QBism

Rüdiger Schack
Royal Holloway, University of London

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Quantum Bayesianism (Carl Caves, Chris Fuchs, RS, PRA 2002)

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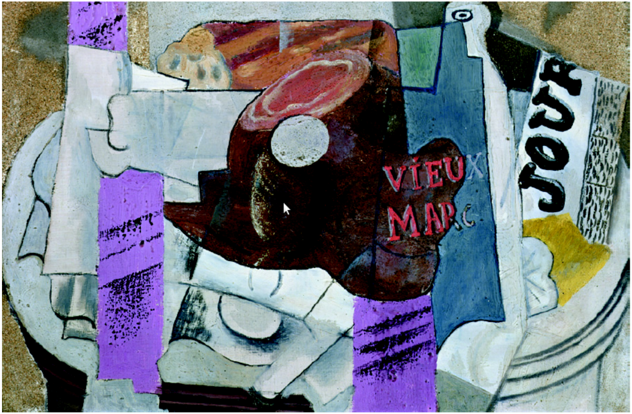
Quantum probabilities as Bayesian probabilities

Carlton M. Caves,[1,*] Christopher A. Fuchs,[1] and Rüdiger Schack[2]
[1]*Bell Labs, Lucent Technologies, 600–700 Mountain Avenue, Murray Hill, New Jersey 07974*
[2]*Department of Mathematics, Royal Holloway, University of London, Egham, Surrey TW20 0EX, United Kingdom*
(Received 15 August 2001; published 4 January 2002)

In the Bayesian approach to probability theory, probability quantifies a degree of belief for a single trial, without any *a priori* connection to limiting frequencies. In this paper, we show that, despite being prescribed by a fundamental law, probabilities for individual quantum systems can be understood within the Bayesian approach. We argue that the distinction between classical and quantum probabilities lies not in their definition, but in the nature of the information they encode. In the classical world, *maximal* information about a physical system is *complete* in the sense of providing definite answers for all possible questions that can be asked of the system. In the quantum world, *maximal information is not complete and cannot be completed*. Using this distinction, we show that any Bayesian probability assignment in quantum mechanics must have the form of the quantum probability rule, that maximal information about a quantum system leads to a unique quantum-

QBism (Chris Fuchs, arXiv 2010)

David Mermin, Nature 2014



Pablo Picasso, *Le Vieux Marc* (oil on canvas), 1912.

QBism puts the scientist back into science

Questions for quantum interpretations

- What does quantum mechanics tell us about the character of the world?
- Is there a simple physical principle underlying the quantum formalism?
- Where should we look for new physics?

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- Is there a simple physical principle underlying the quantum formalism?
- Where should we look for new physics?
- Why is there controversy?

Locality

- Locality is the idea that "an object is directly influenced only by its immediate surroundings".
- Einstein didn't "see how physical laws could be formulated and tested without [it]."
- And yet there are claims everywhere that nature is nonlocal (e.g., NYT October 21, 2015).

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NATURE | NEWS

Quantum ‘spookiness’ passes toughest test yet

Experiment plugs loopholes in previous demonstrations of 'action at a distance', against Einstein's objections — and could make data encryption safer.

Zeeya Merali

27 August 2015

Lambda

The assumption of an ontological model:

For any measurement on a physical system, the outcome probabilities are determined by the system's real properties, λ. (Harrigan and Spekkens, 2007).

(Potentially misleading alternative labels for the same idea: "hidden variables", "realism".)

No-go theorems

Einstein 1927

Assuming λ (elements of physical reality) and locality (no spooky action at a distance) implies that ψ is not in one-to-one correspondence with λ.

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Bell

Assuming λ and locality contradicts quantum mechanics.

Einstein to Schrödinger (1935, not EPR)

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"[...] the real state of (AB) consists precisely of the real state of A and the real state of B, which two states have nothing to do with one another. The real state of B thus cannot depend upon the kind of measurement I carry out on A."

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Implication, assuming locality (Caves,Fuchs,RS 2002):

$|\psi^B\rangle$ is not a function of "the real state at B", i.e., $|\psi^B\rangle$ is not a real property of the system at B.

Loophole-free Bell experiment

You have to give up either locality or λ.

Assuming you don't want to give up both, your choices are:

λ but nonlocality

(1) Probabilities are determined by real properties.
(2) Actions at A can instantaneously influence properties at B.

No λ but locality

(1) Probabilities are not determined by real properties.
(2) Actions at A cannot affect B instantaneously.

QBism rejects λ

Schrödinger to Sommerfeld (1931):

One can only help oneself through something like the following emergency decree:
Quantum mechanics forbids statements about what really exists — statements about the object. It deals only with the object-subject relation. Even though this holds, after all, for any description of nature, it evidently holds in quantum mechanics in a much more radical sense.

Heads or Tails

Tossing a “fair” coin, following *The Logic of Science* by E. T. Jaynes:

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Observation 3

Any probability assignment starts from a *prior probability*.

Personalist probability (de Finetti, Ramsey, Savage)

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- The rules of probability theory are grounded in decision theory ("how should I act").
- They have a normative character.
- They can be derived from the requirement of "no sure loss" (Dutch book coherence).

Dutch book (adapted from Wikipedia)

horse	odds offered				
1	even				
2	1:2				
3	1:3				

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horse	**odds offered**		**amount bet**		
1	even		\$120		
2	1:2		\$80		
3	1:3		\$60		
	total		\$260		

Dutch book (adapted from Wikipedia)

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Dutch book coherence

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How should I gamble?

The Dutch-book derivation results in a theory with a normative character.

Frequencies and repeated trials

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Exchangeability characterises repeated trials

For N trials,

$$\rho^{(N)} \text{ exchangeable} \Longrightarrow \rho^{(N)} = \int \rho \otimes \rho \otimes \ldots \otimes \rho \, d\rho$$

(this is the quantum de Finetti theorem)

Probabilities as degrees of belief

They are not objective, but represent an agent's personal judgments.

They are not epistemic (about knowledge), but inform action.

In QBism, quantum states are personal judgments

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- A quantum state determines probabilities through the Born rule.
- Probabilities are personal judgments of the agent who assigns them.
- HENCE: A quantum state is a personal judgment of the agent who assigns it.

In QBism, quantum states are not "epistemic"

Here is a slightly edited version of Adan Cabello's recent classification of quantum interpretations:

Type I ("intrinsic realism"): probabilities are determined by real properties

(Ia) ψ is a real property ("ψ-ontic")
(Ib) ψ represents knowledge about some real property ("ψ-epistemic")

Type II ("participatory realism"): probabilities are not determined by real properties

(IIa) ψ represents knowledge ("ψ-epistemic")
(IIb) ψ represents belief, informs action ("ψ-doxastic", QBism)

Recent no-go theorems assume Type I and **have no bearing on Type II.**

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- The Born rule provides a connection between my probabilities for the outcomes of different and in general incompatible measurements.
- The Born rule has normative character. "How should I gamble?"
- Unlike probability theory, which can be derived from Dutch book coherence arguments ("no sure loss!"), the Born rule is empirical. It is a statement about the character of the world.

What the Born rule is not

The usual view:

The Born rule, so the story goes, works as a setter of probabilities from something more firm or secure than probability itself, i.e., **the** quantum state.

The QBist point of view:

There is no such thing as **the** quantum state. A quantum state is always ultimately dependent on the agent's priors. There are as many quantum states for a system as there are agents interested in considering it.

Probability of what?

QBism: Quantum mechanics is a tool

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A measurement is an action on the world by an agent that results in the *creation* of an outcome — a new experience for that agent.

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A measurement outcome is not objective,

not a classical pointer reading, but personal to the agent who makes the measurement.

QBism vs. Copenhagen

Copenhagen interpretation:

A measurement outcome is an objective feature of the world.

QBism:

A measurement outcome is personal to the agent who experiences it.

Wigner's friend

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in a closed lab and experiences an outcome. Wigner, outside the lab, doesn't experience an outcome and writes down an entangled state.

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In QBism the paradox does not arise:

In QBism, the friend's measurement outcome is personal to the friend.

Wenn schon, denn schon

"I still do not believe that the Lord God plays dice. If he had wanted to do this, then he would have done it quite thoroughly and not stopped with a plan for his gambling: In for a penny, in for a pound. Then we wouldn't have to search for laws at all."

(Einstein to F. Reiche and wife, August 15, 1942)

Laws are deterministic vs. there are no laws

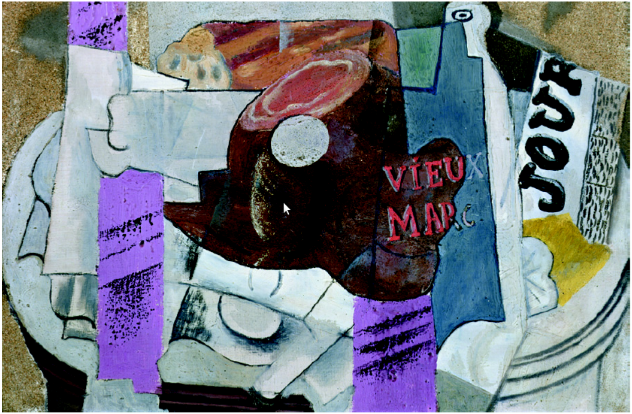
The usual reading: Einstein advocates deterministic laws.

QBist reading: there are indeed no laws.

God has done it thoroughly. There are no laws that determine objective probabilities for measurement outcomes. The world does not evolve according to a mechanism.

What God has provided, on the other hand, is tools for agents to navigate the world, to survive in the world.

Thank you



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