Overview

• Introduction
• Classical vs Quantum Probability
• Brain Information Processing
• Decision Making
• Conclusion
Introduction

• Quantum probability in cognition (Quantum Cognition) applies mathematical formalism to model cognitive phenomena

• Information processing with contextual dependence and probabilistic reasoning

• No relation to quantum mechanics within the brain (Quantum Mind)

• Quantum probability used as opposed to traditional classical probability
Fields of study

- Information processing
- Decision making
- Human probability judgments
- Knowledge representation
- Human memory
- Semantic analysis
- Human perception
- Economics
Classical vs Quantum Probability

• Classical probability of events subsets of a universal set
• Decisions A, B subsets of U
• Independent probabilities of events A, B greater than or equal to 0, with total probability of U (p(U) = 1)
• Follows Boolean algebra for logic formalization (or, not, and)
• Law of total probability, p(B) = p(A and B) or p( not A and B)
Classical vs Quantum Probability

- Quantum probability of events are subspace of Hilbert space, \( H \), gives \( H_a, H_b \), and associated projections \( P_a \) and \( P_b \).
- \( P_a P_b = P_b P_a \) means events \( A \) and \( B \) are compatible.
- Cognitive state is unit length vector \( S \), were probability of event \( A \) is the square magnitude of \( P_a \) times \( S \).
Classical vs Quantum Probability

• The probability of event A is greater than or equal to 0 and the probability of the total Hilbert space is equal to 1.

• Violates total probability since probability of event B does not equal (A and B) or (not A and B)
Classical vs Quantum Probability

• CP is Commutative, ‘A and B’ is equal to ‘B and A’
• Polling results on trustworthiness of politicians differs based on order of choices given
• Principle of complimentary constraint that bounds rationality
  • Posits the existence of incompatible measures
Classical vs Quantum Probability

• “The need for the quantum approach arises when incompatible events are involved, which necessarily imposes a sequential evaluation of events. This incompatibility produces superposition of uncertainty that result in violations of some of the important laws of classical probability theory.”

Brain Information Processing

• The brain operates using cells called neurons
• Neurons are either firing or not firing, no superposition
• Groups of neurons (neural networks) create superposition of neural states
Brain Information Processing

- State vectors, $S$, describe input to neural network
- Projectors map input to output
- Probabilities equal to squared length of projection
Decision Making

• Gambling game: coin toss
• Participant likely to play second round if they know the outcome of the first round whether they won or lost
• When outcome of first round is unknown, unlikely to play a second round
• Equivalent to the Defect/Cooperate choice, violates sure-thing principle
Decision Making

- Quantum probability for decision making to explain paradoxical outcomes from classical viewpoint
- Incompatible and interference effects arise in human preference judgements
- Use geometric properties of Hilbert space representations and measurement principles
Decision Making

• Prisoner’s dilemma game, cooperate or defect
• Cognitive dissonance, people change their beliefs to be consistent with their actions
• Wishful thinking, does not change classical probability model of problem
• Quantum model correlates belief with actions
Active Research Questions

• Dynamic activation of cognition based on quantum theory
• Contextuality for classical probability models
• Quantum probability like functions without quantum computation
• Rationality of quantum probability model
Personal Interests

• Applying learning mechanisms to quantum probability models for human cognition
• Working in reverse, applying quantum probability models to neural network models
Conclusion

• Quantum probability allows for mathematical formalization of human paradoxical nature
• Not related to quantum mechanisms in brain chemistry, but space of possible brain activity
• Human cognition may be more vexing than quantum probability
Questions?