# Multi-Agent Systems

Lecture 1

**University "Politehnica" of Bucarest**
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Adina Magda Florea
adina@cs.pub.ro

**http://turing.cs.pub.ro/blia_2004**
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## Lecture outline

- Motivation for agents
- Definitions of agents → agent characteristics, taxonomy
- Agents and objects
- Multi-Agent Systems
- Agent's intelligence
- Areas of R&D in MAS
- Exemplary application domains

## Motivations for agents

- Large-scale, complex, distributed systems: understand, built, manage
- Open and heterogeneous systems - build components independently
- Distribution of resources
- Distribution of expertise
- Needs for personalization and customization
- Interoperability of pre-existing systems / integration of legacy systems

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## IDC (http://www.idc.com)

- IDC estimates that the global market for software agents grew from $7.2 millions in 1997 to $51.5 millions in 1999
- and that it will **reach $873.2 millions in 2004**,
- with a compound annual growth rate of 76.2% between 1999 and 2004.

## Questions: Examples of agents?

(are they all agents?)

- a thermostat with a sensor for detecting room temperature
- electronic calendar
- log-in into your computer; you are presented with a list of email messages sorted by date
- log-in into your computer; you are presented with a list of email messages sorted by order of importance
- air-traffic control system of country X fails - air-traffic controls in the neighboring countries deal with affected flights

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## Agent?

The term **agent** is used frequently nowadays in:

- Sociology, Biology, Cognitive Psychology, Social Psychology, and
- Computer Science ⊃ AI

- Why agents?
- What are they in Computer Science?
- Do they bring us anything new in modelling and constructing our applications?
- Much discussion of what (software) agents are and of how they differ from programs in general

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## What is an agent (in computer science)?

- There is no universally accepted definition of the term agent and there is a good deal of ongoing debate and controversy on this subject
- The situation is somehow comparable with the one encountered when defining artificial intelligence.
- *Why was it so difficult to define artificial intelligence (and we still doubt that we have succeeded in giving a proper definition) and*
- *Why is it so difficult to define agents and multi-agent systems, when some other concepts in computer science, such as object-oriented, distributed computing, etc., were not so resistant to be properly defined.*
- The concept of agent, as the one of artificial intelligence, steams from people, from the human society. Trying to emulate or simulate human specific concepts in computer programs is obviously extremely difficult and resist definition.

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- More than 30 years ago, computer scientists set themselves to create artificial intelligence programs to mimic human intelligent behaviour, so the goal was to create an artefact with the capacities of an intelligent person.
- Now we are facing the challenge **to emulate or simulate the way human act in their environment, interact with one another, cooperatively solve problems or act on behalf of others, solve more and more complex problems by distributing tasks or enhance their problem solving performances by competition.**

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- It appears that the agent paradigm is one necessarily endowed with intelligence.
- Are all computational agents intelligent?
- The answer may be as well yes as no.
- Not to enter a debate about what intelligence is
- **Agent** = more often defined by its characteristics - many of them may be considered as a manifestation of some aspect of intelligent behaviour.

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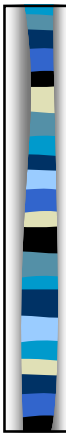

## Agent definitions

- "Most often, when people use the term 'agent' they refer to an entity that functions **continuously** and **autonomously** in an environment in which other processes take place and other agents exist." (Shoham, 1993)
- "An agent is an entity that **senses** its environment and **acts** upon it" (Russell, 1997)

- "Intelligent agents **continuously** perform three functions: **perception** of dynamic conditions in the environment; **action** to affect conditions in the environment; and **reasoning** to interpret perceptions, solve problems, draw inferences, and determine actions. (Hayes-Roth 1995)"
- "Intelligent agents are software entities that carry out some set of operations **on behalf of a user or another program**, with some degree of independence or **autonomy**, and in so doing, employ some knowledge or representation of the **user's goals or desires**." (the IBM Agent)

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- "**Agent** = a hardware or (more usually) a software-based computer system that enjoys the following properties:
- **autonomy** - agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state;

***Flexible autonomous action***

- **reactivity**: agents perceive their environment and respond in a timely fashion to changes that occur in it;
- **pro-activeness**: agents do not simply act in response to their environment, they are able to exhibit goal-directed behaviour by taking initiative."
- **social ability** - agents interact with other agents (and possibly humans) via some kind of agent-communication language;

(Wooldridge and Jennings, 1995)

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## Identified characteristics

**Two main streams of definitions**

- Define an agent in isolation
- Define an agent in the context of a society of agents ➔ **social dimension** ➔ **MAS**

**Two types of definitions**

- Does not necessary incorporate intelligence
- Must incorporate a kind of IA behaviour ➔ **intelligent agents**

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## Agents characteristics

- act on behalf of a user or a / another program
- autonomous
- sense the environment and acts upon it / reactivity
- purposeful action / pro-activity

*goal-directed behavior vs reactive behaviour?*

- function continuously / persistent software
- mobility ?

*intelligence?*

- **Goals, rationality**
- **Reasoning, decision making** ***cognitive***
- **Learning/adaptation**
- **Interaction with other agents - social dimension**

***Other basis for intelligence?***

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## Are these example of agents? If yes, are they intelligent?

- Thermostat ex.
- Electronic calendar
- Present a list of email messages sorted by date
- Present a list of email messages sorted by order of importance
- Air-traffic control system of country X fails - air-traffic controls in the neighboring countries deal with affected flights

- act on behalf of a user or a / another program
- autonomous
- sense the environment and acts upon it / reactivity
- purposeful action / pro-activity
- function continuously / persistent software
- **goals, rationality**
- **reasoning, decision making**
- **learning/adaptation**
- **social dimension**

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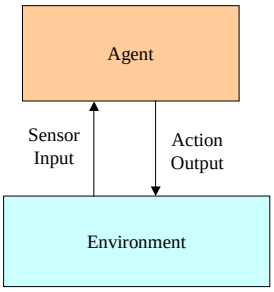
## Agent Environment




**Environment properties**

- Accessible vs inaccessible
- Deterministic vs nondeterministic
- Episodic vs non-episodic
- Static vs dynamic
- Open vs closed
- Contains or not other agents

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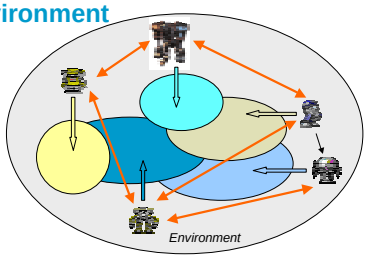
## Multi-agent systems

**Many entities (agents) in a common environment**




*Influenece area* *Interactions*

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## MAS - many agents in the same environment

- **Interactions among agents**

- high-level interactions

- Interactions for - coordination
  - communication
  - organization

**Coordination**

➔ collectively motivated / interested

➔ self interested

- own goals / indifferent
- own goals / competition / competing for the same resources
- own goals / competition / contradictory goals
- own goals / coalitions

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- **Communication**
  - ➔ communication protocol
  - ➔ communication language

- negotiation to reach agreement
- ontology

- **Organizational structures**
  - ➔ centralized vs decentralized
  - ➔ hierarchical/ markets

*"cognitive agent" approach*

**MAS systems?**

- Electronic calendars
- Air-traffic control system

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## Agents vs Objects

- Autonomy - stronger - agents have sole control over their actions, an agent may refuse or ask for compensation
- Flexibility - Agents are reactive, like objects, but also pro-active
- Agents are usually persistent
- Own thread of control

## Agents vs MAS

- Coordination - as defined by designer, no contradictory goals
- Communication - higher level communication than object messages
- Organization - no explicit organizational structures for objects
- No prescribed rational/intelligent behaviour

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## How do agents acquire intelligence?

**Cognitive agents**

The model of human intelligence and human perspective of the world ➔ characterise an intelligent agent using symbolic representations and ***mentalistic notions***:

- knowledge - John knows humans are mortal
- beliefs - John took his umbrella because he believed it was going to rain
- desires, goals - John wants to possess a PhD
- intentions - John intends to work hard in order to have a PhD
- choices - John decided to apply for a PhD
- commitments - John will not stop working until getting his PhD
- obligations - John has to work to make a living

(Shoham, 1993)

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### Premises

- Such a mentalistic or intentional view of agents - a kind of "folk psychology" - is not just another invention of computer scientists but is a useful paradigm for describing complex distributed systems.
- The complexity of such a system or the fact that we can not know or predict the internal structure of all components seems to imply that we must rely on animistic, intentional explanation of system functioning and behavior.

*Is this the only way agents can acquire intelligence?*

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- *Comparison with AI - alternate approach of realizing intelligence - the sub-symbolic level of neural networks*
- *An alternate model of intelligence in agent systems.*

**Reactive agents**

- Simple processing units that perceive and react to changes in their environment.
- Do not have a symbolic representation of the world and do not use complex symbolic reasoning.
- The advocates of reactive agent systems claims that intelligence is not a property of the active entity but it is distributed in the system, and steams as the result of the interaction between the many entities of the distributed structure and the environment.

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### The wise men problem

A king wishing to know which of his three wise men is the wisest, paints a white spot on each of their foreheads, tells them at least one spot is white, and asks each to determine the color of his spot. After a while the smartest announces that his spot is white

### The problem of Prisoner's Dilemma

Outcomes for actor A (in hypothetical "points") depending on the combination of A's action and B's action, in the "prisoner's dilemma" game situation. A similar scheme applies to the outcomes for B.

| Player A / Player B | *Defect* | *Cooperate* |
|---|---|---|
| *Defect* | 2 , 2 | 5 , 0 |
| *Cooperate* | 0 , 5 | 3 , 3 |

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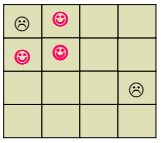
## The problem of pray and predators



- **Cognitive approach**
  - Detection of prey animals
  - Setting up the hunting team; allocation of roles
  - Reorganisation of teams
  - Necessity for dialogue/communication and for coordination
  - Predator agents have goals, they appoint a leader that organize the distribution of work and coordinate actions

**Reactive approach**

- The preys emit a signal whose intensity decreases in proportion to distance - plays the role of attractor for the predators
- Hunters emit a signal which acts as a repellent for other hunters, so as not to find themselves at the same place
- Each hunter is each attracted by the pray and (weakly) repelled by the other hunters

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- *Is intelligence the only optimal action towards a a goal? Only rational behaviour?*

### Emotional agents

- A computable science of emotions
- Virtual actors
  - Listen trough speech recognition software to people
  - Respond, in real time, with morphing faces, music, text, and speech
- Emotions:
  - Appraisal of a situation as an event: joy, distress;
  - Presumed value of a situation as an effect affecting another: happy-for, gloating, resentment, jealousy, envy, sorry-for;
  - Appraisal of a situation as a prospective event: hope, fear;
  - Appraisal of a situation as confirming or disconfirming an expectation: satisfaction, relief, fears-confirmed, disappointment
- Manifest temperament control of emotions

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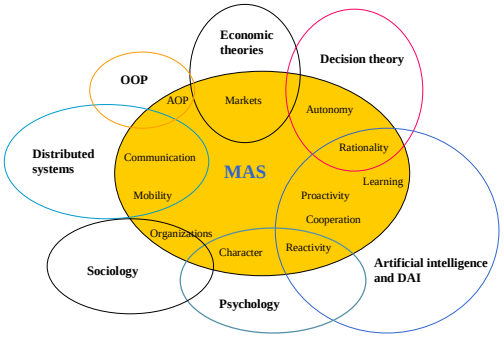
**MAS links with other disciplines**

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## Areas of R&D in MAS

- Agent architectures
- Knowledge representation: of world, of itself, of the other agents
- Communication: languages, protocols
- Planning: task sharing, result sharing, distributed planning
- Coordination, distributed search
- Decision making: negotiation, markets, coalition formation
- Learning
- Organizational theories

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## Areas of R&D in MAS

- **Implementation:**
  - Agent programming: paradigms, languages
  - Agent platforms
  - Middleware, mobility, security
- **Applications**
  - Industrial applications: real-time monitoring and management of manufacturing and production process, telecommunication networks, transportation systems, electricity distribution systems, etc.
  - Business process management, decision support
  - eCommerce, eMarkets
  - Information retrieving and filtering
  - Human-computer interaction
  - CAI, Web-based learning - CSCW
  - PDAs - Entertainment

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## Some examples

- **PDAs**

  **used as interface with the user : manage the interactions with other assistant agents *(meeting organisation, ...)***

  **and with other types of agent *(information search, service, contract negotiation, ...)***

- **Server agents**

**"terminal services"**

**Bounded to applications s.a. database, thematic servers, etc. Achieve a "terminal" service encapsulated in agents**

**"intermediate services"**

**Provide services with an added-value since they brought together terminal services.**

**In a travel agency scenario: it corresponds to the integration of services such as "Hotel reservation", "flight reservation" …**

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## Some examples

- **Marketing agents**
  - **"commercial" agents: used to inform potential users about their services, offers, etc. (broker, intermediate services and assistants)**
  - **"buyer" agents: negotiate the prices of services**
  - **"broker" agents that move on the net and look for interesting information for the user.**

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