Title: Why look beyond quantum theory?

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Abstract: Quantum theory does not define its own landscape. We structure the landscape in response to some contemplated inadequacy of quantum theory. Much foundational work has been motivated by perceived conceptual inadequacies associated with non-locality and the measurement problem. By denying the descriptive function of the quantum state a pragmatist approach may free quantum theory of every conceptual flaw, only to highlight questions we canâ€™t use the theory to address. We should seek to populate the quantum landscape with theories we could use to answer these questions.

Overview

Quantum theory (QT) does not define its own landscape: we do.
So how should we do it?

1) If QT predictions should ever fail, we would need a better theory.
2) If we have no conceptually unproblematic formulation of QT, we need a clearer theory.
3) If QT does not tell us "how it can be like that", we want a theory that will.

(1) Is an important guide in quantum landscaping. Any theory is best tested against well articulated alternatives.

(2) Is *not* an important guide in quantum landscaping. I believe *we have* a conceptually unproblematic formulation of QT. But this leaves many questions unanswered, so

(3) may also be an important guide to the quantum landscaper.

Two kinds of predictive failure

- Failure to yield any predictions
  (Our actual situation in quantum gravity??)
- Yielding *false* predictions.
  (A situation we may face some day)

2. Landscaping and removal

Hasn't QT been proven by experiment? Only in the sense in which 'prove' means 'test'. QT has certainly passed all experimental tests *so far*: but we should continue severely to test it. How?

Compare tests of GR (cf. Will, *Was Einstein Right?*) Here we have a well-developed framework of alternative theories---a GR landscape.
We test GR against these using *eliminative induction.*

On Bayesian or other models of theory confirmation, our confidence in GR may justifiably be increased by elimination of competitors from the landscape: or some day we may end up removing *GR* itself from the landscape!

(Norton [1993] argued that Einstein *discovered* GR by a process of eliminative induction.)

But I have heard physicists say that it is not so easy to set up a similar quantum landscape---a universe of theories including QT that one can use to 'prove' QT by eliminative induction.
QT has exerted a powerful hold on our imagination! How can we break it?

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Measurement

The quantum state assigned to a system does not describe a unique outcome of a measurement on that system. Is this a problem?

A problem arises only if a system's quantum state is supposed to describe its condition and behavior.

That is not why we assign quantum states: we assign them in order to apply the Born rule to generate statistical predictions!

But to say these are just for *measurement results* is to violate Bell's edict banning the term 'measurement' from any precisely formulated theory.

This has motivated the search for a 'measurement'-free alternative to QT---a theory without "the observer".

Non-locality?

Bell proved that any theory meeting a condition he called local causality predicts statistical correlations incompatible with quantum predictions that experiments have since thoroughly verified.

Some have concluded that the world itself is non-local---that there are spooky connections, even between space-like separated events.

But if there are any such connections, QT does not describe them. And Bell even questioned whether we have a formulation of QT precise enough to apply his local causality condition.

Does this provide additional motivation to seek an alternative to QT?

QT has no conceptual rubbish!

Properly understood, QT faces no measurement problem.

A clean formulation of QT may be given without mentioning measurement.

QT is a wonderfully adapted tool for furthering the scientific aims of prediction, control and explanation of natural phenomena.

Any physically situated agent may use it for these purposes, as we have been doing for most of the past century.

In particular, QT helps an agent locally to explain so-called "non-local" correlations.

Neither "the measurement problem" nor non-locality provides a sound motivation for seeking alternatives to QT.

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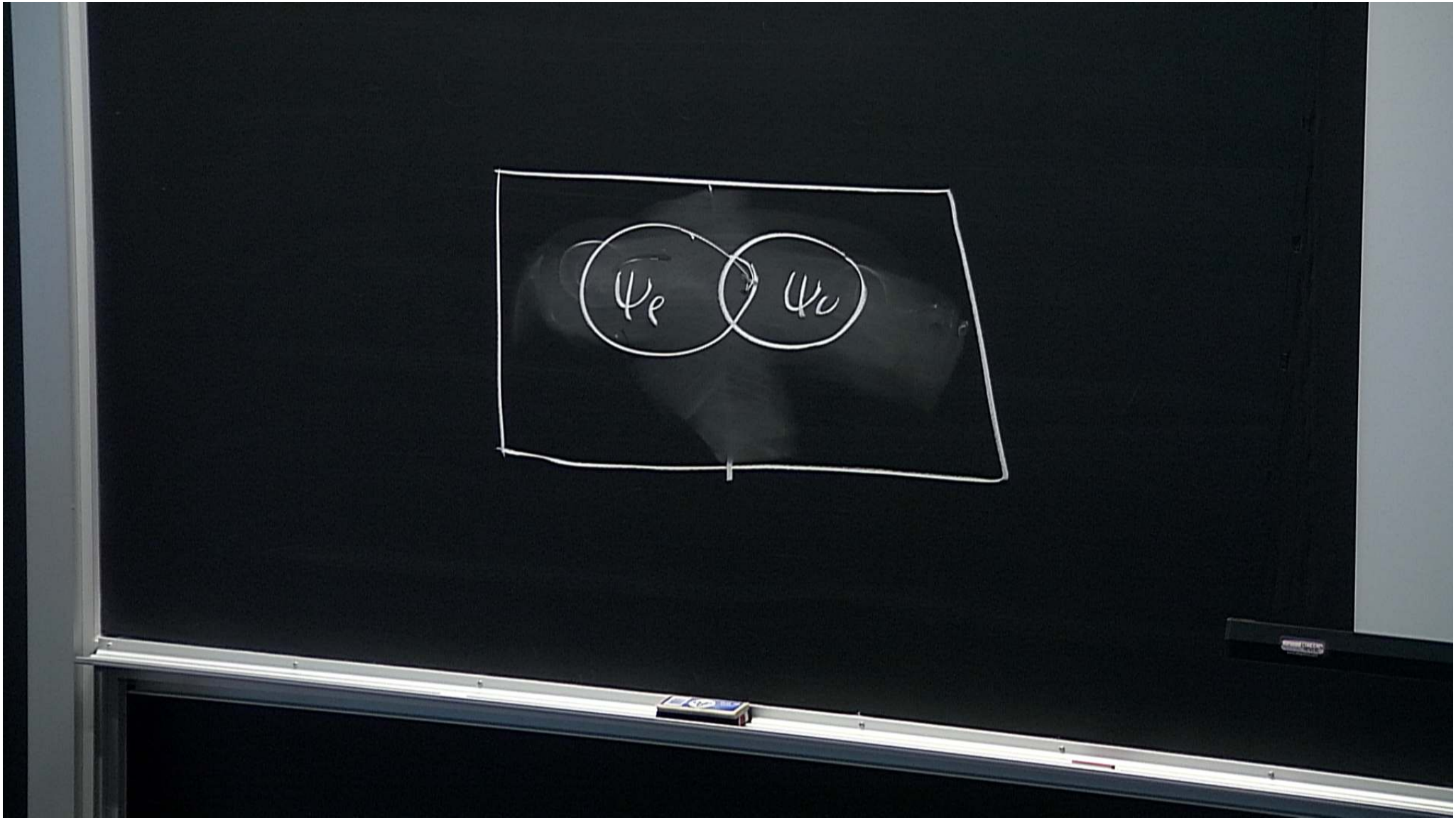
4. The quantum success strategy

(e.g. Healey "Quantum theory: a pragmatist approach" BJPS December 2012)

It is not the role of a quantum state to describe or represent the condition or behavior of a physical system.

Instead, a quantum state functions as a source of good advice about a system's dynamical properties (it's position, energy, current, etc.): an agent's degrees of belief about them should be adjusted using the Born probability rule.

A sufficiently belief-worthy statement about such properties counts as a *prediction* of QT.


ψ_e
ψ_v

ψ-ontic or ψ-epistemic?

Viewed this way, a quantum state does not describe or represent some new structure in the quantum world:
in that sense, the view is not obviously ψ-ontic.

But nor does a quantum state serve to describe or represent the epistemic state of any actual agent:
in that sense, the view is not obviously ψ-epistemic.

A quantum state assignment is objectively true (or false):
in that deflationary sense a quantum state is objectively real.

But its function is not to say what the world is like but to help any agent predict and explain what happens in it.

Since an agent is a physically situated IGUS, differently situated agents should sometimes assign different quantum states to the same system. So
quantum state assignments are objective, but *relational*.

When to apply the Born rule

The Born rule should be applied only to properties of systems "rendered objective" by quantum decoherence.

This is not a physical process described by the Schrödinger equation:
instead, the quantum state functions as an authoritative source of advice on the cognitive significance of a claim about systems' properties.

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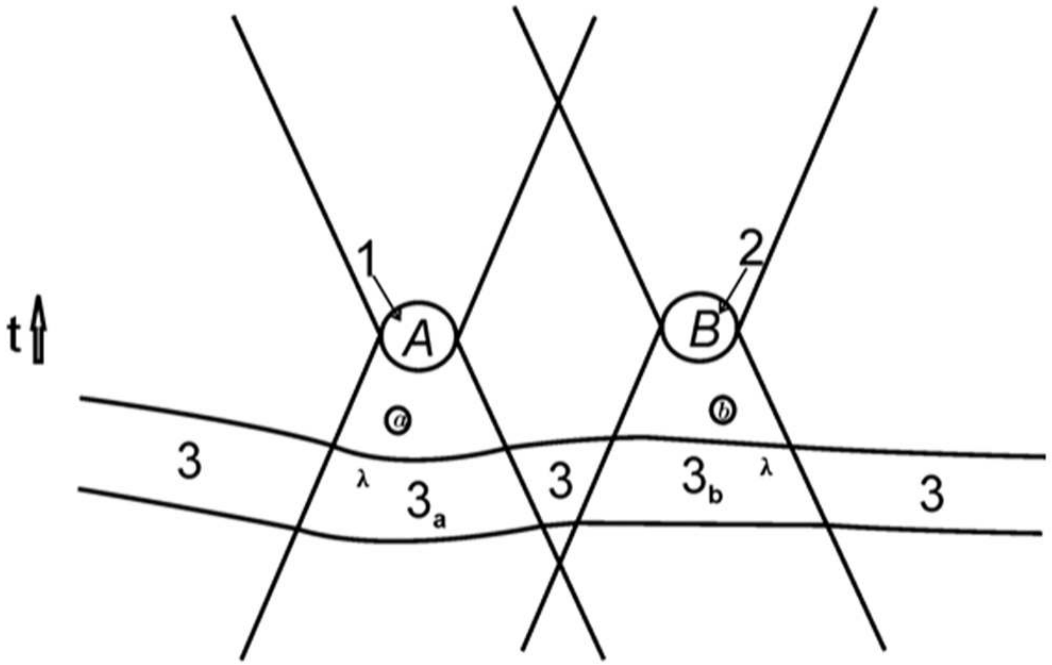
Bell's local causality *condition*

"A theory will be said to be locally causal if the probabilities attached to values of local beables in a space-time region 1 are unaltered by specification of values of local beables in a space-like separated region 2, when what happens in the backward light cone of 1 is already sufficiently specified, for example by a full specification of all local beables in a space-time region $3_{[a]}$" *op. cit.*

sufficiently sharp and clean for mathematics?



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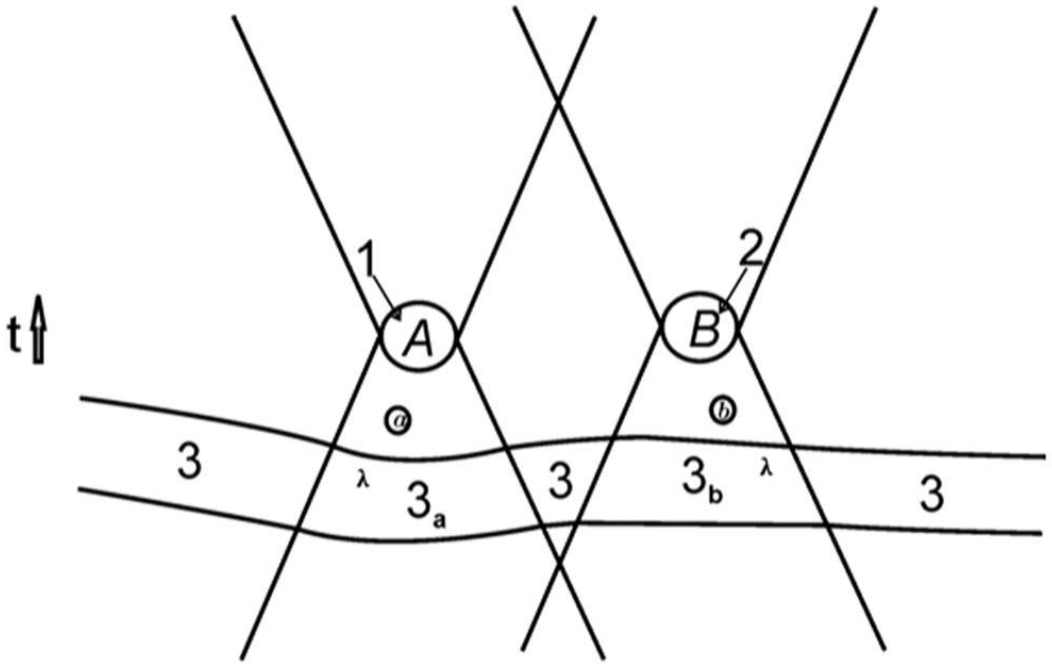

How do Alice and Bob use quantum theory at t_2 to explain Alice's results?

Bob records polarization B for R, ascribes state $|B\rangle$ to L, and uses the Born rule to calculate prob(A)= $|\langle A|B\rangle|^2$ for Alice to record polarization A for L.

Alice ascribes state $\rho = \frac{1}{2}\mathbf{I}$ to L, and uses the Born rule to calculate prob(A)= ½ that she will record polarization A for L.

Each wisely uses the calculated probability to guide his or her expectation about Alice's outcome.

Alice's statistics of her outcomes in many repetitions of the experiment are just what her quantum state $\frac{1}{2}\mathbf{I}$ for L led her to expect, thereby explaining her results.

Bob's statistics for Alice's outcomes (in many repetitions in which his outcome is B) are just what his quantum state $|B\rangle$ for L led him to expect, thereby explaining Alice's results.

This is how each uses quantum theory locally to help explain Alice's results

- There is no question as to which, if either, of the quantum states $|B\rangle$, ½**I** was the *real* state of Alice's photon at t_2.
- The question as to which of the different probabilities $|\langle A|B\rangle|^2$ or ½ gives the *real* "chance" of Alice's outcome at t_2 simply doesn't arise—*even though neither Bob's nor Alice's Born probability is subjective.*
- Alice's and Bob's explanations of Alice's (and also of Bob's) results offer different accounts of what these depend on.

NB This discussion applies independent of the time-order in Alice's frame of the events 1, 2

Recall the condition Bell based on *LC*

"A theory will be said to be locally causal if the probabilities attached to values of local beables in a space-time region 1 are unaltered by specification of values of local beables in a space-like separated region 2, when what happens in the backward light cone of 1 is already sufficiently specified…"

Why should a theory attach (unique) probabilities to values of local beables in a space-time region?

As we've seen, quantum theory *does not*!

Non-locality?

Bell's intuitive local causality *principle (LC)*

"The direct causes (and effects) of events are near by, and even the indirect causes (and effects) are no further away than permitted by the velocity of light"

J.S. Bell, "La Nouvelle Cuisine"

5. Who could ask for anything more?

- QT itself does not give a continuous spacetime description of physical processes
- A quantum state never describes an observation result
- QT does not *entail* classical physics, even in some limit
- QT does not explain the *particular* outcome of an observation

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Alternatives motivated by alleged explanatory deficiencies of QT

- t'Hooft's cellular automaton theory
  "We should plainly ask what is really going on in a world described by quantum mechanics"
  (t'Hooft (2012) arXiv:
- Wharton's Lagrangian only QT
  "This is not a mere *reinterpretation* of quantum theory, but rather an outline of a proposed *explanation*, in the same way that statistical mechanics is an explanation of thermodynamics." (2013) arXiv: 1301.7012v1.
- Adrian Kent's distance-modulated Lagrangian model (?)

Wharton's Lagrangian only theory

Starting from a path-integral formulation of QT, restrictions on paths and imposition of time-symmetric boundary conditions yield an alternative to QT promising a continuous spacetime description of physical processes.

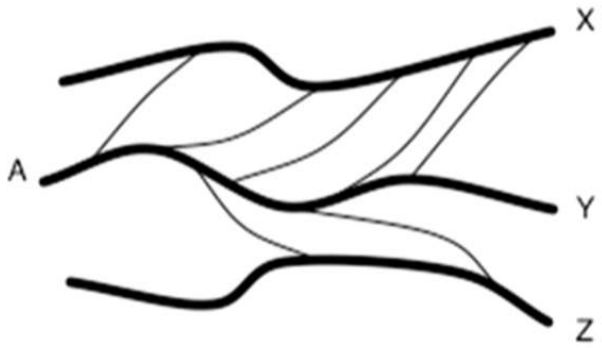
Null **L**agrangian **C**ondition

Apart from external constraints, the only restriction on field variables is that the Lagrangian density is always zero.

Equal ***a priori*** **P**robabilities

All allowable microhistories have an equal *a priori* probability.

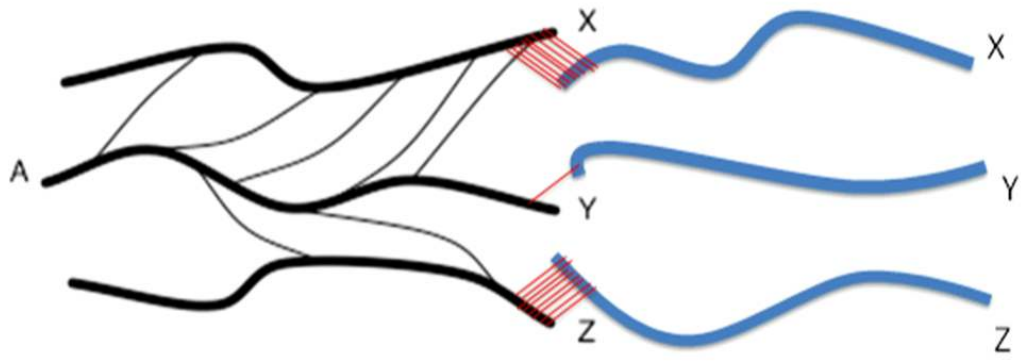
Predictions in a non-dynamical Block Universe



Predictions in a non-dynamical Block Universe

One of these histories is real; the rest are unreal.

A, device



Knowledge of type of future measurement is crucial

Size of solution space → Joint probabilities → Conditional probabilities

$$P(X \mid A) = \frac{P(A,X)}{P(A,X) + P(A,Y) + P(A,Z)} = \frac{5}{5 + 10^{-10} + 2} = 71.4\%$$

6. Einstein's program and Feynman's drain: for Einstein,

Physics is an attempt conceptually to grasp reality as it is thought independently of its being observed. In this sense one speaks of 'physical reality'.

What does not satisfy me in [quantum] theory, from the standpoint of principle, is its attitude towards that which appears to me to be the programmatic aim of all physics: the complete description of any (individual) real situation (as it supposedly exists irrespective of any act of observation or substantiation).

the "real" in physics is to be taken as a type of program, to which we are, however, not forced to cling *a priori*. No one is likely to be inclined to attempt to give up this program within the realm of the "macroscopic" (location of the mark on the paper strip "real"). But the "macroscopic" and the "microscopic" are so inter-related that it appears impracticable to give up this program in the "microscopic" alone. Einstein, 1949.

but, for Feynman…

I think I can safely say that nobody understands quantum mechanics. So do not take the lecture too seriously, feeling that you really have to understand in terms of some model what I am going to describe, but just relax and enjoy it. I am going to tell you what nature behaves like. If you will simply admit that maybe she does behave like this, you will find her a delightful, entrancing thing. Do not keep saying to yourself, if you can possible avoid it, "But how can it be like that?" because you will get 'down the drain', into a blind alley from which nobody has escaped. Nobody knows how it can be like that. Feynman, 1964.

Mixed motives!

"There is nothing absurd or inconsistent about ...the general idea that the state vector serves only as a predictor of probabilities, not a complete description of a physical system. Nevertheless, it would be disappointing if we had to give up the "realist" goal of finding a complete description of physical systems"

Weinberg *Lectures on Quantum Mechanics* (2013), p.95

END

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