Quantum Probability in Cognition

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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 Ha, Hb, and associated projections Pa and Pb
- PaPb = PbPa means events A and B are compatible
- Cognitive state is unit length vector S, were probability of event A is the square magnitude of Pa 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

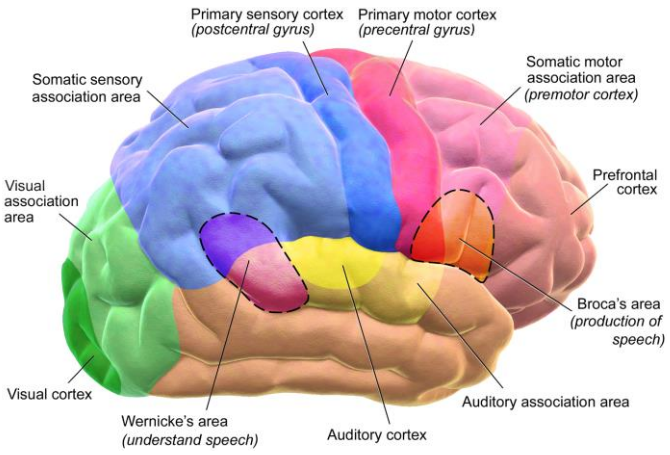
Classical vs Quantum Probability

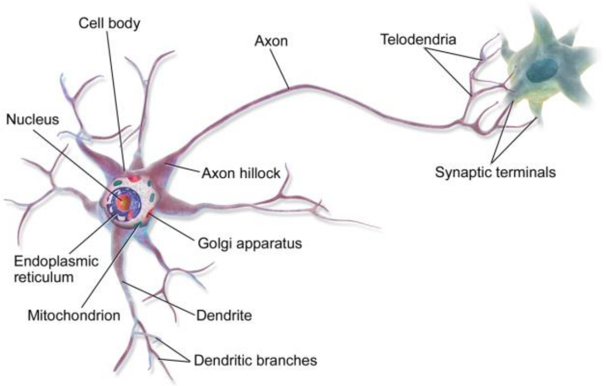
- “The need for the quantum approach arises when incompatible events are involved, which necessarily imposes a sequential evaluation of events. This incompatibility produces superposition of uncertainty that result in violations of some of the important laws of classical probability theory.”

Bruza, Peter D., Zheng Wang, and Jerome R. Busemeyer. "Quantum cognition: a new theoretical approach to psychology." *Trends in cognitive sciences* 19.7 (2015): 383-393.

Brain Information Processing

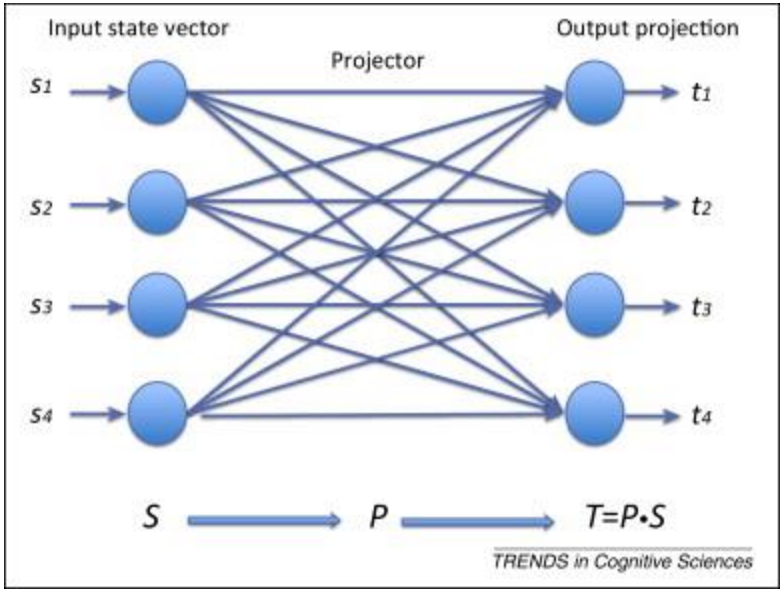
- The brain operates using cells called neurons
- Neurons are either firing or not firing, no superposition
- Groups of neurons (neural networks) create superposition of neural states





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?