Reactive agents & Simulation

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Concrete vs. abstract architectures

- Different ways of specifying the *action*
  - Logic-based: decision function implemented as a theorem prover (plus control layer)
  - *Reactive: (hierarchical) condition $\rightarrow$ action rules*
  - BDI: manipulation of data structures representing *Beliefs, Desires and Intentions*
  - Layered: combination of logic-based (or BDI) and reactive decision strategies
Stimuli and responses

- **Behaviour:**
  the product of an agent’s interaction with its environment

- **Intelligence:**
  patterns that *emerge* from the interactions triggered by different behaviours

- **Emergence:**
  The transition from *local feedback* (human designed) and *global feedback* (product of agent autonomy).
A typical scenario

- Multiple goals
  - sometimes conflicting or inconsistent
- Multiple sensors
  - dealing with varied, sometimes inconsistent readings
- Robustness and fault tolerance
  - w.r.t. loss of agents
- Additivity
  - the more sensors and capabilities, the more processing power the agent needs
Comparing action models

- **Cognitive Agent action model**

  - Sensors
  - Perception
  - Modelling
  - Planning
  - Task execution
  - Motor control
  - Actuators

- **Reactive Agent action model**

  - Sensors
  - Reason about behaviour of objects
  - Plan changes to the environment
  - Identify objects
  - Monitor changes
  - Build maps
  - Explore
  - Wander
  - Avoid objects
  - Actuators
Some reactive architectures

- Situated rules:
  - PENG1 [Chapman and Agre, 1987]
- *Subsumption architecture*
  - [Brooks, 1986]
- Competing tasks (Maes, 1989)
- Eco Agents [Drogoul and Ferber, 1992]
- Neural nets??
- ...
A simple reactive architecture

The subsumption diagram
A Formalisation

- Situated Rules represented as pairs \( < c, a > \) (behaviours)

- The set of all possible behaviours is then:
  \[
  \text{Beh} = \{ < c, a > \mid c \in P \land a \in A \}
  \]

- The subsumption hierarchy will be represented by a total ordering, \( \prec \), on the behaviour relation, \( R \subseteq \text{Beh} \):
  \[
  \prec \subseteq R \times R
  \]

- We say that “\( b \) inhibits \( b' \)” if \( b \prec b' \)
A reactive decision function

1. function \textit{action}(p : P) : A
2. \textbf{var} fired : \wp(R)
3. \begin{verbatim}
4. fired := \{\langle c, a \rangle | \langle c, a \rangle \in R \land p \in c\}
5. for each \langle c, a \rangle \in fired do
6. \quad if \neg (\exists \langle c', a' \rangle \in fired \land
7. \quad \langle c', a' \rangle \prec \langle c, a \rangle)
8. \quad then return a
9. \quad end if
10. \end for
11. return \textit{noop}
12. end function \textit{action}
Time complexity

- For the “naive” algorithm above...
  - action() = \( O(n^2) \),
    where \( n = \text{max}(|R|, |P|) \)
- N.B.: Complexity for each agent
- (In practice, one can often do better than \( O(n^2) \), low time complexity being one of the main selling points of reactive architectures.)
Example: collective problem solving

▶ Case study: Foraging Robots
[Steels, 1990, Drogoul and Ferber, 1992]:

▶ Constraints:
  ▶ No message exchange
  ▶ No agent maps
  ▶ obstacles
  ▶ gradient field
  ▶ clustering of samples
Simple collecting behaviour

Subsumption ordering: (1) ≺ (2) ≺ (3) ≺ (4) ≺ (5) ≺ (6)

1. If obstacle_detected
   then change_direction

2. If carrying_samples and at_base
   then drop_samples

3. If carrying_samples and not_at_base
   then travel_up_gradient

4. If sample_detected
   then pick_up_sample

5. If sample_sensed
   then move_towards_sample

6. If TRUE
   then move_randomly
Same rules (roughly), as described in [Drogoul and Ferber, 1992]
Can we improve on this design?

- What is the problem with the proposed system?
Can we improve on this design?

- What is the problem with the proposed system?
  - Too many random trips when samples in clusters.
- Try Indirect communication: “bread crumbs”, ant pheromones, etc
- Replace rules (3) and (5) by:

  (3’) If carrying samples and not_at_base then drop_crumb and travel_up_gradient

  (5’) If sample_sensed or crumb_sensed then move_towards_sample_or_crumb
After replacing (3) and (5):
Further improvement?

- What is the long-term effect of laying bread crumbs? Is there room for improvement?
Further improvement?

- What is the long-term effect of laying bread crumbs? Is there room for improvement?
- Change (3’) into:

  (3") If carrying_samples and not_at_base then drop_2_crumbs and travel_up_gradient

- and add the following:

  (7) If crumb_detected then pick_up_1_crumb
The subsumption ordering becomes

• $(1) \prec (2) \prec (3'') \prec (4) \prec (7) \prec (5') \prec (6)$
Advantages of this approach

- Low time (and space) complexity
- Robustness
- Better performance
  - (near optimal in some cases)
  - problems when the agent population is large
Agent chains

- New rules ("docker robots") [Drogoul and Ferber, 1992]

  (a) If not_carrying_sample and 
      travelling_down_gradient and 
      detected_sample_carrying_agent 
  then pick_up_other_agents_sample and 
      travel_up_gradient

  (b) If carrying_sample and 
      travelling_up_gradient and 
      detected_empty_agent 
  then deliver_sample_to_other_agent and 
      travel_down_gradient
Behaviour diagram
A simulation
How do the different architectures perform?

Number of cycles

Minimum: 697 cycles (93 robots)
Average: 1805 cycles

Number of robots
Simulation Agents and Reactive Architectures

Agents for

Problem solving
Planning reasoning
Emergent behaviour
Emergent patterns
Artificial life

Simulations
Why use agents in simulations

- challenges for “traditional” modelling methods:
  - how to extrapolate a model to situations where the assumptions on which it is based (described through ODEs or PDEs, for instance) no longer hold;
  - how to explain the macroscopic properties of the systems modelled;
  - how handle heterogeneity;
  - how to handle discontinuity...
Background

- A workshop [Langton, 1989]
- Nonlinear models and complex systems:
  - A few phenomena which resist linearisation: plant growth, weather, traffic flow, stock market crashes, intelligence, ...
- “Understanding by building”:
  - Individual-based Modelling in Biology (population biology, ecology, ...)
  - principles of intelligent behaviour
  - and practical applications
Applications to games

- Artificial Life: cellular automata and the “Game of Life”

- Tamagotchi, The Sims™, etc

- Distributed search and problem solving (e.g. for path-finding)
Examples: Conway’s Life

A “zero-player” game invented by John H Conway in the 70s.

Rules:

1. Any live cell with fewer than two live neighbours dies, as if caused by under-population.
2. Any live cell with two or three live neighbours lives on to the next generation.
3. Any live cell with more than three live neighbours dies, as if by overcrowding.
4. Any dead cell with exactly three live neighbours becomes a live cell, as if by reproduction.

(Demo in http://codepen.io/safx/full/Ewcym \(^1\))

\(^1\)By http://codepen.io/safx/
Entertaining examples: flocking behaviour

- Craig Reynolds page at Sony Entertainment:

- Steering behaviours:

  **Separation**: steer to avoid crowding local flockmates

  ![Separation Diagram]

  **Alignment**: steer towards the average heading of local flockmates

  ![Alignment Diagram]

  **Cohesion**: steer to move toward the average position of local flockmates

  ![Cohesion Diagram]

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\(^2\)http://www.red3d.com/cwr/boids/ see demo Video and applets. Figures borrowed from this website.
Emergence in agent-based simulations

- Emergence in complex systems:
  
  *Stable macroscopic patterns arising from the local interaction of agents.*

- Example: Skewed “wealth” distribution in [Epstein and Axtell, 1996, ch 2]
Advantages of agent-based modelling

- Simplicity: shift from mathematical descriptions of entire systems to rule based specifications of agent behaviour.
- Implementation of complex boundary conditions: in agent-based simulations, environments with irregular shape are not more complex to model than regular ones.
- Inherent parallelism: no code changes when porting to parallel architectures
- Adequacy to modelling of small populations
- Realism (?)
Disadvantages of agent-based modelling

- Memory and processing speed might constrain the size of the agent population in the model.
- Difficulties in exploring the parameter space, if the simulation comprises a large number of rules.
- Understanding how simple local behaviour gives rise to complex global behaviour is not always an easy task; if a model captures too much of the complexity of the world, it may become just as difficult to understand as the world itself.
- “Noise” introduced by the model or its implementation might give rise to phenomena not present in the real system.
Agent modelling toolkits

- Swarm, RePast, StarLogo, Ascape, ...
- What they provide
  - mechanisms for managing resource allocation
  - a schedule
  - basic environment topography
  - graphics, (media handling etc)
  - a scientific computing library
  - basic statistics
  - Usually no built-in agent semantics

Applications of agent-based modelling

- Sociological models (e.g. [Epstein and Axtell, 1996])
- Biological simulations
  - Insect societies
  - bacterial growth
  - forest dynamics
- Molecule interaction in artificial chemistry
- Traffic simulations
- Computer networks (see http://www.crd.ge.com/~bushsf/ImperishNets.html, for instance)
RePast: A (Pure) Java Simulator

- Repast is an acronym for *REcursive Porous Agent Simulation Toolkit*.
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From the Repast web site
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- ??????
Two simulations: 1 - Mouse Traps

- A demonstration of “nuclear fission”:
  - Lay a bunch of mousetraps on the floor in a regular grid, and load each mousetrap with two ping pong balls.
  - Drop one ping pong ball in the middle...

- A discrete-event simulation that demonstrates the dynamic scheduling capabilities of Repast

- The agent programmer defines:
  - an agent (MouseTrap)
  - a model (MouseTrapModel)
“(...) an example of how simple agents acting only on local information can produce complex global behaviour”.

Agents: HeatBugs which absorb and expel heat

Model: HeatBugsModel has a spatial property, heat, which diffuses and evaporates over time. (green dots represent HeatBugs, brighter red represents warmer spots of the world.)

A HeatBug has an ideal temperature and will move about the space attempting to achieve this ideal temperature.
A robust layered control system for a mobile robot.

Pengi: An implementation of a theory of activity.
Technical report, Massachusetts Institute of Technology, A.I. Lab., Cambridge, Massachusetts.
Subm. to the Cognitive Modeling/Science Section of AAAI-87.

From tomt thumb to the dockers: Some experiments with foraging robots.

*Growing Artificial Societies: Social Science From The Bottom Up*.
MIT Press.

*Artificial Life: Proceedings of the First Int. Workshop on the Synthesis and Simulation of Living Systems*.
Addison-Wesley.

Mason: A multiagent simulation environment.
*Simulation*, 81(7):517–527.