Parallel Universes: A New Many-Worlds Interpretation of Quantum Mechanics

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Terminology

- The *wavefunction* is a physical field whose dynamics are given by the *Schrödinger equation*; these dynamics are deterministic.
- As time passes, the wavefunction *decoheres* into increasingly many superposed components with negligible interactions. It is standard to depict this process as a kind of branching.
- A *path* is a way of traversing this branching structure, going one way or the other at every fork in the road, as it were. We can think of a path as a script for how a universe could evolve.
- A *branch* at time t is an equivalence class of paths, under the relation of not yet having decohered from each other by time t (i.e., they've so far taken the same turns at every fork).
- A branch's *weight* is the square of its quantum amplitude. This physical quantity is conserved as the wavefunction branches, such that weights satisfy the axioms of the probability calculus: they correspond to a probability measure over the set of paths.
- A *universe* is a maximally causally interconnected collection of concrete objects. Our universe contains you, me, Earth, etc.
- An *(initially possible) world* is a way that concrete reality could have unfolded given the wavefunction's actual evolution.
- The *Principal Principle* says that our subjective probability in p, conditional on p having objective chance x, should be x.
- The *Born Rule* is physicists' recipe for assigning probabilities to observable outcomes of quantum measurements. In essence, their subjective probabilities 'defer' to the branch weights in precisely the way that the Principal Principle says subjective probabilities ought to defer to the objective chances.

Parallel Universes: the basic idea

- The fundamental physical state of the world is exhausted by the wavefunction (*pace* hidden variable theories); its dynamics are exhausted by the Schrödinger equation (*pace* collapse theories).
- Quantum probabilities are objective chances. (So the Born Rule is an application of the Principal Principle.)
- Therefore, the fundamental physical goings on fail to settle the outcomes of quantum measurements.
- But we needn't reject *physicalism*, understood as the claim that the fundamental physical goings on necessitate the overall *qualitative* structure of concrete reality.

  (Note: This requires accepting *haecceitism*, the view that distinct possibilities can agree on all qualitative facts while differing over which individuals play which qualitative roles.)
- Example: It is a matter of chance whether Schrödinger's cat lives or dies, depending on which path our universe takes. But suppose ours is just one of infinitely many parallel universes. For each universe, the chance of it branching one way or the other is given by the branch weights. The overall qualitative structure of concrete reality is settled by the dynamics of the wavefunction: *every path is guaranteed to be taken by infinitely many universes, and there is no indeterminacy in how many cats will live and how many will die (infinitely many of both).*
  - Why not just one universe? To respect physicalism.

    Compare *magical phenomenal solipsism*, a view that (i) agrees with ordinary physicalist views about which physical profiles are compossible with being conscious, but (ii) holds that, necessarily, only one thing is conscious; so (iii) whether there is ever a conscious philosopher doesn't supervene on the physical history of the world. This view is clearly not compatible with physicalism.
  - Why multiple universes per path? Again, physicalism.

    To illustrate: suppose the wavefunction only branched once, into a live-cat branch with weight .6 and a dead-cat branch with weight .4, with one cat per branch. If each cat had .6 chance of surviving, then both cats surviving had a positive chance; so how many cats survive wouldn't supervene on the physical history of the world.

Parallel universes, more formally

We assume (i) a time-indexed equivalence relation $\sim_t$ on paths saying that two paths are on the same branch at t, and (ii) a probability measure P over sets of paths corresponding to the branch weights.

All indeterminism arises from indeterminism in which universes follow which paths, subject to the constraint that each path is taken by countably infinitely many universes. So we may represent the set W of initially possible worlds using the set of functions mapping countably infinitely many universes to each path: i.e., where Π is the set of all paths and U is the set of all universes:

$$W = \{w \in \Pi^U : |\{u : w(u) = \pi\}| = \aleph_0 \text{ for all } \pi \in \Pi\}.$$

Whereas P is a probability distribution over *events* (sets of paths), the *chances* $C_{w,t}$ (at a given time t in a given world w) are defined on subsets of W, which we call *propositions*. Let $u \mapsto X$ abbreviate the *proposition that u follows a path in X* – i.e., $\{w : w(u) \in X\}$. Let $\beta_{u,t,w}$ abbreviate the *branch that u is on at time t in world w* – i.e., $\{\pi : \pi \sim_t w(u)\}$. The chances obey two constraints:

1. The current chance that event X will occur in universe $u =$ the proportion of paths in u's current branch which are X-paths.

   $$C_{w,t}(u \mapsto X) = P(X|\beta_{u,t,w})$$

2. Each universe's fate is probabilistically independent of all other universes' fates.

   $$C_{w,t}(u \mapsto X) = C_{w,t}(u \mapsto X|\textstyle\bigcap_i (u_i \mapsto X_i))$$
   provided $u \neq u_i$ for all i, and $C_{w,t}(\bigcap_i (u_i \mapsto X_i)) \neq 0$

We define $C_{w,t}$ to be the minimal probability measure satisfying these two constraints.[1]

If we restrict our attention to propositions about the fate of our own universe, then the current chance (at t_1) of a given event X occurring is equal to its prior chance (at t_0) of occurring conditional on our universe ending up on its current branch: $C_{w,t_1}(u \mapsto X) = C_{w,t_0}(u \mapsto X|\beta_{u,t_1,w})$. This is because $\pi_1 \sim_{t_1} \pi_2$ implies $\pi_1 \sim_{t_0} \pi_2$ for times t_1 after t_0 (since decoherence is monotonic).

[1] That is, $C_{w,t}$ is defined on the smallest σ-algebra over W which includes every proposition of the form $u' \mapsto \beta_{u,t,w}$. There is a unique probability measure on this algebra that satisfies the above two constraints.

Comparison with Everettian many-worlds interpretations

- The Everett interpretation is naturally understood as follows:[2]
  1. There is only one universe per path.
  2. Everything supervenes on the state of the wavefunction.
  3. The wavefunction evolves deterministically.
  4. Therefore, there is no indeterminism in what happens.
  5. So the Born Rule (and hence the rational basis for taking our observations to support quantum mechanics in the first place) does not follow from the Principal Principle, and must receive some other justification.
- The most severe criticisms of the Everett interpretation have focused on whether it can rise to the challenge of justifying the Born Rule; but see Wallace (2012), Sebens and Carroll (2018).
- Yet 1 and 2 already amount to a strange form of essentialism. Despite having microphysically identical histories, the two cats Fortunate and Tragic differ in their essential properties: the wavefunction's actual dynamics *necessitate* that it is Fortunate who survives and Tragic who dies!
- Notice that to reject such essentialism is simply to embrace contingency in which individuals play which qualitative roles. Having done so, and having already signed up for an enormous number of parallel universes, why not add a few more universes, assign objective chances to the contingencies in question, and thereby solve (this part of) the measurement problem?

References

David Albert and Barry Loewer. Interpreting the many worlds interpretation. *Synthese*, 77(2):195–213, 1988.

Charles Sebens and Sean Carroll. Self-locating uncertainty and the origin of probability in Everettian quantum mechanics. *British Journal for the Philosophy of Science*, 69(1):25–74, 2018.

David Wallace. *The Emergent Multiverse: Quantum Theory According to the Everett Interpretation*. Oxford University Press, 2012.

[2] I'm setting aside views where, e.g., cats are both alive and dead, or where branching causes cats to go out of existence, to be immediately replaced by a different descendant cat on each branch (by analogy with amoeba splitting).