Not a sure thing: comparing Bayesian and quantum models of decision making

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Introduction and Rationale

- Probability based mathematical models of cognition have been highly researched in recent years due to mathematical advances in the area of probability (Jones & Love, 2011a).
- The **rational level of analysis** concerns itself with optimizing the agent's behavior in terms of environmental demands (Anderson, 1990).
- Must identify the areas of research that deserve the most attention (Pothos & Busemeyer, 2009).

Purpose of this Study

- The purpose of the present study is to compare **Bayesian** and **quantum** models of decision making on **empirical**, **cognitive**, and **mathematical** plausibility.

Bayesian Models

- Bayesian statistics is based upon a classical probability result, known as Bayes' Rule (Griffiths et al., 2001).
- **Bayes' Rule** combines new and old information in the optimal fashion (Bowers & Davis, 2012a).
- **Bayesian Networks** are made from nodes and directed arcs (Griffiths et al., 2001).
- For every random variable in the probability distribution, there is a single node (Griffiths et al., 2001).

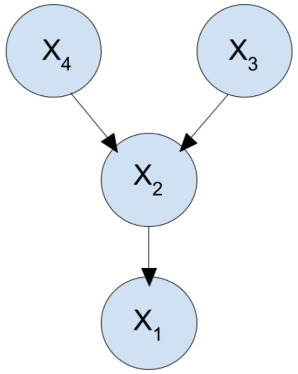

Figure 1
An example Bayesian Network

"The Sure Thing Principle"

- The "Sure Thing Principle" is a phenomenon of classical probability coined by Savage in 1954 (Pearl, 2016).
- A **Bayesian rationality postulate** (Harsanyi, 1978).
- A person has a preference for A if B and a preference for A if C. If the person has no knowledge about whether B or C is true, they should still pick A, making A a "sure thing" (Pearl, 2016).
- **Disjunction effect**: people do not behave as if A is a "sure thing" (Croson, 1999; Ellsberg, 1961; Tversky & Shafir, 1992).

Quantum Models

- Quantum probability theory encompasses classical probability (Busemeyer, 2009).
- The probability equation for an event in quantum is the same as classical probability, but with another term, called an **interference term,** attached (Khrennikova, 2012).
- ABA Effect: What is measured and the order it is measured in has an effect on the measurement outcome (Busemeyer, 2009).
- Quantum models have been **able to explain the disjunction effect** where classical probability based models have not (Moreira & Wichert, 2016; Pothos & Busemeyer, 2009).

Discussion

	Bayesian Models	Quantum Models
Cognitive Plausibility	Neglects mechanism (Jones & Love, 2011b).	Neglects mechanism (Jones & Love, 2011b).
Empirical Viability	Cannot explain disjunction effect (Moreira & Wichert, 2016; Pothos & Busemeyer, 2009).	Can explain disjunction effect (Moreira & Wichert, 2016; Pothos & Busemeyer, 2009).
Mathematical Plausibility	Less generalized (Pothos & Busemeyer, 2009).	More generalized (interference term) (Pothos & Busemeyer, 2009).

References

Anderson, J. (1990). The Adaptive Character of Thought. *Lawrence Erlbaum Associates, Inc.*

Busemeyer, J. R. (2009). Introduction to Quantum Probability for Social and Behavioral Scientists. *Quantum Interaction*. https://doi.org/10.1007/978-3-642-00834-4_1

Croson, R. T. A. (1999). The Disjunction Effect and Reason-Based Choice in Games. *Organizational Behavior and Human Decision Processes, 80*(2), 118–133. https://doi.org/10.1006/obhd.1999.2846

Ellsberg, D. (1961). Risk, Ambiguity, and the Savage Axioms. *The Quarterly Journal of Economics*, *75*(4), 643-669. https://doi.org/10.2307/1884324

Griffiths, T. L., Kemp, C., & Tenenbaum, J. B. (2001). Bayesian Models of Cognition. *The Cambridge Handbook of Computational Psychology,* 59–100. https://doi.org/10.1017/cbo9780511816772.006

Harsanyi, J. C. (1978). Bayesian Decision Theory and Utilitarian Ethics. *The American Economic Review*, *68*(2), 223–228.

Jones, M., & Love, B. C. (2011b). Bayesian Fundamentalism or Enlightenment? On the explanatory status and theoretical contributions of Bayesian models of cognition. *The Behavioral and Brain Sciences*, *34*(4), 169–231.

Khrennikova, P. (2012). Evolution of quantum-like modeling in decision making processes. *American Institute of Physics, 108-114*. https://doi.org/10.1063/1.4773122

Moreira, C., & Wichert, A. (2016). Quantum-like Bayesian networks for modeling decision making. *Frontiers in Psychology*, *7*(11).

Pearl, J. (2016). The Sure-Thing Principle. *Journal of Causal Inference, 0*(0). https://doi.org/10.1515/jci-2016-0005

Pothos, E. M., & Busemeyer, J. R. (2009). A quantum probability explanation for violations of "rational" decision theory. *Proceedings of the Royal Society B: Biological Sciences, 276(*1665), 2171–2178. https://doi.org/10.1098/rspb.2009.0121

Tversky, A., & Shafir, E. (1992). The Disjunction Effect in Choice under Uncertainty. *Psychological Science, 3*(5), 305–310. https://doi.org/10.1111/j.1467-9280.1992.tb00678.x