LECTURE 7: REACTIVE AND HYBRID AGENTS

An Introduction to Multiagent Systems

CIS 716.5, Spring 2006

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.

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.

- 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.

- 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.

- 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.*

- 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)

- Agents will collect samples they find:

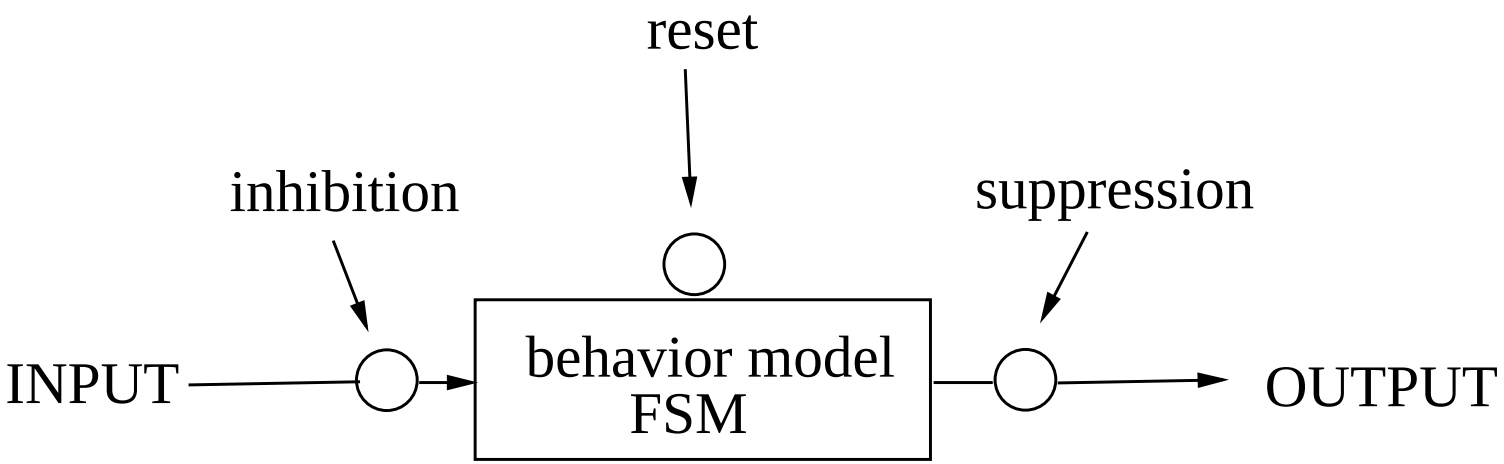
  if detect a sample *then* pick sample up. (4)

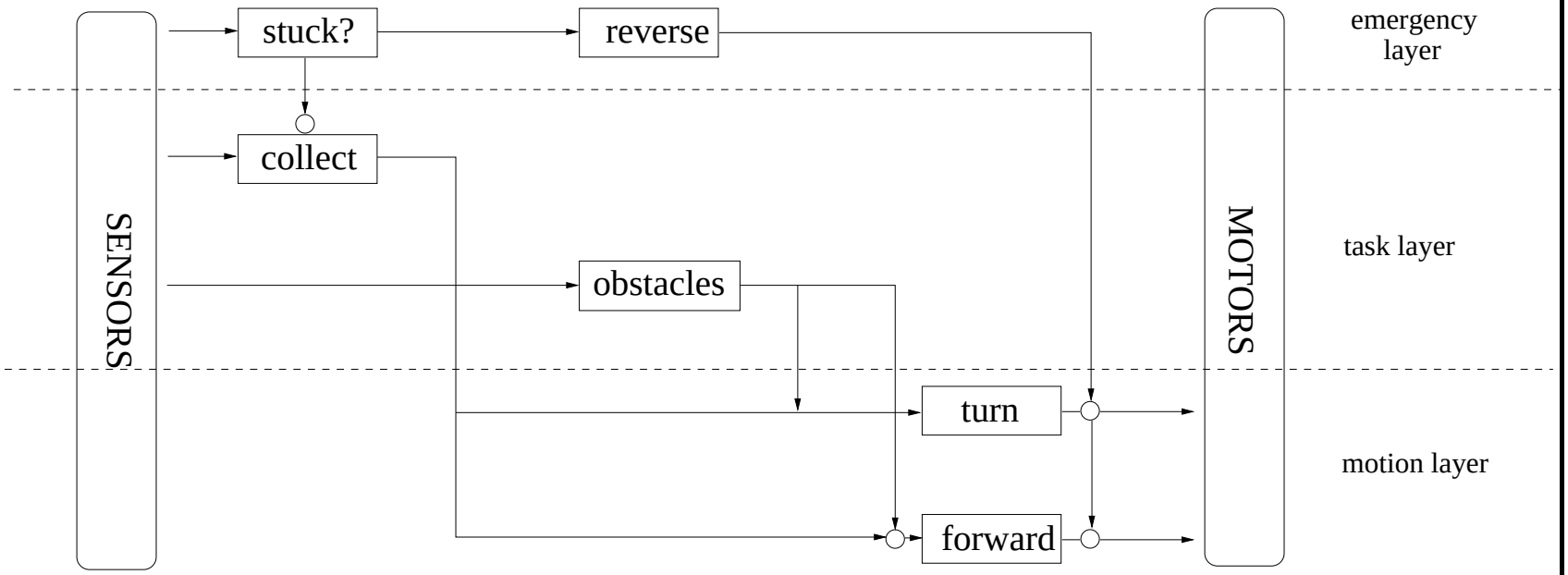
- An agent with “nothing better to do” will explore randomly:

if true *then* move randomly. (5)

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

- 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.

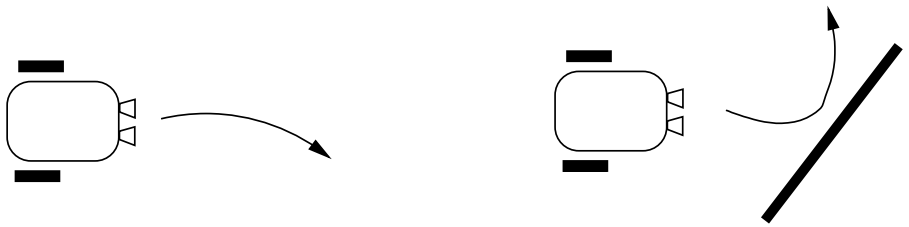
- Is it magic?
  - Sum is greater than the parts
  - Emergent behaviour is more than the controller that produces it
- Interaction and emergence.
  - Interactions between rules, behaviours and environment
  - Source of expressive power for a designer
  - Systems can be designed to take advantage of emergent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

- 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

- We will get the robots to do some flocking in the next project.

Wall following

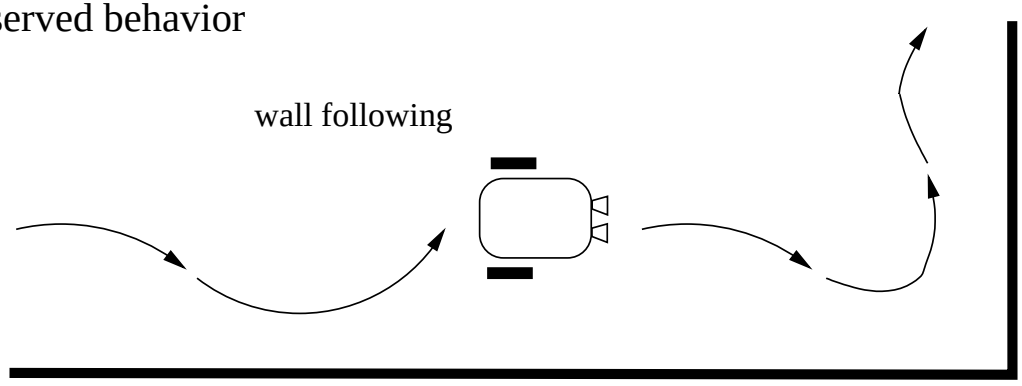
coded behavior



forward motion,
with slight right turn

obstacle avoidance

observed behavior



- 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.

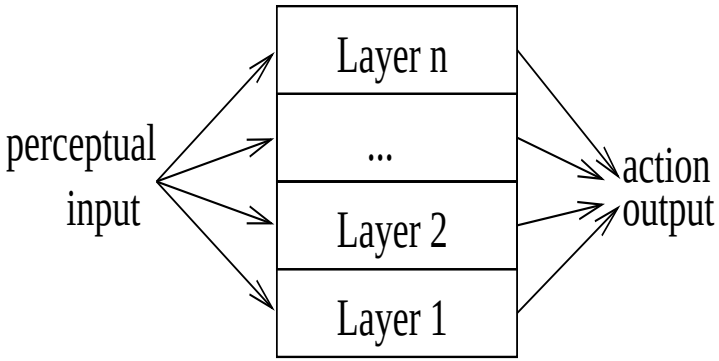
- Often, the reactive component is given some kind of precedence over the deliberative one.
- This kind of structuring leads naturally to the idea of a *layered* architecture, of which TOURINGMACHINES and INTERRAP are examples.
- In such an architecture, an agent's control subsystems are arranged into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

- 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*.

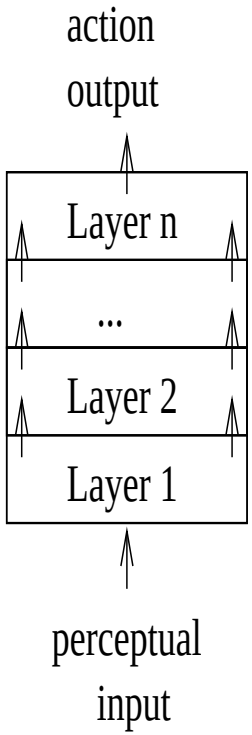
  Layers are each directly connected to the sensory input and action output.

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

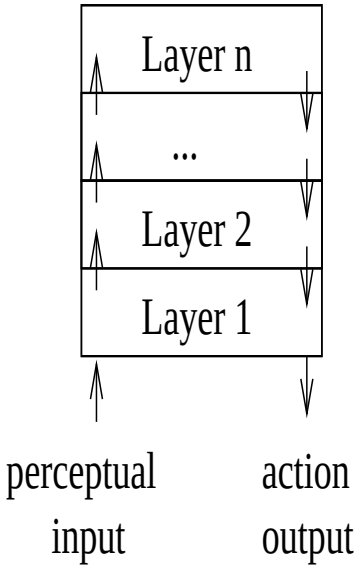
  Sensory input and action output are each dealt with by at most one layer each.



(a) Horizontal layering



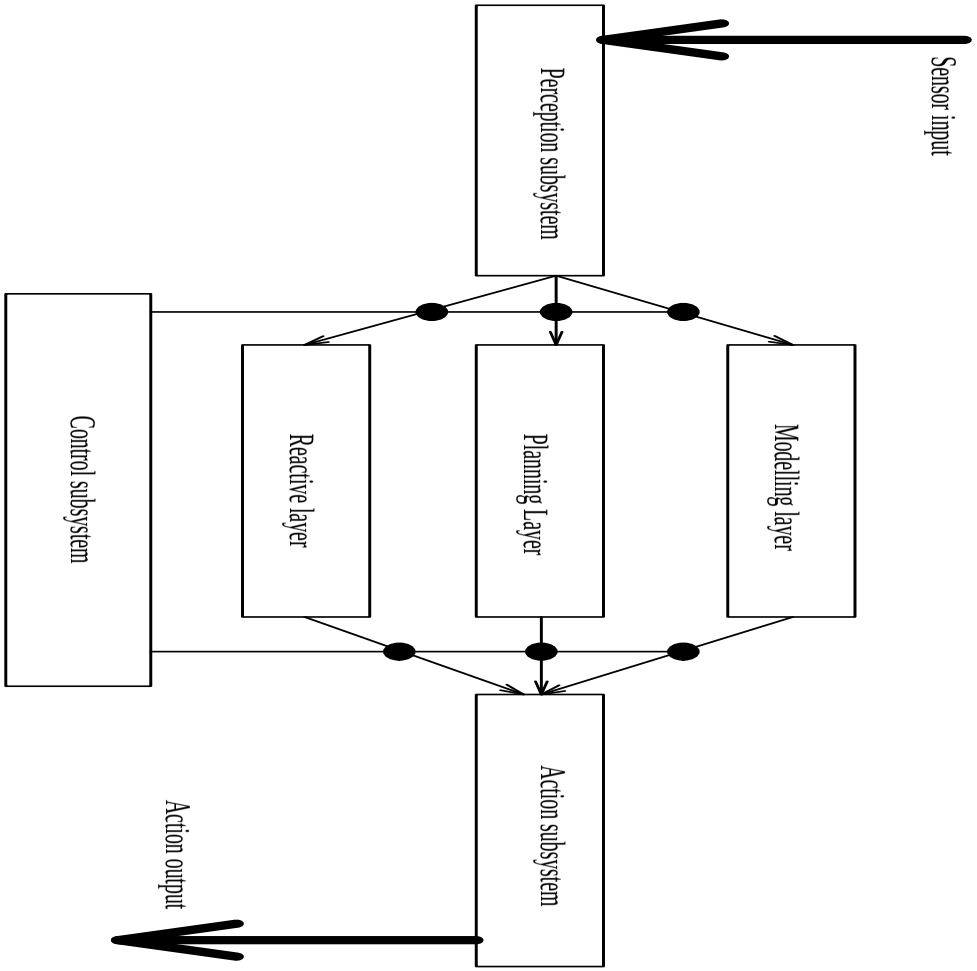
(b) Vertical layering
(One pass control)



(c) Vertical layering
(Two pass control)

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.