Adaptive Systems

Ezequiel Di Paolo
COGS

Autonomous Robotics

Robots: what we'd like to see…

Our current aspirations …

What do you mean autonomous?

- Autonomy means "self-law". We saw that there is a way of defining biological autonomy in terms of the circularity of the processes involved.
- Is that definition good for robotics?
- If you had a truly and fully autonomous robot for space exploration you would have to convince it to go on a mission, offer it a good salary, good pension scheme, etc.

- Ways people have used the term "autonomous":
  - No cables attached.
  - Non teleoperated.
  - Self-recharging
  - Mobile
  - Able to learn
  - Adaptive
  - Robust
  - No special meaning

Relativity of autonomy

- **Autonomy vs. dependence:** Autonomy, in the sense of independence, should perhaps be considered as a relative term. Ultimate autonomy means being cut-off from your environment (i.e., it is not a meaningful concept).
- **Autonomy vs. control:** Controlled systems cannot be autonomous. They follow someone else's law. Add the controller to the system and you have self-control, still not the same as self-law.

Meaningful practical use

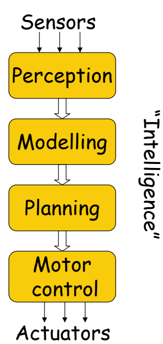
- Degrees of autonomy as degrees of self-sufficiency, self-determination.
- Not a formal definition as in biological autonomy (= organisational closure).
- But related to it.

Brady vs. Brooks

- Intelligent Robotics: Back in the 80s there were some royal arguments and intellectual punch-ups...
- **Brady:** best to compartmentalize. (Section headings from his edited collection *Robotic Science*)
  - Perception
  - Planning
  - Control
  - Design and Actuation
- **Brooks:** The Whole Iguana

The SMPA approach

- Brady: Problems of robotics = Problems of AI
- An **action-neutral** architecture.



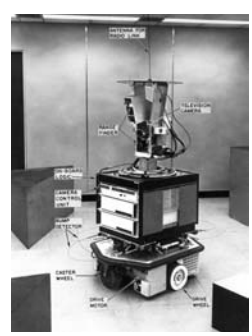
Traditional AI

- Replicate human intelligence
- Based around sequential pipeline of processes
- Implicit in this pipeline model (partly due to Marr) is the idea of functional decomposition, leading to modularization and compartmentalization.
- The body is a design detail.
- All-knowing generalisers instead of opportunistic exploiters of niches.

- Function of perceptual module: Build a reliable internal representation of the world.
- Function of modelling module: Actualize model of the world.
- Function of planning module: Infer consequences of actions based on world model. Plan actions that will lead to the completion of subgoals and goals.
- Function of action module: Devise the best sequence of movements to carry on the plan.

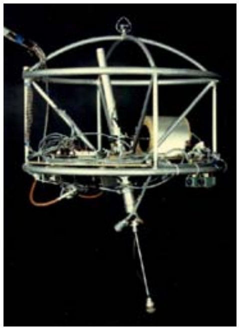
The 70s, Shakey (SRI)

- Prototype robot using traditional pipeline approach (N. Nilsson, Stanford).
- World model
- Perception separated from action
- Carefully engineered world
- No time constraints
- Closed world assumption



Hopping robot

- Raibert's One-Leg Hopper (1983-1984) inspired Brooks' approach
- Actively balanced locomotion can be accomplished with simple control algorithms. It hopped in place, travelled at a specified rate, followed simple paths, and maintained balance when disturbed.



Hopping robot

- 2 actuators, 5 sensors, 3 aspects of behaviour were controlled by a very simple servo mechanism:
- hopping height,
- body attitude,
- forward speed.
- No central model: 3 behaviours integrated by the physics of the machine.

Moravec: precursor to Brooks

- Early advocate of alternatives to AI: Most of animals' control (nervous) system is for everyday sensorimotor coordination. The hard problems of AI are the problems of autonomous robotics.
- High level reasoning is a recent "parlour trick" of little interest for understanding the mechanisms underlying intelligent behaviour. Traditional approach to AI not the most effective.
- *"A mobile way of life favours general solutions that tend towards intelligence, while non-motion favours deep specialization."*

Moravec: precursor to madness

- By equating intelligence with computer power he infers (early 80s) human level capabilities by 2004 and superhuman new order of life soon after.
- Robot intelligence will soon reach "escape velocity"
- Sounds like anyone you know?

Action-oriented approach

- Alternative to SMPA (Behaviour-based, schema-based, evolutionary robotics, nouvelle AI). Three principles:

1. **Situatedness:**
- Exploitation of an ecological niche
- Constant interaction with environment
- Affordances, meaningful action and perception
- Real world openness.

Action-oriented approach

2. **Embodiment:**
- Whole agent integrated design
- Closed-loops of sensorimotor interaction
- "Intelligent" sensors and actuators (exploit physics and regularities)
- Action and perception, two aspects of a single process (active perception, perceptually guided action)

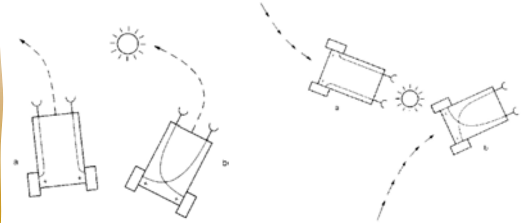
Action-oriented approach

3. Dynamics:

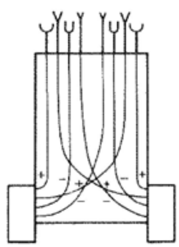
- Real time constraints.
- Time matters
- Opportunistic
- Loose coupling between simple processes giving rise to robust activity.

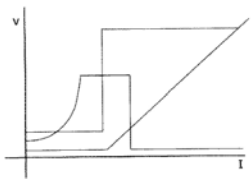
Braitenberg vehicles

- Useful thought experiments in purely reactive robots (1984). Simple vehicles (sensors directly connected to motors) demonstrate interesting behaviours. Uphill analysis vs. downhill invention.



Braitenberg vehicles





Extended vehicles

- *Braitenberg creatures*, (Hogg, et al. 1991): IR sensors. Obstacle avoidance + slight bias forward in motors = a vehicle capable of navigating through mazes.

- Other extensions add more sensor types, internal variables that affect the sensor-motor mapping, action selection problems. (Seth, 1998).

- Homeostatic vehicles. Internal variable integrating sensor activity must be kept within bounds. Otherwise, transfer function changes randomly.

Embodiment

- A widespread misconception: We should build real robots rather than simulations.

- **Embodiment does <u>not</u> mean mere physicality.**

- Two important consequences:
- Physical systems (e.g., Shakey) can still be disembodied in a relevant sense. The fact that they have a body is not critical for what they do.
- Embodied systems can still be studied by means of well designed simulations (Beer), just as rivers and rocks can.

Embodiment means ...

- The body makes a <u>crucial</u> difference

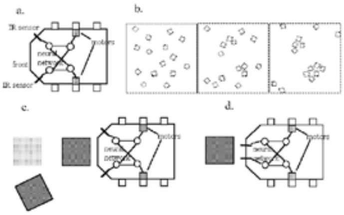
- Morphology affects action and perception just as importantly as the control architecture

- The body can be exploited. Physical dynamics alone can carry you very far, no need to compute a real world model in order to act, (e.g., passive dynamic walkers).

- Proprioception, active perception, intelligent perceptual systems.

More embodiment

- A simple but revealing example (Didabot, Pfeifer et al.) Obstacle avoidance is transformed into clustering behaviour by a slight change in the position of the sensors (same neural network)



Robotics: controlled trajectories

- ASIMO the Honda Humanoid Robot

More embodiment

- Passive dynamic walking
- Tad McGeer and followers (Cornell, Michigan)
- Stable downhill walking with no muscles

Enough embodiment?

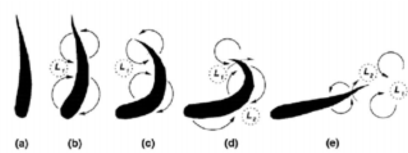
- Still missing from current research:
- Blurring of body/controller boundaries. Softer bodies.
- Body plasticity/body disruptions
- Body development
- Self-presence
- Double aspect of body as perceived and perceivable

Situatedness: exploit a niche

- Define activity so that it will be the outcome of a tight coupling between agent and *relevant* aspects of the environment. (e.g., avoid everything that comes looming towards you).
- Seek out meaningful regularities in your world.
- Achieve desired behaviours through exploitation of environmental dynamics.
- Modify your environment by your own activity, let future activity take advantage of these modifications.

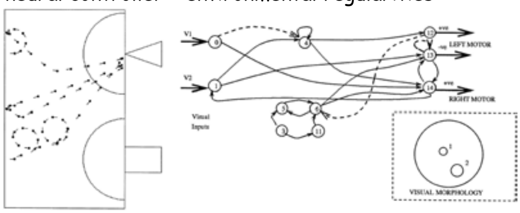
Situatedness

- Much of it implied in embodiment: Fish vortex manipulation for ultra-efficient swimming (MIT RoboTuna, Triantafyllou et al.).



Embodied and situated

- Gantry robot (Sussex). Approach a triangle on the wall, evolve neural controller and sensor morphology.
- Visual task = body rotation + sensor morphology + neural controller + environmental regularities



Summary

- Looking at whole agents
- Less obvious functional de-composition and modularity
- Less emphasis on world reconstruction, representation and planning.
- Aiming at robust, real-world behaviours (not pre-digested toy worlds)
- Looking a complex behaviours out of simple interacting mechanisms

Summary

- Drawing inspiration from biology (looking at evolution and animal intelligence)
- Focusing on the role of the body, the ecological niche and mutual dynamics
- But… Lots of open questions:
  - Scalability
  - Complexity
  - Design methodologies
  - Reliability, explainability