Title: Probabilities from Quantum States, or Quantum States from Probabilities?

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Abstract: I will consider various attempts to derive the quantum probabilities from the HIlbert space formalism within the many-worlds interpretation, and argue that they either fail, or depend on tacit probabilistic assumptions. The main problem with the project is that it is difficult to understand what the state of system X is psi even *means* without already supposing some probabilistic link to definite observed or observable phenomena involving X. I will argue it is better to conceive of quantum states as *representations* of empirically inferred probabilities for quantum processes associated with definite observable phenomena, accepting all the issues this raises concerning what exactly are to count as observable outcomes, and relatedly, what as real, as an unavoidable conundrum but also a potential source of progress in the evolution of physical theory.

Probabilities from quantum states or quantum states from probabilities?

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September, 2009 / New Perspectives on the Quantum State

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Probabilities from states and states from probabilities

Probabilities from states: Quantum states are tools used to calculate probabilities, conditional probabilities ("correlations"): if I do X, what will happen?

States from probabilities: Whatever else it may be, the quantum state of a system is a (compact) representation of the probabilities for the outcomes of possible operations we could perform on the systems. "Operationalism"... Nagging issue of systems we can't/won't experiment on... extrapolation via Gedankenexperiments?

Idealized idea: by repeated experiments, infer probabilities for various preparation/measurement-outcome sequences. Discover that quantum states represent these efficiently and accurately.

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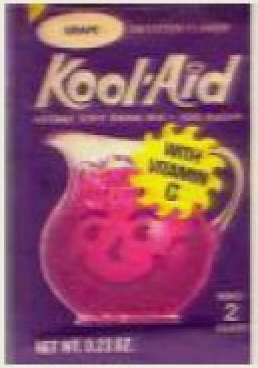
A few asides...

- In reality, quantum states first arose to explain *energy spectrum* of e.g. hydrogen. What might this mean for foundations?

  - I view probabilities that occur in empirical theories as ultimately—whatever else they may be—guides to action. They determine "betting odds", if you like. Personalist Bayesian/Richard Jeffreysian view is just fine with me.



Two kinds of "empirical additions to Bayesian coherence"

1) Math-y: "Quantum probability," passing from the *general* notion that **probabilities** for the outcomes of alternative possible courses of action should govern our actions in situations where we care about the outcomes (e.g. an abstract formulation of theories in terms of states and dual effects, such as Hardy's), to the *much more specific* state/effect structure of states as Hilbert space density matrices, and effects as POVM element.

2) Meaty: "Quantum mechanics", "quantum physics" which adds to this forces, partices, fields, orthonormal bases with physically significant labels, interaction Hamiltonians....

Observables, symmetries, preferred tensor factorizations, specific structures for interaction Hamiltonians help make the transition between these.

Quantum states as representations of probabilities

What if we commit ourselves to no more than this in our view of the quantum state? Is the quantum state perfectly analogous to a classical probability distribution, so that it is not to be conceived of as a fundamental *physical* entity? As *real*? Need it be viewed as a property of, the system whose state it is? Is it localized there? (What would that mean?)

Where I may differ from Chris Fuchs, Rüdiger Schack:

Are quantum states subjective? In the sense of "personalist Bayesian *judgments*", yes. But it is a personalist judgment that the Sun will rise tomorrow.

In the sense in which the fact that the Sun will rise tomorrow is an *objective fact* of physical and astronomical science and perhaps other general human knowledge, I'd grant objectivity to some quantum probabilities.

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Quantum probabilities can be "objective"

Send a well-heralded photon through a polarizing beamsplitter and do high-efficiency photodetection at one output. When the photon passes without a count, *quantum physics* plus general background knowledge determines the probabilities of counts at the outputs of a second photodetector, perhaps differently oriented, placed after the free output of the first—i.e. the state of the polarization degree of freedom.

Argue against this because a quantum analysis of the apparatus is needed? We don't need a full quantum analysis of something to tell us it's a polarizing beamsplittter, though it is nice that it jives with a more everyday story. Somewhat as we don't need neuroscience to (usually) trust in our perceptions, except that "polarizing beamsplitter" is more theory-laden than many terms used in reporting perceptions. Can do statistics, starting from an exchangeable prior for repeated use of the beamsplitter that's not necessarily based on quantum theory.

Elements of reality?

Sometimes it is an objective fact, in light of quantum physics and other knowledge, what the probabilities of certain measurement outcomes would be should we make the relevant measurement. Does that make these probabilities *elements of reality*?

EPR said "yes", at least in the case when a measurement outcome will give probability 1.

I say probabilities can be objective without being elements of reality.

Quantum theory *recommends—or insists on* certain constraints on decisionmaking, in some particular situations in which an agent knows a certain measurement will be performed (or measurement-like situation will arise), and has particular background knowledge.

Quantum state as law-like?

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Is EPR a problem?

In the case of probability 1, one might say this fact about how one should bet describes a *dispositional property* of the system—it is disposed to give a certain outcome, if a particular measurement is performed. Is it **real**? Is it **at the system**?

Should EPR bother us? Instantaneous change of a state of knowledge needn't bother us. Instantaneous communication would bother us. But this doesn't permit it.

The fact about how Alice should bet is not a fact about *how things are at Bob's site*. It's not reasonable to say that quantum theory recommends that Bob should immediately change his betting behavior to the one it recommends for Alice. (Though I suppose it does claim that he'd be better off if he did.)

The theory is about how one should act *if one knows certain things*.

States are for agents, in this version, too.

The determinants of states can be “unproblematic”, macro-facts. E.g. in EPR, Alice’s measurement results, even if relativistic causality prevents them being known to Bob for awhile.

Instrumentalism about the state?

It's certainly a useful instrument even if it isn't real.

It can be an *objective fact* which instrument is useful in a given situation.

The fact that a certain instrument is right to use in a given situation tells us something about how things really are in that situation.

But, maybe more facts than we think about reality are of this nature—enough so that we'll want to call $|\psi\rangle$ real after all?.

"That's a table in front of me" vs. "reality is such that I'm well-advised to use the concept of table, with all the predictive (it will support things) and retrodictive (somebody made it) baggage it brings along, in dealing with this particular situation." Not much difference, is there? Words as tools (Wittgenstein (for Dummies?)). Facts are stated using words. To state a fact is to use a tool?

Importance of counterfactuals

Could the counterfactual (dispositional) nature of the property "will yield spin up in a measurement of σ_x" save it from being real?

But one might argue all, or many, concepts involve such dispositional aspects. Does the notion of reality *require* some counterfactual? Does it necessarily describe agents who manipulate, interact. (Hacking (about entities): "if you can spray them, they are real". (But—is sprayability real?))

Agent relativity

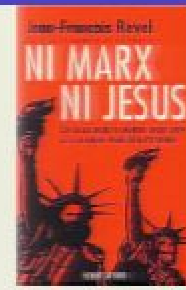
Fuchs (?): State is relative to specification of an agent and system. When I do an experiment on X, X has a wavefunction for me (or I have one for it).

On an more objective-probabilities view: quantum theory sometimes tells me what my wavefunction should be. Still advice for a certain agent, contemplating a certain thing "as quantum".

...At this point it's not clear—and perhaps a matter of taste—whether the state is real in some situations. So...

Ni Bohm ni Everett

What if we take $|\rho\rangle$ as a *nonlocalized, but real* entity?



Still not Everettian, becuase measurement results also real “beables”.

So, Bohmian? No, no deterministic dynamics for these “beables”.

Closer to objective collapse? Taking outcomes as real limits the scope of the superposition principle.

Ironic that Bell advocated choosing position as a beable for de Broglie-Bohm style theories on the grounds that “all measurements are ultimately measurements of position”. Isn’t this basing a fundamental theoretical choice on a vague notion? Don’t our eyes measure photons’ momentum? (Is the position beable really measured in the de Broglie-Bohm theory, anyway?)

Crucial issues for such a view (even without ontic ρ)

1) Are we happy with measurement outcomes as beables? Bell: no, it's too vague and ill-defined a notion.

2) Closely related (?): What sorts of things can count as agents, what as systems? Again, John Bell: the problem is perhaps with measurement as an unanalyzed primitive. Response may be "you can analyze it if you want, by taking measurement device as quantum".

3) Compatibility issues between "measurement outcomes are a primitive notion," and such analysis? Wigner's friend. In EPR, if Bob knows Alice has measured, I want her to describe Alice has having a definite but unknown outcome.

In what kinds of situations is a given system—or aspect of a system (subalgebra? information-preserving structure?)—quantum for an agent? When both agent and system are small parts of the world?

The relational attitude

Can relationalism guide us here? Give a co-ordinated, consistent picture of perspectives and how they fit together?

What do the correlations mean? Do we need a reference-frame to tell us? Just having an observer/observed cut gives us large and small things. Amount of correlation they can have limited by the size of the small thing.

All measurements, states not created equal

Special status of x and p. Relation to classicality, canonical quantization. Symmetries. (Meaty stuff.)

It took quantum computation to give us an idea how we might do arbitrary measurements on two qubits—and to drive home that most of them are impracticable.

Most quantum states cannot be prepared. Smoke that in your—operationalist or realist—pipe.

What counts as quantum?

To contemplate a thing "as quantum" is to envision the possibility of doing different experiments on it?

But things in the past can also be contemplated "as quantum"—and not in a merely imaginative sense of "contemplation". But I think this can worked out (alternative retrodiction experiments?).

Serious issues with the idea that one can take certain things as quantum. Wavefunction of the universe in the sense of *everything*—what interference experiments does that describe?

This is why I am not a many-worldsian—I don't believe you can do interference experiments relevant to the supposed entangled superposition I am in after I look at the dial on the apparatus of my quantum experiment. Not in practice; not in principle.

Relationalist accounts of effective "fundamental decoherence".

How is a macroscopic superposition state different from a dinosaur?

How is a many-worlds-type entangled state like

$$\left|\begin{matrix}\text{Me seeing a click}\\ \text{in the top counter}\end{matrix}\right\rangle \left|\begin{matrix}\text{vertically polarized photon}\\ \text{and some state of rest of universe}\end{matrix}\right\rangle$$
$$+\left|\begin{matrix}\text{Me seeing a click}\\ \text{in the bottom counter}\end{matrix}\right\rangle \left|\begin{matrix}\text{horizontally polarized photon}\\ \text{and some other state of rest of universe}\end{matrix}\right\rangle$$

different from a dinosaur?

Both extend our use of notions and concepts to a less directly observable domain. This is a normal thing for a scientific theory to do.

But theories have been known to become less accurate when applied in a new, untried regime.

How is a macro superposition different from a dino II: Regime creep

(a) the new regime is more drastically different in the case of the macroscopic superposition. A better analogy might be cosmological time scale.

(b) we have dinosaur footprints; we haven't observed, and may not have the means to observe, interference (Deutsch's "shadows") between distinct conscious states (or other complex macro-configurations). Need for isolation. Difficulty of building a quantum computer.

Serious analysis of what would be involved in observing such interference would be valuable. (Lloyd?) Impossible FAPP shading to impossible in principle (relationalism again)?

Worth revisiting in the light of quantum information/computation.

Key issue isn't whether "Dr. Science" could use his isolation tank to do an interference experiment on a human being.

Whether or not that's possible, *we* are not in that position.

Thinking about how difficult it is for Dr. Science to do it may help us explain why it's not in principle doable for the superpositions described in the many-worlds account of quantum measurement.

"In principle" has some force. Thought-experiments not completely irrelevant. Part of the meaning of "Dinosaurs existed". "If we had been there, we would have seen...".

Why is imagining seeing dinosaurs more legit than imagining doing an interference experiment on the universe?

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