1956: ANNUS MIRABILIS

The year 1956 was a turning point in what came to be known as the Cognitive Revolution. Much of the excitement was centered in Cambridge. A conference at MIT brought together psychologists, linguists, and computer scientists for the first time, and three epochal publications by scholars with Harvard ties—George Miller, Jerome Bruner, and Noam Chomsky—opened up research avenues that forever changed the field.

THE MIND AS AN INFORMATION-PROCESSOR

The advent of the computer influenced cognitive psychology in several ways. The very idea of an intelligent mechanism helped to frame new questions on the mind's information-processing capacities. By the early 1960s, the first minicomputers gave cognitive psychologists hands-on familiarity with the way that computers worked. Computers also allowed them to control experiments with infinite flexibility rather than to rely on dedicated hardware.

THE HARVARD CENTER FOR COGNITIVE STUDIES

In 1960, Jerome Bruner and George Miller founded the Harvard Center for Cognitive Studies, the first institute dedicated to what we now call cognitive science. After occupying temporary quarters on Bow Street, it moved to a house at 61 Kirkland Street, and eventually to the 11th and 12th floors of William James Hall, where it remained until its closing in 1973.

The Center was a hothouse for ideas and experimental techniques. Its students, postdocs, and visitors went on to establish cognitive psychology programs all over the world.

The Center is also fondly remembered for its atmosphere of enthusiasm and playfulness. As Roger Brown put it,

> Bruner had the rare gift of providing intellectual stimulus, but also the rarer gift of giving colleagues the sense that problems of great antiquity were on the verge of solution by the group there assembled that very afternoon.

But the members also shared their frustrations with this challenging new science, as seen in this doodle from Bruner.

Sketch from Bruner's notebook recording meetings of the Cognition Project, 1957. Courtesy of the Harvard University Archives.

EXPLORING THE MIND

Many new questions on the mind came to light in the early years of the Center for Cognitive Studies, and soon became major research areas in psychology.

The Magical Number Seven Plus or Minus Two

"My problem is that I have been persecuted by an integer."

So began perhaps the most famous paper in the history of experimental psychology. The Harvard psychologist George Miller, inspired by information theory, aimed to measure the "channel capacity" of the mind. He found that three very different tasks yielded the same estimate:

- People could associate about seven different labels with continuous stimuli (like loudnesses or colors).
- They could rapidly identify the numerosity of up to seven dots without having to count them.
- They could hold about seven items in immediate memory.

And there was an additional twist. The capacity of immediate memory was the same whether each item was a binary digit (1 bit), a decimal digit (3.3 bits), a letter of the alphabet (4.7 bits), or an English word chosen from a list of a thousand (10 bits).

This elasticity suggested that the brain does not just passively transmit incoming information but *recodes* it into mind-friendly units, which Miller called "chunks."

Human information processing is thus constricted by a bottleneck of 7 plus or minus 2 chunks.

George A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *The Psychological Review* 63, no. 2 (1956): 81-97.

George Miller, photograph, circa 1962. Courtesy of the Harvard University Archives.

The Flowchart Replaces the Reflex Arc

In *Plans and the Structure of Behavior* (1960), George Miller (together with Eugene Galanter and Karl Pribram) proposed that psychologists rethink the basic unit of behavior. It should not be the stimulus-response reflex arc, but the feedback loop: Test-Operate-Test-Exit, or TOTE for short. The TOTE was a mechanistic implementation of the idea of a "plan" or "goal," but without any mysterious teleology.

Moreover, TOTEs could be embedded within TOTEs recursively, creating arbitrarily complex plans of behavior.

A Study of Thinking

The title of Jerome Bruner's book with Jacqueline Goodnow and George Austin—*A Study of Thinking*—was another taboo-breaker. Psychologists had long studied concept attainment by presenting people with shapes, signaling that some belonged to a category (such as "red square"), and having them guess which new ones fit the category. Bruner et al. focused not just on the right and wrong answers but also on the subjects' *strategies*—which cards they requested, and how they framed and modified hypotheses. People were treated as constructive problem-solvers rather than passive media that merely superimposed the stimuli into a composite.

Jerome S. Bruner, Jacqueline Goodnow, and George Austin, *A Study of Thinking* (New York: 1956).

Jerome Bruner, photograph with child.

Cards used in concept-attainment experiments, from *A Study of Thinking.*

Syntactic Structures and the Chomskyan Turn

The linguistics of the early 1950s sought to classify the sentences in a given language with little regard to how humans learned or used it. Noam Chomsky, while at the Harvard Society of Fellows between 1951 and 1955 before his move to MIT, worked out a revolutionary agenda for the field. People, he noted, can produce and understand an infinite number of sentences that they have never heard before. That shows that they must have internalized a *grammar*, or set of rules, rather than having memorized a fixed set of responses. Children are not taught this grammar, and so must be innately equipped with a "language acquisition device" that instantiates a "universal grammar."

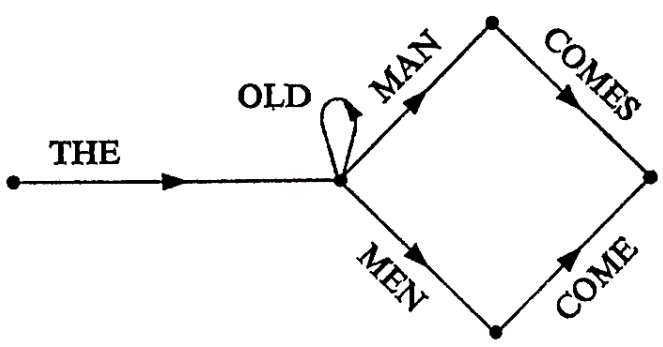
Chomsky's brief 1956 paper laid out ideas that have shaped the science of language to this day. One sentence, which would come to be listed in *Bartlett's Familiar Quotations*, cast doubt on models of language in which each word was associated with the next one in a sentence:

> grammar. There is no general relation between the frequency of a string (or its component parts) and its grammaticalness. We can see this most clearly by considering such strings as
>
> (14) colorless green ideas sleep furiously
>
> which is a grammatical sentence, even though it is fair to assume that no pair of its words may ever have occurred together in the past. Notice that a

And since the sentence *Colorless green ideas sleep furiously* makes little sense, it also shows that grammaticality cannot be reduced to meaningfulness.

Chomsky also proved that a word-by-word associator, like the finite-state device shown in the diagram, could not generate a subset of the English language.

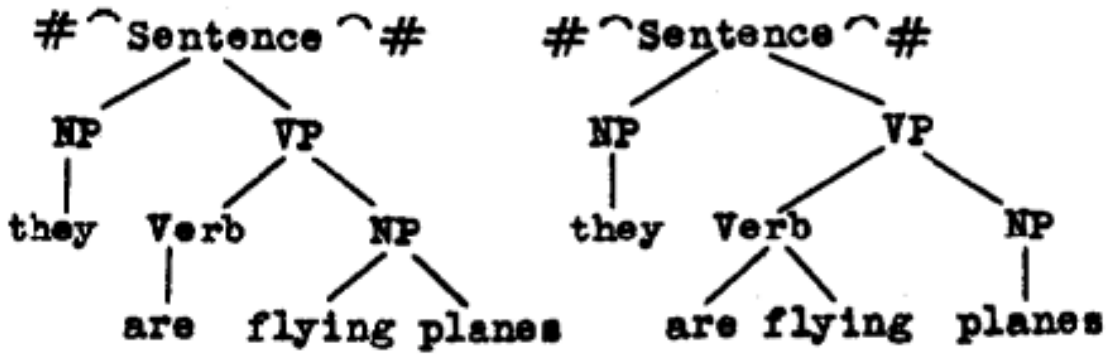
(8)



The reason is that the words at the beginning of a sentence can restrict the choice of words arbitrarily far downstream, like *if* and *then*,

either and *or*, and *the man* and a verb agreeing with it in number, like *comes*.

In a second, better model, a set of rules generates a phrase-structure tree, which can simultaneously specify the beginning and end of a phrase, and recursively embed another phrase in the middle. The phrase-structure tree also helps determine the sentence's *meaning*. The same string of words can have two meanings, depending on the tree, as shown here.



Chomsky then argued that even phrase-structure rules were inadequate. They generated a tree that came to be called a "deep structure," but another kind of rule, the "transformation," was necessary to turn it into a surface structure, which is closer to what we pronounce and hear. For example, the sentence, "The food was eaten by the man," arose from a deep structure such as [*the man*] past-*eat* [*the food*].

The derived transformation t_p^* thus has the following effect:

(48)(i) $t_p^*(Y_1,\ldots,Y_4) = Y_1 - Y_2{}^\frown be{}^\frown en - Y_3 - by{}^\frown Y_1$

(ii) $t_p^*(the{}^\frown man, past, eat, the{}^\frown food) =$
$the{}^\frown food - past{}^\frown be{}^\frown en - eat - by{}^\frown the{}^\frown man.$

Noam Chomsky, photograph, 1961. Courtesy of the MIT Museum.

Noam Chomsky, "Three Models for the Description of Language," *IRE Transactions on Information Theory*, IT-2, no. 3 (1956): 113-124.

The “New Look” In Perception

What We Think Affects What We See and Hear

It is natural to think that perception depends only on the stimuli impinging on the senses from the bottom up. But cognitive psychologists soon showed that knowledge and expectations can affect perception from the top down as well.

In one famous experiment, the Harvard psychologist Jerome Bruner and his student Molly Potter had people identify the object shown in a slide as it gradually came into focus. If viewers made an incorrect hypothesis early on, they tended to persist with it, and had trouble identifying the object even as it became sharp.

Images of a fire hydrant used by Jerome Bruner and Molly Potter in their experiments. Courtesy of Molly Potter.

Kodak slide projector of the kind used in the Bruner and Potter experiments.

Flip book of a series of blurry images, which replaced the slide-projected series used in earlier versions of the experiment. Courtesy of Molly Potter.

George Miller showed a similar effect in one of the first experiments on sentence comprehension. People had no trouble identifying spoken words heard in noise, if the words were arranged in grammatical and sensible sentences, so that their knowledge could guide their perception:

Furry wildcats fight furious battles.
Soapy detergents dissolve greasy stains.

People had much more trouble identifying spoken words when the sentences made no sense:

Furry jewelers create distressed stains.
Soapy wildcats give smoky damsels.

Or when the words were scrambled:

Furry fight furious wildcat battles.
Jewelers respectable appraisals accurate give.

And they had the most trouble when the words fit into no pattern at all:

Furry create distressed jewelers stains.
Cigarettes respectable battles greasy save.

The Child as Scientist

American psychologists also began to pay attention to European behavioral scientists who had never been constrained by behaviorism. These included Niko Tinbergen, Lev Vygotsky, and especially Jean Piaget, whose collaborators were regular visitors to Harvard in the 1960s.

Piaget had devised many demonstrations in which children at particular ages gave strange but systematic responses to questions about simple physical events. This suggested that children are like little scientists, who actively formulate and revise theories about the world.

For example, in the famous "conservation" experiments, children insisted that a tall narrow beaker held more water than a wide shallow one, even as they saw the water poured back and forth between them. The Harvard psychologist Susan Carey, who studied both with Miller and Bruner, replicated these demonstrations and significantly expanded and revised the child-as-scientist theory.

Conservation beakers as depicted in Jerome S. Bruner, "On the Conservation of Liquids" in Jerome S. Bruner, et al. *Studies in Cognitive Growth: A Collaboration at the Center for Cognitive Studies* (New York: 1966).

Susan Carey, photograph, 1969. Courtesy of Susan Carey.

A First Language

The Harvard social psychologist Roger Brown wrote an appendix to *A Study of Thinking* which analyzed the relationship of concepts to language. Brown laid out problems that have occupied psychologists ever since—such as how children learn different names for the same thing (like *Rover, collie, dog, animal,* and *living thing*), and how our language can affect our thoughts.

But Brown's biggest contribution was yet to come: the first systematic study of how children acquire language. With the help of a new invention—the portable tape recorder—Brown and his students transcribed the speech of three children ("Adam," "Eve," and "Sarah") at biweekly intervals for several years. Inspired by Chomsky's theories, Brown fitted grammars to the children's speech at five evenly spaced intervals, documenting the major stages of their grammatical development.

Roger Brown with "Eve," one of the three children whose language development he studied. Photograph, 1968. Courtesy of the Harvard University Archives.

Pages from Roger Brown's grammar for Eve's language, circulated as mimeographed documents. Courtesy of Steven Pinker.

Wollensak tape recorder with tapes, similar to that used in Brown's research.

Miscellaneous Captions

This cartoon on the importance of the organization of memory defied the behaviorist taboo on characterizing the contents of the mind.

From George Miller, “Information and Memory,” *Scientific American*, August 1956.

The PDP-4 was one of the first, commercially-available minicomputers. It cost $65,000 in 1962 and came with 2K of memory, upgradeable to 64K.

Detail of Mark I, the earliest mainframe computer built at Harvard during World War II.

The Center for Cognitive Studies was well funded even by today’s standards, and had a mobile laboratory that could be driven to schools and homes to test children in psychology experiments.

A pigeon in a “Skinner Box” being trained to discriminate colors.