IPP-QM-8: Everettian probability

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The course

1. Basic quantum formalism
2. Density operators and entanglement
3. Decoherence
4. The measurement problem
5. Dynamical collapse theories
6. Bohmian mechanics
7. Everettian structure
8. Everettian probability
9. EPR and Bell's theorem
10. The Bell-CHSH inequalities and possible responses
11. Contextuality
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14. Pragmatism and QBism
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Today

Probability primer

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The incoherence problem

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Two breeds of probability

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Goal: try to understand what objective probabilities could be.

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There's nothing stopping us from having some very odd degrees of belief, but there are plausibly some rules:

- Degrees of belief should fall between 0 and 1.
- And if we'd like to be *rational*, then they'll be a whole lot more constrained.

The Kolmogorov axioms

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1. Probabilities must lie between 0 and 1.
2. If an event p is certain to occur, its probability is 1.
3. Incompatible events satisfy $\Pr(p \text{ or } q) = \Pr(p) + \Pr(p)$.

Dutch books

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- Then I ought to be willing to bet 60p on *p* and 60p on not-*p*.
- If I place both bets, then I will always lose money: whatever happens, I'll pay out £1.20 and win £1.

The Principal Principle

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> **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.

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- Some (e.g. Wallace (2012)) think that **PP** gives a functional *definition* of chance—chances by definition are those structures in the world to which rational agents *should* strive to match their credences.
- The idea of treating **PP** as a functional definition of objective probabilities will be highly relevant in the context of Everett; I'll come back to this later.

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1. Frequentism.
2. Propensity analyses.

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(See (Hájek 2023) for more.)

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- By appealing to a *hypothetical* infinity of runs of some experiment, infinite frequentism decouples itself from empiricism.
- Basic analysis says that infinite frequencies are often ill-defined. (What's the frequency of odd numbers in the rational numbers?)

The Law of Large Numbers

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> *It is well known that the relative frequency of sixes on an (indestructible!) fair die is not* certain *to tend towards* $1/6$ *as the number of throws tends to infinity. The best that can be proven is that the* probability *of the relative frequency diverging by any given amount from* $1/6$ *tends to zero as the number of throws tends to infinity. (This is one form of the Law of Large Numbers) [...] If we are using relative frequencies to* measure *probability, this is reassuring: the more repetitions of the experiment that we perform, the less likely it is that the probabilities are not accurately measured by the relative frequencies. If we are using relative frequency to* define *probability, on the other hand, it is disastrous: if probability* is *limiting frequency, what can it possibly mean to say that the long-run relative frequency approaches the probability with high frequency?* (Wallace 2012, p. 123)

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- (Cf. appeals to spacetime in the dynamics/geometry debate on the SR side of IPP.)

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Does it explain what objective probability is, or does it explain it away? If there are chances out there in the world, they are the 'branch weights'. Most who take the Everett interpretation seriously are agreed on this much: there is branching structure to the wave-function, and there are the (squared) amplitudes of those branches, the branch weights. The branches are 'worlds'—provisionally, worlds at some time. It offers a picture of a branching tree, on one branch of which we are located, where branches never recombine. But whether these weights should be called chances or probabilities is another matter. For some, even among its defenders, it is a disappearance theory of chance; there are no physical chances, probability only lives on as implicit in the preferences of rational agents, or as a 'caring measure' over branches, or in theory-confirmation; probability has no place in the physics itself. (Saunders 2021)

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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?)

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

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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.*

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One will find this line a lot in (Wallace 2012). Clearly though, this doesn't solve the problem in itself!

Three approaches to the incoherence problem

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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.)

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3. *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.)

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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 2012, ch. 7).)

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- But nonetheless, when they are making decisions, they will have to use some measure to weight future branches.
- Greaves (2007) 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; to be discussed shortly!), and that is enough.

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- Here, as alluded to above, **PP** is going to be treated as a functional definition of objective probabilities.

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1. Branch counting.
2. Make the Born rule a basic postulate. ('Born rule primitivism'.)
3. Deutsch-Wallace-style decision theory.

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- Does not obviously cohere with the decoherence-based splitting story. (According to which 'How many worlds?' is not a well-defined question—recall Lecture 3.)
- Implicitly assumes that every world is equally likely, and this might itself need to be justified.

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- But: (a) what are these microstates?; (b) can Saunders really be offering an analysis of Everettian probability, if he assumes equiprobability of the microstates to begin with? What underwrites that assumption? Etc.
- These proposals are interesting but call for careful thinking through.

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- Can't be used to support responses to the incoherence problem.

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- (For more on the formal aspects of these results, see (Wallace 2012, chs. 4–6) and (Mandolesi 2018, 2019).)

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1. Redundancy?
2. Lack of mechanistic explanation?
3. Implausible inputs?
4. Relation to choice in a branching setting?

Worry 1: redundancy?

One worry about the decision-theoretic approach, considered by Dawid & Thébault (2014), Read (2018), and Brown & Ben Porath (2020), is that the Deutsch-Wallace result is *redundant*. Here's how such a worry might go:

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March (2024) resists this, arguing that the Deutsch–Wallace result makes the Born rule a *prediction* of Everettian quantum mechanics.

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- This seems like a mechanistic, physical explanation of these statistics.
- The decision-theoretic Everettian account is nothing like this—it has, rather, to do with the behaviour of idealised rational Everettian agents.
- So how to explain the probabilistic outcomes of QM experiments? Is something lacking?

Worry 3: implausible inputs?

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- Wallace (2012, §5.8) demonstrates *in extenso* that these alternative inputs into the proof are indeed disallowed on pain of irrationality (in this particular case, Albert's proposal violates an axiom called 'diachronic consistency').

Worry 4: relation to choice in a branching setting?

Maudlin (2019, p. 191) worries that

> *even granting the theorem, it has not been shown that accepting the Everettian picture should not radically alter one's understanding of what choosing is and what the consequences of one's choices might be. In that sense, one has not recovered the standard Quantum Recipe.*

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What to make of this? Is it begging the question?

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Over the course of the next four lectures, we'll be looking at various important no-go theorems on hidden variable theories in the foundations of quantum mechanics.

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