Adaptive Systems

Ezequiel Di Paolo
Informatics

Lecture 1: Overview

Organisation of the Course

- Lectures
  - Ezequiel Di Paolo (ezequiel@sussex.uk)
  - Monday 9:00-10:00
  - Monday 10:00-11:00
- Seminars
  - Run by Marieke Rohde (mr58@sussex.ac.uk)
  - and Thomas Buehrmann (tb30@sussex.ac.uk)
  - Weeks 4-6
- Lab Class
  - Week 7 (PG)

Resources

- Course webpage linked from:
  www.informatics.sussex.ac.uk/users/ezequiel/teaching.html
- Includes: Lecture notes, list of online resources, last minute information, advice on choice of programming projects, questions, reading material

Assessment (Undergraduates)

- Exercise 1 (50%)
  - Programming exercise: Based on a robot or GA project. A 2000-word report to be handed in
- Exercise 2 (50%)
  - A 3000-word essay on a relevant topic of your choice (list of topics will be made available)

Assessment (Postgraduates)

- Programming project (100%)
  - A 5000-word term paper (topic to be agreed) based on programming or robotic project and containing essay elements
- Advice
  - You are encouraged to seek feedback on your choice of topic. Suitable topics and format advice will be made available

Objectives

- To gain some familiarity with a number of different approaches to modelling and understanding adaptive processes in natural and artificial systems. In particular, to gain some understanding of approaches (old and recent) to generating adaptive behaviours in autonomous robots.

Rationale

- This course will cover theoretical aspects of biological adaptation and recent work in AI which is geared towards understanding intelligence in terms of the generation of adaptive behaviour in autonomous agents acting in dynamic uncertain environments. Adaptation will be studied at both the evolutionary and the lifetime scale.

Rationale

- Lectures will give a general coverage. Seminars and exercises will guide you deeper into certain topics. You are expected to engage in background reading and follow up references mentioned in the lectures.

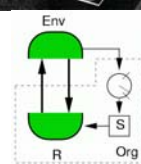
- No single textbook. But lots of books, book chapters, articles, online material, etc.

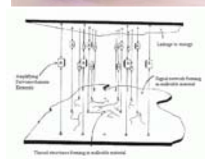
Contents

- The first part of the course will look at conceptual issues in studying and modelling natural adaptive systems (roughly the first 7 lectures). The rest of the course will concentrate on evolutionary techniques, particularly as applied to the design of artificial adaptive systems (robots).

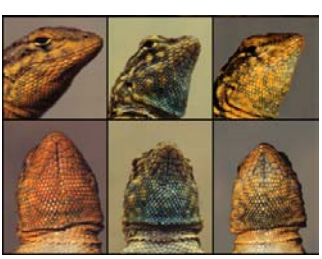
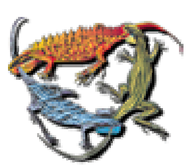
Contents: Cybernetics



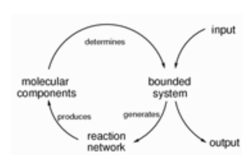


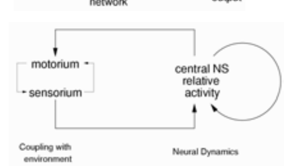


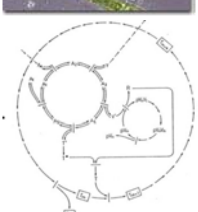
Evolution

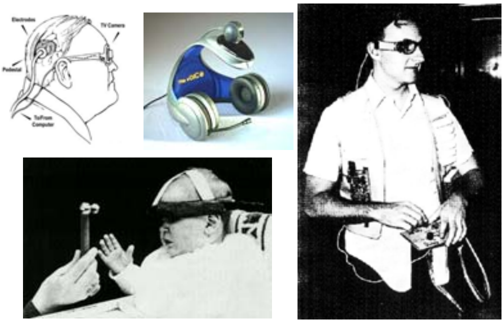
Autopoiesis, minimal living systems



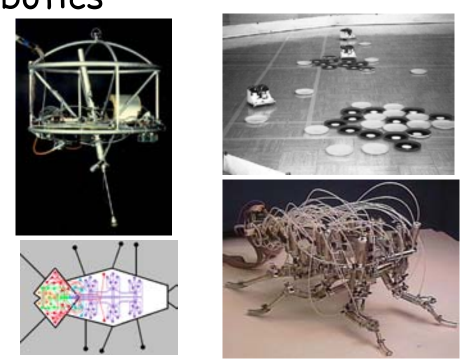


Sensory substitution

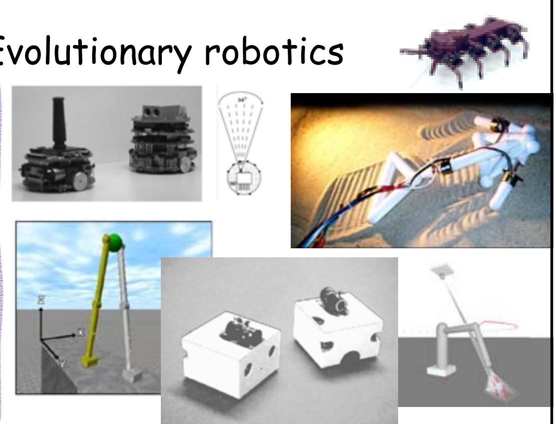


Distorted perception

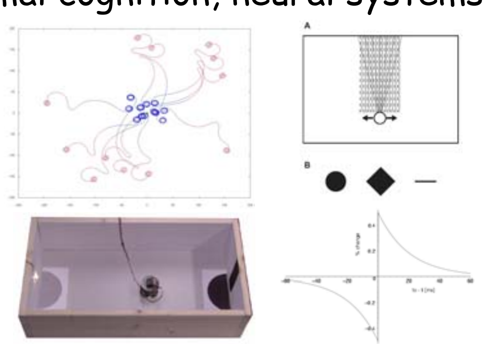
Robotics



Evolutionary robotics



Minimal cognition, neural systems



Contents

- Cybernetic roots of AI
- Adaptation and stability (Ashby)
- Evolutionary theory
- Evolutionary computing
- Somatic adaptation, sensory substitution
- Autopoiesis, autonomy
- Co-adaptation and social behaviour
- Adaptation in artificial systems
- Autonomous robotics
- Embodiment, situatedness
- Dynamical approaches to cognition
- Evolutionary robotics (basics, hot topics)

What is an adaptive system?

- A system that changes in the face of perturbations (e.g., changes in the environment) so as to maintain some kind of invariant (e.g., survival) by altering its properties (e.g., behaviour, structure) or modifying its environment.
- Operationally speaking: a system that maintains some kind of invariant by responding to perturbations in this manner.

Changes…

- The observed change may be due to changes in the structure or internal mechanisms of the system or may stem from its intrinsic dynamics. (A very fine line distinguishing both cases.)

Adaptivity …

… (the ability to adapt) depends on the observer who chooses the scale and granularity of description.

Obstacle avoidance may count as adaptive behaviour if we describe navigation at a microscale where obstacles appear rarely in largely open and unobstructed segments of the environment. If the "normal" environment is viewed at a macroscale as obstacle-rich, then avoidance becomes part of the "normal" behaviour rather than an adaptation.

Different meanings of adaptation

- Adaptation means change, but not just *any* change. It means appropriate change. Adaptation implies a norm.
- Different meanings of "appropriate" correspond to different meanings of "adaptation".

Kinds of adaptation

- **Task-based:** changes that allow the completion of a goal when this is challenged. (Most common meaning when dealing with artificial systems).
- **Sub-organismic:** a system/mechanism within the organism that maintains some internal property (homeostasis in individual cells, etc.) Can give rise to organismic level phenomena such as habituation (which may be non-adaptive at this higher level).
- **Organismic:** changes that maintain essential properties of the organism (e.g., those that guarantee survival, identity, autonomy).

Kinds of adaptation

- **Ecological:** changes that maintain certain patterns of behaviour of one or many organisms. Recovery of sensorimotor invariants and habitual behaviour. Radical adaptation to body reconfiguration. Includes social invariants, group behaviour, social norms, institutions, economies, etc.
- **Evolutionary:** changes in distribution of phenotypes due to differential rates of survival and reproduction. Resulting phenotypic properties can be said to be adapted. Occurs at population level.

Normativity

- In all cases, to say that a change is appropriate means that we are using a framework of normativity. We are saying when things are right and when they are wrong.

  In some cases this framework is easy to obtain. In task-based scenarios it is arbitrarily defined by the designer as the goal to be achieved (a wholly external norm). In other scenarios the situation may be more complicated (co-dependent norms).

Normativity

- Task-based thinking should not be applied uncritically to organismic or evolutionary adaptation. We *theorize* about what the organism should do; if it manages to achieve a goal when challenged we say it has adapted. We propose an external norm, but we could be wrong... An organism may adapt by discarding the achievement of the goal as necessary for "its purposes" (the norm may change). However, applying task-based thinking is what is usually done. (cf. optimality assumptions in biology).

Normativity

- Some normativity frameworks may prove useful and yet lead to unintuitive results, (e.g., the maintenance of *ecological* patterns of behaviour/perception could be used to describe substance addiction as an adaptation which may work against *organismic* survival).

Observer-dependence

- Scale and granularity of description
- Multiple levels and kinds of adaptation
- Alternative valid frameworks of normativity

- All this points to the observer-dependence of adaptation. Yet, observer-dependence does not mean arbitrariness…

Reasons for studying adaptation

- Theoretical
  - nervous systems and the generation of behaviour/perception
  - natural intelligence
  - multi-level processes (physiological/ecological/historical)
  - social behaviour, social institutions,
  - evolutionary dynamics
  - complex multi-component systems (economies, linguistic communities, etc.)

Reasons for studying adaptation

- Practical
  - solving complex search problems
  - designing new tools for scientific enquiry
  - building autonomous robots
  - risky mission robotics
  - a path towards AI
  - intelligent software agents
  - adaptive interfaces as body enhancers
  - Medical (rehabilitation, addiction treatment, prostheses, sensory substitution)

Modelling systems

- Variables/Parameters
  - A *system* is defined as a set of *variables*. These can be chosen arbitrarily, but only a few choices will be significant (state-determined systems). Factors affecting the system which are not variables are called *parameters*.
- State/Transformation
  - The values of the system's variables at a given instant define the *state* of the system. States can change thus introducing a temporal dimension or *transformation*.

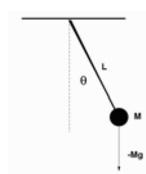
Modelling systems

- Dynamical Law/Constraints
  - Regularities in the transformations of a system can often be described as a special case of a general *law*. General laws can be applied to particular systems by specifying a set of *constraints* that describe the relations that hold between variables and derivatives.
- Continuous/Discrete
  - Some variables may vary *continuously* and some may have a *discrete* set of allowed values. (Some variables may be continuous but fruitfully approximated as discrete).

Modelling systems

- Coupling
  - Two or more systems identified as distinct may interact. This is described as *coupling*: <u>variations in the parameters of one system depend on the value of variables in other system</u>. A useful description if we wish to maintain a distinction between the systems, otherwise they can be seen as a single larger system.
- Autonomy
  - Non-autonomous system: <u>when some parameter or constraint is an independent function of time</u> (e.g., systems driven by some external factor). Otherwise, autonomous. Technical sense (not exactly as will be used in this course, but still relevant).

Example: a pendulum



$$\frac{d^2\theta}{dt^2} = -g\sin\theta$$

<u>Variable</u>: Angle to the vertical θ

<u>Parameters</u>: Length of string, mass, elasticity, air resistance…

<u>Law</u>: Gravitation, Newton's 2nd law

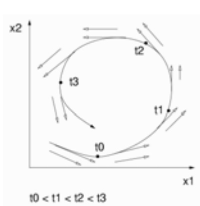
<u>Constraints</u>: Position of mass always at a fixed distance from origin; fixed origin.

<u>Description of dynamics</u>: a differential equation that expresses changes in angular velocity as a function of the dynamical laws and constraints.

<u>Solution of dynamics</u>: angle as a function of time $\theta(t)$, given an initial condition.

State space, vector fields

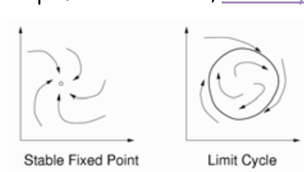
$$\frac{d\vec{x}}{dt} = \vec{F}(\vec{x}, \vec{p}, t)$$



- Generalised equations of motion
- Trajectory in state-space, vector field

Attractors

- Attractors: Asymptotic dynamics ($t \to \infty$)
  Valid concept for autonomous, <u>closed systems</u>.



The whole picture becomes more complex if we add noise or uncertainty: Stochastic processes, distribution of states, etc. For <u>open systems</u>: metastable states, bifurcations, itinerancy.