Mental Processing Is Continuous, Not Like a Computer

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The theory that the mind works like a computer, in a series of distinct stages, was an important steppingstone in cognitive science, but it has outlived its usefulness, concludes a new Cornell University study. Instead, the mind should be thought of more as working the way biological organisms do: as a dynamic continuum, cascading through shades of grey.

In a new study published online this week in *Proceedings of the National Academy of Sciences* (June 27-July 1), Michael Spivey, a psycholinguist and associate professor of psychology at Cornell, tracked the mouse movements of undergraduate students while working at a computer. The findings provide compelling evidence that language comprehension is a continuous process.

"For decades, the cognitive and neural sciences have treated mental processes as though they involved passing discrete packets of information in a strictly feed-forward fashion from one cognitive module to the next or in a string of individuated binary symbols -- like a digital computer," said Spivey. "More recently, however, a growing number of studies, such as ours, support dynamical-systems approaches to the mind. In this model, perception and cognition are mathematically described as a continuous trajectory through a high-dimensional mental space; the neural activation patterns flow back and forth to produce nonlinear, self-organized, emergent properties -- like a biological organism."

In his study, 42 students listened to instructions to click on pictures of different objects on a computer screen. When the students heard a word, such as "candle," and were presented with two pictures whose names did not sound alike, such as a candle and a jacket, the trajectories of their mouse movements were quite straight and directly to the candle. But when the students heard "candle" and were presented with two pictures with similarly sounding names, such as candle and candy, they were slower to click on the correct object, and their mouse trajectories were much more curved. Spivey said that the listeners started processing what they heard even before the entire word was spoken.

"When there was ambiguity, the participants briefly didn't know which picture was correct and so for several dozen milliseconds, they were in multiple states at once. They didn't move all the way to one picture and then correct their movement if they realized they were wrong, but instead they traveled through an intermediate gray area," explained Spivey. "The degree of curvature of the trajectory shows how much the other object is competing for their interpretation; the curve shows continuous competition. They sort of partially heard the word both ways, and their resolution of the ambiguity was gradual rather than discrete; it's a dynamical system."

The computer metaphor describes cognition as being in a particular discrete state, for example, "on or off" or in values of either zero or one, and in a static state until moving on. If there was ambiguity, the model assumed that the mind jumps the gun to one state or the other, and if it realizes it is wrong, it then makes a correction.

"In thinking of cognition as working as a biological organism does, on the other hand, you do not have to be in one state or another like a computer, but can have values in between -- you can be partially in one state and another, and then eventually gravitate to a unique interpretation, as in finally recognizing a spoken word," Spivey said.

Whereas the older models of language processing theorized that neural systems process words in a series of discrete stages, the alternative model suggests that sensory input is processed continuously so that even partial linguistic input can start "the dynamic competition between simultaneously active representations."

Spivey's co-authors are Marc Grosjean of the University of Dortmund, Germany, and Günther Knoblich of Rutgers University.

Source: Cornell University