Multi-Agent Programming

– Programming Organizations of Autonomous Agents –

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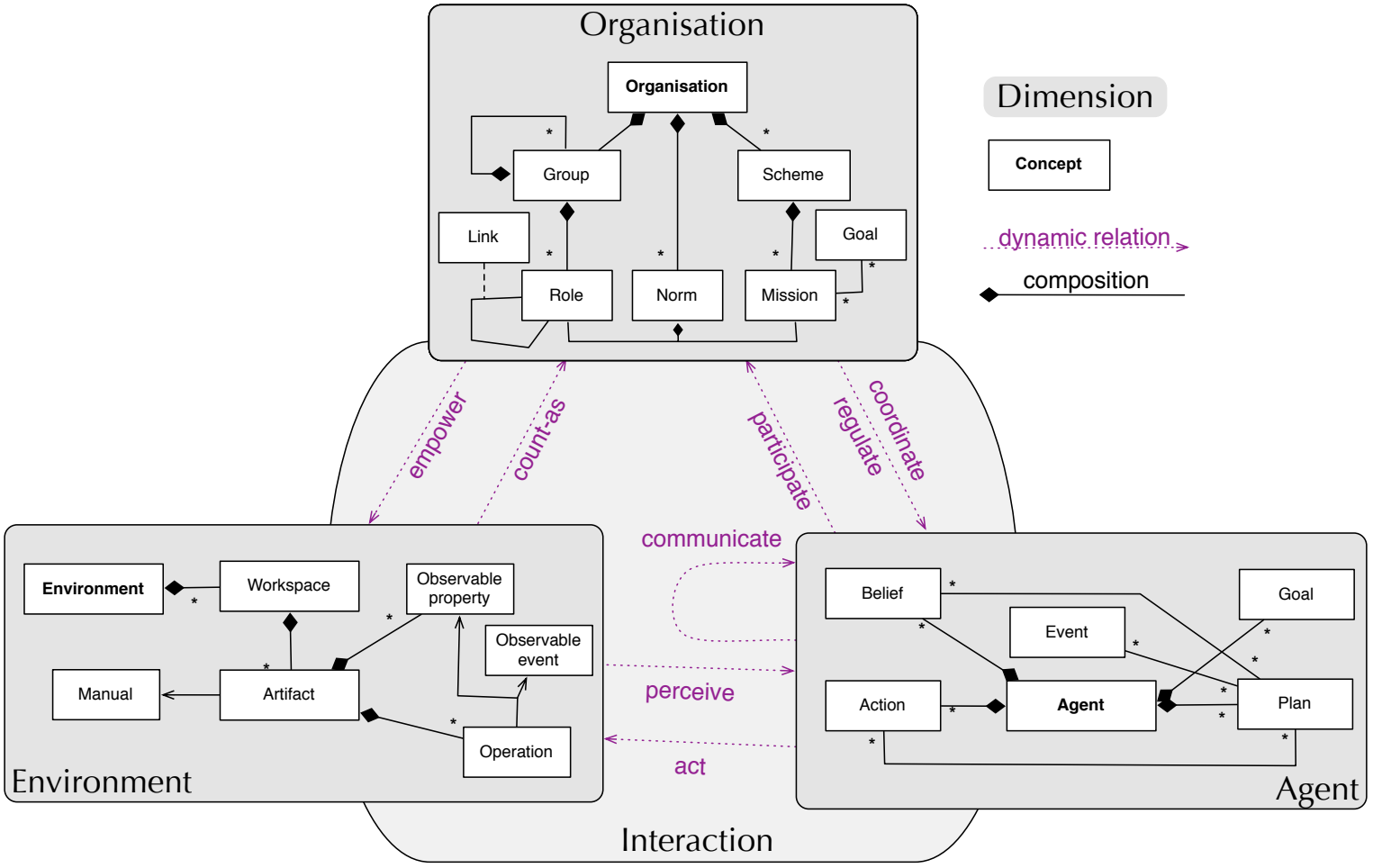
CPS2 M1 – Fall 2020

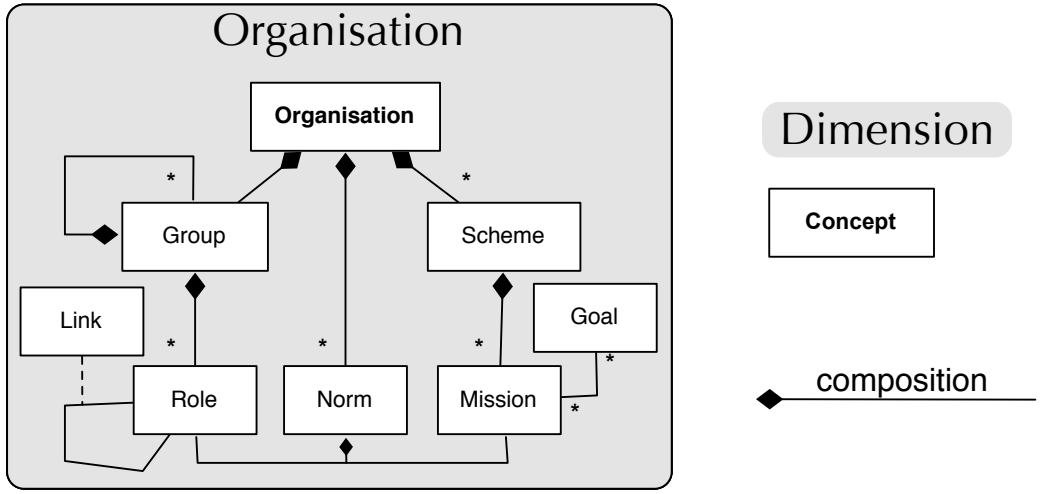
JaCaMo meta-model



Simplified view on JaCaMo meta-model [Boissier et al., 2020, Boissier et al., 2011]

A seamless integration of three dimensions based on Jason [Bordini et al., 2007], Cartago [Ricci et al., 2009], Moise [Hübner et al., 2009] meta-models

Organization dimension



Simplified Conceptual View ($\mathcal{M}$oise meta-model [Hübner et al., 2009])

Excerpts from organisation program:

```
<structural-specification>

<role-definitions>
 <role id="auctioneer" />
 <role id="participant" />
</role-definitions>

<group-specification id="auctionGroup">
 <roles>
  <role id="auctioneer"  min="1" max="1"/>
  <role id="participant" min="0" max="300"/>
 </roles>
</group-specification>
</structural-specification>
```

Structural spec.

```
<functional-specification>
 <scheme id="doAuction">
  <goal id="auction">
    <argument id="Id" />
    <argument id="Service" />
    <plan operator="sequence">
      <goal id="start" />
      <goal id="bid"    ttf="10 seconds" />
      <goal id="decide" ttf="1 hour" />
    </plan>
  </goal>
  <mission id="mAuctioneer" min="1" max="1">
    <goal id="start" />
    <goal id="decide" />
  </mission>
```

Functional spec.

```
<normative-specification>
  <norm id="n1"  type="permission"
        role="auctioneer"
        mission="mAuctioneer" />
  <norm id="n2"  type="obligation"
        role="participant"
        mission="mParticipant" />
</normative-specification>
```

Normative spec.

```
norm n1 : plays(A, auctionneer, G) ->
  forbidden(A,n1,plays(A,participant,G),
    'forever').
```

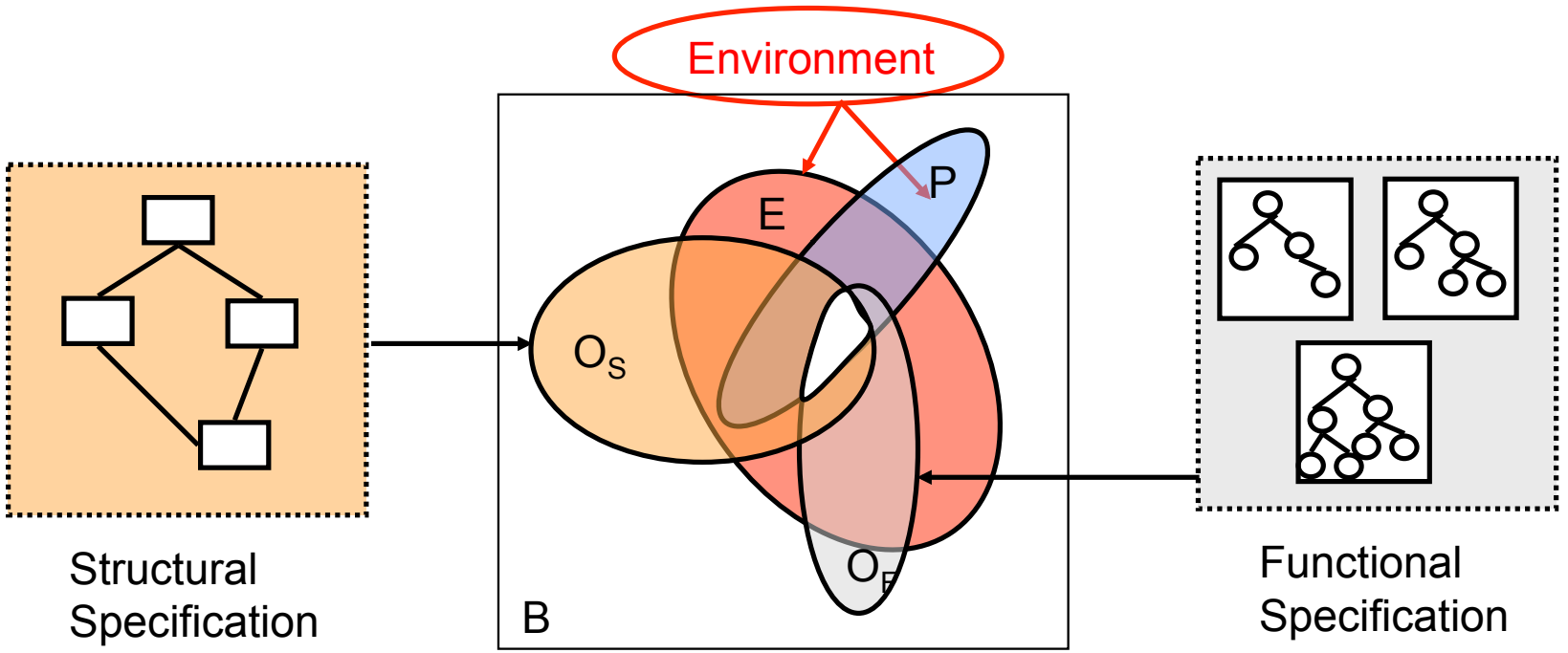
program in NPL

Organisation in JaCaMo: the $\mathcal{M}$oise Framework

- OML (language)
  - Tag-based language
    (issued from $\mathcal{M}$oise [Hannoun et al., 2000],
    $\mathcal{M}$oise$^+$ [Hübner et al., 2002], $\mathcal{M}$oiseInst [Gâteau et al., 2005])
- OMI (infrastructure)
  - developed as an artifact-based working environment
    (ORA4MAS [Hübner et al., 2009] based on CArtAgO nodes,
    refactoring of $\mathcal{S}$-$\mathcal{M}$oise$^+$ [Hübner et al., 2006] and
    $\mathcal{S}$ynai [Gâteau et al., 2005])
- Integrations
  - Environment and Organisation ([Piunti et al., 2009a]), Situated Artificial Institution [de Brito et al., 2015]
  - Agents and Organisation ($\mathcal{J}$-$\mathcal{M}$oise$^+$ [Hübner et al., 2007])

Outline

Moise Modelling Dimensions



Groups, links, roles
Compatibilities, multiplicities
inheritance

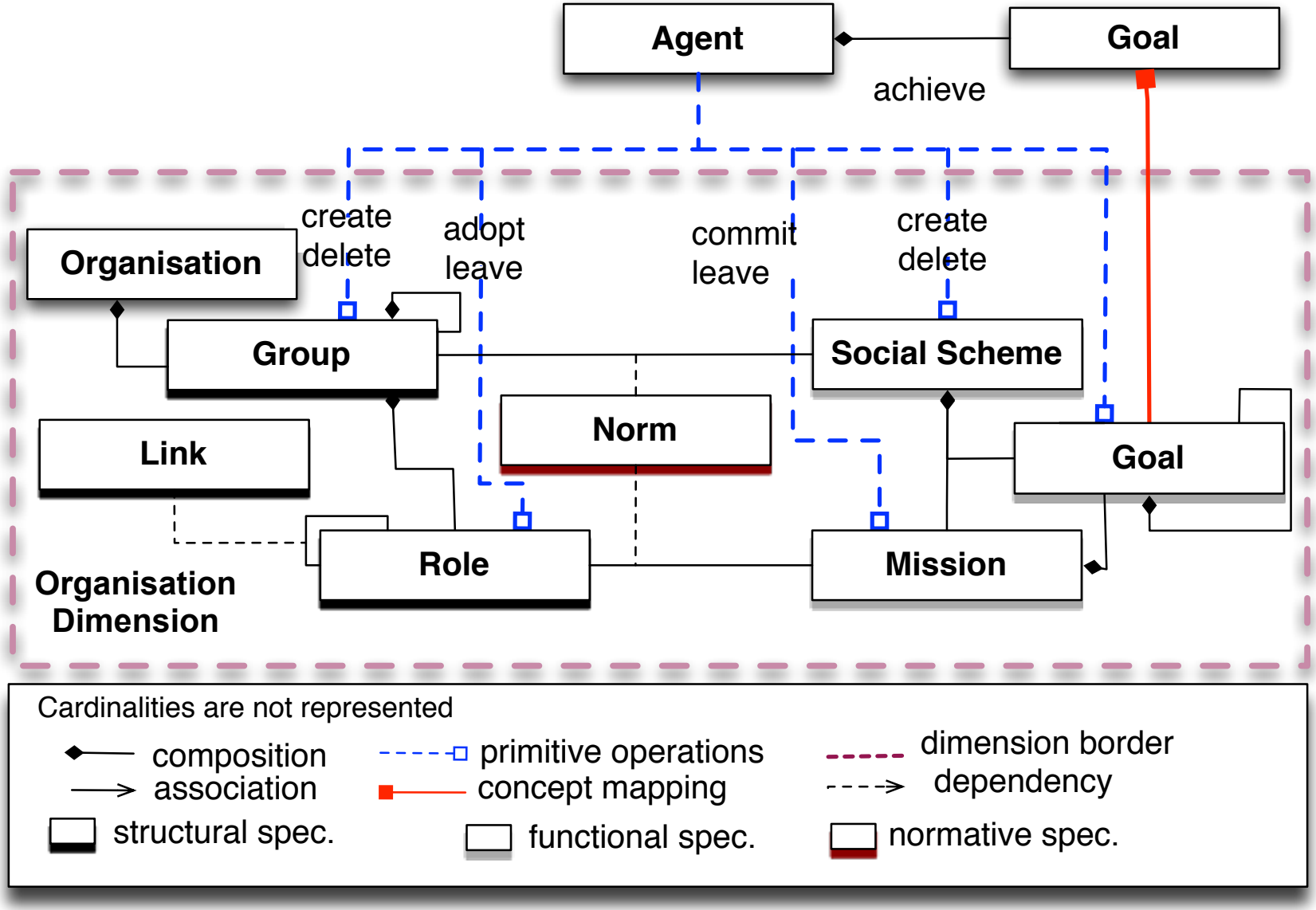
Normative Specification
Permissions, Obligations
Allows agents autonomy!

Global goals, plans,
Missions, schemas,
preferences

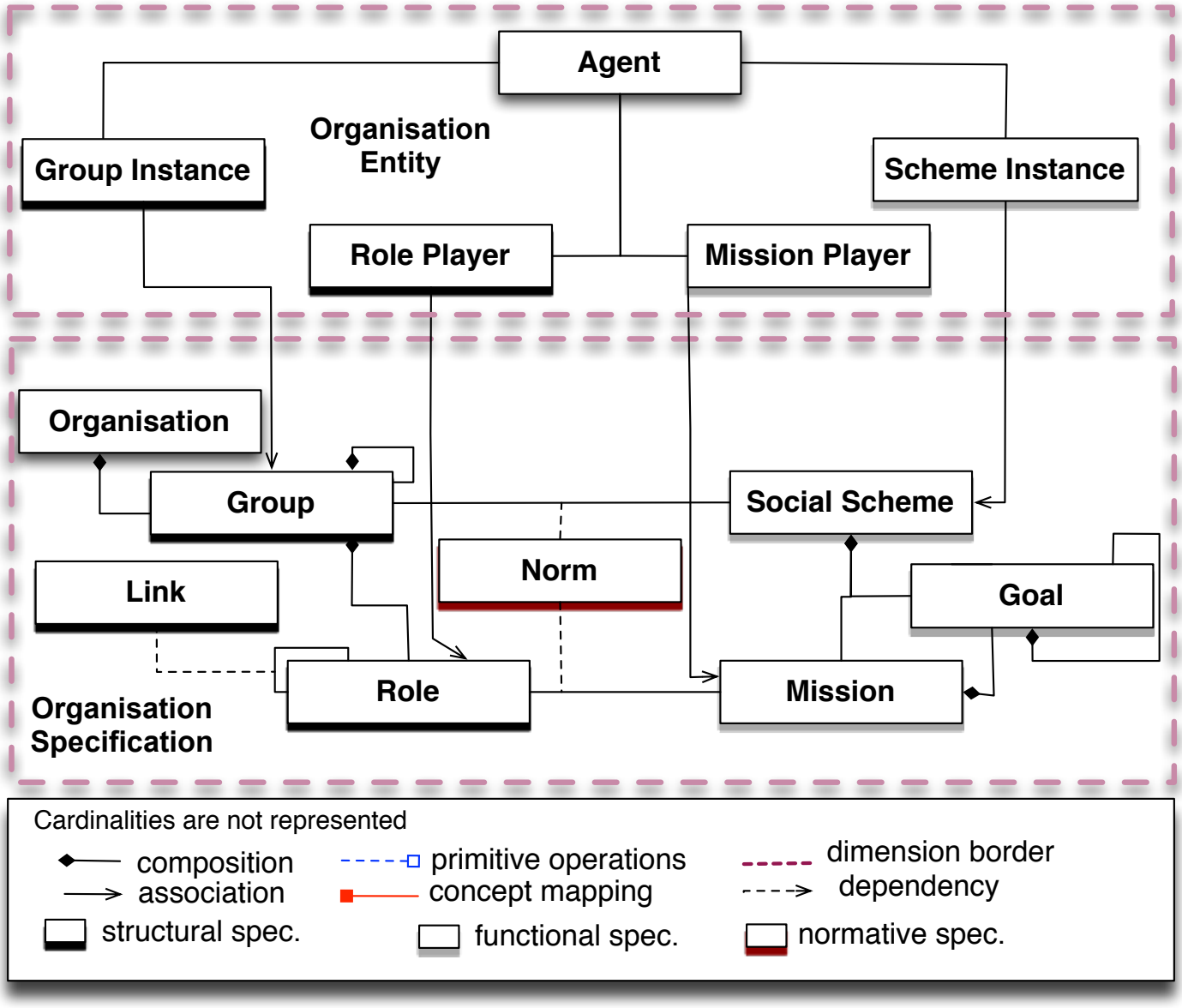
$\mathcal{M}$oise OML

- OML for defining organisation specification **and** organisation entity
- Three independent dimensions [Hübner et al., 2007]
  ($\rightsquigarrow$ well adapted for the reorganisation concerns):
  - **Structural**: Roles, Groups
  - **Functional**: Goals, Missions, Schemes
  - **Normative**: Norms (obligations, permissions, interdictions)
- Abstract description of the organisation for
  - the designers
  - the agents
    - $\rightsquigarrow$ $\mathcal{J}$-$\mathcal{M}$oise [Hübner et al., 2007]
  - the Organisation Management Infrastructure
    - $\rightsquigarrow$ ORA4MAS [Hübner et al., 2009]

Moise OML meta-model (partial & simplified view)



Moise OML global picture



Outline

Structural Specification

- Specifies the structure of an MAS along three levels:
  - **Individual** with **Role**
  - **Social** with **Link**
  - **Collective** with **Group**
- Components:
  - **Role**: label used to assign constraints on the behavior of agents playing it
  - **Link**: relation between roles that directly constrains the agents in their interaction with the other agents playing the corresponding roles
  - **Group**: set of links, roles, compatibility relations used to define a shared context for agents playing roles in it

Structural specification

- Defined with the tag structural-specification in the context of an organisational-specification
- One section for definition of all the roles participating to the structure of the organisation (role-definitions tag)
- Specification of the group including all subgroup specifications (group-specification tag)

Example

```
<organisational-specification
  <structural-specification>
     <role-definitions>  ... </role-definitions>
     <group-specification id="xxx">
       ...
     </group-specification>
  </structural-specification>
  ...
</organisational-specification>
```

Role specification

- Role definition(role tag) in role-definitions section, is composed of:
  - identifier of the role (id attribute of role tag)
  - inherited roles (extends tag) - by default, all roles inherit of the soc role -

Example

```
<role-definitions>
  <role id="player" />
  <role id="coach" />
  <role id="middle"> <extends role="player"/> </role>
  <role id="leader"> <extends role="player"/> </role>
  <role id="r1>
    <extends role="r2" />
    <extends role="r3" />
  </role>
  ...
</role-definitions>
```

Group specification

- Group definition (group-specification tag) is composed of:
  - group identifier (id attribute of group-specification tag)
  - roles participating to this group and their cardinality (roles tag and id, min, max), i.e. min. and max. number of agents that should adopt the role in the group (default is 0 and unlimited)
  - links between roles of the group (link tag)
  - subgroups and their cardinality (subgroups tag)
  - formation constraints on the components of the group (formation-constraints)

Example

```
<group-specification id="team">
   <roles>
        <role id="coach" min="1" max="2"/> ...
   </roles>
   <links> ... </links>
   <subgroups> ... </subgroups>
   <formation-constraints> ... </formation-constraints>
</group-specification>
```

extends-subgroups, scope

extends-subgroups

- Used for links or formation constraints
- if extends-subgroups== true, the link/constraint is also valid in all subgroups
- else it is valid only in the group where it is defined
- Default is false

scope

- Used for links or formation constraints
- if scope==inter-group: link or constraint exists for source or target belonging to different instances of the group
- if scope==intra-group: link or constraint exists for source or target belonging to the same instance of the group

Link specification

- Link definition (link tag) included in the group definition is composed of:
  - role identifiers (from, to)
  - type (type) with one of the following values: authority, communication, acquaintance
  - a scope (scope)
  - and validity to subgroups (extends-subgroups)

Example

```
<link from="coach"
      to="player"
      type="authority"
      scope="inter-group"
      extends-subgroups="true" />
```

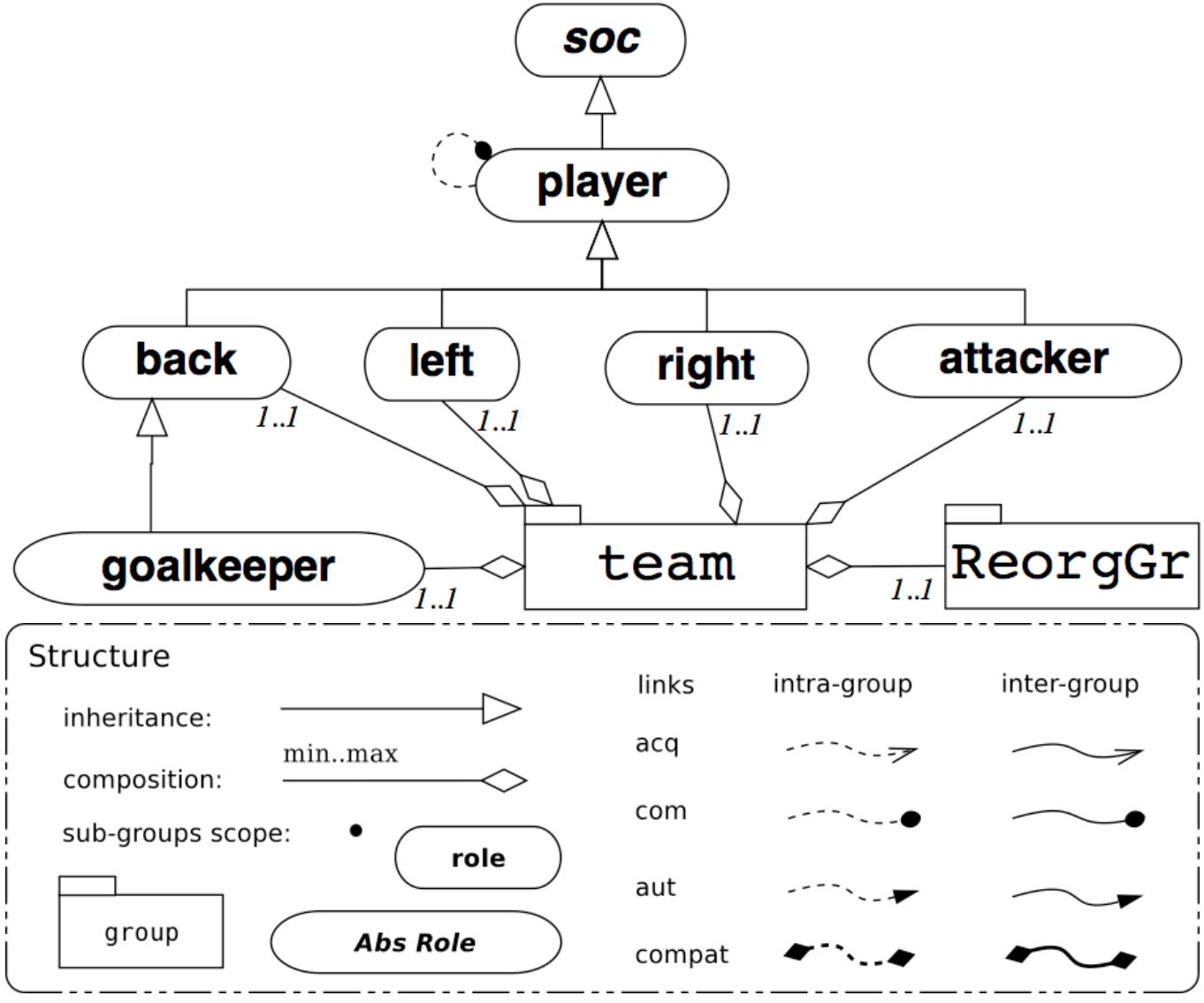
Formation constraint specification

- Formation constraints definition (formation-constraints tag) in a group definition is composed of:
  - compatiblity constraints (compatibility tag) between roles (from, to), with a scope, extends-subgroups and directions (bi-dir)

Example

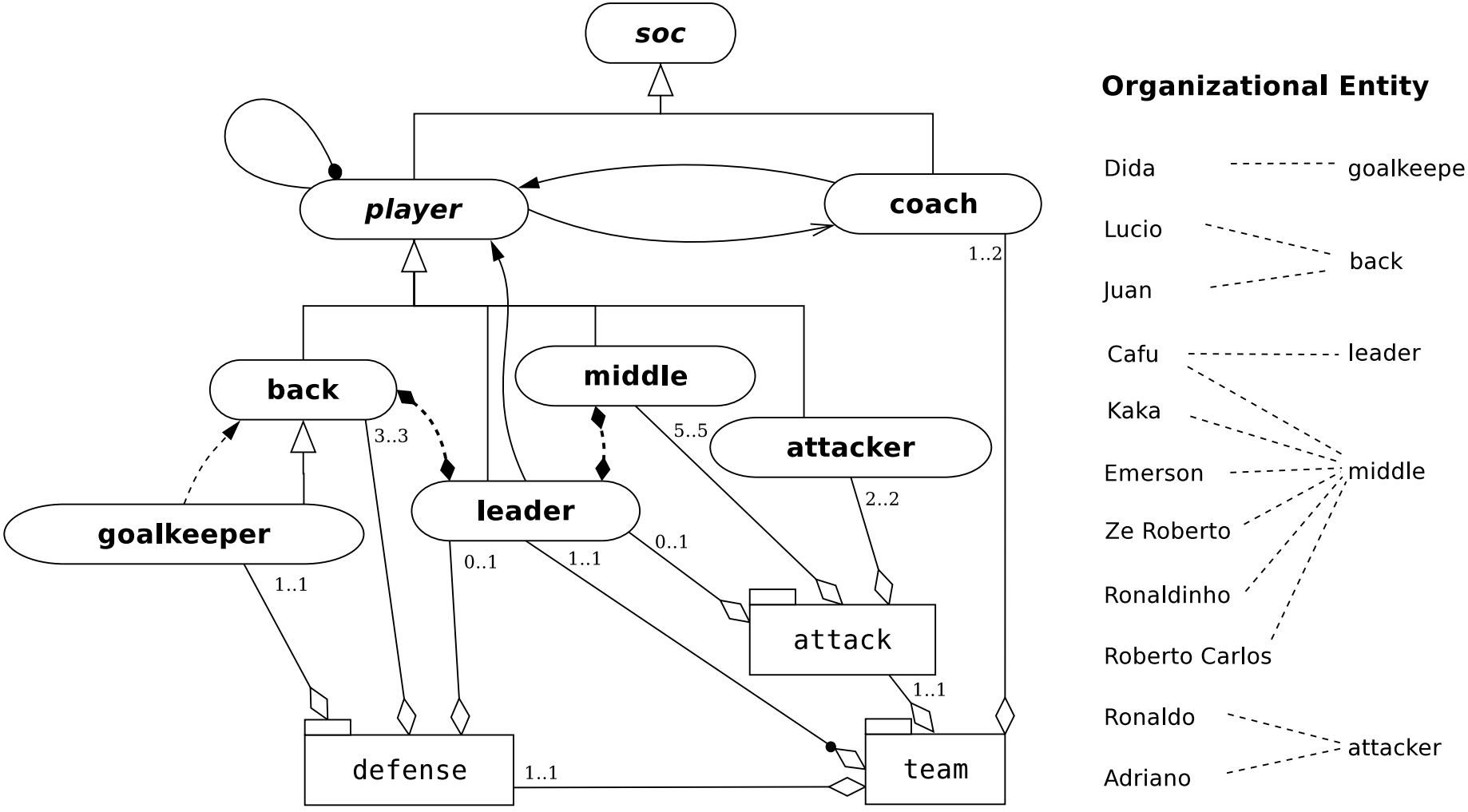
```
<formation-constraints>
  <compatibility from="middle"
                 to="leader"
                 scope="intra-group"
                 extends-subgroups="false"
                 bi-dir="true"/>
  ...
</formation-constraints>
```

Structural specification example (1)



Graphical representation of structural specification of Joj Team

Structural specification example (2)



Graphical representation of structural specification of 3-5-2 Joj Team

Outline

Functional Specification

- Specifies the expected behaviour of an MAS in terms of **goals** along two levels:
  - **Collective** with **Scheme**
  - **Individual** with **Mission**
- Components:
  - **Goals**:
    - **Performance goal** (default type). Goals of this type should be declared as done by the agents committed to them, when realized
    - **Achievement goal**. Goals of this type should be declared as satisfied by the agents committed to them, when realized
    - **Maintenance goal**. Goals of this type are not realized at a precise moment but are pursued while the scheme is running.
      The agents committed to them do not need to declare that they are satisfied
  - **Scheme**: global goal decomposition tree assigned to a group
    - Any scheme has a root goal that is decomposed into subgoals
  - **Missions**: set of coherent goals assigned to roles within norms

Functional specification

- Defined with the tag functional-specification in the context of an organisational-specification
- Specification in sequence of the different schemes participating to the expected behaviour of the organisation

Example

```
<functional-specification>
    <scheme id="sideAttack" >
        <goal id="dogoal" > ... </goal>
        <mission id="m1" min="1" max="5">
            ...
        </mission>
        ...
    </scheme>
    ...
</functional-specification>
```

Scheme specification

- Scheme definition (scheme tag) is composed of:
  - identifier of the scheme (id attribute of scheme tag)
  - the root goal of the scheme with the plan aiming at achieving it (goal tag)
  - the set of missions structuring the scheme (mission tag)
- Goal definition within a scheme (goal tag) is composed of:
  - an idenfier (id attribute of goal tag)
  - a type (performance default, achievement or maintenance)
  - min. number of agents that must satisfy it (min) (default is "all")
  - optionally, an argument (argument tag) that must be assigned to a value when the scheme is created
  - optionally a plan
- Plan definition attached to a goal (plan tag) is composed of
  - one and only one operator (operator attribute of plan tag) with sequence, choice, parallel as possible values
  - set of goal definitions (goal tag) concerned by the operator

Scheme specification example

```
<scheme id="sideAttack">
 <goal id="scoreGoal" min="1" >
  <plan operator="sequence">
    <goal id="g1" min="1" ds="get the ball" />
    <goal id="g2" min="3" ds="to be well placed">
      <plan operator="parallel">
        <goal id="g7" min="1" ds="go toward the opponent's field" />
        <goal id="g8" min="1" ds="be placed in the middle field" />
        <goal id="g9" min="1" ds="be placed in the opponent's goal area" />
      </plan>
    </goal>
    <goal id="g3" min="1" ds="kick the ball to the m2Ag" >
       <argument id="M2Ag" />
    </goal>
    <goal id="g4"       min="1" ds="go to the opponent's back line" />
    <goal id="g5"       min="1" ds="kick the ball to the goal area" />
    <goal id="g6"       min="1" ds="shot at the opponent's goal" />
  </plan>
 </goal>
 ...
```

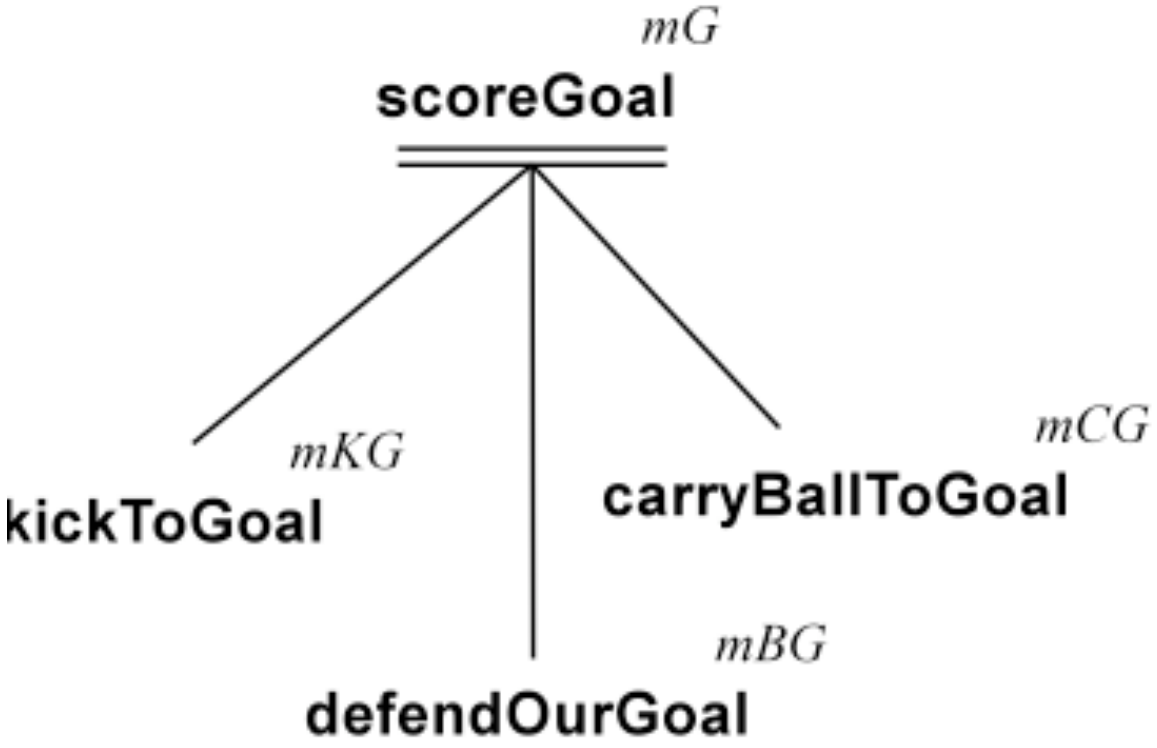
Mission specification

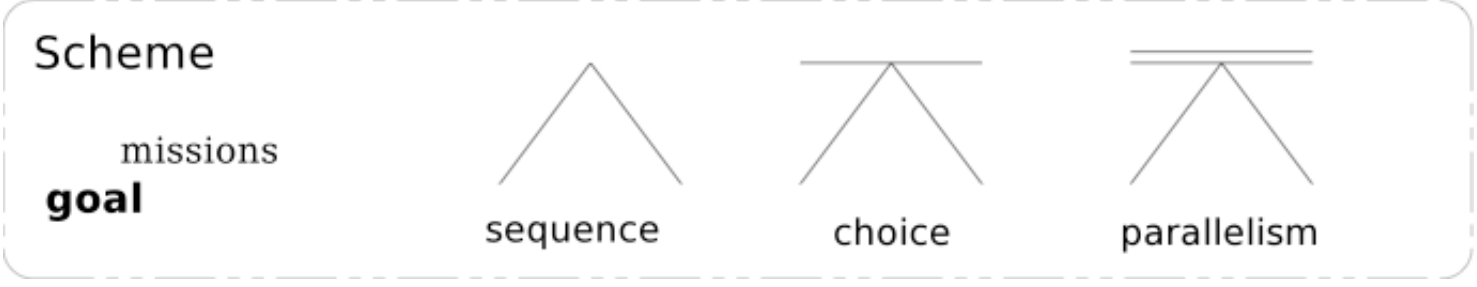
- Mission definition (mission tag) in the context of a scheme definition, is composed of:
  - identifier of the mission (id attribute of mission tag)
  - cardinality of the mission min (0 is default), max (unlimited is default) specifying the number of agents that can be committed to the mission
  - the set of goal identifiers (goal tag) that belong to the mission

Example

```
<scheme id="sideAttack">
  ... the goals ...
 <mission id="m1" min="1" max="1">
    <goal id="scoreGoal" /> <goal id="g1" />
    <goal id="g3" /> ...
  </mission>
  ...
</scheme>
```

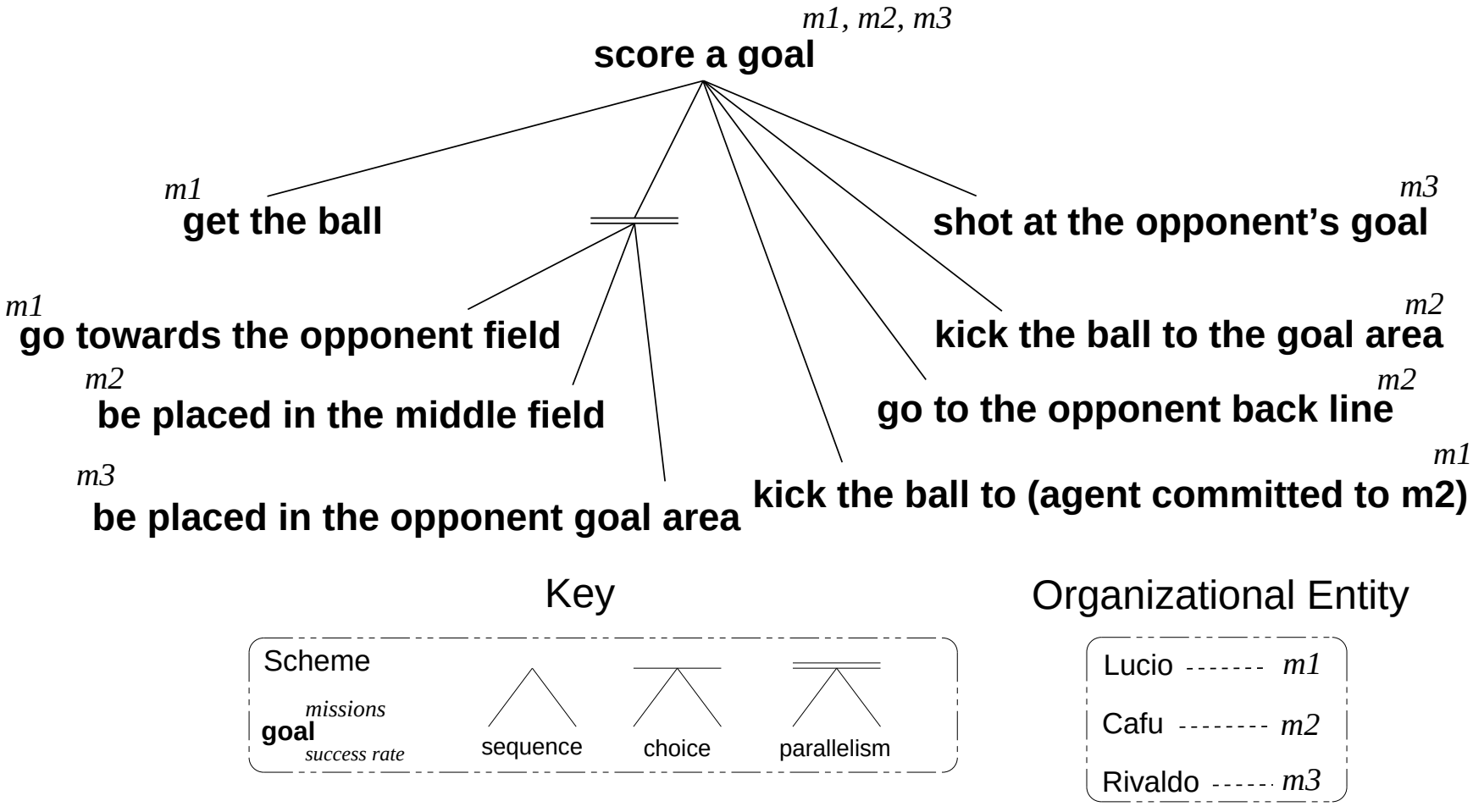
Functional specification example (1)





Graphical representation of social scheme for joj team

Functional specification example (2)



Graphical representation of social scheme "side_attack" for joj team

Outline

Normative Specification

- Explicit relation between the functional and structural specifications
- Permissions and obligations to commit to missions in the context of a role
- The normative specification makes explicit the normative dimension of a role

Normative specification

- Defined in-between the tag normative-specification in the context of an organisational-specification
- Definition in sequence of the different norms participating to the governance of the organisation
- Definition of programs written in Normative Programming Language (NPL)

Example

```
<normative-specification>
    <norm id="n1" ... />
     ...
    <norm id="..." ... />
    <npl-norms>
    ...
    </npl-norms>
</normative-specification>
```

Norm Definition

- Norm definition with norm tag, in the context of a normative-specification definition, with attributes:
  - the identifier of the norm (id)
  - the type of the norm (type) with obligation, permission as possible values
  - a condition of activation (condition) – optional – checking:
    - properties of the organisation (e.g. #role_compatibility, #mission_cardinality, #role_cardinality, #goal_non_compliance)
    - ⇝ unregimentation of organisation properties !!!
    - (un)fulfillment of an obligation stated in a particular norm (unfulfilled, fulfilled)
  - the role identifier (role) on which the norm is applied
  - the mission identifier (mission) object of the norm
  - a time constraint (time-constraint) – optional –

Norm Definition – example

- Any agent playing *back* is *obliged* to commit to mission *m*1 and achieve its goals within 1 minute

```
<norm id = "n1" type="obligation"
      role="back" mission="m1" time-constraint="1 minute"/>
```

- Any agent playing *left* is *obliged* to commit to mission *m*2 and achieve its goals within 1 day

```
<norm id = "n2" type="obligation"
      role="left" mission="m2" time-constraint="1 day"/>
```

- Any agent playing *coach* is *obliged* to commit to mission *ms* and achieve its goals within 3 hour in case obligation of norm n2 has not been fulfilled

```
<norm id = "n4" type="obligation"
      condition="unfulfilled(obligation(_,n2,_,_))"
      role="coach" mission="ms" time-constraint="3 hour"/>
```

Normative Programming Language (NPL)

Norms written in NPL have:

- an activation condition
- a consequence
  Two kinds of consequences are considered
  - regimentations (`fail`)
  - obligations (`obligation`)
- terms starting with an upper case letter are variables

Example (Norm)

```
norm n1: plays(A,writer,G) -> fail.
```

or

```
norm n1: plays(A,writer,G)
      -> obligation(A,n1,plays(A,editor,G),
         ‘now + 3 min‘).
```

Normative Programming Language (NPL)

Example (NPL Program)

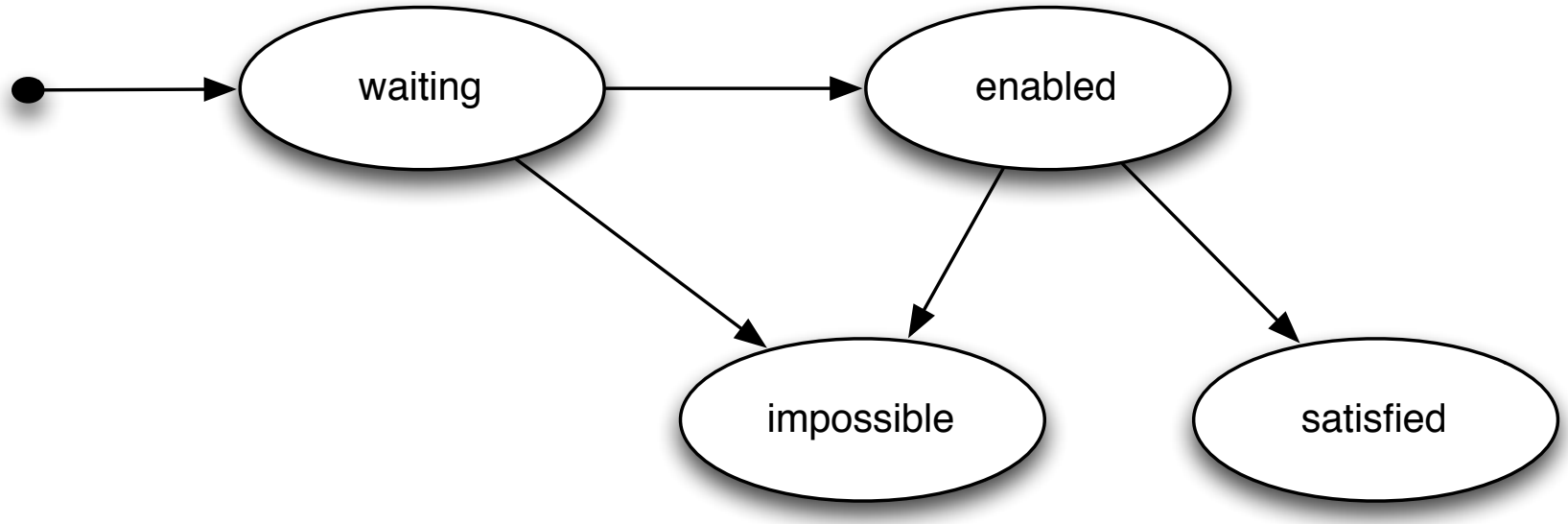
```
<npl-norms>
     a :- t &amp;amp; k.
     norm npl1: a &amp;amp; v(X) ->
          obligation(bob,true,g(X),‘now‘+‘1 day‘).
     norm npl2: a &amp;amp; b    -> fail(test).
</npl-norms>
```

Outline

Organisation entity dynamics

1. Organisation is created (by the agents)
   - instances of groups
   - instances of schemes
2. Agents enter into groups **adopting** roles
3. When a group is well formed, it may become **responsible** for schemes
   - Agents from the group are then obliged to commit to missions in the scheme
4. Agents **commit** to missions
5. Agents **fulfil** mission's goals
6. Agents leave schemes and groups
7. Schemes and groups instances are destroyed

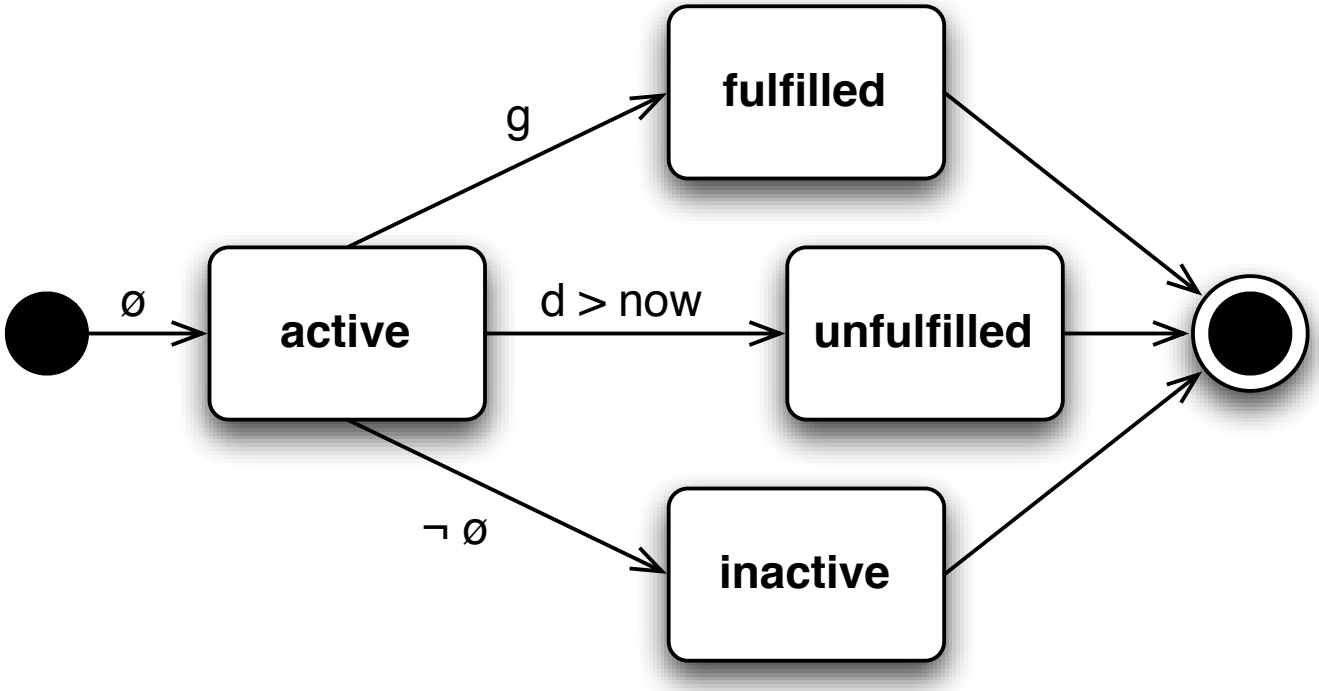
Goal dynamics



waiting	initial state
enabled	goal pre-conditions are satisfied & scheme is well-formed
satisfied	agents committed to the goal have achieved it
impossible	the goal is impossible to be satisfied

Note: goal state from the Organization point of view may be different of the goal state from the Agent point of view

Norm dynamics

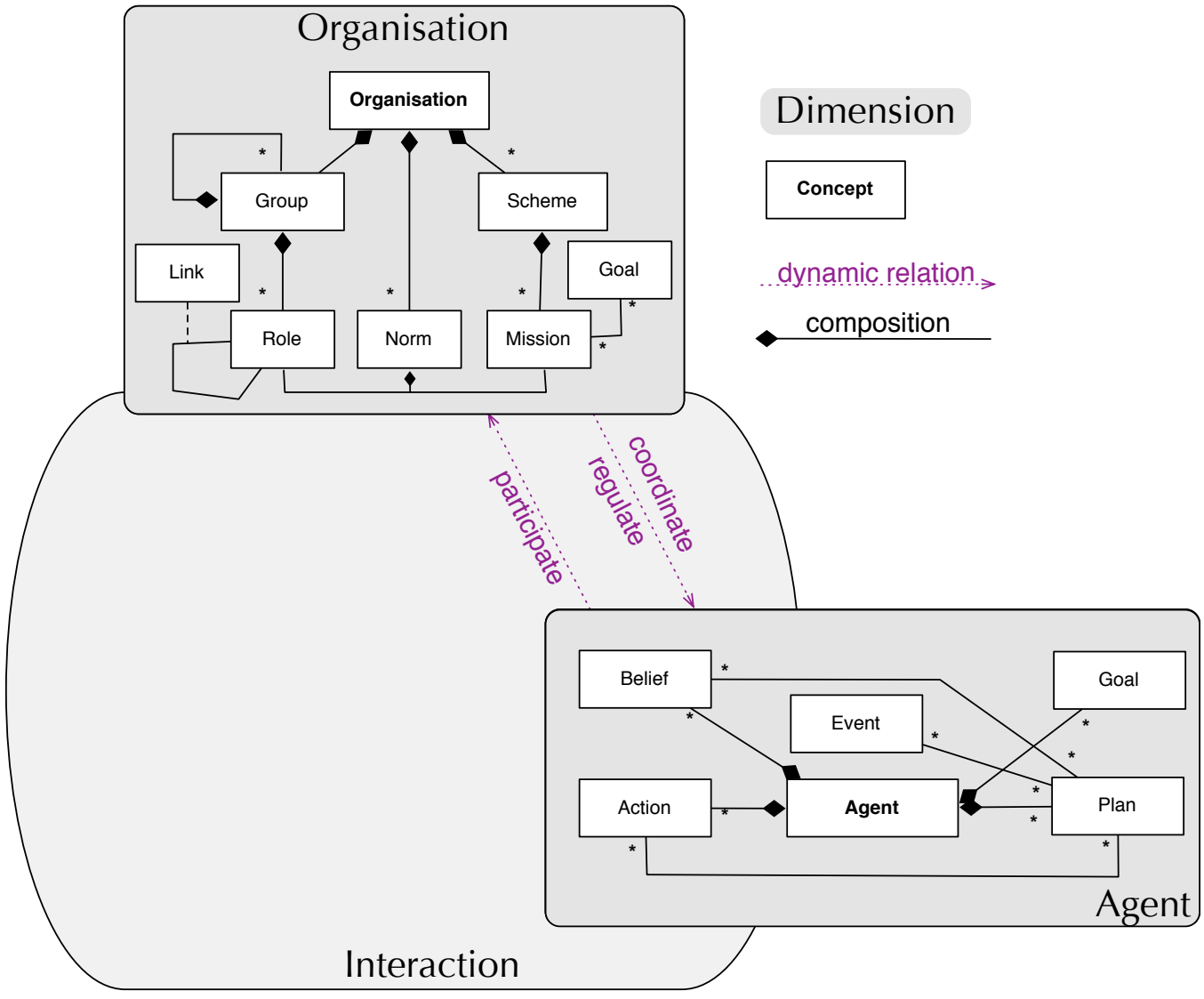


$$norm\ n:\ \phi\ ->\ obligation(a, r, g, d)$$

- ϕ: activation condition of the norm (e.g. play a role)
- g: the goal of the obligation (e.g. commit to a mission)
- d: the deadline of the obligation

Outline

Integrating **A** & **O** dimensions



Integrating **A** & **O** dimensions

Agent integration mechanisms allow agents to be aware of and to deliberate on:

- entering/exiting the organisation
- modification of the organisation
- obedience/violation of norms
- sanctioning/rewarding other agents

e.g. $\mathcal{J}$-$\mathcal{M}$oise$^+$ [Hübner et al., 2007], Autonomy based reasoning [Carabelea, 2007], *ProsA*$_2$ Agent-based reasoning on norms [Ossowski, 1999], ...

Organization actions and beliefs

- **Observable Properties**:
  - group(group_id,group_type,artid): list of the group_id of group_type that exist in the organizational entity
  - scheme(scheme_id,scheme_type,artid): list of the scheme_id of scheme_type that exist in the organizational entity
- **Operations**:
  - createGroup(group) (resp. removeGroup(grid)): attempts to create (resp. remove) group in the organization
  - createScheme(scheme) (resp. removeScheme(schid)): attempts to create (resp. remove) scheme in the organization

Note: available through OrgBoard Artifact created when creating an organization

Group actions and beliefs

- **Observable Properties**:
  - specification: group spec. in the OS
  - player: list of play(agent, role, group)
  - schemes: list of scheme identifiers that the group is responsible for
  - subgroups, parentGroup, formationStatus (if the group is well formed or not)
- **Operations**:
  - adoptRole(role) (resp. leaveRole(role)): attempts to adopt (resp. leave) role in the group
  - addScheme(schid) (resp. removeScheme(schid)): attempts to set (resp. unset) the group responsible for the scheme managed by the SchemeBoard schId
  - setParentGroup(groupid), setOwner(agtid), destroy

Note: available through GroupBoard Artifact created when creating a group in an organization

Scheme actions and beliefs

- **Observable Properties**:
  - specification: scheme spec. in the OS
  - commitments: list of commitment(agent, mission, scheme)
  - groups: list of groups resp. for the scheme
  - goalState: list of goals' current state
  - goalArgument(schemeId,goalId,argId,value): added only if the argument has a value, usually defined by the operation setArgumentValue
  - obligations: list of active obligations in the scheme (obligation(agt,norm,goal,deadline))
  - permissions: list of active permissions in the scheme (permission(agt,norm,goal,deadline))
  - goalArgument: value of goals' arguments, defined by the operation setArgumentValue
- **Operations**:
  - commitMission(mission) (resp. leaveMission): attempts to "commit" (resp "leave") a mission in the scheme
  - goalAchieved(goal): declares that goal is achieved
  - setArgumentValue(goal, argument, value): defines the value of goal's argument
  - resetGoal(goal) (reset the status of a goal), destroy

Norm actions and beliefs

- **Observable Properties**:
  - obligation: current active obligations
- **Operations**:
  - load(nplprogram)
  - addFact (resp. removeFact)

Note: available in Normative board managing obligations/permissions defined in the normative specification

- automatically created when a group becomes responsible for a scheme
- or when loading any NPL program

Organisational **actions** in *Jason* I

Example (GroupBoard)

```
...
joinWorkspace("ora4mas",O4MWsp);
makeArtifact(
    "auction",
    "ora4mas.nopl.GroupBoard",
    ["auction-os.xml", auctionGroup, false, true ],
    GrArtId);
adoptRole(auctioneer);
focus(GrArtId);
...
```

Organisational **actions** in *Jason* II

Example (SchemeBoard)

```
...
makeArtifact(
   "sch1",
   "ora4mas.nopl.SchemeBoard",
   ["auction-os.xml", doAuction, false, true ],
   SchArtId);
focus(SchArtId);
addScheme(Sch);
commitMission(mAuctioneer)[artifact_id(SchArtId)];
...
```

Organisational **actions** in *Jason* III

- For roles:
  - `adoptRole`
  - `leaveRole`
- For missions:
  - `commitMission`
  - `leaveMission`

- Those actions usually are executed under **regimentation** (to avoid an inconsistent organisational state)
  e.g. the adoption of role is constrained by
  - the cardinality of the role in the group
  - the compatibilities of the roles played by the agent

Organisational perception – example

Inspection of agent **bob** (cycle #0)

Beliefs

commitment(bob,mManager,"sch2")[artifact_id(cobj_4),c
cept),artifact_name(cobj_4,"sch2"),artifact_type(cobj_4,"ora4m
commitment(bob,mManager,"sch1")[artifact_id(cobj_3),c
cept),artifact_name(cobj_3,"sch1"),artifact_type(cobj_3,"ora4m
current_wsp(cobj_1,"ora4mas","308b05b0-2994-4fe8
formationStatus(ok)[artifact_id(cobj_2),obs_prop_id("obs_i
obj_2,"mypaper"),artifact_type(cobj_2,"ora4mas.nopl.GroupBo
goalState("sch2",wp,[bob],[bob],satisfied)[artifact_id(cot

Handling organisational **events** in *Jason*

Whenever something changes in the organisation, the agent architecture updates the agent belief base accordingly producing events (belief update from perception)

Example (new agent entered the group)

```
+play(Ag,boss,GId) <- .send(Ag,tell,hello).
```

Example (change in goal state)

```
+goalState(Scheme,wsecs,_,_,satisfied)
    : .my_name(Me) & commitment(Me,mCol,Scheme)
   <- leave_mission(mColaborator,Scheme).
```

Example (signals)

```
+normFailure(N) <- .print("norm failure event: ", N).
```

Typical plans for obligations

Example

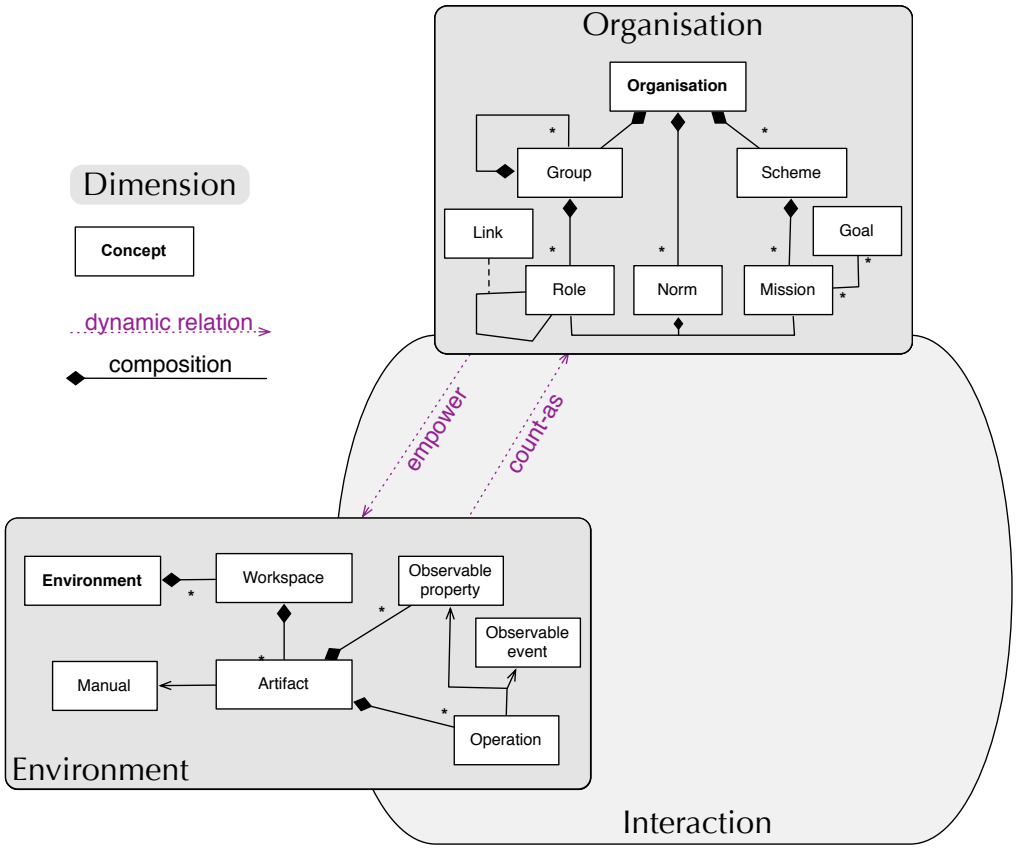
```
+obligation(Ag,Norm,committed(Ag,Mission,Scheme),DeadLine)
    : .my_name(Ag)
   <- .print("I am obliged to commit to ",Mission);
      commit_mission(Mission,Scheme).

+obligation(Ag,Norm,achieved(Sch,Goal,Ag),DeadLine)
    : .my_name(Ag)
   <- .print("I am obliged to achieve goal ",Goal);
      !Goal[scheme(Sch)];
      goal_achieved(Goal,Sch).

+obligation(Ag,Norm,What,DeadLine)
   : .my_name(Ag)
   <- .print("I am obliged to ",What,
             ", but I don't know what to do!").
```

Outline

Integrating O & E dimensions

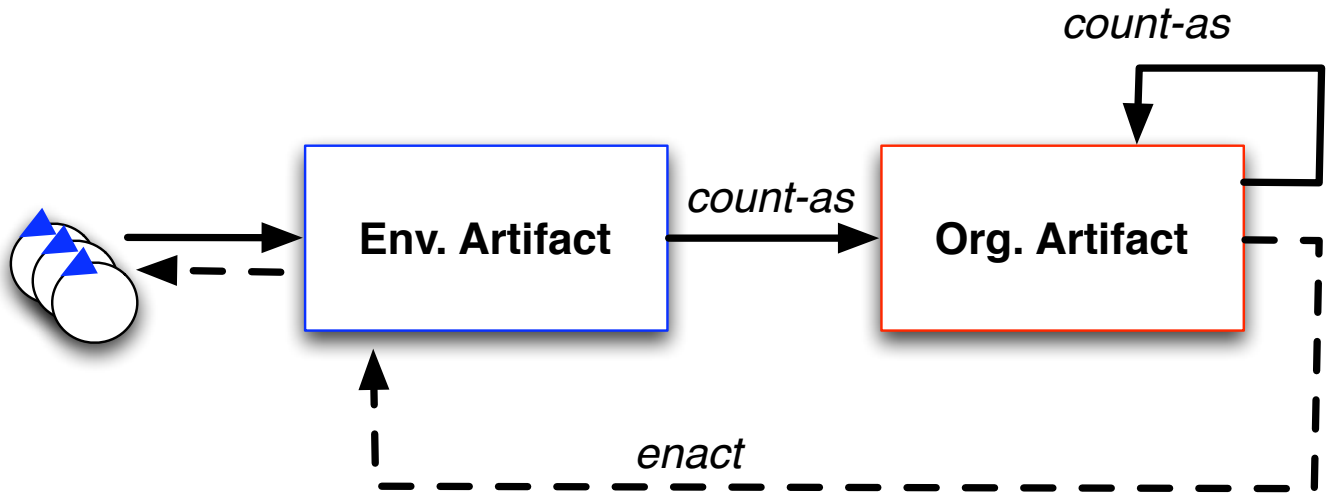


Transforming organisations into embodied organisations [de Brito et al., 2012], [Piunti et al., 2009b], [Okuyama et al., 2008] so that:

- organisation may act on the environment (e.g. enact rules, regimentation)
- environment may act on the organisation (e.g. count-as rules) based on Situated Artificial Institution [de Brito et al., 2015]

Environment integration

- Organisational Artifacts enable organisation and environment integration
- Embodied organisation [Piunti et al., 2009a]



status: ongoing work

Constitutive rules

Count-As rule

An event occurring on an artifact, in a particular context, may "count-as" an institutional event

- transforms the events created in the working environment into activation of an organisational operation

$\rightsquigarrow$ indirect automatic updating of the organisation

Enact rule

An event produced on an organisational artifact, in a specific institutional context, may "enact" change and updating of the working environment (i.e., to promote equilibrium, avoid undesiderable states)

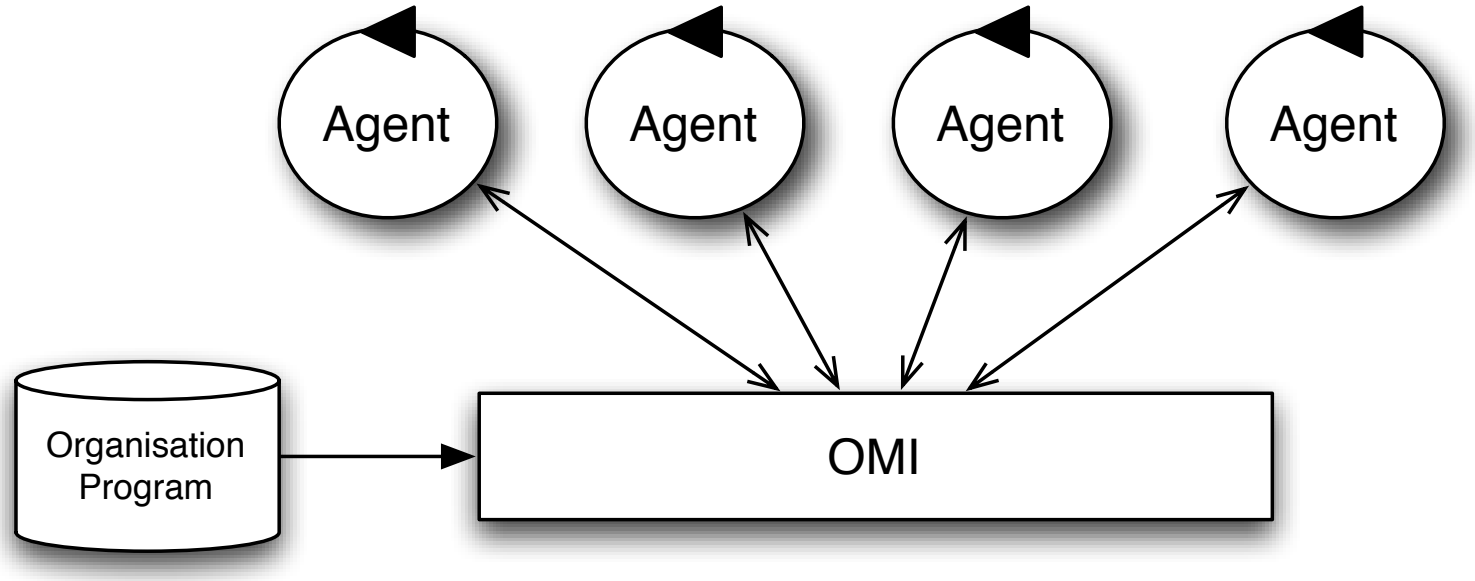
- Installing automated control on the working environment
- Even without the intervention of organisational/staff agents (regimenting actions on physical artifacts, enforcing sanctions, ...)

Outline

Organisation management infrastructure (OMI)

Responsibility

- Managing – coordination, regulation – the agents' execution within organisation defined by an organisational specification

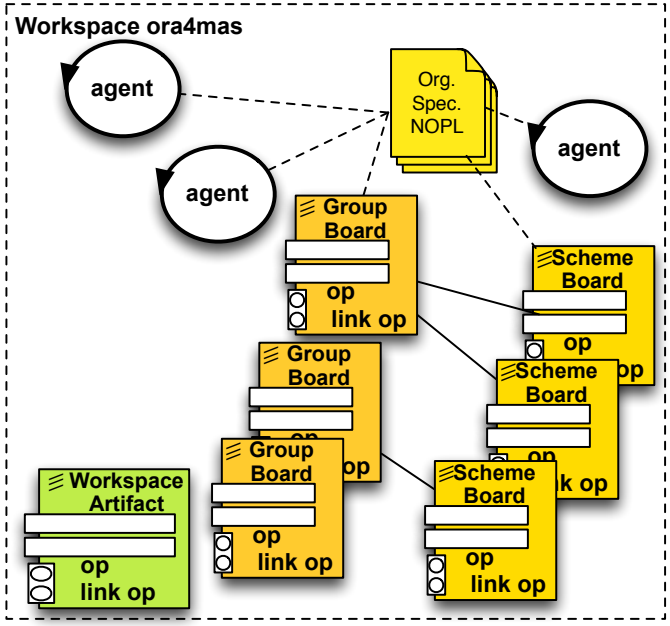


(e.g. MadKit, AMELI, $\mathcal{S}$-$\mathcal{M}$oise$^+$, ...)

ORA4MAS: OMI within JaCaMo

Based on A&A and $\mathcal{M}$oise.
Agents' working environment is instrumented with Organizational Artifacts (OA) offering "organizational" actions
$\rightsquigarrow$ **Distributed** management of the organization with a clear separation of concerns:

- Agents:
  - create, handle OAs and act on them
    $\rightsquigarrow$ deploy and manage their OMI
  - perceive the organization state and violations of norms from the OAs
  - decide about:
    - actions on the organization, on norms
    - sanctions to apply
- OAs are in charge of interpreting Normative Programs
  - to detect and evaluate norms compliance
  - or to regiment norms



Outline

ORA4MAS– OrgBoard artifact

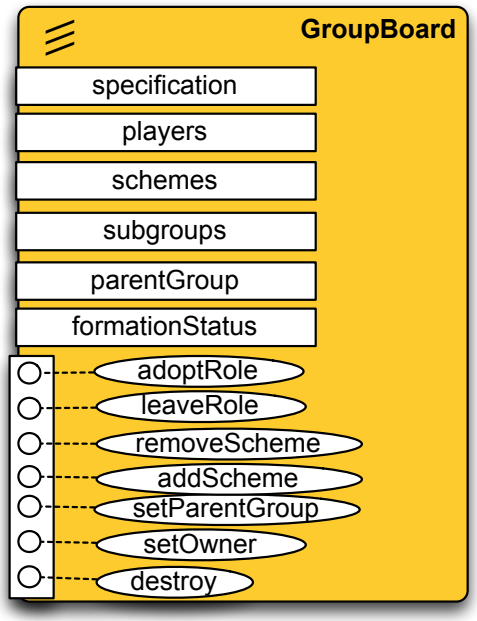
Manages all artifacts of an organisation.

- **Observable Properties**:
  - group(group_id,group_type,artid): list of the group_id of group_type that exist in the organizational entity
  - scheme(scheme_id,scheme_type,artid): list of the scheme_id of scheme_type that exist in the organizational entity
- **Operations**:
  - createGroup(group) (resp. removeGroup(grid)): attempts to create (resp. remove) group in the organization
  - createScheme(scheme) (resp. removeScheme(schid)): attempts to create (resp. remove) scheme in the organization

ORA4MAS– GroupBoard artifact

Manages the functioning of an instance of group in the organization.

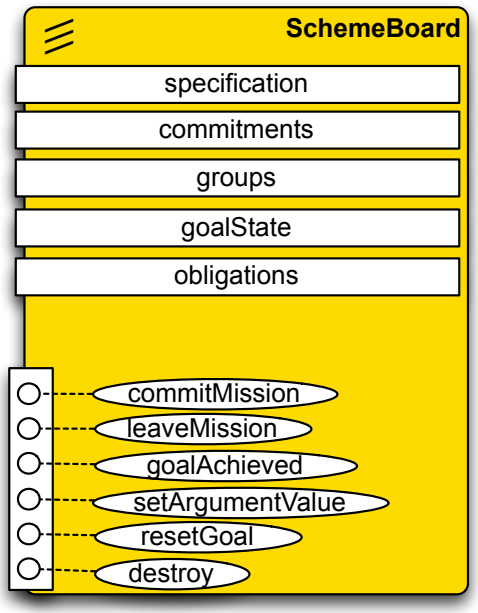
- **Observable Properties**:
  - specification: group spec. in the OS
  - player: list of play(agent, role, group)
  - schemes: list of scheme identifiers that the group is responsible for
  - subgroups, parentGroup, formationStatus (if the group is well formed or not)
- **Operations**:
  - adoptRole(role) (resp. leaveRole(role)): attempts to adopt (resp. leave) role in the group
  - addScheme(schid) (resp. removeScheme(schid)): attempts to set (resp. unset) the group responsible for the scheme managed by the SchemeBoard schId
  - setParentGroup(groupid), setOwner(agtid), destroy



ORA4MAS– SchemeBoard artifact

Manages the functioning of an instance of social scheme in the organization.

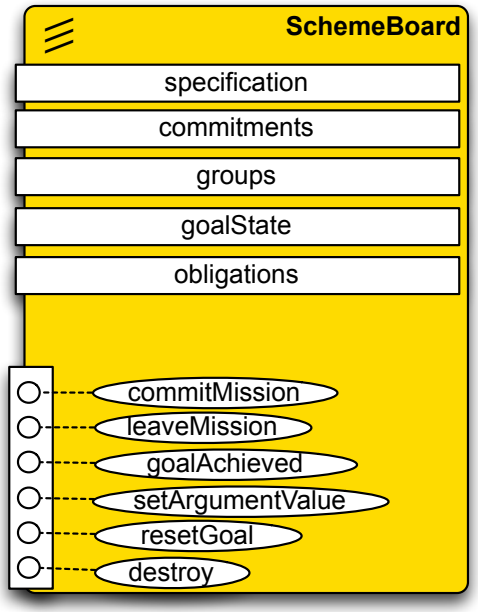
- **Observable Properties**:
  - specification: scheme spec. in the OS
  - commitments: list of commitment(agent, mission, scheme)
  - groups: list of groups resp. for the scheme
  - goalState: list of goals' current state
  - goalArgument(schemeId,goalId,argId,value): added only if the argument has a value, usually defined by the operation setArgumentValue
  - obligations: list of active obligations in the scheme (obligation(agt,norm,goal,deadline))
  - permissions: list of active permissions in the scheme (permission(agt,norm,goal,deadline))
  - goalArgument: value of goals' arguments, defined by the operation setArgumentValue



ORA4MAS– SchemeBoard artifact (Contd)

Manages the functioning of an instance of social scheme in the organization.

- **Operations**:
  - commitMission(mission) (resp. leaveMission): attempts to "commit" (resp "leave") a mission in the scheme
  - goalAchieved(goal): declares that goal is achieved
  - setArgumentValue(goal, argument, value): defines the value of goal's argument
  - resetGoal(goal) (reset the status of a goal), destroy



admCommand in Scheme/Group Boards

```
// in some plan of some agent
admCommand(setCardinality(role,editor,0,10));
admCommand(setCardinality(role,writer,0,20));

lookupArtifact("s1", SId); // get artifact id of scheme "s1"
admCommand(setCardinality(mission,mColaborator,0,3))[aid(SId)];
admCommand(setCardinality(mission,mManager,0,2))[aid(SId)];
```

Only the owner of the group/scheme can perform admCommands

ORA4MAS– NormativeBoard artifact

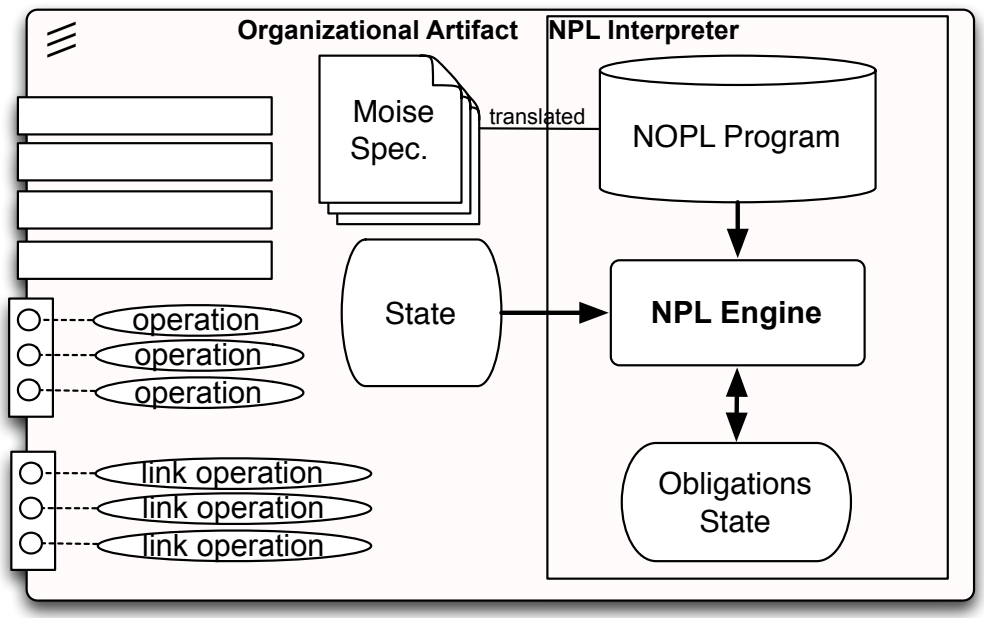
- It can be loaded with any NPL program
- is used to manage obligations/permissions defined in the normative specification
- When a group becomes responsible for a scheme, an instance of this artifact is created automatically.

- **Observable Properties**:
  - obligation: current active obligations
- **Operations**:
  - load(nplprogram)
  - addFact (resp. removeFact)

Organisational Artifact Architecture

Org. Artifacts managing groups and social schemes execution:

- interpret programs written in Normative Programming Language (NPL) [Hübner et al., 2010] coming from the automatic translation of $\mathcal{M}$oise programs
- generate signals
  - oblCreated(o), oblFulfilled(o), oblUnfulfilled(o)
  - oblInactive(o), normFailure(f)
    (o = obligation(to whom, reason, what, deadline))



Generic control cycle of an Organisational Artifact

```
// oe: current state of the org. managed by the artifact
// p: current NOPL program
// npi: NPL interpreter
When operation o is triggered by agent a do
 oe' <- oe \\ creates a ''backup'' of current oe
 oe <- executes(o,oe)
 f <- a list of predicates representing oe
 r <- npi(p,f) \\ runs the interpreter for the new state
 If r == fail then
   oe <- oe' \\ restore the state backup
   fail operation o
 else
   update observable properties from obligations state
   success operation o
```

Outline

Structural Operational Semantics

A normative system configuration is a tuple: $\langle F, N, ns, OS, t \rangle$
with

- F is a set of facts
- N is a set of norms
- ns is the state of the normative system (sound state $\top$ or a failure state $\bot$)
- OS is a set of obligations
  each element $os \in OS$ is $\langle o, ost \rangle$
  where o obligation and ost its state
- t is the current time

The initial configuration of a NP P is $\langle P_F, P_N, \top, \emptyset, 0 \rangle$

- P_F and P_N are the initial facts and norms defined in the normative program P

Rules for Norm Management

- Failure detection:

$$\frac{n \in N \qquad F \models n_\varphi \qquad n_\psi = \texttt{fail}(\_)}{\langle F, N, \top, OS, t\rangle \longrightarrow \langle F, N, \bot, OS, t\rangle} \qquad \textbf{(Regim)}$$

when any norm n becomes active (i.e., its **condition** component holds in the current state) and its **consequence** is `fail(_)`, the normative state is no longer sound but in failure ($\bot$).

- Roll back from failure:

$$\frac{\forall n \in N.(F \models n_\varphi \implies n_\psi \neq \texttt{fail}(\_))}{\langle F, N, \bot, OS, t\rangle \longrightarrow \langle F, N, \top, OS, t\rangle} \qquad \textbf{(Consist)}$$

Rules for Norm Management (continued)

- Creation of obligation:

$$\frac{n \in N \qquad F \models n_\varphi \qquad n_\psi = o \qquad o\theta_d > t \qquad \neg\exists \langle o', ost \rangle \in OS \;.\; (o' \overset{\text{obl}}{=} o\theta \wedge ost \neq \textbf{inactive})}{\begin{array}{c}\langle F, N, \top, OS, t \rangle \longrightarrow \\ \langle F, N, \top, OS \cup \langle o\theta, \textbf{active} \rangle, t \rangle\end{array}} \qquad (\textbf{Oblig})$$

where θ is the m.g.u. such that $F \models o\theta$

Rules for Obligation Management

$$\frac{os \in OS \qquad os = \langle o, \textbf{active} \rangle \qquad F \models o_g \qquad o_d \geq t}{\langle F, N, \top, OS, t \rangle \longrightarrow \langle F, N, \top, (OS \setminus \{os\}) \cup \{\langle o, \textbf{fulfilled} \rangle\}, t \rangle} \quad (\textbf{Fulfil})$$

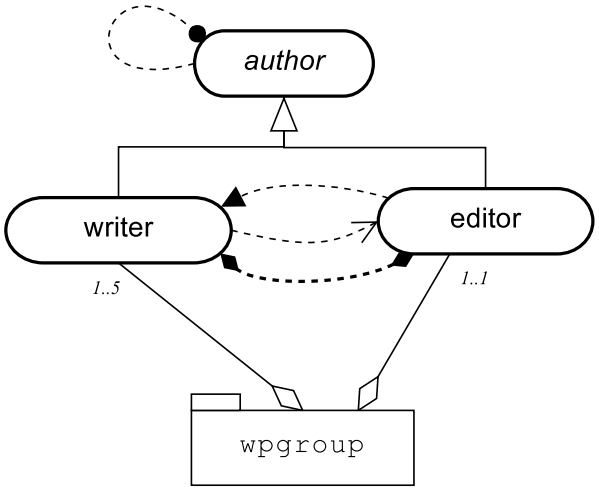
$$\frac{os \in OS \qquad os = \langle o, \textbf{active} \rangle \qquad o_d < t}{\langle F, N, \top, OS, t \rangle \longrightarrow \langle F, N, \top, (OS \setminus \{os\}) \cup \{\langle o, \textbf{unfulfilled} \rangle\}, t \rangle} \quad (\textbf{Unfulfil})$$

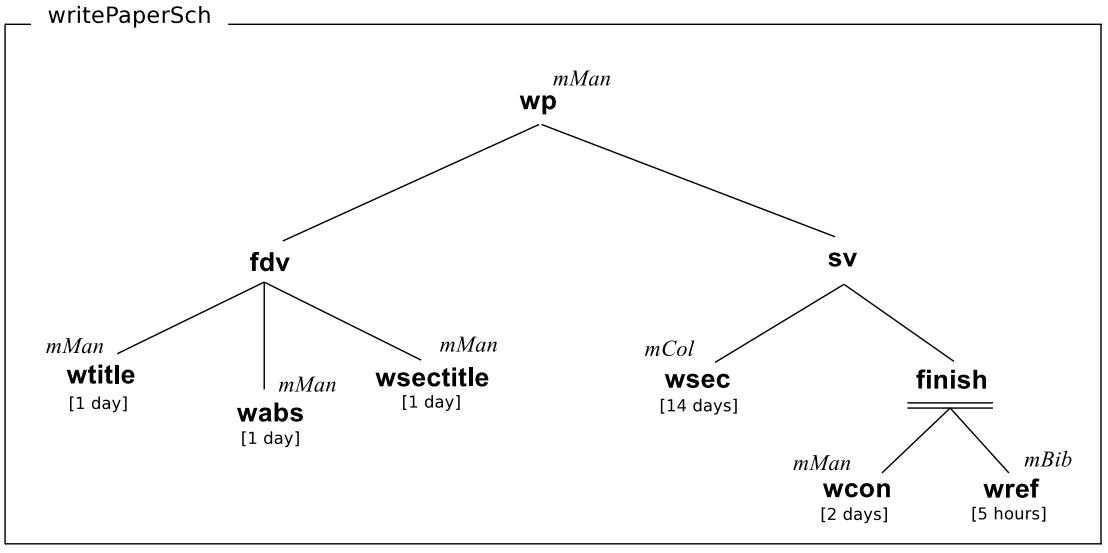
$$\frac{os \in OS \qquad os = \langle o, \textbf{active} \rangle \qquad F \not\models o_r}{\langle F, N, \top, OS, t \rangle \longrightarrow \langle F, N, \top, (OS \setminus \{os\}) \cup \{\langle o, \textbf{inactive} \rangle\}, t \rangle} \quad (\textbf{Inactive})$$

NOPL

Normative Organisation Programming Language

- NOPL is a particular class of NPL: facts, rules and norms are specific to a OML (eg. $\mathcal{M}$oise NOML):





id	condition	role	type	mission	TTF
n2		writer	obl	*mCol*	1 day
n3		writer	obl	*mBib*	1 day
n4	unfulfilled(n2)	editor	obl	*ms*	3 hours
n5	fulfilled(n3)	editor	obl	*mr*	3 hours
n6	#gnc	editor	obl	*ms*	3 hours
n7	#rc	editor	obl	*ms*	30 minutes
n6	#mc	editor	obl	*ms*	1 hour
...	...	...	...	...	...

#gnc = goal_non_compliance
#rc = role_compatibility
#mc = mission_cardinality

OS in $\mathcal{M}$oise OML to NOPL translation

Example (role cardinality norm – regimentation)

```
group_role(writer,1,5).

norm ncar: group_role(R,_,M) &
           rplayers(R,G,V) & V > M
  -> fail(role_cardinality(R,G,V,M)).
```

Example (role cardinality norm – agent decision)

```
norm ncar: group_role(R,_,M) &
           rplayers(R,G,V) & V > M &
           plays(E,editor,G)
  -> obligation(E,ncar,committed(E,ms,_),
                `now + 1 hour`).
```

$\mathcal{M}$oise Social scheme — NOPL — Facts

- Static facts:
  - scheme_mission(m,max,min): cardinality of mission m;
  - goal(m,g,*pre-cond*,‘*ttf*‘): mission, preconditions and TTF for goal g.
- Dynamic facts (provided at run-time by the organisational artifact in charge of the management of the social scheme instance):
  - plays(a,ρ,gr): agent a plays the role ρ in the group instance identified by gr.
  - responsible(gr,s): the group instance gr is responsible for the missions of the scheme instance s.
  - committed(a,m,s): the agent a is committed to mission m in scheme s.
  - achieved(s,g,a): the goal g has been achieved in the scheme s by the agent a.

*M*oise Social scheme — NOPL — Rules

- Example of rules used to infer the state of the scheme:
  - Number of players of mission *M* in scheme *S*:

```
mplayers(M,S,V) :-
    .count(committed(_,M,S),V).
```

  - Wellformedness property of scheme *S*:

```
well_formed(S) :-
    mplayers(mBib,S,V1) & V1 >= 1 & V1 <= 1 &
    mplayers(mCol,S,V2) & V2 >= 1 & V2 <= 5 &
    mplayers(mMan,S,V3) & V3 >= 1 & V3 <= 1.
```

  - Readyness of goal *G* in scheme *S* (i.e. goal is ready to be achieved):

```
ready(S,G) :-
    goal(_, G, PCG, _) & all_achieved(S,PCG).
all_achieved(_,[]).
all_achieved(S,[G|T]) :-
    achieved(S,G,_) & all_achieved(S,T).
```

Moise Social scheme — NOPL — Norms

Norms for goals

- Agents are obliged to achieve their ready goals

```
norm ngoa:
 committed(A,M,S) & goal(M,G,_,D) &
 well_formed(S) & ready(S,G)
-> obligation(A,ngoa,achieved(S,G,A),‘now‘ + D).
```

Norms for properties

- Mission cardinality as regimentation

```
norm mission_cardinality:
 scheme_mission(M,_,MMax) & mplayers(M,S,MP) &  MP > MMax
-> fail(mission_cardinality).
```

- Mission cardinality as obligation

```
norm mission_cardinality:
 scheme_mission(M,_,MMax) & mplayers(M,S,MP) &  MP > MMax
 responsible(Gr,S) & plays(A,editor,Gr)
-> obligation(A,mission_cardinality,
              committed(A,ms,_), ‘now‘+‘1 hour‘).
```

$\mathcal{M}$oise — NOPL — Norms

- ⇝ Definition of similar kinds of facts, rules and norms for the groups, roles in the structural specification
- Domain norms:
  - Each norm in the normative specification of the OS has a corresponding norm in the NOP
  - Since in the OS, obligations refer to roles and missions, norms in corresponding NOP identify the agents playing the role in groups responsible for the scheme and take into account the property conditions.

```
norm n2:
  plays(A,writer,Gr) & responsible(Gr,S) &
  mplayers(mCol,S,V) & V < 5
-> obligation(A,n2,committed(A,mCol,S),`now`+`1 day`).
```

Partial Synthesis

- NPL, based on obligation and regimentation, formalised using operational semantics, specialised into NOPL
- Automatic translation of OS written in $\mathcal{M}$oise OML into several NOPs
- Implementation in ORA4MAS, artifact-based OMI: Organisational Artifacts act as interpreters of NOPs.
  - **NOPL** (80%): dynamic of obligations (several aspects of the $\mathcal{M}$oise OS have been translated to norms)
  - **CArtAgO** (10%): interface for agents
  - **Java** (10%): dynamic of organisational state

Outline

Writing paper example

Organisation Specification

```
<organisational-specification
  <structural-specification>
     <role-definitions>
        <role id="author" />
        <role id="writer"> <extends role="author"/> </role>
        <role id="editor"> <extends role="author"/> </role>
     </role-definitions>

     <group-specification id="wpgroup">
        <roles>
           <role id="writer" min="1" max="5" />
           <role id="editor" min="1" max="1" />
        </roles>
        ...
```

Writing paper sample I

Execution

jaime	action: jmoise.create_group(wpgroup)
all	perception: group(wpgroup,g1)[owner(jaime)]
jaime	action: jmoise.adopt_role(editor,g1)
olivier	action: jmoise.adopt_role(writer,g1)
jomi	action: jmoise.adopt_role(writer,g1)
all	perception: play(jaime,editor,g1) play(olivier,writer,g1) play(jomi,writer,g1)

Writing paper sample II

Execution

jaime	action: jmoise.create_scheme(writePaperSch, [g1])
all	perception: scheme(writePaperSch,s1)[owner(jaime)]
all	perception: scheme_group(s1,g1)
jaime	perception: permission(s1,mManager)[role(editor),group(wpgroup)]
jaime	action: jmoise.commit_mission(mManager,s1)
olivier	perception: obligation(s1,mColaborator)[role(writer),group(wpgroup), obligation(s1,mBib)[role(writer),group(wpgroup)
olivier	action: jmoise.commit_mission(mColaborator,s1)
olivier	action: jmoise.commit_mission(mBib,s1)
jomi	perception: obligation(s1,mColaborator)[role(writer),group(wpgroup), obligation(s1,mBib)[role(writer),group(wpgroup)]
jomi	action: jmoise.commit_mission(mColaborator,s1)

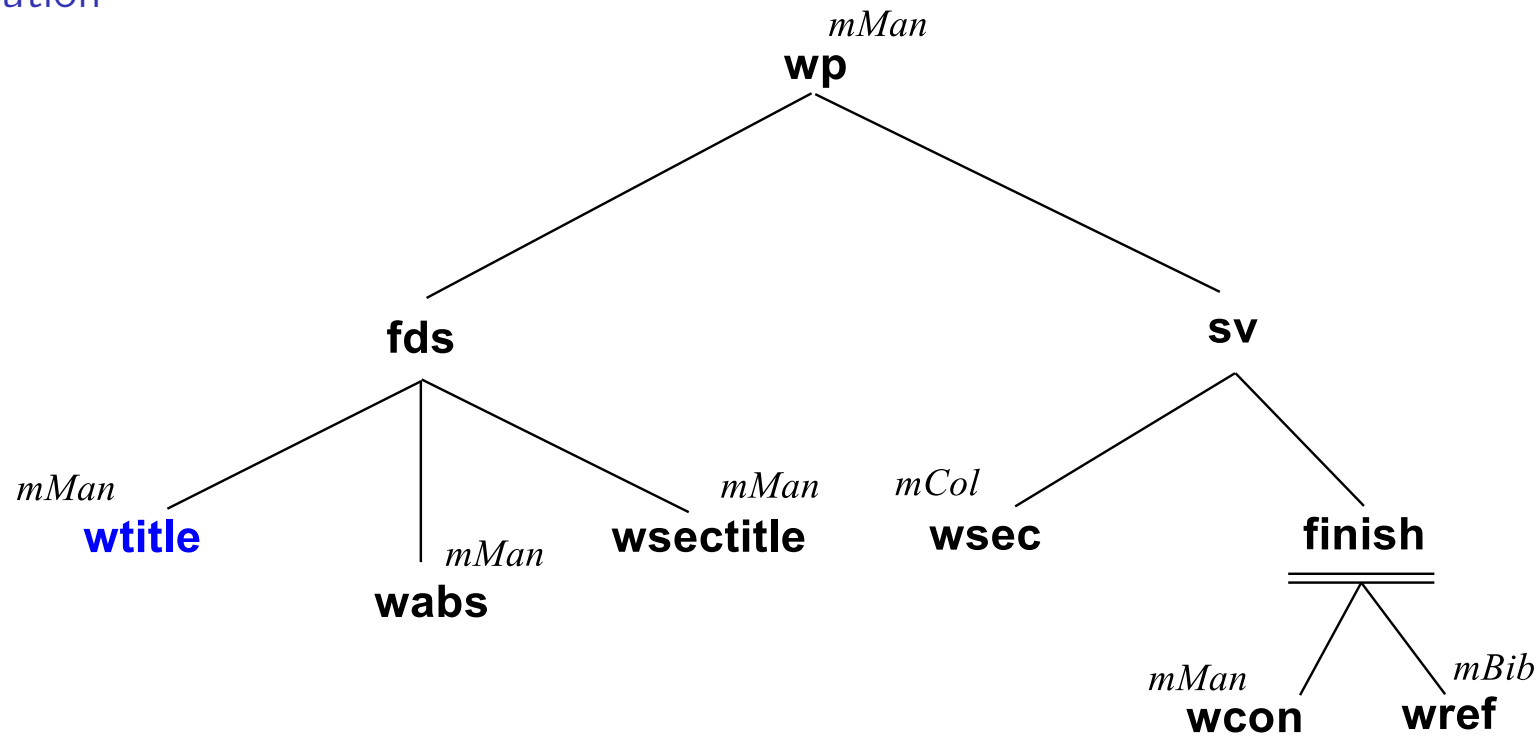
Writing paper sample III

Execution

all perception:
commitment(jaime,mManager,s1)
commitment(olivier,mColaborator,s1)
commitment(olivier,mBib,s1)
commitment(jomi,mColaborator,s1)

Writing paper sample IV

Execution

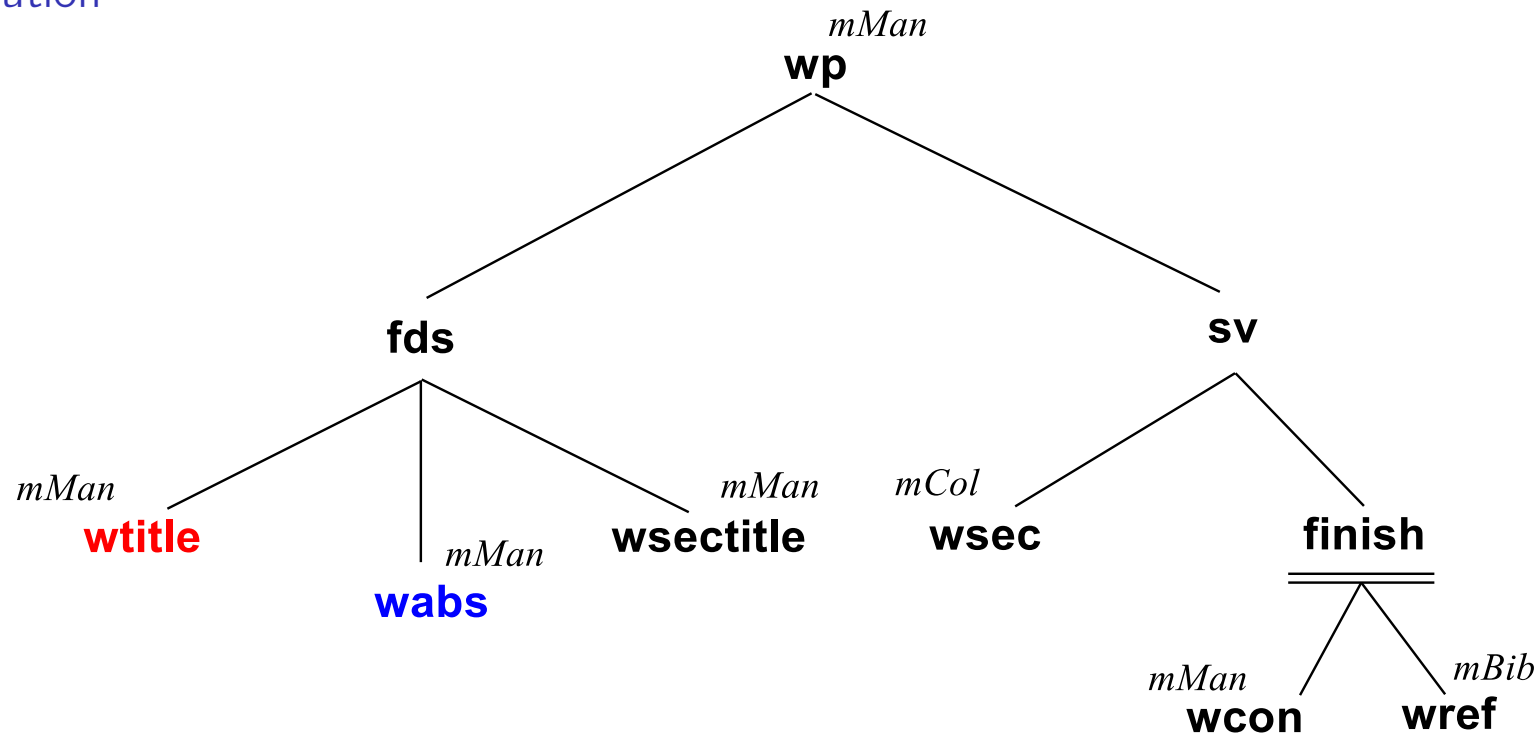


all perception: goal_state(s1,*,unsatisfied)

jaime (only wtitle is possible, Jaime should work)
event: **+!wtitle**
action: jmoise.set_goal_state(s1,wtitle,satisfied)

Writing paper sample V

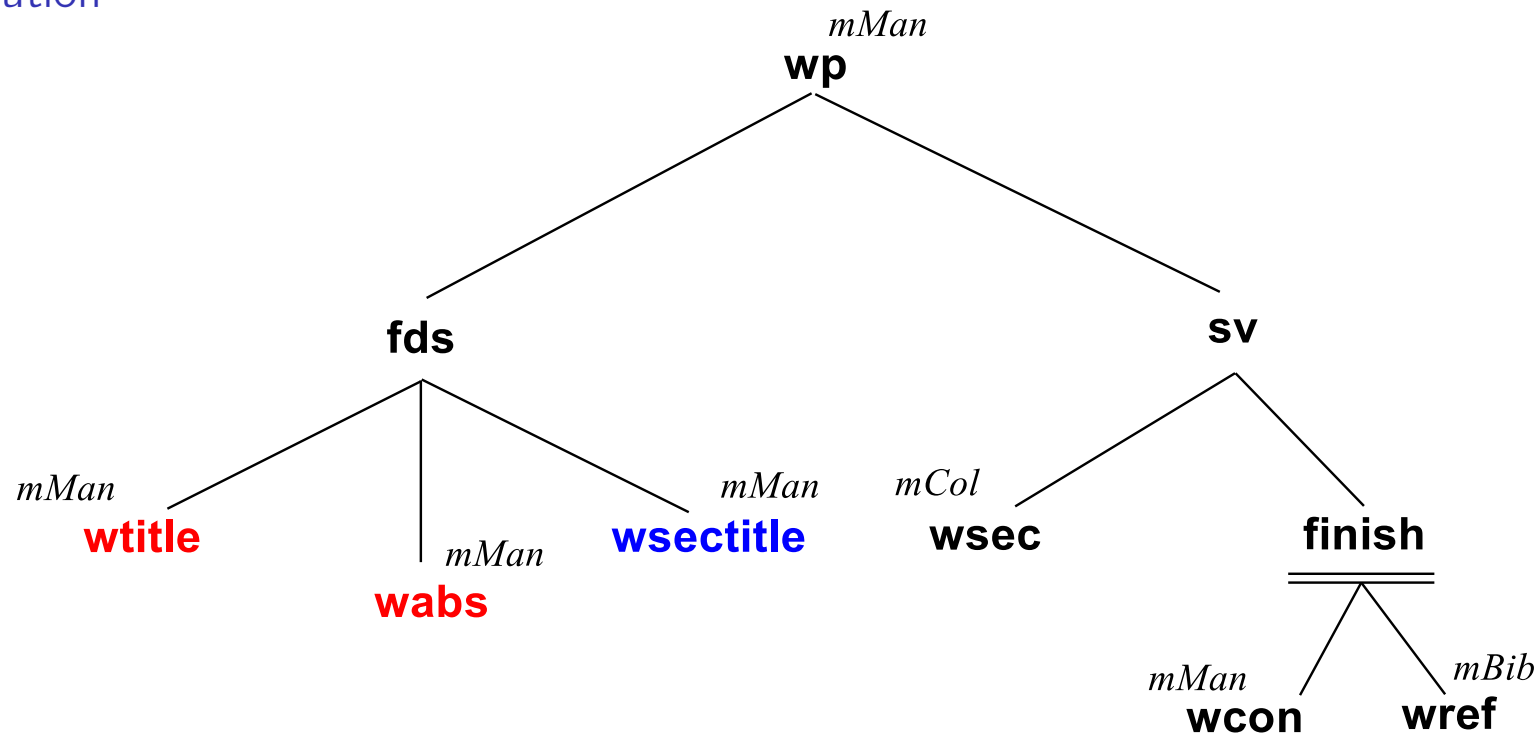
Execution



jaime event: +!wabs
action: jmoise.set_goal_state(s1,wabs,satisfied)

Writing paper sample VI

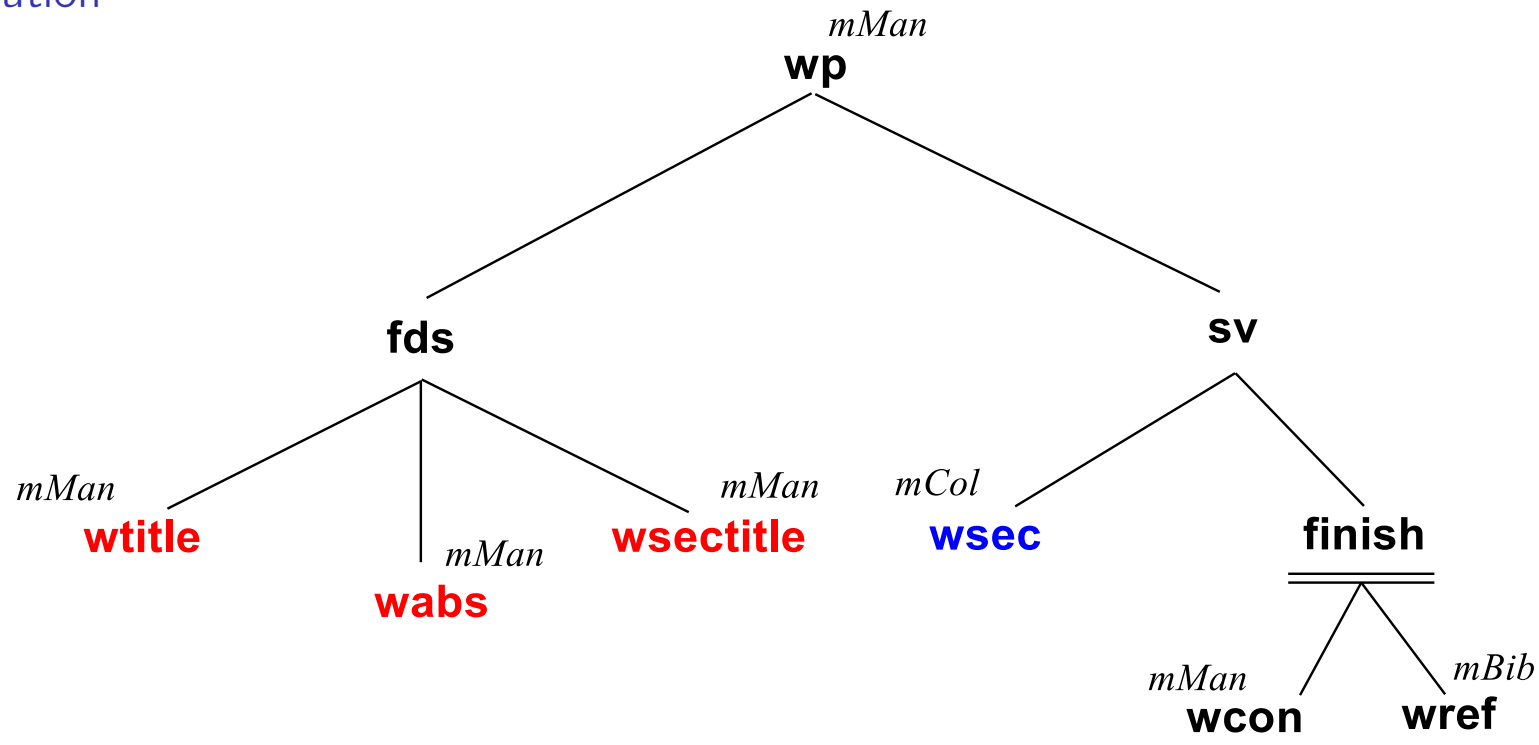
Execution



jaime event: **+!wsectitles**
action: jmoise.set_goal_state(s1,wsectitles,satisfied)

Writing paper sample VII

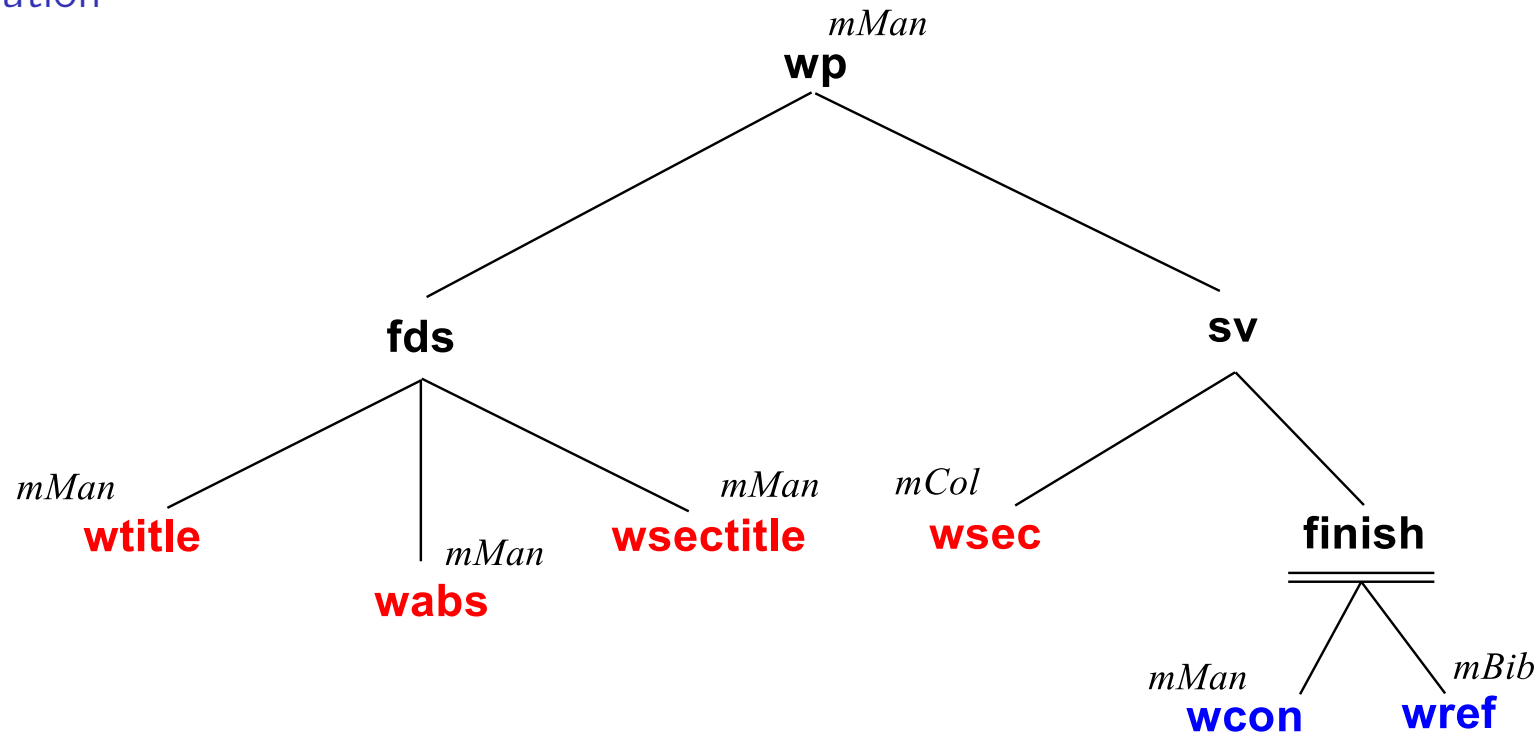
Execution



olivier, jomi event: +!wsecs
action: jmoise.set_goal_state(s1,wsecs,satisfied)

Writing paper sample VIII

Execution



jaime event: +!wcon; ...

olivier event: +!wref; ...

Writing paper sample IX

Execution

all action: jmoise.remove_mission(s1)

jaime action: jmoise.jmoise.remove_scheme(s1)

Useful tools — Mind inspector

play(gaucho1,herder,gr_herding_grp_13)[source(orgManager)].
play(gaucho4,herdboy,gr_herding_grp_13)[source(orgManager)].
play(gaucho5,herdboy,gr_herding_grp_13)[source(orgManager)].
pos(*45*,*44*,*128*)[source(percept)].
scheme(herd_sch,sch_herd_sch_18)[owner(gaucho3),source(orgManager)].
scheme(herd_sch,sch_herd_sch_12)[owner(gaucho1),source(orgManager)].
scheme_group(sch_herd_sch_12,gr_herding_grp_13)[source(orgManager)].
steps(*700*)[source(self)].
target(*6*,*44*)[source(gaucho1)].

- Rules

```
random_pos(X,Y) :-
    (pos(AgX,AgY,_418) & (jia.random(RX,40) & ((RX > 5) & ((X = ((RX-20)+AgX)) & ((X >
```

- Intentions

Sel	Id	Pen	Intended Means Stack (hide details)
	16927	suspended-self	+!be_in_formation[scheme(sch_herd_sch_12),mission(help
			+!be_in_formation[scheme(Sch),mission(Mission)]

Outline

Wrap-up

- Model to specify global orchestration

$\rightsquigarrow$ team strategy defined at a high level

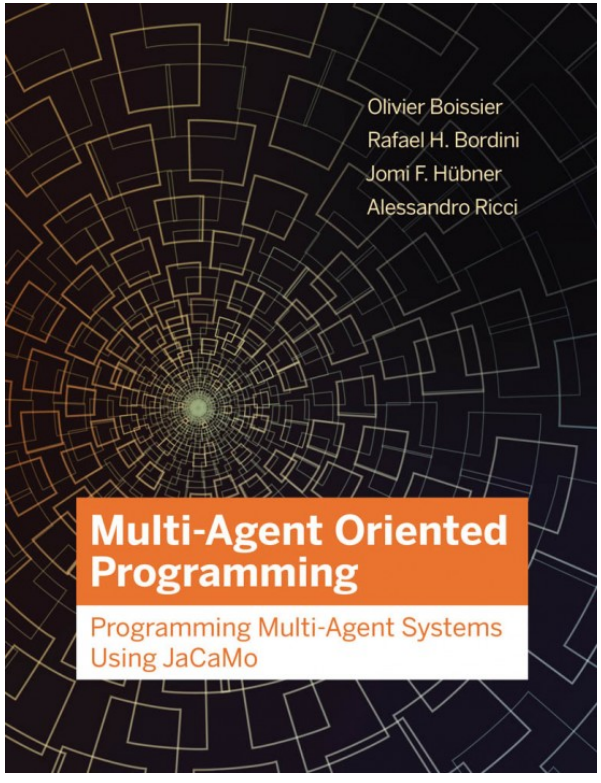
- Ensures that the agents follow some of the constraints specified for the organisation
- Helps the agents to work together
- The organisation is **interpreted at runtime**, it is not hardwired in the agents code
- The agents 'handle' the organisation (i.e. their artifacts)
- It is suitable for open systems as no specific agent architecture is required
- Organization can easily be changed by the developers or by the agents themselves

- All available as open source at

`http://moise.souceforge.net`

Further Resources

- `http://jacamo.sourceforge.net`
- O. Boissier, R.H. Bordini, J.F. Hübner, and A. Ricci
  Multi-Agent Oriented Programming: Programming Multi-Agent Systems Using JaCaMo
  MIT Press, 2020.



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