The 4Quadrant meta-model
Towards an integrative approach for representing MAS

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From societies to MAS

History
Societies: agents interacting through an environment

Use "real life" collective systems as metaphors for building computer systems

Multi-agent systems

Step 1: end of 80’s

Distributed Artificial Intelligence
Use MAS as tools for modeling societies

Step 1: beginning of 90's

Modeling and simulation

Design simulators

The most common meta-model for MAS

Environment

Agent

State of the agent
- location, variables, parameters
- Operations
  - actions in the environment
  - sendMessage(..)
  - do() //what to do next...

Actions are performed by agents that modify the state of the environment
Building a MAS is done by subclassing already defined classes.

**Advantages**
- Meta-model is simple: easy to understand
- Easy to start a new simple model

**Drawbacks**
- Confusion between variables of the "mind" (reasoning/representation) and variables of the "body" (location, life points, age, weight,...)
- No organizational constructs: how to introduce groups and roles
- No cultural issues: how to deal with shared knowledge, global representations, cultural values, etc..
- How to deal with multiple environments:
  - Fishing places, fish market, acquaintance network

**The meta-model is so poor that all new constructs have to be done by the modeler**
- Ad-hoc techniques
- Difficult to explain to others
- Problems with publication of results (Rouchier)
- Difficult to compare different approaches
- Lots of possible bias
A step forward in multi-agent systems meta-models

- Most multi-agent systems are still based on concepts inherited from the end of 80's
  - Agents, environment, message passing,
- Most agent architectures have been introduced in the 90's
  - BDI (Belief, Desire, Intention) - Goal driven agents
  - Subsumption architectures, task competition, neural networks
  - Classifier systems, Q-learning agents, ...
- Organizational constructs have been introduced in the end of 90's
  - Aalaadin/AGR (Ferber & Gutknecht 98)
- Recently works has been done on the nature of environments ...
  - Problem of simultaneous actions (Ferber & Muller 96)(Michel 2004)
  - Weyna et al. (2003)
- And on norms and institutions
  - Norms as deontic logic (Dignum 2002)(Castlefranchi, Conte 2001)

We are now on the point where it is possible to combine all these constructs in an "integrative" meta-model for designing MAS

Axis for analysis

A multiagent system (as a social system) may be analyzed along two axis

- Axis: individual/collective
- Axis: exterior (behavioral) / interior (architecture, internal states)

What does it do

How does it think
### 4Quadrant approach

<table>
<thead>
<tr>
<th>Individual</th>
<th>Collective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interior-Individual (I-I)</strong></td>
<td><strong>Exterior-Individual (E-I)</strong></td>
</tr>
<tr>
<td>I (je) subjectivity</td>
<td>it, this Objectivity</td>
</tr>
<tr>
<td>&lt;mental states, emotions, beliefs desires, intentions, cognition&gt;</td>
<td>&lt;agent behavior, object, process, physical entities&gt;</td>
</tr>
<tr>
<td>Interiority</td>
<td>Observables, exteriority</td>
</tr>
<tr>
<td><strong>Interior-Collective (I-C)</strong></td>
<td><strong>Exterior-Collective (E-C)</strong></td>
</tr>
<tr>
<td>We intersubjectivity</td>
<td>Them, all this Interobjectivity</td>
</tr>
<tr>
<td>&lt;shared / collective knowledge social codes, ontologies, informal norms and conventions&gt;</td>
<td>&lt;reified social facts and structures, Interference between local dynamics, organizations&gt;</td>
</tr>
<tr>
<td>Noosphere</td>
<td>Sociosphere (social structures)</td>
</tr>
</tbody>
</table>

### Example: Warbot

**Objective:**
- Describe the mind of a set of robots in order to destroy the bases of the enemy army

**Bodies:**
- Explorer, Rocketlauncher, Base

**Capabilities**
- Move, turn(angle)
- Shoot // for Rocketlaunchers
- Get(food), Deposit(food)
- TransformFoodIntoAgents // for Bases

**Objective:**
- Importance of cooperation between agents!!
Interior/exterior in Warbot

Simulation, execution

Exterior point of view, description, observation,

Interior point of view

Observer/external

Mental states, What’s inside the mind of agents

Making hypothesis

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Example

Decision and act

Bodies

Social bodies

Different Types of mind (BDI, subsumption, Neural, etc.)

Cultural groups Ex: defendersA

???

Cultural events: Ex: TeamA has won

E-C

Arena

TeamA

Events: Ex: base destroyed

Rules: ex. it is forbidden to send messages to agents of the other team

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How to design MAS using a 4Quadrant approach

- **Separation between ‘mind’ and ‘body’**
  - An agent is composed of an interior aspects, its mind, and an exterior aspect, its bodies.
  - An agent has multiple bodies: physical body and many social bodies, its "roles".

- **Influence/reaction**
  - An agent cannot directly change the state of the world. It can only “influence” the dynamic of the world.
  - Bodies are part of the physical and social worlds.
  - Interactions are done through the environment.
  - The dynamics of the exterior side (physical and social world) results from the combination of all the influences.

- **Social bodies and spaces**
  - Consider physical spaces and social spaces (groups) as different kind of the same “abstract space”.
  - An agent act in a group through a social body.

- **Distinction between mere facts and their institutionalized interpretations** (J. Searle)

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Differenciating between Mind and Body

**Separation mind / body** [Magnin, 96], [Michel, 04]

- **Mind:** reasoning and decision making process
  - Action selection
  - Part of the interior of agents
  - Maybe cognitive, reactive, ...

- **Body:** physical part
  - Physical state
  - Capabilities
  - Can act on the environment

Belongs to the environment and follows « universe » laws
Exterior: environment

Beliefs
Desirs
Intentions

State
Age: 40
Weight: 70 kg
Name: Arthur

Capabilities
• GoForward
• Turn(angle)
• Perceive(distance, angle)
• Kick(ball)

Physical body

Physical space

Other physical entities (objects, pheromones, plants, etc.)

Note: a body is an entity

Mind, bodies, spaces

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Relation between spaces

Space relation: a relation R which specify how an entity of space A is related to an entity of B.

Environnement

Every interaction takes place in the environment, through traces, (entities, objects situated in the environment)
Influence / reaction model

- A model of action which allows for simultaneous actions
  - Ex: pushing something with two agents, mating
  - [Ferber & Müller, 96] [Weyns & Holvoet 03] [Michel, 04] [Helleboogh et al 07]

\[ \gamma = \gamma_a \oplus \gamma_b \]

Influences

World state \( \sigma \)

Reaction

- An agent cannot act, it produces influences that may change the world dynamic through its body
- The environment collects the set of influences and produce its own reaction (dynamic state change)

Influence reaction and mind-body model

Local evolution

\( \delta_a \)

\( \delta_b \)

Interference laws

Reaction laws

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The whole dynamics of the exterior

Produce influences and apply reaction laws

Evolution of the world and all its entities

Resolve conflicts

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Organizations

- Structures: groups
- Functions and status associated to agents: roles
- Constitution of cultural entities: institutions
- Regulation of behaviors: norms

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 Organizations #1

- Simplified meta-model of AGR (Agent/Group/Role) [Ferber & Gutknecht 98]
- A role is used as a type which describes the expected behavior and function of an agent
- A role offers a “social body” by which an agent may act in a group

An example in AGR

- Program committee Group
- Evaluation Groups
- Submission Group
- Submission receiver
- Program chair
- PC member
- Reviewer
- Reviewing manager
- Author
Groups

- Groups as embedded social structures
  - Located in the C-E quadrant
- Groups as cultural entities
  - Located in the C-I quadrant

Institutions

- (Searle) Institutional facts exist only by the collective belief in their existence
  - They need language and a shared knowledge (ontologies, rules, etc.) to live
  - Ex: a 5 € bill – its value exists only because everybody (in Europe) believes in its value.
  - Two parts: a physical aspect (a piece of paper), a cultural aspect (its value for buying something)
Culture norms

- Ontologies
  - Descriptions of things: types of entities and their relationship

- Institutional entities / facts
  - "note president of xxx, parent (as responsible for kids"

- Constitutive laws (creation of institutional facts and entities)
  - A person is constituted "president" if he(she) has been 'elected'. Where 'election' is a process which is formally defined (formal rule)
  - A goal is given to a team when the ball has crossed over a specific line (formal rule)
  - If you wear a specific hat, then you may be considered as a member of the group "xxx" (informal rule)
  - The leader of the band is the person that no one dares to fight with or the one who wins in a fight (informal)
  - You are the parent of a child if you are an adult an you recognize him/her (genitor, adoption)

- Regulative laws (laws that are related to institutional facts and entities)
  - It is forbidden for a non authorized person to enter this room
  - It is forbidden for bidders to communicate before bidding
  - As a parent you have to take care of your children.

Two realms

- Brute spaces
  - Exterior spaces
- Institutional spaces

Institutional laws

Regulation laws

Institution: Set of constitutive an regulative laws
Institutional laws

- **Formal institutional laws (and groups) are described as physical inscription in the exterior domain**
  - Law codes, regulation documents, contracts, etc...
  - They may be perceived by agents which may learn them and be aware of them
- **Informal institutional laws (and groups) do not have physical inscription. They have been produced through an emergent process**
  - Ex: Schelling model of social aggregation

Two sides of a role

- **A role has two aspects**
  - Expected behavior (status-function in Searle terminology)
  - A set of capabilities to perform some acts in a social group

![Diagram of a role with manager, goal, expected behavior, obligation, permissions, interdictions, and send orders, use devices]
Social and physical spaces

**Beliefs**
- Pseudo: kingarthur
- Status: Online
- InGroupSince: 07/09/2006
- Authorisation: full access
- Email adress: arthur@truc.com

**Desirs**
- Mind
  - influence
  - percept

**Intentions**
- Social environment (group)
- Other social entities (documents, messages, certificate, etc.)

**Capabilities**
- SendMessage(m)
- Turn(angle)
- Perceive(distance,angle)
- Kick(ball)

- Social spaces when they may be seen from the exterior
  - Discussion forum
  - Multi-user online games
  - Laboratory
  - Enterprise

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Back to the 4Quadrants

**Different Types of mind**
- (BDI, subsumption, Neural, etc.)

**Cultural groups**
- Ex: defendersA

**Social environments**
- Arena
  - Events: Ex: base destroyed

**Decision and act**
- E-C
  - Rules: ex. it is forbidden to send messages to agents of the other team

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How to relate culture and mind

**Holism**: explain how minds are related to culture.
How a mind “has access to the cultural quadrant

**Individualism**: explain how to reduce the cultural quadrants to mind items

- Cultural items are internalized as “beliefs” in minds
- Internalization is performed through adaptation and acquisition
- Adaptation of behaviors in groups (learning and growth process)
  - Imitation, (“doing like someone else”)
  - Perception and generalization of events ("learning the cultural laws by looking at others")
  - Being told ("it is forbidden to do xxx", "you have to do yyy")
  - Test and rewards - penalties ("yes it’s good, no it’s bad")
- Acquiring, by perception, formal institutional rules
  - Ex: learning the rules of a game before playing

Towards an integrative meta-model

- Proposed a general framework to take into account various “social” and “physical” constructs in order to be “runnable” in a computer
- Does provide for a general framework of what should be considered when designing models
  - More “interior-individual”, more “exterior”, more “interior-collective”
- Does not impose an epistemological point of view
  - Individualism vs Holism
- Still lots of work to do on the “cultural quadrant” to get a simple and practical view of it