

# Distributed Artificial Intelligence and Intelligent Agents

Mihhail Matskin:

[misha@kth.se](mailto:misha@kth.se)

# Course info

## **Coordinator**

Mihhail Matskin  
**misha@kth.se**  
tel. 08-790 41 28

## **Assistant**

- Shatha Jaradat (Course assistant)  
E-mail [shatha@kth.se](mailto:shatha@kth.se)
- Cosar Ghandeharioon (Course assistant)  
E-mail [cosarg@kth.se](mailto:cosarg@kth.se)

## **Lectures:**

see schedule

## **Exercises:**

see schedule

## **Written examination ( 4.5 p.)**

January 13 at 14-18

Registration at least 14 days before exam period

## **Homework and project assignments (3 p.)**

# Some details of Schedule

- October 30, 31, November 3, 6, 7, 13, 14, 20, 27, 28  
December 1 (first slot), 5 – Lectures
- November 10, 17, 24, December 1 (second slot), 7 –  
Homework session

# Homework

**There are 3 Homework with deadlines.**

<b>Start Date</b>	<b>Due Date</b>	<b>Description</b>
2017-11-10	2017-11-17	Homework 1
2017-11-17	2017-11-24	Homework 2
2017-11-24	2017-12-01	Homework 3

It is assumed that the Homework are done by groups of 2 student – you can do it also alone but there will be no additional bonus for doing them alone

# Project

## Aims of the project

To apply knowledge obtained during the course to design and implementation of an agent-based system

## Your task

You are supposed to design an agent system from suggested areas. You can also make your own project proposal for the system - the proposal must be approved by the course coordinator (the last date for approval of your own project proposal is **December 01**).

# Bonus

1. Delivering all Homework 1,2,3 in due time gives 5 bonus points to written exam (this assumes that all Homework are approved)
2. Delivering the project before December 21 gives 5 bonus points to written exam (this assumes that the project work is approved)

**Bonuses are only valid on the first examination on January 10**

# Course literature

- M. Wooldridge: *An Introduction to Multi-Agent Systems*. John Wiley and Sons, Second edition (Chichester, England).
- lecture notes
- selected papers (an additional listing of literature may be provided in the course)

# Very Tentative Lecture Plan

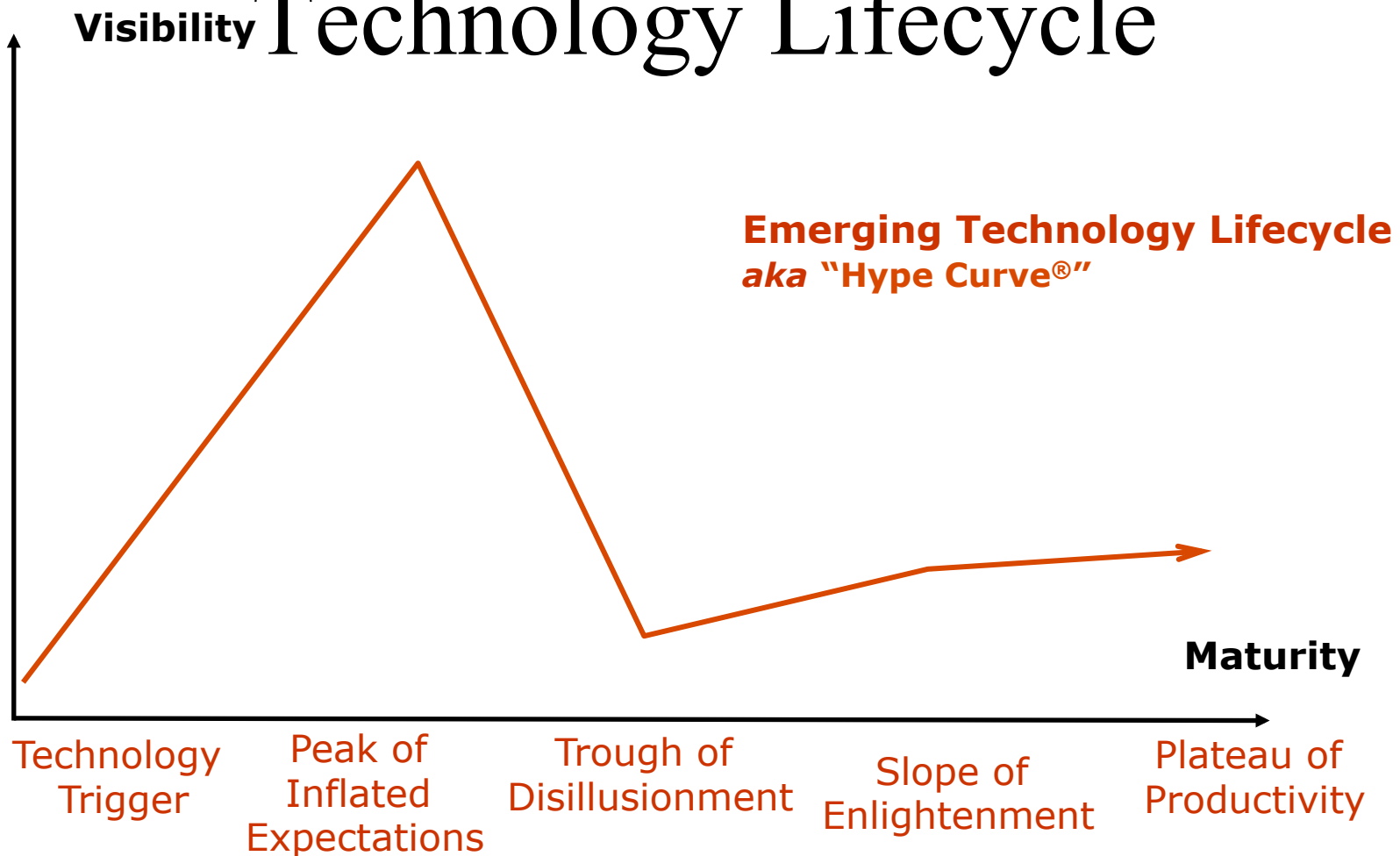
	Date	Lecture
1	30.10.2017	Introduction and Overview
2	31.10.2017	Negotiation in MAS
3	03.11.2017	Negotiation in MAS
4	06.11.2017	Negotiation in MAS
5	07.11.2017	Communication in MAS
6	13.11.2017	Communication in MAS Coordination in MAS
7	14.11.2017	Coordination in MAS
8	20.11.2017	Multi-agent Systems Architectures
9	27.11.2017	Agent-oriented Software Engineering
10	28.12.2017	Agent Theory
11	01.12.2017	Agent Architectures
12	05.12.2017	Mobile Agents and other Applications. Summary



# **What will you learn from this course?**

- 1. Learn what agents and multi-agent systems are**
- 2. Have a good overview of important agent issues:**
  - ⇒ Agent Coordination, Negotiation, and Communication**
  - ⇒ Agent-Oriented Software Engineering**
  - ⇒ Micro (intra-Agent) and Macro (agent systems) agent architectures**
  - ⇒ Agent Intelligence Mechanisms**
- 3. Get valuable hands-on experience in developing agent systems**
- 4. Being able to distinguish hype from "golden nuggets" in the area of Software Agents**

# But, Remember the Emerging Technology Lifecycle



Source: "The Hype Cycle," Gartner Group, ©1995-2004

# Introduction (content)

- Definition of an Agent
- Individual and Group Perspective
- Distributed AI and Multi-Agent Systems
- Overview of the course topics
- Summary



# What is an Agent?

## Scenario 1

”When a space probe makes its long flight from Earth to outer planets, a ground crew is usually required to continue to track its progress and decide how to deal with unexpected eventualities. This is costly and, if decisions are required quickly, it is simply not practical. For these reasons, organizations like NASA are seriously investigating the possibility of giving the probes richer decision making capabilities and responsibilities.”

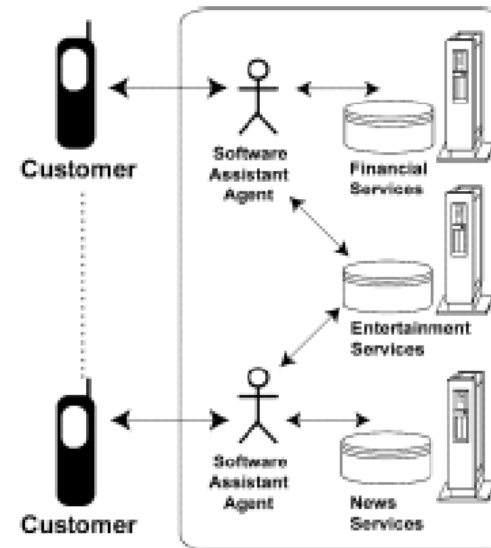
## Scenario 2 (intelligent home)

We assume that most of devices in your home (such as refrigerator, washing machine, dish-washing machine, even wardrobe etc.) are software assistants (at least they are represented by software assistants). You are also represented by your software assistant. Imagine that you told your software assistant about your menu for dinner. The assistant then communicate to refrigerator assistant and asks which products are available for the selected menu. The refrigerator assistant answers with the list of products and their amount (it also may keep track of expiration dates for products). Your assistant plans purchasing missing products (taking into account a healthy diet, of course). At this time wardrobe assistant asks your agent about your schedule for tomorrow and recognizes that you go to the Opera but there is no dinner jacket (smoking) in the wardrobe and you have to rent it. So your assistant contacts a renting company for a smoking (of course, it knows your size).

When you come home at evening all necessary products are ordered from the Internet shop and delivered (as well as dinner jacket). We don't assume that intelligent stove made ready your dinner according to menu (we still try to be realistic ...)

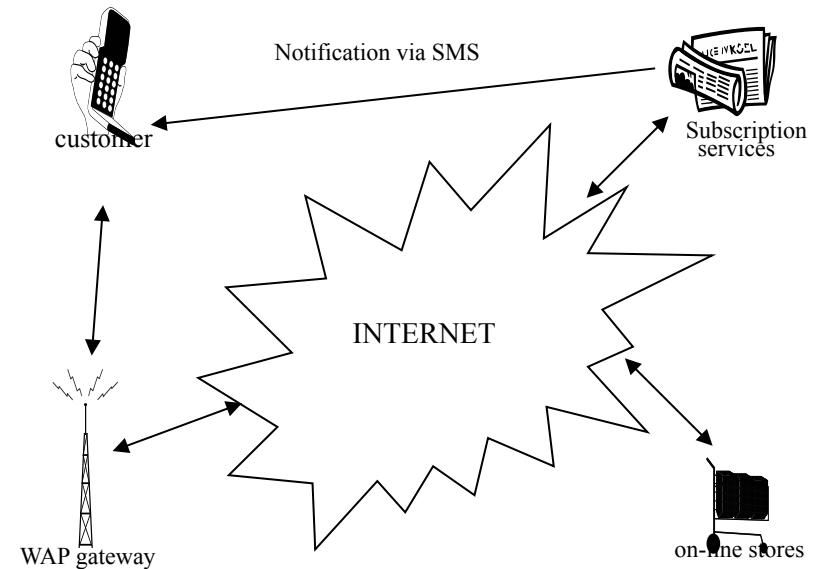
# Scenario 3 (financial adviser)

You have stocks and worry about stock quotas. You would like to be immediately notified about changes in stock quotas that are significant for you. Your software assistant monitors stock quotas, performs market analysis reflected your preferences, consult with other assistants and notify you by sending email or SMS to your mobile phone.



# Scenario 4

You are looking for a 3D-player and have a limited amount of money to buy it. Your software assistant searches for different Internet shops, gets recommendations from sellers, brokers, other assistants. It may negotiate about price or form shopping coalitions with other agents in order to obtain discount. The assistant brings you the best available offer for your approval.



# Definitions of Agents

American Heritage Dictionary:



”... One that acts or has the power or authority to act ... or represent another”

Negroponte:

”Digital sister in law”



# Definitions of Agents

Russel and Norvig:

”An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors.”

Maes, Pattie:

”Autonomous Agents are computational systems that inhabit some complex dynamic environment, sense and act autonomously in this environment, and by doing so realize a set of goals or tasks for which they are designed”.

# Definitions of Agents

Smith, Cyper and Spohrer:

“Let us define an agent as a persistent software entity dedicated to a specific purpose. "Persistent" distinguishes agents from subroutines; agents have their own ideas about how to accomplish tasks, their own agendas. "Special purpose" distinguishes them from multifunction applications; agents are typically much smaller.”

# Definitions of Agents

IBM:

“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 doing so, employ some knowledge or representations of the user’s goals or desires”.

Coen:

“Software agents are programs that engage in dialog [and] negotiate and coordinate transfer of information.

# Why do we have activity around agents?

- more and more everyday tasks are computer-based
- the world is in a midst of an information revolution
- increasingly more users are untrained
- users require agents to assist them in order to understand the technically complex world we are in the process of creating

More practical reason:

**Lack of programming paradigm for program/system construction in distributed and decentralized environment.**

# More questions

What is a problem and why former paradigms (F/E OOP) can not completely satisfy our needs?

They were designed for constructing programs/systems in a completely specified environment. The world was closed!

What do we have in case of distributed IT (now)?

An environment (in most cases) can not be specified completely.

Why it is problematic to specify distributed environment completely?

Because of our distributed "world" (environment) is not closed any more

# How can we work in an open environment?

Similar to "human's" way of behavior

- perceiving the environment
- affecting the environment
- having a "model" of behavior
- having intentions/motivations to be fulfilled by implementing corresponding goals
- communicate with other

# Fields that inspired agents

- Artificial Intelligence
  - Agent intelligence, micro aspects
- Software Engineering
  - Agent as an abstraction
- Distributed systems and Computer Networks
  - Agent architectures, multi-agent systems, coordination

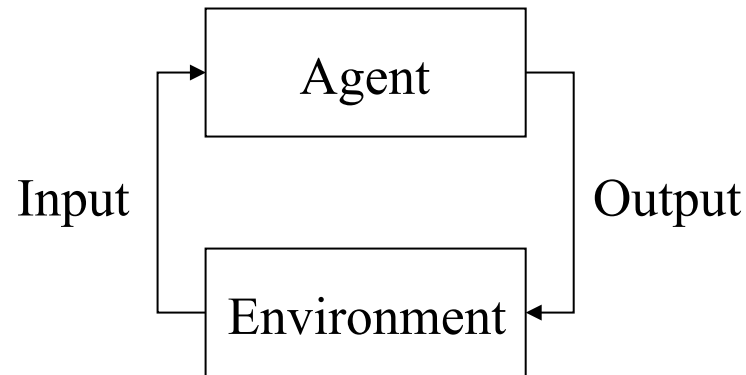
# Overview

- Five ongoing trends have marked the history of computing:
  1. Ubiquity
    - Reduction in the cost of computing capability
  2. Interconnection
    - Computer systems are networked into large distributed systems
  3. Intelligence
    - The complexity of tasks that can be automated and delegated to computers
  4. Delegation
    - Judgment of computer systems are frequently accepted
  5. Human-orientation
    - Use concepts and metaphors that reflect how we understand the world



# Definitions of Agents (continue)

- An agent is *autonomous*: capable of acting independently, exhibiting control over its internal state.
- An agent is *a computer system capable of autonomous action in some environment*.



# Some (Trivial) Autonomous Agents

- Thermostat
- UNIX daemon
- Help wizzards
- The animated paper-clip agent in Microsoft Oce



- ...



# What is an agent?



Wooldridge, Jennings (weak notion):

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

# Agents and Objects - What is this famous 'autonomy' ?

- Jennings and Wooldridge:
  - “[In contrast with objects, we] **think of agents as encapsulating *behavior*, in addition to state**. An object does not encapsulate behavior: it has no control over the execution of methods – if an object  $x$  invokes a method  $m$  on an object  $y$ , then  $y$  has no control over whether  $m$  is executed or not – it just *is*. In this sense, object  $y$  is not autonomous, as it has no control over its own actions.... Because of this distinction, we do not think of agents as invoking methods (actions) on agents – rather, we tend to think of them *requesting* actions to be performed. The decision about whether to act upon the request lies with the recipient.”

# Agents vs. Objects

Main differences:

- **Degree of autonomy**: agents embody a stronger notion of autonomy than objects, in particular, agents decide for themselves whether or not to perform an action.
- **Degree of smartness**: capable of flexible (reactive, pro-active, social) behaviour; standard object models do not have such behaviour.
- **Degree of activeness**: a multi-agent system is inherently multi-threaded in that each agent is assumed to have at least one thread of active control.

# What is an agent (strong notion)?

- *Mentalistic notions*, such as beliefs and intentions are often referred to as properties of strong agents.
- Other properties are:
  - Veracity: agent will not knowingly communicate false information.
  - Benevolence: agents do not have conflicting goals and always try to do what is asked of it.
  - Rationality: an agent will act in order to achieve its goals and will not act in such a way as to prevent its goals being achieved.
  - Mobility: the ability of an agent to move around a network.

# Summary of definitions

Basic agent features:

- acts on behalf of other entities
- has weak agent characteristics (Wooldridge, Jennings)
- may have strong agent characteristics (Wooldridge, Jennings)

# Which other terms are used in the context of agency?

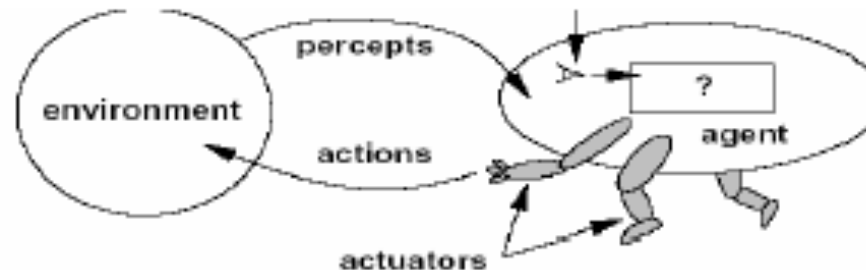
There are many synonyms of the term "intelligent agent" in literature. However they are mostly a specialization of agency with respect to implementation, operating environment, roles or functionality.

- **robots** - agents which inhabit the physical world (factory etc.)
- software agents (**softbots**) - agents which inhabit the programming environments (networks)
- **knowbots** - knowledge-based robots
- **taskbots** - task-based robots
- **userbots** - user oriented agents
- ...



# Humans, Robots, Agents

- A **human** agent: has eyes, ears, and other organs for sensors and hands, legs, mouth, and other body parts as actuators
- A **robotic** agent: might have cameras and infrared range finders for sensors and various motors for actuators
- A **software** agent receives keystrokes, file contents, and network packets as sensory inputs and acts on environment by displaying on the screen, writing files, and sending network packets



# Software Engineering

## **Imperative programming**

- modularization
- procedures and functions

## **Object oriented programming**

- encapsulation of states
- inheritance

## **Agent oriented programming**

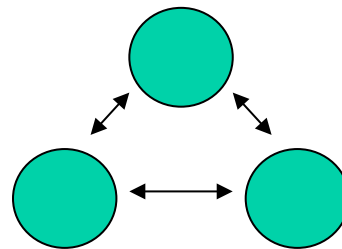
- autonomy
- deliberation and decision making capabilities
- utility and preferences

# Agents dimensions

- Individual agents perspective
- Group agents perspective

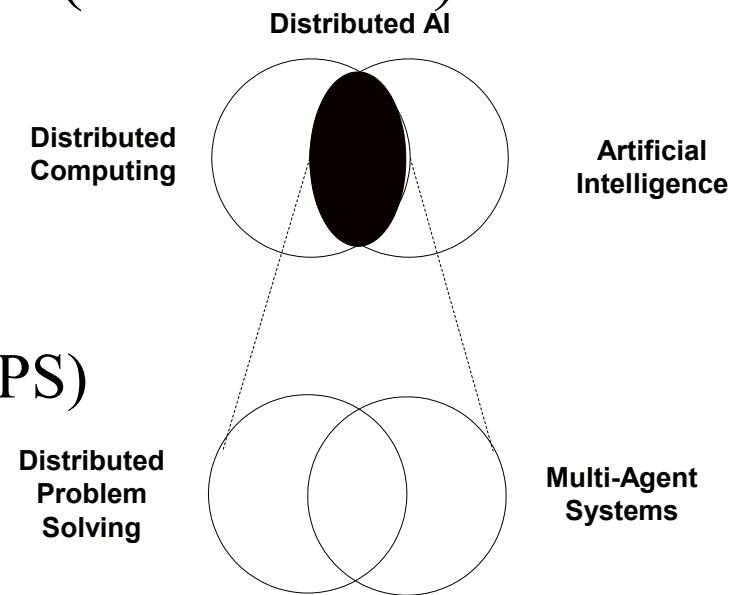
# Two Key Problems

1. How do we build agents that are capable of independent, autonomous actions in order to successfully carry out the tasks that we delegate to them? (Micro aspects)
2. How do we build agents that are capable of interacting (cooperating, coordinating, negotiating) with other agents in order to successfully carry out the tasks we delegate to them? (Macro aspects)



# Distributed Artificial Intelligence (DAI)

- DAI is a sub-field of AI
- DAI is concerned with problem solving where several agents solve (sub-)tasks (macro level)
- Main areas of DAI
  1. Multi-Agent Systems (MAS)
  2. Distributed Problem Solving (DPS)



*Reference: B. Moulin, B. Chaib-draa. "An Overview of Distributed Artificial Intelligence". In: G. M. P. O'Hare, N. R. Jennings (eds).*

*Foundations of Distributed Artificial Intelligence, John Wiley & Sons, 1996, pp. 3-56.*

# DPS

- **DPS** considers how the task of solving a particular problem can be divided among a number of modules that cooperate in dividing and sharing knowledge about the problem and its evolving solution(s).
  - In pure DPS systems, all interaction strategies are incorporated as an integral part of the system
  - DPS has focused on achieving goals under varying environmental conditions, having agents with established properties.

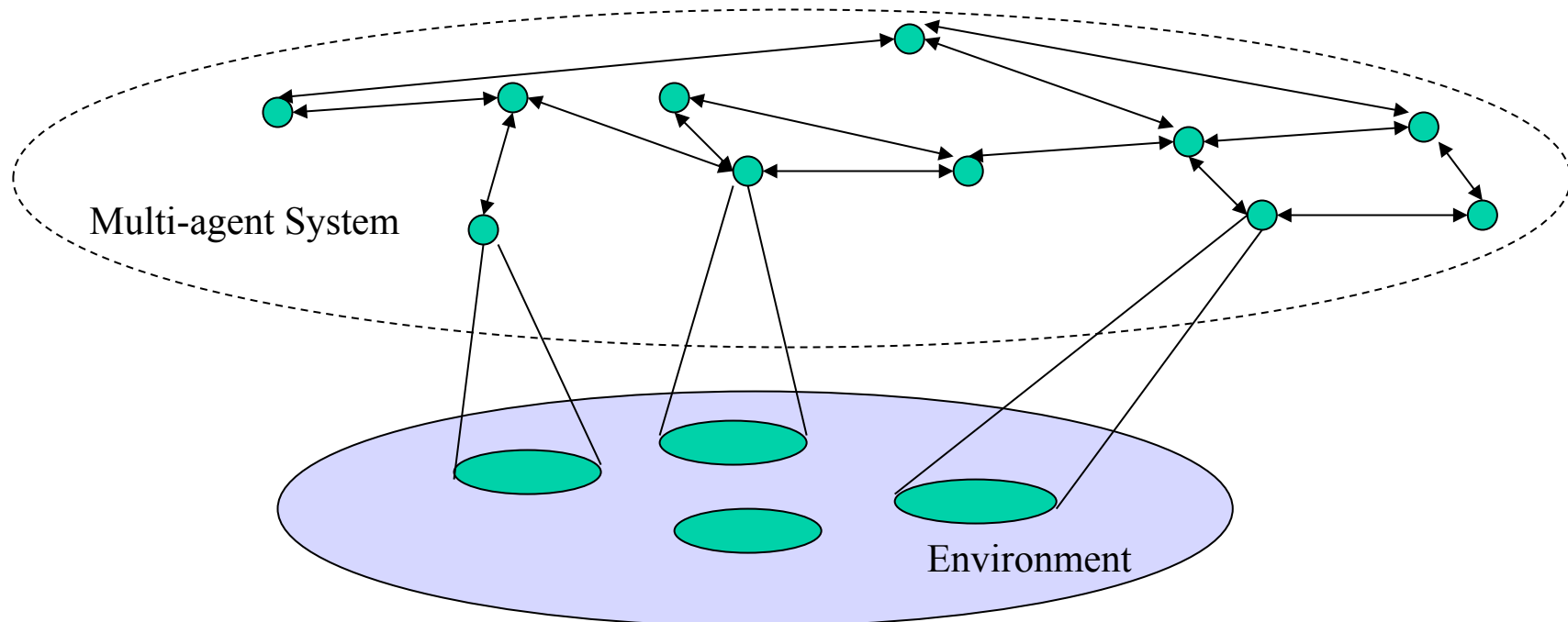
# MAS

- **MAS** is concerned with the behavior of a collection of autonomous agents aiming to solve a given problem - how agents with individual preferences will interact in particular environments such that each will consent to act in a way that leads to desired global goal. MAS asks how, for a particular environment, can certain collective goal be realized if the properties of agents can vary uncontrollably
  - "loosely-coupled networks of problem solvers (agents) that work together to solve problems that are beyond their capabilities"
  - no necessary guarantees about other agents

# Multi-agent Systems (MAS)

Contains a number of agents which interact with one another through communication. The agents are able to act in an environment; where each agent will act upon or influence different parts of the environment.

*Reference: Wooldridge, An Introduction to Multiagent Systems*





# Decentralisation

- An important concept in MAS
  - No central control; control is distributed
  - Knowledge or information sources may also be distributed

# Motivation for MAS

- To solve problems that are too large for a centralized agent
- To allow interconnection and interoperation of multiple legacy systems
- To provide a solution to inherently distributed problems
- To provide solutions which draw from distributed information sources
- To provide solutions where expertise is distributed
- To offer conceptual clarity and simplicity of design

# Cooperative and Self-interested MAS

- Cooperative
  - Agents designed by interdependent designers
  - Agents act for increased good of the system
  - Concerned with increasing the performance of the system
- Self-interested
  - Agents designed by independent designers
  - Agents have their own agenda and motivation
  - Concerned with the benefit and performance of the individual agent
    - *More realistic in an Internet setting?*

# DAI Dimensions

- Agent granularity
- Heterogeneity of agents
- Communication possibilities
- Methods of distributing control among agents

# Benefits of MAS

- Faster problem solving
- Decrease in communication
- Flexibility
- Increased reliability

# DAI is not concerned with:

- Issues of coordination of concurrent processes at the problem solving and representational level
- Parallel Computer Architectures, Parallel Programming Languages or Distributed Operating Systems

# Summary of definitions

## **Distributed Computing**

- Focus on low-level parallelization and synchronization.

## **Distributed AI**

- Intelligent control as well as data may be distributed. Focus on problem solving, communication and coordination.

## **DPS**

- Task decomposition (task sharing) and/or solution synthesis (result sharing): information management

## **MAS**

- Behavior coordination and management

# Course Topics for Agents Group Perspective

- Agent Negotiation – conflict resolution
- Agent Coordination – achieving coherent behavior
- Agent Communication – interoperability
- Multi-Agent System Architectures
- Software Engineering of Multi-Agent Systems



# Negotiation (Example)

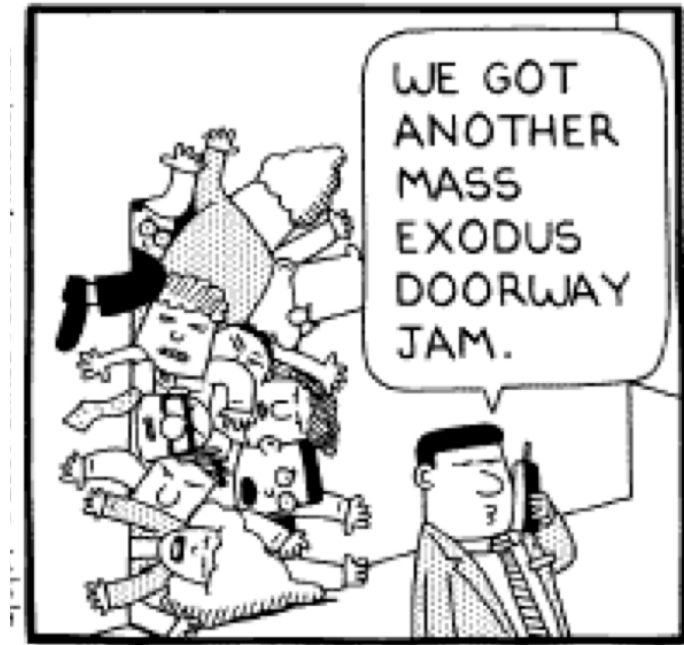
2 agents are trying to set up a meeting. The first agent wishes to meet later in the day while the second wishes to meet earlier in the day. Both prefer today to tomorrow. While the first agent assigns highest worth to a meeting at 16:00hrs, s/he also assigns progressively smaller worths to a meeting at 15:00hrs, 14:00hrs....

By showing flexibility and accepting a sub-optimal time, an agent can accept a lower worth which may have other payoffs, (e.g. reduced travel costs).



# Coordination Problem

- Managing the interdependencies between the activities of agents. e.g.
  - You and I both want to leave the room. We independently walk towards the door, which can only fit one of us. I graciously permit you to leave first.



Cartoon taken from Klein, AAMAS2002

# Coordination

- Preventing anarchy or chaos
- Meeting global constraints
- Distributed expertise, resources or information
- Dependencies between agents' actions
- Efficiency

# Software interoperation (communication)

Interoperation - exchange of information and services with other programs, thereby solving problems that cannot be solved alone

Main problems:

- heterogeneity
  - different people
  - different time
  - different languages

# Communication in MAS

- To successfully coordinate and negotiate agents need ability to communicate
- Basic methods for *communication*:
  - Plan /message passing
  - Information exchange using shared repositories
- Important characteristics of communication:
  - Relevance of the information
  - Timeliness
  - Completeness

# Components of a system for effective interaction and interoperability

- common language
- common understanding of the knowledge exchanged
- ability to exchange whatever is included in the previous items

➤ *Agent Communication Language (ACL)*



## FBI Agents Ordering Pizza

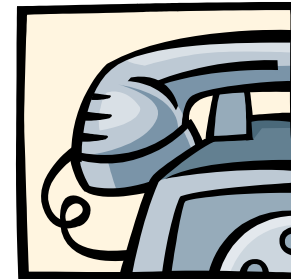


FBI agents conducted a raid of a psychiatric hospital in San Diego that was under investigation for medical insurance fraud. After hours of reviewing thousands of medical records, the dozens of agents had worked up quite an appetite. The agent in charge of the investigation called a nearby pizza parlour with delivery service to order a quick dinner for his colleagues. The following telephone conversation took place and was recorded by the FBI because they were taping all conversations at the hospital.

*Source: [http://jewel.morgan.edu/~salimian/humor/humor\\_094.html](http://jewel.morgan.edu/~salimian/humor/humor_094.html)*

## FBI Agents Ordering Pizza, contd.

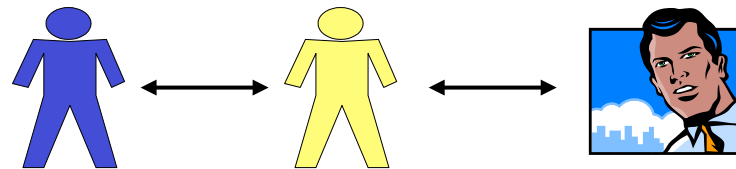
- *Agent*: Hello. I would like to order 19 large pizzas and 67 cans of soda.
- *Pizza Man*: And where would you like them delivered?
- *Agent*: We're over at the psychiatric hospital.
- *Pizza Man* : The psychiatric hospital?
- *Agent* : That's right. I'm an FBI agent.
- *Pizza Man* : You're an FBI agent?
- *Agent* : That's correct. Just about everybody here is.
- *Pizza Man* : And you're at the psychiatric hospital?
- *Agent* : That's correct. And make sure you don't go through the front doors. We have them locked. You will have to go around to the back to the service entrance to deliver the pizzas.
- *Pizza Man* : And you say you're all FBI agents?
- *Agent* : That's right. How soon can you have them here?
- *Pizza Man* : And everyone at the psychiatric hospital is an FBI agent?
- *Agent* : That's right. We've been here all day and we're starving.
- *Pizza Man* : How are you going to pay for all of this?
- *Agent* : I have my checkbook right here.
- *Pizza Man* : And you're all FBI agents?
- *Agent* : That's right. Everyone here is an FBI agent. Can you remember to bring the pizzas and sodas to the service entrance in the rear? We have the front doors locked.
- *Pizza Man* : I don't think so. Click.





# Multi-Agent Systems Architecture

- The context of multi-agent systems widens the notion of software architecture in 2 ways:
  1. An agent's "user" that imparts goals to it and delegates tasks might be not only a human, but also another agent.
  2. An agent must be designed with explicit mechanisms for communicating and interacting with other agents.



# What is Multi-agent Architecture

- The infrastructure for a MAS can be defined as a set of services, conventions and knowledge that support complex social interactions (e.g. negotiations, agree on commitments/coordination).
- In particular, agents need services to:
  - Enable them to find each other in open environments
  - Communicate
  - Warrant that proper security constraints are satisfied
  - ...

# Agent Oriented Software Engineering (AOSE)

Successful industrial deployment of agent technology requires techniques that reduce the risk inherent in any new technology. Two ways that reduce risk in the eyes of potential adopters are:

- to present the new technology as an incremental extension of known and trusted methods, and
- to provide explicit engineering tools that support industry-accepted methods of technology deployment.

# Course Topics for Individual Agents Perspective

- Agent Theory
- Agent Architectures
- Agent Mobility

# Agent Theory

- intentional systems
- knowledge, belief, desire, goal, intention
- traditional AI approaches

# The Wise Men puzzle (knowledge about knowledge)

There are three wise men.

It's common knowledge -- known by everyone, and known to be known by everyone, etc. -- that there are three red hats and two white hats. The king puts a hat on each of the wise men, and ask them sequentially if they know the color of the hat on their head. Suppose the first man says he does not know; then the second say he does not know either.

It follows that the third man must be able to say that he knows the color of his hat.

Why is this, and what color has the third man's hat?

# Agent architectures

- Deliberative
- Reactive
- Hybrid

# Mobility

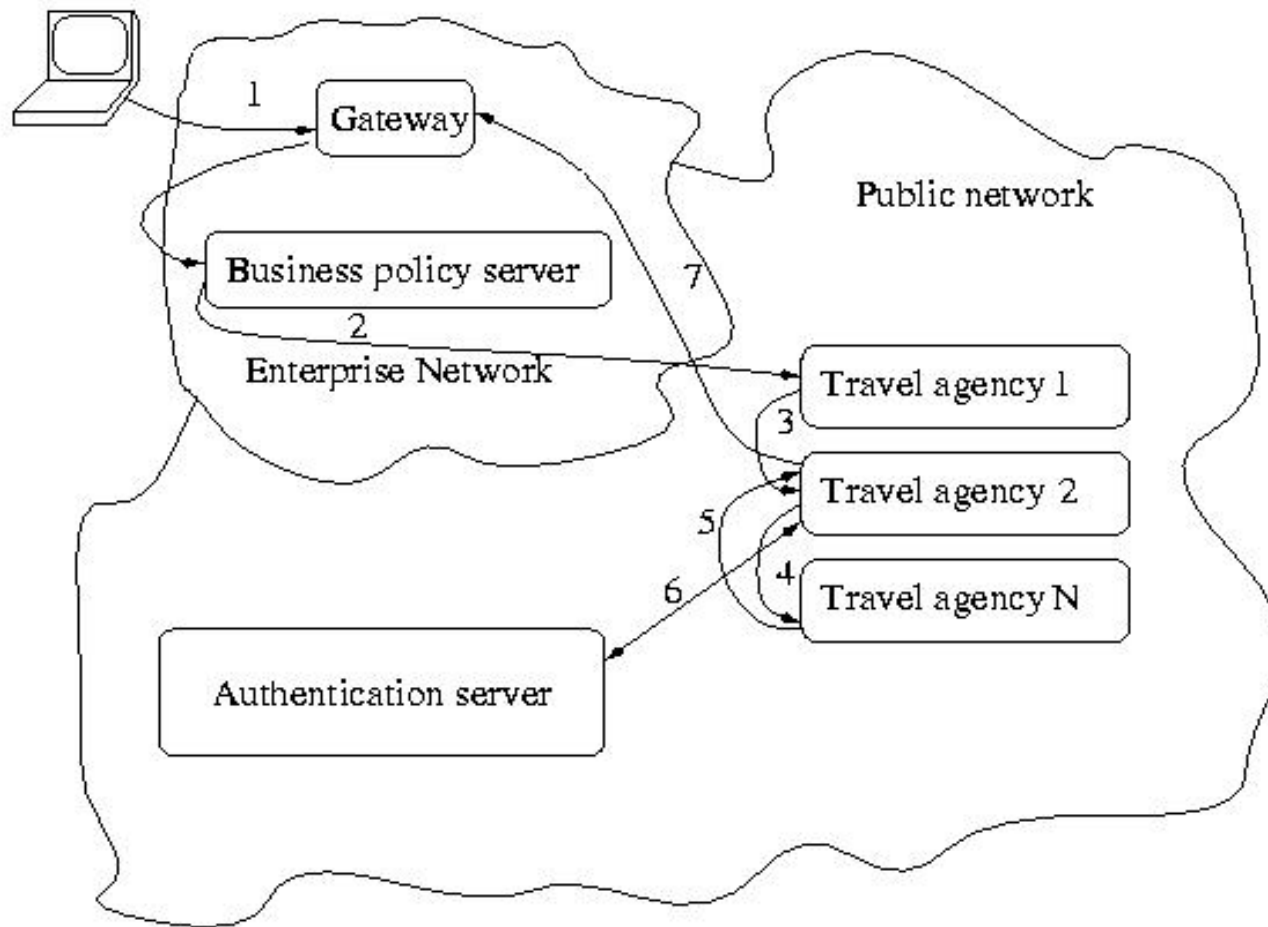


- Agents are capable of transmitting themselves – their programs and their state – across a computer network, and recommencing execution at a remote site.
  - The program chooses when and where to migrate.
  - It can suspend its execution at an arbitrary point, transport itself to another machine and resume execution.
- *Moving programs while they run!*



# Mobile agent scenario

Travel reservation scenario using mobile agents



# Summary

- DAI is a part of AI
- MAS is a part of DAI
- MAS - "macro" issues of agent systems
- intelligent agents - "micro" issues of agent systems

# **Next Lecture: Multi-agent Negotiation**

Will be based on:

Chapters 11, 12, 14, 15

in

Wooldridge: "Introduction to MultiAgent  
Systems"