David Keil, CSCI 400 Artificial Intelligence
Framingham State University

Topic 7: Distributed AI

1. What is distributed artificial intelligence?
2. Multi-agent systems
3. Stigmergy and self-organizing systems

Inquiry

- Is intelligence *emergent* and *decentralized*?
- Do persistent, dynamic, physical environments pose problems solvable only with multi-agent systems and distributed AI?
- What is the role of indirect interaction in intelligence?

Objectives

7a. Describe multi-agent solution approaches

7b. Explain the relationship of intelligence to indirect interaction, self organization, and emergent behavior

1. What is distributed AI?

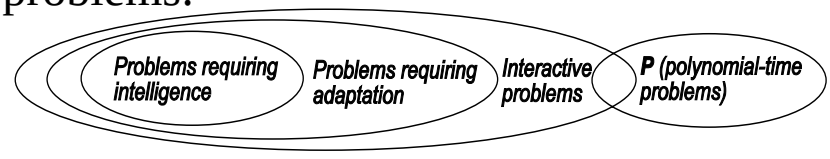
- DAI is intelligent (rational, adaptive) behavior of multi-agent systems in an interactive environment
- A multi-agent system is a set of agents that *coordinate* for a common mission
- Multi-stream interaction may produce self-organization and emergent behavior

Distributed AI and other AI

Old AI	New AI
Find a computational path	Learn a policy, using coordination
Reasoning in a closed world	Open systems
Human intervention	Autonomy
Heuristics	Emergent behavior
Toy environment	Real-world environment
Brittle solutions	Scalable solutions

Changes in AI

- AI has moved away from algorithmic computing and reasoning, in a closed world, toward rational-agent behavior
- AI is more and more associated with distributed and multi-stream systems
- A hierarchy of difficulties of interactive problems:



2. Multi-agent systems

- A system of problem solvers situated in interactive environments
- Features of agents:
  - Situated
  - Autonomous
  - Flexible
  - Social

Adaptation and multi-agent systems

- MASs enable *distributed AI*
- *Behavior:* action to change the environment
- *Adaptation:* learning that changes behavior; occurs in dynamic persistent environments
- MASs are often flexible enough to adapt well
- *Sociogenetic adaptation*, contrasted, with *ontogenetic* (simple-agent) and *phylogenetic* (evolutionary) is adaptation by multi-agent systems

Multi-agent planning

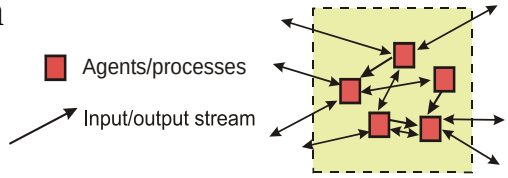
- *Joint plans* are solutions if they achieve the goal when all agents act according to plan
- Agents need a way to *coordinate* execution of joint plan
- Environment is *dynamic* because multiple agents are present and may act
- *Synchronization* is necessary
- Joint plan is a partially ordered graph of joint actions (tuples of actions by multiple agents)

Concurrent action planning

- *Concurrent action list* specifies actions that must be executed concurrently
- *Examples:*
  - For A to hit the ball, other agents must *not* concurrently do so
  - For agents to carry a large container, two agents must do so concurrently
- *Time relations* of <, >, and = are valid
- *Conventions* such as “stay on the right side of the road” are required

Multi-stream interaction

- **Definition:** Interactive computation involving more than two entities
- Multi-stream interaction may include:
  - *Asynchrony*
  - *Nondeterminism* when attempts to write collide
  - *Dynamic linking* and unlinking, creation/destruction
  - *Indirect interaction* via a shared environment



Indirect interaction and multiagent systems

- In a MAS characterized by locality of interaction and mobility of agents, it is only possible for agents to influence overall system behavior remotely, i.e., indirectly
- Richness of multiagent interaction:
- due partly to ability of each agent to interact with multiple others
- hence indirectly with *all* others (otherwise system partitions)

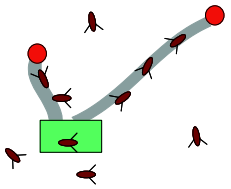
Multi-agent evolutionary computation

- *Swarm* or *ant* computing
- *Coevolution:* Evolution of species whose instances interact in multi-agent systems
- *Particle swarm optimization:* Particles are candidate solutions to a problem in *n*-dimensional space, particles are accelerated through this space in relation to each other and to objective function

3. Stigmergy and self-organizing systems

- *Stigmergy:* A variety of self-organization in which mobile agents interact via their shared environment
- *Contrast to:* direct interaction; centralized interaction
- Examples:
  - termites gathering chips,
  - ants foraging,
  - slime mold aggregation

Stigmergy in nature



1. Ants foraging for food: Ants leave pheromone trail, prefer existing trails, blaze shorter and shorter trails to and from food

2. Termites gathering chips into pile: Move at random, pick up chip when encountered, put down when another chip found; the pile structure is used to coordinate creation of pile (*StarLogo*)

3. Slime mold dividing and aggregating: These amoeba may aggregate by emitting a chemical, migrating toward its greatest concentration

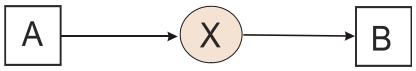
Q: Is stigmergy essential for some tasks?

Bees and ants

- Bees communicate direction and distance of pollen sources by “waggle dance”, an example of *message passing*
- Ants communicate via pheromone trails; the “message” is the entire trail followed by an ant, i.e., no single ant sends a message to another single ant
- *Conjecture:* Difference in means of communication is due to difference in foraging environments

Indirect interaction

- *Interaction via persistent, observable state changes, in which the destination of output is any agent that observes these state changes*
- Features:
  - anonymity (recipient ID not used in access)
  - time delay (state changes persist)
  - space decoupling (agents *A*, *B* need not meet)
- Agents *A* and *B* (below) may interact with each other *indirectly* via shared variable *x*



Ubiquity of indirect interaction

- **Social biology**: Social insects interact by modifying common structures or through pheromones
- **Operating systems**: Processes communicate via *semaphores* in shared memory
- **Coordination languages**: Shared *tuple spaces* enable coordination in Linda
- **Anatomy**: Cells exchange information via *hormones* in the blood stream
- **Economics**: A *market* is an environment for buyers and sellers that serves as a medium for indirect interaction

Properties of indirect interaction

- **Time decoupling (asynchrony):** State changes persist
- **Anonymity:** Recipient ID not used in access
- **Space decoupling:** Agents need not meet
- **Non-intentionality:** Agents need not have goal of communicating
- **Hybrid nature:** Physical environment may play role
- **Late binding** of recipient

Environments for multi-agent systems

E4MAS 2005 Proceedings cited as examples the environments of:

- visitors to a web site;
- a system of autonomous guided vehicles;
- a system of manufacturing control;
- a PDA-based system of agents to help support activities of museum visitors.

All involve indirect interaction

A taxonomy of environments

Amnesic vs.	Static vs.	Virtual vs.
Persistent	**Dynamic**	**Physical**

- An environment is ***amnesic*** if its outputs depend only on its *immediately preceding* inputs
- An environment *E* is ***static*** with respect to an agent or MAS *A* if its outputs to *A* are *strictly dependent* on its previous inputs from *A*
- A ***virtual*** environment is accessed digitally; a *physical* environment is observable only by analog sensors.

Indirect interaction and multi-agent systems

- In a MAS characterized by *locality* of interaction and *mobility* of agents, it is only possible for agents to influence overall system behavior by use of indirect interaction
- Richness of multiagent interaction:
- It is due partly to ability of each agent to interact with multiple others
- Hence each agent interacts indirectly with *all* others (otherwise system partitions).

Self-organizing system

- *Definition:* a multi-agent system with a coher-ent global structure or pattern shaped by local interactions among components, rather than by external forces
- Associated with *decentralization*

Decentralized systems

- Lend themselves to flexibility and adaptiveness
- *Where required*: in environments that are dynamic, persistent, multi-agent, decentralized, and self-organizing.
- *Decentralized system:* a multi-agent system whose components do not respond to commands from an active director or manager component, and do not execute prespecified synchronized roles under a design or plan.

Concepts

anonymity
asynchrony
autonomy
behavior
concurrent action list
configuration space
decentralized system
distributed AI
emergent behavior
emergent intelligence
indirect interaction
joint plan
mobility
model based approach
multi-agent system
multi-stream interaction
self-organizing system
social biology
sociogenetic adaptation
space decoupling
stigmergy

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