Cybernetics, AI, Cognitive Science and Computational Neuroscience: Historical Aspects

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Cybernetics

The Founding Fathers: Warren McCulloch and Norbert Wiener

- logic-based physiological theory of knowledge
- the brain performs logical thinking ...
- ... which is described by logic
- therefore ... the operation of the brain could and should be described by logic
Cybernetics

The Founding Fathers: Warren McCulloch and Norbert Wiener

- “Behavior, Purpose and Teleology”

- Feedback control

“Control and Communication in the Animal and the Machine”

Voluntary nervous system may control the environment

- Theory of goal-oriented behavior: a new framework to understand the behavior of animals, humans, and computers
The Founding Fathers: Warren McCulloch and Norbert Wiener

The Macy conferences (1946 - 1953)

- Applicability of a Logic Machine Model to both Brain and Computer
- Analogies between Organisms and Machines
- Information Theory
- Neuroses and Pathology of Mental Life
- Human and Social Communication
Cybernetics

John von Neumann: The Computer and the Brain

- Set Theory
- Quantum Mechanics
- Game Theory
- Computer Architectures
- The Computer and the Brain
Von Neumann architecture

The IAS Computer was named for the Institute for Advanced Study, Princeton. The machine was built there under the direction of John von Neumann. It cost several hundred thousand dollars. The goal of developing the IAS was to make digital computer designs more practical and efficient. The project to build it began in 1946 and the computer was ready for use in 1952.

Designers of the IAS were required to make their plans available to several other government-funded projects, and several other machines were built along similar lines: JOHNNIAC, MANIAC, ORDVAC, and ILLIAC. -> also IBM 701 (from the website of the Smithonian Museum)

- has three basic hardware subsystems: a CPU, a main-memory system and an I/O system
- is a stored-program computer
- carries out instructions sequentially
- has, or at least appears to have, a single path between the main memory system and the control unit of the CPU; this is often referred to as the von Neumann bottleneck
The Computer and the Brain
The Computer and the Brain in broader context

- McCulloch-Pitts and the Cybernetic movement

- Self-replicating automaton: the machine and its description

- Reliable calculation with unreliable elements

- Analog vs. digital machines

- Specialized memory unit

- Language of the brain: "Thus the outward forms of our mathematics are not absolutely relevant from the point of view of evaluating what the mathematical or logical language truly used by the central nervous system is"
From Cybernetics to AI and back?

- August 1955: coincidence:
- von Neumann was diagnosed with cancer
- A proposal for the Dartmouth summer research project on Artificial Intelligence
- mechanism vs. function
- zeros and ones vs. general symbol manipulation
From Cybernetics to AI and back?

While it seemed to be an analogy between Brain and Computer

+ at the elementary hardware level

+ at the level of mathematical (quasi)-equivalence

the Organization Principles are very different

The importance of the actual biological substrate:

Synaptic organization !!

"...Eccles has shown how excitation and inhibition are expressed by changes of membrane potential.."
Cybernetics

Second-order cybernetics

- autonomous system, role of observer, self-referential systems
- Heinz von Foerster (1911–2002)
- radical constructivism
- knowledge about the external world is obtained by preparing models on it

It is difficult to reconstruct the story, but it might be true that a set of cyberneticians, who felt the irreducible complexity of the system-observer interactions, abandoned to build and test formal models, and used a verbal language using metaphors. They were the subjects of well-founded critics for not studying specific phenomena (Heylighen and Joslyn 2001)
Cybernetics

The dissolution/dissemination of cybernetic ideas

At least four disciplines have crystallized from cybernetics

• Biological control theory
• Neural modeling
• Artificial Intelligence
• Cognitive psychology

Preliminary crystal seeds:

Turing’s paper on computing machinery and intelligence (Turing 1950)

Rashevsky’s continuous neural models (Rashevsky 1933).
Artificial Intelligence: The physical symbol system hypothesis (Alan Newell and Herbert Simon)

A physical symbol system has the necessary and sufficient means for intelligent action

- Necessity: Anything capable of intelligent action is a physical symbol system
- Sufficiency: Any (sufficiently sophisticated) PSS is capable of intelligent action

Four basic ideas

- Symbols are physical patterns
- Symbols can be combined to form complex symbol structures
- The system contains processes for manipulating complex symbol structures
- The processes for representing complex symbol structures can themselves be symbolically represented within the system
Artificial Intelligence: The physical symbol system hypothesis (Alan Newell and Herbert Simon)

- Thinking and the PSSS

- Problem solving: heuristic search

  Problems are solved by generating and modifying symbol structures until a solution structure is reached

- GPS starts with symbolic descriptions of the start state and the goal state

- aims to find a sequence of admissible transformations that will transform the start state into the goal state
Connectionism: From Perceptron to the Artificial Neural Network Movement

Perceptron

- delta rule: difference between the actual and the expected output
- adjusting threshold and weights
- linearly separable functions
- Minsky - Papert
- multilayer perceptron: backpropagation
Back to Neurobiology: Computational Neuroscience - bottom up and top down

Top down

- starts from behavioral data
- information processing circuit
- implementation of neural mechanisms

Bottom up

- starts from anatomical and physiological reality
- rhythms
- behavior

Figure 1: Brain as a multi-level system. Neural mechanisms $\rightarrow$ computational algorithms.
Cognitive Science: where we are now?

History of cognitive science: preliminary remarks

Fundamental **philosophical** questions since Aristotle and Plato:

1. What is the nature of mind? Metaphysics and nature of reality
2. What is the nature of knowledge? Epistemology and nature of knowledge

**Psychology:** 1890s. Behaviorism: can’t study what is in the mind
(from "philosophical psychology" towards "experimental psychology")
1950’s. Miller, etc.: mind has structure
3. How do we think? **Neuroscience**:
4. How does the brain make a mind?

**Artificial intelligence:** 1956. Minsky, Newell, Simon, McCarthy
5. How to construct mind?

6. Innateness?

**Anthropology:** social, cultural aspects of knowledge
7. Is there any cultural difference in the thinking of people?

The need of **INTEGRATION:**
How can all these fields, with different histories and methodologies can be integrated to produce an understanding of mind?
Key concepts

Mental representation and Computational procedures

Thinking = Mental representations + computational procedures

more precisely: Thinking = representational structures + procedures that operate on those structures. Analogy between computation and thinking:

data structures  mental representations

+ algorithms  + procedures

= running programs  = thinking

Methodological consequence: study the mind by developing computer simulations of thinking
Beyond the classical paradigm of cognitive science

- Emotions
- Embodied cognition
- Consciousness
- Dynamical systems
- Integrative approaches
- Multilevelism
# Multilevelism

After Paul Thagard

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