Title: Self-locating uncertainty and the many worlds interpretation

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Abstract: According to the many worlds interpretation (MWI), quantum mechanics in its simplest form (no collapse or hidden variables) is complete. A primary objection to the MWI is that it fails to account for the Born rule. The most prominent response to this objection comes from the decision-theoretic program, which aims to derive a rationality postulate according to which a believer in the MWI ought to act as if the Born rule is true. I argue that the existence of alternative coherent rationality postulates undermines this response. A different response, based on self-locating uncertainty, avoids this objection and may explain the Born rule in the MWI. I conclude by considering whether this framework is capable of explaining the weak trace of particles in certain difficult cases.

Self-locating uncertainty and the many worlds interpretation

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The measurement problem

- In a quantum measurement the formalism (Schrödinger equation + wave function) corresponds to a superposition of all possible outcomes.
- But it seems we observe *just one* of these outcomes.

2

Three possible solutions

- Introduce dynamical collapse
  - Spontaneous collapse
    - Pearle [1976], Ghirardi et. al. [1986].
  - Gravity-induced collapse
    - Diosi [1987], Penrose [1996].

- Introduce additional variables
  - Bohmian mechanics
    - Bohm [1952].
  - Two-state interpretation
    - Aharonov et. al. [2014].

- Introduce nothing, retain formalism.
  - Many worlds interpretation
    - Everett [1957].

3

The many worlds interpretation (MWI)

- An object in a macroscopic superposition is interpreted as a *multiplicity* of macroscopic objects.
- So, in a quantum measurement, the measurement device *branches* into multiple devices, each records a different outcome.
- The environment, due to its entanglement with the device, will branch too.
- Measurements *only seem* to have one outcome, since each outcome is observed in a different world.

Structure of talk

- The probability problem for the many worlds interpretation.
- Solution: the self-locating uncertainty approach.
- TSVF and the ontology of many worlds.

5

The probability problem

- The incoherence problem
  - How can probability make sense when all outcomes are realized?
- The quantitative problem
  - How can the MWI explain the Born rule?

The self-locating uncertainty approach

- The aim is to establish:
  - **Born-Vaidman rule**: *pre-observation descendants* should assign *self-locating probabilities* in accord with the Born rule.
    - Vaidman [1998], Tappenden [2011].
- Pre-observation descendants:
  - An experimenter creates *descendants*, even before they have observed the results of the experiment.
- Self-locating probabilities:
  - Pre-observation descendants are uncertain as to what world they are in. This defines a *probability* measure.

7

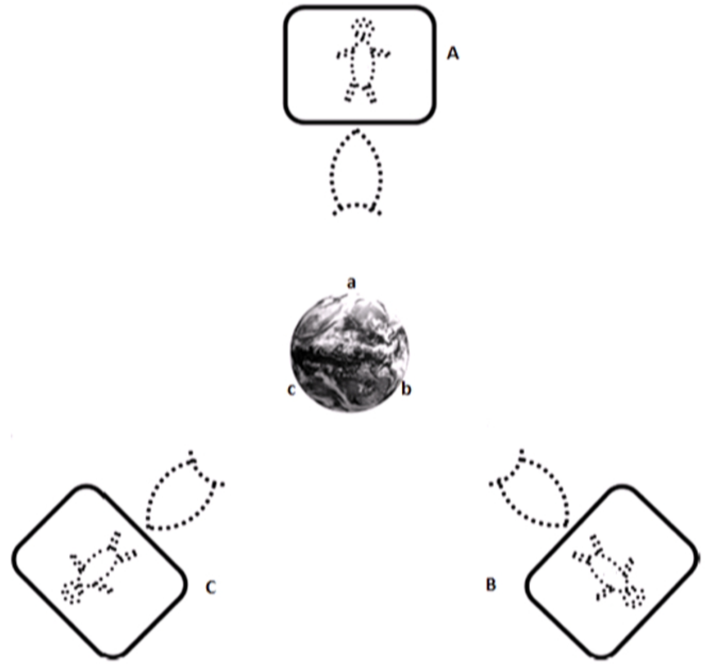
The Born rule from symmetry

- Particle p is in equally weighted superposition of being detected by three symmetrically arranged detectors at locations a, b, and c.

$$\sqrt{\frac{1}{3}}\left(|a\rangle + |b\rangle + |c\rangle\right)_p$$

- Depending on the result, a blind observer O is sent to one of 3 symmetrically arranged rooms, located at A, B and C.

- Symmetry explains why each descendant should assign 1/3 probability to each outcome.
  - Born rule proved for amplitude √(1/N) for symmetric situations.



$$\sqrt{\frac{1}{3}}\left(|a\rangle_p |A\rangle_O + |b\rangle_p |B\rangle_O + |c\rangle_p |C\rangle_O\right)$$

8

The Born rule from locality

- Observer assigns 1/3 probability to being in branch A.
- Now imagine he is told the *other* branches are going to change (e.g. be further split).

$$\sqrt{\frac{1}{3}}\left(|A\rangle+|B\rangle+|C\rangle\right)\xrightarrow{C-world\_splits}\sqrt{\frac{1}{3}}\left(|A\rangle+|B\rangle\right)+\sqrt{\frac{1}{6}}\left(|C_1\rangle+|C_2\rangle\right)$$

- There is no nonlocal action at a distance in the MWI.
  - Vaidman [2015].
- So, observer should *not change* his probability assignment to world A.
  - Born rule proved for *any* branch with amplitude √(1/N).

- For any branch with amplitude √(M/N), split it into M branches each with probability 1/N.
- Probability to find myself in one branch is sum of probability of descendant branches.
  - Born rule proved for any branch with amplitude √(M/N).
    - See Deutsch [1999, sec. 3] for generalisation to irrational coefficients.

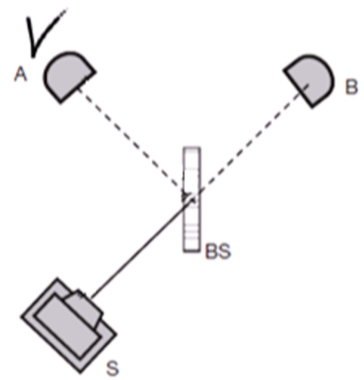
Quantum ontology

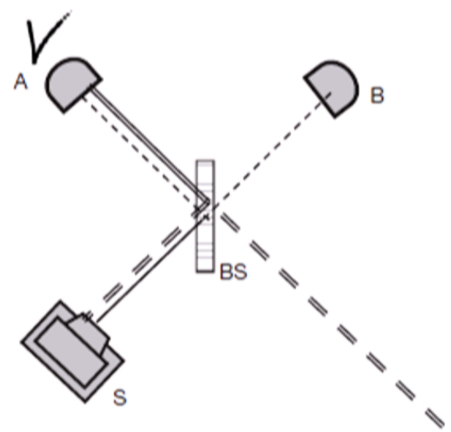
- Fundamental ontology
  - The reality described by a complete physical theory.
    - The wave function.
- Non-fundamental ontology
  - The reality described by true descriptions given in vague language.
    - Artefacts, biological systems, minds, *worlds*...
- World ≡ a unified temporally-extended totality of well-localised macroscopic objects.

10

Refining our concept of "world"

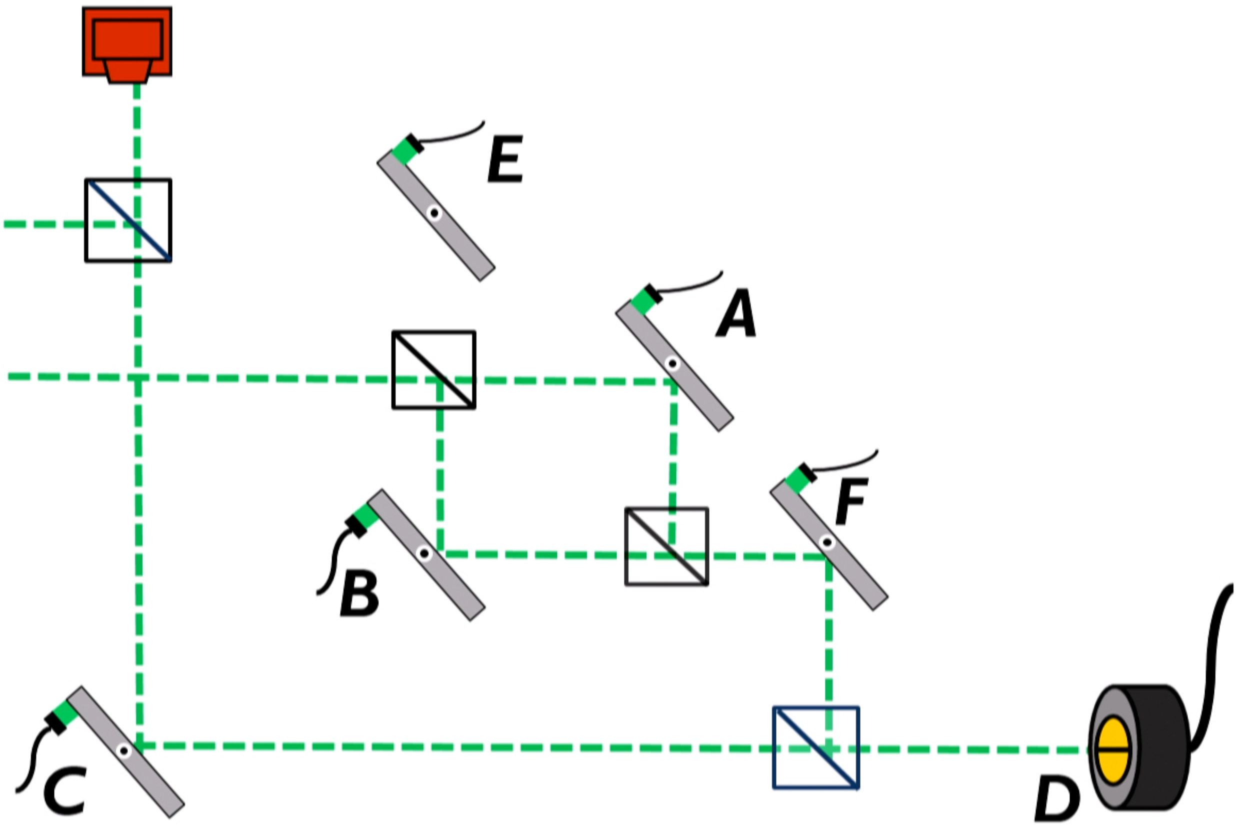
- Can worlds contain microscopic particles?
  - In this case, a particle in a superposition has created two "worlds". Is it "part" of these worlds? If, so, *where was it*?
- Options:
  - (1) The particle was in a superposition of being on two paths.
    - Not so useful: the B-path leaves no trace in the A-world.
  - (2) The particle was on the continuous trajectory where it could pass.
  - (3) The particle was where it left a weak trace.





Past of a pre- and post-selected photon

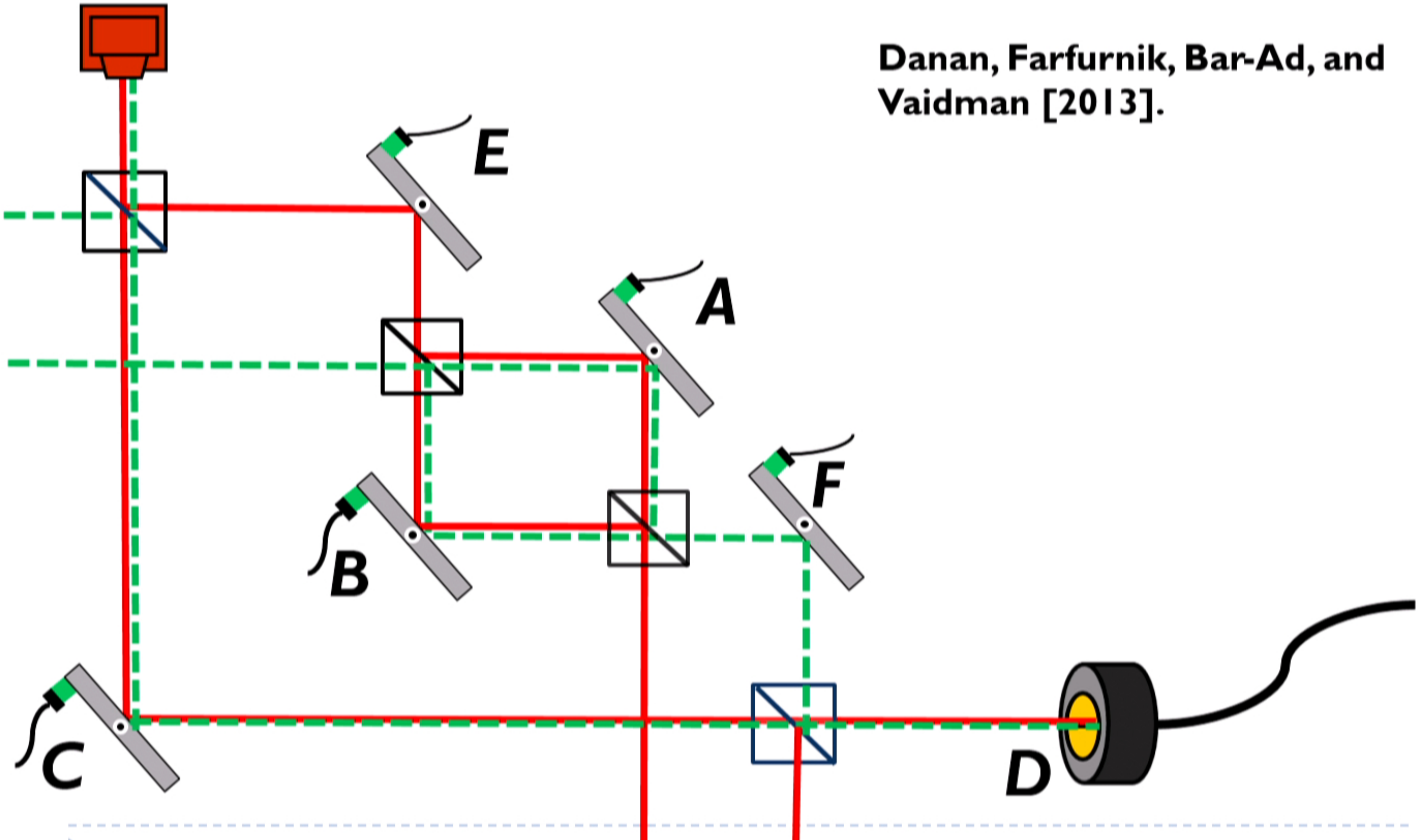
BACKWARD EVOLVING QUANTUM STATE



Past of a pre- and post-selected photon

FORWARD EVOLVING QUANTUM STATE
BACKWARD EVOLVING QUANTUM STATE

Danan, Farfurnik, Bar-Ad, and Vaidman [2013].



Weak trace and "in-world" particles

- Recall our three options:
  - (1) The particle was wherever its Schrödinger wave did not vanish.
    - Not so useful: particle leaves no trace on certain paths.
  - (2) The particle was on the trajectory through which it could pass.
    - Not useful for cases of discontinuous weak trace.
  - (3) The particle was where it left a weak trace.
    - Allows us to describe a broader range of cases.
- TSVF helps us to extend our concept of "world" into the micro-realm.

19

Summary

- According to the MWI, there is no measurement problem, so no need to change QM formalism to resolve it.
- The self-locating uncertainty account offers a solution to the major outstanding problem for the MWI (the probability problem).
- The TSVF helps us to further clarify the ontology of worlds.

Thanks for your attention!

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