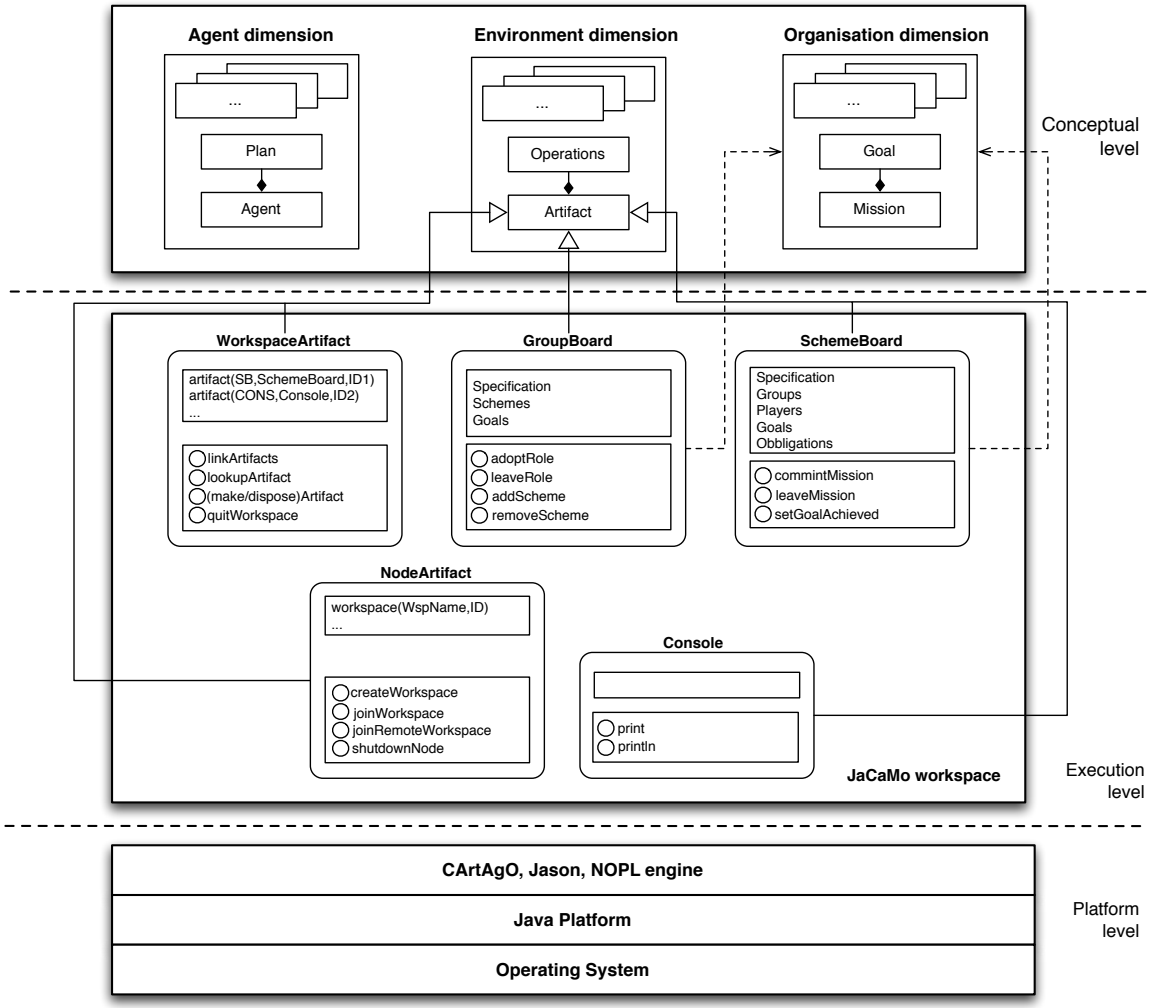
Outline

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

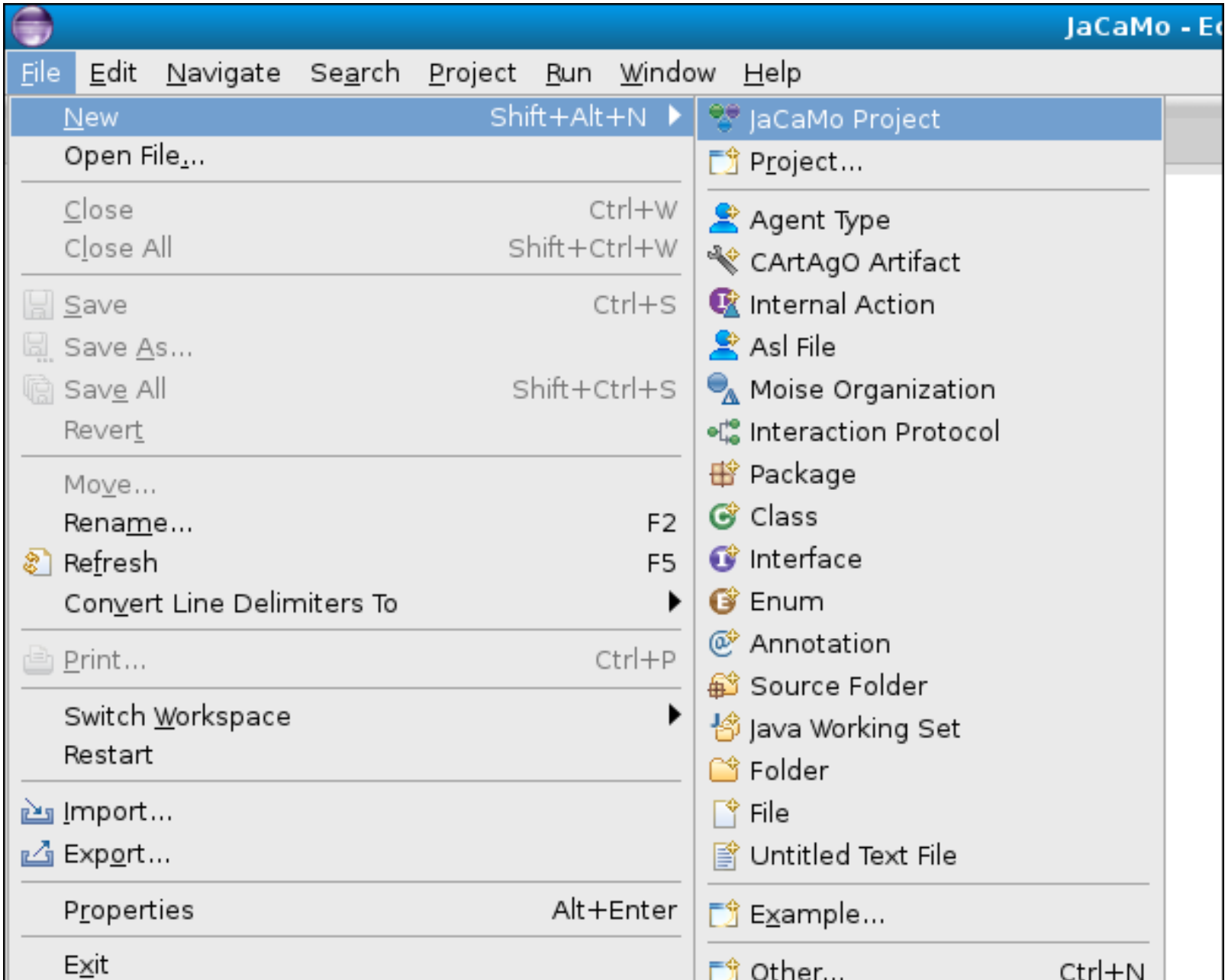
- Simple way of defining a multi-agent system within the JaCaMo Platform

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**

..:: Mind Inspector ::..

Agents

majordomo

orgmajordomo

Agent Inspection

Inspection of agent **orgmajordomo**

- **Beliefs**

commitment(italian,mItaly,"jacamoPlan")[...].

commitment(french,mFrench,"jacamoPlan")[...].

commitment(brazilian1,mBrazil,"jacamoPlan")[...].

commitment(brazilian2,mBrazil,"jacamoPlan")[...].

current_wsp(cobj_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(cobj_2)[...].

my_ssch("jacamoPlan")[...].

my_ssch_id(cobj_3)[...].

Agent History

Cycle 0

Run 1 cycle(s) for all agents view as: html

Organization Structure **inspector**

..:: Organisation Inspector ::..

:: Group Board jacamoTeam (jacamoGr) ::

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

jacamoTeam | jacamoPlan

Structural Specification

Roles

- greeter extends soc.
- greetere 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

Organization Structure **inspector**

..:: Organisation Inspector ::..

:: Group Board jacamoTeam (jacamoGr) ::

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

jacamoTeam | jacamoPlan

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

History

Organization Functioning **inspector**

..:: Organisation Inspector ::..

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

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

jacamoTeam | jacamoPlan

Functional Specification

Scheme *jacamoSch*

goal	mission	type	# agents that should satisfy	ttf	description	arguments	plan
greetings	mFrench	achievement	all				greetings_fran greetings_bra greetings_italy eetings_uk_do
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

jacamoTeam | jacamoPlan

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_do etings_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
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
```

Integration of Multi-Agent technologies

- Agent: *Jason* agents [Bordini et al., 2007]
- Environment: CArtAgO platform [Ricci et al., 2009b]
- Organisation: $\mathcal{M}$oise framework with the extended/refactored version of the $\mathcal{M}$oise OMI: ORA4MAS [Hübner et al., 2009a]
- Interaction: 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 $\mathcal{J}$-$\mathcal{M}$oise$^+$ [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
  - implementing mobile computing applications on top of the Android platform
  - `http://jaca-android.sourceforge.net`
- Web Services
  - building SOA/Web Services applications
  - `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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