LECTURE 3: REACTIVE AND HYBRID AGENTS

An Introduction to Multiagent Systems

CIS 716.5, Spring 2010

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 agents based on his *subsumption architecture*.

- Genghis:

- 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.

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

  if carrying samples *and* at the base *then* drop samples

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

The “gradient” in this case refers to a virtual “hill” that slopes up to the mother ship/base.

- Agents will collect samples they find:

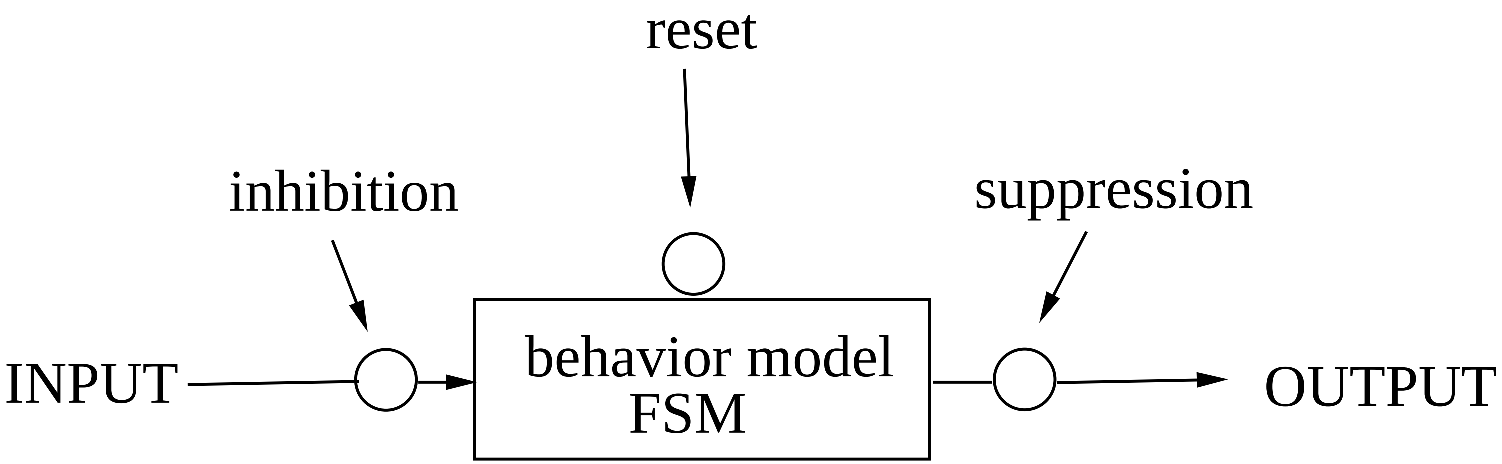
  if detect a sample *then* pick sample up.

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

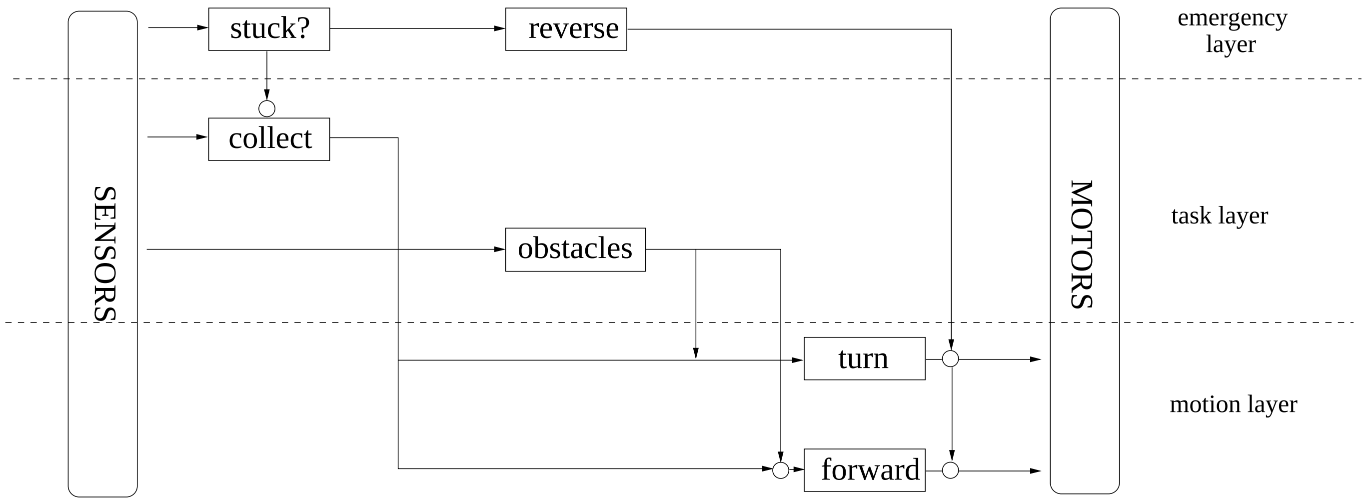
  if true *then* move randomly.

Abstract view of subsumption architecture

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



- A subsumption architecture machine:



- Can build sophisticated machines this way.
- Matarić's Toto was able to map spaces and execute plans all without a symbolic representation.

Situated Automata

- Approach proposed by Rosenschein and Kaelbling.
- An agent is specified in a rule-like (declarative) language.
- 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.)

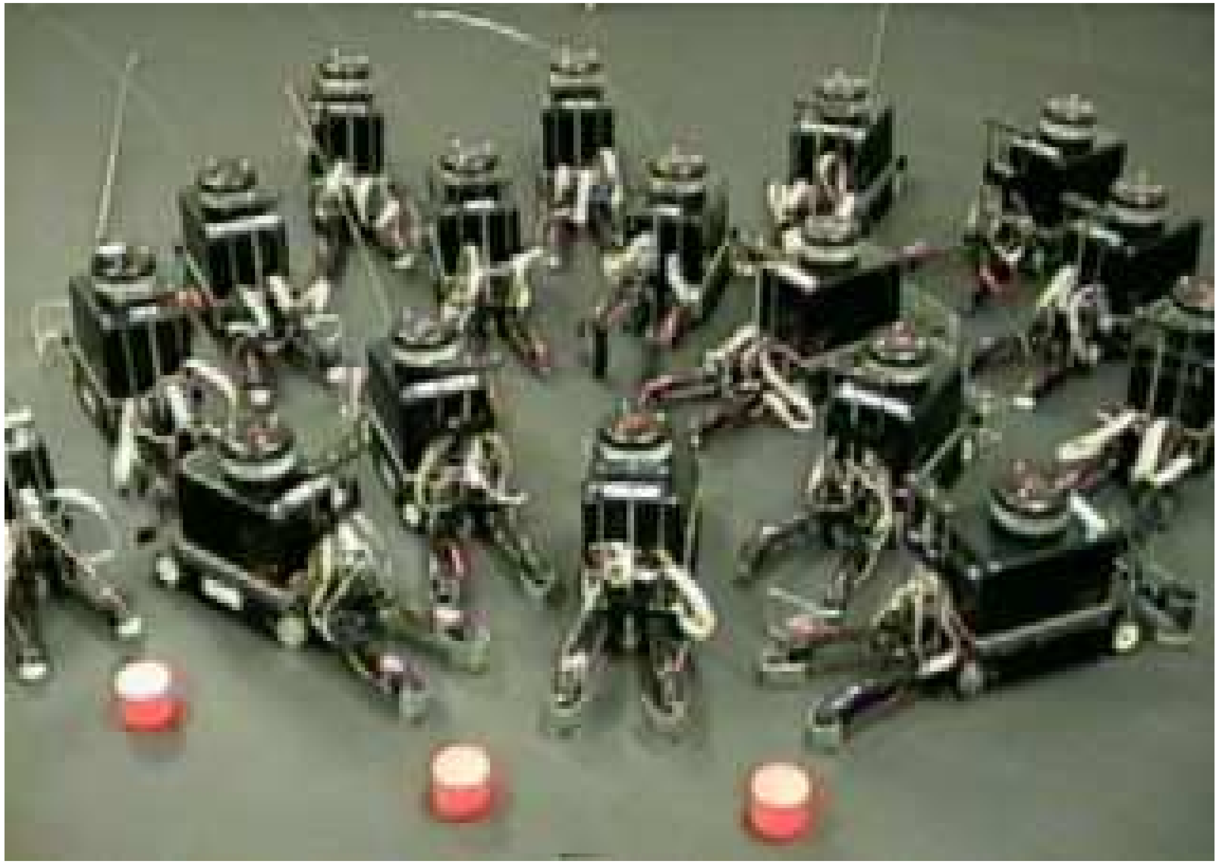
Emergent behaviour

- Important but not well-understood phenomenon
- Often found in behaviour-based/reactive systems
- Agent behaviours "emerge" from interactions of rules with environment.
- Sum is greater than the parts.
  - The interaction links rules in ways that weren't anticipated.

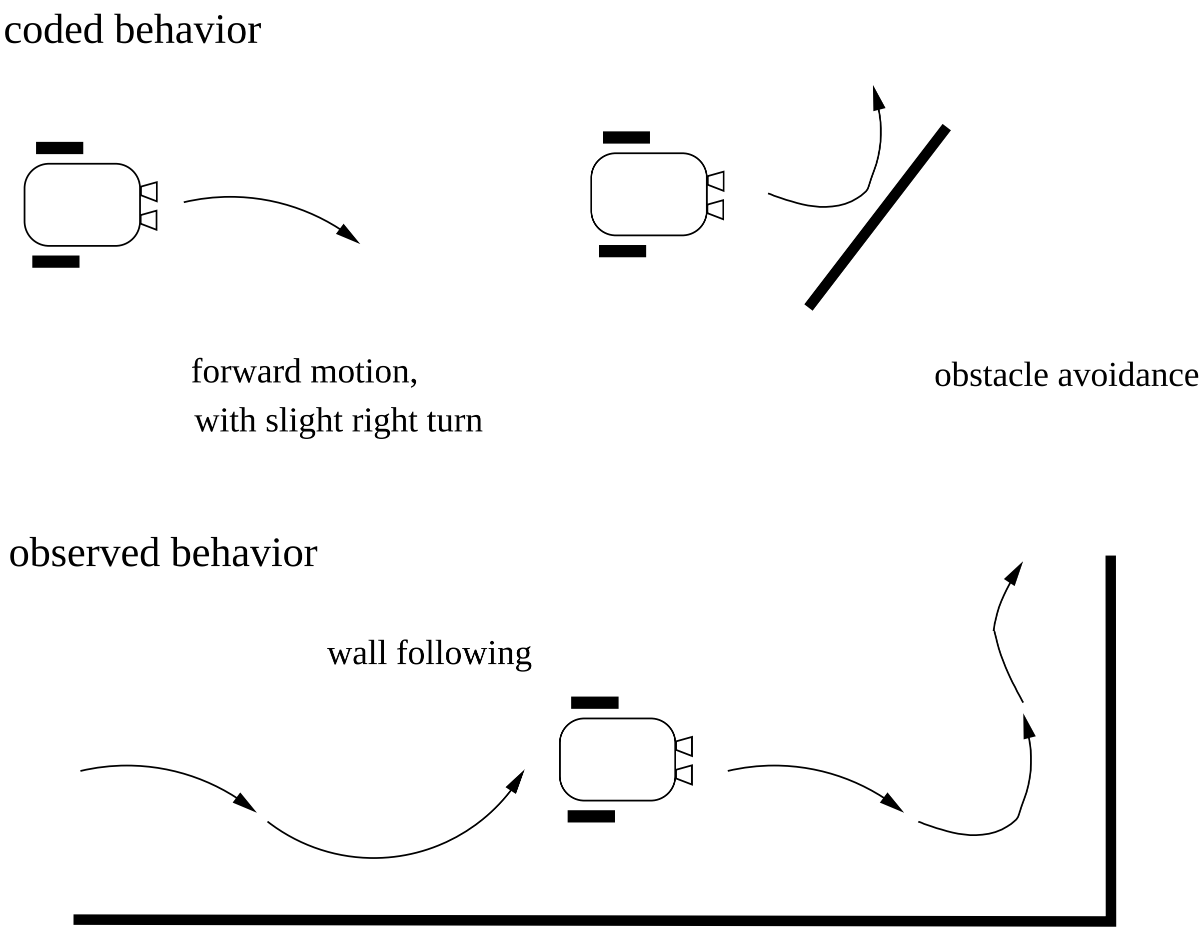
- Coded behaviour
  - In the programming scheme
- Observed behaviour
  - In the eyes of the observer
- There is no one-to-one mapping between the two!
- When observed behaviour “exceeds” programmed behaviour, then we have emergence.

- Emergent flocking.
- Classic example of emergence
  - Reynolds “Boids”
- 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

- Matarić’s “nerd herd” showed flocking behavior:



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 behavior?

- 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
- But once I have seen this work, I can program the robot expecting it to happen!

Learning reactive behavior

- We can discover reactive behavior.
- If we have utilities of states, and actions that take our agent from state to state (sound familiar) we can discover the utility of every state.
- The utility of a state e_i is a function of the utility of the states the agent can get to from it (e_j) and the cost of getting to those states:

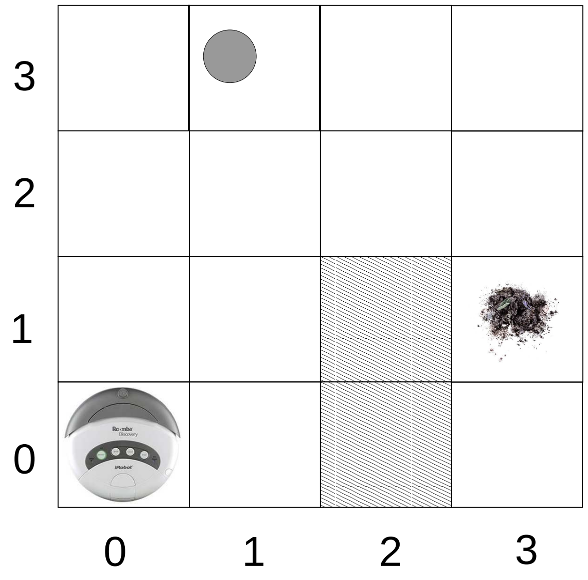
$$V(e_i) = max_j(V(e_j) - c(e_j, e_i))$$

- If we start by assuming all states with unknown utilities have utilities of zero, and recursively update using:

$$V(e_i)_{t+1} = V(e_i)_t + max_j(V(e_j)_t - c(e_j, e_i))$$

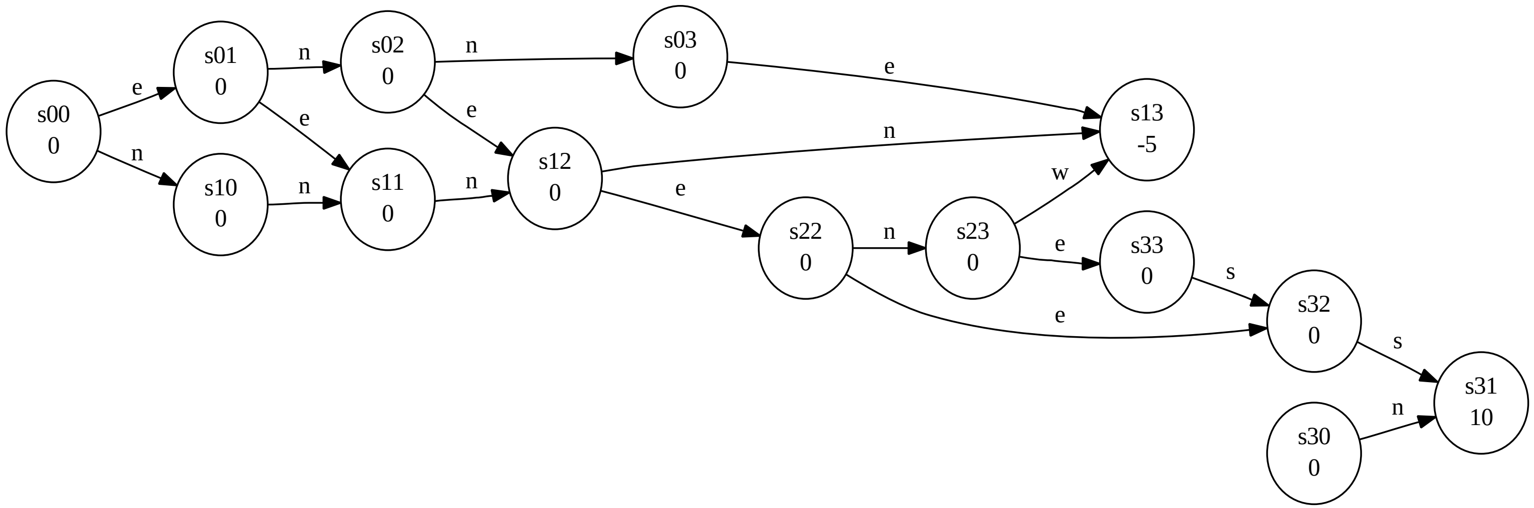
- We can establish the utility of every state.

- Here's an example world, like Vacuum world, but with some places the robot can't go, and a place with negative utility (a hole, say).



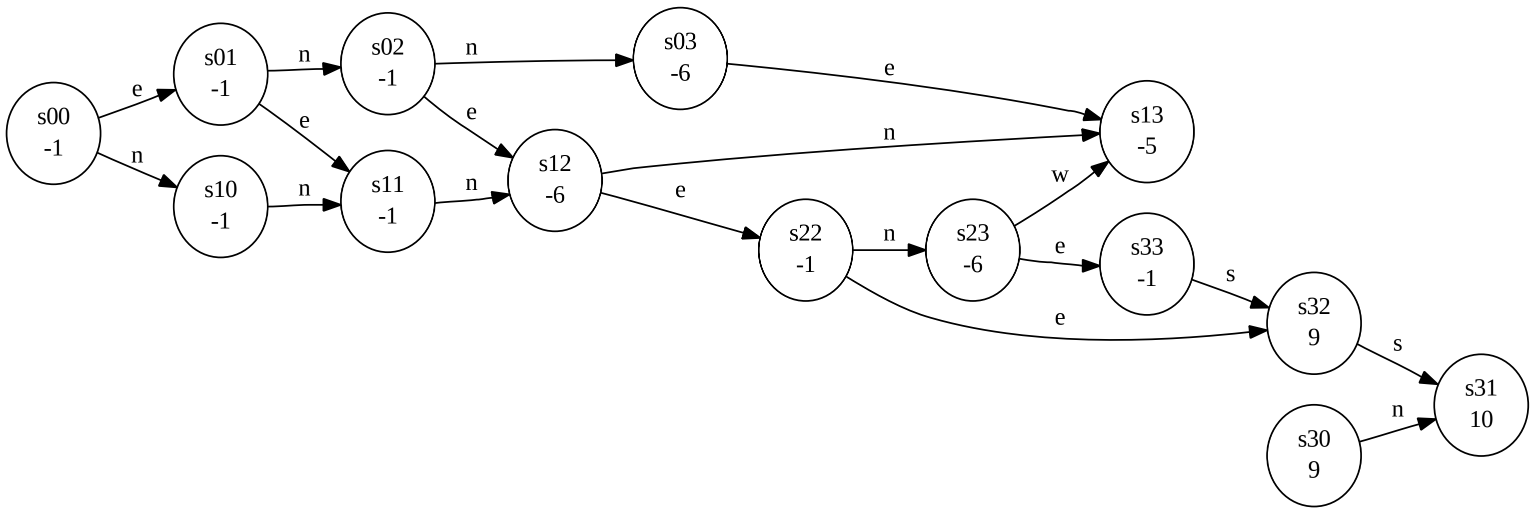
- The robot can go north (up the page), south, east and west. Each action costs 1

- Here is a state/action graph that covers all of the states and some of the actions and initial utilities.

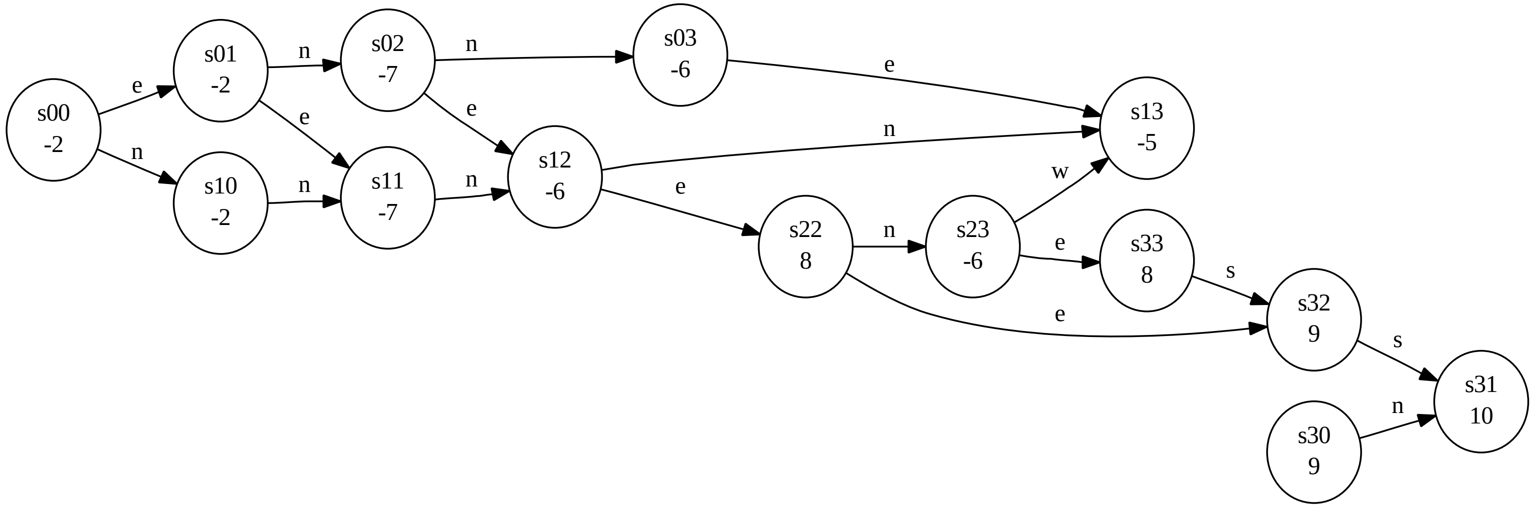


- Now let's run the the recursive updates.

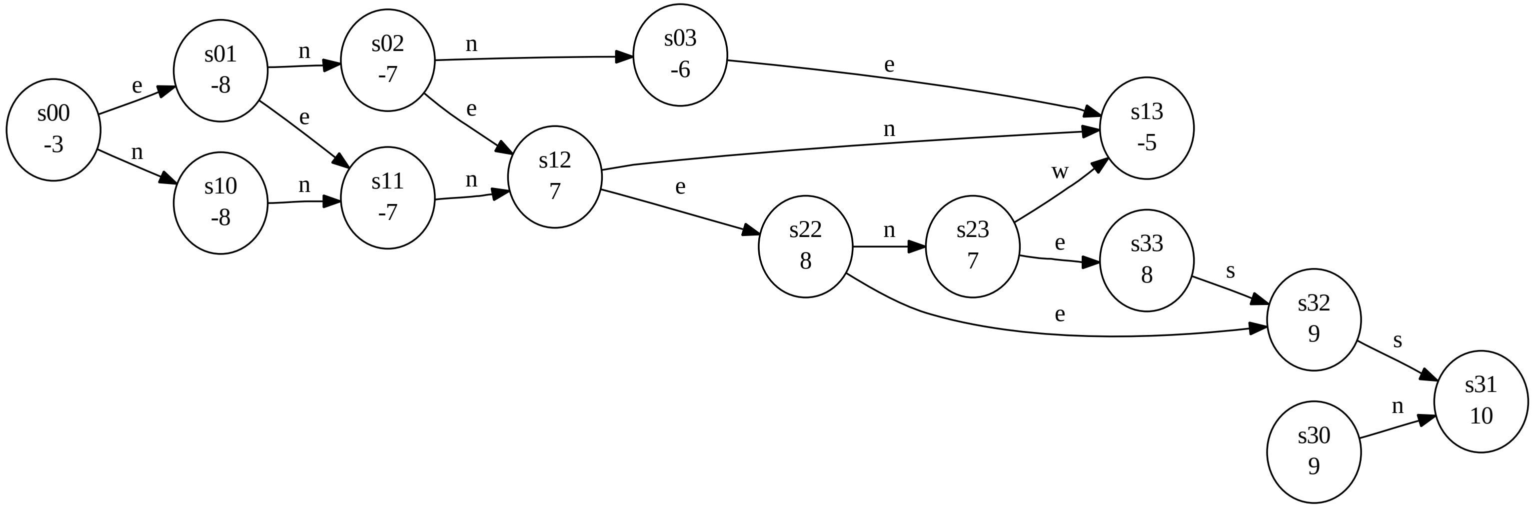
- After one step.



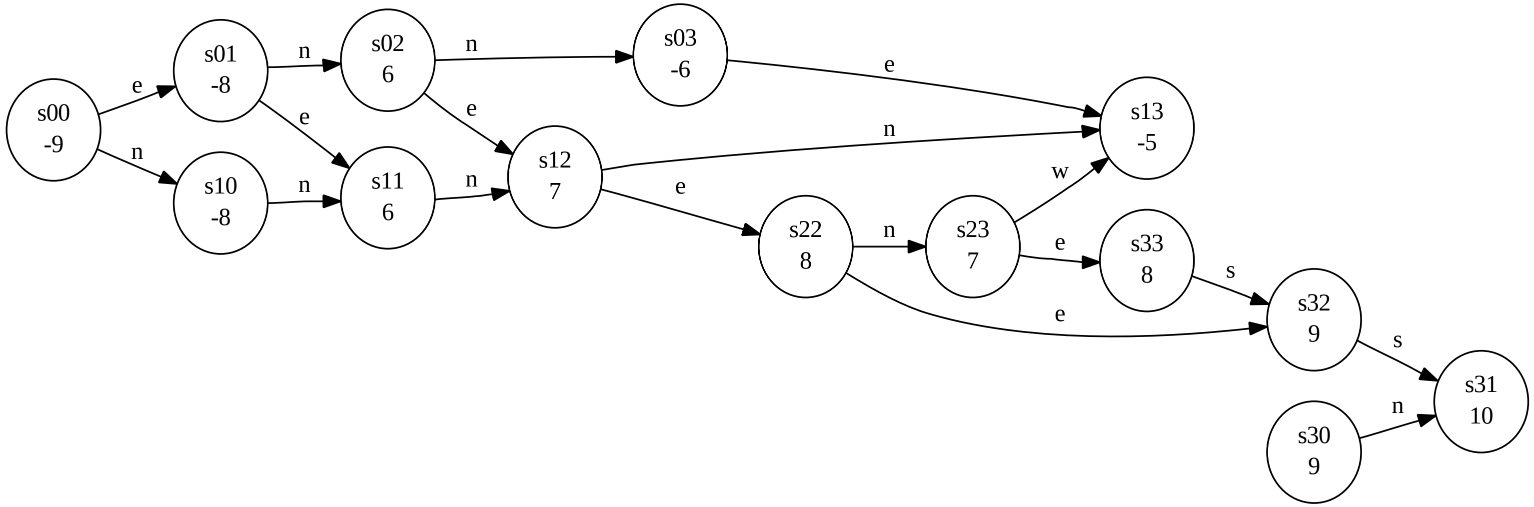
- After two steps.



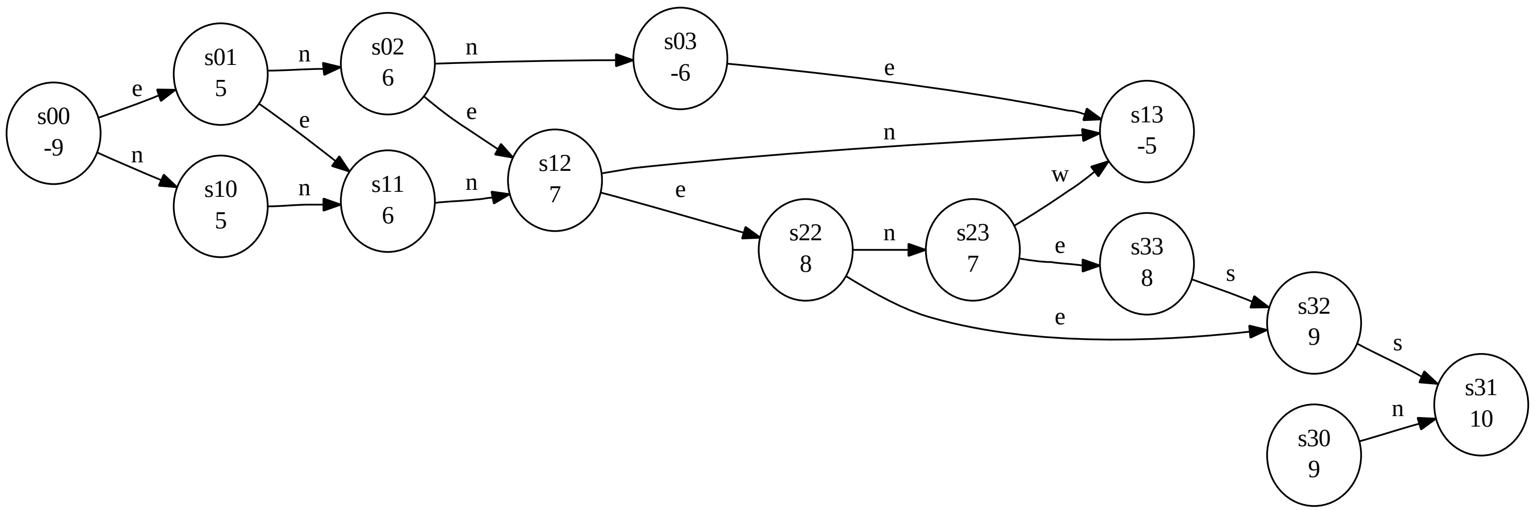
- After three steps.



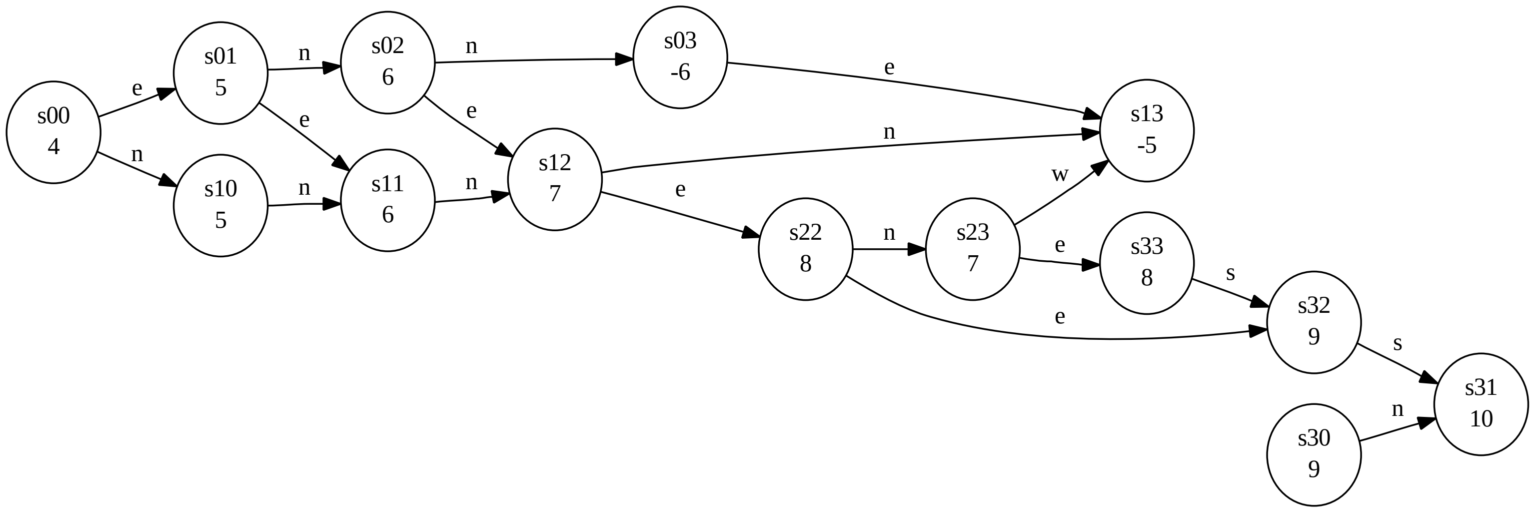
- After four steps.



- After five steps.



- After six steps.



- There will be no more updates.

- Once the values have stabilised, we have a program for the reactve agent.
- At each step we pick the state with the highest utility.
- Again (as with situated automata) we can push the computation off-line.
  - Online the agent only needs a look-up table.
- We can also compute utilities online, as in reinforcement learning.

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.

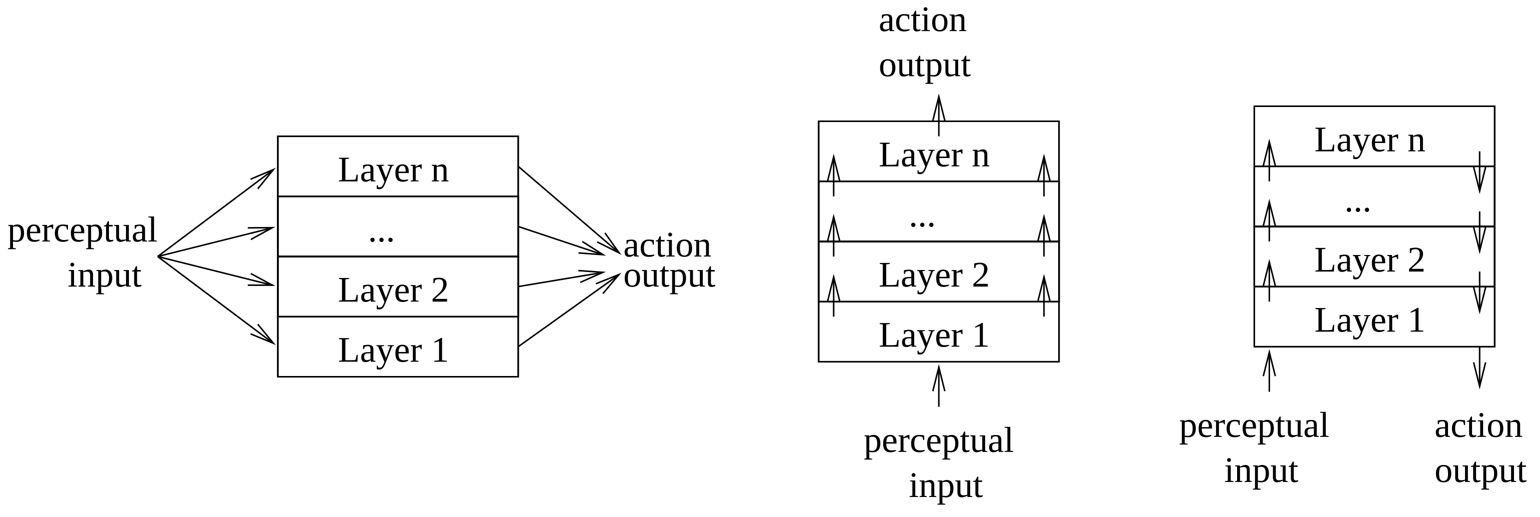
- Often, the reactive component is given some kind of precedence over the deliberative one.
- This kind of structuring leads naturally to the idea of a *layered* architecture, of which TOURINGMACHINES and INTERRAP are examples.
- In such an architecture, an agent's control subsystems are arranged into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



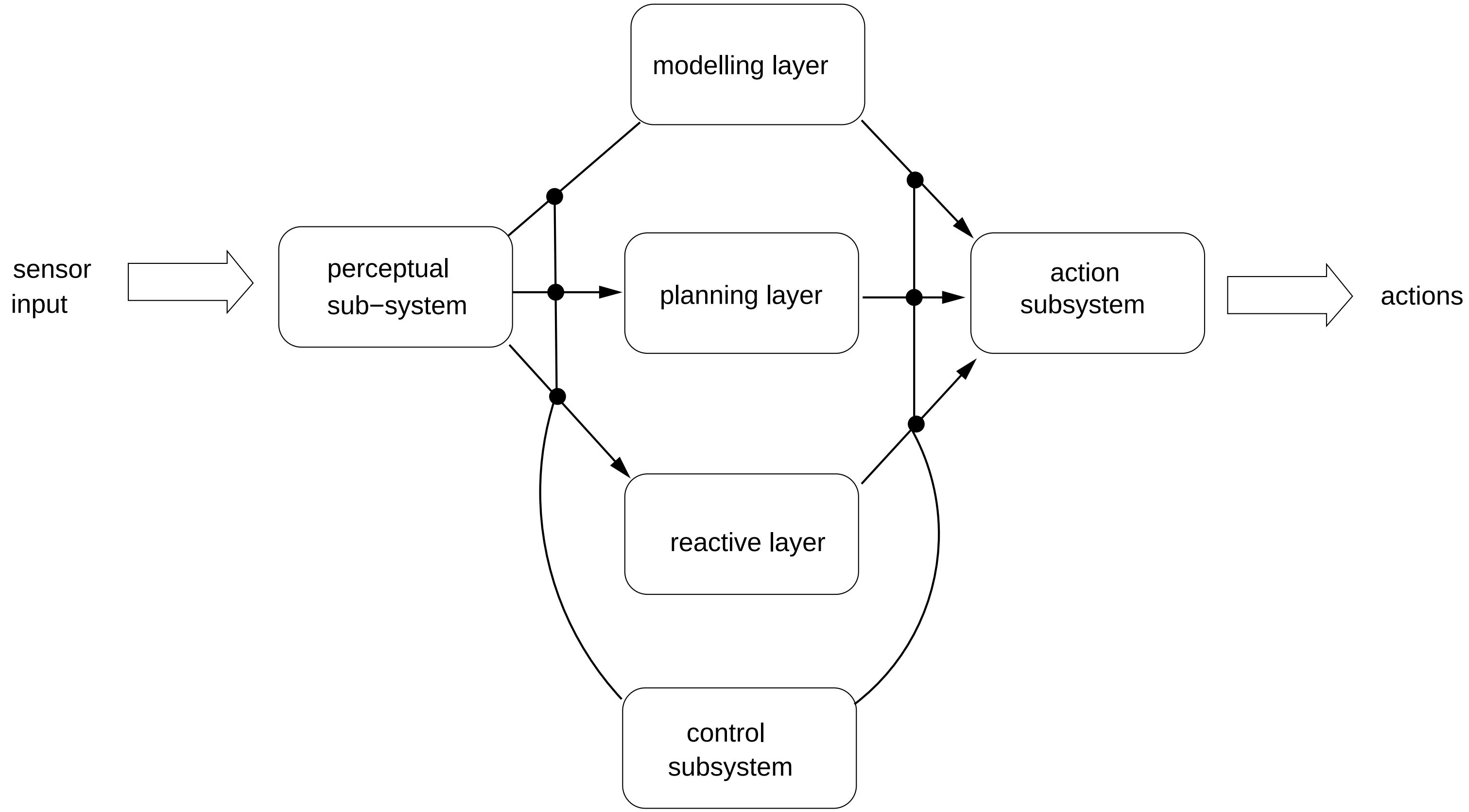
(a) Horizontal layering

(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.
- A horizontally layered architecture.


modelling layer
sensor
input
perceptual
sub−system
planning layer
action
subsystem
actions
reactive layer
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))
```

- 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.

