Adaptive Systems

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Behaviour-based Robotics

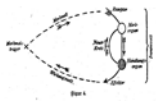
This lecture

- Behaviours (not representations, information, ideas, ...) are primary components of adaptation/cognition
- Basic history of the very idea
- Some classical robotic examples
- Behaviour Based Robotic Architectures
- Some implications

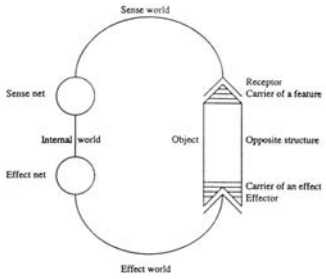
Behavioural patterns

- We are continuously *enacting*, or sustaining, behavioural patterns: habits, skills, instincts, reactions ...
- Even when attending a lecture:
  - Proprioceptive loops: balance
  - Sensorimotor attentional loops: visual tracking to lecturer and board.
  - Writing: visual tracking of text + proprioceptive feedback of hand-arm
  - etc...

Behavioural patterns as sensorimotor loop



- von Üexkull: functional circle or sensorimotor loop



History and Context

- Long history of taking behavioural patterns as the foundation of adaptive and cognitive systems
- Biology & Ethology:
  - Von Üexkull: functional feedback circle
  - Lorenz: *Fixed Action Patterns*, instinctive responses that occur systematically in the presence of specific stimuli
- Psychology:
  - Behaviourism (Thorndike, Wattson, Skinner): Stimulus-Response pairings.
  - Piaget: sensorimotor-schema
- Philosophy:
  - Pragmatists: Dewey, Pierce, ...
  - Phenomenologists: Heidegger, Merleau-Ponty, Dreyfus
- **Robotics**: Grey-Walter, Braitemberg

Behaviour Based Robotics

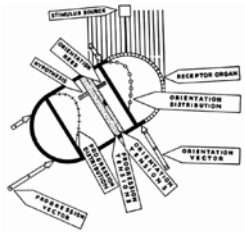
- Behaviour-based robotics describes a design methodology for robots based mainly on Brooks' subsumption or layered architecture (1986).
- BBR is a "style" of building robots and thinking about adaptive behaviour. Brooks pushed the idea forward and many followed
- It emphasizes the relevance of *situatedness, embodiment* and *dynamics*.
- Clashes with representations, rational abstract thinking, planning, etc.
- The object of engineering design is the full sensorimotor loop (controller-body-environment) and the selective activation, coordination, nesting, and sequencing of such loops.

Precursors of behaviour based robotics

- Tolman's Sowbug (1939)
  - Endo, Y., & Arkin, R. C. (2001). Implementing Tolman's schematic sowbug: behavior-based robotics in the 1930's. In *IEEE International conference on robotics and automation* (Vol. 1, pp. 477–484).
- Grey Walter Tortoises or *Machina speculatrix* (50s)
  - Walter, W. G. (1953). *The Living Brain*.
- Braitenberg vehicles (80s)
  - Braitenberg, V. (1986). *Vehicles: experiments in synthetic psychology*. MIT Press.

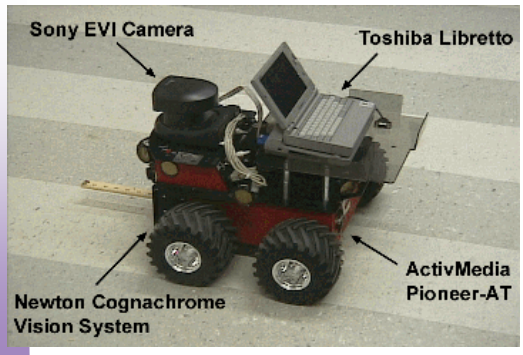
Tolman's sowbug

- 1939. A simple architecture with internal states such as motivation
- Orientation and Progression vectors
- Able to do simple learning



Tolman's sowbug

- Purely a paper exercise in 1939.
- In 2000, Arkin implemented it in simulation – it worked (you can download the code)
- And on a real robot – that worked too.



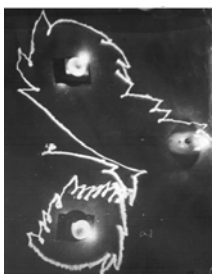
Grey Walter

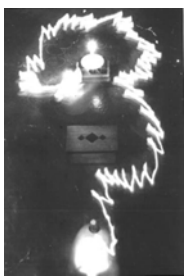
- Walter, W. Grey, "An Imitation of Life," *Scientific American*, May 1950, p42-45

Principal behaviours:

- Low light: Cycloidal wandering (both motors)
- Medium light: Phototaxis (driving motor only)
- Bright light: cycloidal motion with different relative speeds of motor
- Touch: alternate turning and driving

'Buridan's ass', 'discernment'





Recharging Interaction Narcissism

Braitenberg vehicles (1984)

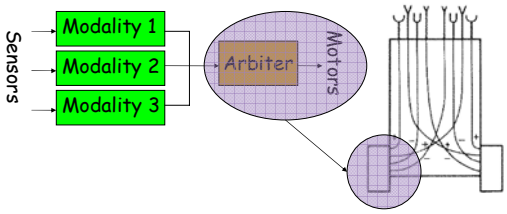
A book exploring what can be done using simple sensors connected to motors either directly, or via a simple arbitration scheme.

He never built any robots!

And he never mentioned Grey Walter!

Still alive and important neuroscientist in the Max Planck Institute for Biological Cybernetics

Braitenberg vehicles (1984)



Rodney Brooks: the subsumption architecture

- Brooks, R. A. (1986). Robust layered control system for a mobile robot. *IEEE journal of robotics and automation*, RA-2(1), 14-23.
- Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence* (pp. 139-159).

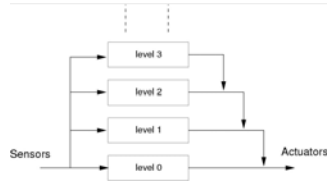
- MIT Lab end 80's:
  - Not much success with traditional approaches
  - H. Dreyfus around (Heidegger, Merleau-Ponty)
- Behavioural decomposition vs. functional
- Distributed vs. central

Instead of …

Why not …

Levels of competence

- Conceptual design representing a specification of the robot's desired behaviours.

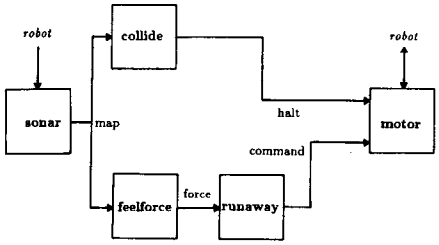


- They separate what the robot should be able to do into levels. E.g., robot should be able to avoid obstacles, but also to explore, pick up interesting objects, etc.

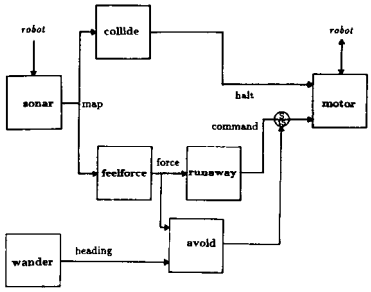
Behavioural layers

- Each *level of competence/behaviour* is implemented as a *control layer* in the robot architecture
- Layers can be built incrementally from the most basic level up.
- Layers remain present all the time, even though they can be inhibited/modified under special circumstances.

L0: Avoid collision



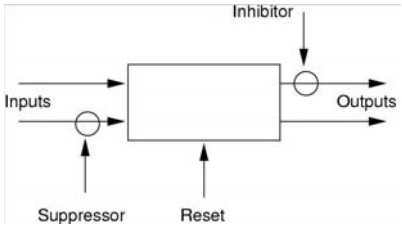
L1: Wander



Coordination

- Coordination between layers through:
  - Inhibition: Outgoing signals from a module are inhibited
  - Reset: The internal state of a module is restarted
  - Suppression: the input to a module is suppressed and replaced by a different signal

Coordination



Coordination

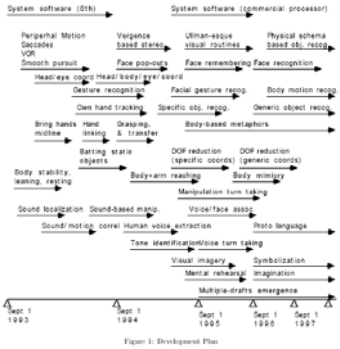
- Low-bandwidth internal communication
- Message passing via machine registers
- Fixed topology (no plasticity)
- Output of lower layer accessible by higher levels (but not the other way around in principle)
- Effective communication through the world itself.

Hexapod robot

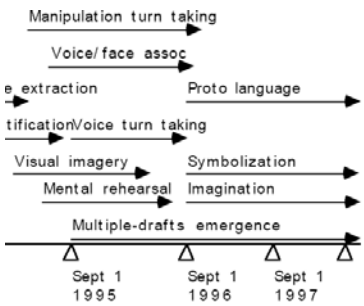
- Genghis (1989): walks over rough terrain, follows people. 12 motors, 12 force sensors, 6 pyroelectric sensors, 1 inclinometer and 2 whiskers.

COG project

- *COG* (1993-2003): Ambitious BBR project at the humanoid level.



Brooks & Stein (1993).MIT AI lab memo



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Brooks 1986

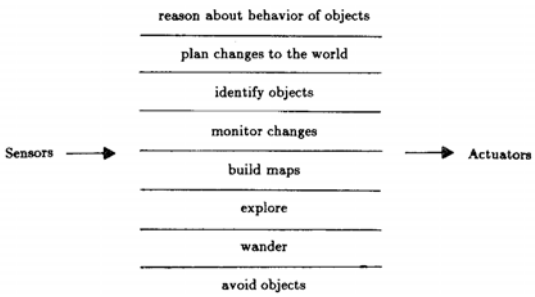


Fig. 2. Decomposition of a mobile robot control system based on task-achieving behaviors.

But in reality…

- The original formulation included representations at the higher levels
- Only one really complex robot was built using these principles (by Jonathan Connell) and it is uncertain whether all the parts ever worked at the same time.
- *COG* was never completed, and only partial systems were ever shown working. Here's a movie…

Schema-based robotics

- R. Arkin *Behaviour-based robotics*, MIT Press, 1998).
- Michael Arbib: *From schema theory to language*: (psychology, animal behaviour, AI, neuroscience…)
- Reactive control -- Schema-based
- **Schema:** Basic unit of motor behaviour from which complex actions can be constructed.
- Schemas (behaviours) are selected to enable the robot to interact successfully with unexpected events while satisfying higher-level goals.

Schema-based robotics

- No explicit planning
- Multiple active schemas present, each produces a velocity vector driving the robot in response to sensory stimulus. (This approached was pioneered by Luc Steels, but not very successfully).
- Vectors are summed to give a single velocity.
- Continually updated. No explicit arbitration between schemas (as in subsumption architecture)

Examples of schemas

`avoid-static-obstacle`

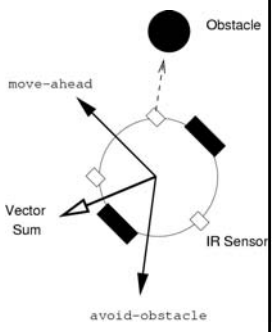
`move-to-goal`

`stay-on-path`

`noise` (move at random)

`probe` (move towards most open space)

`escape`

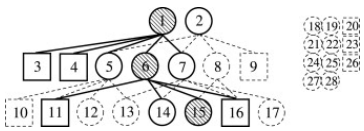


Parameters for schemas

- E.g., `move-to-goal`, `avoid-obstacle`, and `noise`, controlled by five parameters:
  - goal gain - strength for approaching goal
  - obstacle gain - strength with which to move away from obstacle
  - obstacle sphere of influence - distance from obstacle at which robot is repelled
  - noise gain - amplitude of random wandering
  - noise persistence - number of time steps the noise vector is held constant
- Schemas largely hand-designed but GAs can be used to tune parameters effectively.

Dynamic Schema Hierarchy

- Cañas, J., & Matellán, V. (2002). Dynamic Schema Hierarchies for an Autonomous Robot. In *Advances in Artificial Intelligence* — IBERAMIA 2002 (pp. 903-912).
- Schemas are nested in a hierarchy
- Schemas are activated/deactivated
- Activated schemas compete



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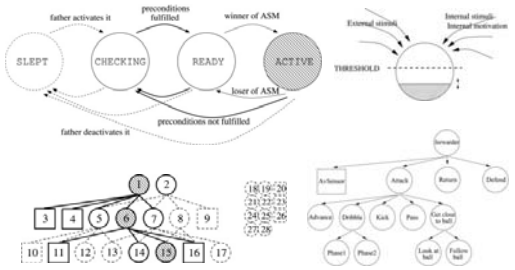
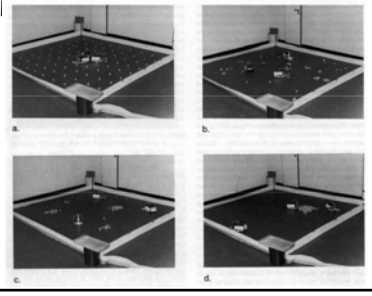


Collective behaviour

- Beckers et al. 1994. Inspiration from social insects. Uses the concept of stigmergy – an agent changes the world in such a way that sensing the wor



Collective action

- Three behaviours, in order of priority (high to low)
  - Avoid hitting other robots and walls by turning away from the first proximity sensor to be activated
  - If pushing more than three pucks, stop, reverse, and do a random turn.
  - Move in a straight(ish) line
  - No explicit coordination – it happens 'through the world' via stigmergy

Is BBR purely reactive?

- Most of the time it is considered to be so.
- However, internal modules in the control layers may change state so there is no in-principle reason why the architecture as it is should be confined to reactive behaviour.
- It is mostly a question of timescales. Internal modules change state at a relatively fast timescale. Connell stated that no internal state should last for more than 3 seconds. There is little opportunity for long-term plasticity.

Questions

- How will this methodology scale?
- Design gets harder as you try to scale up. Can't keep track of the effect of different parameters.
- How about human level cognition? (In fact, how about a dog, an iguana, a fly?)
- Should we care?

Questions

- Importance of distinguishing between behaviour and mechanism.
  - Behaviour = observed ongoing agent-environment interaction.
  - Mechanism = agent-side structure generating this interactivity *when* coupled to body+environment.
  - Seth (2002). *Agent-based modelling and the environmental complexity thesis.* Proc. SAB 2002. Seth (2007). *The ecology of action selection: Insights from Artificial Life.* Phil. Trans. R. Soc. B.

Questions

- For example, many simple robots do wall following – if there's a wall to follow.
- What will happen if there's just a lamppost in the arena?
- You'll see pole-circling – a different behaviour from the same mechanism.