Multiagent Systems

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Motivation

To solve problems that are

- Complex
- Realistic
- Large-scale
- In distributed, open systems
- Heterogeneous
- Beyond the capabilities of an individual agent, which is limited by its knowledge, computing resources, and perspective.

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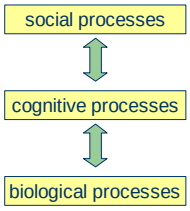
Cognition and Computation

Distributed AI
- Model of corporate memory
- Knowledge management

Knowledge Representation
- Model of episodic knowledge
- Personal memory assistant

Sub-symbolic AI
- Models of synaptic plasticity
- Neural network simulator



Distributed Artificial Intelligence

Definition: DAI is the study, construction, and application of systems in which several interacting, intelligent agents pursue some set of goals or perform some set of tasks.

Goal: to answer the question

When and how to interact with whom?

Previous DAI Research

Started in the late 70s

Brought together multiple disciplines
- Artificial intelligence
- Computer science
- Sociology
- Economics
- Organizational & management sciences
- Philosophy

Progress in the 90s
- Domain-independent frameworks emerged
- Standard protocol definitions
- Extensive models of collaboration

Traditional AI vs. DAI

Traditional AI
- Concentrates on agents and stand-alone systems
- Intelligence is a property of the *agent*
- Focus is on *cognitive* processes
- Inspired by psychology and cognitive science

DAI
- Concentrates on agents as part of a connected system
- Intelligence is a property of *interacting agents*
- Focus is on *social* processes
- Inspired by sociology and economics

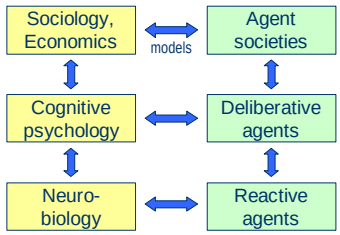
DAI Systems

Two types of DAI systems:

- Multi-agent systems
  - ¡ Several agents coordinate their knowledge and activities by reasoning about the problem solving process.
- Distributed problem solving
  - ¡ A particular problem is solved by dividing tasks among a number of generally equivalent nodes who divide and share knowledge about the program.

Modern multi-agent systems actually cover both.

Computational Modeling



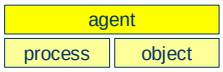
Modularity

A number of (nearly) modular components

- *Specialized* ¡ functionally specific for solving a particular problem aspect
- *Heterogeneous* ¡ using the most appropriate paradigm for solving its particular problem
- *Coordinated* ¡ managing interdependency via peer-to-peer interactions
  - ¡ Negotiation
  - ¡ Cooperation

Abstraction

- Object abstraction
  - ¡ Encapsulate data and algorithms
- Process abstraction
  - ¡ Encompass its own thread of control



Agent Abstraction

- Control
  - ¡ Agents control their behavior
  - ¡ Objects control their states
- Interaction
  - ¡ Agents request actions from other agents
  - ¡ Objects invoke methods of other objects
- Autonomy
  - ¡ Agents are capable of adaptive (reactive, proactive & social) behavior

Autonomous Behavior

- Classical software engineering
  - ¡ The programmer anticipates in the design of the system every possible action the system must perform.
- Agent-based software engineering
  - ¡ The programmer designs a system that decides for itself what to do in order to satisfy its design objectives.

Definition: MAS [Durfee & Lesser, 1989]

A loosely coupled network of problem solvers that interact with each other and their environment to solve problems that are beyond the individual capabilities or knowledge of each problem solver.

The problem solvers, or agents, are

- Autonomous
- Heterogeneous

Characteristics of MAS

Each agent has incomplete information or capabilities for solving the problem, and thus has a limited viewpoint.

There is no system global control.

Data are decentralized.

Computation is asynchronous.

Agent Interaction

Agents may be affected by other agents (including humans) in pursing their goals.

Interaction may take place directly via a communication language.

Interaction may take place indirectly via the environment.

Common Characteristics

Inherent distribution

- Geographical / spatial
- Temporal
- Semantics ¡ different ontologies & languages
  e.g. multiple existing legacy systems
- Functional ¡ different cognitive capabilities/expertise

Inherent complexity

- The problem is too large to be solved by a single, centralized system

MAS Example: RoboCup

Competition

Cooperation

Robustness

Situated behavior

- Position of the ball
- Other players

Autonomous

- No central control
- Non-command-driven

Agent Architecture

Single agent architectures

- Purely reactive
- Purely deliberative
- Layered / Hybrid
- Subsumption

Multi-agent Infrastructure

- RETSINA (CMU)
  http://www-2.cs.cmu.edu/~softagents/retsina_agent_arch.html
- agentTool (Kansas State University)
  http://www.cis.ksu.edu/~sdeloach/ai/agentool.htm

MAS Diversity

Agent	Interaction	Environment
Number	Frequency	Predictability
Uniformity	Persistence	Accessibility
Goals	Level	Dynamics
Architecture	Control flow	Diversity
Capability	Variability	Resources
	Purpose	

Challenging Issues

When and how should agents interact, either cooperate or compete, to successfully meet their design objectives?

Approaches

- Bottom up ¡ search for specific agent-level capabilities that result in sufficient group capabilities
- Top down ¡ search for group-level conventions that appropriately constrain interaction at the agent level

Planning Issues

Decompose tasks and goals

Allocate sub-goals and sub-tasks to other agents

Synthesize partial results

Represent and reason about the actions and plans of other agents

Interaction Issues

Agent communication languages & protocols

Represent and reason about

- Knowledge of other agents
- State of their interactions

In order to interact with them

Recognize & handle conflicts between agents

- Negotiate and contract
- Organizational structures

System Issues

Engineer practical multi-agent systems

Balance local computation vs. communication

Formal specification

- Multi-agent systems
- Interaction between agents

Correctness

MAS Applications

Electronic commerce
Modeling and control of transportation systems
Information handling
Automatic meeting scheduling
Real-time monitoring and control of networks
Industrial manufacturing and production
Electronic entertainment
Re-engineering of enterprise information flow
Investigation of complex social phenomena