In quantum theory of cognition, memories are created by the act of remembering

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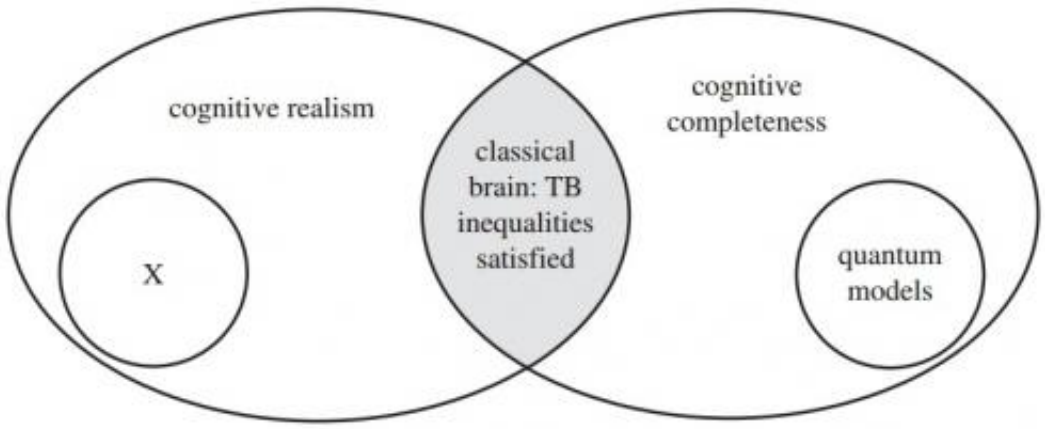

Venn diagram showing the relationship between the assumptions of cognitive realism and cognitive completeness, and their overlap, which defines classical cognitive models. Quantum models satisfy cognitive completeness but not cognitive realism, and a model in the class 'X' would satisfy cognitive realism but not cognitive completeness. Credit: Yearsley and Pothos. ©2014 The Royal Society

(Phys.org) —The way that thoughts and memories arise from the physical material in our brains is one of the most complex questions in modern science. One important question in this area is how individual thoughts and memories change over time. The classical, intuitive view is that every thought, or "cognitive variable," that we've ever had can be assigned a specific, well-defined value at all times of our lives. But now psychologists are challenging that view by applying quantum probability

theory to how memories change over time in our brains.

"There are two lines of thought when it comes to using quantum theory to describe cognitive processes," James M. Yearsley, a researcher in the Department of Psychology at City University London, told *Phys.org*. "The first is that some decision-making processes appear quantum because there are physical processes in the brain (at the level of neurons, etc.) that are quantum. This is very controversial and is a position held by only a minority. The second line of thought is that basic physical processes in the brain at the level of neurons are classical, and the (apparent) non-classical features of some human decision-making arises because of the complex way in which thoughts and feelings are related to basic brain processes. This is by far the more common viewpoint, and is the one we personally subscribe to."

Memory construction

In their study, Yearsley and Emmanuel M. Pothos, also at City University London, have proposed that quantum probability theory may be used to assign probabilities to how precisely our thoughts, decisions, feelings, memories, and other cognitive variables can be recalled and defined over time. In this view, recalling a memory at one point in time interferes with how we remember perceiving that same memory in the past or how we will perceive it in the future, much in the way a measurement may change the outcome of something being measured. This act of recall is sometimes called "constructive" because it can change (or construct) the recalled thoughts. In this view, the memory itself is essentially created by the act of remembering.

As Yearsley explains, the idea that measurements might be constructive in cognition can be understood with an example of chocolate cravings.

"It's a little bit like how you can be sitting at your desk happily working

away until one colleague announces that they are popping out to the shop and would you like anything, at which point you are overcome with a desire for a Twix!" he said. "That desire wasn't there before your colleague asked, it was created by that process of measurement. In quantum approaches to cognition, cognitive variables are represented in such a way that they don't really have values (only potentialities) until you measure them. That's a bit like saying as it gets towards lunchtime there is an increased potentiality for you to say you'd like a Twix if someone asks you, but if you're hard at work you might still not be thinking consciously about food. Of course, this analogy isn't perfect."

This quantum view of memory is related to the uncertainty principle in quantum mechanics, which places fundamental limits on how much knowledge we can gain about the world. When measuring certain kinds of unknown variables in physics, such as a particle's position and momentum, the more precisely one variable can be determined, the less precisely the other can be determined.

The same is true in the proposed quantum view of cognitive processes. In this case, thoughts are linked in our cognitive system over time, in much the same way that position and momentum are linked in physics. The cognitive version can be considered as a kind of entanglement in time. As a result, perfect knowledge of a cognitive variable at one point in time requires there to be some uncertainty about it at other times.

Overturning classical assumptions

The scientists explain that this proposal can be tested by performing experiments that try to violate the so-called temporal versions of the Bell inequalities. In physics, violation of the temporal Bell inequalities signifies the failure of classical physics to describe the physical world. In cognitive science, the violations would signify the failure of classical models of cognition that make two seemingly intuitive assumptions:

cognitive realism and cognitive completeness.

As the scientists explain, cognitive realism is the assumption that all of the decisions a person makes can be entirely determined by processes at the neurophysiological level (although identifying all of these processes would be extremely complicated). Cognitive completeness is the assumption that the cognitive state of a person making a decision can be entirely determined by the probabilities of the outcomes of the decision. In other words, observing a person's behavior can allow an observer to fully determine that person's underlying cognitive state, without the need to invoke neurophysiological variables.

Neither of these assumptions is controversial; in fact, both are central to many kinds of cognitive models. A quantum model, however, does not rely on these assumptions.

"I think the greatest significance of this work is that it succeeds in taking the widely held belief that cognitive variables such as judgments or beliefs always have well-defined values and gives us a way to put that intuition to experimental test," Yearsley said. "Also, assuming we do find a violation of the temporal Bell inequalities experimentally, we would be ruling out not just a single model of cognition, but actually a very large class of models, so it's potentially a very powerful result."

Interpreting a possible violation of a temporal Bell inequality is not straightforward, since one would have to decide which of the two assumptions—realism or completeness—should be abandoned. The researchers argue that for the purposes of creating models of cognition it makes more sense to assume that cognitive realism is not valid, thus rejecting the idea that decisions can thought of as being be fully determined by underlying neurophysiological processes. A key implication would be that an individual may not have a well-defined judgment at all points in time, which may offer insight into aspects of

cognition which have so far resisted formal explanation. One such example is the creation of false memories.

The scientists hope that future research will help clarify the role of quantum probability in cognitive modeling, and shed light on the complicated process that make up all of our memories, thoughts, and identities.

More information: James M. Yearsley and Emmanuel M. Pothos. "Challenging the classical notion of time in cognition: a quantum perspective." *Proceedings of The Royal Society B*. DOI: 10.1098/rspb.2013.3056

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