Interdisciplinary Cognitive Science

Discipline-based and interdisciplinary research

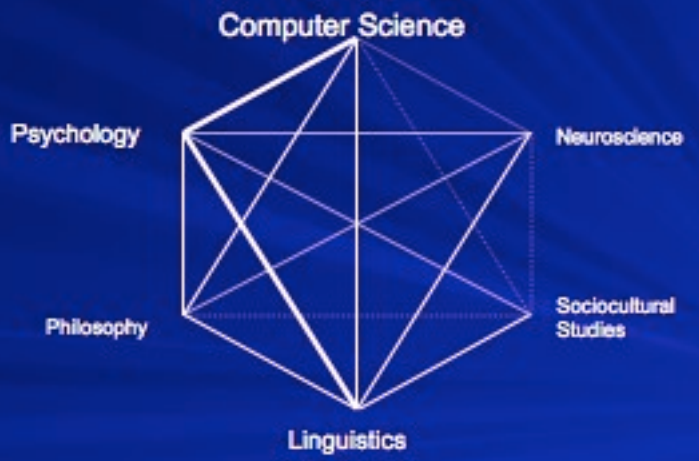
- Cognitive science is an interdisciplinary endeavor (don't be deceived by the presence of a cognitive science department at UCSD)
- What does a discipline contribute to the development of science?
- What are the purposes of working beyond disciplinary boundaries?
- What risks/costs are born by interdisciplinary pursuits?

Clicker Question

Which of the following was not a discipline participating in cognitive science?

A. Philosophy
B. Economics
C. Anthropology
D. Linguistics

Early Cognitive Science: 1956-1985

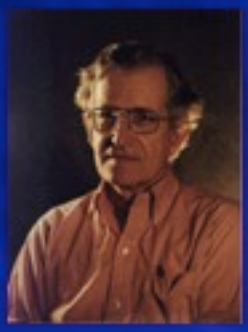


Chomsky's 1959 Review of Skinner's *Verbal Behavior*

Emphasis on the novelty of linguistic constructions

Inadequacy of probabilistic models (Markov processes) and need for a generative system governed by rules

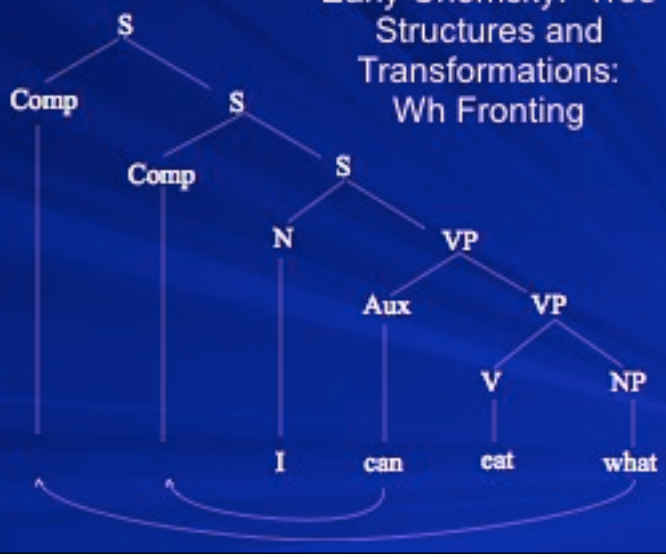
Poverty of the stimulus: from data too impoverished to support behaviorist learning, young children learn their language



Setting the Task for a Grammar

- **There are an infinite number of grammatically correct sentences in a natural language (English, French)**
- Goal: a finite account (using recursion) that can generate all and only the grammatically well-formed sentences of the language (e.g., a procedure that could be run on a computer)
- Employ the hypothetical-deductive method:
  - Hypothesize a grammar
  - Determine what would be legitimate sentences given that grammar
  - Test whether those are in fact grammatically correct sentences of the language
  - If not, revise the grammar

Early Chomsky: Tree Structures and Transformations: Wh Fronting



Competence vs. Performance

Chomsky uses ordinary speakers (e.g., himself) to test his grammars

But ordinary speakers make grammatical mistakes all the time

Chomsky proposed that these are due to *performance* limitations

Chomsky's claim: we all possess perfect linguistic *competence*, and hence can evaluate sentences even if our performance is flawed

Universal Grammar and Nativism

The underlying grammatical processes are same for all languages

The implementation differs (different parameters)

Thus, grammar is universal

Grammar is too difficult to learn in restricted time given the linguistic evidence available to children (*Poverty of the Stimulus*)

Universal Grammar must be innate

Children only have to figure out which implementation is found in their language

Clicker Question

In 1959 Chomsky wrote a scathing review of Skinner's *Verbal Behavior*. What would have been his most fundamental criticism of Skinner

A. Conditioning plays no role in people's linguistic behavior
B. Skinner proposal that we start by randomly producing verbal behavior and being rewarded cannot explain developing a grammar
C. Without knowing the grammar of the language, we cannot identify the utterances of the language

Miller and the Psychological Reality of Grammar

- Chomsky's arguments about the inadequacy of finite state automata for constructing grammars adequate to natural languages and the need for transformational grammars led Miller to redirect his program.
- Does transformational grammar characterize language processing?
  - Early evidence that processing difficulty corresponded to number of transformations in sentence's derivation
  - Chomsky subsequently changed his grammar, getting rid of the transformations for which the evidence had been collected
- But the idea of cognition involving operations on structures was shared across the cognitive sciences

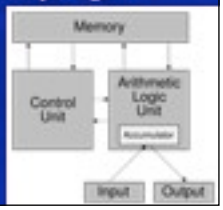
11

The Turing Machine

- Turing's models for a machine capable of computing all decidable functions were humans who were called computers.
  - Individuals who calculated sums on paper for a living
  - How did such individuals perform their job?
- Turing Machine: finite state device operating on a potentially infinite tape
  - Argued that there was a Turing machine for any decidable function
  - And a (Universal) Turing machine that could realize any actual Turing machine

Introducing the Digital Computer

- The first general function digital computer, Electronic Numerical Integrator and Computer (ENIAC), was developed by John Mauchly and J. Presper Eckert at the Moore School of Electrical Engineering, U. Penn
  - Purpose: calculate artillery firing tables
  - Went into operation too late for WWII (15 February 1946)
  - First used for problems related to design of the hydrogen bomb
  - Decommissioned on 2 October 1955
- John von Neumann advanced the idea of a stored program in his proposal for EDVAC
  - Von Neumann architecture



Clicker Question

Which of the following was particulary influential in the development of artificial intelligence

A. The development of modern logic
B. Decartes' emphasis on thought being productive
C. Chomsky' view that grammar involved transformations of representations
D. The creation of computer programs to play checkers and chess

Inspiration for Linking Computers with Thought: Logic

George Boole: 1854: *An Investigation of the Laws of Thought on which are Founded the Mathematical Theories of Logic and Probability*: Natural deduction as a model of thought

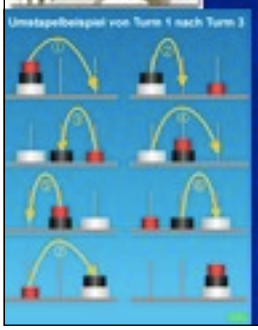
1.	A v –B	:Premise
2.	(-B & C) ⊃ D	:Premise
3.	C & -D	:Premise
| 4.	-A	:Assump
| 5.	-B	:1,4 v-elim
| 6.	C	:3 &-elim
| 7.	-B & C	:5,6 &-intro
| 8.	D	:2,7 ⊃-elim
9.	-A ⊃ D	:4,8 ⊃-intro

Logic Theorist: Computer program to prove theorems of logic

Human Problem Solving

Take verbal protocols as humans solve problems such as those of cryptoarithmetic

```
   DONALD
+  GERALD        D=5
   ROBERT
```



or Tower of Hanoi

Figure out general strategies that would enable computer to perform these tasks

Importance of means-ends reasoning and reasoning backwards

Production Systems

Working Memory	Rules	Working Memory

G
B
D
H
	If (A & B) → -A & +D
	If C → -C & +D & +E
	If (B & D) → -D & +J
	If (G & J) → -J & +A
		G
		B
		J
		H

The Physical Symbol System Hypothesis

- **A physical symbol system consists of a set of entities, called *symbols*, which are *physical patterns* that can occur as components of another type of entity called an expression (or symbol structure).**
- A physical symbol system is a machine that produces through time an evolving collection of symbol structures.
- ***A physical symbol system has the necessary and sufficient means for general intelligent action.***

– Allen Newell and Herbert Simon, 1975

Advances in Symbolic AI

- Early AI achieved some success
  - But these tended to be program of limited purpose
- Challenge: how to scale up to the sorts of tasks humans perform on a regular basis
- One type of task researchers took up was understanding stories
  - Oliver and Cleo went to Tony's. Cleo slipped the maitre d' a $20, and they were directed to a very nice table. They considered the entrées on the menu, but decided to order the salmon special. They asked for the salmon to be well cooked. They waited a long time for their dinner to come, and consumed nearly all their wine while waiting. When the waiter brought the salmon, it was nearly raw. They complained to the waiter but he insulted them for their unsophisticated taste. They finished their entrées, but decided to skip desert. They left a very small tip.

Answering Questions

- How do we measure comprehension? Ability to answer questions
  - On this evening:
    - Were Oliver and Cleo seated at their table?
    - Did the waiter bring them menus?
    - Did they read them?
    - Did they order a bottle of wine?
    - Did they eat the salmon?
    - Did they pay the check?
    - Were they unhappy when they left?
- Even though this information was not stated in the story, all of us are able to answer these questions.

Roger Schank's Restaurant Script

Schank proposed that we reason about such problems using larger-scale knowledge structures, into which we fit the information we are given. They specify what typically happens in events such as going to a restaurant. In addition to typical props, roles, entry conditions, etc. they are comprised of a sequence of primitive actions such as:

S MTRANS signal to **W**
W PTRANS W to table
S MTRANS 'need menu' to **W**
W PTRANS W to menu (from the coffee shop track)

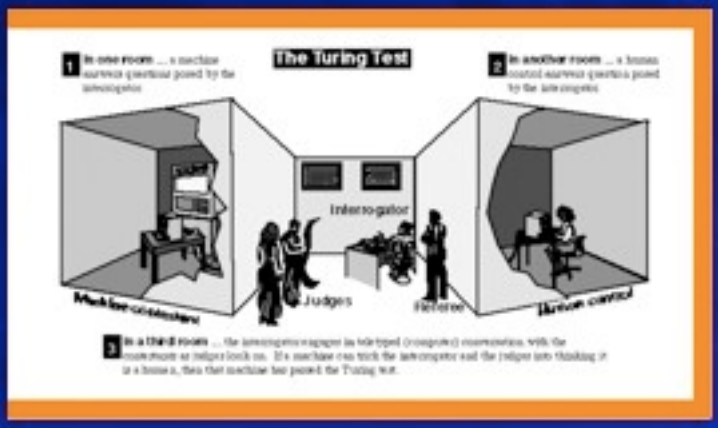
Scripts contain tracks for common variations, such as going to a fast food restaurant, coffee shop, fancy restaurant.

The Centrality of Representation and Computation

- What integrates the approaches of linguistics, cognitive psychology, and AI are
  - A view that in some way there are representations inside the mind
    - Structures which can be operated on internally but that have mean (intentional content) outside the mind
  - That the mind performs computations (sets of operations) over these representations
- Cognitive scientists diverge in their views as to
  - What representations are (and how they relate to content)
  - What counts as performing computation

22

Do Machines Really Think?



Implications of AI for Understanding the Human Mind

- The mind is a symbol processing system
  - It manipulates symbolic structures in accordance with rules
- The mind's native symbols constitute a language—the language of thought
  - This language must be innate—all learning depends upon constructing and testing hypotheses
- Evidence for the language of thought: thought is
  - productive
  - systematic
- Only a system with a composition syntax and semantics will exhibit these properties

24

Clicker Question

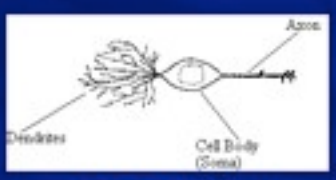
It is 1975 and you need to come up with a name for the new interdisciplinary field. What might you choose?

A. Cognitive Studies
B. Cognitive Science
C. Human Information Processing
D. Intelligence Theory

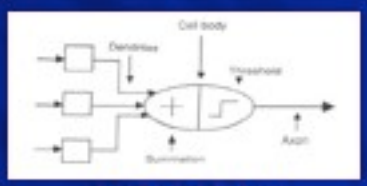
Gaining An Identity

- The term *cognitive science* appears to have been first used in print in 1975
- The journal *Cognitive Science* began in 1977
  - "This discipline might have been called applied epistemology or intelligence theory, but someone on high declared it should be cognitive science and so it shall" (Allan Collins, Editorial, Why Cognitive Science)
- In 1977 the Alfred P. Sloan Foundation began its Particular Program in Cognitive Science that over ten years provided $17.4 million to numerous institutions
  - UCSD used part of its funding to run the La Jolla Conference on Cognition, which became the first meeting of the Cognitive Science Society

A non-Symbolic Alternative: Artificial Neural Networks (Connectionism)



Biological Neurons

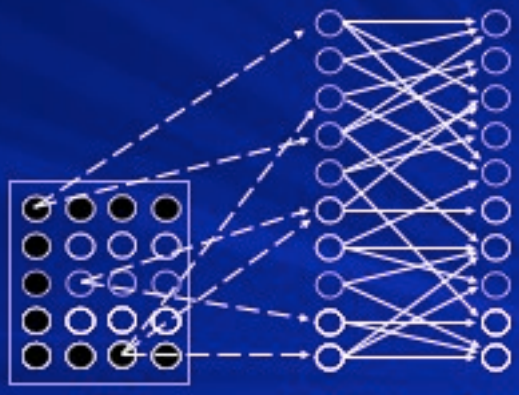


Artificial Neurons

McCulloch and Pitts (1943) saw how to build sentential logic networks out of artificial neurons: negation, and-gates, or-gates

Pitts and McCulloch (1947) saw the potential to model perception, etc. with less structured networks

Rosenblatt's Perceptrons

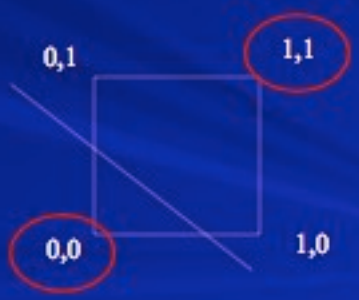


Papert and Minsky: The Demise of Perceptrons

Exclusive Or

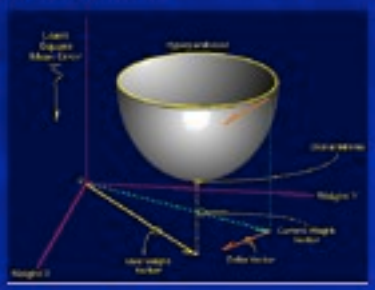
A	B	A xor B
1	1	0
1	0	1
0	1	1
0	0	0

Failure of linear separability

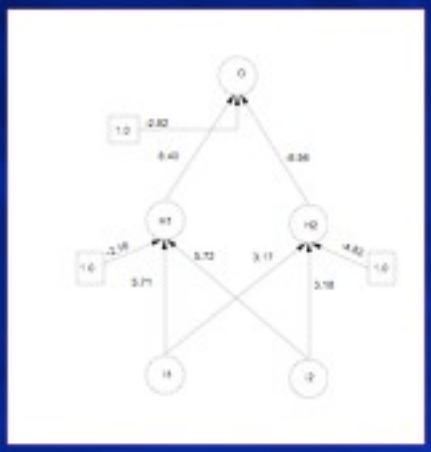


Connectionism Returns

New learning rules: Delta Rule and Backpropogation



Solving XOR with Backpropogation



Nets learn to talk: NETtalk

Corpus presented to network

- Started with random weights
- Error backpropogated through network to adjust weights

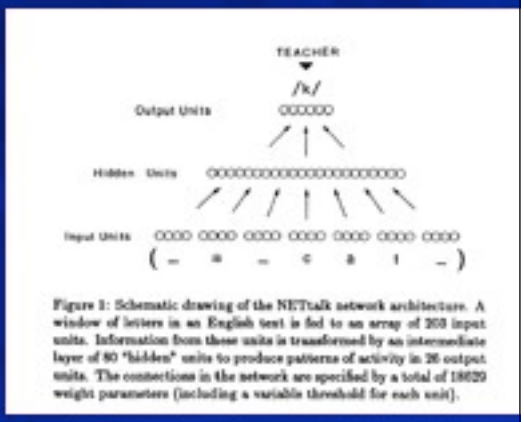


Figure 1: Schematic drawing of the NETtalk network architecture. A window of letters in an English text is fed to an array of 203 input units. Information from these units is transformed by an intermediate layer of 80 "hidden" units to produce patterns of activity in 26 output units. The connections in the network are specified by a total of 18629 weight parameters (including a variable threshold for each unit).

Cognitive Science 1985-2010