CHAPTER 5: REACTIVE AND HYBRID ARCHITECTURES

An Introduction to Multiagent Systems

http://www.csc.liv.ac.uk/˜mjw/pubs/imas/

0.1 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.

0.2 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:

$$\textit{if} \text{ detect an obstacle } \textit{then} \text{ change direction.} \tag{1}$$

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

$$\textit{if} \text{ carrying samples } \textit{and} \text{ at the base } \textit{then} \text{ drop samples} \tag{2}$$

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

$$\textit{if} \text{ carrying samples and } \textit{not} \text{ at the base } \textit{then} \text{ travel up gradient.} \tag{3}$$

- Agents will collect samples they find:

$$\textit{if} \text{ detect a sample } \textit{then} \text{ pick sample up.} \tag{4}$$

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

$$\textit{if} \text{ true } \textit{then} \text{ move randomly.} \tag{5}$$

0.3 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.)

1 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.

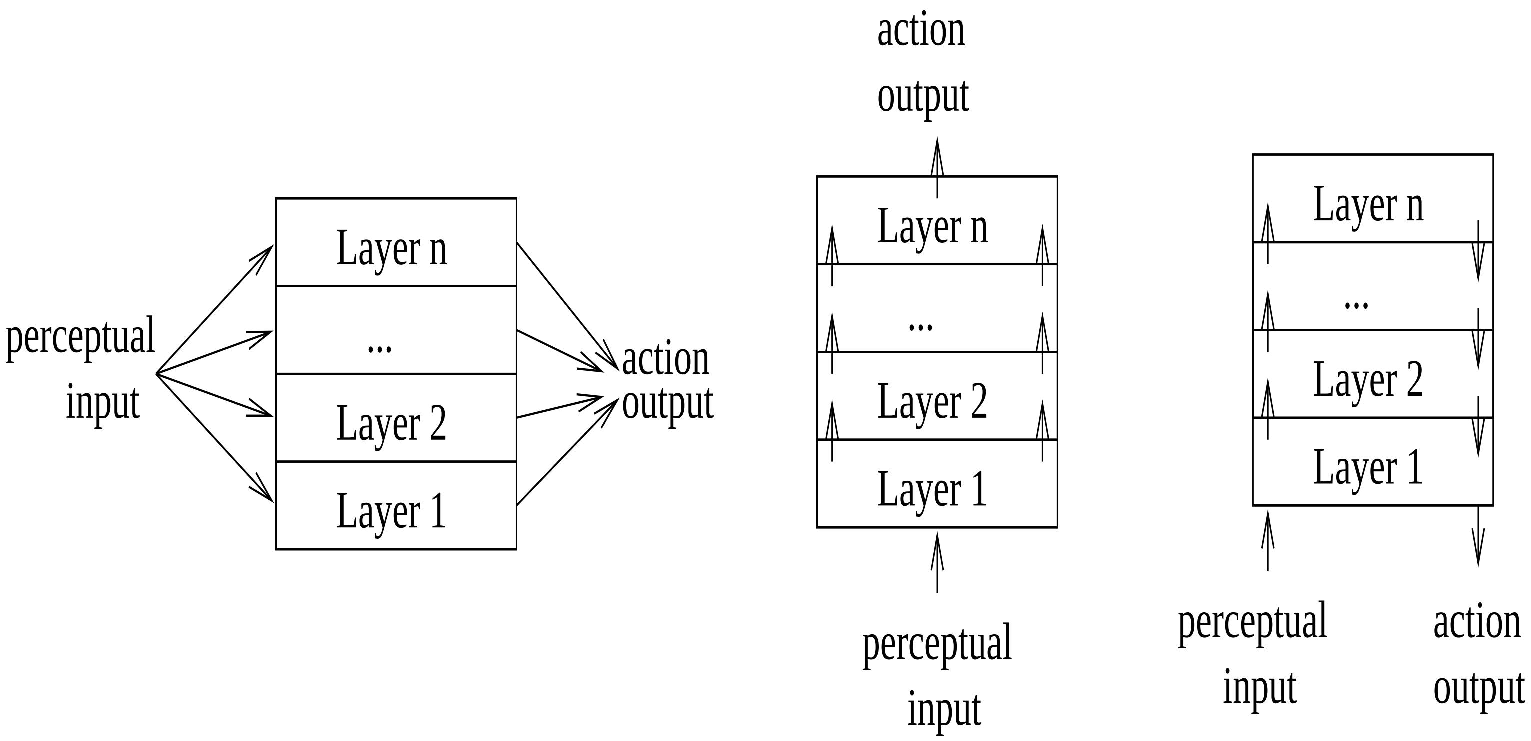
- Often, the reactive component is given some kind of precedence over the deliberative one.
- This kind of structuring leads naturally to the idea of a *layered* architecture, of which TOURINGMACHINES and INTERRAP are examples.
- In such an architecture, an agent's control subsystems are arranged into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

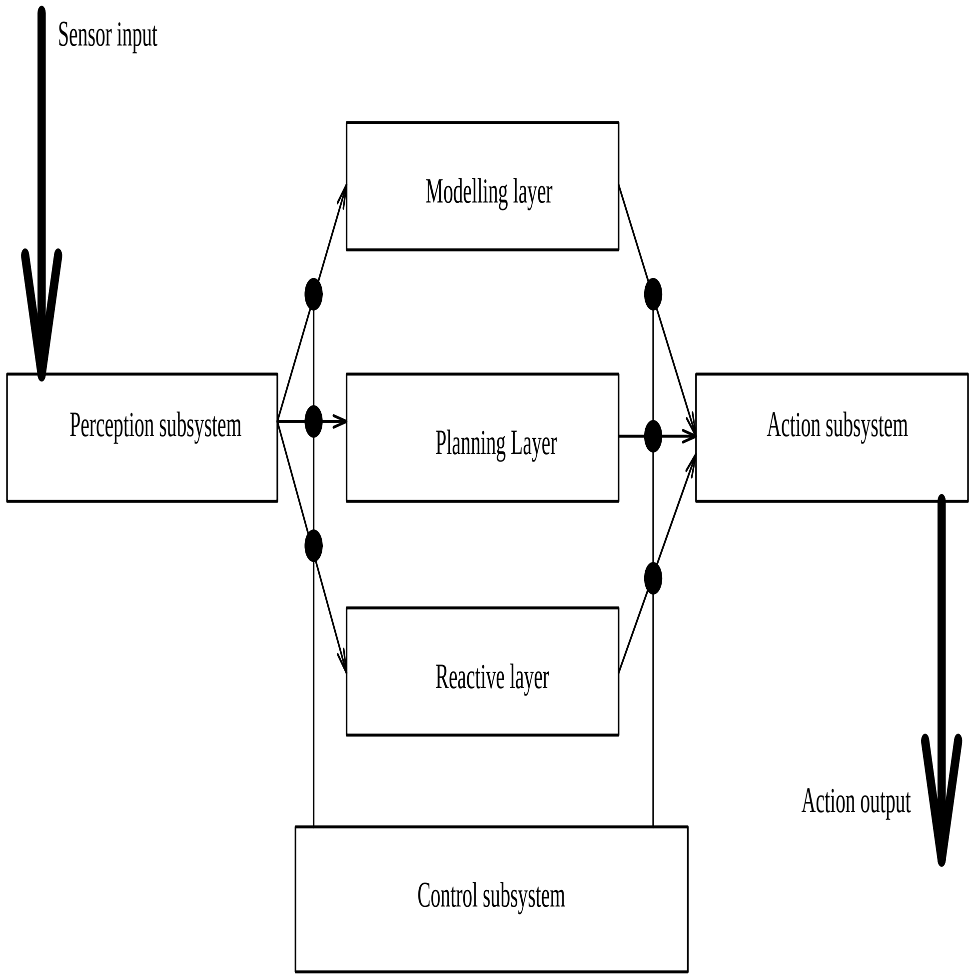
  Sensory input and action output are each dealt with by at most one layer each.



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

2 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.


Sensor input
Modelling layer
Perception subsystem
Planning Layer
Action subsystem
Reactive layer
Action output
Control subsystem

- 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))
```