IPP-QM-7: Everettian structure

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MT24

The course

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2. Density operators and entanglement
3. Decoherence
4. The measurement problem
5. Dynamical collapse theories
6. Bohmian mechanics
7. Everettian structure
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Today

Everett introduced

The preferred basis problem

Functionalism and emergence

Objections to Everettian structure

Next steps

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Bell's dichotomy reprise

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Modern Everettians contend that this is a false dichotomy. As Wallace writes:

> *We have indeed seen that states like* $|\psi\rangle$*—a superposition of states representing macroscopically different objects—are generic in unitary quantum mechanics, but it is actually a* non sequitur *to go from this to the claim that macroscopic objects are in indefinite states.* (Wallace 2012, p. 4)

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- They seek to *endow the formalism of unitary quantum mechanics with a realist interpretation, without modification or supplementation*.

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- Now, with work by Deutsch, Saunders, Wallace, Greaves, and others, it is a serious and mainstream approach to quantum mechanics.

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This is closely related to the above-mentioned *preferred basis problem*, which I'll now introduce.

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- What, then, in the structure of the quantum state alone can pick out one basis decomposition over another?
- This seems to be necessary for the Everettian to say that there are so-and-so many worlds (or even any worlds at all)—because (obviously) the number of *terms* in a superposition can change under a change-of-basis.

DeWitt on the preferred basis problem

Decompositions [...] are not to be regarded as meaningful if they are merely abstract mathematical exercises in Hilbert space. Indeed such mathematical decompositions can be performed in an infinity of ways. Only those decompositions are meaningful which reflect the behavior of a concrete dynamical system. (DeWitt 1971, p. 210)

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How do we make good on the final sentence here?

Old many worlds (DeWitt, Graham, Deutsch)

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- The universe branches in a particular way.
- There is, in effect, *extra structure* to the universe than just the wavefunction and Schrödinger evolution.
- This extra structure determines the basis in which quantum events occur.
- But: if you have to postulate extra structure, what advantage does this have over (single world) hidden variable theories?

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- Rather, macroscopic objects emerge from large scale decoherent processes.
- The preferred basis problem, indeed, is *solved by decoherence*.
- Let's see how this goes...

Decoherence and the preferred basis problem

Recall from Lecture 3 that the evolution of (the reduced density matrix of) some subsystem under decoherence can be modelled as:

$$\rho_0 = \begin{pmatrix} |\alpha|^2 & \alpha\beta^* \\ \alpha^*\beta & |\beta|^2 \end{pmatrix} \longrightarrow \rho_+ \approx \begin{pmatrix} |\alpha|^2 & 0 \\ 0 & |\beta|^2 \end{pmatrix}.$$

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We saw in Lecture 3 that often (but not always) this will be the position basis.

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- By now, the consensus is that decoherence does indeed solve the preferred basis problem for the Everettian.
- However, there's clearly much more work to be done in making many worlds a fully fleshed-out interpretation capable of tackling the measurement problem.
- The first thing to tackle is why this is indeed a theory of *many worlds*.

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Emergent entities

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To make further progress, Everettians appeal to *emergence*. Here's Wallace:

> *It is simply untrue that any entity not directly represented in the basic axioms of our theory is an illusion. Rather, science is replete with perfectly respectable entities which are nowhere to be found in the underlying microphysics.* (Wallace 2012, p. 47)

Hofstadter and Dennett on emergence

Our world is filled with things that are neither mysterious and ghostly not simply constructed out of the building blocks of physics. Do you believe in voices? How about haircuts? Are there such things? What are they? What, in the language of a physicist, is a hole—not an exotic black hole, but just a hole in a piece of cheese, for instance? Is it a physical thing? What is a symphony? Where in space and time does 'The Star-Spangled Banner' exist? Is it nothing but some ink trails in the Library of Congress? Destroy the paper and the anthem would still exist. Latin still exists *but it is no longer a living language. The language of the cavepeople of France no longer exists at all. The game of bridge is less than a hundred years old. What sort of thing is it? It is not animal, vegetable, or mineral.* (Hofstadter and Dennett 1981)

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Everettians claim that what goes through for such entities goes through *mutatis mutandis* for the worlds of the Everett interpretation:

> *[W]orlds, in the Everett interpretation, are likewise emergent entities ... [T]his is actually a rather mundane claim ... it puts Everettian worlds on a par with all manner of unmysterious, scientifically respectable entities.* (Wallace 2012, p. 48)

Everettian worlds as emergent entities

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> ***Dennett's criterion:*** *A macro-object is a pattern, and the existence of a pattern as a real thing depends on the usefulness—in particular, the explanatory power and predictive reliability—of theories which admit that pattern in their ontology.* (Wallace 2012, p. 50)

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> *Science is interested with interesting structural properties of systems, and does not hesitate at all in studying those properties just because they are instantiated 'in the wrong way'.* (Wallace 2012, p. 58)

Two commitments

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Functionalism: 'To be X is to play the X-role'.

- The first justifies our belief in high-level patterns in the wavefunction as entities.
- The second justifies our understanding those entities to be (quasi-)classical *worlds*.

Everettian emergence of worlds

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> *[I]f we apply the same principles to quantum mechanics as we apply in general through science to identify higher-level ontology, we find that, since both the histories [$|$alive$\rangle$] and [$|$dead$\rangle$] represent a state of affairs where the system in question is structured like a cat, they represent a state of affairs where the system in question is a cat. We recover, then, what we would expect to recover: that macroscopically definite quantum states represent classical states of affairs in just the way that they are usually taken to.* (Wallace 2012, p. 60)

Back to decoherence

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> *In general [...] there is no inference between the live-cat and dead-cat states, and so both lots of structure continue to be present. The reason we can be confident of this is because of decoherence, which in general prevents the macroscopic degrees of freedom of quantum systems from interfering, and so guarantees that structures instantiated by the macroscopic degrees of freedom of quantum systems are not erased when those systems are in superpositions of macroscopically definite states.* (Wallace 2012, p. 62)

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> *And of course, in reality, no cat-containing box can be isolated from its surroundings. The room in which the box sits will get entangled with the box—and then there will be two rooms, and soon after that, two planets, and soon after that, two solar systems. And so unitary quantum mechanics, interpreted realistically, is a many-worlds theory—not because the 'worlds' are present in some microphysically fundamental sense but because the quantum state instantiates many different macroscopic systems.* (Wallace 2012, p. 63)

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4. So applying, again, the same general principles of functionalism, this state represents a system containing both a dead cat, and a live cat.
5. Superposition has become multiplicity at the level of structure: the 'cat' state instantiates two independent lots of macroscopic structure, and so represents two distinct macroscopic systems at once.

‘Horizontal’ versus ‘vertical’ readings of the state

Consider the following time evolution of some (decohered) quantum state:

$$
\begin{aligned}
|\psi\rangle &= \alpha_1 |\phi_1(t_0)\rangle + \alpha_2 |\phi_2(t_0)\rangle + \ldots + \alpha_n |\phi_n(t_0)\rangle \\
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- However, Everettians will maintain that does not detract from there existing robust, emergent structures which function as (quasi-)classical worlds!
- Almost all higher-level, emergent entities are not precisely defined, in exactly the same way.

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1. A worry about 'local beables'. (Maudlin 2019)
2. A worry about incoherence. (Dawid & Thébault 2015)

Worry 1: Local beables

- Maudlin (2019) objects to the Everett interpretation on the grounds that (he claims) it lacks a ‘primitive ontology’ of ‘local beables’—i.e., a basic ontological commitment to localised entities in 3-space.

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- Maudlin avers that exactly this is necessary in order to recover our empirical experience.
  (**Question:** Really?? Why?)

Maudlin's worries

What, if anything, are the local beables in this theory, and how does the basic physical ontology of the theory connected to the sorts of facts that are accepted as data?
When analyzing both collapse theories and the pilot wave theory, we solved this problem via local beables. If there are particles, or flashes, or continuous matter density distributed throughout space-time, then we know how to proceed. The precise microscopic matter distribution in a model determines the macroscopic situation by simple aggregation. Applying the theory yields empirical predictions. In contrast, if the theory postulates no local beables, it is not clear how to proceed? (Maudlin 2019, p. 196)

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Response (and to repeat): why think that local beables need be *fundamental*? Should someone call the string theorists?

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1. One must appeal (so the claim goes) to probabilities in order to justify neglecting off-diagonal elements in a density matrix, and so to obtain an emergent ontology of worlds.
2. But the only way to make sense of probabilities in the Everett interpretation is to already have done this (see next lecture).

Worry 2: Incoherence

The basic worry here, raised by Zurek (2005), Baker (2007) and Dawid & Thébault (2015, 2024), is this:

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2. But the only way to make sense of probabilities in the Everett interpretation is to already have done this (see next lecture).
3. So, the approach seems to be circular/incoherent.

Dawid & Thébault on this worry

In order to neglect small values in favour of larger values, we have to establish that the magnitude of the corresponding variable is related to the entry's effect on the measurement to be performed. Since experimental testing and the entries in the density matrix are related in terms of the probabilities for measuring certain outcomes, in order to establish the negligibility of small entries in the density matrix we must introduce the Born rule. (Dawid & Thébault 2015)

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- Compare e.g. the non-relativistic limit ($v/c \to 0$) limit of special relativity. There, do we use probabilities to ignore special relativistic effects if they're empirically/dynamically irrelevant? Obviously not!
- (One can also find objections to the incoherence charge in (Saunders 2021).)

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So far, we've presented the Everett interpretation in its decoherence-based, modern guise, and have assessed a couple of objections to it.

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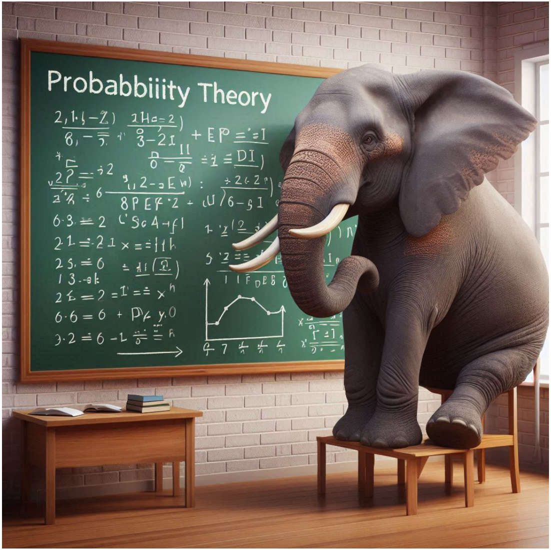
However, there's an elephant in the room....


Probabbiiity Theory

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To repeat: next time we'll be looking at *probabilities in Everett*.

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