Title: Probability in the Everett interpretation: state of play

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Abstract: I will review the current state of the probability problem. My main focus will be on the attempts by David Deutsch and myself to provide a proof of the Born Rule starting from Everettian assumptions, but I will also attempt to locate these attempts within the more general framework of the probability problem.

INTERPRETATION OF QUANTUM MECHANICS 101 – TERM PAPER

Probability in the Everett interpretation and in the rest of physics – compare and contrast

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Making sense of classical probability

Premise: physics uses, and needs to use, a notion of "objective" probabilities. What are they?

3 strategies:

- **Frequentism**
  (doesn't work)
- **Symmetry principles**
  (doesn't work)
- **"Functionalism"**
  (doesn't really even try to work)

Probability as limit of relative frequency

Starting point: we seem to measure probabilities by relative frequencies. Isn't "probability-talk" just shorthand for talk about long-run relative frequency?

Problems:

- The single case (or indeed, the arbitrarily many single cases)

- Circularity

(what we want to prove: as $N \rightarrow \infty$, relative frequency $\rightarrow$ probability.
what we can prove: as $N \rightarrow \infty$, relative frequency $\rightarrow$ probability
... probably.)

Probability from symmetry (I)

Starting point: We seem to use probabilities as a guide to action – in particular, as a way of deciding which bets to take.

"It's much more likely than not that the Democrats will take the White House in '08"

- *arguably* just a statement of opinion – psychology, not physics

"That die is fair" (i.e., each of its faces is as likely as any other to come up)

- *seems* objectively true or false
- *but why?* Because there are six possibilities and nothing to prefer one to another? ("Principle of Indifference") But there aren't six possibilities; there are infinitely many.

Probability from symmetry (II)

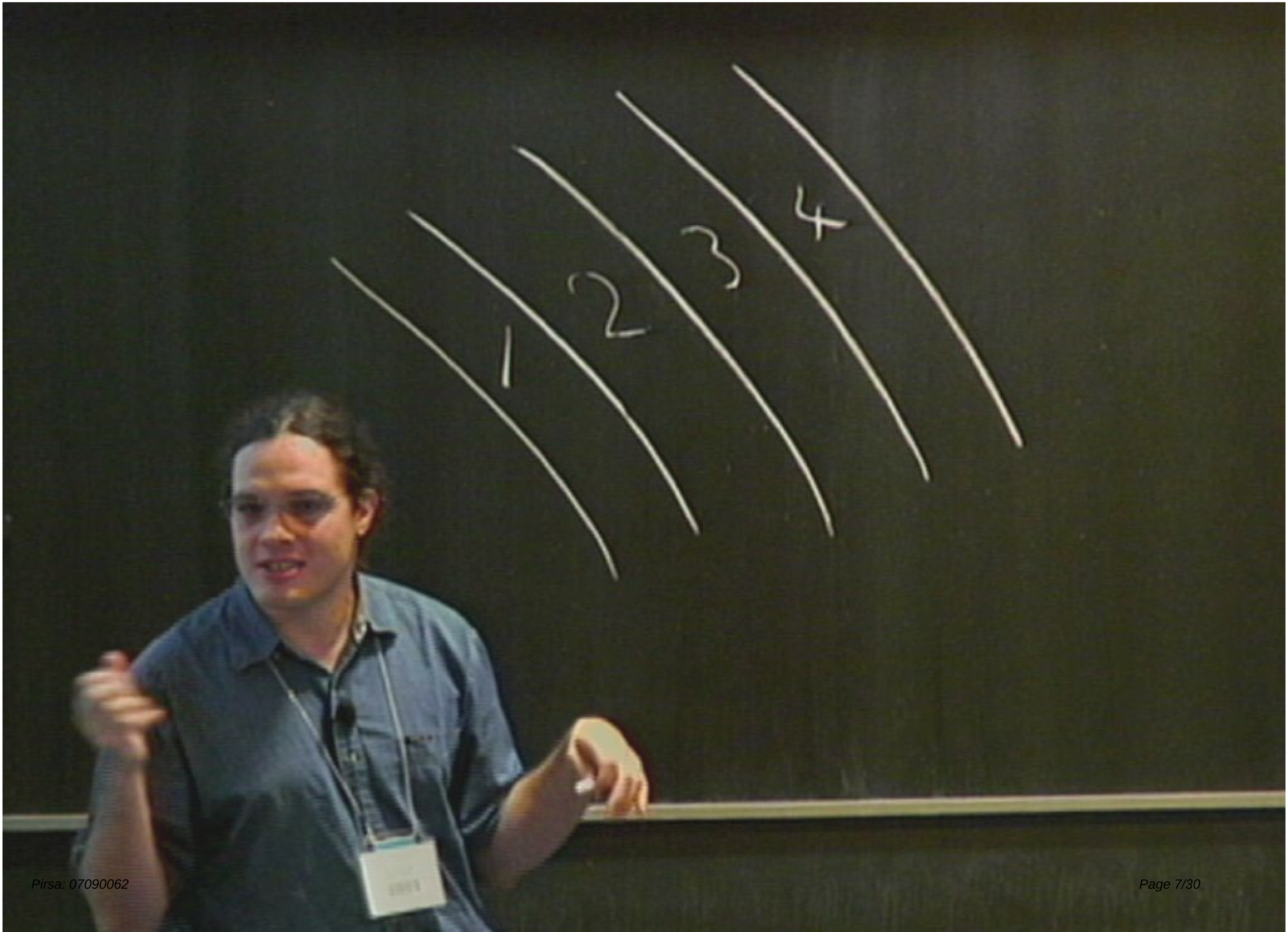
The die is symmetric. The configuration with 6 on the top differs from the configuration with 1 on top only by choice of labels.

That is:

- Swapping the "6" and "1" labels can't change the probability that the "6" side comes up.
- But the swapped system is physically identical to the original system in a state where the "1" side comes up

Problems:

- how do we know swapping the labels doesn't matter? Maybe "1" is lucky! *(dubious)*
- *complete* symmetry isn't compatible with one outcome actually occurring!... we have to supplement the theory with additional *probabilistic* assumptions *(serious)*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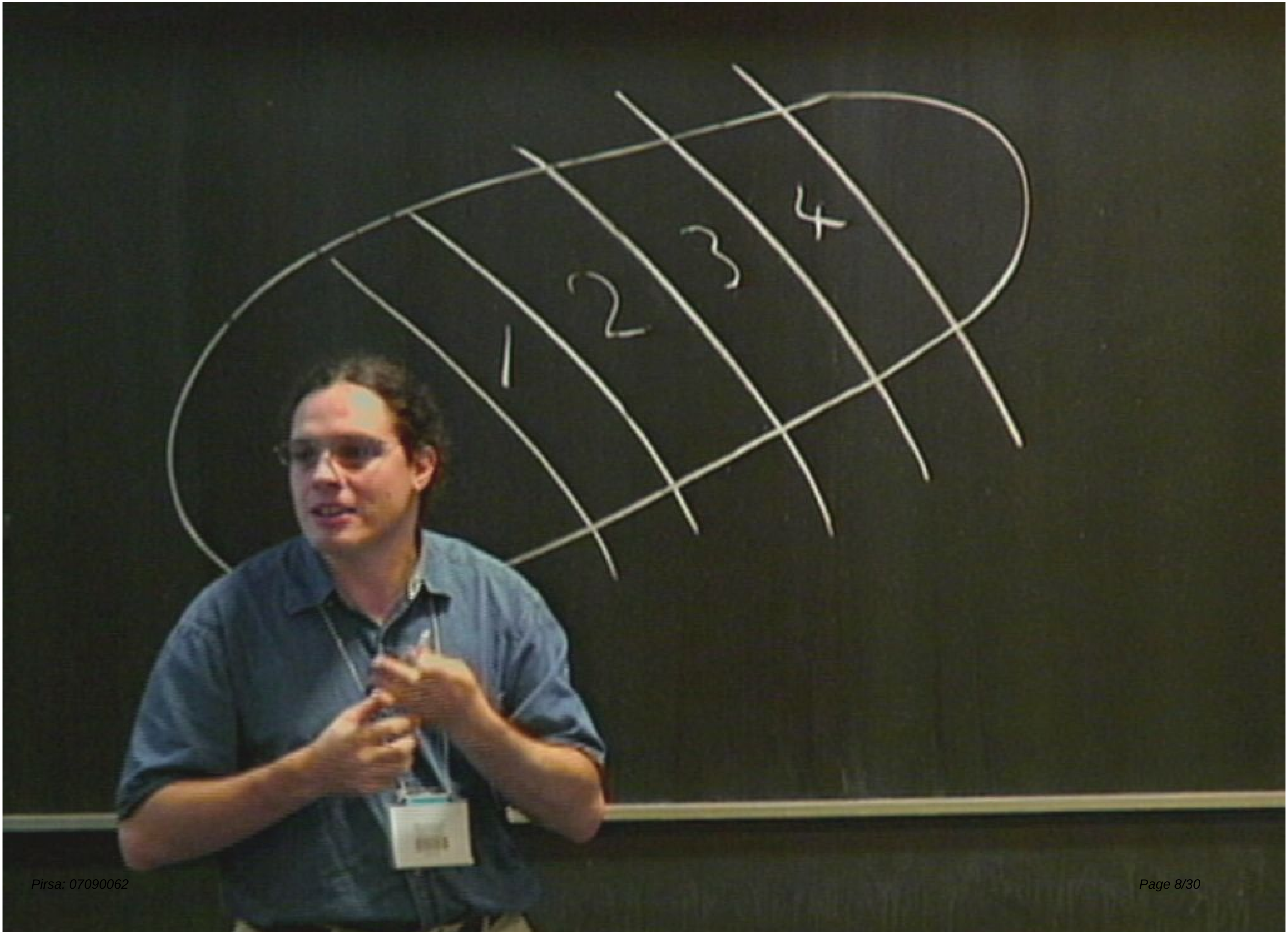
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Functionalising Probability

How do we *use* the probability concept?

- as a guide to action
- as something to be tested by frequency assumptions

(& in fact *if* we understood the former, we could deduce the latter)

So we can say:
"What it *is* for some magnitude in our theory to be probability is for it to be the thing we should use as a guide to action"

Compare:

"What it *is* for some magnitude in our theory to be electric charge is for it to attract other charges like … and to respond to EM fields like …

Everett vs non-Everett probabilities

Non-Everett

"Probability" is a measure on the space of histories of the system.

That "space of histories" is not real: only one history within it is real.

We have *no* understanding of what this measure is, except that…

It's supposed to be some sort of guide to action, and we understand exactly *how* it is…

… but we have no idea *why* it is

Everett

"Probability" is a measure on the space of (emergent, quasiclassical) histories of the system.

The space of histories is real: all its elements are physical (albeit as emergent overlapping structures)

We have a rather *good* understanding (dynamically) of what this measure is, but in addition…

It's supposed to be some sort of guide to action, and we understand exactly *how* it is…

… and just maybe we know *why* it is

Why might probability be *worse* for Everett?

- Because there is no unique outcome?
  (but the "unique outcome" assumption isn't actually leading us to an *understanding* of probability, so why assume it's required?)

- Because every possibility occurs somewhere?
  (but although this is unintuitive, it doesn't stop us using the probability concept, and there are classical analogues)

- Because "mod-squared amplitude" already has a defined meaning in the theory?
  (but why is it any worse to postulate that an *existing* physical magnitude is probability, than to stipulate that a *new* one is probability?)

- Because the obvious rational choice is to value all branches equally?
  (but that only works if we can actually talk sensibly about "the number of branches", and we can't – branching is continuous, branch number is indeterminate.)

Everett and frequentism

In the classical case:

Relative frequency tends to probability … probably

In the quantum case:

Relative frequency tends to weight … with high weight

No better than in the classical case (but no worse either)

Everett and symmetry

In the classical case:

The *laws* may have a certain symmetry, but the *state* can't also have that symmetry, else no asymmetric outcome could obtain.

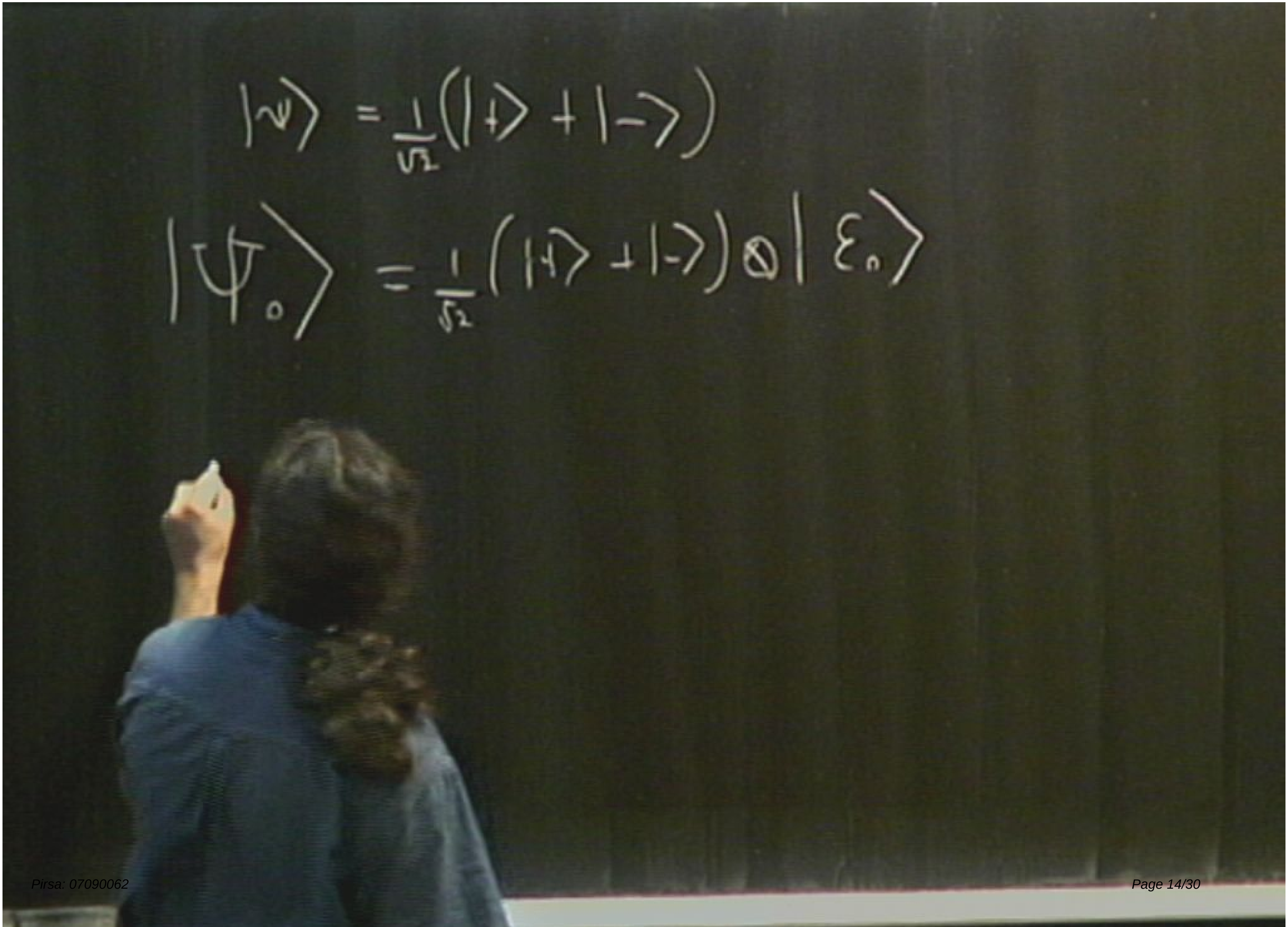
(So we put the symmetry in the *probability distribution over states* and go around in circles)

In the Everettian case:

Not only can the laws have a certain symmetry but the *state itself* can have that symmetry, because there *is* no single asymmetric outcome.

e.g. if I measure |+> + |->, I get two equally weighted branches, one with "+" and one with "-"

So there is a prospect of making a symmetry-based argument *work*.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$$\alpha|+\rangle + \beta|-\rangle$$

$$\Downarrow U$$

$$\alpha|\text{“}+\text{”}\rangle + \beta|\text{“}-\text{”}\rangle$$

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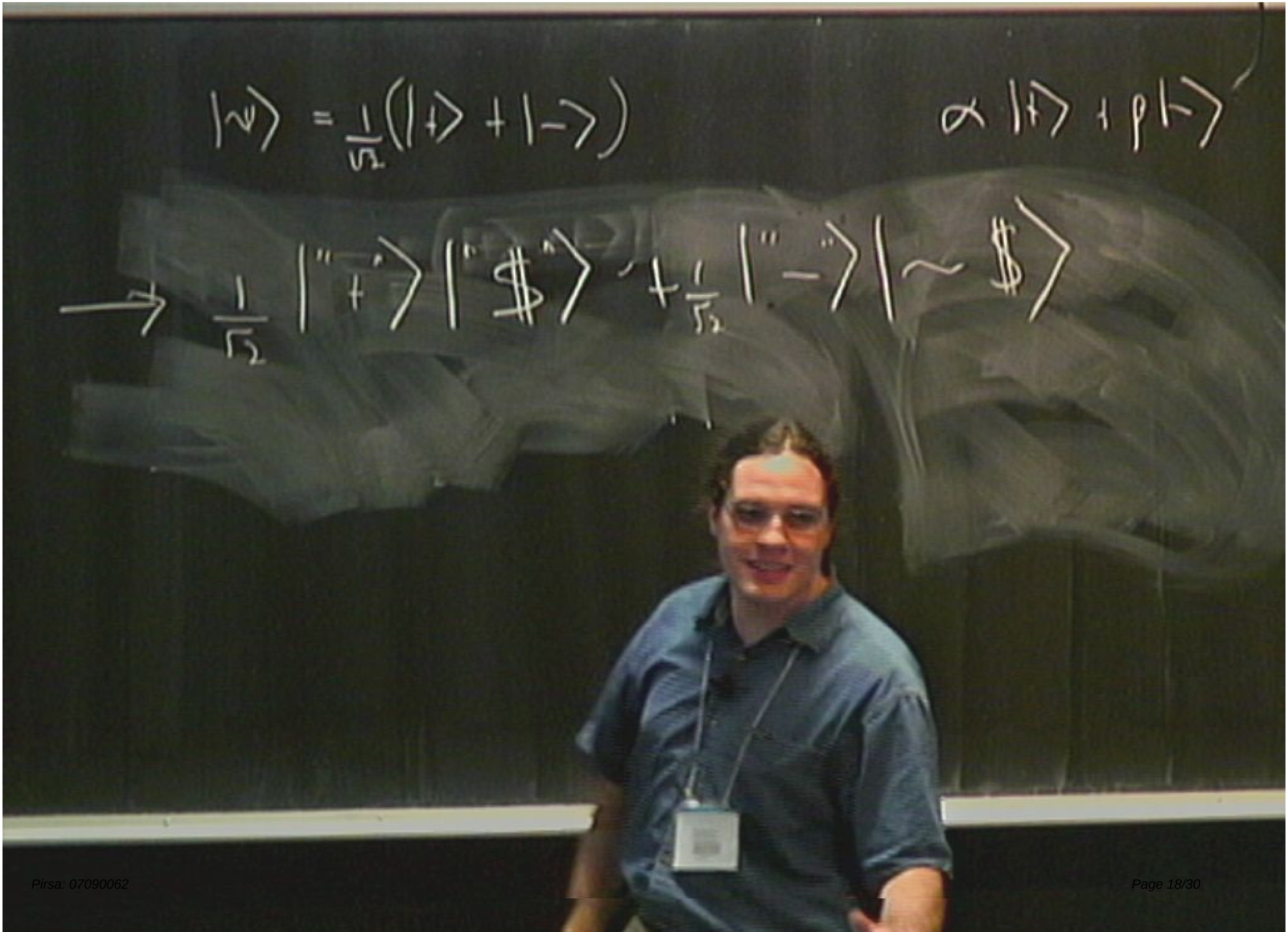
$$\alpha|``+"\rangle + \beta|``-"\rangle$$

$$\rightarrow \alpha|``-"\rangle + \beta|``+"\rangle$$


|ψ⟩ = 1/√2 (|+⟩ + |−⟩)
α|+⟩ + β|−⟩
→ 1/√2 |"+"⟩|"$"⟩ + 1/√2 |"−"⟩|~$⟩

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|+\rangle + |-\rangle\right) \qquad \alpha|+\rangle +$$

$$\rightarrow \frac{1}{\sqrt{2}}|``+"\rangle|``\$"\rangle + \frac{1}{\sqrt{2}}|``-"\rangle|\sim\$\rangle$$

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The "coming up with an alternative" objection

"There *must* be something wrong with that argument, because we can imagine someone choosing their probabilities by:

- Giving each branch equal weight
- Violating non-contextuality
- Using some property of the branches other than (or: in addition to) branch weight to determine probabilities
- Evaluating the probabilities with respect to a state other than the "real" quantum state"

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Successes and "Failures" of the Everett interpretation

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- The mass of the proton
- Why mathematics is effective in physics
- How consciousness can emerge from mere physical matter
- How to solve the Arab-Israeli conflict

… and this is not a problem because *no other* physical theory does either – and these are not in general the sort of things we *expect* our physical theories to solve.

We had no particular reason to expect the Everett interpretation to explain what probability is, either. That it just might do so anyway is an unexpected bonus.

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