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Comments

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Book Review: QBism: The Future of Quantum Physics by Hans Christian von Baeyer (Harvard University Press, 2016)

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I was excited to read this new book on QBism by von Baeyer because QBism is the reason I do research in quantum foundations, or, more accurately, Chris Fuchs is. Around the early 2000's, Chris appeared at almost every conference I went to, preaching the gospel of what was then called Quantum Bayesianism, now QBism[a]. As a student who wanted to delve into the meaning of quantum theory, but who had chosen to study quantum information as a more practical option, those were heady times. Here was a guy claiming to be able to solve all the mysteries of quantum theory with a simple change in how we understand quantum probabilities, i.e. as subjective Bayesian probabilities rather than relative frequencies or objective chances. As a natural skeptic, I thought that there must be something wrong with this and resolved to determine what. In the two month break between my Ph.D. and my first postdoc, I read everything that had then been written on the subject by the core Quantum Bayesians: Chris Fuchs, Rüdiger Schack and Carlton Caves. However, instead of finding problems, the more I read, the more I found that I agreed with them.

I started my first postdoc as a committed Quantum Bayesian, but my position has drifted far from QBism in the intervening years. However, this review is not about me, it is about QBism, so let me start with a brief description of what QBism is.

QBism is one of a class of neo-Copenhagen interpretations of quantum theory, which attempt to flesh out the ideas of Neils Bohr et. al. in a more modern and coherent way. The idea that the quantum state is not an intrinsic property of an individual quantum system, but rather an

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[a] QBism is a radical offshoot of Quantum Bayesianism, currently promoted by Chris Fuchs and Rüdiger Schack, without their initial collaborator Carlton Caves. One of the main differences is that QBism views absolutely everything in the quantum formalism, except perhaps Hilbert space dimension, as a description of an agent's degrees of belief. Early Quantum Bayesianism was less specific about this, only demanding that quantum states be viewed in this way, as well as anything that would entail a specific quantum state assignment, but Hamiltonians, for example, could still be objective on this view. QBism is also more explicitly perspectival than early Quantum Bayesianism.

expression of an agent's beliefs, knowledge, or information[b] about the system, is common to all of these interpretations. They are also anti-realist about the microphysical world, so we are not dealing with beliefs/knowledge/information about some underlying physical reality, but rather about what will occur when the agent interacts with the quantum system, e.g. makes a measurement.

What singles out QBism amongst these views is the idea that all probabilities, including quantum probabilities, are to be understood as subjective Bayesian probabilities, i.e. the degrees of belief of a decision making agent. Since quantum states are determined by the probabilities they assign, this implies that quantum states are also subjective, i.e. depend on an agent's beliefs rather than objective facts about the external world. QBism is also radically perspectival compared to most neo-Copenhagen views, i.e. each agent has their own private truth, based on their own experiences, and these cannot generally be combined in any consistent way to form a global, agent-independent, truth. Perspectivalism is important in the QBist treatment of the Wigner's friend experiment and the Einstein-Podolsky-Rosen (EPR) experiment, which we shall discuss shortly.

Von Baeyer's book is an attempt to describe and advocate QBism to a non-technical audience, who might know little or nothing about quantum theory. I do not think that many popular science readers have a burning desire to know about QBism, as opposed to quantum theory more generally, so its actual audience is more likely to be physicists, philosophers, and students who are already interested in the foundations of quantum theory. Nonetheless, since von Baeyer

[b] Phrases used to describe the meaning of quantum states in neo-Copenhagen interpretations include: beliefs, knowledge, information, advice, or "what we can say" about a quantum system. The commonality is that they all view the quantum state as a device used for computing probabilities, and not something that exists "out there" as a property of the system.

thinks that QBism is a revolution in physics, with widespread implications for the rest of human knowledge, the goal of describing it for a popular audience is admirable.

The book is short, succinct, and extremely readable. It could easily be consumed on a couple of plane journeys. Anyone who wants to grasp the essential points of QBism is going to have a much easier time with this book than I did with the original papers.

The book is divided into four parts: Part I on quantum theory, Part II on the foundations of probability, Part III on QBism itself, and Part IV on the worldview, or wider implications of QBism.

The first part of the book is a tour through standard topics in the foundations of quantum theory, e.g. the double-slit experiment, wave-particle duality, the uncertainty principle, collapse of the wavefunction, etc. Readers with a background in quantum theory can easily skip this section, but it is a clear and concise introduction, comparable to other recent popular treatments of these topics[1].

Part II of the book, on the foundations of probability, is the weakest part of the book. Conveying this subject accurately at a non-technical level is challenging. Von Baeyer does a good job of outlining the subjective Bayesian position itself, i.e. the definition of degrees of belief in terms of betting behavior and the use of Bayes' rule in probabilistic inference. However, the only alternative view of probability he compares this with is frequentism, i.e. probabilities are long-run relative frequencies in a series of independent trials. Von Baeyer's definition of frequentist probability is "the number of favorable outcomes […] divided by the number of possible outcomes", but this reads more like the classical Laplacian definition of probability, i.e. the probability of a dice roll coming up 4 is equal to 1/6 because there are 6 possible outcomes only one of which is 4. Reading between the lines, it is obvious he means “in a long sequence of trials”, but not stating this explicitly would be confusing for a non-technical reader who has probably not encountered formal probability theory since high school.

Further, pure frequentism is not a very widely held view amongst philosophers of probability[2]. Following Lewis[3], a much more popular view is that subjective Bayesian probabilities (usually called “credences” in this context) do indeed exist, but there are also objective probabilities (called “chances”), which are not strictly identified with relative frequencies. The idea is that, when we are making personal decisions, such as which horse to bet on in a race, we are of course using our credences, but physical theories, such as quantum theory and statistical mechanics, also supply chances, which, if we believe in those theories, constrain our credences.

The credence/chance theory offers many of the benefits that von Baeyer claims uniquely for subjective Bayesianism. For example, credences can be assigned to single-case, one-off events and, in some variants, so can chances. The use of credences allows different agents to assign different probabilities to the same event, since they may have different knowledge about the chances.

I am not particularly fond of objective chances, but I would have liked to see an argument against them, given that their existence is a mainstream opinion in the philosophy of probability. In quantum theory, most chance theorists would restrict the assignment of different credences to cases where the quantum state is a mixed density operator, and maintain that pure state assignments give objective chances. This would not allow the QBist resolution of the measurement problem to go through, so there is still an argument in favor of QBism’s pure subjective Bayesianism to be made here.

In Part III of the book, which outlines the QBist position, there is a good discussion of the QBist resolution of Schrödinger's cat and the measurement problem. Briefly, there is no contradiction in having two different quantum states describing the same experiment – they just represent the perspectives of two different agents, one who has seen the measurement outcome and one who has not.

This resolution is one of the principal benefits of QBism, but it is common to all interpretations of quantum theory that do not view quantum states as intrinsic properties of individual quantum systems. I would have liked to see more discussion of how the QBist take on this differs from other neo-Copenhagen approaches.

In particular, I think that one of the key departures of QBism from other neo-Copenhagen interpretations is its perspectivalism, which is clear from its handling of the Wigner's friend and EPR experiments. In the Wigner's friend experiment, Wigner places his friend inside a sealed box containing a spin-1/2 particle and the friend then measures the spin of the particle. Prior to opening the box, Wigner describes his friend as being in a coherent superposition of having seen both outcomes, whereas the friend describes the spin-1/2 particle with the collapsed state corresponding to the whichever outcome she has seen. In von Bayer's discussion, this is just another case where one observer has different information from another. However, from Fuchs' discussion of this experiment[4], it is clear that the QBist take on this is radically perspectival. It is not just that, according to Wigner, the friend has observed a definite outcome but Wigner just doesn't know what it is yet, but rather, for Wigner, there is no fact of the matter until he opens the box and asks his friend what she saw. The outcome is an objective truth for the friend once she sees it, but does not exist at all for Wigner until it enters his experience.

In the EPR/Bell experiment, if Bob makes a measurement on one half of an EPR pair, there is no instantaneous change of Alice's quantum state, since her state only depends on her own experience, and she has not experienced Bob's measurement outcome yet. This much is described accurately by von Baeyer. However, if there were a fact of the matter about Bob's outcome for Alice at the time Bob made the measurement, even if that fact is unknown to her, then Bell's theorem would still imply nonlocality. It is crucial that the measurement outcome does not actually come into existence for Alice until she compares notes with Bob. Only then, for Alice, can everything can be said to have happened locally along her own worldline.

Since perspectivalism is a key departure of QBism from other neo-Copenhagen interpretations, I would have liked to see it more clearly emphasized.

There are a couple of other problems with von Baeyer's treatment of nonlocality. Firstly, von Baeyer sets up the assumptions of Bell's theorem as *locality* and *realism*, and then states that the QBist position is to deny realism, quoting favorably Asher Peres' dictum, "unperformed measurements have no results".

This tactic of setting up Bell's theorem as a conflict between locality and realism is common amongst neo-Copenhagen advocates, but does not fairly represent the views of scientific realists[5]. *Realism* in von Baeyer's account is the idea that quantum observables should be assigned definite values at all times, and is justified for situations in which there are perfect correlations, such as the GHZ experiment described by von Baeyer, by appeal to the EPR criterion of reality: "If, without in any way disturbing a system, we can predict with certainty … the value of a physical quantity, then there exists an *element of reality* corresponding to that quantity." *Locality* is the idea that, even if we knew the full state of reality, we would not be able to use that information to send superluminal signals (this is called *parameter independence* in the literature).

On this way of setting things up, denying the overly strong criterion of realism is clearly an appealing way out. By denying that measurements have pre-existing results, we can save this notion of locality.

However, this is not how scientific realists usually set up the assumptions of Bell's theorem. Their notion of realism is really just that systems have some objective properties that are correlated in some way to the things that we observe – they do not have to fully determine the measurement outcomes, but may be correlated only probabilistically, nor do they have to remain undisturbed by the process of measurement. Locality is then formulated as the idea that correlations should have a causal explanation, along the lines of Reichenbach's principle of common cause[6]. This leads directly to Bell's local causality condition. On this view, locality cannot even be formulated without realism, as we need some physical properties to play the role of a common cause, screening off the correlations. So, for the realist, there is no option to save locality while denying realism – the former is dependent on the latter.

According to the realist, what the neo-Copenhagen account does is deny the need for a causal account of correlations. This is not a completely unreasonable position to take, but it should be made clear that this is what realists think is going on. Formulating the argument in the neo-Copenhagen way that von Baeyer does is something of a straw man for most realists.

Secondly, von Baeyer's discussion of the locality of Feynman diagrams is irrelevant to the issues at hand. Feynman diagrams are not literally space-time diagrams, and virtual particles can be off mass shell, so they would not respect the locality of special relativity even if they were. They are an extremely elegant and convenient way of breaking down the computations of perturbation theory into manageable pieces, but bear no relation to the QBist account of locality, which is that every experience happens for a given agent along their own world-line. Discussing these things together in a chapter on locality seems a bit muddled.

Part IV discusses speculations that various QBists have made about the ramifications of QBism for our overall worldview. This section will be much more controversial than the rest of the book, but von Baeyer is mostly just reporting what other QBists have said here, and it is interesting to see all of these views put together in one place. Here, I will describe just two of them.

Firstly, Fuchs has promoted the idea that QBism supports John Wheeler's thesis of "participatory realism". When we interact with a quantum system and observe a measurement outcome, this is to be understood as an "elementary act of observer participancy". It brings into being something that did not exist before, and would not have existed without the interaction. The most controversial part of this is that Fuchs turns the usual realist reasoning on its head, regarding the unpredictability of measurement outcomes as argument for why there must be an objective external world: "We believe in a world external to ourselves because we find ourselves getting unpredictable kicks (from the world) all the time."

Presumably, if we lived in a fantasy world of our own creation, we might always be completely certain about what would happen in our future. However, I do not see why unpredictability per se implies that the "kicks" are necessarily coming from an objective external world. In fact, this seems at odds with the subjective Bayesian view of the nature of probability, as well as with the structure of the quantum theory itself. Bruno de Finetti, one of the early proponents of subjective Bayesianism, cautioned against drawing metaphysical conclusions from uncertainty[7]:

> Probabilistic reasoning—always to be understood as subjective—merely stems from our being uncertain about something. It makes no difference whether the uncertainty relates to an unforeseeable future, or to an unnoticed past, or to a past doubtfully reported or forgotten; it may even relate to something more or less knowable (by means of a computation, a logical deduction, etc.) but for which we are not willing to make the effort; and so on.

If I can apply the same rules of probability to my uncertainty about a fixed past as to an unforeseeable future, then how does the fact that I cannot predict the outcome of a quantum measurement tell me anything about whether it is an objectively indeterministic "kick" coming from the world? In fact, quantum theory has a retrodictive formalism for making inferences about the past that is mathematically identical to the usual predictive formalism for making inferences about the future[8]. Since the probability calculus is the same for both cases, and the past is presumably fixed, I think the correct subjective Bayesian position would be that we can draw no metaphysical conclusions from quantum theory as to whether or not there are objective indeterministic "kicks" from the world. On de Finetti's view, uncertainty has no implications for metaphysics.

Secondly, von Baeyer describes a proposed QBist resolution to the "problem of the Now" due to David Mermin. In most physical theories, there is no preferred moment of time that is singled out as the present moment, or "the Now". This is certainly true of relativity, which takes place in the four dimensional arena of space-time. It is also true of most approaches to quantum theory, in which time appears as a parameter in the equations. On the other hand, "the Now" is certainly a feature of our experience, so where does it come from if not from fundamental physics? Most physicists would probably subscribe to the idea that "the Now" is not fundamental, but an emergent feature of the complex interactions that constitute a conscious agent. However, Mermin points out that, in QBism, all of physics ultimately refers to the subjective experiences of such agents, so fundamental physics actually had "the Now" built into it all along, only we did not notice it until QBism.

In my view, this argument merely passes the buck. Instead of finding "the Now" in the equations of fundamental physics, we instead have to define what we mean by a decision-making agent that is capable of having a personal "Now". For the QBist, that account cannot involve looking at the physics of agents, since that would be circular. Further, it is not at all clear that Bayesian agents have to have a well-defined "Now". In standard decision theoretic accounts of Bayesian probability, rationality requirements are indeed only applied at a single instant of time (this is called *synchronic* coherence), but some Bayesians accept rationality requirements that hold over multiple instances of time (this is called *diachronic* coherence). Diachronic arguments are necessary if you want to argue that Bayesian conditioning is the unique rational method for updating degrees of belief. In light of this, it is not obvious that a Bayesian agent has to be an entity that has experiences that are localized in time. Would the aliens in the recent film "Arrival"[9], who experience the events in space-time as a whole rather than in localized instants, be incapable of reasoning according to Bayesian probability? One could appeal to "observer participancy" to argue that it is a matter of fact that agents in our universe have a well-defined "Now", i.e. the moment where an elementary act of creation is happening. However, since the argument for participatory realism is not very strong, I think this move would be question begging.

In summary, von Baeyer presents a concise and accessible introduction to the main ideas of QBism. Readers inclined to scientific realism, such as myself, are bound to poke holes in many of the arguments. Nonetheless, I do think that neo-Copenhagen approaches are often given short shrift in studies of the foundations of quantum theory. We ought to take them more seriously given that the current alternatives involve things like explicit nonlocal influences or multiple universes. In particular, I think this book would be good supplementary reading for an introductory course on the philosophy of quantum theory for a non-technical audience, as existing accessible texts such as Albert[10] or Lewis[11] are strongly committed to scientific realism.

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[1] J. Polkinghorne, "Quantum Theory: A Very Short Introduction" (Oxford University Press, 2002). C. Orzel, "How to Teach Quantum Physics to Your Dog" (Scribner, 2009).

[2] See A. Eagle (ed.), "Philosophy of Probability: Contemporary Readings" (Routledge, 2011), D. Gillies, "Philosophical Theories of Probability" (Routledge, 2000), T. Childers, "Philosophy and Probability" (Oxford University Press, 2013) for contemporary introductions to the philosophy of probability.

[3] D. Lewis, "A subjectivist's guide to objective chance" in R. C. Jeffrey (ed.), *Studies in Inductive Logic and Probability* (University of California Press, 1980) pp. 83-132.

[4] C. A. Fuchs, "QBism, the Perimeter of Quantum Bayesianism" https://arxiv.org/abs/1003.5209 (2010).

[5] See H. Wiseman, "The Two Bell's Theorems of John Bell", *J. Phys. A: Math. Theor.* 47:424001 (2014) for an account of the two different takes on Bell's theorem described here.

[6] F. Arntzenius, "Reichenbach's Common Cause Principle", *The Stanford Encyclopedia of Philosophy* (Fall 2010 Edition), E. N. Zalta (ed.), URL = <https://plato.stanford.edu/archives/fall2010/entries/physics-Rpcc/>.

[7] B. de Finetti, *Theory of Probability* (Wiley, New York, 1974), Vol. 1, Preface pp. x–xi.

[8] M. S. Leifer and R. W. Spekkens, "Towards a formulation of quantum theory as a causally neutral theory of Bayesian inference", *Phys. Rev. A* 88:052130 (2013).

[9] *Arrival*. Denis Villeneuve. Paramount Pictures, 2106. Film.

[10] D. Z. Albert, *Quantum Mechanics and Experience*, (Harvard University Press, 1994).

[11] P. J. Lewis, *Quantum Ontology: A Guide to the Metaphysics of Quantum Mechanics* (Oxford University Press, 2016)