LECTURE 7: REACTIVE AND HYBRID AGENTS

An Introduction to Multiagent Systems

CIS 716.5, Spring 2005

Reactive Architectures

- There are many unsolved (some would say insoluble) problems associated with symbolic AI.
- These problems have led some researchers to question the viability of the whole paradigm, and to the development of *reactive* architectures.
- Although united by a belief that the assumptions underpinning mainstream AI are in some sense wrong, reactive agent researchers use many different techniques.
- In this presentation, we start by reviewing the work of one of the most vocal critics of mainstream AI: Rodney Brooks.

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Brooks — behaviour languages

- Brooks has put forward three theses:
  1. Intelligent behaviour can be generated *without* explicit representations of the kind that symbolic AI proposes.
  2. Intelligent behaviour can be generated *without* explicit abstract reasoning of the kind that symbolic AI proposes.
  3. Intelligence is an *emergent* property of certain complex systems.

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- He identifies two key ideas that have informed his research:
  1. Situatedness and embodiment: 'Real' intelligence is situated in the world, not in disembodied systems such as theorem provers or expert systems.
  2. Intelligence and emergence: 'Intelligent' behaviour arises as a result of an agent's interaction with its environment. Also, intelligence is 'in the eye of the beholder'; it is not an innate, isolated property.

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- To illustrate his ideas, Brooks built some based on his *subsumption architecture*.
- A subsumption architecture is a hierarchy of task-accomplishing *behaviours*.
- Each behaviour is a rather simple rule-like structure.
- Each behaviour 'competes' with others to exercise control over the agent.
- Lower layers represent more primitive kinds of behaviour, (such as avoiding obstacles), and have precedence over layers further up the hierarchy.

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- The resulting systems are, in terms of the amount of computation they do, *extremely* simple.
- Some of the robots do tasks that would be impressive if they were accomplished by symbolic AI systems.
- Steels' Mars explorer system, using the subsumption architecture, achieves near-optimal cooperative performance in simulated 'rock gathering on Mars' domain:

  The objective is to explore a distant planet, and in particular, to collect sample of a precious rock. The location of the samples is not known in advance, but it is *known that they tend to be clustered.*

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- For individual (non-cooperative) agents, the lowest-level behavior, (and hence the behavior with the highest "priority") is obstacle avoidance:

  if detect an obstacle *then* change direction. (1)

- Any samples carried by agents are dropped back at the mother-ship:

  if carrying samples *and* at the base *then* drop samples (2)

- Agents carrying samples will return to the mother-ship:

  if carrying samples and *not* at the base *then* travel up gradient. (3)

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- Agents will collect samples they find:

  if detect a sample *then* pick sample up. (4)

- An agent with "nothing better to do" will explore randomly:

  if true *then* move randomly. (5)

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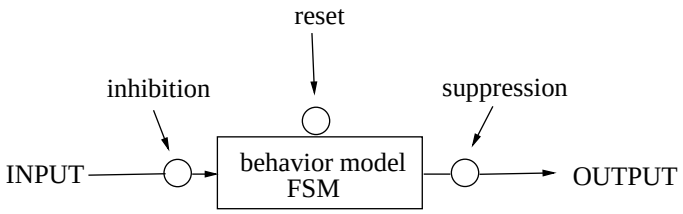
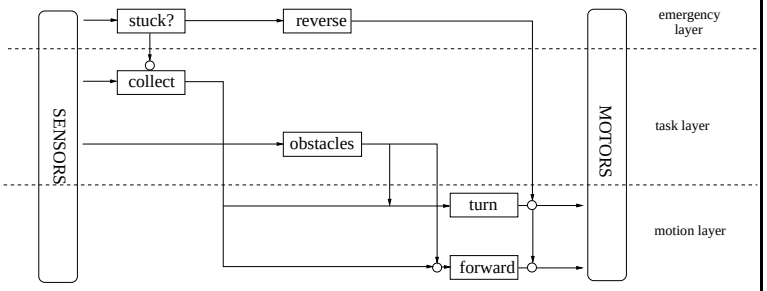
Abstract view of subsumption architecture

- Layered approach based on levels of competence
- Augmented finite state machine:





Situated Automata

- A sophisticated approach is that of Rosenschein and Kaelbling.
- In their *situated automata* paradigm, an agent is specified in a rule-like (declarative) language, and this specification is then compiled down to a digital machine, which satisfies the declarative specification.

  This digital machine can operate in a *provable time bound*.
- Reasoning is done *off line*, at *compile time*, rather than *online* at *run time*.

- The theoretical limitations of the approach are not well understood.
- Compilation (with propositional specifications) is equivalent to an NP-complete problem.
- The more expressive the agent specification language, the harder it is to compile it.

  (There are some deep theoretical results which say that after a certain expressiveness, the compilation simply can't be done.)

Emergent behaviour

- Important but not well-understood phenomenon
- Often found in behaviour-based/reactive systems
- Agent behaviours “emerge” from
  - Interactions of rules
  - Interactions of behaviours
  - Interactions of either with environment

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- Coded behaviour
  - In the programming scheme
- Observed behaviour
  - In the eyes of the observer
- There is no one-to-one mapping between the two!
- When Observed behaviour “exceeds” programmed behaviour, then we have emergence.

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- Is it magic?
  - Sum is greater than the parts
  - Emergent behaviour is more than the controller that produces it
- Interaction and emergence.
  - Interactions between rules, behaviours and environment
  - Source of expressive power for a designer
  - Systems can be designed to take advantage of emergent behaviour

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- Emergent flocking.
- Program multiple agents:
  - Don’t run into any other robot
  - Don’t get too far from other robots
  - Keep moving if you can
- When run in parallel on many agents, the result is flocking

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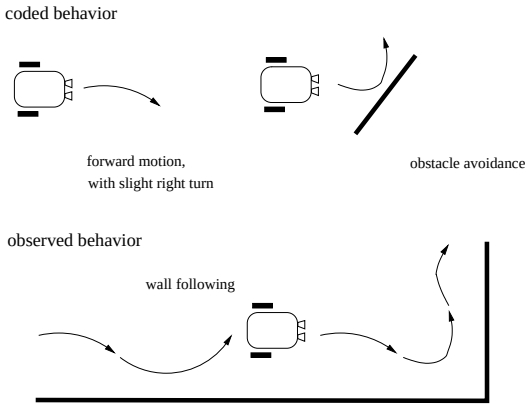
Wall following



- Can also be implemented with these rules:
  - If too far, move closer
  - If too close, move away
  - Otherwise, keep on
- Over time, in an environment with walls, this will result in wall-following
- Is this emergent behaviour?

- Can argued yes because
  - Robot itself is not aware of a wall, it only reacts to distance readings
  - Concepts of “wall” and “following” are not stored in the robot’s controller
  - The system is just a collection of rules
- Notion of emergence depends on two aspects:
  - Existence of an external observer, to observe and describe the behaviour of the system
  - Access to the internals of the controller itself, to verify that the behaviour is not explicitly specified anywhere in the system

- Unexpected vs emergent.
  - Some researchers say the above is not enough for behaviour to be emergent, because above is programmed into the system and the “emergence” is a matter of semantics
  - So emergence must imply something unexpected, something “surreptitiously discovered” by observing the system.
  - “Unexpected” is highly subjective, because it depends on what the observer was expecting
  - Naïve observers are often surprised!
  - Informed observers are rarely surprised
- Once a behaviour is observed, it is no longer unexpected
- Is new behaviour then “predictable”?

Hybrid Architectures

- Many researchers have argued that neither a completely deliberative nor completely reactive approach is suitable for building agents.
- They have suggested using *hybrid* systems, which attempt to marry classical and alternative approaches.
- An obvious approach is to build an agent out of two (or more) subsystems:
  - a *deliberative* one, containing a symbolic world model, which develops plans and makes decisions in the way proposed by symbolic AI; and
  - a *reactive* one, which is capable of reacting to events without complex reasoning.

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- Often, the reactive component is given some kind of precedence over the deliberative one.
- This kind of structuring leads naturally to the idea of a *layered* architecture, of which TOURINGMACHINES and INTERRAP are examples.
- In such an architecture, an agent's control subsystems are arranged into a hierarchy, with higher layers dealing with information at increasing levels of abstraction.

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- A key problem in such architectures is what kind control framework to embed the agent's subsystems in, to manage the interactions between the various layers.
- *Horizontal layering*.

  Layers are each directly connected to the sensory input and action output.

  In effect, each layer itself acts like an agent, producing suggestions as to what action to perform.
- *Vertical layering*.

  Sensory input and action output are each dealt with by at most one layer each.

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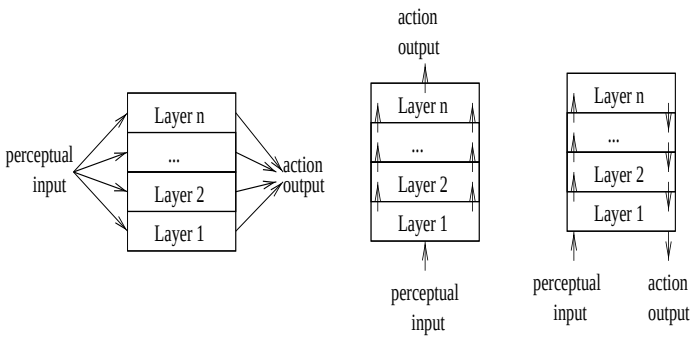

(a) Horizontal layering (b) Vertical layering (One pass control) (c) Vertical layering (Two pass control)

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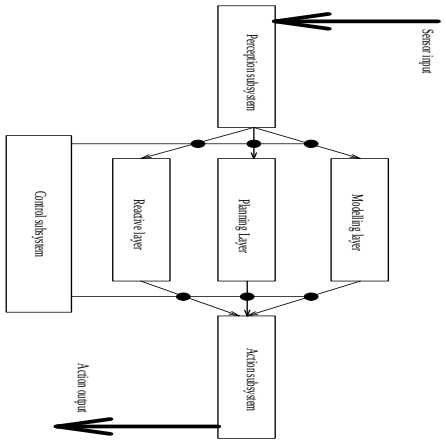
Ferguson — TouringMachines

- The TouringMachines architecture consists of *perception* and *action* subsystems, which interface directly with the agent's environment, and three *control layers*, embedded in a *control framework*, which mediates between the layers.



- The *reactive layer* is implemented as a set of situation-action rules, *à la* subsumption architecture.

  Example:

```
rule-1: kerb-avoidance
    if
        is-in-front(Kerb, Observer) and
        speed(Observer) > 0 and
        separation(Kerb, Observer) < KerbThreshHold
    then
        change-orientation(KerbAvoidanceAngle)
```

- The *planning layer* constructs plans and selects actions to execute in order to achieve the agent's goals.

- The *modelling layer* contains symbolic representations of the 'cognitive state' of other entities in the agent's environment.
- The three layers communicate with each other and are embedded in a control framework, which use *control rules*.

  Example:

```
censor-rule-1:
    if
        entity(obstacle-6) in perception-buffer
    then
        remove-sensory-record(layer-R, entity(obstacle-6))
```

- Such control structures have become common in robotics.

Summary

- This lecture has looked at two further kinds of agent:
  - Reactive agents; and
  - Hybrid agents.
- Reactive agents build complex behaviour from simple components.
- Complex to build complex agents.
- Hybrid agents try to combine the speed of reactive agents with the power of deliberative agents.
- Hybrid agents are common in robotics.

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