CHAPTER 5: REACTIVE AND HYBRID ARCHITECTURES

An Introduction to Multiagent Systems

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

Reactive Architectures

- Many problems with symbolic reasoning agents.
- These problems have led some researchers to question the viability of the whole paradigm, and to the development of *reactive* architectures.

Brooks — behaviour languages

- Brooks 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 agents based on his *subsumption architecture*.
- A subsumption architecture is a hierarchy of task-accomplishing *behaviours*.
- Each behaviour is a 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.

- 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)

Situated Automata

- In the *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.

Hybrid Architectures

- Many researchers have argued that neither a completely deliberative nor completely reactive approach is suitable for building agents.
- 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.

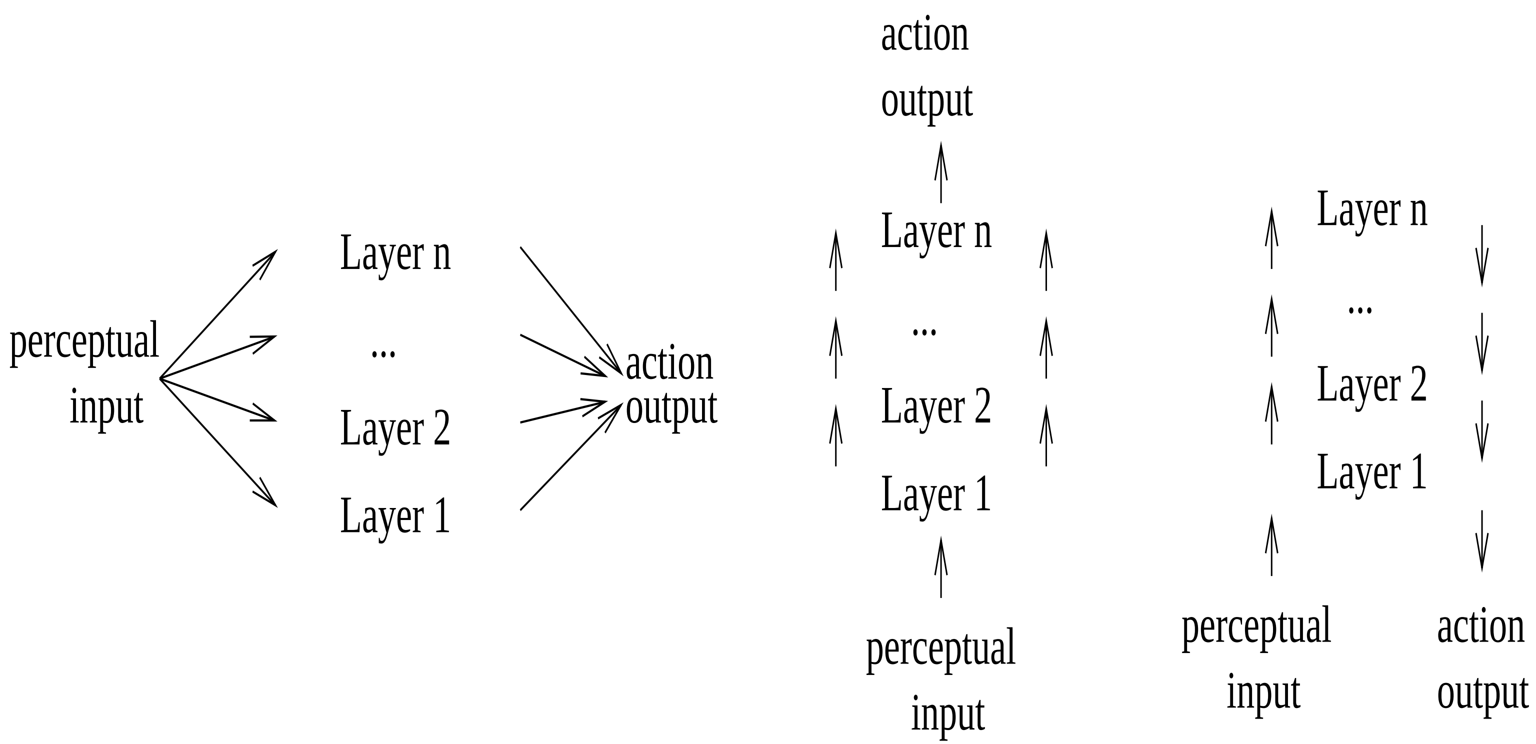
- Often, the reactive component is given some kind of precedence over the deliberative one.
- This kind of structuring leads naturally to the idea of a *layered* architecture, of which TOURINGMACHINES and INTERRAP are examples.
- In such an architecture, an agent's control subsystems are arranged into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



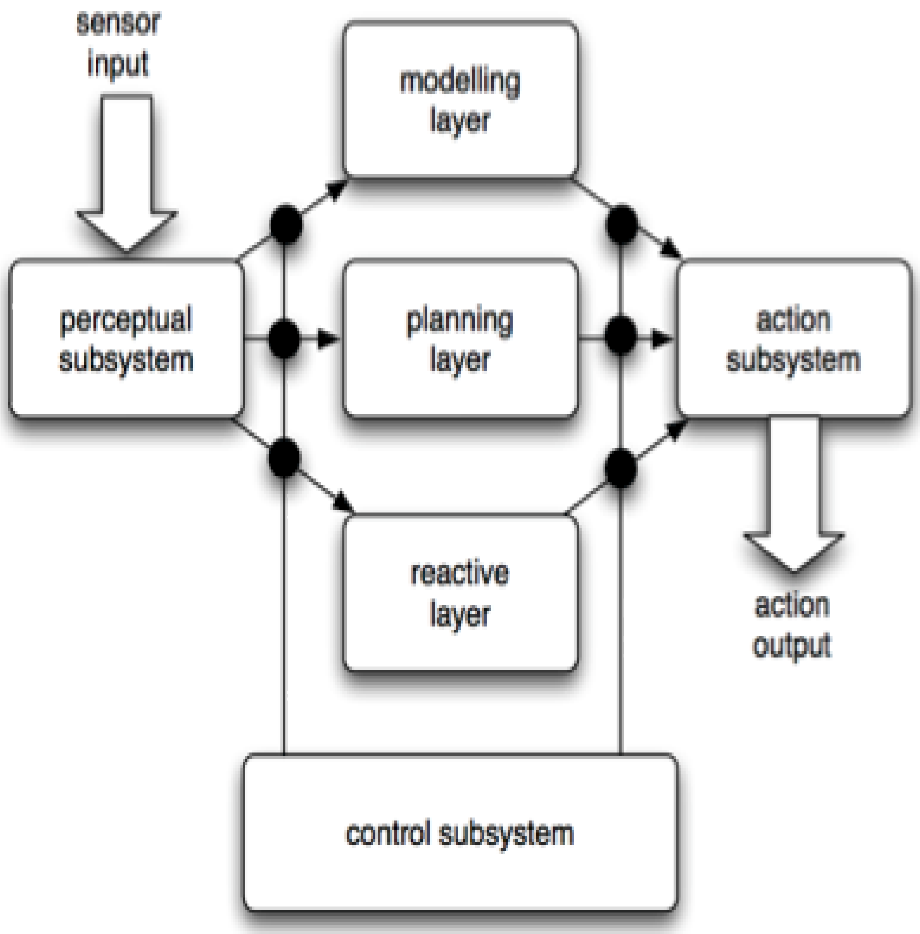
(a) Horizontal layering

(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.


sensor
input
modelling
layer
perceptual
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))
```