Medical Xpress

Quantum Theory May Explain Wishful Thinking

April 14 2009, By Lisa Zyga

Table 1. Example pay-off matrix for a Prisoner's Dilemma game.

you defect	you cooperate
other defects	
other: 10	other: 25
you: 10	you: 5
other cooperates	
other: 5	other: 20
you: 25	you: 20

This example pay-off matrix for a Prisoner's Dilemma game shows that defecting is the rational choice, since a player receives greater pay-offs when defecting (10 or 25) than when cooperating (5 or 20). However, if both players cooperate, each will receive a larger pay-off (20) than if both defect (10). Using a quantum probability model, scientists provide a psychological explanation for why a player might choose to cooperate without any knowledge of his opponent. Image credit: Pothos and Busemeyer.

(PhysOrg.com) -- Humans don't always make the most rational decisions. As studies have shown, even when logic and reasoning point in one direction, sometimes we chose the opposite route, motivated by personal bias or simply "wishful thinking." This paradoxical human behavior has resisted explanation by classical decision theory for over a decade. But now, scientists have shown that a quantum probability model can provide a simple explanation for human decision-making - and may eventually help explain the success of human cognition overall.

If you were asked to gamble in a game in which you had a 50/50 chance to win $200 or lose $100, would you play? In one study, participants were told that they had just played this game, and then were asked to choose whether to try the same gamble again. One-third of the participants were told that they had won the first game, one-third were told they had lost the first game, and the remaining one-third did not know the outcome of their first game. Most of the participants in the first two scenarios chose to play again (69% and 59%, respectively), while most of the participants in the third scenario chose not to (only 36% played again). These results violate the "sure thing principle," which says that if you prefer choice A in two complementary known states (e.g., known winning and known losing), then you should also prefer choice A when the state is unknown. So why do people choose differently when confronted with an unknown state?

In a recent study, psychologists Emmanuel M. Pothos of Swansea University in the UK and Jerome R. Busemeyer of Indiana University in the US have presented an alternative framework for modeling decision-making of this kind, based on quantum probability. As they note, the original motivation for developing quantum mechanics in physics was to explain findings that seemed paradoxical from a classical point of view. Possibly, quantum theory can better explain paradoxical findings in psychology, as well. In recent years, a growing number of researchers have investigated using quantum formalism in cognitive situations, such as in modeling human judgment and perception. Pothos and Busemeyer's results are published in a recent issue of *Proceedings of the Royal Society B*.

"A few decades ago, Tversky and Kahneman (1974) challenged ubiquitous assumptions regarding what is the most suitable framework for modeling human cognition," Busemeyer told *PhysOrg.com*. "Until then, most psychologists sought to understand cognition using classic probability theory. In our paper we raise the question, which

mathematical framework is most appropriate for cognitive modeling? In this article, for the first time, we present a fundamentally different, and more powerful, approach to probabilistic models of cognition, based on quantum principles. Employing minimal assumptions, we derive a Hamiltonian directly from the parameters of the problem (e.g., the payoffs associated with different actions) and known general principles of cognition (e.g., a well known phenomenon of cognitive dissonance); every step in our model is psychologically interpreted and rigorously justified."

Defecting Dilemma

In their study, the scientists compared two models, one based on Markovian classical probability theory and the other based on quantum probability theory. They modeled a game based on the Prisoner's Dilemma, which is similar to the gambling game. Here, participants were asked if they wanted to cooperate with or defect from an imaginary partner. Overall, each partner would receive larger pay-outs if they defected, making defecting the rational choice. However, if both partners cooperated, they would each receive a higher pay-out than if both defected. Similar to the results from the gambling games, studies have shown that participants who were told that their partner had defected or cooperated on the first round usually chose to defect on the second round (84% and 66%, respectively). But participants who did not know their partner's previous decision were more likely to cooperate than the others (only 55% defected). It seems as if these individuals were trying to give their partners the benefit of the doubt, at the expense of making the rational choice.

As the scientists showed, both classical and quantum probability models accurately predict an individual's decisions when the opponent's choice is known. However, when the opponent's action is unknown, both models predict that the probability of defection is the average of the two

known cases, which fails to explain empirical human behavior. The problem is that the models are purely rational, meaning they try to maximize utility.

To address this problem, the scientists added another component to both models, which they call cognitive dissonance, and can also be thought of as wishful thinking. The idea is that people tend to believe that their opponent will make the same choice that they do; if an individual chooses to cooperate, they tend to think that their opponent will cooperate, as well. If both partners cooperate, both will receive a higher pay-out than if both defected. (And if an individual thought that his opponent would cooperate and so decided to defect to maximize his own pay-out, he would then be compelled to assume that the opponent would also defect, according to cognitive dissonance.) In other words, an individual views his opponent as a mirror of himself.

The difference between the classical and quantum models lies in how the rational component and the cognitive dissonance component are combined. Even after adding the second component, the classical model predicts that the probability in the unknown scenario must equal the average of the probability for the two known cases. As such, the classical model continues to obey the law of total probability, and fails to explain the violations of the sure thing principle.

In the quantum model, on the other hand, the addition of the cognitive dissonance component produces interference effects that cause the unknown probability to deviate from the average of the known probabilities. While in the classical model an individual is committed to exactly one preference at any given time, in the quantum model an individual experiences a superposition of these preferences. Mathematically, the probability (or amplitude) of defecting in the unknown scenario is obtained from the superposition of probabilities (amplitudes) for the two known cases. These interference effects enable

the probability of unknown events to be lower than the probability of either event individually, which is observed in the empirical studies.

“Cognitive dissonance can arise in other decision making situations and is not limited to games with an intelligent opponent,” Busemeyer said. “In the gambling game, you play against nature. In this case, however, your belief that you will win the game becomes coordinated with your intentions to play the game. Cognitive dissonance effects are not even limited to adult humans but have also been found with young children and even with nonhuman primates.” (See Egan, L. C., Santos, L. R. & Bloom, P. (2007). The origins of cognitive dissonance: evidence from children and monkeys. *Psychological Science*, 18, 978- 983.)

Quantum Cognition

While classical probability theory is too restrictive to fully describe human decision-making, this study shows that quantum theory provides a promising framework for modeling human cognition. In addition to making accurate predictions of the gambling game and Prisoner’s Dilemma, the quantum model also agrees with the empirical evidence that people make the same decision in back-to-back identical scenarios. In classical models, on the other hand, back-to-back choices remain probabilistic, which fails to explain human behavior.

“Classic probability theory, including Markov processes, must obey the law of total probability,” said Busemeyer. “However, human judgments often exhibit interference effects which violate the law of total probability. Quantum probability was originally developed specifically for the purpose of explaining interference effects found in physics. This same mathematical formalism provides an explanation for interference of thoughts in human judgments.”

Pothos and Busemeyer hope that further research on quantum

probability models of human cognition could help answer fundamental questions about the nature of how we think. For example, what does it mean to be rational? Another example is Schrodinger's equation, which predicts a periodic oscillation between choices after a minimum length of time. This oscillation matches with electroencephalography signals and may explain why the longer you debate on a decision, the more you fluctuate. Overall, if our brains use quantum principles, and quantum computation is known to be fundamentally faster than classical computation in computers, then perhaps quantum principles can even help explain the success of human cognition.

More information: Pothos, Emmanuel M. and Busemeyer, Jerome R. "A quantum probability explanation for violations of 'rational' decision theory." Proc. R. Soc. B. doi:10.1098/rspb.2009.0121.