PHYS/PHIL 329 Lecture 17: The tails problem for dynamical collapse theories

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Essay 3 due April 17. Essay questions:

- (i) Albert (and Vaidman) argue that it is a problem for the GRW theory that it might not guarantee measurement outcomes e.g. in the experiment with television screens (Albert, pp.100-106) and in the hypothetical experiment of John (Albert, pp.107-110). Is this really a problem for the GRW theory?

- (ii) It is an open question as to why probability (esp. the Born rule) plays such a central role in quantum mechanics. On some views (Spekkens toy model, de Broglie-Bohm theory), we cannot predict the outcomes of measurements with certainty, because we don't (and can't) know everything about the present physical state. Quantum probabilities are therefore *subjective* and based partly on our ignorance. But on collapse theories, we could indeed know everything about the present physical state yet still not be able to predict future measurement outcomes with certainty. For nature herself behaves randomly. Quantum probabilities are therefore *objective* and based on the structure of nature. This raises the question, why does nature behave randomly, in accord with the Born rule? Why doesn't nature act (i.e. *collapse*) in accord with some other rule (like the equal-probability-rule)? Does the proof of McQueen and Vaidman (2019 section 4.1) help to answer these questions?

- (iii) What is the tails problem and what is the most plausible solution to it? Here, you should consider whether any of the responses to the problem outlined in McQueen (2015 section 4) are plausible (or perhaps you could devise your own solution).

- (iv) Could consciousness cause collapse? Is there a precise way of formulating a consciousness causes collapse theory? Does it face any serious problems?

Today's Lecture

- Does GRW guarantee definite measurement outcomes?
  - Challenge 2: the tails problem.
- Disambiguation of "the" tails problem
  - The bare tails problem.
  - The structured tails problem.
  - The multiverse tails problem.
  - The tails dilemma.
- The buffet of proposed solutions:
  - Overview of the variety of solutions (esp. to the structured tails problem) that have been proposed by collapse theorists, and challenges to those solutions.

Recap: how GRW meet the constraints

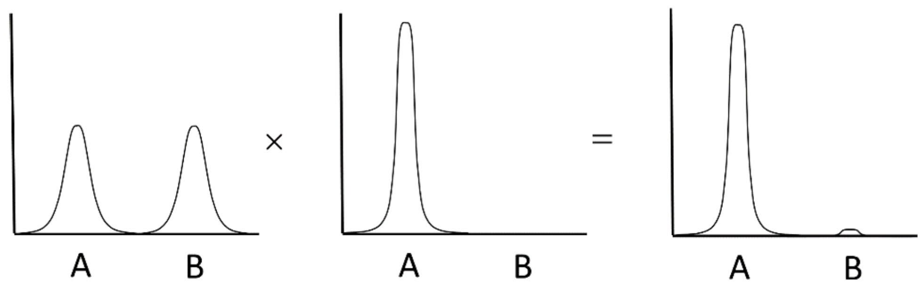
- *Constraint 1*: Guarantee consistency with experiments on isolated particles.
  - GRW: an isolated particle localizes, on average, every hundred million years.
- *Constraint 2*: Guarantee that measurements have specific outcomes.
  - GRW: measurement outcomes are recorded in the positions of macroscopic objects.
  - GRW: via amplification, the smallest macroscopic objects undergo a localization every 10^{-7} seconds.
- *Constraint 3*: Guarantee that measurements have outcomes *with the right probabilities*.
  - GRW: The probability that a collapse is centred on a given superposition component is given by the familiar (Born) probability rule.

Does GRW really meet constraint 2?

- *Constraint 2*: Guarantee that measurements have specific outcomes.
  - GRW: measurement outcomes are recorded in the positions of macroscopic objects.
  - GRW: via amplification, the smallest macroscopic objects undergo a localization every 10^{-7} seconds.

- The tails problem:
  - The move to *Gaussian collapse functions* leave behind "tails" which are difficult to interpret.

GRW Gaussian collapse function



(a) (b) (c)

- *Figure (a)* represents a particle in a superposition of regions A and B.
  - Horizontal axis represents a dimension of space, vertical axis represents probabilities of position measurement outcomes.
- *Figure (b)* represents the GRW Gaussian collapse function centred on A.
  - Although not visible in the image (since they are so close to zero on the vertical axis), the Gaussian has tails heading off to infinity in both directions.
- *Figure (c)* represents their product, and the *consequence of collapse*: the particle collapses to region A, *but with a tail still in B.*
  - Multiplying the B-region (in (a)) with a tail (from (b)), dramatically *reduces* the probability to find the particle at B, but *does not eliminate it.*

The tails problem

- Due to the tails of the GRW gaussian collapse function, superpositions and entanglements are never destroyed.

- If the initial state is:

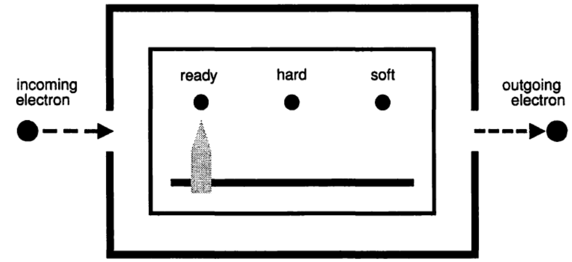
$$\frac{1}{\sqrt{2}}(|X_5\rangle_1|X_{55}\rangle_2 + |X_9\rangle_1|X_{99}\rangle_2)$$

- And the collapse is centred on the $|X_9\rangle_1|X_{99}\rangle_2$ term, then the post-collapse state is not given by this term, but by (where ε is tiny but nonzero):

$$\sqrt{1-\varepsilon^2}|X_5\rangle_1|X_{55}\rangle_2 + \varepsilon|X_9\rangle_1|X_{99}\rangle_2$$

- Now consider a hardness measurement:

$$|"ready"\rangle_m \frac{1}{\sqrt{2}}(|hard\rangle_e + |soft\rangle_e)$$



- Let's say the pointer collapses to "hard". The post-measurement state is:

$$\sqrt{1-\varepsilon^2}|"hard"\rangle_m|hard\rangle_e + \varepsilon|"soft"\rangle_m|soft\rangle_e$$

- Notice that the "mod-square" of the soft coefficient (i.e. $|\varepsilon|^2$) is very small *but nonzero*.
- *Tails problem*: it is not clear whether this really counts as a measurement outcome!

The bare tails problem

- The traditional formulation of the tails problem is that propositions (i), (ii), and (iii) are inconsistent:

(i) The eigenstate–eigenvalue link (EEL).

(ii) The wave-function evolves in accord with the GRW dynamics.

(iii) Measurements have definite outcomes.

- EEL: a system S has a measureable property P when and only when S's quantum state is an eigenstate of P.
  - In other words: S has P if and only if S has some value of P *with probability one*.
- But the pointer in the GRW post-collapse state…

$$\sqrt{1-\varepsilon^2}|"hard"\rangle_m|hard\rangle_e + \varepsilon|"soft"\rangle_m|soft\rangle_e$$

- …is not an eigenstate of the property "displaying a single definite measurement outcome".
  - Although the eigenstate "pointing at "hard"" has a mod-square (probability) value *close* to one, it isn't *exactly* one.

Solution: replace EEL with the Fuzzy link

- Since GRW post-collapse states *come close* to position eigenstates perhaps one only needs to relax EEL.
- Albert and Loewer (1996) replace EEL with:
  - ***Fuzzy-link principle***: particle p is in region R if and only if the proportion of the total mod-square value of p's quantum state associated with points in R is greater than 1 minus q.
- Now reconsider:

$$\sqrt{1-\varepsilon^2}|\text{"}hard\text{"}\rangle_m|hard\rangle_e + \varepsilon|\text{"}soft\text{"}\rangle_m|soft\rangle_e$$

- The pointer (labelled m) is made of many particles. For each particle, the proportion of the total mod-square value of its quantum state associated with the region under the "hard" label is greater than 1- q.
  - The fuzzy link thereby entails that the pointer is pointing to "hard".
- What is the status of the fuzzy-link principle?
  - It's not a law of nature:
    - The value of q is defined to meet constraints 1 and 2 – but many values accomplish this.
    - q is not a fundamental constant: given an initial quantum state and GRW dynamics, different q-values will not lead to different future quantum states.
  - It's like a *linguistic* rule for connecting "particle talk" to "quantum state talk".

The Structured Tails problem

- The structured tails problem:
  - If the collapse centre determines a particle configuration, then so does the tail, because the tail and the collapse centre are structurally isomorphic (or at least, relevantly structurally similar).
  - Nothing about low mod-square (probability) values can suppress this isomorphic structure.
  - The consequence (if the collape centre does determine a particle configuration) is a many-worlds ontology.
- Now reconsider (again):

$$\sqrt{1-\varepsilon^2}|"hard"\rangle_m|hard\rangle_e + \varepsilon|"soft"\rangle_m|soft\rangle_e$$

- To be fair to GRW, we should not assume a macroscopic superposition. We can rewrite it as:

$$\sqrt{1-\varepsilon^2}|H-state\rangle_m|hard\rangle_e + \varepsilon|S-state\rangle_m|soft\rangle_e$$

  - $H-state$: a complicated quantum state component structured so that ***if*** it determines particles, then it determines a pointer pointing at "hard".
  - $S-state$: an equally complicated component structured so that ***if*** it determines particles, then it determines a pointer pointing at "soft".
- Restatement of structured tails problem:
  - GRW assert that only $H-state$ determines particles, but do not explain *why*.
  - The only relevant difference between the two states are the different mod-square values.
  - But why would this difference make a difference to what particles exist?

Responses

- Collapse theorists have offered a bewildering variety of responses to this problem, without any consensus as to which response to correct.
- We will consider the responses of:

1. Clifton and Monton.
2. Ghirardi, Grassi and Benatti.
3. Tumulka.
4. Albert.
5. Monton and Gao.
6. Chalmers.
7. Lewis.

Clifton and Monton

- They say:
  - “If one is willing to entertain the thought that events in a quantum world can happen without being mandated or made overwhelmingly likely by the wavefunction, then it is no longer clear why one should need to solve the measurement problem by collapsing wavefunctions! [...] one supposes there to be a plausible intuitive connection between an event's having a high probability according to a theory, and the event actually occurring”.
- Problem: apparently confuses the role of probability in collapse theories.
  - The probability of a superposition component is the objective probability for that component to become a collapse centre.
  - It is not the objective probability for that component to have “actually occurring” status.
  - In GRW the entire quantum state exists (simpliciter), including tails.
  - Could degrees of existence help?

Ghirardi, Grassi and Benatti's response

- The tails are "inaccessible" i.e. observers cannot directly measure them.
- The tails are therefore "not objective".

- Problems:
  - What's real (what's objective) is not determined by what we happen to be able to "access".
  - Ghirardi et al. cannot *without circularity* appeal to observers until they have solved the tails problem. For aren't the tails accessible to observers in the tails?

Tumulka's response

- Consider a *classical* marble in a box:
  - In most cases, some parts of the marble (vapor particles) will be outside the box.
  - We *still* say the particle is in the box.
- Now consider a quantum marble in a box:
  - $\sqrt{1-\varepsilon^2}|In\ box\rangle_{marble} + \varepsilon|Outside\ box\rangle_{marble}$
  - For the same reason, we should still say that the marble is in the box.

- Problem:
  - For this example, perhaps. But for a more complex example such as:

$$\sqrt{1-\varepsilon^2}|"hard"\rangle_m|hard\rangle_e + \varepsilon|"soft"\rangle_m|soft\rangle_e$$

  - …it is more difficult to see how the soft component could be made analogous to some negligible invisible vapor trail.
  - After all, the soft component takes the shape of the pointer etc.

Albert's response

- Albert considers a billiard ball (ball 1) in a superposition of travelling to point P and travelling to point Q *from the left*, and another (ball 2) that is in a superposition of travelling to point P and travelling to point Q *from the right*.
- Prior to collision we have (where α = $\sqrt{1-\varepsilon^2}$):

$$(\alpha|\rightarrow P\rangle_1 + \varepsilon|\rightarrow Q\rangle_1)\,(\alpha|P \leftarrow\rangle_2 + \varepsilon|Q \leftarrow\rangle_2)$$

- After collision, we have:

$$\alpha^2|\leftarrow P\rangle_1|P \rightarrow\rangle_2 + \varepsilon^2|\leftarrow Q\rangle_1|Q \rightarrow\rangle_2 + \alpha\varepsilon|Q \rightarrow\rangle_1|\leftarrow P\rangle_2 + \alpha\varepsilon|P \rightarrow\rangle_1|\leftarrow Q\rangle_2$$

- Albert then distinguishes the "high density" sector ($\alpha^2|\leftarrow P\rangle_1|P \rightarrow\rangle_2$) from the "low density sector" (the other three terms).
- In the high-density sector we have a familiar type of collision…
  - "But look at the low-density sector: what happens there is that two balls converge at Q and pass right through one another–and (in the meantime) two new balls appear, which then recede, in opposite directions, from P"(2015: p154).
  - The implication is that high-density matter and only high-density matter has the structural and functional credentials tocount as genuine macroscopic stuff.
- Problem:
  - There appears to be little motivation to lump all the low probability terms together (into the "low density sector") and try to interpret them all at once.

Monton's and Gao's response

- "A certain assumption about psychophysical parallelism needs to be made."
- For example, take this state:

$$\sqrt{1-\varepsilon^2}|"hard"\rangle_{brain}|"hard"\rangle_m|hard\rangle_e + \varepsilon|"soft"\rangle_{brain}|"soft"\rangle_m|soft\rangle_e$$

- The left term describes a brain recording a "hard" outcome.
- The right term describes a brain recording a "soft" outcome.
- The psychophysical assumption: a brain determines a conscious experience only if it has a sufficiently high probability.
  - Hence, the state determines a single measurement outcome because there is an experience of a pointer pointing to "hard", but no other experience.
- Problem:
  - But this apparently leaves us with tails containing human brains that are unconscious. …Zombies!

Chalmers' response

- Many properties are "response-dependent" in that they are defined in terms of the sorts of experiences that normally functioning humans have in response to seeing them.
  - 'Red' is that property of surfaces that normally cause red experiences.
  - "the property of being two metres away from one might be picked out as the spatial relation that normally brings about the experience of being two metres away from one."

- Chalmers then proposes to solve the zombie problem as follows:
  - "One can then argue that on a collapse interpretation, the properties and relations that normally bring about the relevant sort of spatial experiences are precisely properties and relations requiring the wavefunction's amplitude to be largely concentrated in a certain area" (2012: 295–296).

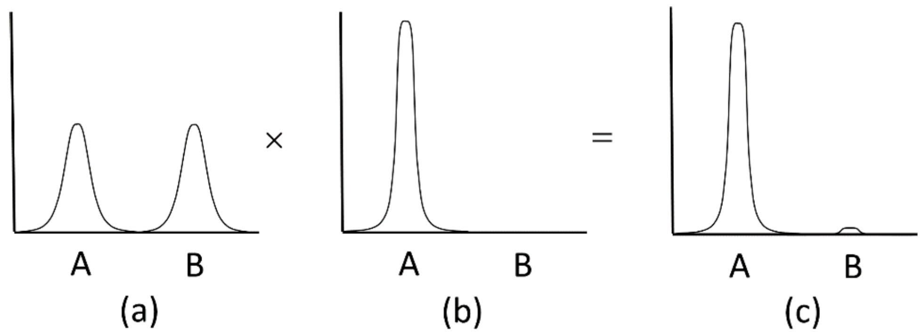
- Problems:
  - Why can't we state the problem using non-phenomenal concepts?
  - Aren't we just hiding the tails problem behind the mind-body problem?

Lewis' response

- "The GRW theory [...] requires rejecting Dennett's criterion, since macro-objects are essentially tied to a particular kind of microphysical structure, namely high-amplitude structure. [...] But since the many-worlds theory also violates apparently obvious principles, the violation of Dennett's criterion is not in itself a reason to exclude the GRW theory from the set of solutions to the measurement problem"(Lewis, 2007: 800).
  - *Dennett's criterion*: macroscopic objects are patterns in configurations of microscopic objects.

- Problem:
  - Does our formulation of the structured tails problem really assume Dennett's criterion?
  - Don't we still need an *explanation* for why we should accept an alternative criterion for identifying macroscopic objects given a microphysical description?

Multiverse tails problem



- It has been realized that the tail (the one that is not quite visible in (b), but that extends past region B), actually displaces the bump above B (in (c)) towards A slightly.
  - It has been calculated (by Wallace, and later, by Pearle) that if tails determine particles, then the GRW collapses will kick nucleons out of their nucleus, leading to lethal radiation emissions.

- *The multiverse tails problem*:
  - If the collapse centre determines a particle configuration, then so does the tail, because the tail and the collapse centre are structurally isomorphic (or at least relevantly structurally similar).
  - Nothing about low mod-square value (probability) can suppress this isomorphic structure.
  - The consequence (if the collape centre does determine a particle configuration) is a **possible** many-worlds ontology.

The tails dilemma

- Why not just cut off the tails?
  - Why not replace the Gaussian collapse function with a collapse function with compact support?
- Collapse theorists have not taken this option, even though it seems to be the most straightforward solution.
  - The theory becomes very difficult to reconcile with relativity theory, and it may even lead to superluminal signaling.
  - For example, if a particle is localized to a small region, then it will immediately acquire tails that shoot out to infinity.
- The strategy seems to be:
  - Don't replace the Gaussian collapse functions unless absolutely necessary.
  - The tails problem is a conceptual, or philosophical problem, which can be solved if we think hard enough about it!
- The tails dilemma:
  - Either cut the tails off and face up to the relativistic problems, or retain the tails and find an adequate conceptual solution to the tails problem.