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Scientists Model Words as Entangled Quantum States in our Minds

February 18 2009, By Lisa Zyga

Researchers have modeled the human mental lexicon as consisting of words that cannot be separated from other words, which may explain why words have many associations, a feature which helps us communicate. Credit: Flickr.com by surrealmuse.

(PhysOrg.com) -- When you hear the word "planet," do you automatically think of the word's literal definition, or of other words, such as "Earth," "space," "Mars," etc.? Especially when used in sentences, words tend to conjure up similar words automatically. Further, human beings' ability to draw associations and inferences between words may explain why we're generally able to communicate complex ideas with each other quite clearly using a limited number of words.

Research has shown that words are stored in our memories not as isolated entities but as part of a network of related words. This explains why seeing or hearing a word activates words related to it through prior experiences. In trying to understand these connections, scientists visualize a map of links among words called the mental lexicon that shows how words in a vocabulary are interconnected through other words.

However, it's not clear just how this word association network works. For instance, does word association spread like a wave through a fixed network, weakening with conceptual distance, as suggested by the "Spreading Activation" model? Or does a word activate every other associated word simultaneously, as suggested in a model called "Spooky Activation at a Distance"?

Although these two explanations appear to be mutually exclusive, a recent study reveals a connection between the explanations by making one novel assumption: that words can become entangled in the human mental lexicon. In the study, researchers from the Queensland University of Technology (QUT) in Australia and the University of South Florida in the US have investigated the quantum nature of word associations and presented a simplified quantum model of a mental lexicon.

Classical vs. Quantum Correlations

The researchers begin by explaining the difference between classical correlations (in the Spreading Activation model) and quantum correlations (in the Spooky Activation at a Distance model). Specifically, no pre-existing elements or hidden variables exist in quantum correlations as they do in classical correlations. For example, a classical correlation would be a scenario in which someone writes the same number on two pieces of paper, and sends them to two distant ends of the Universe. When received, both papers have the same number, but this correlation is due to a pre-existing action.

On the other hand, the quantum analogue of this scenario is much stranger. At one end of the Universe, someone writes a number on a blank piece of paper. At the other end of the Universe, another individual discovers that the same number is written on another piece of paper. Called quantum entanglement, this scenario doesn't occur in everyday life, but it has been observed at the quantum scale and is referred to as "non-locality."

Non-Separable Entities

In this study, the researchers ask if quantum entanglement might exist for systems beyond modern physics, such as word correlations.

"We take the position that quantum entanglement in modern physics is a physical manifestation of something more general called 'non-separability,'" coauthor Peter Bruza of QUT told *PhysOrg.com*. "We view quantum theory as an abstract framework for developing models of non-separability in a variety of domains including cognition. Note that, even though we are using quantum theory to model the non-separability of words in human memory, we make no claim that this corresponds to a physical manifestation of entanglement in the brain."

In the researchers' word entanglement model, each associated word can either be recalled or not recalled. An entangled state would occur when two associated words (e.g. "Earth" and "space") are either both recalled or both not recalled in relation to a cue word (e.g. "planet"). Intuitively, this makes sense: when visualizing Earth, it's hard to not also visualize the surrounding space. In this example, Earth and space make up a non-separable entity.

Word Recall Probability

Next, the researchers suggest that the probability of a word being activated in memory lies somewhere between Spreading Activation (in which words are individually recalled based on individually calculated conceptual distance) and Spooky Activation at a Distance (in which the cue word simultaneously activates the entire associative structure). Most likely, Spreading Activation underestimates the strength of activation, while Spooky Activation at a Distance overestimates the strength of activation.

“Even though both the Spreading Activation and Spooky-Activation-at-a-Distance models are based on an underlying network, both models are still fundamentally reductive in nature and assume that words are separate, distinct entities in human memory,” Bruza explained. On the other hand, the quantum-based model doesn’t assume that words are separate entities.

In the new model, associative word recall probability depends on how strongly connected the associated words are to each other. For instance, “Earth” and “space” are entangled in the context of “planet,” but “Earth” and “gas giant” may not be entangled (though “Jupiter” and “gas giant” may be). Words that are entangled with many other words have a greater probability of being recalled, while words that are entangled with few or no other words have a smaller recall probability. While the idea of word entanglement may sound odd, Bruza explained that it may be just one example of a strange concept.

“We think it is odd that entanglement occurs at all,” he said. “As a phenomenon, it suggests that the world is not the separable and reducible place that we have always taken it to be. If entanglement is found in other types of (non-physical) systems, it will suggest that the quantum formalism is modeling non-separability per se, and this will indicate that quantum theory could provide a whole new approach to the study of complex systems, i.e. non-separable and irreducible systems."

The Future of Quantum Cognition

The researchers explain that their model is overly simplified, and it would be very difficult to extrapolate to a more realistic model due to the vastness of the human mental lexicon. However, experiments involving memory tests might be able to distinguish between the predictions of the three different models. Currently, researchers are performing an empirical analysis using the University of South Florida's "Free Association Norms," a database of word association norms which involves data from more than 6,000 participants producing nearly three-quarters of a million responses to 5,019 stimulus words. Eventually, all this analysis of semantic models may have applications for future technology, Bruza explained.

"Current information processing technology is very efficient at processing symbols, but is largely clueless as to what they mean," he said. "Our position is that, in order for such technology to better align with humans, it needs to process 'meanings' like those we harbor. As our information environment becomes more complex, we will need technology that can draw context-sensitive associations like the ones we would draw, but increasingly don't as we lack the cognitive resources to do so. Therefore, such the 'meanings' processed by such technology should be motivated from a socio-cognitive perspective."

This kind of research is an example of an emerging field called "quantum cognition," the aim of which is to use quantum theory to develop radically new models of a variety of cognitive phenomena ranging from human memory to decision making. Although speculative, this research is gaining momentum. For instance, later this year, the highly regarded *Journal of Mathematical Psychology* will publish a special issue of quantum models of cognition. In addition, quantum cognition is a prominent theme within the Quantum Interaction Symposia, which provide a forum for a growing body of researchers applying quantum theory to non-quantum domains.

More information: Bruza, Peter; Kitto, Kristy; Nelson Douglas; McEvoy, Cathy. “Extracting Spooky-activation-at-a-distance from Considerations of Entanglement.” To appear in Proceedings of the Third Quantum Interaction Symposium, Lecture Notes in Artificial Intelligence, vol 5494, Springer, 2009. Available at arXiv:0901.4375v1.