Full Day Tutorial on Quantum Models of Cognition and Decision

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General Purpose

This ***full day*** tutorial is an exposition of a rapidly growing new alternative approach to building computational models of cognition and decision based on quantum theory. The cognitive revolution that occurred in the 1960s was based on classical computational logic, and the connectionist/neural network movements of the 1970s were based on classical dynamical systems. These classical assumptions remain at the heart of both cognitive architecture and neural network theories, and they are so commonly and widely applied that we take them for granted and presume them to be true. What are these critical but hidden assumptions upon which all traditional theories rely? Quantum theory provides a fundamentally different approach to logic, reasoning, probabilistic inference, and dynamical systems. For example, quantum logic does not follow the distributive axiom of Boolean logic; quantum probabilities do not obey the disjunctive axiom of Kolmogorov probability; quantum reasoning does not obey the principle of monotonic reasoning. It turns out that humans do not obey these restrictions either, which is why we consider a quantum approach. In addition, quantum contextuality has important and little known consequences for the development of probabilistic models of cognitive phenomena.

This tutorial will provide an exposition of the basic assumptions of classical versus quantum theories. These basic assumptions will be examined, side-by-side, in a parallel and elementary manner. We will show that quantum theory provides a unified and powerful explanation for a wide variety of paradoxes found in human cognition and decision ranging from attitude, inference, causal reasoning, judgment and decision, and memory. This tutorial introduces and trains cognitive scientists on this promising new theoretical and modeling approach.

Presenters

Peter Bruza is Professor of Information Systems at Queensland University of Technology. He is a computer scientist who is researching quantum cognition with the goal of providing a robust and comprehensive formal framework for providing user models of human information behavior. Jerome Busemeyer is Distinguished Professor of Cognitive Science at Indiana University and fellow of the Cognitive Science Society. He is author with Peter Bruza of the book *Quantum models of Cognition and Decision*. Zheng (Joyce) Wang is a Professor professor at The Ohio State University. She was Co-Editor for a special issue on quantum cognition that appeared in *Topics in Cognitive Science* (2013), Vol. 5 (4)). Peter Kvam is a post doctoral researcher at Indiana University who has published many articles on quantum cognition including in top journals such as PNAS.

Previous Tutorials and Symposia

The tutorial has been presented at the Cognitive Science meetings in Nashville (2007), Washington DC (2008), Amsterdam (2009), Sopporo (2012), Berlin (2013), Quebec City (2014), Pasadena (2015), and Philadelphia (2016) with about 30 to 50 participants each time. The ratings from participants after the tutorial were all very positive. Last year, 2017, we held a workshop on quantum cognition supported by the Estes Foundation to 60 participants at joint meeting of the the Society for Mathematical Psychology and the International Conference on Cognitive Modeling at University of Warwick, UK. Also, this tutorial follows a symposium on quantum cognition at the Cognitive Science meeting 2011 whose papers appeared as a special issue in *Topics in Cognitive Science* (2013).

Participants Background

This tutorial will introduce participants to an entirely new area and no previous experience or background with quantum theory will be assumed. ***No background in physics is required.*** In fact, except for a few simple examples to motivate the idea, little or no reference to physics will be made during main part of the tutorial. What is required is an elementary background in classical logic and probability.

Material to be Covered

1. Introduction and background (2 hours). First, we will examine major differences between classical versus quantum theories of probability. The concept of superposition is introduced and distinguished from classical probability mixtures. The important issue of measurement in classical and quantum systems will be compared and examined. We will include several dramatic empirical examples illustrating empirical violations of the classical laws of probability (e.g., conjunction, disjunction, and total probability) and the parsimonious explanation of all these violations by quantum theory.

2. Quantum dynamics (2 hours). Next, we will examine the differences between classical and quantum dynamical systems. The basic idea of Markov processes will be introduced and compared with quantum processes. A parallel development of Markov and quantum cognitive models will be shown and applied to a concrete empirical example. In doing so, we will distinguish between classical and quantum representations of a state and compare the effects of measurement on these states for Markov and quantum systems. A key goal is to show when and how quantum processes depart from Markov processes, and how we can empirically test whether a system is best represented by a Markov or quantum framework.

3. Quantum heuristics (2 hours) We introduce quantum logic and show that it addresses many of the issues arising in models based on classical logic. In particular, we will demonstrate how several fast and frugal heuristics can be reconstructed by integrating them with a quantum logic structure. As part of this, we will introduce the concepts of qubits, U-gates, and state evaluation and how they can be used to model information processing that goes on when these strategies are executed. This approach opens a number of new questions and predictions, which we address by reviewing existing literature on expertise, game theory, recognition memory, decision making under uncertainty, and the hindsight bias. The results suggest that integrating heuristics with a quantum logic structure can enhance the empirical accuracy of heuristics as well as ground quantum logic in psychological theory by giving it specific processing rules to implement.

Quantum contextuality (1 hour) Models of a probabilistic models assume that the underlying random variables, which define a measurable set of outcomes, can be defined independent of the measurement context. The phenomenon is deemed contextual when this assumption fails. Contextuality is an important issue in quantum physics.
However, there has been growing speculation that it manifests outside the quantum realm with human cognition being a particularly prominent area of investigation. This section of the tutorial aims to first deliver a conceptual understanding of contextuality as well as why it is relevant for cognitive scientists. Secondly, hypergraphs will be introduced as a flexible, underlying theoretical framework which allows experiments to modelled in modular way as well as determining whether the phenomenon being examined is contextual. The theory will be illustrated with some simple examples expressed in a probabilistic programming language which can be mapped to hypergraphs. The section will conclude with some speculation on the implications of contextuality for probabilistic modelling in cognitive science.

See the references and the website below for some of the material to be covered and relevant background material: http://mypage.iu.edu/~jbusemey/quantum/Quantum CognitionNotes.htm

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