

# Multi-Agent Oriented Programming

## – Introduction –

O. Boissier

Univ. Lyon, IMT Mines Saint-Etienne, LaHC UMR CNRS 5516, France

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Multi-Agent Oriented Programming

## **Introduction to Multi-Agent Systems**

# Outline

Open & Decentralized AI Systems

Definitions

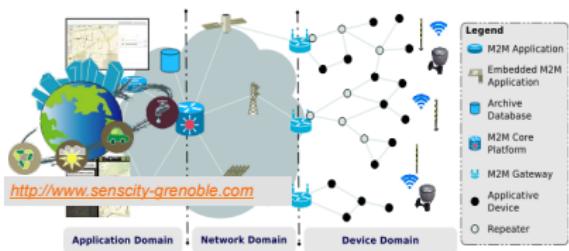
Positioning

Global View

Multi-Agent Programming

# Open & Decentralized AI Systems

## Agile governance of M2M infrastructure [Persson et al., 2012]



## Supporting human organizational awareness [de Brito et al., 2016]



## Social Web of things [Ciortea et al., 2017]



- ▶ Strong inter-connection of physical, digital and social worlds to build long-lived socio-technical and cognitive systems
- ▶ Openness, distribution, no centralization, intensive use of knowledge

# Requirements

## Open & Decentralized AI Systems

- ▶ Openness, non centralization & distribution
- ▶ Situated into dynamic and complex environments
- ▶ Representation and reasoning on various types of knowledge
  - ▶ e.g. expert knowledge, policy/norms, legal knowledge, ...
- ▶ Flexible micro-macro loops combining local and global computations
- ▶ Modularity, extensibility, reusability, ...

How to **engineer** such applications?

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# Definitions

An organisation of autonomous agents interacting with each other within a shared environment

- ▶ **Agents:** autonomous entities able to react to events while pro-actively defining goals and directing actions to achieve them
  - ~ (soft/hard)ware, (coarse/small)-grain, (hetero/homo)geneous,
- ▶ **Environment:** shared medium providing the surrounding conditions for agents to exist and act (e.g. comm. and coord. infra., topology of spatial domain, support of an action model)
  - ~ virtual/physical, passive/active, deterministic or not, ...
- ▶ **Interaction:** motor of dynamic and interoperability in the MAS
  - ~ direct communicative / indirect actions through the environment
- ▶ **Organisation:** abstractions to declare and make accessible to agents their expected collective structure and functioning in a shared environment (e.g. coordination and regulation activities)
  - ~ pre-defined/emergent, static/adaptive, open/closed, ...

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# Definitions

An organisation of autonomous agents interacting with each other within a shared environment

MAS **is more than** a simple set of agents

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# Principles

## Definitions

### Multi-agent system principles

- ▶ **Distribution** of knowledge, resources, reasoning/decision capabilities
- ▶ **Decentralisation** of control, authority (loosely coupled agents)
- ▶ **Coordination & Regulation** models and mechanisms to install coordination & regulate the autonomous agents
- ▶ Flexible interlacement of **emergent**, **social order**, **normative** functioning

### Agent principles

- ▶ **Situated, Reactive, Pro-Active, Social & Organization-aware** entities
- ▶ **Autonomy**: agents may exhibit activities that are not the one expected by the other agents in the system
- ▶ **Delegation**: agents may receive some control over their activities

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# Some History

## Positioning

- ▶ 1973: Distributed Artificial Intelligence (DAI)
  - ▶ Hearsay II (1973): blackboard architecture for speech recognition
  - ▶ Actor Languages (1973): messages as control structures
  - ▶ Beings (1975), Society of Minds (1978)
- ▶ 1980: Agents in the Artificial Intelligence (AI) area
  - ▶ From AI to DAI ↵ to Decentralized AI (DzAI) ↵ to Multi-Agent Systems (MAS)
- ▶ 1990: Agents invade other domains
  - ▶ Personal Assistants, Avatars, Mobile Agents, Reactive Agents, ...
- ▶ 1995: Agents spread in other domains, Application domains are enlarging
  - ▶ Artificial Life, Economic Agents, ...
  - ▶ **1st ICMAS Conference in 1996**
- ▶ 2000 -:
  - ▶ Web, Ambient Computing, Internet of Things, ...
  - ▶ **Since 2002, AAMAS Conferences**

# Inter-disciplinary Domain

## Positioning

- ▶ Direct Links with:
  - ▶ Programming, Object Oriented Programming ...
  - ▶ Artificial Intelligence
  - ▶ Distributed Systems, Parallelism, Concurrent Programming
- ▶ But also:
  - ▶ Complex System (physics, ..., ethology, ecology, ...)
  - ▶ Artificial Life, Neural networks, ...,
  - ▶ Social Psychology, Sociology, Activity Theory, Economy, ...

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# Global picture (from AAMAS 2018, 2019 Topics of Interests)

## Global View

- ▶ **Agent Theories and Models**: Belief-Desire-Intention theories and models, Cognitive models, Models of emotions, ...
- ▶ **Communication and Argumentation**: Commitments, Communication languages and protocols, Speech act theory, Argumentation-based dialogue and protocols, ...
- ▶ **Agent Cooperation**: Biologically-inspired approaches and methods, Collective intelligence, Distributed problem solving, Teamwork, team formation, teamwork analysis, Coalition formation, ...
- ▶ **Knowledge Representation and Reasoning**: Ontologies for agents, Reasoning in agent-based systems, Single and multi-agent planning and scheduling, Reasoning about action, plans and change, Reasoning about knowledge, beliefs, goals and norms, ...
- ▶ **Agent Societies and Societal issues**: Organizations and institutions, Social networks, Socio-technical systems, Normative systems, Values in MAS (privacy, safety, security, transparency, ...), Coordination and control models for multiagent systems, Trust and reputation, Policy, regulation and legislation, Self-organization
- ▶ ...

~ large set of concepts and approaches have been produced in the



# Action Domains

- ▶ Open and Decentralized AI Systems
  - ▶ Integration of intelligent applications, with humans, organizations and the physical world
  - ▶ Making them interoperate, interact, cooperate in a flexible and consistent manner with each other
- ▶ Problem solving
  - ▶ Modeling and solving problems by cooperation between local solvers
  - ▶ Installing top-down and/or bottom-up (emergent) solving process
- ▶ Multi-agent based simulation
  - ▶ Modeling and reproducing complex phenomena of interacting entities in the real world in order to understand or to explain their behavior

# Technologies

- ▶ Agent Architectures and Theories
- ▶ Coalition formation mechanisms
- ▶ Multi-Agent Planning
- ▶ Agent Communication Languages, Interaction Protocols
- ▶ Auction mechanisms
- ▶ Negotiation strategies and mechanisms, Argumentation
- ▶ Electronic Institutions, Organisations, Norms
- ▶ Reputation, Trust
- ▶ Mono & multi-agent Learning
- ▶ Self-organisation, emergence, ...

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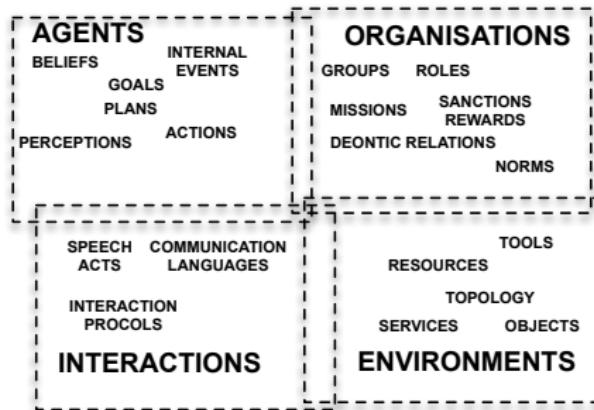
# Current Landscape of Multi-Agent Programming

- ▶ Many Agent Oriented Software Engineering (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!

# Multi-agent programming: concepts

## Multi-Agent Programming

VOWELS' perspective [Demazeau, 1995]:



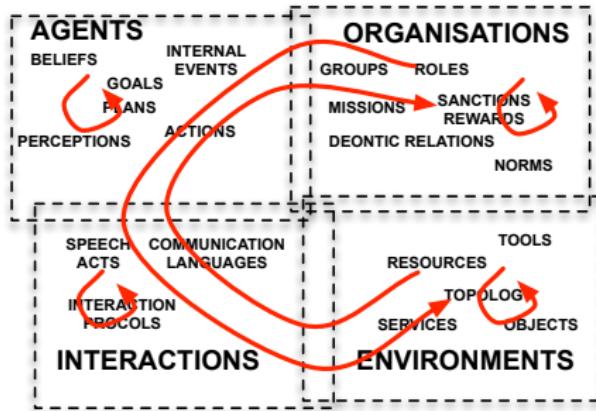
- ▶ **O:** abstractions for structuring and ruling the behaviours and interactions of agents in shared environment
- ▶ **A:** abstractions for the definition of the decision and reasoning architectures of autonomous entities
- ▶ **I:** abstractions for defining interactions among entities
- ▶ **E:** abstractions for defining and structuring resource/processing entities shared among the agents

~ A rich set of abstractions to address applications complexity!

**However** no consensus on the concepts, on their grouping, on the boundaries

# Multi-agent programming: dynamics

## Multi-Agent Programming



- ▶ Various life/control cycles among the concepts exist
- ▶ Coordination of the system may be programmed using one or several families of concepts [Boissier, 2003]
- ~~> Interlacement of the various dynamics into bottom-up / top-down global cycles

~~> A rich palette of dynamics to address applications complexity!!

# Multi-agent programming: approaches

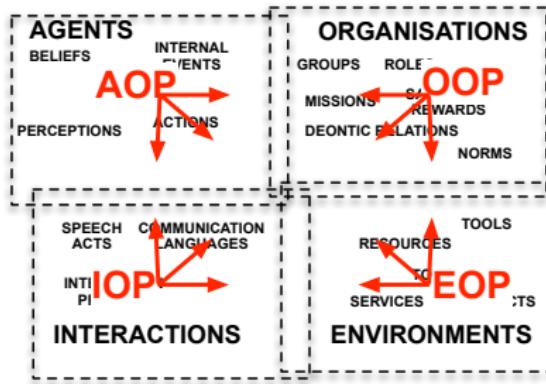
## Multi-Agent Programming

### Agent Oriented Programming

[Shoham, 1993]

### Interaction Oriented Programming

[Huhns, 2001]



### Organisation Oriented Programming

[Pynadath et al., 1999]

### Environment Oriented Programming

[Ricci et al., 2010]

# Multi-agent programming: platforms

## Multi-Agent Programming

- ▶ Platforms not covering the whole set of abstractions:
  - ▶ JADE [Bellifemine et al., 1999, Bellifemine et al., 2000], Java-based Intelligent Agent Componentware [Lützenberger et al., 2013].
  - ▶ JACK [Winikoff, 2005, Howden et al., 2001] Jason [Bordini et al., 2007] 2APL [Dastani et al., 2003], GOAL [Hindriks, 2009]
  - ▶ Jadex [Pokahr et al., 2005, Pokahr et al., 2014]
- ▶ Integrated programming approaches:
  - ▶ Volcano platform [Ricordel and Demazeau, 2002], MASK platform [Occello et al., 2004], MASQ [Stratulat et al., 2009], Situated E-Institutions [Campos et al., 2009], MANET [Tampitsikas et al., 2011], ANTE [Cardoso et al., 2016], Electronic Institutions - EI/EIDE [Noriega and de Jonge, 2016], InstAL [Padget et al., 2016], ROMAS/MAGENTIX2 [García et al., 2016], RTEC [Artikis et al., 2016], SARL [Rodriguez et al., 2014]
  - ▶ BRAHMS[Sierhuis et al., 2003]
  - ~ Socio-cognitive systems [Aldewereld et al., 2016]

**However** some families of concepts lose their control & visibility!

Difficulty to integrate and keep alive the families of concepts!



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