What's the predicted outcome? Explanatory and predictive properties of the QP framework

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Quantum probability, intuition, and human rationality

Mike Oaksford
Department of Psychological Sciences, Birkbeck College, University of London, London WC1E 7HX, United Kingdom.
mike.oaksford@bbk.ac.uk
http://www.bbk.ac.uk/psych/Staff/Academic/Oaksford

Abstract: This comment suggests that Pothos & Busmeyer (P&B) do not provide an intuitive rational foundation for quantum probability (QP) theory to parallel standard logic and classical probability (CP) theory. In particular, the intuitive foundation for standard logic, which underpins CP, is the elimination of contradictions—that is, believing p and not-p is bad. Quantum logic, which underpins QP, explicitly denies non-contradiction, which seems deeply counterintuitive for the macroscopic world about which people must reason. I propose a possible resolution in situation theory.

One of the motivations underlying the psychology of human reasoning has been the assessment of human rationality: that is, comparing human reasoning performance with some standard of rationality provided by a normative theory, be it standard bivalent logic, Bayesian probability theory, expected utility theory, or quantum probability (QP) theory (Chater & Oaksford 2012). Whether this is a proper function of psychological theories of reasoning has been debated within the pages of Behavioral & Brain Sciences (Elqayam & Evans 2011), but QP is a competitor to classical probability (CP) theory precisely at the computational, normative level. Pothos & Busmeyer (P&B) are quite explicit on this point when they observe that under a QP interpretation, the conjunction fallacy is not fallacious. This assertion makes sense only with the understanding that it conforms to the dictates of QP, considered as a normative theory of how people should reason. However, P&B do not provide an account of why, intuitively, QP is rational. Rather, in section 5, “The rational mind,” they concentrate on pointing out existing problems with the claims of CP, to provide an account of rationality.

Although as P&B observe, there are problems for existing normative theories, there are very clear underlying intuitions about why they are rational. For standard bivalent logic, the primary intuition is that contradictions are bad—that is, it is irrational to believe both p and not-p (e.g., chalk is white and chalk is not white). If one follows the laws of logic, one will never fall into contradiction, and, therefore, logic can provide a rational standard. Similarly for probability theory, the primary intuition is that making bets that one is bound to lose is bad. If one follows the laws of probability in the Kolmogorov axioms, one will never make a bet one is bound to lose, and therefore it can provide a rational standard. P&B provide no similar intuitive understanding of how QP is rational, even if this understanding is ultimately deficient in some respects, as they point out for CP. Rather, P&B observe that QP is loosely like bounded rationality, and is consistent with the isotropic and the Quinean nature of human thought.

The lack of an intuitive grasp of rationality in QP relates to the closing sentence of section 5: “For the real, noisy, confusing, ever-changing, chaotic world, QP is the only system that works in physics and, we strongly suspect, in psychology as well.” The world they describe here is actually the microscopic world of quantum events that supplies the underlying domain of QP—that is, the world whose behaviour is it trying to describe. However, the world that provides the appropriate domain for logic and CP is a relatively stable macroscopic world of which we have varying states of knowledge. Insofar as the statements of these theories describe these worlds, they provide a theory of what these statements mean. There are obvious complexities here, but one requirement of a formalism is that, in Susan Haack’s (1978) terminology, it should be capable of respecting the appropriate depraved semantics (Haack 1978, p. 188)—that is, people’s intuitive understanding of a domain.

Logic and CP, to the extent they have a rational foundation, assume a world where events cannot both occur and not occur and where there are objective values. The extent to which one might be inclined to adopt QP is the extent to which one is willing to view the macroscopic world as being much more like the microscopic world than we have so far considered, hence it can provide an appropriate depraved semantics. One might also question whether the actual world of everyday experience is the “noisy, confusing, ever-changing, chaotic” place or whether this is the product of our situatedness within in it. However we view it, one should not underestimate the magnitude of the change in the conception of the macroscopic world underlying human cognition that QP entails.

For example, in quantum logic (Haack 1974), which underpins QP in the same way that classical logic underpins CP, the law of the excluded middle, or non-contradiction (not(p and not-p)), does not hold—that is, the intuitive rational basis of classical logic is explicitly denied. Therefore, in the microscopic world, quantum events can occur and not occur. But to embrace QP is—for some events at least, that is, when questions are incompatible—to require people to reject non-contradiction for some macroscopic events, which seems deeply counterintuitive. However, this may not be quite as counterintuitive as it seems.

Although there is no scope to develop the connections here in any detail, there is a semantic account more readily compatible with QP. This account is provided by situation theory (see Barwise & Perry 1983; for a recent review, see Stojanovic 2012), in which situations—construed as something between the physical and the psychological, simplistically, the bit of world one can see that can include other people who might have a different perspective on the same situation—are the basic building blocks, and objects and regularities only emerge as uniformities against the background of the ever-changing situations in which we find ourselves. Joining such a world view with QP may provide an intuitive, rational handle on QP. For example, perspectival terms, such as “behind” (which are often assimilated to indexicals), reveal apparent breakdowns of non-contradiction. Therefore, for example, “the table is behind the sofa” may be true from my perspective in a situation, but it may be false from yours. “Perspectival relativity” is an important feature of situation semantics.

In summary, whereas one cannot help but be impressed by the empirical grasp of QP, its potential to provide an alternative rational foundation for human reasoning requires further consideration, as for some events, the failure of non-contradiction at the macroscopic level seems deeply counterintuitive. However, there are accounts of the semantics of natural language that appear compatible with QP, and those may provide a much needed intuitive foundation.

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Timothy J. Pleskac, Peter D. Kvam, and Shuli Yu
Department of Psychology, Michigan State University, East Lansing, MI 48824.
pleskact@msu.edu, kvampete@msu.edu, yushuli@msu.edu
www.msu.edu/~pleskact

Abstract: Quantum probability (QP) provides a new perspective for cognitive science. However, one must be clear about the outcome the QP model is predicting. We discuss this concern in reference to modeling the subjective probabilities given by people as opposed to modeling the choice proportions of people. These two models would appear to have different cognitive assumptions.
What is sometimes required is not more data or more refined data but a different conception of the problem.
—Roger Shepard (1987, p. 1318)

Shepard made this statement in arguing that a universal law of generalization could be had only by formulating it around stimuli existing in a psychological, not a physical, space. Only then, according to Shepard, could principles of generalization be established that were invariant to context. Pothos & Busemeyer (P&B) are making a very similar argument. They contend that the probabilistic nature of cognition may adhere not to the assumptions of classical probability (CP), but instead to the properties of quantum probability (QP).

Perhaps this is the reconceptualization that is needed. Phenomena that were errors according to CP, such as violations of the conjunction rule, order effects, and violations of the sure-thing principle, are consistent within the structural constraints of QP. Moreover, a quantum account can offer a more parsimonious explanation of the phenomena. Take, for example, the Linda problem. The typical explanation of this problem has been the representativeness heuristic in which people substitute similarity for probability (Kahneman 2003). In comparison, similarity is implicit in the QP calculation (reflected in the angle of the initial state vector relative to the bases).

The QP model of the Linda problem and other judgments of subjective probability (Busemeyer et al. 2011) are intriguing because they describe how people actually assign probabilities. However, P&B use the same QP modeling framework to describe both the process of making subjective probabilities (e.g., the Linda problem) and the process of making a choice (e.g., Clinton vs. Gore honesty choice). This failure to distinguish between subjective probabilities and choice proportions presents a concern. To illustrate, consider another version of the Linda problem that researchers have used, in which people have to identify which of two statements is more probable (e.g., the Linda problem) and the process of making a choice (e.g., Clinton vs. Gore honesty choice). This failure to distinguish between subjective probabilities and choice proportions presents a concern. To illustrate, consider another version of the Linda problem that researchers have used, in which people have to identify which of two statements is more probable (e.g., "Linda is a bank teller" or "Linda is a bank teller and is active in the feminist movement") (e.g., Tversky & Kahneman 1983). When applied to choice proportions, QP is used to predict the objective probability of choosing either statement by projecting onto a basis vector. However, in modeling subjective probabilities, the model uses the same operator; therefore, it is as if people have direct access to the probability of entering into that state. Is the same cognitive system used for these different responses? To suppose these two models are of the same class seems to be an error. To do so would be to assume that subjective ratings of probability are the same as the probability of choosing a particular response.

The distinction between modeling the probability distributions over behaviors and modeling probability judgments is important. In the Linda problem, the probability judgment response is only one of many responses in which the conjunction fallacy is observed. The primary data, for example, were in terms of ranking eight possible hypotheses in order from least to most likely (Tversky & Kahneman 1983). We also know that the extent to which people commit the conjunction fallacy changes based on the format of the response, such as with bets (Tversky & Kahneman 1983), or with frequency formats (Mellers et al. 2001). It would seem that a more complete process level account of the conjunction fallacy would explain how these different response formats (or measurements) work, and would inform any model predicting the effect.

A more general comment regarding the thesis of the article is that quantum theory can provide a “better” probabilistic framework for cognition. The flexibility of QP theory may become a concern, as skeptics might argue that it lacks specific predictions. However, many predictions may be overlooked simply because they reflect common sense or because the theory is new enough that due scrutiny has not been afforded to uncover psychological inferences from Gleason’s theorem or the Hilbert space. Take, for example, the prediction that projecting a state vector to a lower dimensional subspace will result in lost amplitude. This does appear to be consistent with the famous Korea/China asymmetry in similarity judgments (Tversky 1977), and certainly similar predictions can be made in other areas, such as comparing emotions of different dimensionality.

Perhaps the more difficult aspect is explanation. This seems tricky, as we are asked to take a different interpretation of a cognitive system under QP. For example, under a classical view, a change in the state of a system, at any given time point, is in a particular state. However, in QP we have superposition meaning a cognitive system is in no state at all! This idea would appear to change our ability to point to information as a causal mediating mechanism, as well as our understanding of the nature of mental events themselves. It also seems to change the very nature of what it means to explain cognition, as superposition seems almost uninterpretable. Hughes (1989) suggests that an explanation in terms of QP is a structural explanation. That is, it shows how the stochastic nature of cognition and its probability functions can be modeled using Hilbert spaces.

Is a structural explanation sufficient for psychologists? This concern and the larger set of issues it raises may not come as a particular surprise, as QP theory was originally designed only to predict the probability of outcomes of physical events. The challenge of modeling subjective judgments and mental processes is obviously a new challenge for QP, and, therefore, it may simply be that more work is needed to adapt the QP framework to address psychological, rather than physical, problems. Even so, we suspect that the success of QP in cognitive modeling will depend largely on its reinterpretation, reapplication, and resulting predictive power rather than its narrative explanation.

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If quantum probability = classical probability + bounded cognition; is this good, bad, or unnecessary?
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Tim Rakow
Department of Psychology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, United Kingdom.
timrakow@essex.ac.uk
http://www.essex.ac.uk/psychology/department/people/rakow.html

Abstract: Quantum probability models may supersede existing probabilistic models because they account for behaviour inconsistent with classical probability theory that are attributable to normal limitations of cognition. This intriguing position, however, may overstate weaknesses in classical probability theory by underestimating the role of current knowledge states and may under-employ available knowledge about the limitations of cognitive processes. In addition, flexibility in model specification has risks for the use of quantum probability.

The case for using quantum probability that Pothos & Busemeyer (P&B) present seems to be that quantum probability—like classical Bayesian probability—supports a probabilistic approach to cognitive modelling, but unlike classical probability—predicts behaviour consistent with the attributes of bounded cognition such as the normal limitations in memory, processing capacity, and attentional control. However, before accepting this intriguing proposal, there are questions to consider. Is classical probability theory truly inconsistent with behavioural phenomena attributable to bounded cognition? Do we need alternatives to existing models that already incorporate insights concerning bounded cognition? Are there dangers in a unified quantum probability framework that subsumes classical probability and bounded cognition?