Philosophy of Quantum Mechanics: Week 10

Probabilities in Everett

How to make sense of probabilities in Everett? There are two worries here:

1. *The incoherence problem*: Unitary quantum mechanics is deterministic, so it's not clear that it even makes sense to talk about probabilities in this context.
2. *The quantitative problem*: Why are probabilities of Everettian branches given by the Born rule? (I.e., why should probabilities in Everett be associated with the modulus-square of the branch amplitudes?)

To see how serious these challenges are, consider the fact that *all* of our evidence for quantum mechanics is probabilistic in nature:

- Half-lives for radioactive substances.
- Decay times for various particles.
- Probabilistic results of e.g. Stern-Gerlach experiments (to measure e.g. electron spin).

If either the very concept of probability is inapplicable in Everett, or there is no reason to treat the modus-squared branch amplitudes as probabilities in this interpretation, then we don't have good reason to accept Everett in the first place!

The Incoherence Problem

One response that the Everettian may offer against the incoherence problem is the following: "No one, in classical physics, or in alternative solutions to the measurement problem of quantum mechanics, provides a well worked-out account of probability. So, Everettians must not automatically be held to higher standards."

Clearly though, this doesn't solve the problem in itself! Three possible Everettian solutions to the incoherence problem are the following:

1. *Subjective uncertainty*: Argue that there *do* exist probabilities in Everett, because the correct attitude of an agent in a branching universe is uncertainty. (Saunders, and earlier Wallace.)
2. *Objective determinism*: Bite the bullet, i.e. accept that there's nothing quite like probability in Everettian quantum mechanics, and that my attitude to branching shouldn't be quite like other credence situations, but argue that I should care about my Everettian 'descendants', and that a 'caring measure' looks a lot like probability. (Greaves.)
3. *Bare functionalism*: Insist that probability is functionally defined, and that we don't need to meet the challenge of dealing with the incoherence problem before addressing the quantitative problem. (Later Wallace.)

Subjective uncertainty

Suppose that we know we live in an Everettian universe, and we're about to open a Schrödinger cat box. Should we feel uncertain about what we'll see? One way to think about this is as a question of *semantics*. In order to feel uncertain, we should assent to:

(A) "X might happen" is true iff X happens on some branch.

However, we had better not assent to:

(B) "X will happen" is true iff X happens on some branch.

One way to defend these semantics is to think of the splitting case as one with *two* agents, whose futures diverge. We can think of the relevant uncertainty as a kind of *self-locating uncertainty*: until we look into the box, we don't know which of the two agents we are. (For more, see Wallace, *The Emergent Multiverse*, ch. 7.)

Objective determinism

Some Everettians have argued that the correctly-informed Everettian agent should not, in fact, be uncertain as to what's going to happen. But nonetheless, when she is making decisions, she will have to use some measure to weight future branches. Greaves calls this a 'caring measure'. We can show that this measure plays the right kind of role in decision theory (via our response to the quantitative measure), and that is enough.

Bare functionalism

The later Wallace (see e.g. *The Emergent Multiverse*, chs. 4-6) takes a *functionalist* approach to the definition of objective probabilities. If the Everettian can identify something in the formalism of unitary quantum mechanics which plays the *functional* role of objective probabilities, then (the claim goes) the incoherence problem is solved. (See below for how this story goes!)

The Quantitative Problem

None of the above responses to the incoherence problem seem *obviously* flawed. So, let's return to the quantitative problem. Why think that branch amplitudes have anything to do with probabilities? Here are some possible Everettian strategies for dealing with the quantitative problem:

1. World-counting.
2. Make the Born rule a basic postulate.
3. Wallace-style decision theory.

World counting

Proposal: Probabilities proportional to the number of branches.[1] But here are some worries:

- If we allow irrational probabilities, we'll need an infinite number of worlds. (Question: How problematic actually is this?)
- Does not obviously cohere with the decoherence-based splitting story. (According to which "How many worlds?" is not a well-defined question.)
- Implicitly assumes that every world is equally likely, and this might itself need to be justified.

The Born rule as a basic postulate

This option is not usually considered to be attractive:

- May undermine the Everettian's claim to be doing bare realist quantum mechanics.
- Can't be used to support responses to the incoherence problem.

The decision-theoretic strategy

Since it's such a hot topic, it's worth considering this third approach to the quantitative problem in more detail. To see how it proceeds, first recall some details of Lewis' *Principal Principle*.

The Principal Principle

The connection between objective and subjective probabilities is typically taken to proceed via the *principal principle*, due to David Lewis. Here's how Saunders puts it: (*Many Worlds?*, intro.)

[1] Orla in the 4pm class raised this suggestion back in week 8.

PP: Let S be the statement that the objective probability of event E at time t is P, and suppose our background knowledge K is 'admissible' (i.e. it excludes information as to whether or not E happened): then our subjective probability of E, conditional on S and K, should be P.

Put simply, **PP** states that one should set one's subjective probabilities equal to whatever one has the best evidence to believe are the objective probabilities in nature.

Some (including the later Wallace) think that **PP** gives a kind of functional *definition* of objective probabilities—objective probabilities are those structures in the world to which rational agents *should* strive to match their subjective probabilities.

Everettian functionalist reasoning

- Deutsch and Wallace address the problem of how to connect an agent's decision-theoretic preferences (i.e. her subjective probabilities) to the quantum state by specifying a set of decision-theoretic axioms, from which they derive that an agent who believes that Everettian quantum mechanics is true and that the quantum state of the system in question is $|\psi\rangle$ *must* align her subjective probabilities in accordance with the Born rule. This is now known as the *Deutsch-Wallace theorem*.
- Given this, it seems that Everettian branch weights (i.e., the amplitudes associated with Everettian branches) play the *functional* role of object probabilities, as defined by **PP**. Wallace claims, therefore, that Everettian branch weights *just are* objective probabilities.

Here are two worries/questions regarding Wallace's approach:

(a) Quantum mechanics was *constructed* on the basis of certain statistical evidence. The laws of quantum mechanics are a codification of that evidence. Surely, then, it *just is* rational to bet in accordance with the Born rule, insofar as one is betting in accordance with past evidence. So is the Deutsch-Wallace decision-theoretic machinery overkill?

(b) Insofar as we buy into the mantra that 'observed statistics trump symmetry arguments', would the Deutsch-Wallace machinery only be of practical value if we had *no* past statistical evidence to go on?