Adaptive Intelligence

Lecture 7

MONASH UNIVERSITY CLAYTON'S SCHOOL OF INFORMATION TECHNOLOGY

What is Adaptive Intelligence?

- An understanding of intelligence in terms of the generation of adaptive behaviour in autonomous agents.
- The ability to act in dynamic and uncertain environments.
- Adaptation occurs at both evolutionary and lifetime time scales.
- Related:
  - Cybernetics
  - Autopoiesis
  - Dynamical Systems
  - Evolutionary learning

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.

These notes adapted from Ezequiel Di Paolo's *Adaptive Systems* Master's course, Infomatics, University of Sussex

Changes...

- The *observed* change may be due to changes in the structural 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 choses 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 (cont.)

- **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 the 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 is 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 (cont.)

- 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 tasks based thinking is what is usually done. (cf. optimality assumptions in biology).

Normativity (cont.)

- 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 an 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 (cont.)

- Practical
  - solving complex search problems
  - designing new tools for scientific enquiry
  - building autonomous robots
  - risky mission robots
  - 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*.

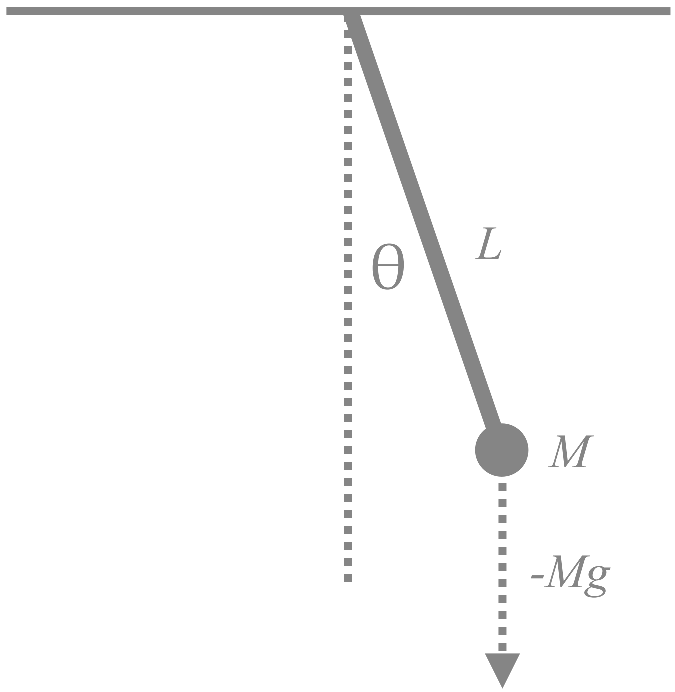
Modelling Systems (cont.)

- Dynamical Law / Constraints
  - Regularities in the transformation 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 (cont.)

- Coupling
  - Two of more systems identified as distinct may interact. This is described as *coupling*: variations in the parameters of one system depend on values of variables in another system. A useful distinction if we wish to maintain a distinction between the systems, otherwise they can be seen as a single larger system.
- Autonomy
  - Non-autonomous system: when some parameter or constraint is an independent function of time (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



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

Variable: Angle to the vertical θ

Parameters: Length of string, mass, elasticity, air resistance…

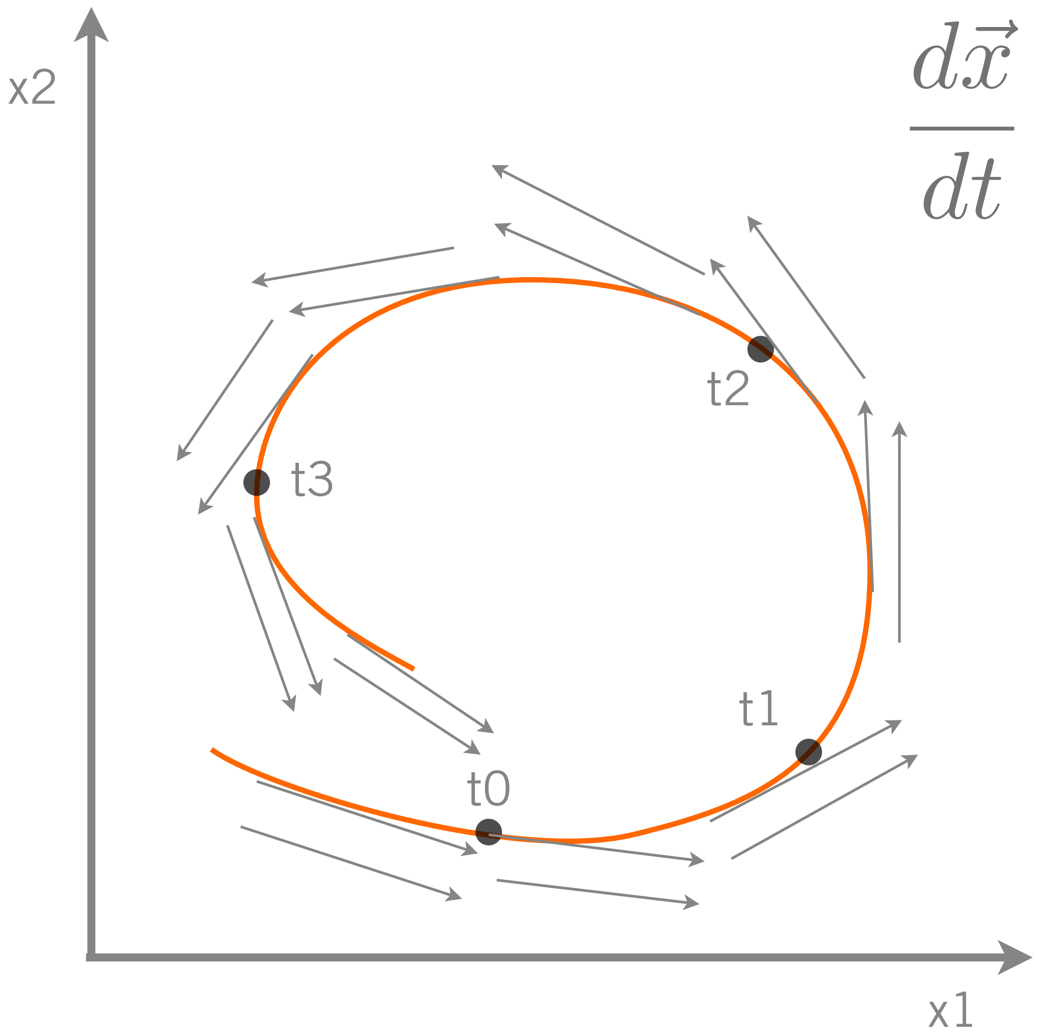
Law: Gravitation, Newton's 2nd law

Constraints: Position of mass always at a fixed distance from origin; fixed origin.

Description of Dynamics: a differential equation the expresses changes in angular velocity as a function of the dynamical laws and constraints.

Solution of dynamics: angle as a function of time θ(*t*), given an initial condition.

State space, vector fields

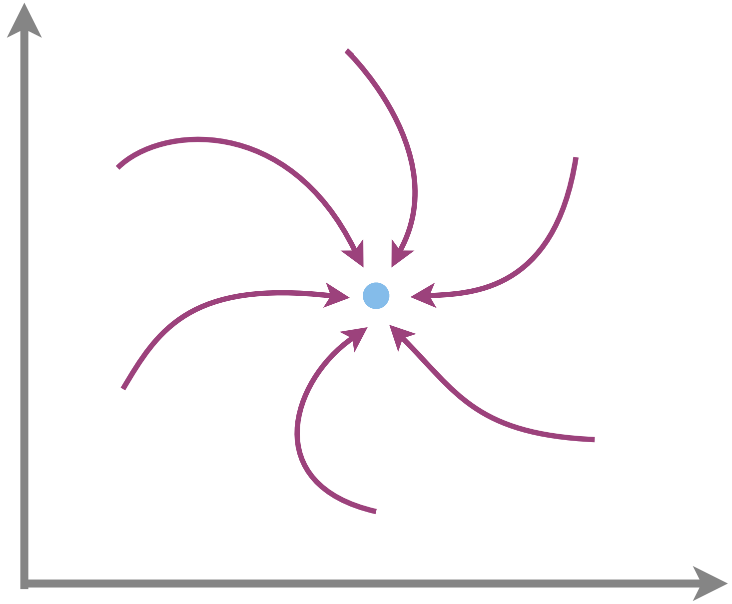


$$\frac{d\vec{x}}{dt} = \vec{F}(\vec{x}, \vec{p}, t)$$

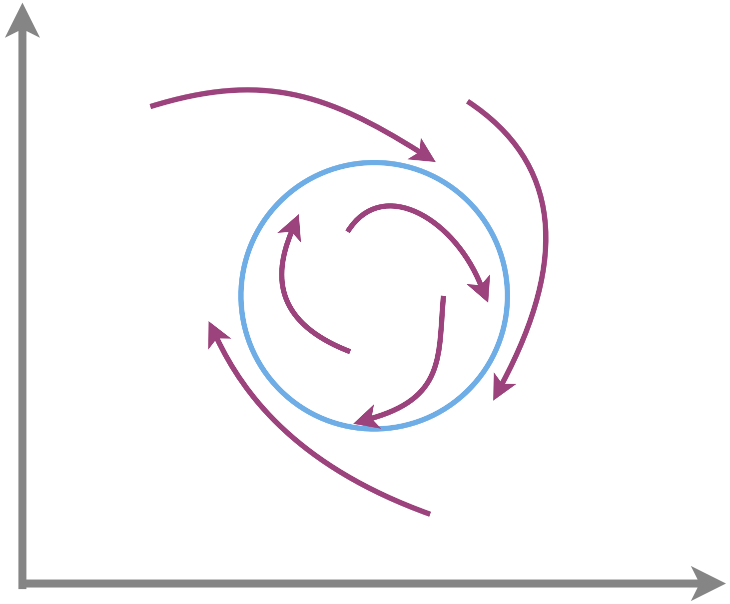
- Generalised equations of motion
- Trajectory in state-space, vector field

Attractors

- Attractors: asymptotic dynamics ($t \rightarrow \infty$) valid concept for autonomous, *closed systems*.



Stable Fixed Point



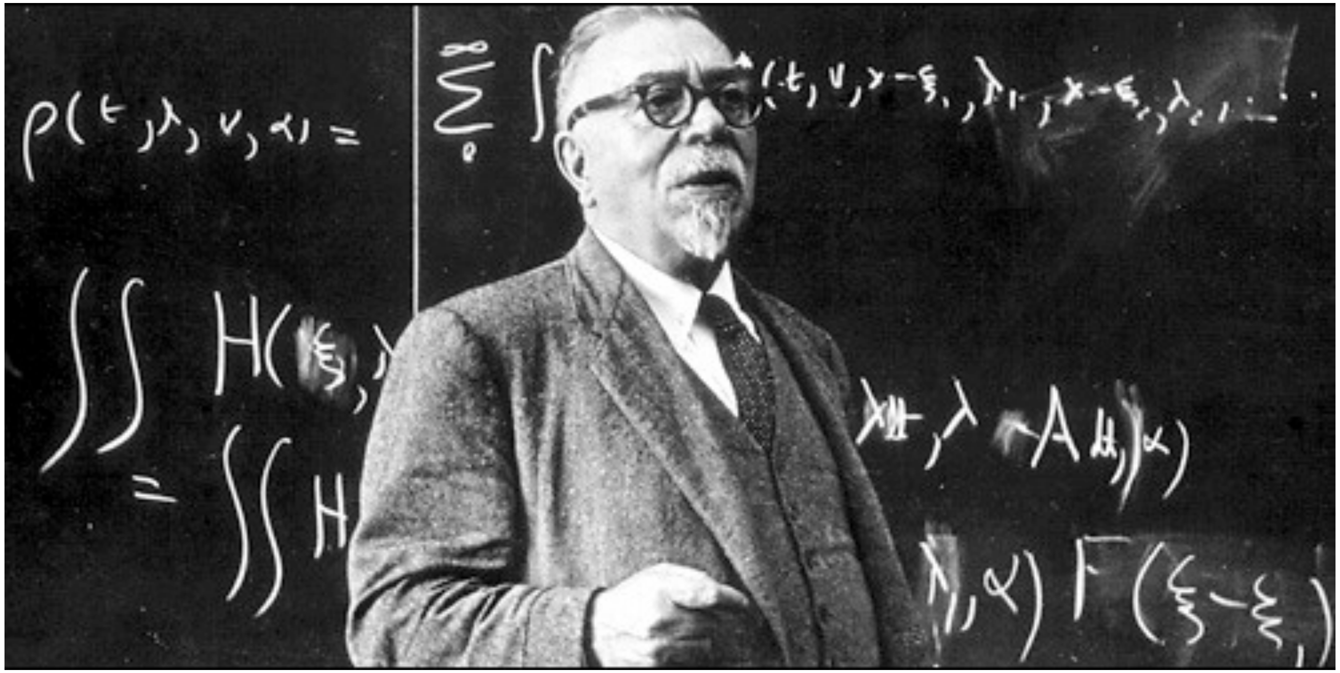
Limit Cycle

- The whole picture becomes more complex if we add noise or uncertainty: Stochastic processes, distribution of states. For *open systems:* metastable states, bifurcations, itinerancy.

Cybernetics

- Founding names: Norbert Wiener, Arturo Rosenblueth, Warren McCulloch, Walter Pitts, John von Neumann, Claude Shannon
- Cybernetics (from the Greek for "steerman") is the study of the control and communication in animals and machines.
- It aims at offering unifying principles for general classes of phenomena. For this reason it works at abstract levels introducing concepts such as control, feedback, signal, information, and so on, in models that could be applied to brains, ecologies, economies, societies, etc. Black Box Models.
- AI: a subset of the central aims of cybernetics.

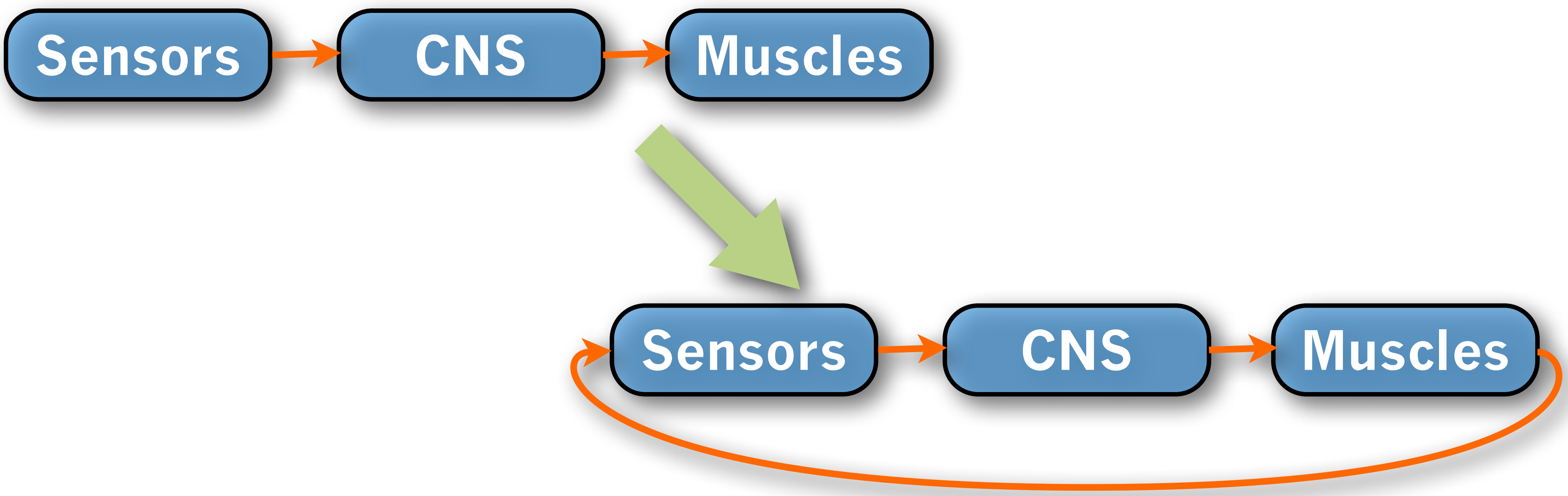
Norbert Wiener



- 1894 – 1964, Mathematician
- *"Cybernetics: or control and communication in the animal and machine"* (1948)

Norbert Wiener (cont.)

- Tried to reconcile purposeful behaviour and mechanistic views by introducing the idea of *feedback*. [Behaviour, purpose and teleology", Rosenblueth, A., N. Wiener & J. Bigelow, *Philosophy of Science,* 10, pp. 18-24, 1943]



Sensing and acting tightly coupled. Not the standard view at the time (even now).

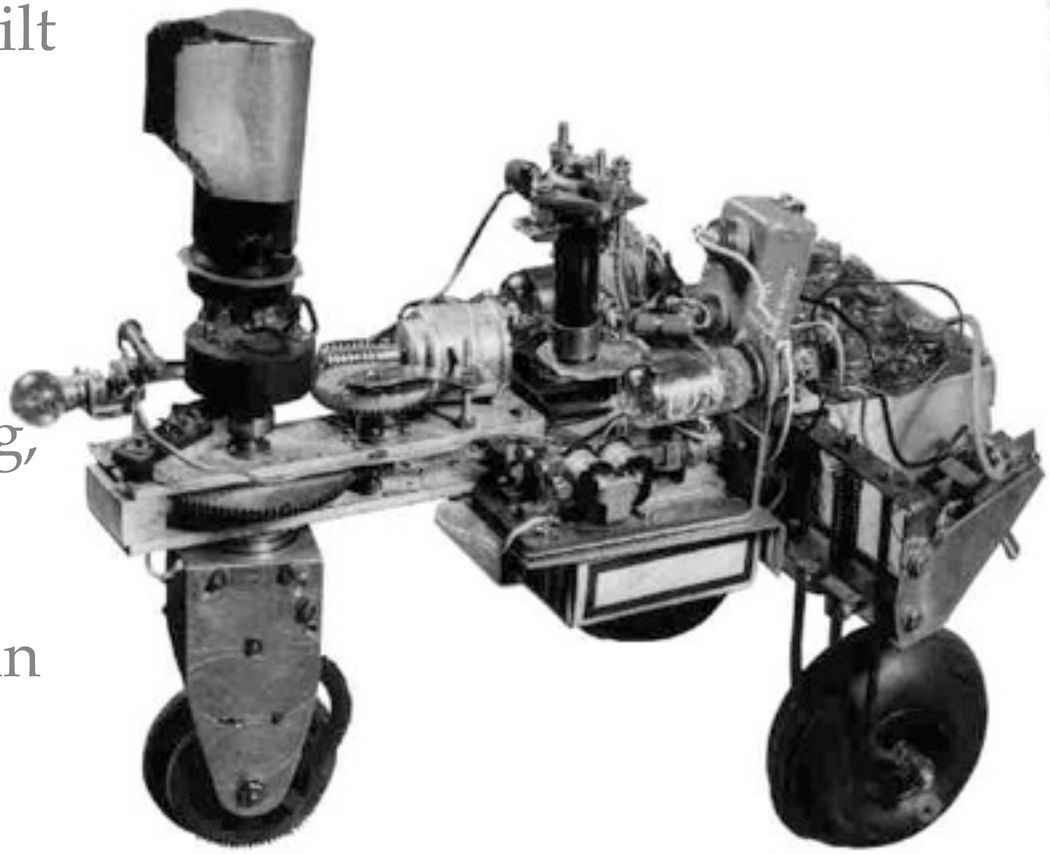
Warren McCulloch

- 1898 – 1972, Mathematician, neuroscientist, philosopher
- Developed the first neural network model. A formalisation of brain activity viewed as a network of logical elements, including loops and delays. Precursor of the connectionist movement in the 1980s.
- *"What the frog eye tells the frog brain"*, Lettvin, J.Y., H. Maturana, W. McCulloch & W.H. Pitts, Proc. IRE 47:1940-51, 1959. Showed topological organisation of neurons. "Processing" is not centralised but happens in the sensors themselves that extract action relevant features from the visual image. No general purpose mechanisms, Kantian synthetic *a priori.*

W. Grey Walter's *Turtle*

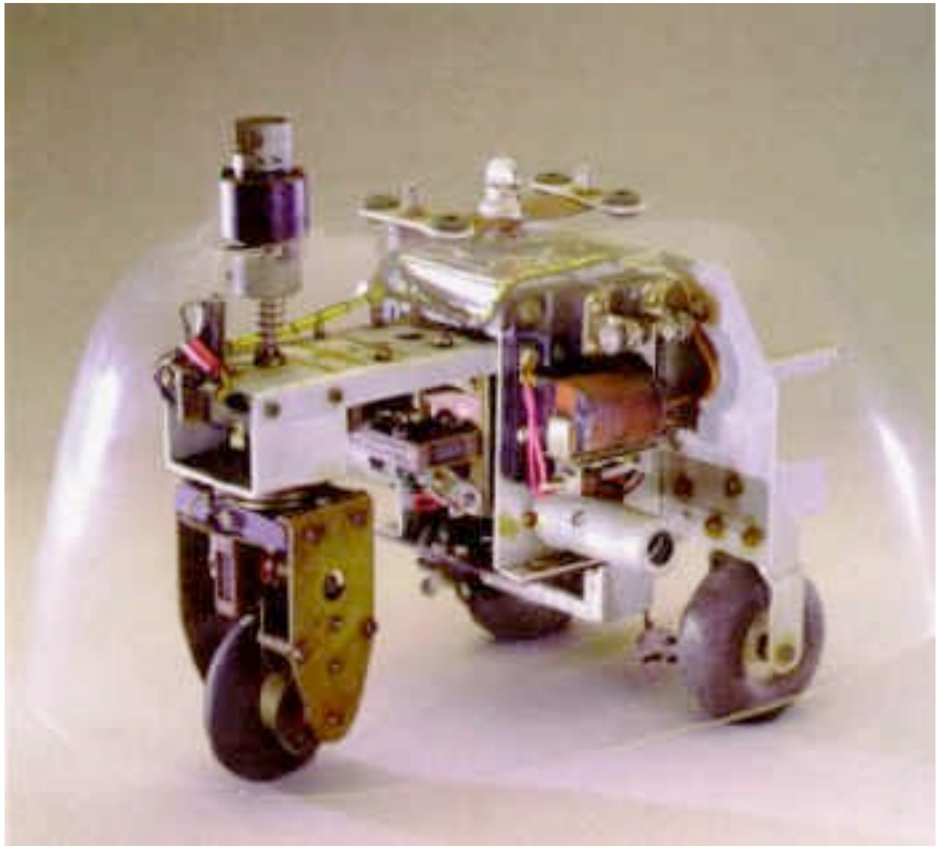
- Elmer and Elsie – the first autonomous robot turtles, built in 1948–49 ("Machina Speculatrix")

- "It began flickering, twittering, and jigging like a clumsy Narcissus", he wrote. If seen in an animal he argued this "might be accepted as evidence of some degree of self-awareness".

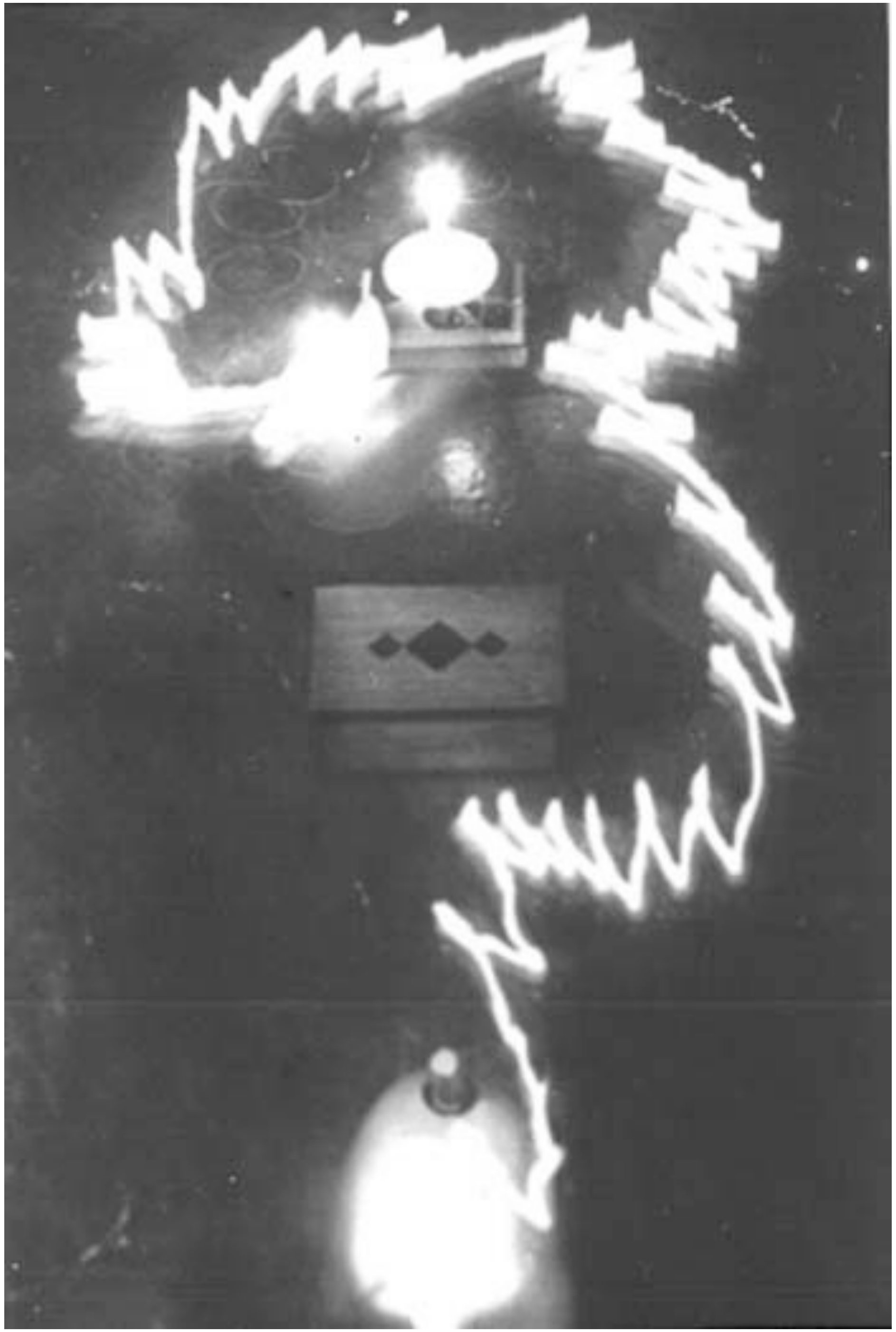


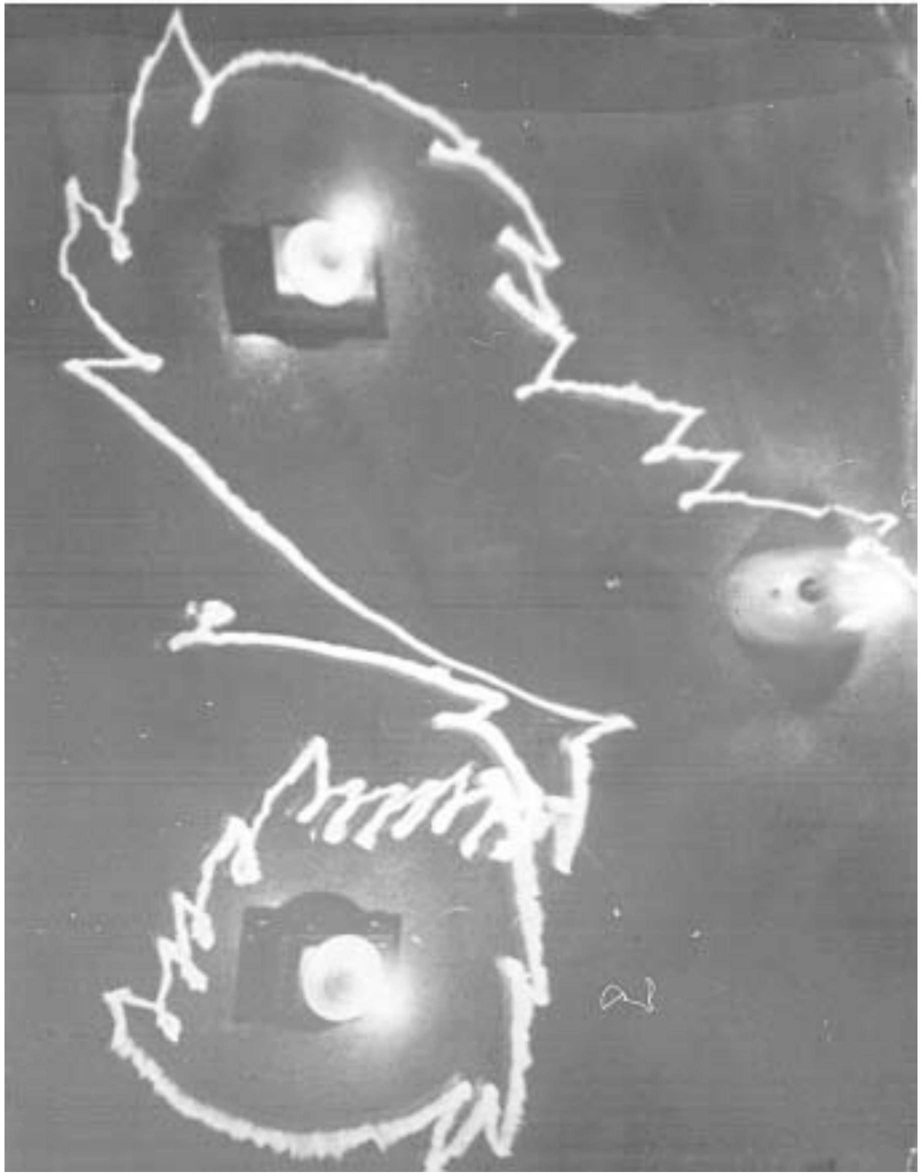
W. Grey Walter's Tortoises

- Two "neurons", two sensors (light and contact) and two motors. Contrasting ideas with GOFAI: design a whole machine, exploit interactions with the environment (active perception), internal interaction of different "behaviours" (subsumption architecture) – rediscovered by R. Brooks in late 1980s.

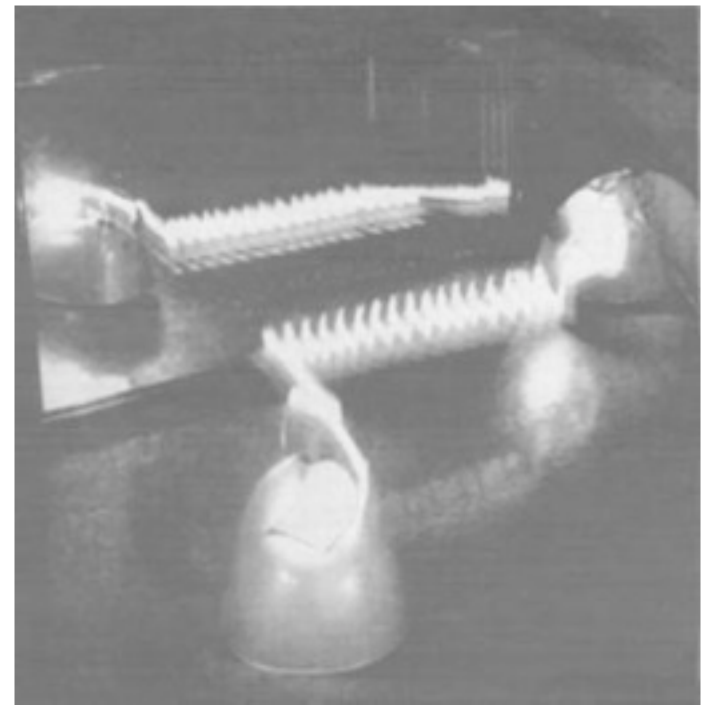


Obstacle-avoidance, Phototaxis





Recharging Interaction Narcissism



Growing an Ear

- Gordon Pask (1928 – 1996), polymath
- Developed a chemical adaptive system that learns to perform a task by growing threads of low conductivity in a ferrous solution (1958). The threads gradually disappear if they are not used, but lower the resistance to current if they are. Managed to grow an artificial “ear” in this way.
- Functionality and structure change continuously in response to history

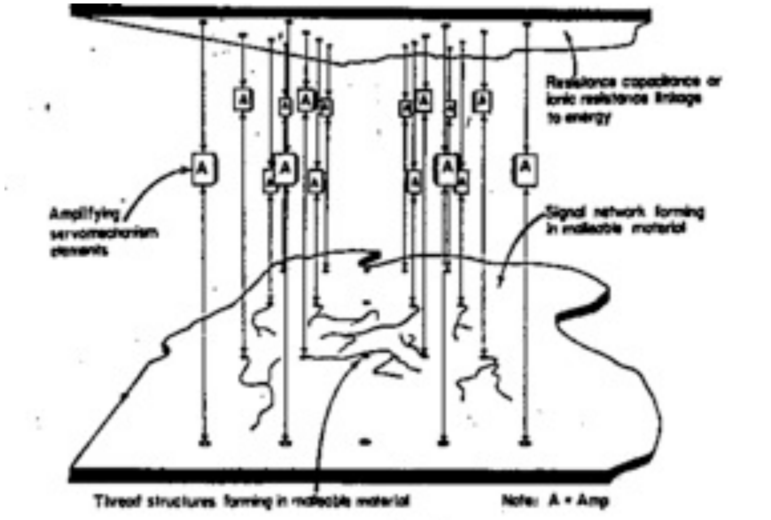


Figure 1. Pask's schematic indicating the relationship between the electrode array and the ferrous sulphate medium. From [28].

See: http://homepage.mac.com/cariani/CarianiWebsite/PaskPaper.html

W. Ross Ashby

- 1903 – 1972, Cybernetician
- "Design for a Brain", 1952, (Second Ed. 1960)
- "An introduction to Cybernetics", 1956

W.Ross Ashby, Warren McCulloch, Grey Walter, and Norbert Wiener at a meeting in Paris (from Latil, P de: *Thinking By Machine*, 1956)

Adaptive Framework: The Problem and Method

- **The Problem:** what mechanisms underlie the production of adaptive behaviour in living organisms? In particular, how does the brain produce adaptive behaviour?
- **The Method:** An operational, dynamical-systems approach. The organism is viewed primarily as a purposeless machine instead of a purposeful, goal seeking device.
- **Consequence:** Purposeful behaviour, adaptivity, etc. must be *explained* rather than *assumed.*

Ashby's Adaptive Framework (cont.)

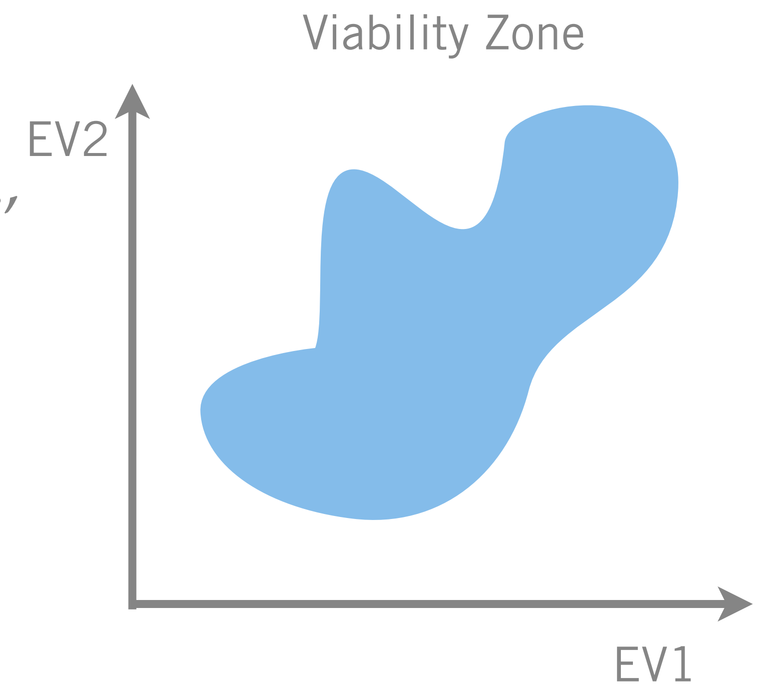
- Focuses on nervous system activity: learned behaviour over a lifetime (somatic adaptation)
- Non-teleological explanations (Teleology: purposeful accounts of behaviour)
- *A machine or animal behaves in a certain way at a certain time because its physical and chemical nature at that moment allow it no other option.*
- The problem: to identify the nature of changes which show as learning and to find out why such changes should tend to cause better adaptation of the whole organism.

Organism and Environment

- The organism is defined as a set of **variables.**
- The environment is defined as a system whose variables affect the organism through coupling and which are in turn affected by it.
- Organism and environment *taken together* form a state-determined system. They can also be treated as coupled systems (in which case the environment need not be state determined, e.g., if we allow for fluctuations, uncertainty, etc., but the organism is still state-determined.

Essential Variables

- Essential variables of an organism are a closely related set of physiological variables strongly linked to survival (e.g., body temperature, sugar levels, oxygen intake, etc.)
- In order for an organism to survive, its essential variables must be kept within variable limits.
- Otherwise the organism faces the possibility of disintegration and/or loss of identity (dissoloution/death).



Adaptation as Stability

- Behaviour is adaptive if it contributes if it contributes to the maintenance of *essential variables* within variable limits.
- *Homeostasis* is a low-level example of a self-correcting mechanism.
- An adaptive system is a stable system, the region of stability being part of the state space where all essential variables are within physiological limits.
- Blindly obeying its nature or skilfully returning to equilibrium in spite of disturbances?

Ultrastability

- Double feedback:
  - Sensorimotor coupling
  - Through essential variables acting on parameters
- Ashby claims that many organisms undergo two forms of disturbance:
  - Frequent small impulses to main variables
  - Occasional step changes to its parameters
- If this is so it provides a good framework for adaptation
- In real organisms the actual mechanisms remain to be specified.

Ashby’s Homeostat

8/2 THE HOMEOSTAT

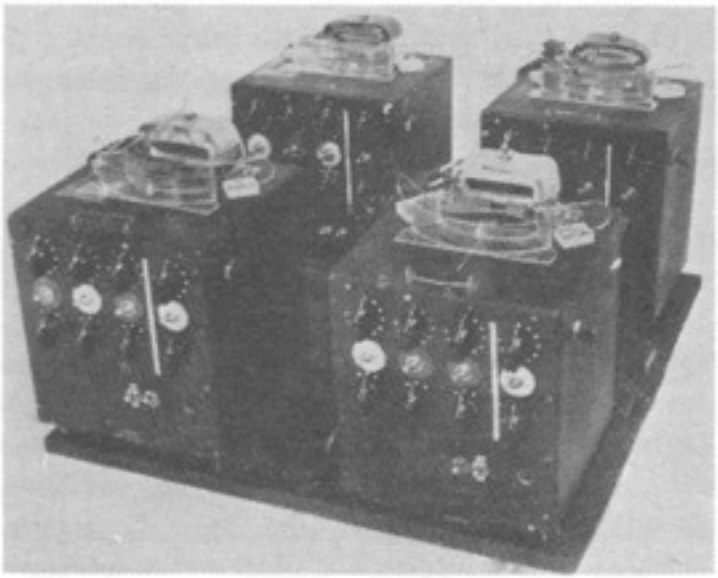


FIGURE 8/2/1: The Homeostat. Each unit carries on top a magnet and coil such as that shown in Figure 8/2/2. Of the controls on the front panel, those of the upper row control the potentiometers, those of the middle row the commutators, and those of the lower row the switches *S* of Figure 8/2/3.

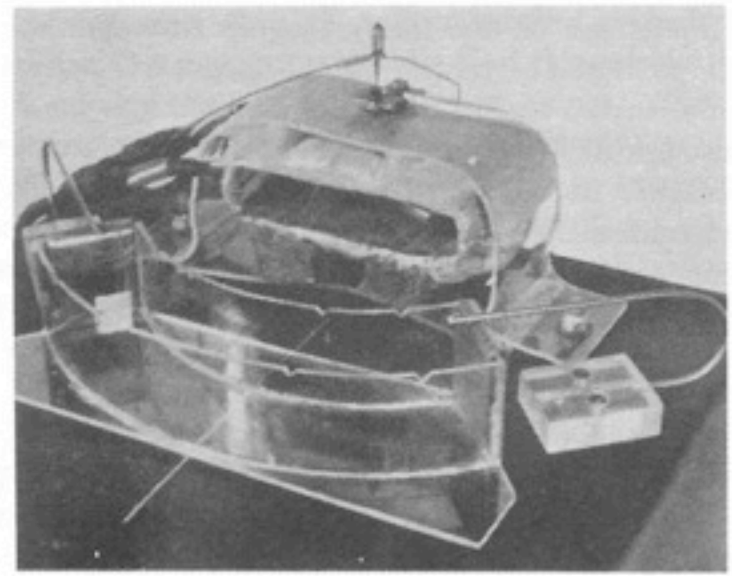


FIGURE 8/2/2: Typical magnet (just visible), coil, pivot, vane, and water potentiometer with electrodes at each end. The coil is quadruple, consisting of *A*, *B*, *C* and *D* of Figure 8/2/3.

W. Ross Ashby’s *Homeostat* : an ultrastable adaptive system, 1952

The Homeostat

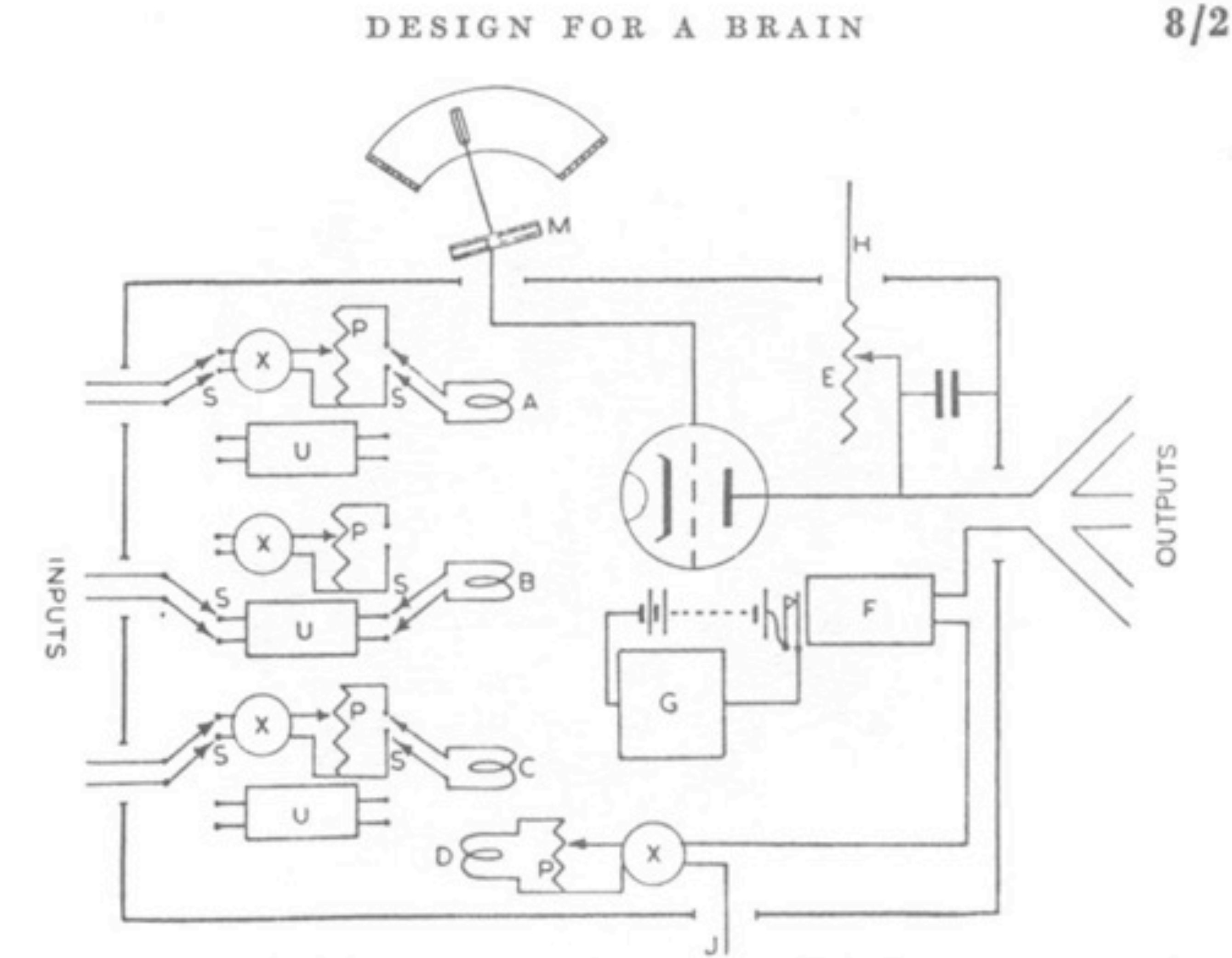


FIGURE 8/2/3: Wiring diagram of one unit. (The letters are explained in the text.)

- 4 units in a fully-connected network: each unit sends its output to the inputs of the other three