Artificial Cognitive Systems

Module 2: Paradigms of Cognitive Science

Lecture 1: the different paradigms of cognitive science; the cognitivist paradigm of cognitive science

David Vernon
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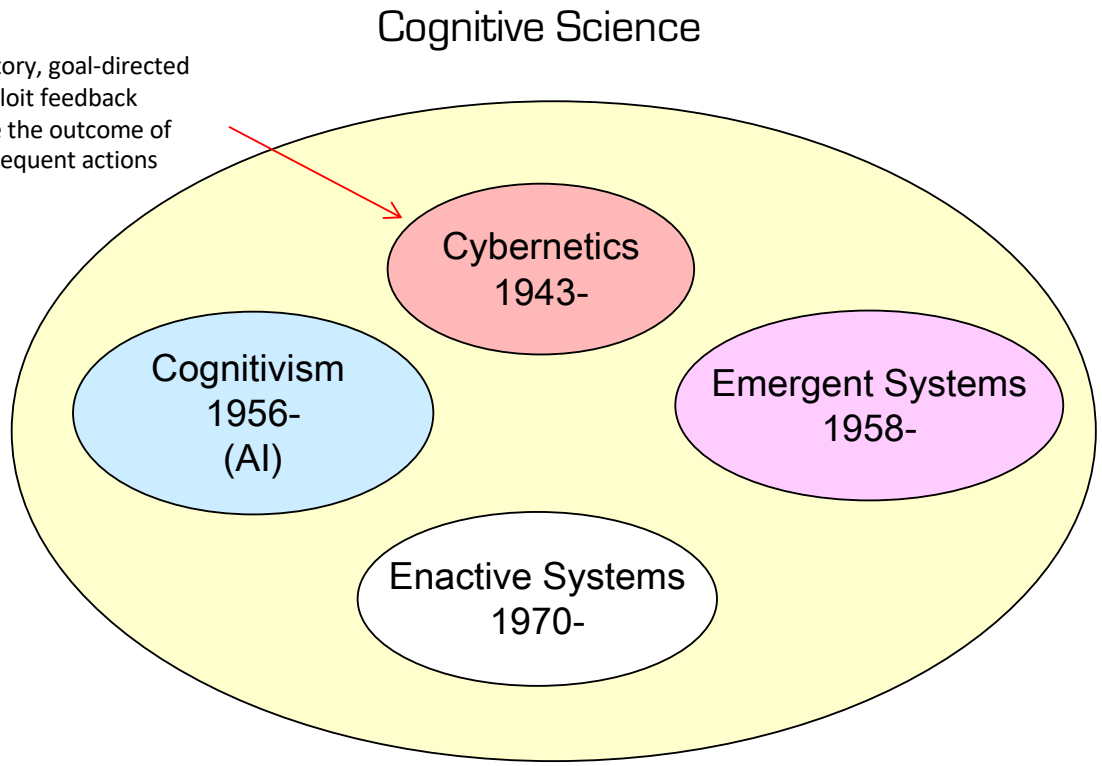
The study of adaptive, regulatory, goal-directed (purposeful) systems that exploit feedback – or circular causality – where the outcome of actions provide input for subsequent actions



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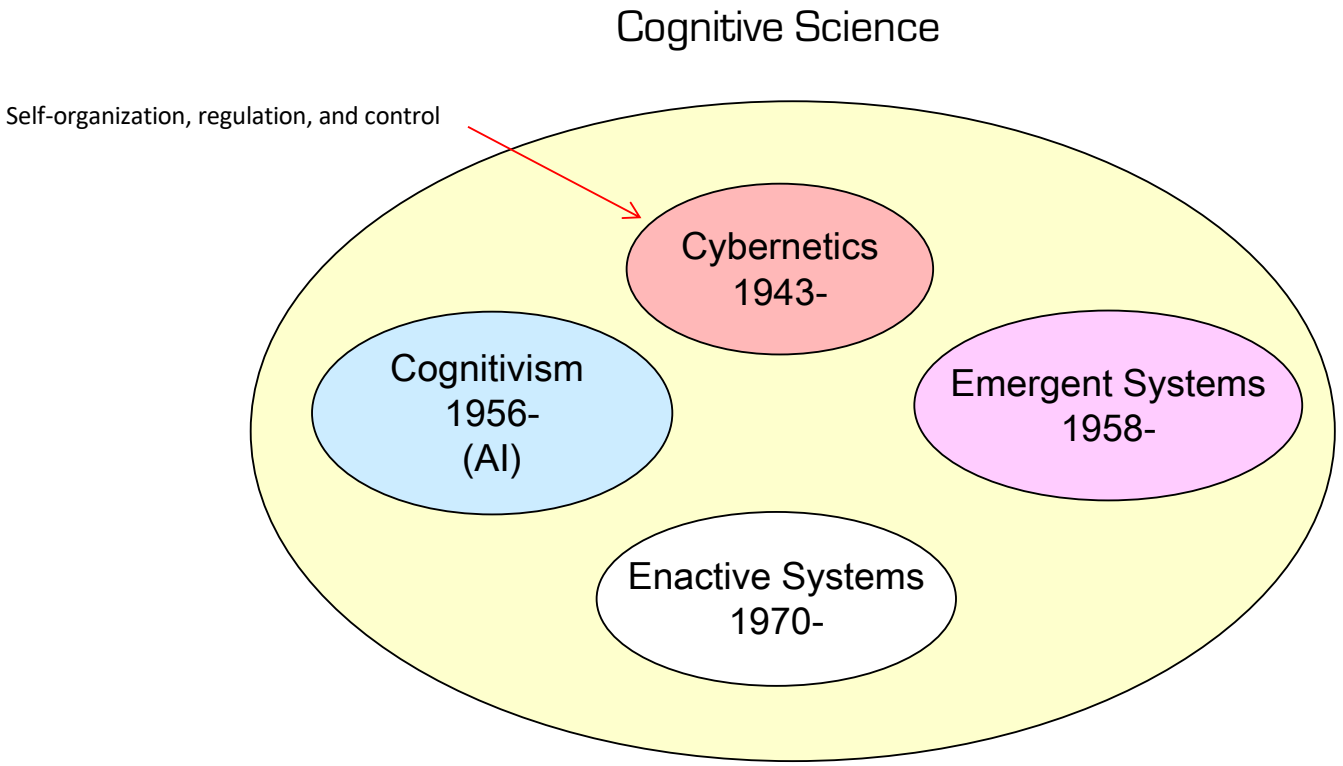

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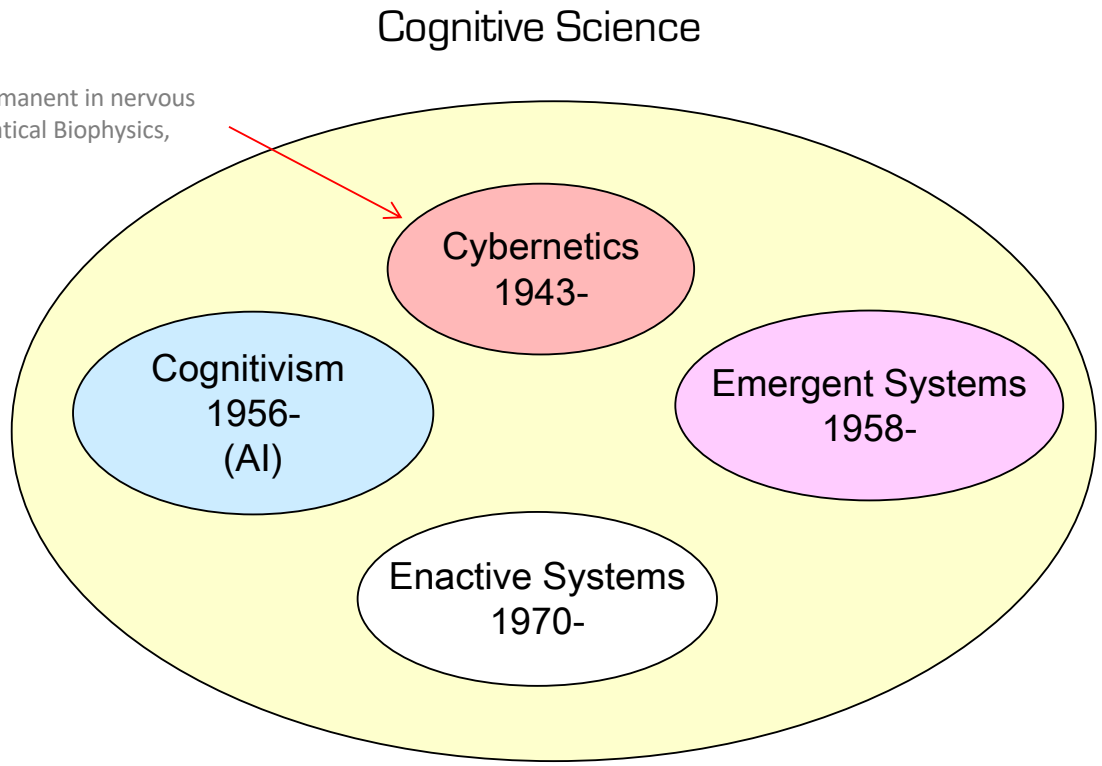
W. S. McCulloch and W. Pitts.
"A logical calculus of ideas immanent in nervous activity", Bulletin of Mathematical Biophysics, 5:115–133, 1943.



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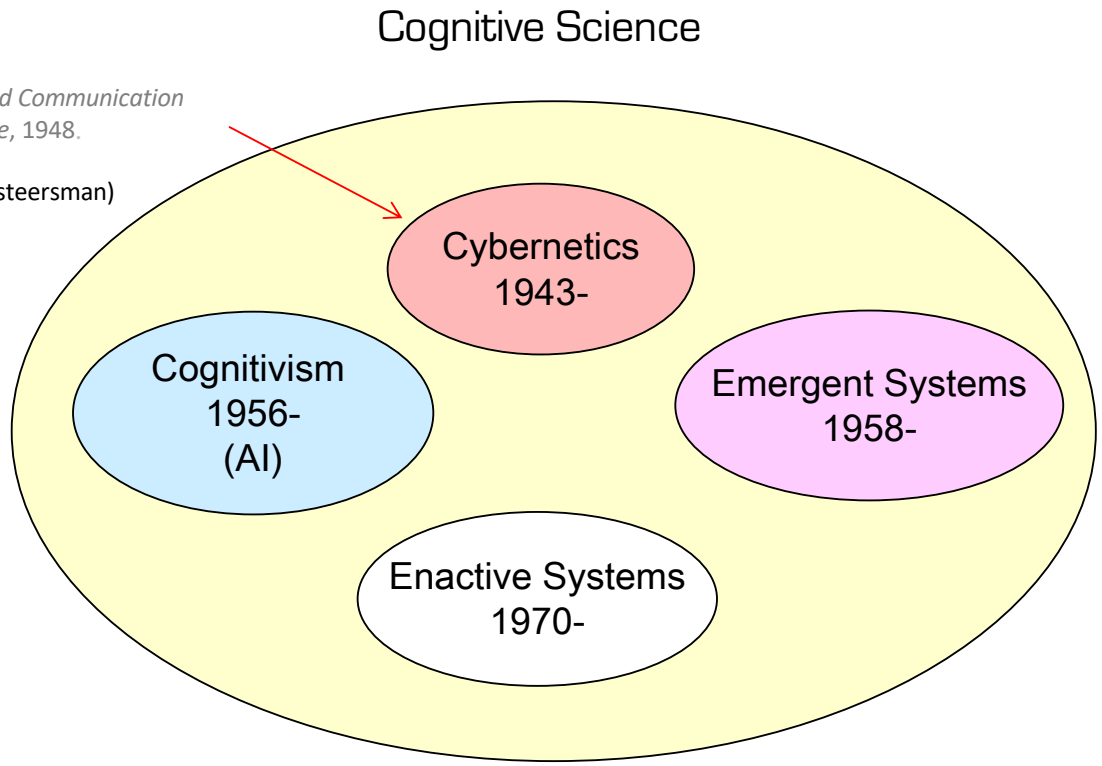
(*κυβερνητης* or kybernetes: steersman)



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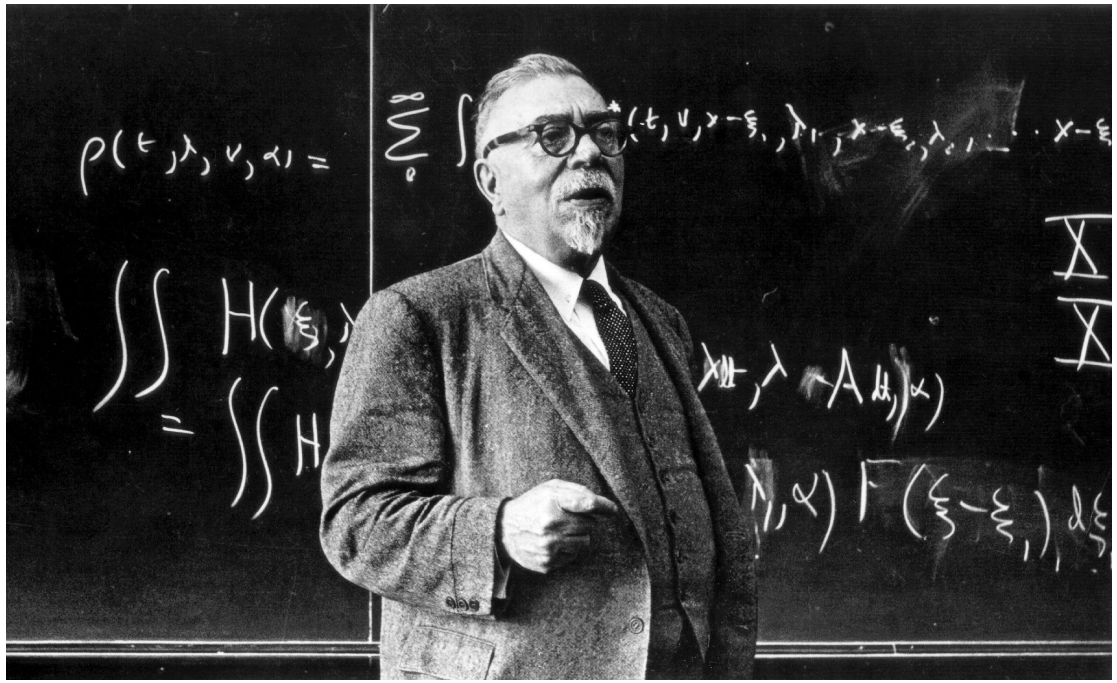

Norbert Wiener

https://www.nytimes.com/2013/05/21/science/mit-scholars-1949-essay-on-machine-age-is-found.html

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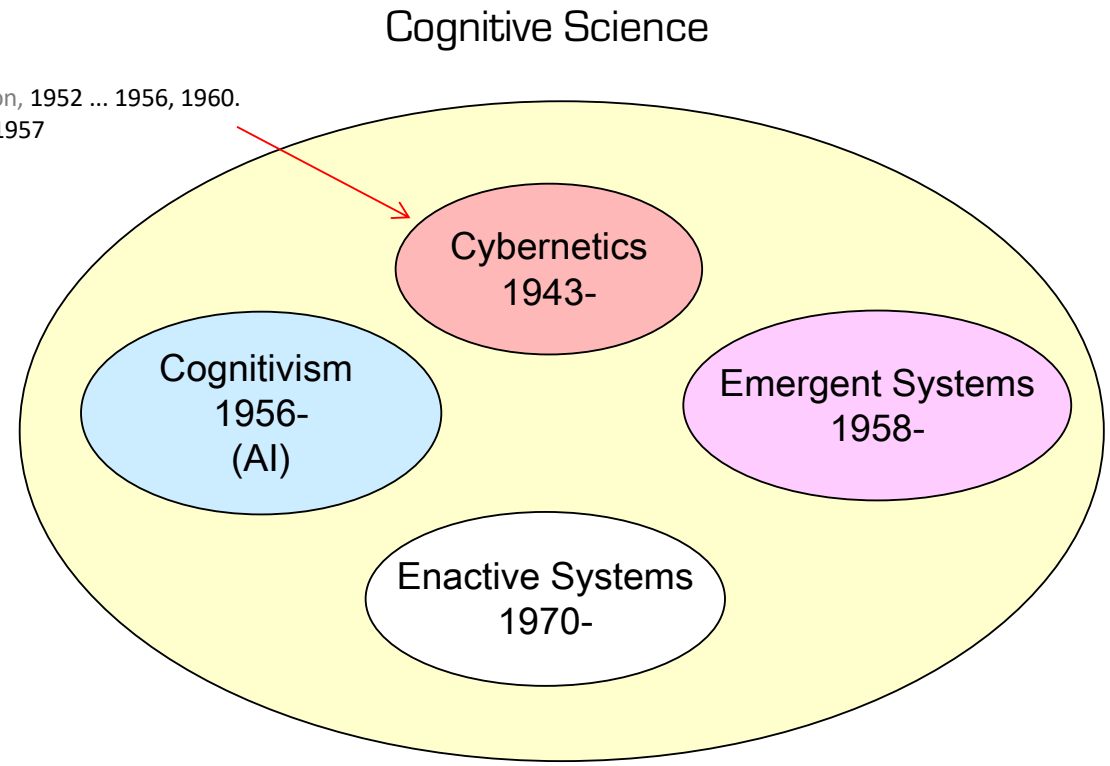
Introduction to Cybernetics, 1957



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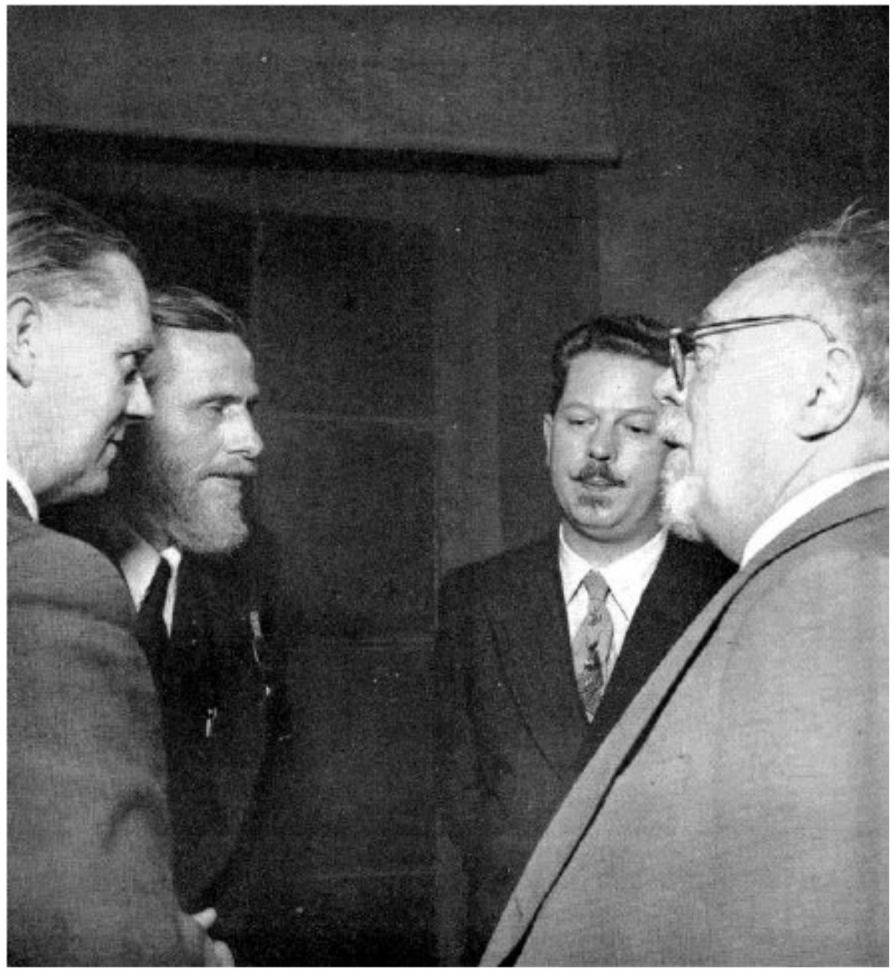
W. Ross Ashby

http://www.rossashby.info/index.html

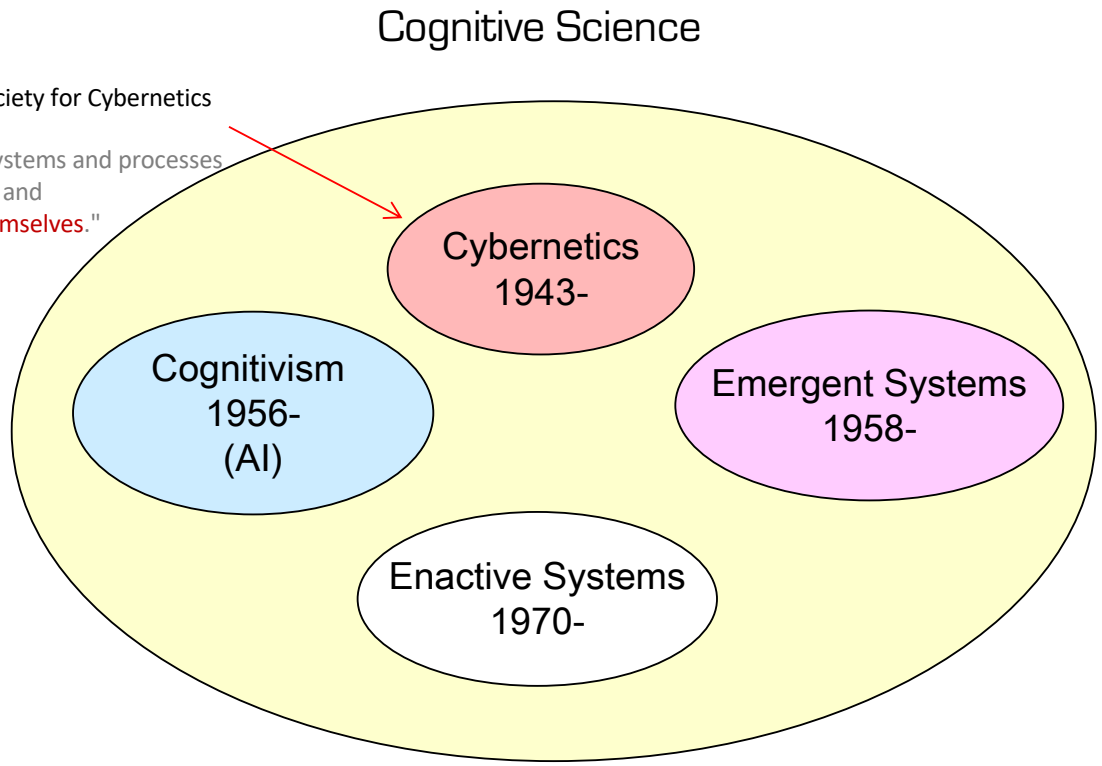


W. Ross Ashby, Warren McCulloch, Grey Walter, Norbert Wiener
at the 1951 Congress on Cybernetics, Paris

https://www.researchgate.net/publication/287293010_Warren_McCulloch_and_the_British_Cyberneticians/figures?lo=1

Louis Kauffman
President of the American Society for Cybernetics

"Cybernetics is the study of systems and processes that interact with themselves and produce themselves from themselves."



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Cybernetics

Central focus

- Prediction and control of behaviour
- In telelogical, purposeful, goal-directed machines
- Circular causal chains involving feedback coupling goal-directed sensation and action

Cybernetics

"The essential goal of cybernetics is to understand and define the functions and processes of systems that have goals and that participate in circular, causal chains that move from action to sensing to comparison with desired goal, and again to action." [Wikipedia]

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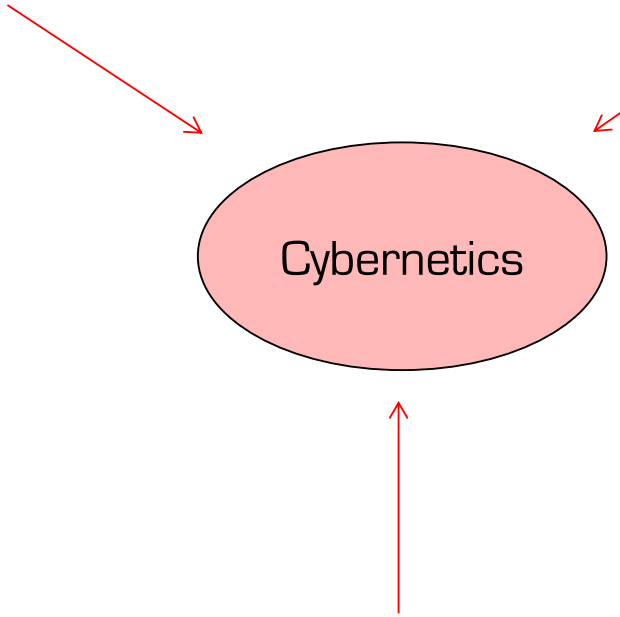

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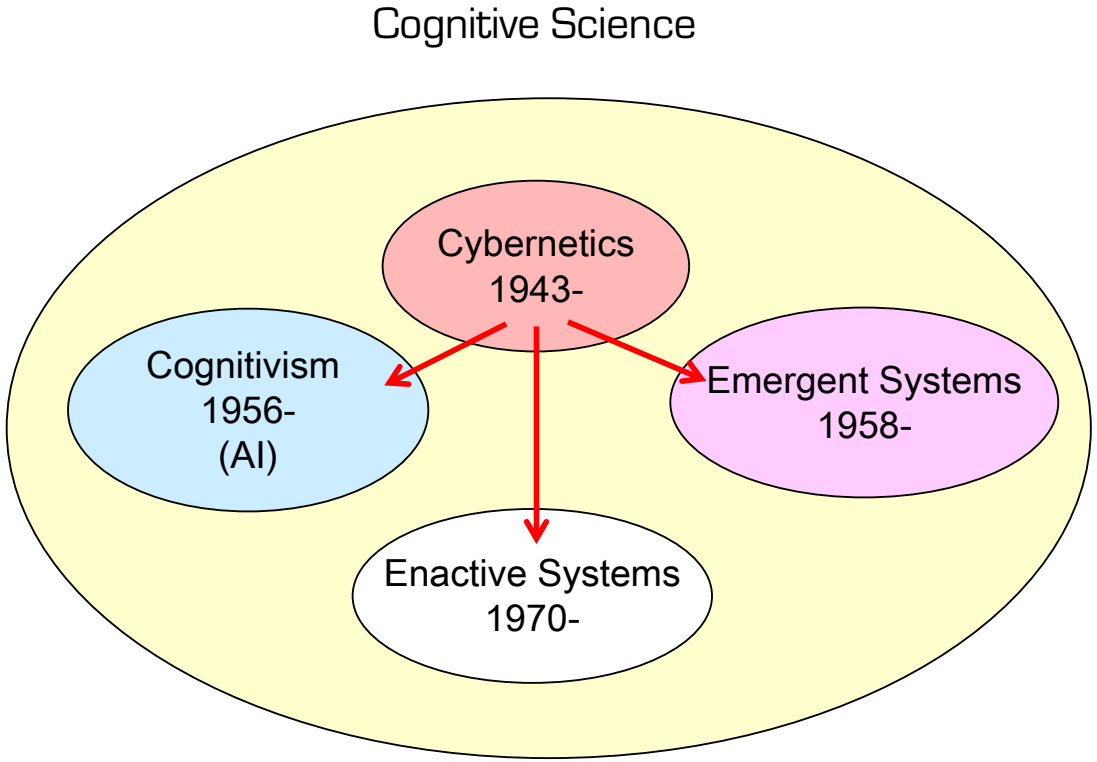

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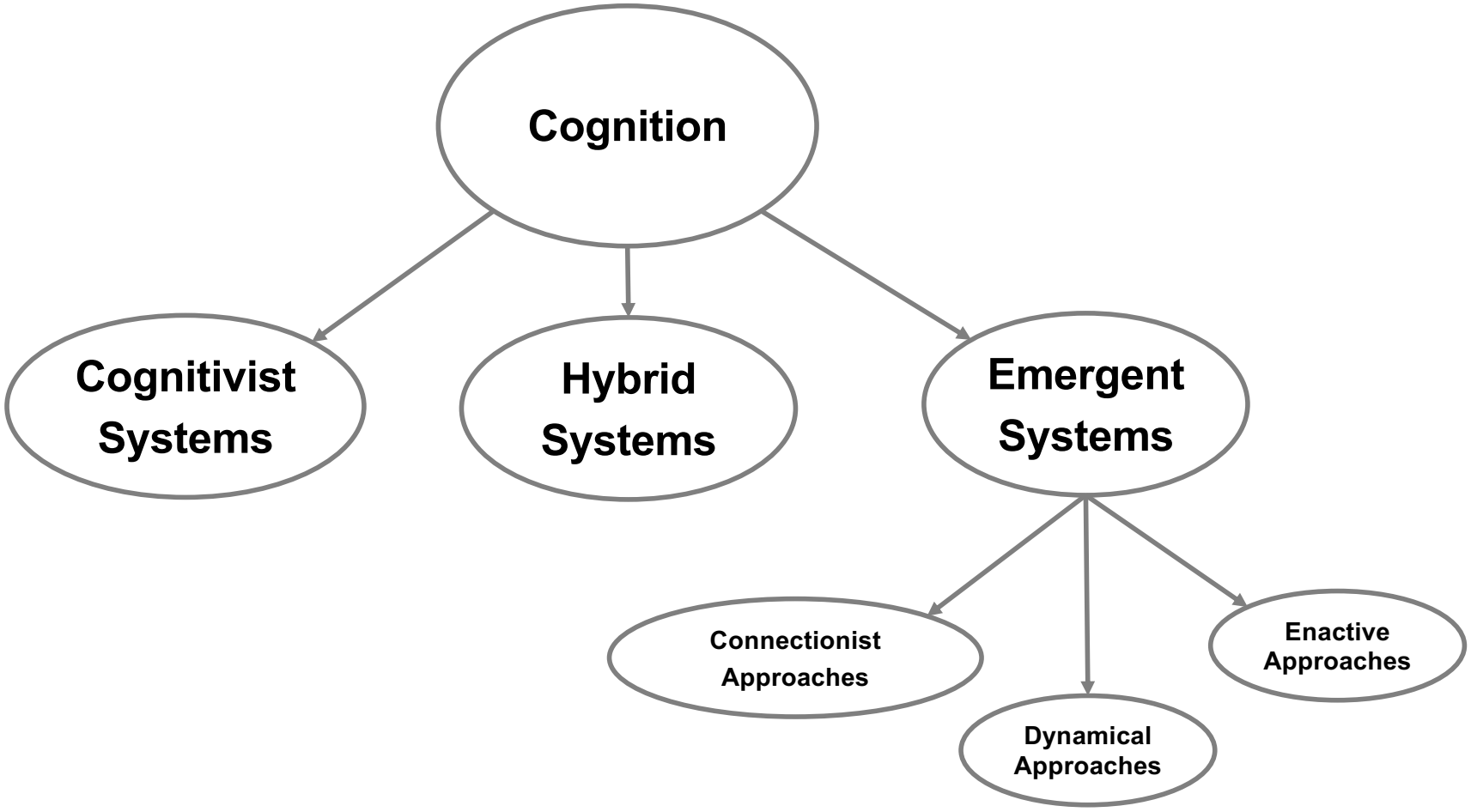
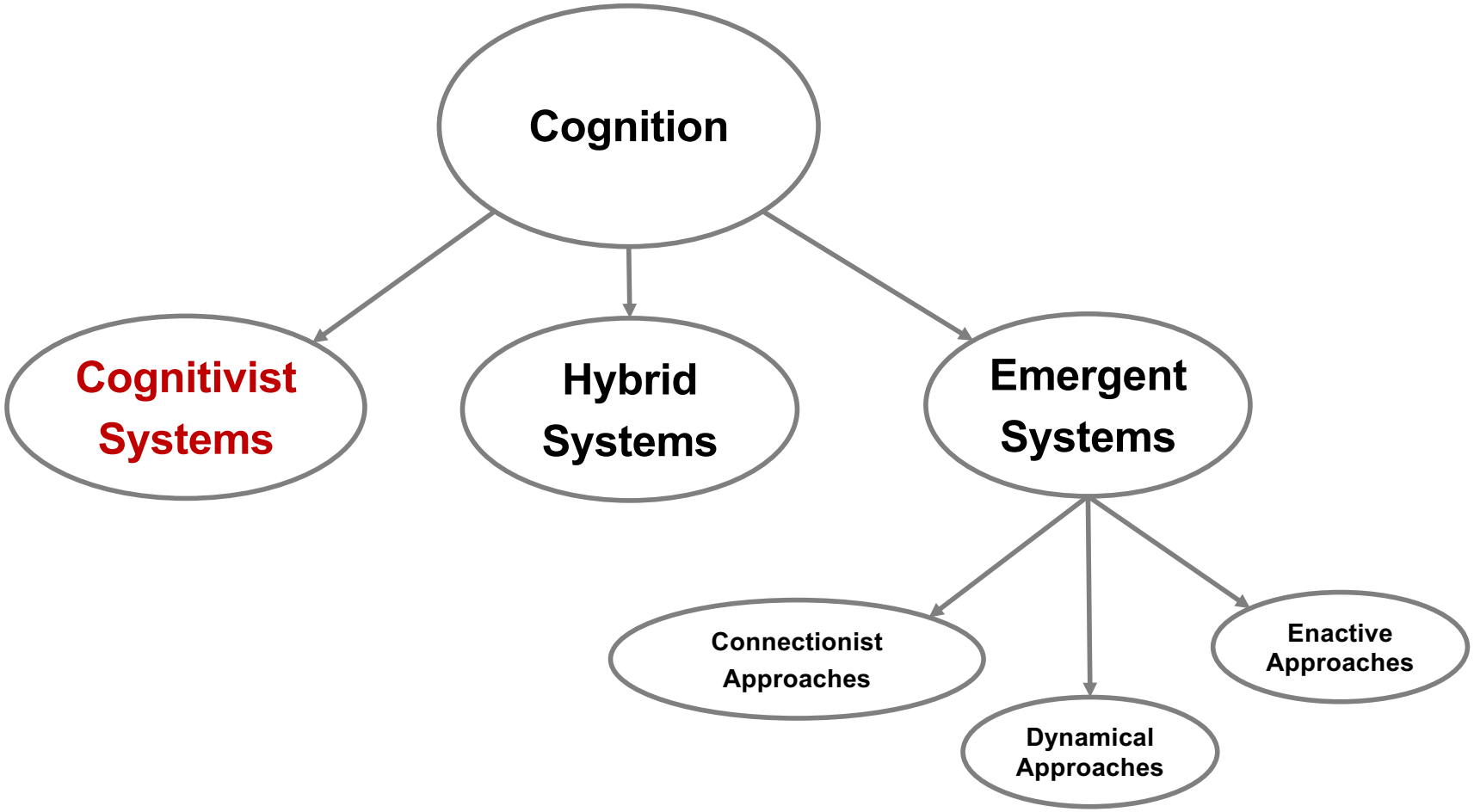

Cognition
Cognitivist Systems
Hybrid Systems
Emergent Systems
Connectionist Approaches
Dynamical Approaches
Enactive Approaches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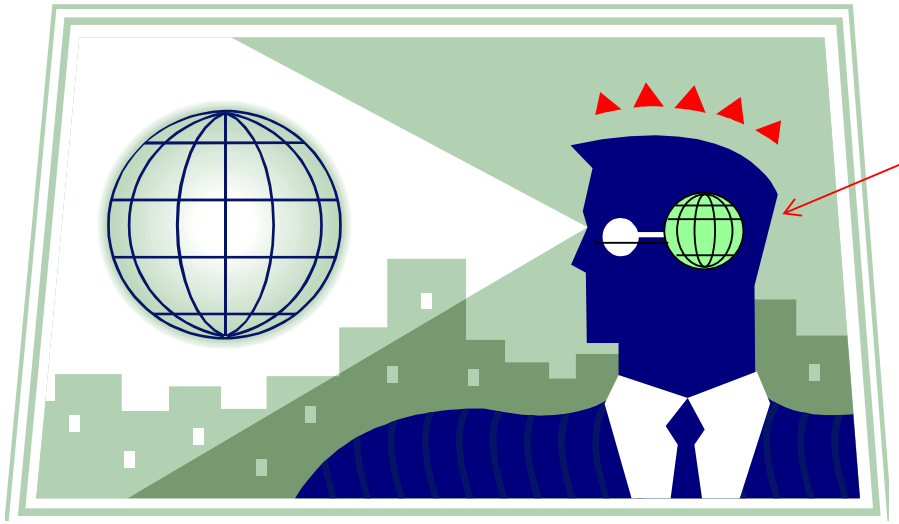


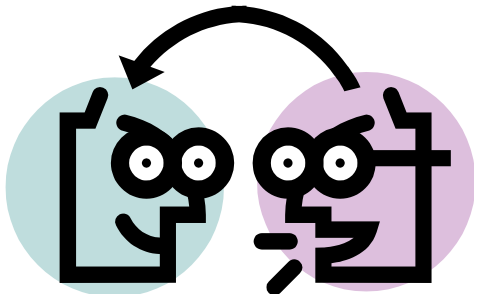
Explicit & symbolic

Representations denote external objects

Isomorphic

Absolute and accessible ontology

That is consistent with human expression



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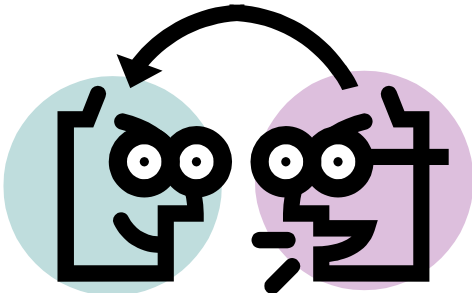
Cognitivist Systems

Representations

- Descriptive product of a human designer
- Can be directly accessed & understood by humans
- Human knowledge can be directly injected into an artificial cognitive system



Cognitivist Systems

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Robots That Use the Web as an Information Resource

By Moritz Tenorth, Ulrich Klank, Dejan Pangercic,and Michael Beetz

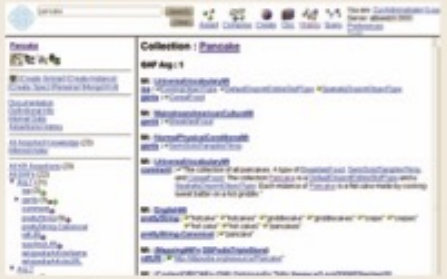
Web-Enabled Robots

Actions in a Task

- ehow.com, wikihow.com
- Step-by-Step Instructions for Everyday Tasks

Ontological Relations

- opencyc.org
- Very Large Encyclopedic Knowledge Base



Commonsense Knowledge

- openmind.hri-us.com
- Commonsense Knowledge from Internet Users

Object Appearance

- germandeli.com, images.google.com
- Pictures of Products and Other Object Classes

Object Shape

- sketchup.google.com/3dwarehouse/
- 3-D CAD Models of Household Items

Object Properties

- germandeli.com
- Object Properties Extracted from Shopping Web sites

Tenorth et al. 2011

Cognitivist Systems

- But …

  Programmer-dependent representations can bias the system …

- … can you anticipate every eventuality in your design?

- The semantic gap between symbols and what the symbols represent or denote

- … the Symbol Grounding problem (more in Module 8)

Cognitivist Systems

Plugging the gap by …

- Machine learning
- Probabilistic modelling
- Better models
- Better logics
- Better reasoning
- Better ontologies
- …

Cognitivism & Artificial Intelligence

- Physical symbol system approach to AI
- Intelligence
  - The degree to which a system approximates a knowledge-level system [Unified Theories of Cognition, Newell 90]
  - A knowledge-level system: can bring **all** its knowledge to bear on **every** problem
    - Perfect knowledge & complete use of knowledge
    - Humans aren't there yet!!

Cognitivism & Artificial Intelligence

- Physical symbol system approach to AI
- Intelligence
  - Principle of rationality [Newell 82]
    - 'If an agent has knowledge that one of its actions will lead to one of its goals, then the agent will select that action'
  - Rational analysis [Anderson 89]
    - 'The cognitive system optimizes the adaptation of the behaviour of the organism'.

Cognitivism & Artificial Intelligence

Physical Symbol Systems

- Symbols are abstract entities that can be instantiated as tokens

- A physical symbol system has [Newell 90]:
  - Memory (to contain the symbolic information)
  - Symbols (to provide a pattern to match or index other symbols)
  - Operations (to manipulate symbols)
  - Interpretations (to allow symbols to specify operations)
  - Capacities for
    - Composability, Interpretability, Sufficient memory

- Symbol systems can be instantiated but … behaviour is independent of the particular form of the instantiation

Cognitivism & Artificial Intelligence

Physical Symbol Systems

- The Physical Symbol System Hypothesis

  A physical symbol system has the necessary and sufficient means of general intelligence

- What are the implications for humans???

- Natural and artificial intelligence is equivalent (why?)

Cognitivism & Artificial Intelligence

Physical Symbol Systems

[Newell and Simon 1976]

The Physical Symbol System Hypothesis

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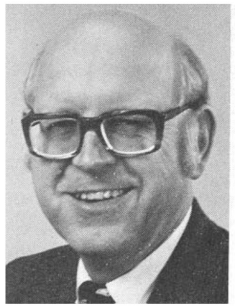
Computer Science as Empirical Inquiry: Symbols and Search

Allen Newell and Herbert A. Simon



Computer science is the study of the phenomena surrounding computers. The founders of this society understood this very well when they called themselves the Association for Computing Machinery. The machine—not just the hardware, but the programmed, living machine—is the organism we study.

This is the tenth Turing Lecture. The nine persons who preceded us on this platform have presented nine different views of computer science. For our organism, the machine, can be studied at many levels and from many sides. We are deeply honored to appear here today and to present yet another view, the one that has permeated the scientific work for which we have been

Key Words and Phrases: symbols, search, science, computer science, empirical, Turing, artificial intelligence, intelligence, list processing, cognition, heuristics, problem solving.
CR Categories: 1.0, 2.1, 3.3, 3.6, 5.7.

The authors' research over the years has been supported in part by the Advanced Research Projects Agency of the Department of Defense (monitored by the Air Force Office of Scientific Research) and in part by the National Institutes of Mental Health.
Authors' address: Carnegie-Mellon University, Pittsburgh.

Cognitivism & Artificial Intelligence

Physical Symbol Systems

[Newell and Simon 1976]

The Heuristic Search Hypothesis

The task of intelligence is to avert the ever-present threat of the exponential explosion of search

Computer Science as Empirical Inquiry: Symbols and Search

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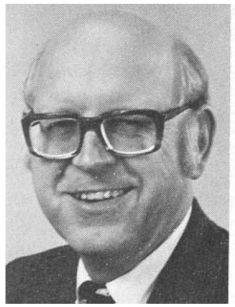

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Cognitivism & Artificial Intelligence

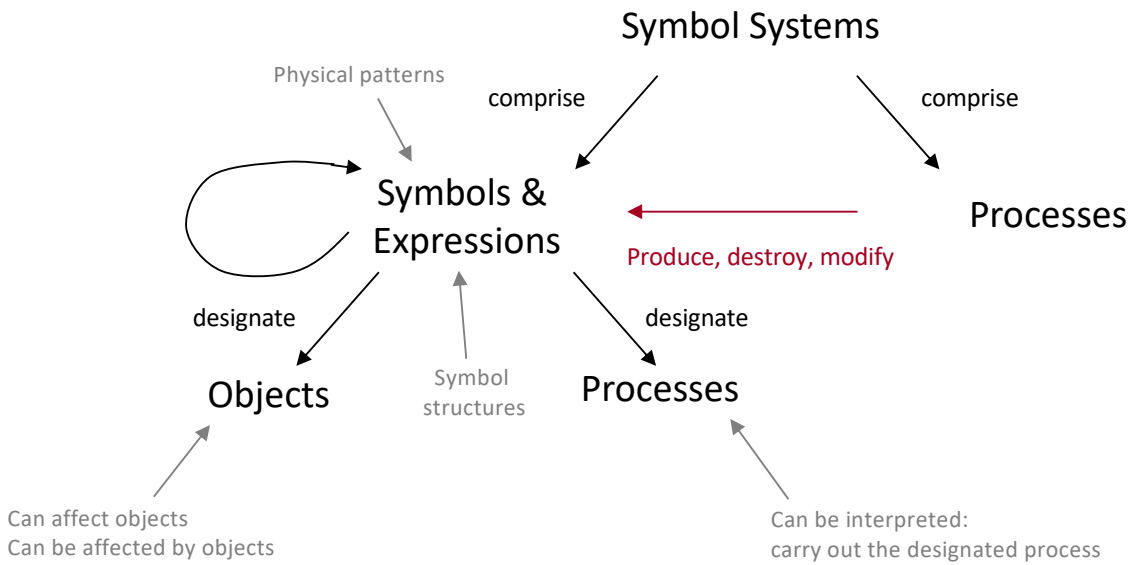
Physical Symbol Systems

- The Heuristic Search Hypothesis
  - The solutions to problems are represented as symbol structures
  - A physical symbol system exercises its intelligence in problem-solving by search
    - Generating and progressively modifying symbol structures until it produces a solution structure
    - Effective and efficient search
  - 'The task of intelligence is to avert the ever-present threat of the exponential explosion of search'

Cognitivism & Artificial Intelligence

Physical Symbol Systems

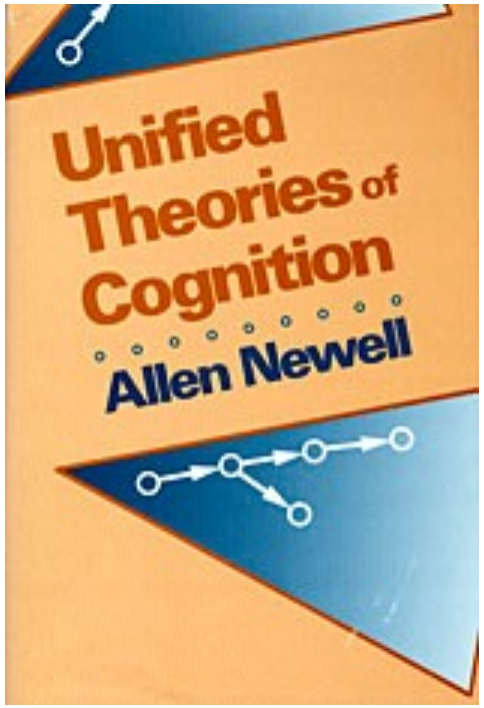
(Newell and Simon, 1976)



Cognitivism & Artificial Intelligence

Unified Theories of Cognition

- Attempts to explain all the mechanisms of all problems in its domain
- Now plausible (Newell) *cf* the Soar project
- Applies to both natural and artificial cognition



Cognitivism & Artificial Intelligence

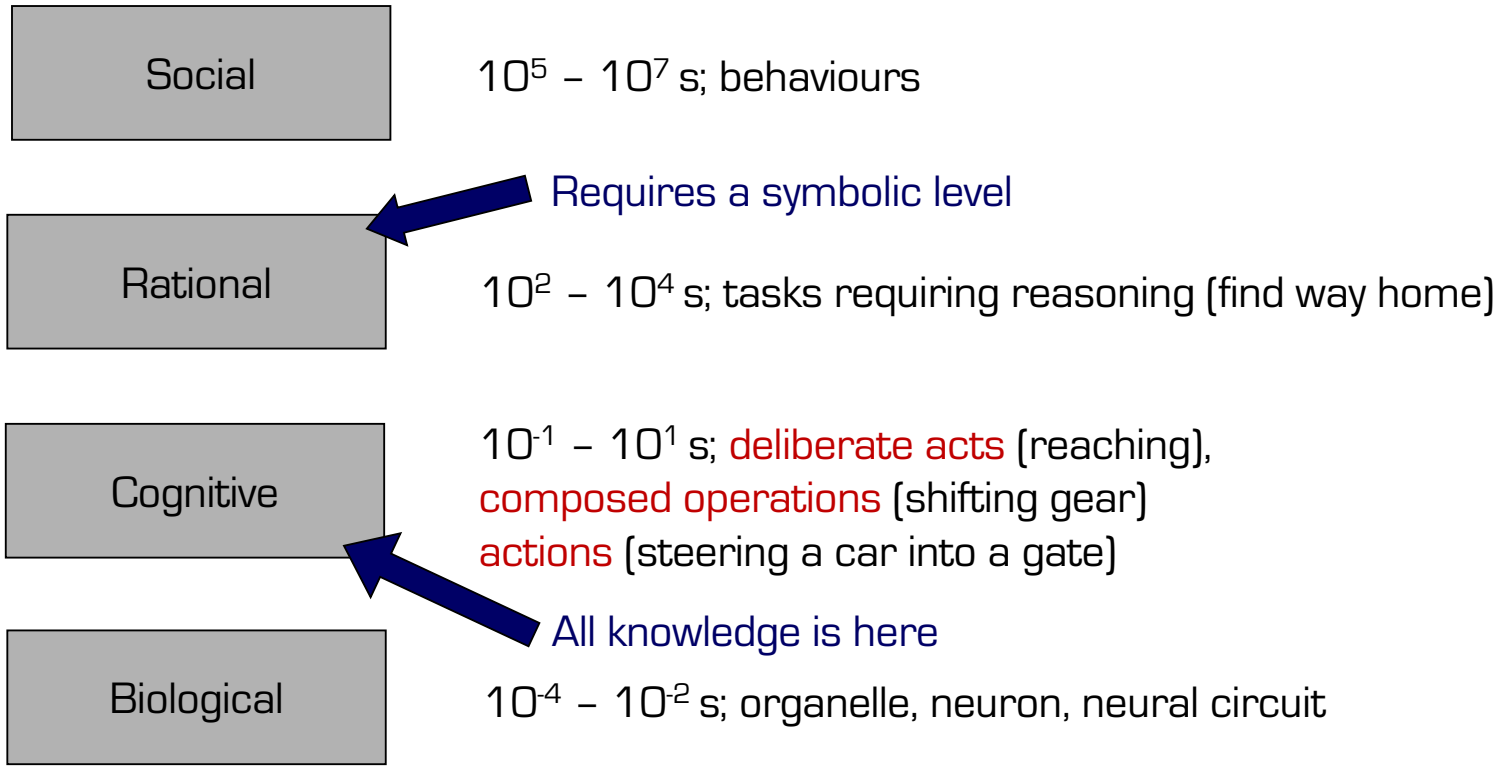
Newell's Time Scales of Human Action

Scale (sec)	Time Units	System	World (theory)
10^7	months		
10^6	weeks		Social Band
10^5	days		
10^4	hours	Task	
10^3	10 min	Task	Rational Band
10^2	minutes	Task	
10^1	10 sec	Unit task	
10^0	1 sec	Operations	Cognitive Band
10^{-1}	100 msec	Deliberate act	
10^{-2}	10 msec	Neural circuit	
10^{-3}	1 msec	Neuron	Biological Band
10^{-4}	100μs	Organelle	

J.R. Anderson / Cognitive Science 26 (2002) 85–112

Cognitivism & Artificial Intelligence

Newell's four bands



Cognitivism & Artificial Intelligence

- (Cognitive) Architecture: defines the manner in which a cognitive agent manages the primitive resources at its disposal
- Dictates representations and their deployment
- Dictates properties of cognitive system
  - Organization & control strategies (coordination/cooperation; modular/hierarchical)
  - Memory, knowledge, representation (world models, declarative representations, procedural representations, associative memory, episodic knowledge, meta-knowledge, representational structures)
  - Types of learning (deliberative vs reflexive; monotonic vs non-monotonic)
  - Types of planning
  - Behaviour (coherence, saliency, & adequacy: consistency, relevance, sufficiency)

Cognitivism & Artificial Intelligence

Non-functional Attributes of Cognitive Architectures

- Generality (breadth of tasks)
- Versatility (ibid.)
- Rationality (cf. consistency and repeatability)
- Scalability (cf. complexity)
- Reactivity (cf. unpredictability)

Cognitivism & Artificial Intelligence

Non-functional Attributes of Cognitive Architectures

- Efficiency (cf. time and space constraints)
- Extendibility (cf. reconfigurability)
- Taskability (cf. external direction)
- Psychological validity (cf. human models)

Reading

D. Vernon, Artificial Cognitive Systems – A Primer, MIT Press, 2014; Chapter 2, pp. 19-32.

A. Cangelosi and D. Vernon, "Artificial Intelligence: Powering the Fourth Industrial Revolution", in Grand Challenges for Society at the Horizon 2050, C. Hildago (Editor-in-Chief), European Physical Society, in press.