Philosophy of Modern Physics

PHIL3622 Lecture 13: 31/10/2013
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Today's lecture

- Recap: Bohmian mechanics
- Albert on mentality
- Albert on Incommensurability with Many-Minds dualism
- Incompatibility with special relativity
- The Everett-in-denial problem
- Wrap-up: quantum metaphysics

Recap: Bohmian mechanics

Basic ontology of Bohmian mechanics

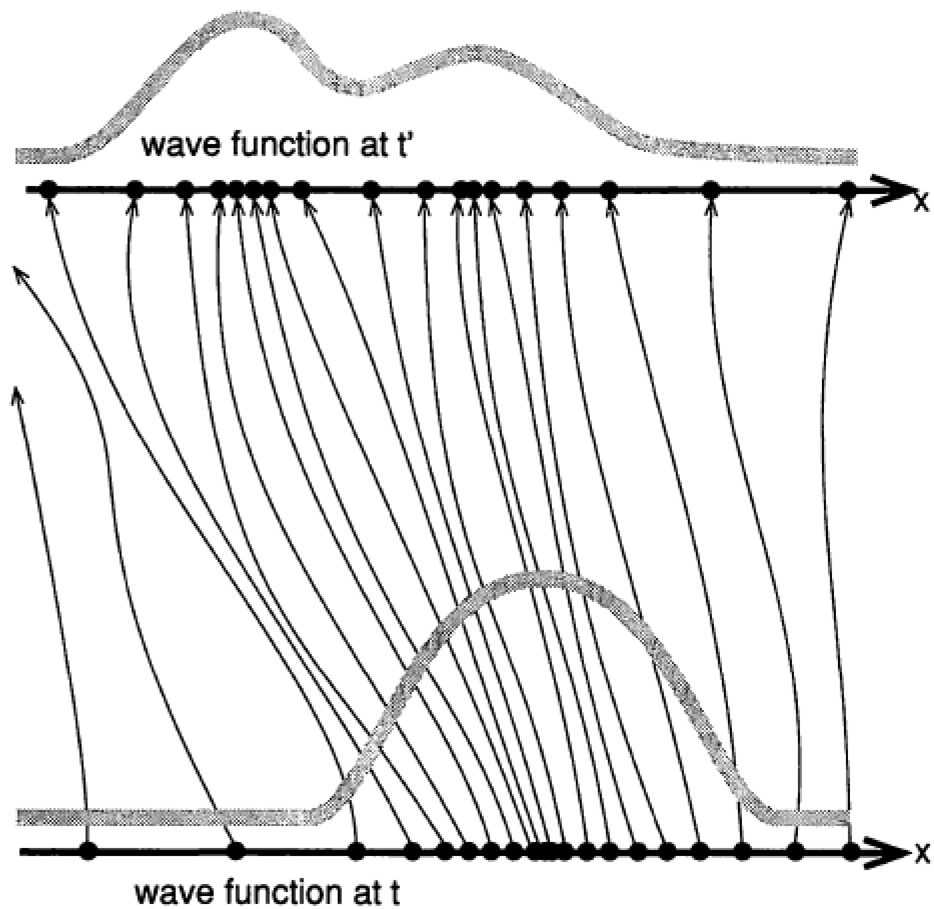
- Wave-functions are not descriptions of the physical states of particles.
  - So this: |black›|ψ_a(x)› does not say that some particle is black and is positioned in region a.
- Wave-functions are (something like) real physical force fields.
  - Every particle is associated with one.
  - Wave-functions push particles around.
  - So this: |black›|ψ_a(x)› is a description of a wave-function.
  - This bit: |ψ_a(x)› tells us that if a particle is sitting on region a, then it will be guided by this wave-function.
  - This bit: |black› tells us that if the wave-function goes through a colour box, it will exit through the black aperture, and so take the particle with it.

Bohm's laws

- The Schrödinger equation.
  - The wave-function always evolves linearly and deterministically.
  - The wave-function therefore never collapses.
- The velocity function (the "guidance equation").
  - Given the particle's position and its coordinate space wave-function:
    - you can calculate the particle's exact velocity and therefore its exact position at the next instant.
  - Given only the particle's coordinate space wave-function:
    - you can calculate *the probability* that the particle will be at some position at the next instant (using Born's rule).
  - One-way law (wave-function to particle).
    - Particles don't causally effect wave-functions.

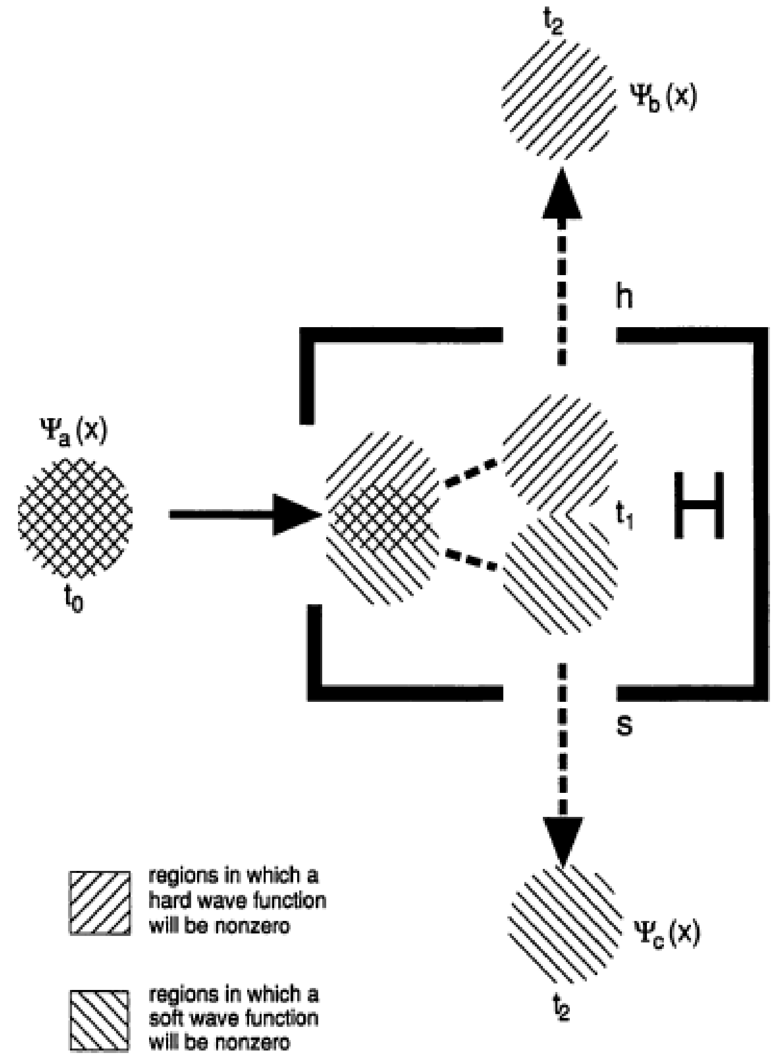
Bohmian determinism

- If you know p's velocity at time t then you know p's position at the next instant t'.
  - Now find the wave-function at t' in the standard way (Schrödinger equation).
  - Now reapply the velocity function and you've got p's position at the next instant (t'').
  - And so on...
    - So you can calculate deterministic trajectories.



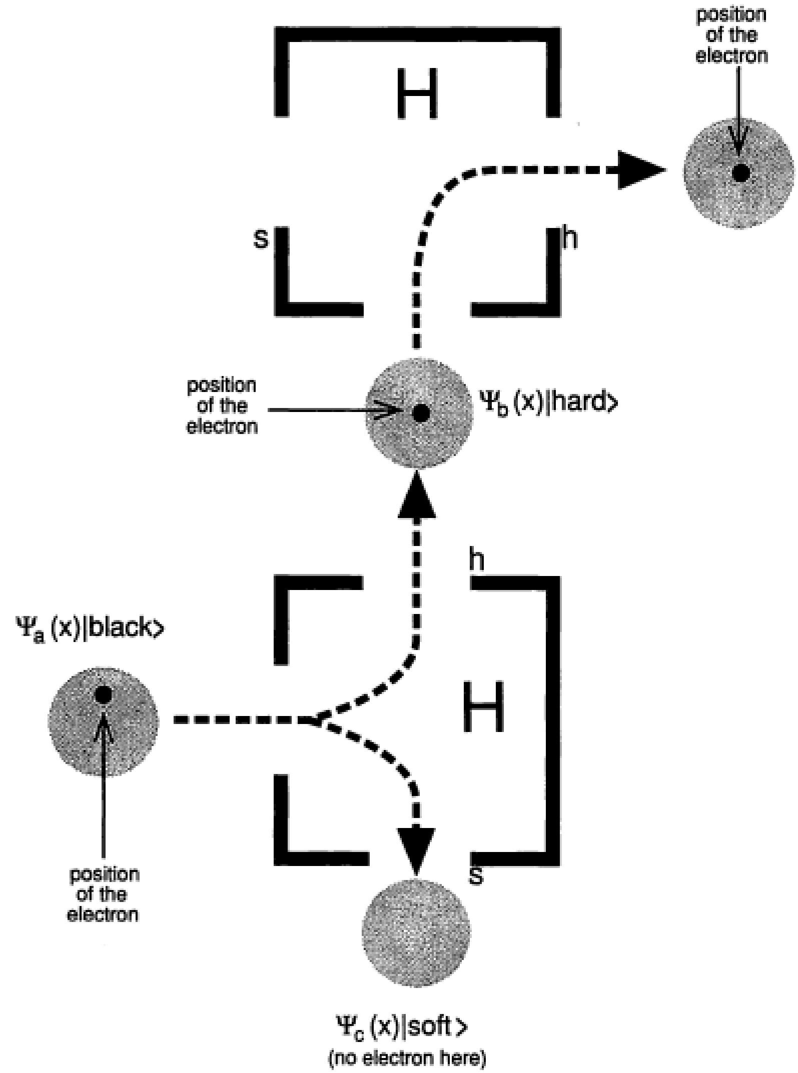
Spin boxes

- Consider a w-f described by:
  - |black›|ψ_a(x)›
    - |ψ_a(x)› = w-f nonzero only in the a-region and travelling right.
- A hardness box will *spatially separate* this wave-function into components:
  - 1/√2(|hard›|ψ_b(x)›+ |soft›|ψ_c(x)›)
- Where the electron exits depends on where in region a it was initially positioned.
  - i.e. upper or lower half.



Spin boxes

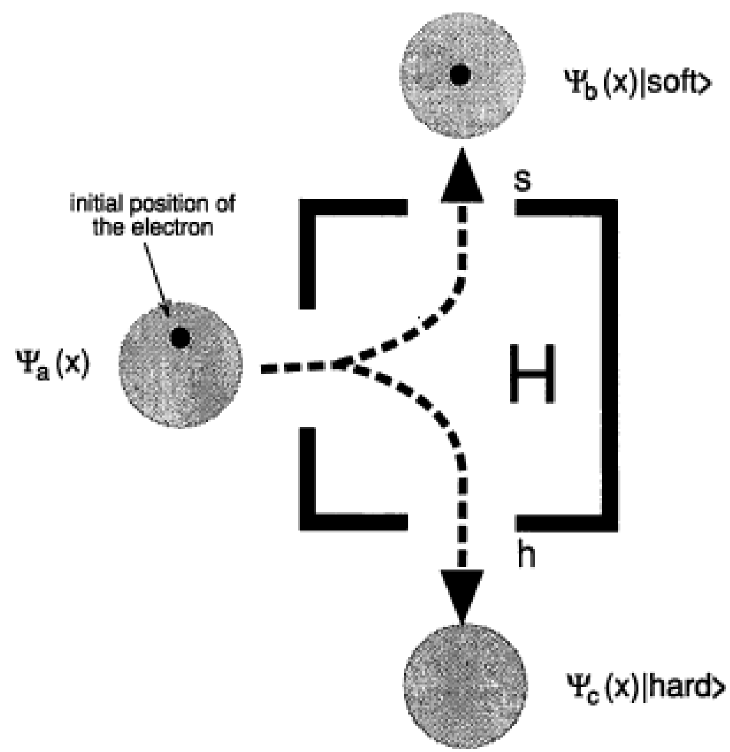
- If e was positioned in the upper half then the wave-function will guide it through the hard aperture.
  - Depicted in bottom image.
- The wave-function is then:
  - $1/\sqrt{2}(|\text{hard}\rangle|\psi_b(x)\rangle + |\text{soft}\rangle|\psi_c(x)\rangle)$
- Electron now located in region b so *only* guided by the |hard› component.
  - This is *effective collapse*.
  - Depicted in the top image.



Contextuality

- Now flip the hardness box over.

- Rather than:
  - $|\text{black}\rangle|\psi_a(x)\rangle$
  - $\rightarrow$
  - $1/\sqrt{2}(|\text{hard}\rangle|\psi_b(x)\rangle + |\text{soft}\rangle|\psi_c(x)\rangle)$
- We get:
  - $|\text{black}\rangle|\psi_a(x)\rangle$
  - $\rightarrow$
  - $1/\sqrt{2}(|\text{soft}\rangle|\psi_b(x)\rangle + |\text{hard}\rangle|\psi_c(x)\rangle)$



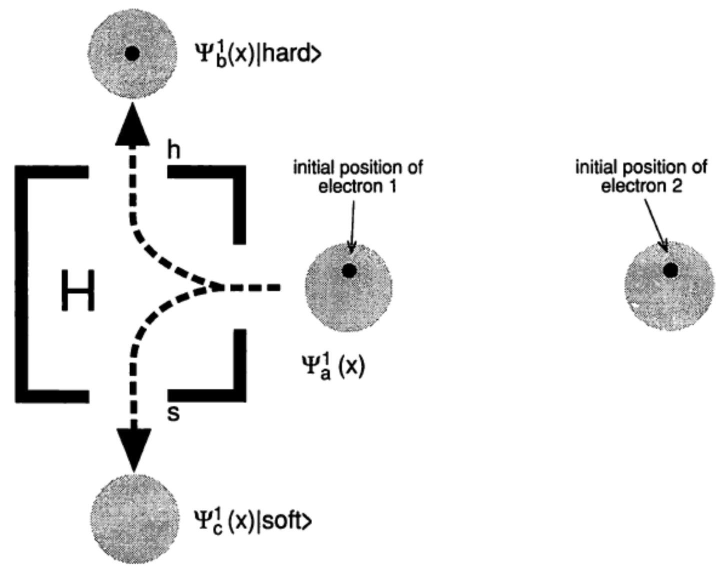
- So electron exits soft aperture.

Nonlocality

- Now consider the EPR state:

$$1/\sqrt{2}\left(|\text{hard}\rangle_1|\psi_a(x)\rangle_1|\text{soft}\rangle_2|\psi_f(x)\rangle_2 - |\text{soft}\rangle_1|\psi_a(x)\rangle_1|\text{hard}\rangle_2|\psi_f(x)\rangle_2\right)$$

- Electron 1 is in upper-half of region a. Electron 2 is in upper-half of region f.
- E1 goes through a H-box and ends up in *the b-region*. The resultant w-f is:



$$1/\sqrt{2}\left(|\text{hard}\rangle_1|\psi_b(x)\rangle_1|\text{soft}\rangle_2|\psi_f(x)\rangle_2 - |\text{soft}\rangle_1|\psi_c(x)\rangle_1|\text{hard}\rangle_2|\psi_f(x)\rangle_2\right)$$

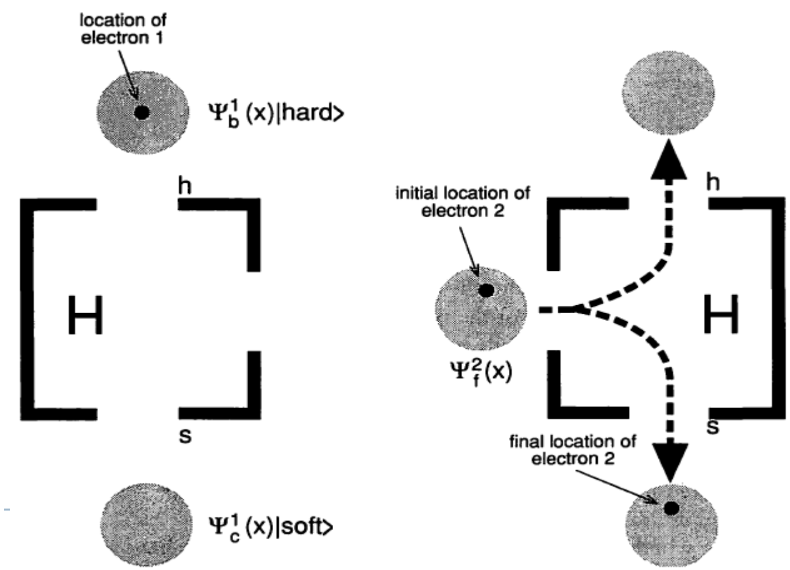
- E1 has effectively collapsed.
- But *so has e2…*

Nonlocality

- The 1+2 composite system is at a point in 6D space where the second term is zero.

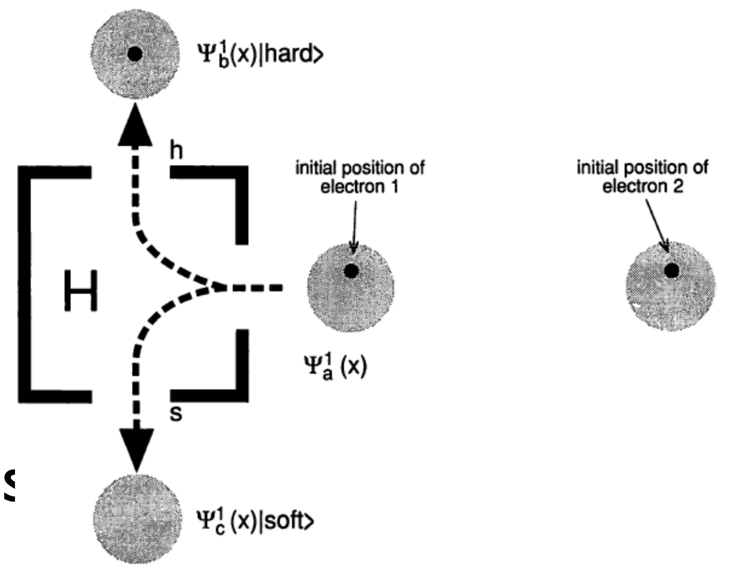
$$1/\sqrt{2}\,(|\text{hard}\rangle_1|\psi_b(x)\rangle_1|\text{soft}\rangle_2|\psi_f(x)\rangle_2 \;-\; |\text{soft}\rangle_1|\psi_c(x)\rangle_1|\text{hard}\rangle_2|\psi_f(x)\rangle_2)$$

- So the second term has no effect on the system.
  - Which clearly includes e2.
- That's how Bohm's laws guarantee that e2 effectively collapses too.
  - E1 will behave as if it were hard.
  - E2 will behave as if it were soft.
    - Depicted:



Instantaneous communication

- If e1 goes through the h-box then e1 will be effectively hard and e2 will be effectively soft.



- If (instead) e1 goes through an *upside-down* hardness box then e1 is be effectively hard.

- So knowing the initial positions and wave-functions of entangled particles will enable you to send messages (instantaneously over any distance) just by rotating the device.

But we can't know particle positions

- To discover whether e is in the upper or lower half we would have to measure its position.
- But then we would entangle e's wave-function to the wave-function of the measuring device.

$$|\mathrm{r}\rangle_m |\psi_a(x)\rangle_e |\mathrm{black}\rangle_e \rightarrow$$

$$|+\rangle_m |\psi_a^+(x)\rangle_e |\mathrm{black}\rangle_e + |-\rangle_m |\psi_a^-(x)\rangle_e |\mathrm{black}\rangle_e$$

- Where + means upper half, - means lower half.
  - Imagine also 1/√2 amplitudes.
- If e's coordinate space w-f effectively collapses to + then the outcome of an upcoming hardness measurement will depend on *where in the top half* e was located.
    - 0.5 prob for top quarter, 0.5 prob for next-to-top quarter.

The statistical postulate

- If you don't know:
  - The present position of the particle
- But you do know:
  - The present wave-function of the particle
- Then to calculate the future trajectory of the particle:
  - The square of (the absolute value of) the **present** wave-function at a position will give the probability for the particle being located at that position (at the **present** time).
  - The square of (the absolute value of) the **future** wave-function at a position will give the probability for the particle being located at that position (at the **future** time).
- Because (as we've seen) we cannot know the present position of any particle, Bohmian mechanics recovers the standard probabilistic predictions of QM.

Albert on “Mentality”

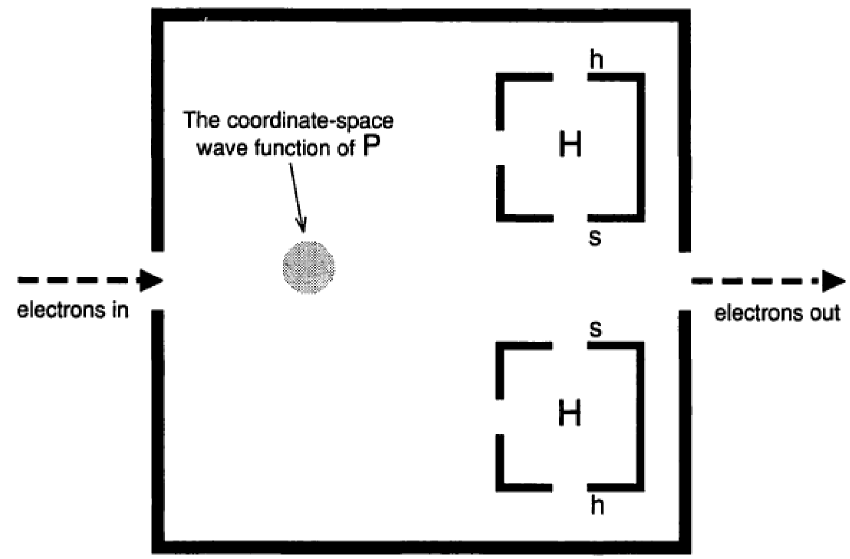
Explaining outcomes: Bohm Vs GRW

- Does Bohmian mechanics gaurantee that every sort of measurement even has an outcome?
  - Recall GRW:
    - Measurements recorded in macroscopic positions.
    - Problem cases where this may not be so (chapter 5).
  - Compare Bohm:
    - Measurements recorded in position (macro or micro).
    - Bohm therefore does better.

- Albert thinks that Bohm still has problems answering this question.
  - Although it requires a pretty far out possibility to show why!

Albert's example: the device

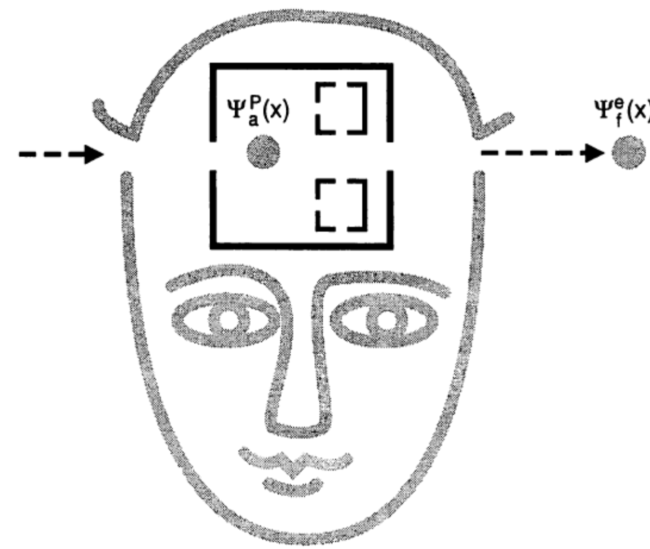
- This hardness box measures hardness of incoming e's by measuring the effect those e's have on the hardness of a particle p inside the box.
  - If p ends up soft then e is hard.
  - If p ends up hard then e is soft.



- P's hardness (after it interacts with e) is itself determined by one of the internal hardness boxes.
  - Note that the bottom one is upside down.

Albert's example: John-2

- This device determines John's belief about the hardness of the e's that enter the device:
  - When e's hardness has been recorded (only) in P's hardness, John may announce that he *knows* e's hardness.



John-2

- Further catch: which internal box John uses to report the outcome depends on how he chooses to report the outcome.
  - If verbal report then p goes through upper box.
  - If written report then p goes through lower box.

Albert's example

- Put a white e through the device and request that John remember the result.
  - Then the quantum state of the p/e composite is:

$$1/\sqrt{2}(|\text{soft}\rangle_P|\psi_a(x)\rangle_P|\text{hard}\rangle_e|\psi_f(x)\rangle_e - |\text{hard}\rangle_P|\psi_a(x)\rangle_P|\text{soft}\rangle_e|\psi_f(x)\rangle_e)$$

- If John is asked to verbally report (or write down) the result then he will verbally report (or write down) "hard" or "soft".
- Since the actual particles (e and p) will be associated with only one of the two superposition-components, all subsequent measurements will confirm John's report ("effective collapse").
- So far so good.

Albert's example: the twist

- Given Bohm's theory, the answer John gives will depend on how John reports that result.
  - If we ask John for a verbal report then John puts P through right-side-up box and responds with (say) "hard".
  - But were we to have asked for a written report then John would have put P through the upside-down box and written "soft".

- Why does Albert take this to suggest that not all measurements (given Bohmian mechanics) have outcomes?

Incommensurability with Many-minds

Many-minds dualism

- Recall the Everett interpretation:
  - Wave-function gives complete account of the physical state of the universe, dynamics is completely given by deterministic linear Schrödinger equation.
- Dualist Everettianism:
  - The probability problem is so severe that the Everett interpretation only works if minds are non-physical and evolve indeterministically.
- Many-minds dualism:
  - Brains are associated with a continuous infinity of minds and when brains superpose the minds evolve probabilistically into one of the superposition components.

Empirical equivalence

- Assume that either Bohmian mechanics is true or many-minds dualism is true.

- Is there any (in principle) way of empirically deciding which is true?
  - Both entail that:
    - The wave-function is governed only by the deterministic linear dynamics.
    - The outcome of any measurement is determined (probabilistically) by applying the Born rule to the wave-function.
  - So they do not make different predictions about the outcomes of any measurement.

Empirical equivalence

- Suppose we never find experimental evidence for collapse.
  - Then provided we have no non-experimental reasons for favouring one theory over the other...
    - ...do we?
  - ...then we have no reason to accept one over the other.
  - And then we cannot ever decide between the issues that these theories disagree on.
    - Whether the universe is deterministic.
    - Whether there is a preferred reference frame.
    - Whether physicalism is true.
- Still: the theories disagree on *which* experiments *have* outcomes.

Empirical incommensurability

- We will therefore not know what the content of physics *is about*:
  - Bohm: physics is about where things go (and (sometimes) there's no there's matter of fact about what observers think).
  - Many-minds: physics is about what observers think (and there is no matter of fact about where things go).

- Note: the many-minds claim "no matter of fact about where things go" assumes the basis problem.
  - Since decoherence arguably resolves this we need not think of many-minds this way.
  - And as we shall see it may also undermine Bohmian mechanics ("Everett-in-denial problem").

Conflict with relativity theory

Conflict with relativity theory

- From: *Can Bohmian Mechanics Be Made Relativistic?* (2013). Dürr, Goldstein, Norsen, Struyve, Zanghi.
    - arxiv.org/abs/1307.1714
  - "Thus we are not in fact able to answer the question posed in this paper's title. We stress however that these criteria revolve around aspects of locality that are largely incompatible with quantum mechanics. Thus if Bohmian mechanics indeed *cannot* be made relativistic, it seems likely that quantum mechanics can't either."
- A (relatively non-technical) review of various "Bohm-like" relativistic extensions can be found in:
  - Oliver Passon's: *What you always wanted to know about Bohmian mechanics but were afraid to ask* (2006).
    - arxiv.org/abs/quant-ph/0611032

The Everett-in-denial objection

Basic idea

- Everettian ontology *is only* the wave-function governed *only by* the Schrödinger equation.
  - (Supposed) result: many worlds.

- Bohm's ontology *includes* the wave-function governed *only by* the Schrödinger equation.
  - So, *same result* plus whatever other ontology Bohm postulates?

- In that case, Bohm's theory fails to solve the measurement problem.
  - Except in the sense that it reduces to the many-worlds interpretation, and the additional ontology is redundant.

Brown & Wallace

- Let's start with Brown and Wallace's statement of the objection.
  - Brown, Harvey R. and Wallace, David. 2005. "Solving the Measurement Problem: de Broglie-Bohm loses out to Everett". *Foundations of Physics,* 35: 517-40.
    - See course website.

- To warm-up they note that "the predictable case" is generally thought to be unproblematic:
  - $|\text{'ready'}\rangle_h|\text{'ready'}\rangle_m|\text{black}\rangle_e$
  - ...is generally thought to perfectly well describe a definite measurement outcome.
  - But on Bohmian mechanics, although it's (usually) taken to be a physical description, a measurement outcome does not obtain until "corpuscles" are added.

The main argument

- Given the basic idea, why is Bohm not simply postulating excess ontology?
- Until the late 1980's the answer was: it postulates *less*:
  - The preferred basis problem means that we need e.g. additional minds (Albert's many-minds dualism).
- But in light of decoherence theory:
  - Sufficiently complex wave-functions will (in a given basis) evolve effectively non-interacting branches exhibiting quasi-classical dynamics and (seemingly) determinate measurement outcomes in each branch.
- So surely Bohmians should bite the bullet on this...

Potential Bohmian responses

- 1. Deny that sufficiently complex wave-functions generate many decohering branches in some basis.
  - Somewhat speculative…
- 2. Deny the (concrete, physical) existence of the wave-function.
  - Valentini: the wave-function is an abstract mathematical entity, not a physical thing. "Empty" branches merely "simulate" worlds.
    - Valentini, Antony. 2010. "De Broglie-Bohm Pilot-Wave Theory: Many Worlds in Denial?" In *Many Worlds? Everett, Quantum Theory, and Reality*, edited by S. Saunders, J. Barrett, A. Kent, and D. Wallace. Oxford University Press.
- 3. Deny that the generated (concrete, physical) decohering branches are sufficient for the emergence of "worlds".
  - Lewis: Bohmians should reject "functionalism" or the "patterns ontology".
    - Lewis, Peter J. 2007. "Empty Waves in Bohmian Quantum Mechanics". *British Journal for the Philosophy of Science*, 58(4): 787-803.

1. Questioning decoherence

- What if decoherence picks out other bases and thus undermines the objectivity of Everettian branching?

- Saunders (anthropic response):
  - Suppose several bases support information processing systems. Then we observe one rather than another because *we happen to be* information processing systems in one but not other bases.

- B&W (too speculative):
  - "This a long shot given the success of the decoherence program for simpler (but increasingly complicated) models".

2. Deny concreteness of wave-function

- Perhaps the wave-function is just an abstract mathematical object.

- B&W:
  - """Reality" is not some property which we can grant or withhold in an arbitrary way from the components of our mathematical formalism."
  - The wave-function:
    - Is contingent (its form depends on contingent initial conditions).
    - Evolves over time.
    - Dynamically influences corpuscles and (seemingly parts of itself).
    - Plays a causal-explanatory role (e.g.) in the two-slit experiment.
  - We need strong grounds to dismiss something that does *these things* as a mere mathematical fiction.
    - Compare: gravitational field considered real when it was realised it had such properties.

2. Deny concreteness of wave-function

- Perhaps the wave-function is just an abstract mathematical object.

- Valentini:
  - "If one wishes one may identify the [wave-function] with a set of trajectories representing parallel worlds. [...] This is fair enough from a many-worlds point of view. But if we start from pilot-wave theory understood on its own terms [...] such a step would amount to a reification of mathematical structure. If one does so reify, one has constructed a different theory, with a different ontology."

- Brown ("Reply to Valentini") complains that Valentini does not deal with the B&W argument (previous slide) and so parodies this line...

2. Deny concreteness of wave-function

- Prof. X is a mind-body dualist who only believes in his own mind but is a "solipsist" about all others.
  - Other minds are here analogous to other worlds.
- Prof. Y (a physicalist) asserts that minds are just whatever play certain causal-functional roles.
  - So since other bodies play the relevant roles they are conscious for the same reason Prof. X is.

- Brown thinks it illegitimate for Prof X. to reply:
  - "If one wishes one may identify minds with what plays those roles. [...] This is fair enough from a physicalist point of view. But if we start from dualistic-solipsism understood on its own terms [...] such a step would amount to postulating unnecessary entities. If one does so postulate, one has constructed a different theory, with a different ontology."

2. Deny concreteness of wave-function

- Brown: The further onus is to explain how "the matter assumption" (the idea that *only* corpuscles compose macro-systems) even *makes sense* in the light of the possibility that the wavefunction is sufficiently structured on its own to account for macro-systems.

- Is Brown's parody fair?
- Is Brown right about the burden of proof?
  - Note that in phil-mind dualists are usually *required* to tell us what is wrong with a functionalist-based physicalism.

3. Deny that branches yield "worlds".

- Let's grant that the wave-function is a concrete physical thing that forms independently evolving branches (that corpuscles are supposed to "ride on").

- Peter Lewis argues that this alone does not entail many worlds.
  - Note that Brown's "burden of proof" argument presupposed *functionalism* (or: "Dennett's criterion").
- "Dennett's criterion is sufficient to establish that branches are worlds [but] to entertain Bohm's theory is to entertain the falsity of Dennett's criterion."

Dennett's criterion

- **Dennett's criterion**: A macro-object is a pattern, and the existence of a pattern as a real thing depends on the explanatory power and predictive reliability of theories which admit that pattern in their ontology.
  - From Daniel Dennett's "Real Patterns" (1991).
  - See also David Wallace's "Decoherence and Ontology"
    - In the "Many worlds" collection on course website.

- Special sciences (biology, geology, psychology etc.) delineate natural patterns (natural kinds) in nature.
  - They are patterns *within the microphysics*.
  - The *natural* patterns are the useful explanatory ones.

3. Deny that branches yield "worlds".

- Lewis' solution:
  - "Bohm's theory violates Dennett's criterion in that it presupposes that macro-objects are tied to a particular kind of microphysical stuff; a pattern in Bohmian particles can constitute an object, but the analogous pattern in wavefunction-stuff cannot."
  - "But then Dennett's criterion cannot be taken for granted in arguing that Bohm's theory fails to solve the measurement problem."

- Is this is a legitimate move?
- Is there any (independent) reason to think Dennett's criterion is false?

3. Deny that branches yield "worlds".

- Lewis does not object to Dennett's criterion:
  - "D's criterion is part of a well-entrenched functionalist tradition in philosophy, and is arguably as securely established as any philosophical position."
- But then how does this help Bohm?
  - "My point is that *every* proposed solution to the measurement problem succeeds at solving the measurement problem only if it is allowed to violate some well-entrenched position."
  - For many-worlds, Lewis cites the entrenched assumption that probability requires uncertainty about the future.
    - Recall Papineau: "conceptual baggage imposed on us by orthodox metaphysics".

3. Deny that branches yield "worlds".

- Is Lewis' argument plausible?
- Is the analogy with the probability problem adequate?

- Some doubts:
  - The Everettians don't merely assert that orthodox probabilistic thinking is false.
    - They (arguably) have an extensive decision-theoretic defence of their denial of orthodox probabilistic assumptions.
  - It is not obvious that Bohmians have more than the assertion that Dennett's criterion is false.

Comparison with the tails problem

- Lewis (sec. 6) applies his argument to the GRW tails problem.
  - "The GRW theory, like Bohm's theory, requires rejecting Dennett's criterion, since macro-objects are essentially ties to high amplitude structure."

- Are Bohm and GRW on a par here?
  - GRW appeal not to a distinction *in kind*, but to a property that *comes in degrees*.
  - Arguably the need to provide and motivate a positive replacement for Dennett's criterion is even greater.
    - Also: why does the high-amp branch generate macro-objects *at all* if not via Dennett's criterion?

Wrap-up: quantum metaphysics

Metaphysics

- Metaphysics typically deals with the reconciliation of the manifest world and the world described by science:
  - How is consciousness possible in a fundamentally causally closed physical universe?
  - How is free will possible in a fundamentally deterministic universe?
  - How is morality possible in a fundamentally non-normative world?
  - Etc.

Supervenience / grounding

- We are offered a picture of the world at a more fundamental level, and we must *locate* manifest properties (consciousness, free will, morality, etc.).
  - What does "locating" amount to?
    - Supervenience, grounding, functionalism, patterns etc.

- Strict adherence to science plus strict "locating" principles yield:
  - Eliminativist materialism, hard determinism, moral nihilism.
- Strict adherence to science plus liberal "locating" principles yield:
  - Physicalism, compatibilism, moral realism.

Quantum metaphysics

- Quantum metaphysics deals with the reconciliation of the manifest world and the world described by quantum theories:
  - How is probability possible in a fundamentally Everettian universe?
  - How are single determinate outcomes possible in a fundamentally GRW universe?
  - How are single determinate outcomes possible in a fundamentally Bohmian universe?
  - Etc.

- How we answer these questions depend (in part) on how we understand notions like "supervenience".

Quantum supervenience / grounding

- Strict "locating" principles may yield:
  - Probabilities cannot be "located" in the Everettian ontology.
  - Single definite outcomes cannot be "located" the GRW ontology.
  - Single definite outcomes cannot be "located" the Bohmian ontology.
    - Implication: the measurement problem still leaves us in the dark about the nature of reality.
- Liberal "locating" principles yield:
  - Everett, Bohm, GRW meet their explanatory goals.
    - Implication: the measurement problem is no more, we just need to work out which is the correct theory.

- You're hopefully now in a position to locate yourself somewhere in between these two extremes.