Introducing Quantum Models of Cognition and Decision
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Quantum Models of Cognition and Decision

Jerome R. Busemeyer
Peter D. Bruza

Much of our understanding of human thinking is based on probabilistic models. This innovative book by Jerome R. Busemeyer and Peter D. Bruza argues that, actually, the underlying mathematical structures from quantum theory provide a much better account of human thinking than traditional models. They introduce the foundations for modeling probabilistic decision-making using two aspects of quantum theory. The first, "nonclassicality," is a way to understand invariance across a wide range of inferences and decisions under conditions of uncertainty. The second, "quantum entanglement," allows cognitive phenomena to be modeled in a non-reductive way, employing these principles drawn from quantum theory allows us to view human cognition and decision in a totally new light. Introducing the basic principles in an easy-to-follow way, this book does not assume a physics background or a quantum brain and comes complete with a tutorial and fully worked-out applications in important areas of cognition and decision.

Jerome R. Busemeyer is a Professor in the Department of Psychological and Brain Sciences at Indiana University, Bloomington, USA.

Peter D. Bruza is a Professor in the Faculty of Science and Technology at Queensland University of Technology, Brisbane, Australia.
Other Books


Web Sites

http://mypage.iu.edu/~jbusemey
Click Quantum Cognition on home page

http://www.quantuminteraction.org/

http://www.quantum-cognition.de

Wikipedia: Quantum Cognition
Special Issues

• *Journal of Mathematical Psychology 2009*
  – 11 articles on decision making, probability judgments, Conceptual combinations, Categorization and decision

• *Topics in Cognitive Science in press*
  – Introduction plus 5 articles on judgment and decision making, recognition memory, conceptual combinations, bi-stable perception
Quantum Interaction Conferences

Organizers: Bruza, Sofge, Lawless, van Rijsbergen

• 2007 AAAI Symposium Stanford University
• 2008 Conference Oxford University
• 2009 Conference Saarbruken Germany
• 2010 AAAI Symposium Washington DC
• 2011 Conference in Aberdeen, Scotland
• 2012 Conference in Paris
Funding

• US National Science Foundation (Busemeyer & Wang)

• US Air Force Office of Scientific Research (Busemeyer, Wang, Balakrishnan)

• Flemish Fund for Scientific Research (Aerts)

• Australian Research Council (Bruza)

• Swiss National Science Foundation (Sornette and Yukalov)
Journals

• *Proceedings of the Royal Society* (Pothos and Busemeyer)
• *Psychological Review* (Busemeyer, Pothos, Franco, Trueblood)
• *Brain and Behavioral Sciences* (Pothos and Busemeyer)
• *Cognitive Science* (Trueblood and Busemeyer)
• *Theory and Decision* (Yukalov and Sornette)
• *Physical Review Letters* (Cheon & Takahishi)
Why use quantum probability to model cognition & decision?

- Quantum probability
- Quantum dynamics
- Quantum entanglement
Why use quantum probability to model cognition & decision?

- Quantum probability
- Quantum dynamics
- Quantum entanglement
This research is **NOT** concerned with modeling the brain using quantum mechanics, nor is it directly concerned with the idea of the brain as a quantum computer.

Instead it turns to quantum theory as a fresh conceptual framework for explaining empirical puzzles, as well as a rich new source of mathematical modeling tools.
Why Quantum?

• Human behavior is both probabilistic and dynamic

• There are two ways to build such systems:
  – Classic probabilistic dynamics
  – Quantum probabilistic dynamics

• Previous theorizing is based on classic systems. This is an exploration of a Quantum approach.
Classic Probability Theory

- Evolved over several centuries
- Culminated in the 1930’s
  - Kolmogorov (1933)
  - an axiomatic foundation for classic probability theory
Classic Probability Theory

- Events are represented as subsets of a larger set called the sample space, and a measure is proposed for these events.
- The logic of subsets (equivalent to the axioms that events are distributive, commutative, and additive) is used.
- Boolean logic includes some fairly strict laws: the law of total probability, full additivity (classical logic), the independence of events.
- Considering these questions:
  - Is this the only way to think about events and probabilities?
Quantum Mechanics

• Discovered in 1920’s
  – Bohr, Heisenberg, Schrödinger, Born, Dirac, etc.
  – Changed the nature of our world!
Quantum Probability Theory

- 1920’s
  - Bohr, Heisenberg, Schrödinger, Born, Dirac, etc.
  - Quantum mechanics

- 1930’s
  - Von Neumann (1932)
  - Quantum Logic and Quantum Probability
Quantum Probability Theory

- **1920’s**
  - Heisenberg, Schrödinger, Born, Dirac, etc.
  - Quantum mechanics

- **1930’s**
  - Von Neumann
  - Quantum Logic and Quantum Probability

- **1950’s**
  - Feynman
  - Quantum computing
Quantum Probability Theory

• Events are represented as subspaces of a vector space, and an additive measure is proposed to assign probabilities to events

• A new logic: the logic of subspaces

• It relaxes some of the axioms of Boolean logic.
  • The closure property does not always hold
  • Does not entail that events are always commutative and distributive
Why Quantum?

• Human cognition and decision seems to demand these relaxations.

• Principles from quantum theory resonate with deeply rooted psychological intuitions and conceptions about human cognition and decision.
  • e.g., superposition: ambiguity, uncertainty
  • complementarity: constructive view of judgment
1. Superposition

- e.g., superposition: ambiguity, uncertainty
- Suppose you are a juror trying to judge whether a defendant is guilty or innocent.
Is the defendant Guilty or Innocent?
Quantum Information Processing

Is the defendant Guilty or Innocent?

• **Superposition principle:**
• Our beliefs don’t jump from state to state, instead we experience a feeling of *ambiguity* about all of the states simultaneously
2. Cognitive Measures Create rather than Record

• e.g., *complementarity*: constructive view of judgment

• Suppose you are trying to understand an emotion you are feeling when experiencing an arousing situation
Cognitive system is in a **definite** state with respect to each possible measure.

**Take** a measure e.g. Similarity, Preference, Emotion, Memory.

**Simply record** what existed immediately before our measurement was taken.
Quantum Information Processing

Cognitive system is in an **indefinite** state with respect to each possible measure.

**Impose** a measure, e.g., Similarity, Preference, Emotion, Memory.

Create a **definite** state, bringing into existence a reality which was not there before.
Quantum Theory Can Help Explain Many Puzzling Cognitive Phenomena

- Disjunction & conjunction effects in probability judgments
- Violations of distance axioms observed with similarity judgments
- Violations of the sure thing principle for decisions
- Non monotonic reasoning in conceptual combinations
- Over and under extension effects found with membership judgments of conceptual combinations
- Bistable perception of ambiguous figures
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