Psychology 354
Elements Of Classical Cognitive Science

Mechanizing The Infinite Using Recursion
Physical Symbol Systems and Universal ity
The Poverty of the Stimulus
Intentionality and Cognition
The Language Of Thought
Weak and Strong Equivalence

The Disembodied Mind

- **Cartesian skepticism: "From time to time I have found that the senses deceive, and it is prudent never to trust completely those who have deceived us even once" (Descartes, 1641, p. 12)**
- **Descartes abandoned belief in the existence of his own body: "I shall consider myself as not having hands or eyes, or flesh, or blood or senses, but as falsely believing that I have all these things" (Descartes, 1641, p. 15)**
- **Descartes was left with the notion of a disembodied mind, the mind as a thinking thing: "A thing that doubts, understands, affirms, denies, is willing, is unwilling, and also imagines and has sensory perceptions" (p. 19)**
- **The disembodied mind is a persisting notion within classical cognitive science**

Descartes

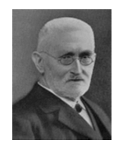
Mechanizing The Infinite

- **The infinity of the mind led Descartes to dualism**
- **"An essential property of language is that it provides the means for expressing indefinitely many thoughts and for reacting appropriately in an indefinite range of new situations" (Chomsky, 1965, p. 6)**
- **Is it possible to unite such infinity with materialism?**
- **"For language is quite peculiarly confronted by an unending and truly boundless domain, the essence of all that can be thought. It must therefore make infinite employment of finite means"**
- **What sort of finite means are capable of explaining the infinite creativity of language?**

Wilhelm von Humboldt

Recursion

- **Recursion permits finite operators to generate infinite variety**
- **A function is recursive when it operates by referring to itself**
- **Example: successor function in arithmetic:**
- **0, 1, 2, … = 0, s(0), s(s(0)), …**
  - **In this definition, s(s(0)) is an example of recursion**
- **In the 19th century, recursion of this type was used by Richard Dedekind and Guiseppe Peano to define the infinite set of natural numbers – infinite from finite!**

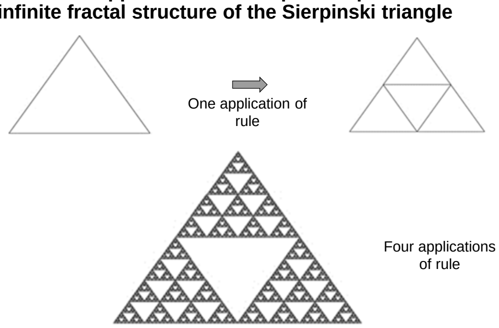


Dedekind

Peano

Mathematical Recursion

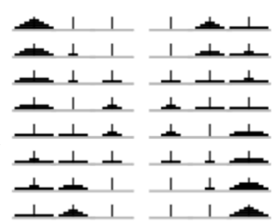
- **Recursive application of a simple rule produces the infinite fractal structure of the Sierpinski triangle**



Recursive Problem Solving

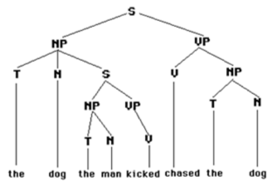
- **Recursion solves the Towers of Hanoi**
- **Movestack() is recursive, for it calls itself**

```
MoveStack (N, Start, Spare, Goal)
 If N = 0
  Exit
 Else
  MoveStack (N-1, Start, Goal, Spare)
  Move remaining disk from Start to Goal
  MoveStack (N-1, Spare, Start, Goal)
 EndIf
```



Structure of Language

- Chomsky used the phrase marker as a complex token to represent the structure of sentences
- Phrase markers make explicit linear order of words, parts of speech, and constituent structure
- What kind of process could create any possible phrase marker



Phrase Marker

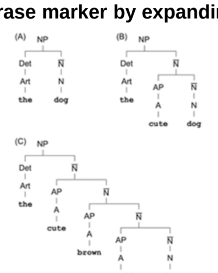
Recursion and Language

- Phrase markers can be produced by using a context free grammar
- It is a finite set of re-write rules
- It can generate an infinite variety of phrase markers
- This is because the rules can be applied recursively

S → NP VP
NP → ART NOUN
NP → NP PP
PP → P NP
VP → VERB NP
VP → VERB NP PP
ART → the
ART → a
NOUN → telescope
NOUN → man
NOUN → spider
VERB → saw
VERB → complimented
P → with
P → in

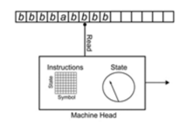
Recursive Elaboraton

- The repeated, recursive use of the rewrite rules of a context free grammar can be used to infinitely elaborate a phrase marker by expanding its clauses

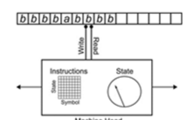


Recursive Machines

- Recursive rule application is not possible for all information processing devices
- A finite state automaton has no memory, therefore does not have the power to recursively elaborate linguistic structure
- A more powerful device, the Turing machine, is required to permit recursive power



Finite State Automaton



Turing Machine

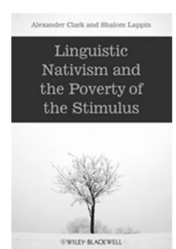
Classical Computation

- Claims that a particular theory is unable to accommodate particular structures are results from the computational level of analysis
- These results are arrived at by performing mathematical or logical derivations
- Proofs, not experiments
- Examples from language include the Chomsky hierarchy and the terminal metapostulate argument
- Such proofs led to the demise of behaviorism


Noam Chomsky

Example: Underdetermination

- Gold (1967) defined language learning as identifying a grammar in the limit
- Such learning could proceed in two ways, as text learning or as informant learning
- Gold proved that text learning was not powerful enough to teach human grammars
- This is an example of the poverty of the stimulus, or more generally the problem of underdetermination
- How are such problems solved? By adopting some form of nativism, a typical feature of classical cognitive science



Physical Symbol Systems

- How does one bring a recursive rule system to life?
- By building a general purpose symbol manipulator called a physical symbol system
- The concept "physical symbol system" defines "a broad class of systems that is capable of having and manipulating symbols, yet is also realizable within our physical universe" (Newell, 1980, p. 136)
- The modern digital computer is but one example of a physical symbol system

Allen Newell

Jacquard's Programmable Loom

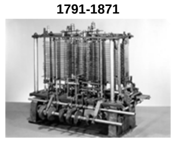
- Jacquard's automatic loom, built in 1801, is a physical symbol system
- Jacquard strung together a sequence of cards, held together by string, to define – literally – a program for producing a fabric of a particular design
- A typical fabric required 4000 cards of programming
- If the set of cards was changed, the same loom would create a new design in the fabric

Weaving Information

- Babbage was inspired by Jacquard's invention of the programmable loom
- He imagined a program that would control the operations of a device whose actions were not to weave thread, but instead to weave numbers
- The result were the first computers, made of rotating geared cylinders

Charles Babbage

1791-1871



Analytical Engine 1871

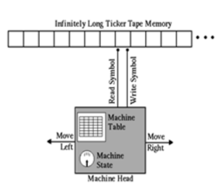
Turing's "Loom"

- Alan Turing's universal machine was a logical extension of both Jacquard and Babbage
- The underlying machinery is very simple, because it processes parts instead of wholes
- Complexity comes from using a program to control the sequence of simple actions
- It was used to prove that mathematics was not decidable and, perhaps more importantly, it was the basis for modern computers

Alan Turing

The Turing Machine

- Main characteristics:
  - Structure-process distinction
  - Process manipulates symbols that exist in a separate memory
- These characteristics are shared by classical cognitive science



A Machine Table

Symbol On Tape

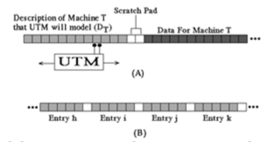
Current Machine State

	B	0	1
1	Write 1 to tape Adopt State 6	Write B to tape Adopt State 2	Move 1 cell left Adopt State 1
2	Move 1 cell left Adopt State 2	Write B to tape Adopt State 3	EH?
3	Move 1 cell left Adopt State 3	Write B to tape Adopt State 4	Write B to tape Adopt State 5
4	Move 1 cell right Adopt State 4	EH?	Move 1 cell left Adopt State 6
5	Move 1 cell right Adopt State 5	EH?	Move 1 cell left Adopt State 1
6	Write 0 to tape Adopt State 6	STOP!!	Move 1 cell left Adopt State 3

An Excel Example

- **A question is written on the tape**
- **The TM rewrites the tape to provide the answer**
- **Here is an example of a working Turing machine, written for an Excel worksheet**

The Universal Machine



- **Turing was able to prove that one version of his machine was universal, in the sense that it could pretend to be any other Turing machine**
- **Description of machine to be imitated is added to tape**
- **UTM moves back and forth between description and data, using the scratch pad to remember key information (e.g., machine state)**

Implications Of The UTM

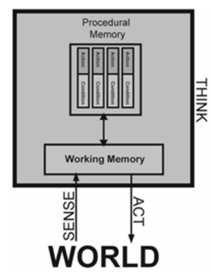
- **"It followed that one particular machine could simulate the work done by any machine…It would be a machine to do everything, which was enough to give anyone pause for thought" (Hodges, 1983, p. 104).**
- **The UTM was the most powerful computational device in existence**
- **The Church/Turing thesis: "Any process which could naturally be called an effective procedure can be realized by a Turing machine" (Minsky, 1963, p. 108)**

Andrew Hodges

Marvin Minsky

A Classical Architecture

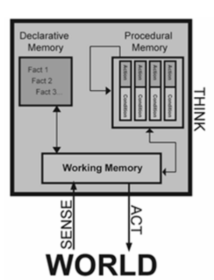
- **The Turing machine is not psychologically plausible**
- **One of the most prototypical, and psychologically plausible, architectures of classical cognitive science is the production system developed by Newell and Simon**
- **It is as powerful as a UTM**



Herbert Simon and Allen Newell

Classical Evolution

- **Anderson modified Newell and Simon's work by introducing a declarative memory and a mechanism for learning.**
- **The resulting production system was called ACT (for *adaptive control of thought*)**



John R. Anderson

Classical Sandwich

- **The early production systems of Newell, Simon, and Anderson are all prototypical examples of the sense-think-act cycle that defines classical cognitive science**
- **Sensing and acting are external to thinking. Thinking processes inputs from senses, and then decides what actions to execute**
  - **"One problem with psychology's attempt at cognitive theory has been our persistence in thinking about cognition without bringing in perceptual and motor processes" (Newell, 1990, p. 15).**
  - **The ACT architecture "historically was focused on higher level cognition and not perception or action" (Anderson et al., 2004, p.1038).**
- **Hurley called the sense-think-act cycle the classical sandwich, it reflects the disembodied nature of the classical mind!**

Susan Hurley

Intentionality

- Universal machines are not aware of the contents of their representations
- However, a standard view in cognitive science is that mental states are intentional – they are about some state of affairs in the world
- Intentionality is *aboutness*
- The modern source of this view is the phenomenology of Franz Brentano
  - "We found that the intentional in-existence, the reference to something as an object, is a distinguishing characteristic of all mental phenomena. No physical phenomenon exhibits anything similar" (Brentano, 1874 p. 97)

Franz Clemens Brentano
1838-1917

The Intentional Stance

- Consider how we explain or predict the behavior of an agent
- One approach is to adopt what has been called Dennett's intentional stance:
  - Assume an agent is rational
  - Assume an agent possesses beliefs, desires, goals
  - Assume these mental states are intentional in Brentano's sense
  - Use the contents of the intentional states to make behavioral predictions
  - For instance, "J. is a 354 student. J. believes that studying weeks before the final exam improves exam performance, and J. desires to do well in the course. Using the intentional stance, I predict that J. will begin studying weeks before the final exam"
- The intentional stance assumes that the agent is a representational system, and that contents of representations are rationally related to behavior

Daniel Dennett

Cognitive Vocabulary

- Many classical cognitive scientists, in adopting the intentional stance, require cognitive theories to use a cognitive vocabulary
- "The cognitive vocabulary is roughly similar to the one used by what is undoubtedly the most successful predictive scheme available for human behavior – folk psychology" (Pylyshyn, 1984, p. 2)
- Some claim that this vocabulary results from computational level analyses

Zenon Pylyshyn

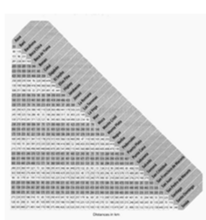
Language of Thought

- Classical cognitive science needs a cognitive vocabulary, but also needs cognitive operations to be material
- They accomplish this by assuming that cognition is produced by a physical symbol system
- This device carries out mental algorithms, written in what Fodor called the language of thought
- The language of thought specifies the functional architecture in terms of primitive symbols and operations that can be applied to them
- Haugeland speaks of the dual life of a symbol – its physical life and its semantic life

John Haugeland

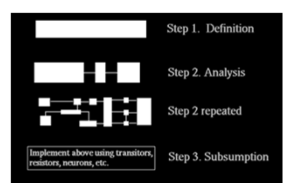
The Structure/Process Distinction

- Classical cognitive science makes a key distinction between structure and process – in any physical symbol system, rules are distinct from symbols
- However, though distinct, the two are related
- Particular structures make some information easily available, and hide other information
- Particular operations are designed to process the information that is easily available
- Classical cognitive science must discover the structure/process pairings that are employed in different cognitive systems!



Functional Analysis

- Classical cognitive scientists seek the language of thought by performing functional analysis
  - Define the function being computed by the system
  - Decompose this function into a system of subfunctions. Repeat as necessary to the subfunctions.
  - Stop the decomposition when the subfunctions are so simple that they can be carried out by simple machines

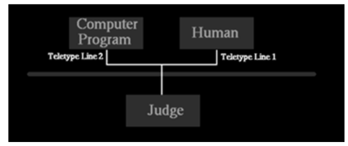


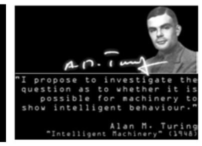
Comparative Cognitive Science

- Functional analysis identifies possible algorithms, as well as possible architectures – languages of thought
- Many such proposals have appeared in cognitive science
- Empirical evidence must be collected to determine the validity of such proposals
- Computer simulations of theories are compared to human performance

Example Architecture	Representative Publication
brainstate-in-a-box	Anderson et al. (1977)
Boltzman machine	Ackley, Hinton & Sejnowski (1985)
CHARM	Eich (1982)
conceptual structure	Jackendoff (1983)
dual-coding theory	Paivio (1971)
feature maps	Treisman & Gelade (1980)
frames	Minsky (1975)
full primal sketch	Marr (1982)
geons	Biederman (1987)
generalized cylinders	Marr (1982)
Hopfield net	Hopfield (1982)
mental images	Kosslyn (1980)
levels of processing	Craik & Lockhart (1972)
mental models	Johnson-Laird (1983)
metric spaces	Tourangeau & Sternberg (1981)
multilayer perceptron	Rumelhart, Hinton & Williams (1986a)
production system	Newell & Simon (1972)
propositions	Pylyshyn (1973)
prototypes	Rosch & Mervis (1975)
scripts	Schank & Abelson (1977)
semantic features	Rips, Shoben & Smith (1973)
semantic networks	Collins & Quillian (1969)
textons	Julesz (1981)
transformational grammar	Chomsky (1965

The Turing Test



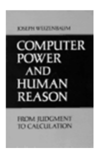


- How will we know if we have built an intelligent machine?
- Turing provided a behavioristic answer to this question in 1950, an answer now called the Turing test
  - For 1 hour, the judge can communicate about anything to both participants.
  - Then the judge must decide which participant is the program.
  - If this cannot be done, then the programmed computer is deemed to be intelligent

ELIZA And The Turing Test

- ELIZA was a program that passed a version of the Turing test by carrying out impressive conversations
- ELIZA generates the right output for the wrong reasons
- Its misinterpretation drove Weizenbaum from AI
- "It was a demonstration of how successful one could be in creating an apparently intelligent interactive system with relatively simple rules"

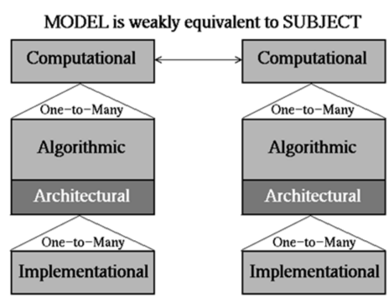
Joseph Weizenbaum



- Men are all alike.
  - In what ways?
- They're always bugging us about something or other.
  - Can you think of a specific example?
- Well, my boyfriend made me come here.
  - Your boyfriend made you come here.
- He says I'm depressed much of the time.
  - I'm sorry to hear that you are depressed.
- I need some help, that much seems certain.
  - What would it mean to you if you got some help?
- Perhaps I could learn to get along with my mother.
  - Tell me more about your family.
  - ....What else comes to mind when you think of your father?
- Bullies.
  - Does that have anything to do with the fact that your boyfriend made you come here?

Weak Equivalence

- A system that generates the right output for the wrong reasons, like ELIZA, demonstrates weak equivalence



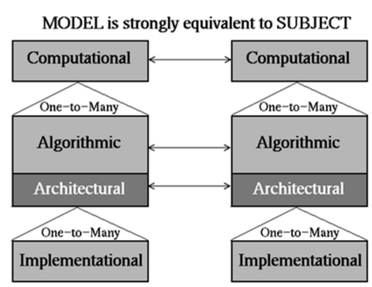
Two Equivalences

- Eliza demonstrates a weakness of the Turing test
- Two systems are said to be *weakly equivalent* if they solve the same problem, but do so in different ways
- Eliza is a weakly equivalent system, or is Turing equivalent
- Two systems are said to be *strongly equivalent* if they solve the same problem, but do so "in the same way"
- Cognitive science must go beyond the Turing test and seek out strong equivalence

Zenon Pylyshyn

Strong Equivalence

- Strongly equivalent systems generate the right behavior by running the same algorithm on the same functional architecture



Evidence For Equivalence

- **Functional analysis involves collecting a variety of evidence to establish strong equivalence:**
- **Error Evidence**
  - **Does the model make the same kinds of errors as the subject?**
- **Relative Complexity Evidence**
  - **Are different problems of the same relative difficulty for model and subject?**
- **Intermediate States Evidence**
  - **Do the model and subject go through the same intermediate information processing steps?**
- **Cognitive Penetrability**
  - **Is a function independent of beliefs, and therefore "wired in"?**

What Is Classical Cognitive Science?

- **Endorses the physical symbol system hypothesis: "the necessary and sufficient condition for a physical system to exhibit general intelligent action is that it be a physical symbol system" (Newell, 1980, p. 170)**
  - **Inspired by digital computer**
  - **Cognition is rule-governed symbol manipulation**
- **Cognition must be explained at multiple levels**
  - **Computational, algorithmic, architectural**
  - **Endorses functionalism, so implementational equivalence not required**
- **Adopts functional analysis to collect evidence for strong equivalence, seeking the language of thought**