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Intelligent Multi-Agent Systems

Prof. Hani Mahdi
Computer And Systems Engineering Department
Faculty of Engineering, Ain Shams University
Cairo, Egypt

Outline

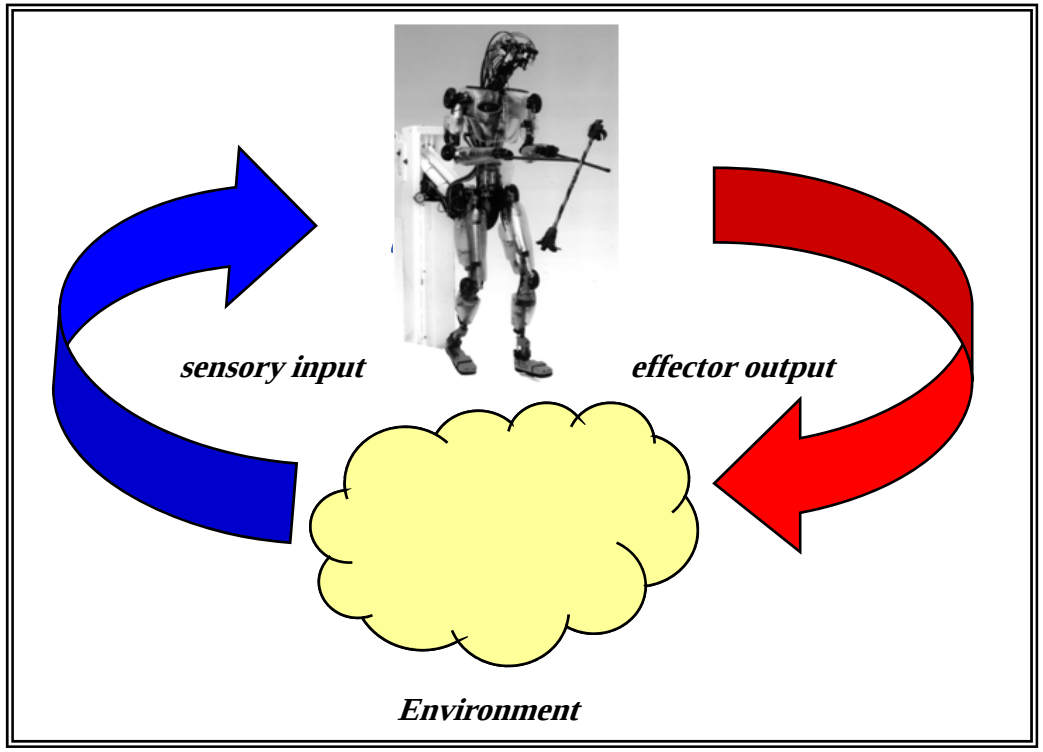
- Agents and Environments
- Foundation for Intelligent Physical Agents
- Multi-Agent Systems
- Challenging Issues

Background

- Mid 1990s, the agent concept has become important in both artificial intelligence (AI) and mainstream computer science.
- In 2000s agent-based and multi-agent systems (MASs) gain attentions beyond traditional computer science and artificial intelligence (AI).
- In 2002, Agent-Oriented Software Engineering (AOSE).

Agent Sense and Respond

- An **Agent** is anything that can be viewed as ***perceiving*** its **Environment** through ***sensors*** and ***acting*** upon that environment through ***actuators***



Some Agent Definitions

Merriam-Webster Online Dictionary:

1: one that acts or exerts power

2: something that produces or is capable of producing an effect **:** an active or efficient cause

3: a means or instrument by which a guiding intelligence achieves a result

4 : one who is authorized to act for or in the place of another:

→ Software Agent

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

Wooldridge and Jennings: “An agent is a hardware and/or software-based computer system displaying the properties of autonomy, social adeptness, reactivity, and proactivity

Other Agent Definitions

Coin: "Software agents are programs that engage in dialogs and negotiate and coordinate the transfer of information."

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."

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."

Agent Key Feature

There is a consensus that Autonomy, the ability to act without the intervention of humans or other systems, is a key feature of an agent.

Beyond that, different attributes take on different importance based on the domain of the agent.

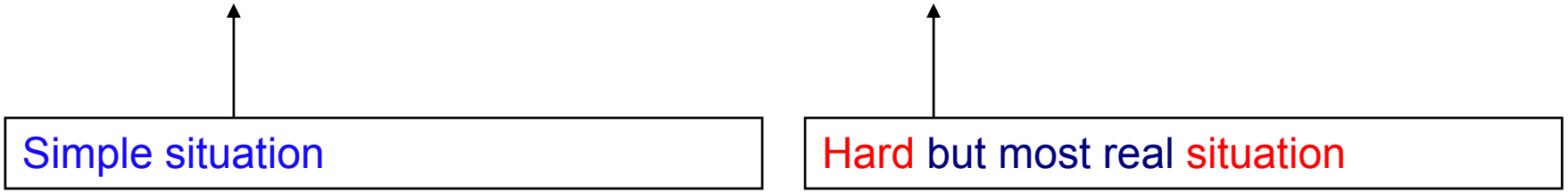
Stanford Racing Team Cars

2005

2007

Simple and Hard Environment

- Fully Observable (vs. Partially Observable)
- Deterministic (vs. Stochastic)
- Episodic (vs. Sequential)
- Static (vs. Dynamic)
- Discrete (vs. Continuous)
- Single agent (vs. Multiagent)



A Viewpoint

- A program deserves to be called a *Software Agent* only if it *exhibits a human agent behavior in at least one of properties of Hard Environment* (including Non-deterministic) properties and may go beyond human performance

Environments

To design a Rational Agent, we must specify its task environment.

PEAS – way to describe the Task Environment

- Performance Measure
- Environment
- Actuators
- Sensors

Example: Fully Automated Taxi

PEAS description of the environment:

- Performance Measure
  - Safety, destination, profits, legality, comfort
- Environment
  - Streets/freeways, other traffic, pedestrians, weather,, …
- Actuators
  - Steering, accelerating, brake, horn, speaker/display,…
- Sensors
  - Video, sonar, speedometer, engine sensors, keyboard, GPS, …

Main Agent Properties

- Ongoing, Non-terminating Software
- Internal Processes remain Encapsulated
- Capable of Autonomous action
- Guided by its own Goals

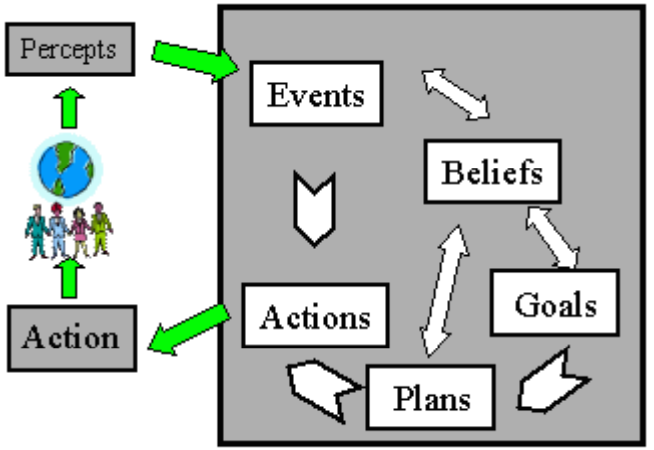
Main Intelligent Agent Properties

An Intelligent Software Agent is capable of operating in a non-deterministic environment.

- Responds in a Timely Manner
- No External Dictation
- May be Proactive - take the Initiative
- May have to possess Social ability
- May be able to Learn

Basic Agent Concepts

- **Actions** and **Percepts** interfacing with the environment.
- **Events** are for reactivity
- **Beliefs** are for achieving goals
- **Goals** are for proactivity
- **Planning** are for changing environments



The Structure of Agents

- The job of AI is to design the **Agent Program** that implements the Agent Function mapping percepts to actions.
  The **Agent Program** will run on some sort of computing device with physical sensors and actuators-we call this the **architecture**

- Agent = Architecture + **Program** .

Agent's Function and Program

- The difference between them
  the Agent Program takes the current percept as input, and
  the Agent Function takes the entire percept history.
- If the agent's actions depend on the entire percept sequence, the agent will have to remember the percepts.

Analyzing Tool!

- The Concept (Notion) of an Agent is meant to be a Tool for Analyzing Systems, NOT an absolute characterization that divides the world into Agents and Non-Agents.

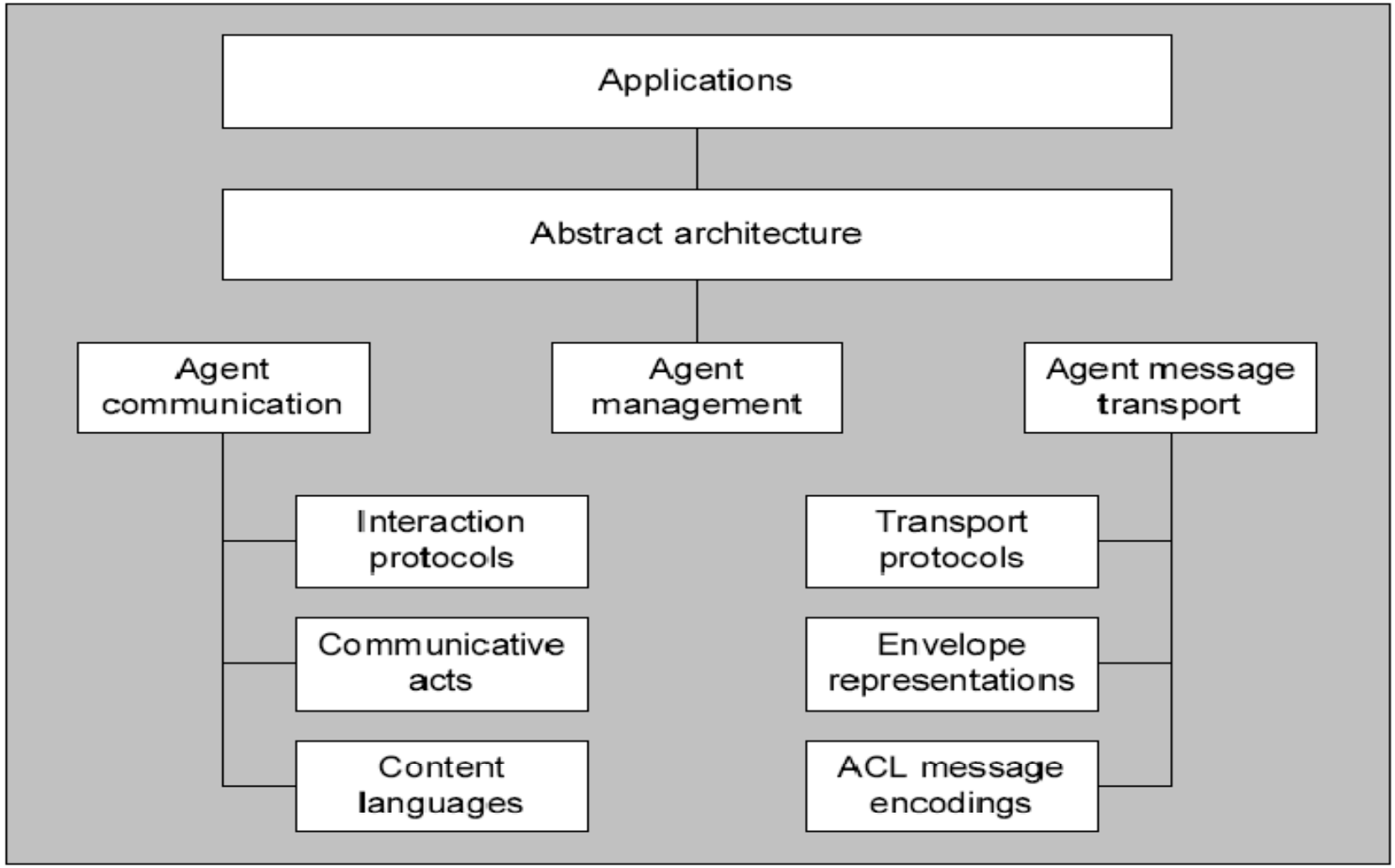
Misusing/Overusing the Name

- Search Agents, Report Agents, Presentation Agents, Navigation Agents, Management Agents, Help Agents, Smart Agents, User Agents, Collaborative Agents, Interface Agents, Mobile Agents, Information Agents, Hybrid Agents, Reactive Agents, …
  to name a few

FIPA Standards Overview

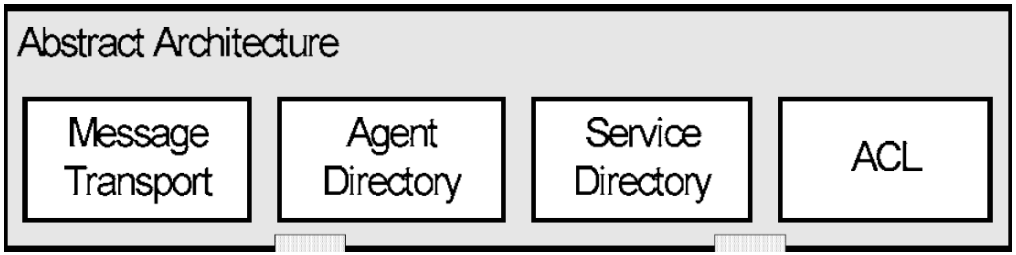
- Foundation for Intelligent Physical Agents
- FIPA - the Standards Organization for Agents and Multi-agent Systems (1996)
- Developing Specifications supporting inter-operability among agents and agent-based applications.
- FIPA was officially accepted by the IEEE as its eleventh standards committee on 2005.

Overview of the FIPA Standards



FIPA Abstract Architecture Scope

- A model of Services and discovery of services available to agents
- Message Transport interoperability
- Supporting various forms of ACL (Agent Communication Language) representations and Content Languages
- Supporting the representations of multiple Directory Services



Abstract and Concrete Specs

- From Abstract to Concrete Specifications
- Abstract Architecture cannot be implemented
- Abstract Architecture forms the basis for the development of Concrete Architectural Specifications.

Concrete Specifications

- Concrete Specifications describe how to construct an agent system, including the Agents and the Services that they rely upon, in terms of Concrete Software Artefacts, such as
  - Programming Languages,
  - Applications Programming Interfaces,
  - Network Protocols,
  - Operating System Services,
  - ...

FIPA Compliant

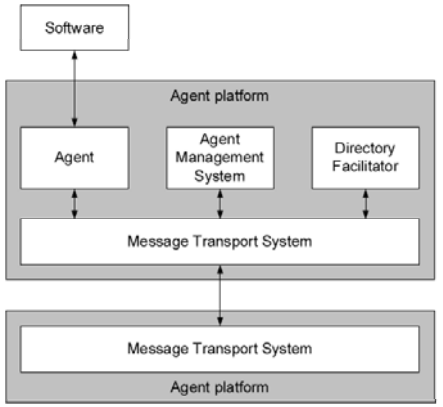
- A Concrete Architectural Specification must have certain Properties to be FIPA Compliant.
- The Concrete Architectural must include Mechanisms for
  Agent Registration
  Agent Discovery and
  Inter-Agent Message Transfer.
- These Services must be explicitly described in terms of the corresponding elements of FIPA Abstract Architecture.

Minimum Required Elements

- FIPA Abstract Architecture does not *prohibit* the introduction of elements useful to make a good agent system, it merely sets out the *Minimum* Required Elements.

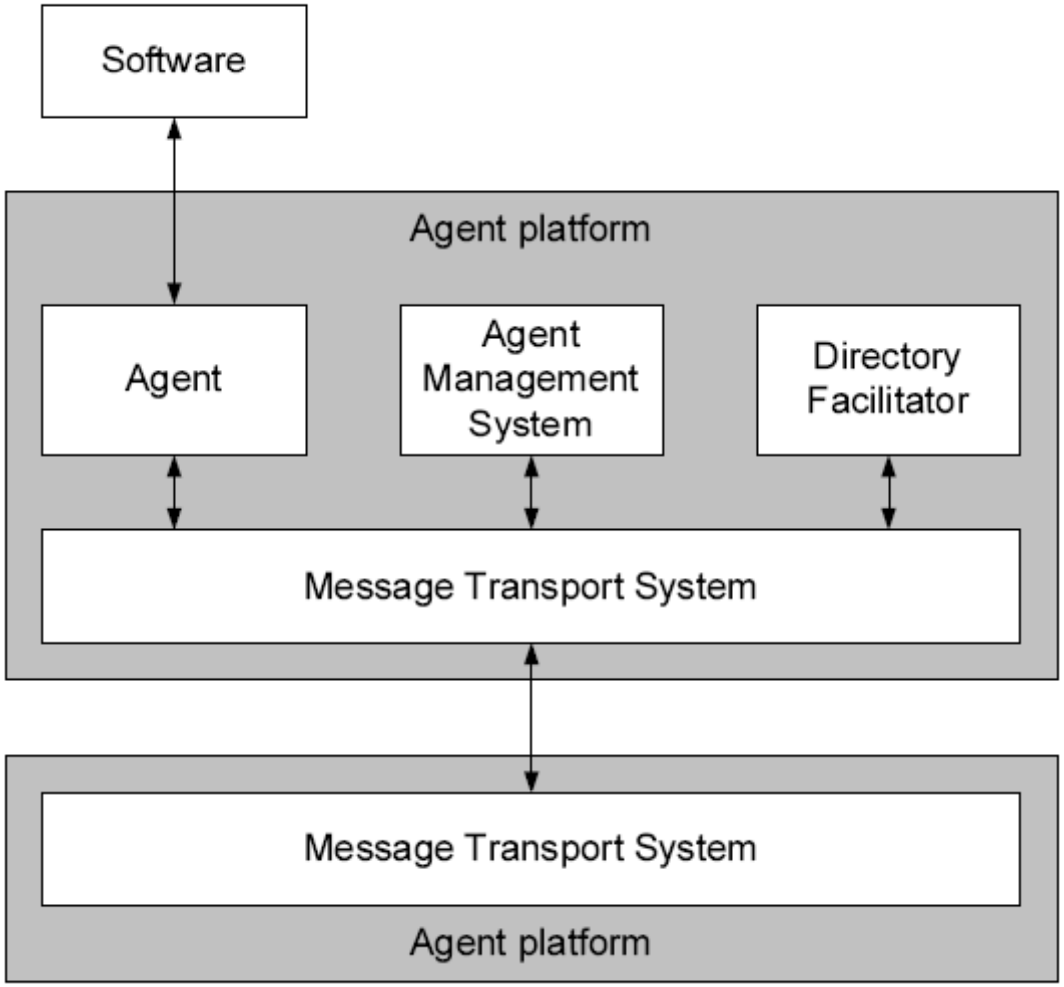
The Reference Model

The Agent Management Reference Model consists of the following logical components



- An Agent
- An Agent Platform (AP)
- A Directory Facilitator (DF)
- An Agent Management System (AMS)
- A Message Transport Service (MTS)

Management Reference Model



Agent Communications Language

Two popular and acknowledge ACLs :

- FIPA-ACL (by the Foundation for Intelligent Physical Agents, a standardization consortium)
- KQML (Knowledge Query and Manipulation Language) a language and protocol for communication among software agents and knowledge-based systems

Multi-Agent Systems (MASs)

Informal definitions:

- An Agent is a computer program and an architecture those capable of flexible and autonomous action in a Dynamic Environment, usually an Environment Containing Other Agents.

  The Society in which they operate is called a Multi-Agent System.

MASSIVE

Software

Agents on film…

“Fellowship of the Ring” battle scenes by Weta digital.

Motivations for MAS construction

In a MAS, the agents co-operate to perform some task that a single agent can't do on its own because

- A Single Agent doesn't have all the Capabilities or Knowledge required to perform the task
- A Single Agent would be Too Slow

Multi-Agent System - Viewpoint

- Like the notion of an ‘Agent’,
  a ‘Multi-Agent System’ is an Analysis Tool:

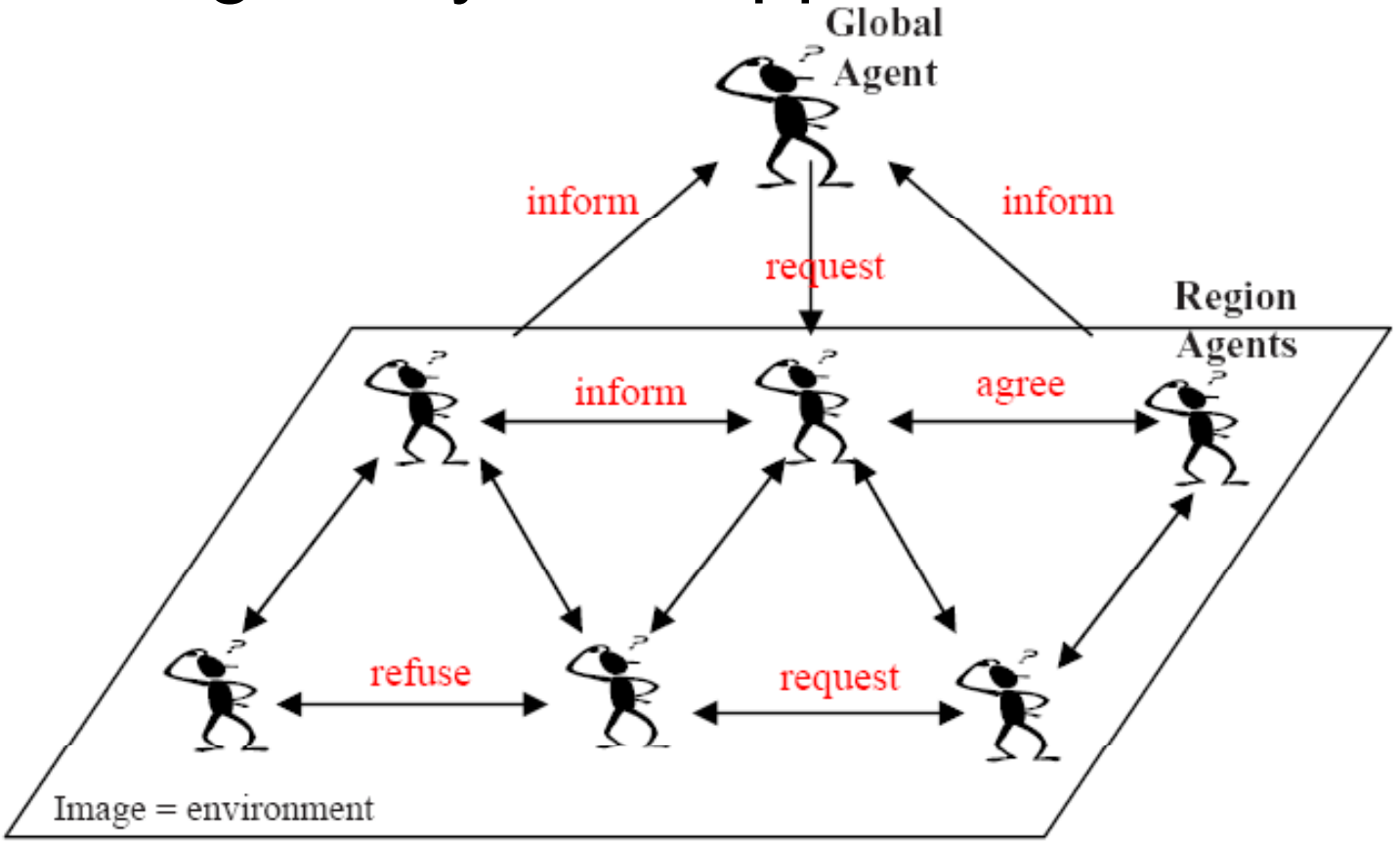
- It is worthless trying to identify precisely which systems are really Multi-Agent Systems
- the Key Point is whether we gain by looking at a System as a Multi-Agent System.

Perspectives of MAS

- **Sociological** Perspective
  Members of an Agent Society
- **AI** Perspective
  Intelligent and Autonomous Behavior
- **Economic** Perspective
  Economically Rational behavior
- **Application** Perspective
  Examples*:* Mechanical Engineering, Robotics, Production Planning, Control, …

An Example

- Medical Image Segmentation by a Multi-Agent System Approach



MAS and DAI

- Distributed Artificial Intelligence (DAI) is a subfield of Artificial Intelligence (AI) which is concerned with a society of problem solvers or agents interacting in order to solve a common problem

Three Broad Areas which fall under DAI,

- Multi-Agent System (MAS)
- Distributed Problem Solving (DPS), and
- Parallel AI (PAI).

Key Properties of a MAS

- The Key Properties of MAS are

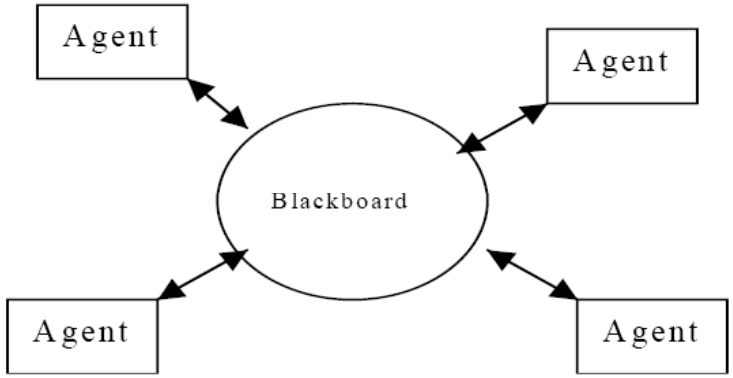
  Communication and Interaction
  Structures and Roles

Agent Communication

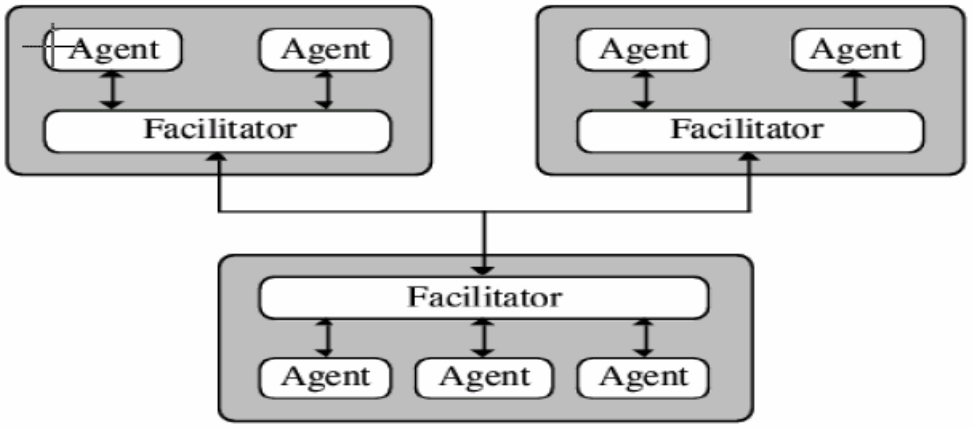
- Agent Communication
  encourages autonomy and
  the existence of societies
  avoids the regard of other agent's internal structure
- Different Agents (interface, programmers, developed language, platform, …) a Common Communication Language for the Information Exchange.

Communication Architectures

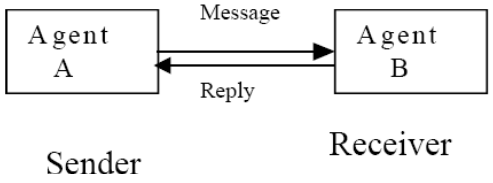
Three Communication Architectures are commonly used



Blackboard



Facilitation Architecture

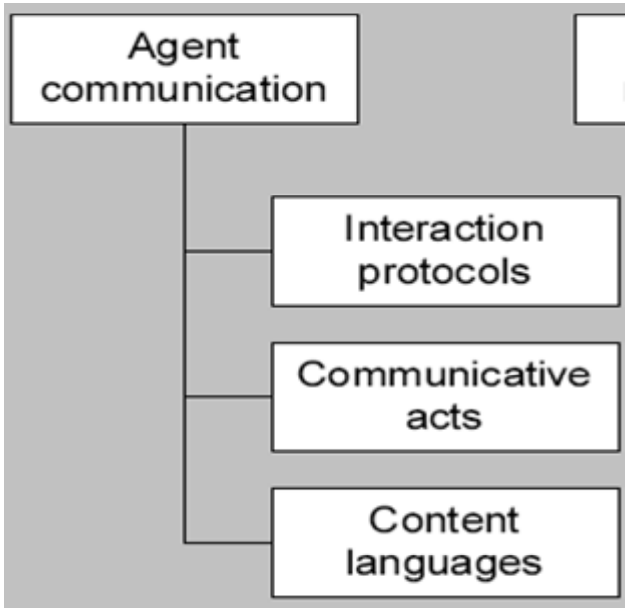


Message Architecture

Communication Sub-Sections

Three Sub-Sections

- Interaction Protocol: Intended High Level Strategy; such as negotiation schemes, auctions, contracts, etc.
- Communication Language: Used to exchange the contents of the messages.
- Transport protocol: the transportation mechanism; such as TCP, IP, SMTP, HTTP.



MAS Architectures

- Several Architectural Styles have been used in the development of Multi-agent Systems.

Four Known Organizations:

- Hierarchical Architecture
- Flat Architecture
- Subsumption Architecture
- Modular Architecture

Hierarchical Architectures

- agents communicate according to a hierarchical structure, such as a tree.
- The root is known as a broker or facilitator agent.
- Disadvantage: Reduce
  the Autonomy of The Individual Agents.
- Advantage: Reduce
  the amount of Required Communications
  the Complexity and Reasoning capabilities

Flat Architecture

- any agent may contact any of the others.
- Disadvantage: Increase
  Communications between Agents
  Needs the locations of their partners or
  Agent Location Mechanisms such as
  yellow pages services
- Advantage: Increase
  Agent Autonomy
- Suitable for Small Multi-agent Systems

Subsumption Architecture

- Agents are Themselves made up of other Agents.
- the subsumed agents are completely controlled by the containing agents.
- Disadvantage: Reduce
  the Flexibility of the system
- Advantage: Increase
  The Efficiency of the system

Modular Architecture

- A Modular Multi-Agent System is comprised of a Number of Modules.
- Each module normally employs a Flat Structure, while inter-module communications is relatively limited.
- It is Advantageous for Specific Applications where the agents can be grouped according to their inter-communications

Challenging Issues - 1

Challenging Issues in MASs:

- How to Decompose a Problem, Allocate Subtasks to agents, and Synthesize Partial Results.
- How to handle the Distributed Perceptual Information. How to enable agents to maintain consistent shared models of the world.
- How to Implement Decentralized Control and build Efficient Coordination Mechanisms among agents.

Challenging Issues - 2

- How to Design Efficient Multiagent Planning and Learning Algorithms.
- How to Represent Knowledge. How to enable agents to Reason About the Actions, Plans, and Knowledge of other Agents.
- How to Enable Agents to Communicate. What Communication Languages and Protocols to use. What, when, and with whom Should an Agent Communicate.

Challenging Issues - 3

- How to Enable Agents to Negotiate and Resolve Conflicts.
- How to enable agents to Form Organizational Structures like teams or coalitions. How to Assign Roles to agents.
- How to Ensure Coherent and Stable System Behavior.

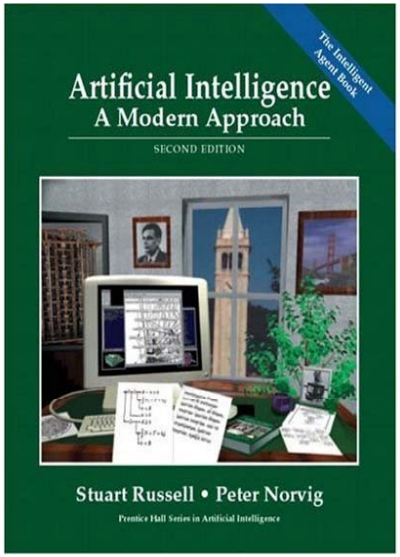
Traditional Textbook

- Artificial Intelligence: A Modern Approach (AIMA), Second Edition, Stuart Russell & Peter Norvig, Pearson Education, 2003, ISBN 0-13-790395-2.

  http://www.cs.berkeley.edu/~russell/aima

- AIMA repository, /afs/cu/class/cs451/aima

  Lisp, Java, Python



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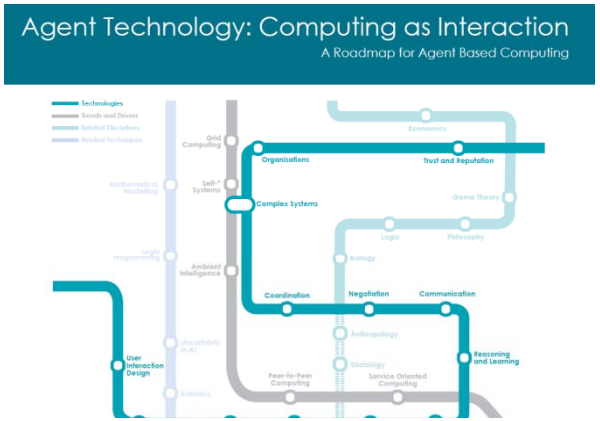

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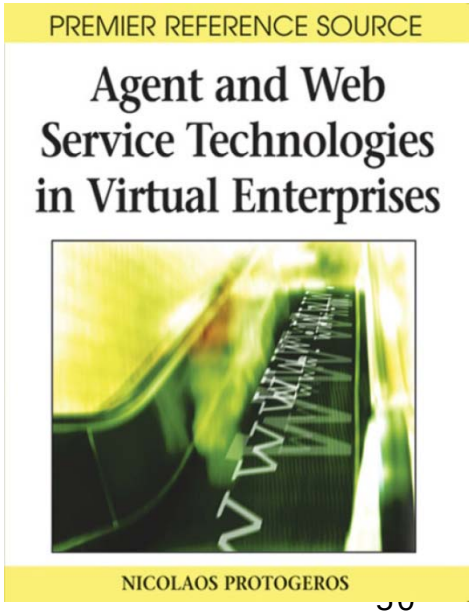

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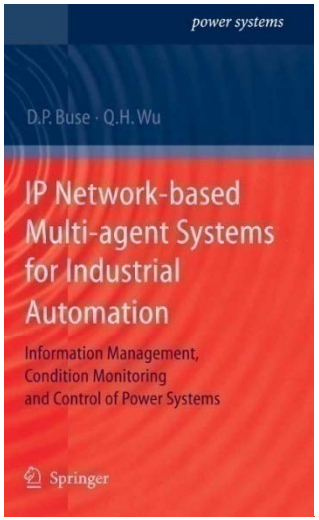

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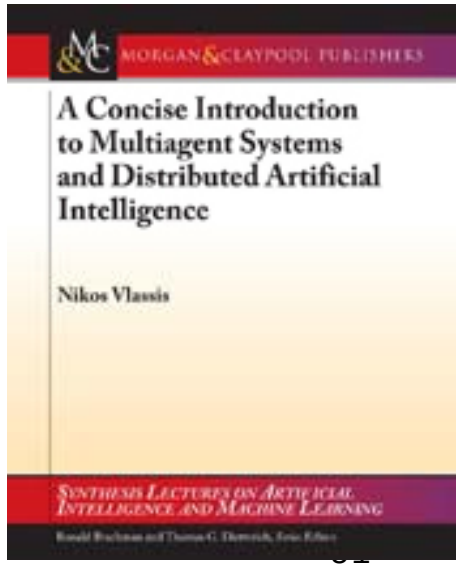

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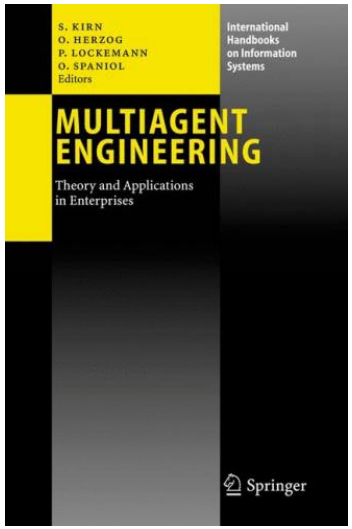

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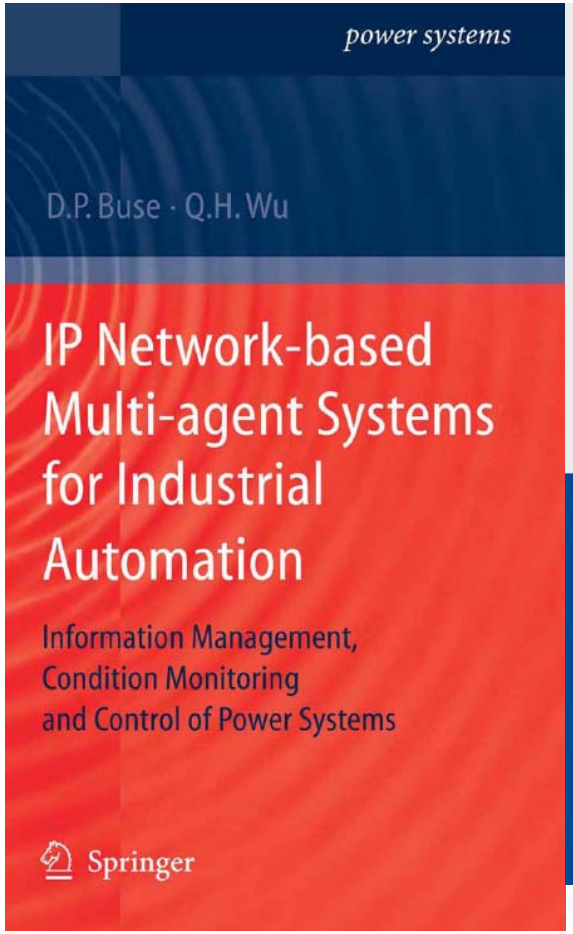
- Foundation for Intelligent Physical Agents (FIPA)
  http://www.fipa.org/index.html

Textbooks


power systems
D.P. Buse · Q.H. Wu
IP Network-based Multi-agent Systems for Industrial Automation
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Whitestein Series in Software Agent Technologies
Roland Zimmermann
Agent-based Supply Network Event Management
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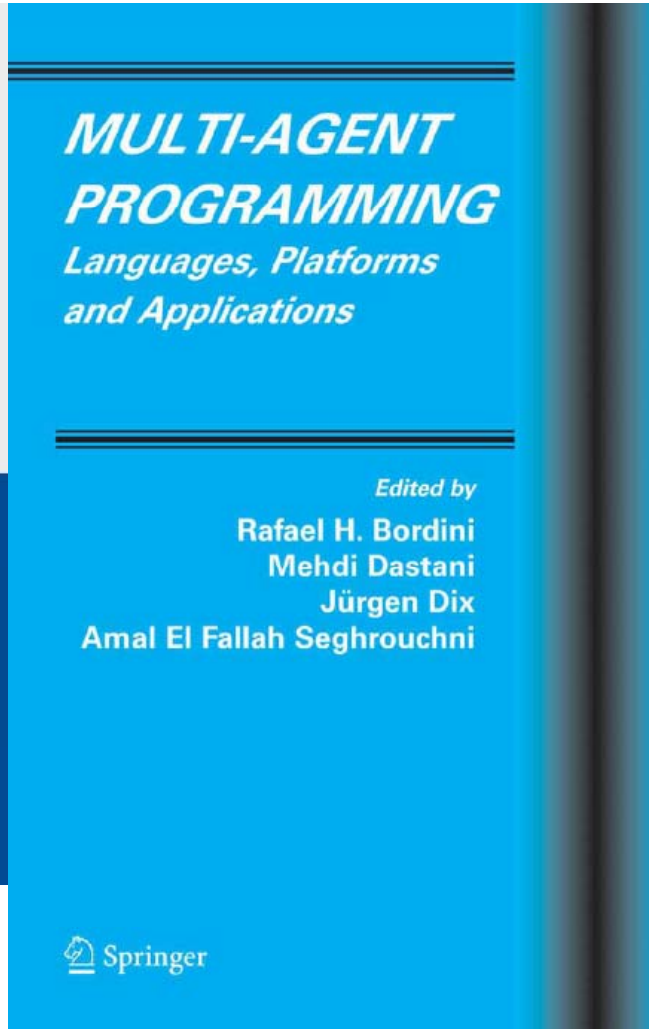
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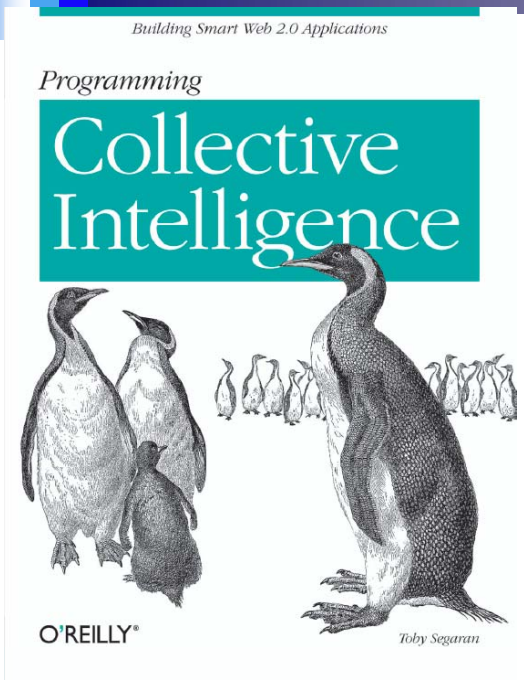
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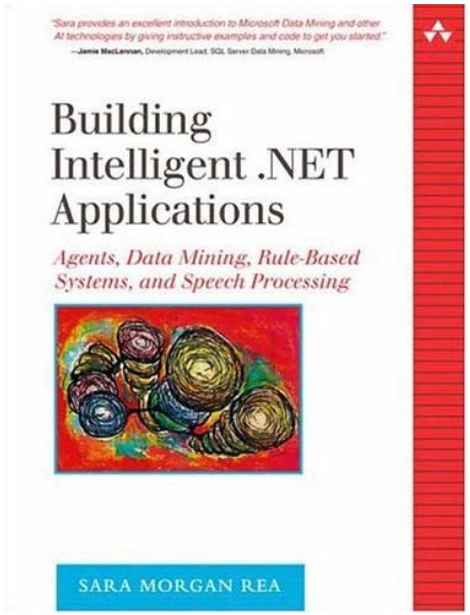
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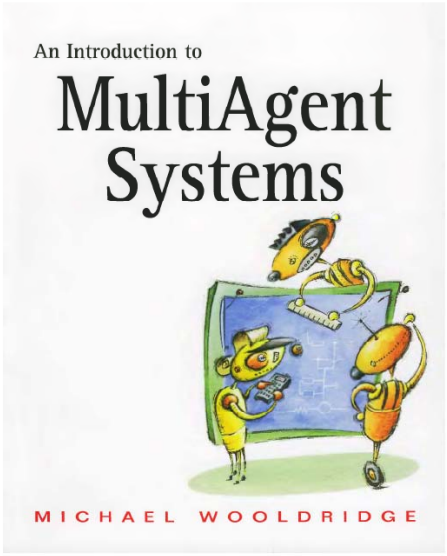
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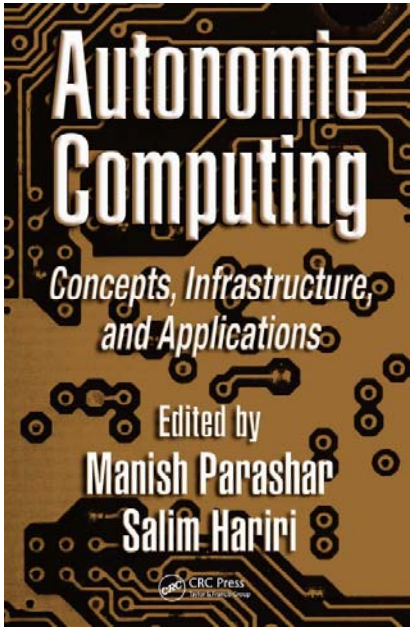
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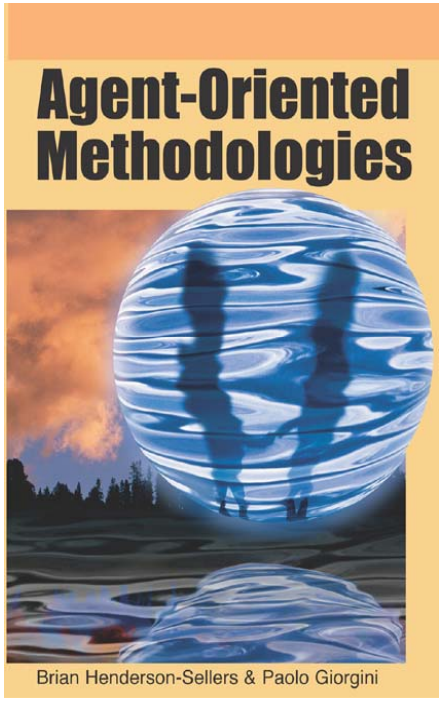
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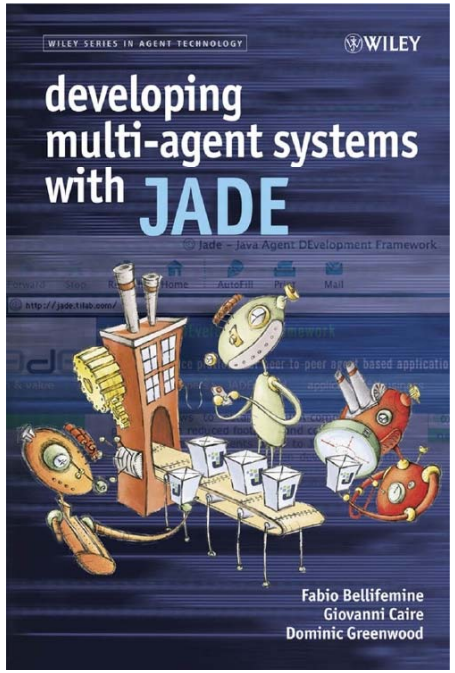
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