Title

Full Day Tutorial on Quantum Models of Cognition and Decision

Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 38(0)

Authors

Trueblood, Jennifer S.
Yearsley, James M.
Kvam, Peter
et al.

Publication Date

2016

Peer reviewed

Full Day Tutorial on Quantum Models of Cognition and Decision

Jennifer S. Trueblood (jennifer.s.trueblood@vanderbilt.edu)
Department of Psychology, Vanderbilt University, Nashville, TN 37240 USA

James M. Yearsley (james.m.yearsley@vanderbilt.edu)
Department of Psychology, Vanderbilt University, Nashville, TN 37240 USA

Peter Kvam (kvam.peter@gmail.com)
Department of Psychology, Michigan State University, East Lansing, MI 48824 USA

Zheng (Joyce) Wang (wang.1243@osu.edu)
School of Communications, Center for Cognitive and Brain Sciences
The Ohio State University, Columbus, OH 43210 USA

Jerome R. Busemeyer (jbusemey@indiana.edu)
Cognitive Science, Indiana University, 1101 E. 10th Street, Bloomington, IN 47405 USA

Keywords: classical information processing; quantum information processing; logic and mathematical foundation; Bayesian probability; quantum probability; Markov and quantum processes; decision making; quantum entanglement; memory.

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 1960's was based on classical computational logic, and the connectionist/neural network movements of the 1970's 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.

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

Jennifer Trueblood is an assistant professor at Vanderbilt University. She has published many articles on the topic of quantum cognition, and her work has been funded by NSF. James Yearsley is a postdoctoral fellow at Vanderbilt University. He has a PhD in the foundations of quantum theory from Imperial College, London and worked in the Centre for Quantum Information and Foundations at the University of Cambridge. Peter Kvam is a graduate student at Michigan State who has published many articles on quantum cognition including in top journals such as PNAS. Zheng (Joyce) Wang is an associate 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)). Her work on quantum cognition has been funded by NSF and AFOSR. Jerome Busemeyer is Provost Professor of Psychological and Brain Sciences at Indiana University. He is Editor of *Decision* and Associate Editor of *Psychological Review*, and was Editor of *Journal of Mathematical Psychology*. He is also author with Peter Bruza of the book *Quantum models of Cognition and Decision*.

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), and Pasadena (2015) with about 30 to 50 participants each time. The ratings from participants after the tutorial were all very positive. 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 (1.5 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.

Then we will examine the differences between classical and quantum dynamical systems. The basic idea of a Markov processes will be introduced and compared with quantum processes. A parallel development of Markov and quantum processes will be shown using a concrete empirical example. The concept of a state will be distinguished for Markov and quantum systems. The effects of measurement on the state of the system are compared 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 Markov or quantum.

2. **Quantum logic and heuristics (1 hour).** Cues indicating the state of the world play a critical role in decision-making in both inferential and preferential tasks, and are the focus of many heuristic models of cognitive processes. In this section, we present the formal logical structure that is used by most classical information processing models, including fast and frugal heuristics. We review the structure of these heuristics and show that they make a number of implicit assumptions arising from their reliance on a classical binary logic of bits and logic gates. However, many of these assumptions are inconsistent with empirical data from decision tasks, suggesting that there is much to be gained by revising the structure of heuristic models.

As an alternative, we introduce quantum logic and show that it addresses many of the issues arising in classical logic models. We then demonstrate how several fast and frugal heuristics can be reconstructed by integrating them with a quantum logic structure, introducing qubits, U-gates, and state evaluation to model how information is processed when these strategies are executed. This approach opens up 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.

3. **Implementing Quantum Models using Bayesian Statistics (2 hours)**. In this section, we will provide hands-on experience with an easy to use computer program (JAGS) that will allow you to implement quantum models in a Bayesian framework. We will present the details of classical and quantum models of causal reasoning and illustrate how Bayesian modeling can be used to fit the models. At the end of this section you will have gained the technical skills to implement quantum models.

4. Future Directions (30 minutes). Finally, we will review progress in quantum cognition research and propose future directions.

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 Cognition Notes.htm

References

Busemeyer, J. R., & Bruza, P. D. (2012). *Quantum models of cognition and decision*. Cambridge, UK: Cambridge University Press.

Busemeyer, J. R., Pothos, E., Franco, R., & Trueblood, J. S. (2011). A quantum theoretical explanation for probability judgment 'errors.' *Psychological Review*, *118*, 193-218.

Kvam, P. D., Pleskac, T. J., Yu, S., & Busemeyer, J. R. (2015). Interference effects of choice on confidence: Quantum characteristics of evidence accumulation. *PNAS*, 112(34), 10645–10650.

Pothos, E. M., & Busemeyer, J. R. (2013). Can quantum probability provide a new direction for cognitive modeling? *Behavioral & Brain Sciences*, *36*, 255-274.

Trueblood, J. S. & Busemeyer, J. R. (2011). A Quantum probability account of order effects in inference. *Cognitive Science*, *35*, 1518-1552.

Wang, Z., Busemeyer, J. R., Atmanspacher, H., & b Pothos, E. M. (2013). The potential of using quantum theory to build models of cognition. *Topics in Cognitive Science*, *5*, 672-688.

Wang, Z., Solloway, T., Shiffrin, R. M., & Busemeyer, J. (2014). Context effects produced by question orders reveal quantum nature of human judgments. *PNAS*, *111*(26), 9431-9436.

Yearsley, J.M. and Pothos E.M. (2014). Challenging the classical notion of time in cognition: a quantum perspective. *Proc. R. Soc. B* 281, 1781, 20133056.

Acknowledgments

This tutorial is supported by U.S. National Science Foundation (SES-1153726, SES-1153846, SES-1556415, DGE-142487) and AFOSR (FA9550-15-1-0343).