Reactive and Emergent Behaviour

Traditional 'deliberative' AI:

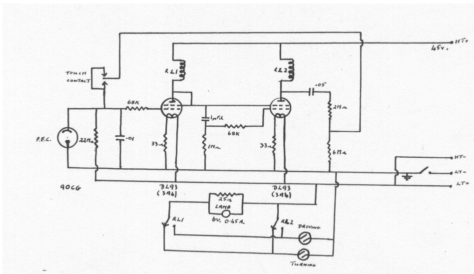
- To build an intelligent autonomous robot requires:
  - Sensory systems that gather information from the environment
  - Processing to construct an internal representation of the situation ('world model')
  - Reasoning methods to compute next action
  - Translation of action plan into motor output

Traditional 'deliberative' AI:

- Problems to address:
  - Need more detailed and accurate sensory devices
  - Want more complete internal model
  - Use representations that allow application of reasoning methods e.g. to address frame problem
  - Improve problem solving methods e.g. to deal with uncertainty or time constraints
  - Translating plan into action
  - Monitor execution, allow rescue or re-planning

But is this necessary?

- Worse sensing is sometimes advantageous
  - Simple whisker sensor may be better than a camera to stop robot from hitting things
  - Sometimes see more with blurred vision:
- Complex behaviour may reflect simple system in complex world – Simon's ant
- Can get surprising capability from a couple of vacuum tubes and relays…Grey Walter's 'tortoise'1950



Starts with: drive motor in series with lamp and turning motor full on; get cycloid movement that scans for light.

Light input: passes through two amplifiers, switching relay 2, short circuit; so stops turning and drives double speed.

Steers at increasingly shallow angle towards light source

Strong light: switches relay 1, turning motor in series with lamp; turns smoothly away from light.

- Approaches then circles light   Inspects different light sources
- If battery low: won't reach threshold to turn away from light, so enters hutch to recharge.

During scanning for light, own lamp is on.
When moving to light, own lamp is off.

- 'Recognises' self in mirror and 'dances'
- Complex interactions of two robots

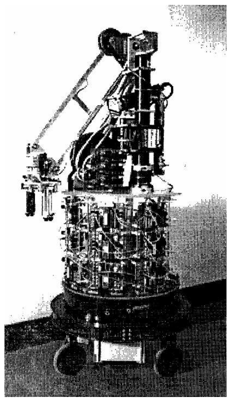
Shell collision: closes touch contact, output of amplifier 2 becomes input to amplifier 1; produces oscillator.

- Rapidly alternates driving and turning speeds, overriding effects of light input, till clear of obstacle.
- Can get round obstacles to find light.
- Also tends to push small obstacles out of the way, gradually clearing the area.

- Reactive behaviour: direct mapping from current sensor input to motor output.
  - Strict definition: no internal state or memory.
  - Loose definition: no deliberation or use of internal models.
- Emergent behaviour: interesting capability that is not explicitly programmed but emerges from interaction of:
  - sets of reactive behaviours
  - the robot with the environment
  - multiple robots with each other

Emergent sequences

- "Herbert" (Connell, 1989)
  - IR to follow walls, compass, laser scanner to detect soda cans, hand contact sensors
- Behaviours:
  - Follow walls on left, go south
  - If see soda can, drive within arms reach and stop
  - If stopped, reach out arm so fingers are around can
  - If can breaks IR beam between fingers, close hand
  - If hand closed, retract arm and follow walls on right, go north



Emergent navigation

- Anderson & Donath (1990)
- Built in set of reflex behaviours:
  - Passive avoidance
  - Active avoidance
  - Location attraction
  - Forward attraction
  - Object attraction
  - Object following (clockwise or counterclockwise)
  - Open space attraction
- Binary switching allows selection of subsets

Forward attraction + Passive Avoidance + Active Avoidance = Generalised Wandering

Location attraction + Passive Avoidance + Active Avoidance = Primitive navigation

Object attraction + Follow object + Passive Avoidance + Active Avoidance = Perimeter following

Emergent co-operation

- Holland (1995) ‘Stigmergy’
- Robots:
  - – Front scoop tends to collect pucks
  - – Lever triggers switch if pushing two or more, makes robot back up, leaving pucks behind
  - – Also avoid walls and each other using IR.
- Result is gradual aggregation of pucks in a single pile

Emergent co-operation

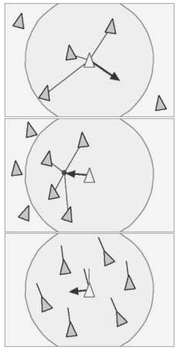
- Melhuish et al (2000)
- Robots can carry puck, detect gradient and notice if cross a boundary line.
- Simple rules:
  - – If hit another object, drop puck
  - – If cross boundary going up gradient, move short distance and drop puck
  - – If cross boundary going down gradient, back-up short distance and drop puck

Emergent group behaviour

Flocking: (Reynolds 1987)

Assumes all ‘boids’ are identical and follow the same local rules:

1. **Collision Avoidance:** Separate from other boids.
2. **Centering:** Stay close to other boids.
3. **Velocity matching:** travel in same direction.



•Have been many robot implementations, e.g. Mataric’s “nerd herd”

•Not well-solved when robots themselves have to sense the relevant information i.e. no global knowledge

Inverse flocking: modelling duck behaviour by simple flocking rules to produce sheepdog control algorithm

(Vaughan et al 2000)

Summary

- Many behaviours don’t require an internal world model:
  - – Using the world as its own best model
  - – “Intelligence without representation”
- Combining simple reactive behaviours can be effective
- But does this scale up?

References

W. Grey Walter (1950) *An Imitation of Life*, **Scientific American**, May, p42-45
See also: http://www.ias.uwe.ac.uk/Robots/gwonline/gwonline.html
Owen Holland (2003) *Exploration and high adventure: the legacy of Grey Walter*, Philosophical Transactions of the Royal Society, 361:2085-2121
Jonathan Connell (1989) *A Colony Architecture for an Artificial Creature* AI Technical Report 1151, ftp://publications.ai.mit.edu/ai-publications/1000-1499/AITR-1151.ps
Tracy L. Anderson and Max Donath (1990) *Animal behavior as a paradigm for developing robot autonomy*. Robotics and Autonomous Systems 6:145-168
Owen Holland and Chris Melhuish (1999) *Stigmergy, self-organization, and sorting in collective robotics* Artificial Life 5:173 - 202
Craig W.Reynolds (1987) *Flocks, Herds, and Schools: A Distributed Behavioral Model*, in Computer Graphics, 21(4) (SIGGRAPH '87 Conference Proceedings) pages 25-34. (http://www.red3d.com/cwr/papers/1987/boids.html)
Maja J. Mataric. *Behavior-Based Control: Examples from Navigation, Learning, and Group Behavior*. In Journal of Experimental and Theoretical Artificial Intelligence, 9(2), 1997.
Vaughan, R., Sumpter, N., Henderson, J., Frost, A. and Cameron, S. *Experiments in Automatic Flock Control* (2000) Journal of Robotics and Autonomous Systems 31 pp.109-117