Informatics 1 Cognitive Science

Lecture 6: Modelling the Brain

Matthias Hennig

School of Informatics
University of Edinburgh
mhennig@inf.ed.ac.uk

Overview

A History of Models in Neuroscience

Three Levels of Brain Modelling

The Brain-Computer Analogy

Modern Approaches to Brain Models

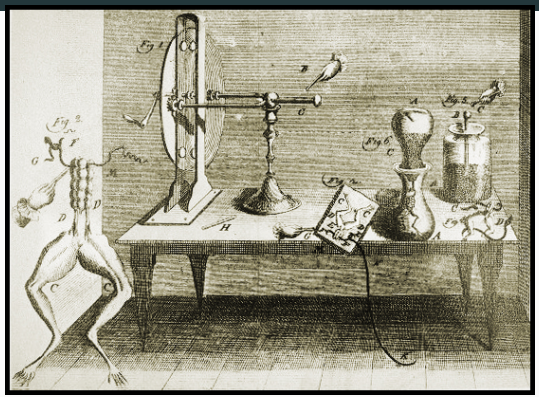
A History of Models in Neuroscience

Brain models - your thoughts

Analogies and Models: Hydraulics

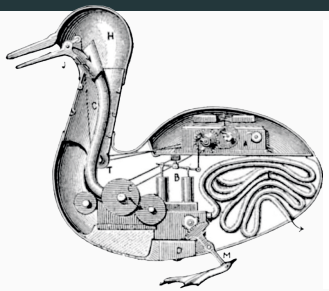
- From ancient Greeks to René Descartes.
- Cells transmit a fluid between parts of the body.
- The brain as connector between soul and body.
- Mechanisms based on hydraulics.

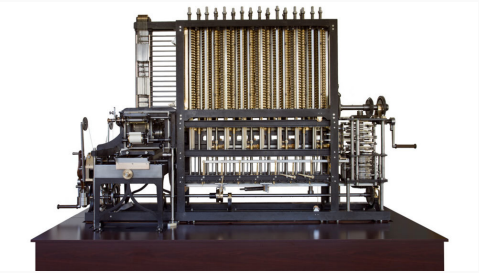
Analogies and Models: Electricity



- 1791: The Galvanis established the role of electricity in the nervous system.
- The brain as an electrical device.
- Telegraph metaphor, focus on communication.

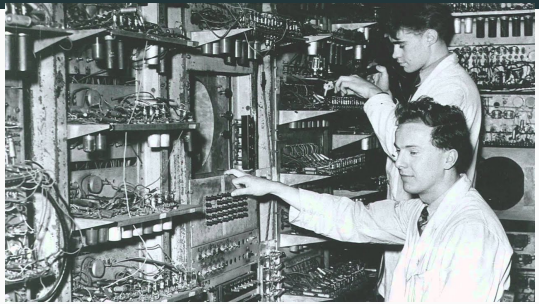
Analogies and Models: Mechanics and early Computers





- 1800s: The brain as a calculator.
- Inspired by clockworks, steam engines and other mechanical artifacts.
- Formalised by Lovelace and Babbage who wanted to build a mechanical brain.
- Lovelace also realised: *The Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform.*

Analogies and Models: Computer and the Turing Machine



- 1930s - now: The brain as a computer, it stores and processes information.
- Early results in neural networks established mechanistic foundations.
- Turing 1951: *The whole thinking process is still rather mysterious to us, but I believe that the attempt to make a thinking machine will help us greatly in finding out how we think ourselves.*

Three Levels of Brain Modelling

David Marr's Levels of Analysis

Poggio, Marr and Crick, about 1979

1. Computational: Problem specification.
2. Algorithmic: Solution of the problem in mathematical terms.
3. Implementational: Physical substrate, computations performed by neurons.

Similar to Guest & Martin (lecture 2), but here used as a hierarchy of levels of analysis.

Marr's Levels capture complementary cognitive science approaches

1. Computational: The problem to be investigated, e.g. object recognition or navigating an environment. Used to design experiments and organise knowledge.
2. Algorithmic: A concrete model, which ideally predicts (or post-dicts) experiments. Often the question determines the choice of model:
   - Logic, e.g. language
   - Bayesian, e.g. reasoning
   - Information and communication theory, e.g. sensory systems
   - Fluid dynamics, e.g. large scale brain activity
   - ...and many other approaches
3. Implementational: Which neural circuit can implement the algorithmic level? BackProp is currently hotly debated.

The Brain-Computer Analogy

Is the Brain a Computer? Is a Computer a Brain?

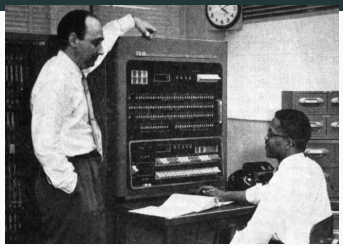
Electronic 'Brain' Finds Lost Planets

Cincinnati, Jan. 8 (U.P.)—Astronomers are finding more "lost" planets today because an "electronic brain" has been put to work tracking them down.

The General Electric Co., Schenectady, has developed a giant computing device called the IBM 701 which figures out their orbits in a matter of minutes.

The Cincinnati Observatory director, Paul Herget, used it to rediscover the planet Athalia, lost for some 50 years.

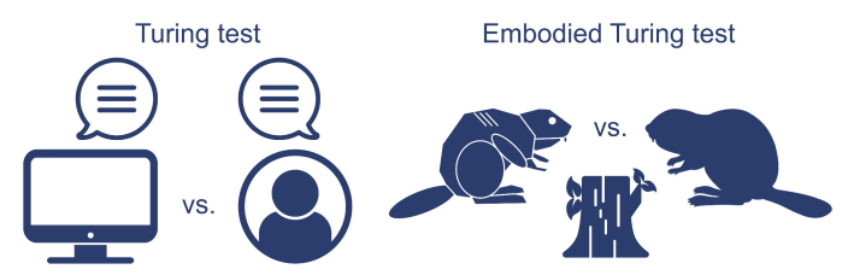
Another expert, Herbert R. J. Grosch, spent more than 1,000 man-hours on calculations that rediscovered Jupiter's eighth satellite in 1941. Grosch said it would take him just one minute to do the job today by using the "electronic brain."



Brooklyn Daily Eagle (1955)

1. Can a computer program produce intelligent behaviour?
2. What level of description is sufficient or necessary?
3. Are there generalisable principles or is the brain a patchwork of specialised modules?
4. Does brain function depend on a specific implementation?
5. The "Cartesian Error" – separation of mind and body?

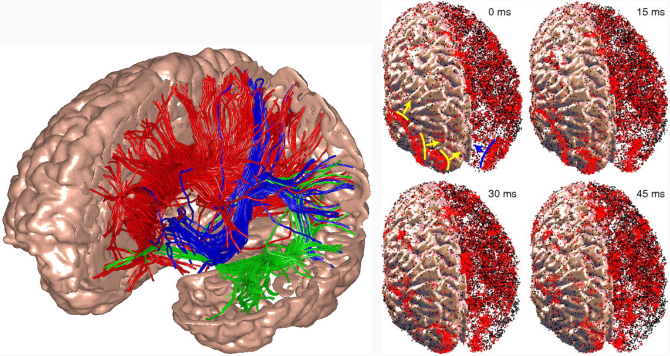
The embodied Turing test



Zador, A., Escola, S., Richards, B., Ölveczky, B., Bengio, Y., Boahen, K., ... & Tsao, D. (2023). Catalyzing next-generation artificial intelligence through neuroai. Nature Communications, 14(1), 1597.

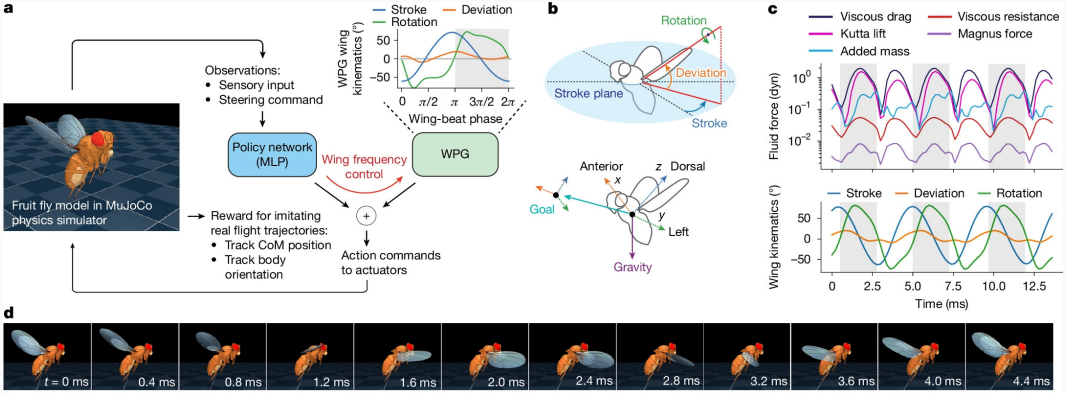
Modern Approaches to Brain Models

Network models



A large scale model of the connections between thalamus and cortex (left), with about 500 million synapses. It exhibits spontaneous activity and emergence of waves and rhythms. Original publication: Izhikevich, E. M., & Edelman, G. M. (2008). Large-scale model of mammalian thalamocortical systems. Proceedings of the National Academy of Sciences, 105(9), 3593-3598.

Whole Animal Models



Original publication: Vaxenburg, R., Siwanowicz, I., Merel, J., Robie, A. A., Morrow, C., Novati, G., ... & Turaga, S. C. (2025). Whole-body physics simulation of fruit fly locomotion. Nature, 1-3.

Summary

- Brain models often start as analogies (hydraulics $\rightarrow$ electricity $\rightarrow$ mechanics $\rightarrow$ computers).
- Models serve different purposes: explain, predict, and help design experiments.
- Marr's levels link questions to models: computational (what/why), algorithmic (how), implementational (with what).
- Modern models across scales: large network simulations and whole-animal physics-based models.