Modeling indirect interaction in multiagent systems

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Intelligence is interactive

- What kind of interaction is needed to act intelligently?
- *Example:* Mars rovers need not just to compute answers to questions, but to *adapt* to a changing environment.
- The interactive environment defines the problem.
- Intelligence is the ability to adapt in an interactive, changing environment.
- Our interest: intelligent behavior through *self-organization*, via *indirect interaction*, in *multiagent systems*

Five dimensions to classify environments

- accessible vs. inaccessible;
- deterministic vs. non-deterministic;
- episodic vs. nonepisodic;
- static vs. dynamic;
- discrete vs. continuous

(Russell-Norvig, 1995)

Adaptation

- Definition: learning that changes behavior
- The aim of behavior is to change one's environment in a favorable way
- Key type of environment:
  - *dynamic* (environment may change independently of agent)
  - *persistent* (environment's state is subject to change in response to agent)

Some interaction patterns in natural settings

1. **Termites gathering chips**
   Move at random, pick up chip when encountered, put down when another found
2. **Ants foraging for food**
   Ants leave chemical trail, prefer existing trails, blaze shorter and shorter trails to and from food
3. **Slime mold dividing and aggregating**
   These amoeba may aggregate by emitting a chemical, migrating toward its greatest concentration

Self-organization and emergent behavior

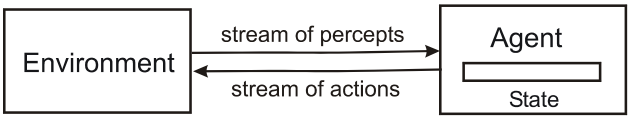
- *Definition:* **Self-organization** is the decentralized interaction of a set of processes or structures at a lower level of a system to yield global structures or behavior at a higher level
- *Example:* Chemical reactions
- *Contrast to:* Centralized, algorithmic behavior
- System behavior that is not the sum of component behaviors is called *emergent*

Stigmergy

- *Definition:* 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

Sequential interaction

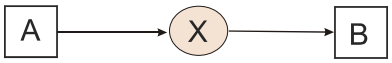
- *Definition:* An *interactive computation* is an ongoing exchange of data among computing agents, such that the output of each may causally influence its later inputs
- *Definition:* An *agent with persistent state* (APS) is an entity that accepts inputs, emits outputs, and has a *state* or *memory* whose value may change from one I/O step to the next



Indirect interaction

Defn: Interaction via persistent, observable state changes, in which the destination of output is any agent that observes these state changes

- Agents *A* and *B* (right) may interact with each other *indirectly* via shared variable *x*



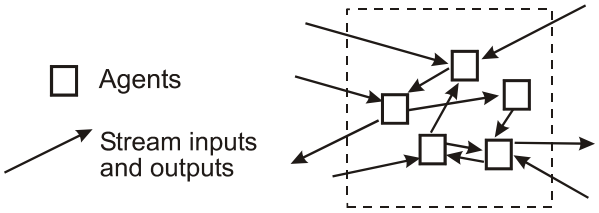
- Features:
  - anonymity (recipient ID not used in access)
  - time delay (state changes persist)
  - space decoupling (agents *A*, *B* need not meet)

The power of persistence

- *Discussion:* It can be shown that computing agents with persistent state are capable of a wider range of behaviors than ones without persistent state
- *Example*: By remembering past answers, prosecutor may ask questions that force a witness to tell the truth or contradict self
- Persistence of environment is what enables termites, ants, slime mold to coordinate actions

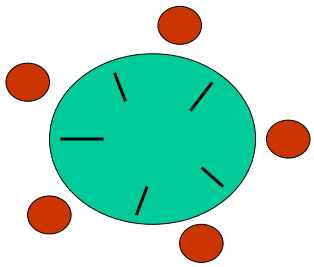
Multiagent interaction

- MAI is characterized by *multiple concurrent streams* of input/output, and by *creation/destruction* of these streams during a computation
- MAI is distinguished from *sequential interaction* and is more powerful



Dining Philosophers

- *Rule:* Philosophers sit in circle, with one chopstick between each pair
- *Activity of each*: Eat, think, eat, think…
- *Global goal*: coordinate to avoid starvation
- *Features of problem*:
  - Locality
  - Anonymity
  - Asynchrony
  - Non-intentionality
- Solution requires indirect interaction



Multiagent systems require indirect interaction

Theorem:

- *Let S be a multiagent system that contains agents and possibly shared variables that form a DPE w.r.t. the other agents.*
- *Then indirect interaction occurs in S.*

Significance: Since indirect interaction is an *essential* feature of multiagent *systems*, we must *model* this form of interaction

Proof

1. Let *S* be a multiagent system in which some subset of agents, and possibly shared variables, form a dynamic persistent environment with respect to the others.
2. Suppose *S* is characterized by direct interaction only.
3. A pair of agents in *S* interacts, by definition, only if each affects its own later inputs by its actions.
4. But because (2) rules out indirect interaction, no pair of agents in *S* communicates via state changes created by one and observable by the other in a common environment.
5. Hence no part of *S* has persistent state, hence no part can be a DPE w.r.t. the other part, contradicting (1). Hence (2) must be false.

References

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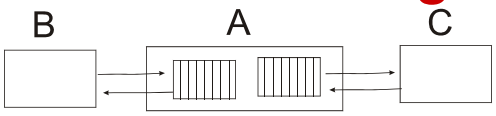
Additional ideas
Difficult environments

- **Definition:** A class *A* of environments is *more difficult* than a class *B*, with respect to set *S* of adaptive agents, iff *A*'s range of observable behaviors is a strict superset of *B*'s.
- **Lemma:** The set of system behaviors observable in dynamic persistent environments strictly includes the set of behaviors observable in amnesic environments.

Indirect interaction and multiagent systems

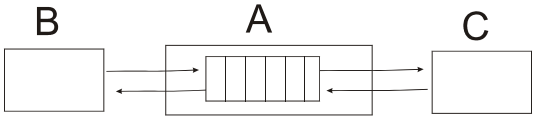
- In a MAS characterized by *locality* of interaction and *mobility* of agents, it is only possible for agents to influence overall system behavior by use of indirect interaction
- Richness of multiagent interaction:
  - It is due partly to ability of each agent to interact with multiple others
  - Hence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

Trivial vs. meaningful MAI



(b) partitioned state

- When agents *B* and *C* each interact with *A* via their own partitions of A's state, they do not interact with each other (b).
- When *B* and *C* share access to the same memory in *A*, they interact, *indirectly* (a).



(a) shared state