SWEN90004
Modelling Complex Software Systems

Lecture Cx.07
Agent-Based Models I

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Semester 1, 2019

Outline

What is an “agent-based” model?

Like cellular automata (CA), agent-based models (ABMs) are an approach to modelling complex systems that focuses on the *components* of the system and the *interactions* between them.

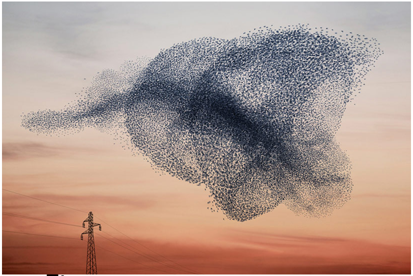
An ABM typically has three elements:

- agents
- environment (including other agents)
- interactions

ABMs *differ* from CA in that allow more flexibility in how they represent agent behaviour and interaction structure.

An example: flocking behaviour

Flocking behaviour, as exhibited by large groups of birds and fish, was earlier introduced as a canonical example of complex system.



FigureA murmuration of starlings

http://www.alaindelorme.com/

Craig Reynolds, a computer graphics and animation expert who has worked for Electronic Arts, DreamWorks Animation and Sony, develped an early (1986) ABM model of flocking behaviour.

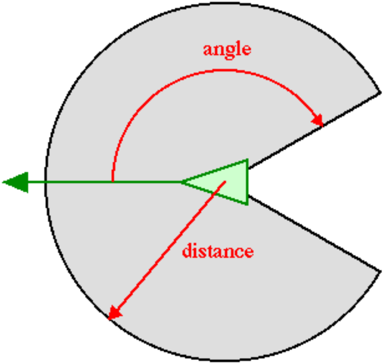
‘Boids’ model of flocking behaviour

The agent (Reynolds used the term *boid*)

Agent behaviours include:

- forward motion
- turning left or right
- (perhaps) acceleration and deceleration

The boids neighbourhood function

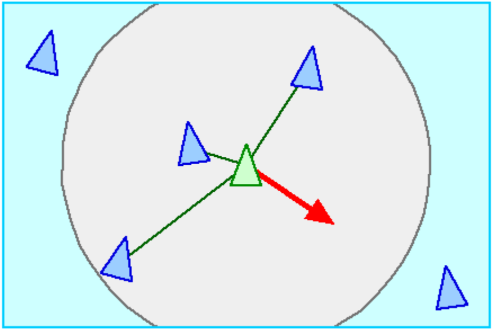


http://www.red3d.com/cwr/steer/gdc99/

- The environment consists of the other boids in the flock.
- The neighbourhood function is the sensory range of the boid (how far away it can perceive other agents).
- Boids 'interact' according to the following three rules...

Rules for flocking behaviour

1. Separation



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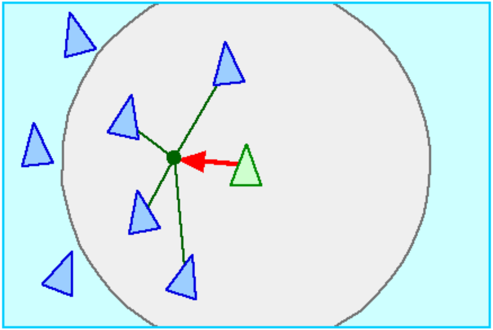
Boids will steer to avoid crowding nearby boids—*collision avoidance*

Rules for flocking behaviour

2. Cohesion



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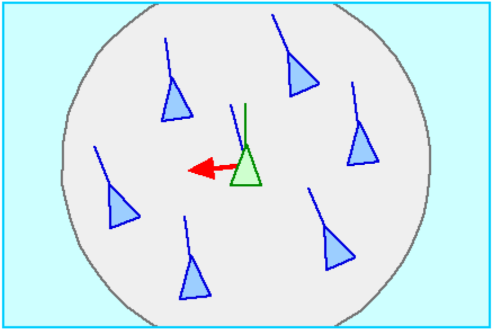
Boids will steer towards the average location of nearby boids—*safety in numbers*

Rules for flocking behaviour

3. Alignment



http://www.red3d.com/cwr/steer/gdc99/

Boids will steer toward the average bearing of nearby boids

Outline

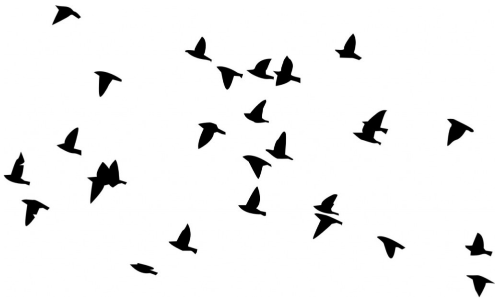
Introduction to agent-based models

Characteristics of agents

Environment and interactions

Agent decision making

Essential characteristics: self-contained



An agent is a modular component of a system, is has a boundary and can be clearly distinguished from and recognised by other agents.

Flocking model: the boids are clearly distinguishable and 'recognised' (though not uniquely) by other boids.

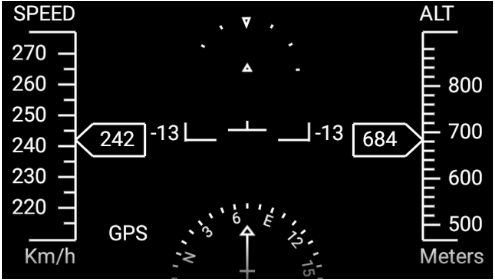
Essential characteristics: autonomous

http://pixabay.com/

An agent can function independently in its environment, and in its interactions with other agents (within the scope of the defined model).

Flocking model: the behaviour of each boid is entirely defined by the information it obtains about its local environment

Essential characteristics: dynamic state



http://www.hudforglass.com/

An agent has attributes, or variables, that can change over time. An agents current state is what determines its future actions and behaviour.

Flocking model: a boid's state consists of its current heading and speed. This state determines the motion of the boid, and is modified on the basis of information it recieves about its local environment.

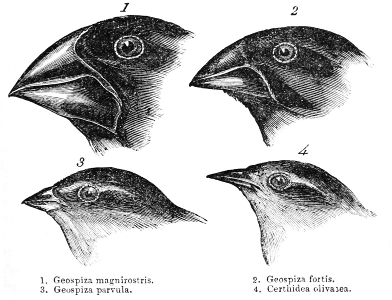
Essential characteristics: social

http://www.alexanderwild.com/

An agent has dynamic interactions with other agents that influence their behaviour.

Flocking model: boids ‘interact’ by perceiving and reacting to the location and behaviour of other boids.

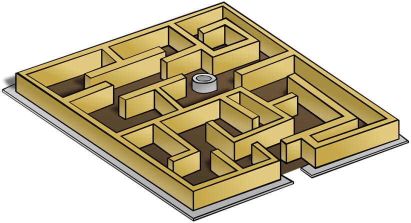
Other characteristics: adaptive



An agent may have the ability to learn and adapt its behaviour on the basis of its past experiences.

For example, imagine if prey boids in predator-prey model observed that predators more often attacked boids on their right than their left (becuase of the location of their sensors/eyes), they might be able to 'learn' to move to the left of a predator and hence escape detection.

Other characteristics: goal-directed



An agent may have goals that it is attempting to achieve via its behaviours.

For example, imagine that, in addition to avoiding predators, prey boids also have the goal of collecting materials to build a nest... This would be another factor influencing their behaviour.

Other characteristics: heterogeneous

A system may be comprised of agents of different types: these differences may be by design (eg, predators and prey), or a result of an agents' past history (eg, the 'energy level' of predators, based upon whether it has eaten recently)

More complex ABMs might include a wide array of different types of agents; for example, models of land use may include residents, planners, infrastructure providers, businesses, developers and lobbyists, etc.

Outline

Environment

- Agents monitor and react to their *environment*—the physical or virtual space in which the agent 'functions'.
- The one- and two- dimensional grids of CA were very simple environments.
- Environments may be *static* (unchanging over time), or they may change as a result of agent behaviour, or they may be independently *dynamic*.
- Real environments are typically dynamic (and often stochastic). Therefore we may not be able to foresee all possible 'states' of the environment and how agents will respond to them.

Interactions

- A defining characteristic of complex systems is *local interactions* between agents, as defined by the agent *neighbourhood*.
- Depending on the structure of the system, the composition of an agent's neighbourhood may be *dynamic* (ie, change over time as it moves through its environment)
- Neighbourhoods, and hence patterns of interaction, are not always defined in *spatial* terms—they may also be *networks* with a particular topology (more on this next week)

Example: Foraging in ant colony

Ant colonies are able to achieve remarkable feats of organisation—constructing elaborates nests and efficiently foraging for food—"*without chief, overseer or ruler*"

- Work by evolutionary biologist Edmund O. Wilson in the 1960s and 1970s led to new understanding of how ant societies operate.
- Individual ants perform a limited range of tasks—picking up and dropping food and building materials—based on relatively simple decision rules.
- The inputs to these decision rules are chemical signals (pheromones). These signals can come from both:
  - direct interactions with nearby ants; and
  - *stigmergic* interactions via pheromones deposited by ants in the environment

Ant colony foraging

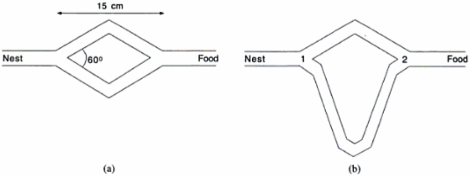


Figure 1.1
Experimental setup for the double bridge experiment. (a) Branches have equal length. (b) Branches have different length. Modified from Goss et al. (1989).

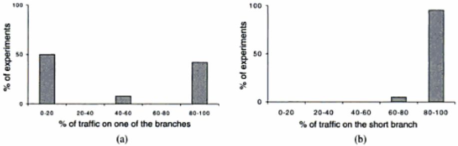


Figure 1.2
Results obtained with *Iridomyrmex humilis* ants in the double bridge experiment. (a) Results for the case in which the two branches have the same length ($r = 1$); in this case the ants use one branch or the other in approximately the same number of trials. (b) Results for the case in which one branch is twice as long as the other ($r = 2$); here in all the trials the great majority of ants chose the short branch. Modified from Goss et al. (1989).

Dorigo M, Stutzle (2004) *Ant Colony Optimization*, MIT Press

NetLogo 'Ants' model

Ant rules

1. If an ant is not carrying food:
   - move randomly around its environment
   - if it encounters *food* pherommenes, move in the direction of the strongest signal
2. If an ant encounters food:
   - pick it up
3. If an ant is carrying food:
   - follow the *nest* pheromone gradient back toward the nest
   - deposit *food* pheromones into the environment while moving

Environment

- There is a *nest* pheromone gradient diffusing out from the nest
- *food* pheromones evaporate over time

Outline

Agent decision making

Agents are often designed to make *rational* decisions: they will act to maximise the expected value of their behaviour given the information they have received thus far.

Note that:

- rational $\neq$ omniscient: an agent's percepts may not supply *all* required information
- rational $\neq$ clairvoyant: an agent's actions may not produce the expected outcome
- therefore, rational $\neq$ successful (necessarily)
- rational $\rightarrow$ exploration, learning, adaptation, ...

Agent decision making

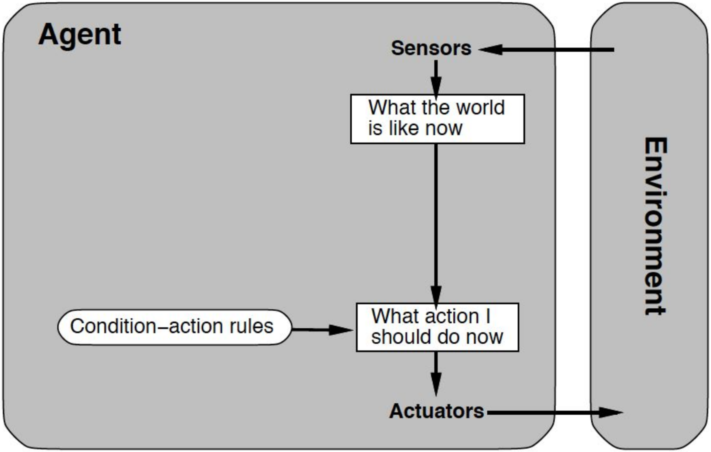
Agent decision making may be:

- probabilistic: representing decisions using distributions
- rule-based: modelling the decision making process
- adaptive: agents may *learn* via reinforcement or evolution

The choice will often depend on the purpose of the model (what question is it being used to answer?)

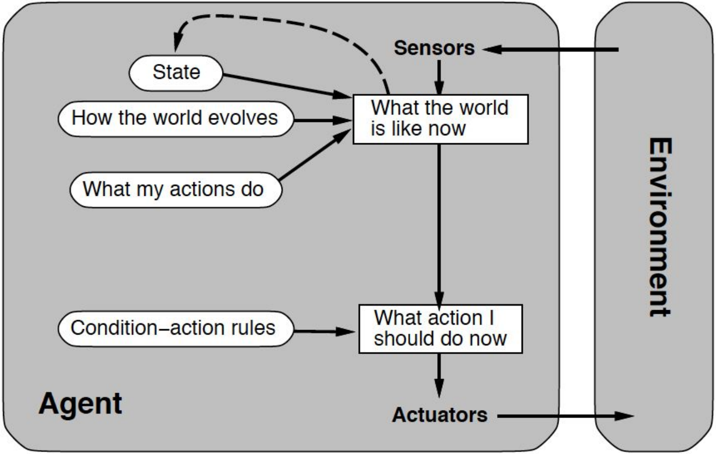
Agent decision making can range from simple to complex...

Reflexive agents



Russell and Norvig (2009) *Artificial Intelligence: A Modern Approach*, Prentice Hall

Reflexive agents with internal state



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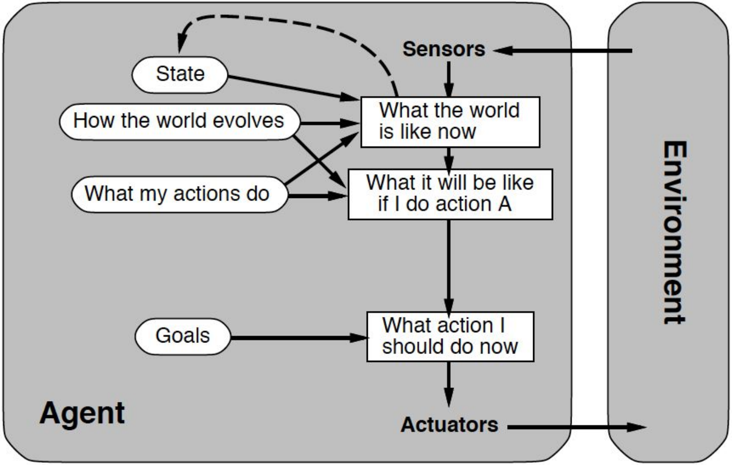
Goal-driven agents



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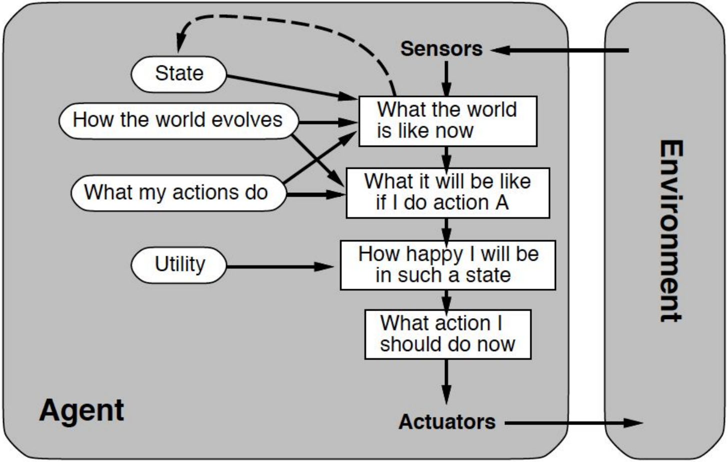
Utilitarian agents



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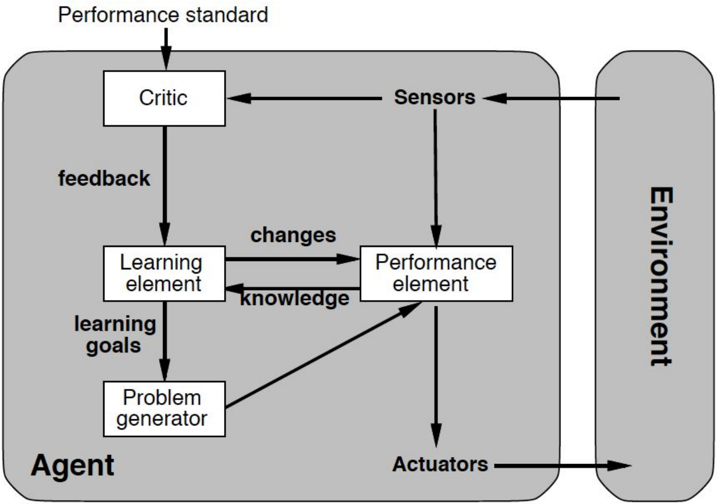
Learning agents



Russell and Norvig (2009) *Artificial Intelligence: A Modern Approach*, Prentice Hall

Summary

- Agent-based models consist of agents, an environment, and interactions between agents and (a) other agents and (b) the environment.
- ABMs feature *decentralised* information and decision making, and can reproduce the *emergent* behaviour and *self-organisation* found in complex systems.
- ABMs are employed in a wide variety of domains: ecology, social science, economics, political science, etc.
- ABMs can be much more elaborate than CAs.

Follow up activites!

Explore the Flocking, Ants and Segregation models in NetLogo

Think about:

- What are agents? What state variables do they have? What decisions do they make?
- What is the environment? Is it static or dynamic?
- What interactions take place? Between agents? Between the agents and the environment?

References

- Macal CM, North MJ (2010), Tutorial on agent-based modeling and simulation. *Journal of Simulation* 4:151–162
- Reynolds C (1987) Flocks, herds and schools: a distributed behavioral model, *SIGGRAPH '87: Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques*, Association for Computing Machinery, pp 25–34
- Schwarz N, Kahlenberg D, Haase D, Seppelt R (2012) ABMland—a Tool for Agent-Based Model Development on Urban Land Use Change, *Journal of Artificial Societies and Social Simulation* 15(2):8
- Bonabeau E, Theraulz G, Deneuborg J-L, Aron S, Camazine S (1997) Self-organization in social insects, *Trends in Ecology and Evolution* 12(5):188–193