

The Anti-Växjö Interpretation of Quantum Mechanics

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Abstract

In this note, I try to accomplish two things. First, I fulfill Andrei Khrennikov’s request that I comment on his “Växjö Interpretation of Quantum Mechanics,” contrasting it with my own present view of the subject matter. Second, I try to paint an image of the hopeful vistas an information-based conception of quantum mechanics indicates.

Andrei Khrennikov has asked me to make a few remarks contrasting my view of the foundations of quantum mechanics to his view—something he calls “The Växjö Interpretation of Quantum Mechanics.”¹ I would certainly be loath to let him down on this occasion, not least of all because of the time and loving devotion he spent in organizing our beautiful 2001 midsummer’s meeting in Växjö. Indeed, those who know Andrei Khrennikov know that he loves nothing better than a good fight! What better tribute might I offer him than a playful article titled “The Anti-Växjö Interpretation?”

Still, the constraint imposed by a timely publication of this proceedings volume makes it hard for me to do the job properly. In the present note I first content myself to giving the reader a few pointers to some of the literature that I think best captures my own view. Following that, I rely on the mode of expression that flows so freely from me when I write a personal letter—but never flows from me when I write a proper paper!—to give a brief survey of what I deem to be the big picture of my efforts. Here goes.

First the pointers. Much of my own (forming) view of what is going on in quantum mechanics is documented at my website:

<http://netlib.bell-labs.com/who/cafuchs/>

In particular, my most relevant document there is the one titled “Quantum States: What the Hell Are They? (*The Post-Växjö Phase Transition*)” Another important website (though some of the material there is not completely in line with the way I see things) is the one of Carlton M. Caves:

<http://info.phys.unm.edu/~caves/>

¹See A. Khrennikov, “Växjö Interpretation of Quantum Mechanics,” [quant-ph/0202107](http://netlib.bell-labs.com/who/cafuchs/quant-ph/0202107).

There, the most important file is the one titled “Resource Material for Promoting the Bayesian View of Everything.”

Beyond that, let me recommend four other articles. The first two are the most technically important for the enterprise I promote in my other contribution to this volume: Namely, to secure a transfer from our present abstract, axiomatic formulation of quantum mechanics to a more physically meaningful one. I think some elements in Lucien Hardy’s papers *almost* carry us to the brink of that. In his work, I think the right emphasis is finally being placed on the right mathematical structures. The papers are:

1. L. Hardy, “Quantum Theory From Five Reasonable Axioms,” [quant-ph/0101012](#).
2. L. Hardy, “Why Quantum Theory?,” [quant-ph/0111068](#).

For its pleasant explanation of the similarities of the “measurement problem” in classical physics and quantum physics, I recommend,

3. R. Duvénhage, “The Nature of Information in Quantum Mechanics,” [quant-ph/0203070](#).

Finally, Chris Timpson’s undergraduate(!) thesis deserves note for its emphasis on the proper way to think about *what* the Church-Turing Thesis is an attempt to formalize:

4. C. G. Timpson, “Information and the Turing Principle: Some Philosophical Considerations,” available at <http://users.ox.ac.uk/~quee0776/>.

Getting ideas like that straight, I now believe, form the better part of the uphill slope we must climb to understand quantum mechanics.

I should point out, however, that in all four of the above references, I think significant improvements could be made by adopting a sufficiently Bayesian stance toward the use and meaning of probability.

Now let me transfer attention to a set of personal letters I include in this contribution. The first three were written to Andrei Khrennikov himself, and have explicitly to do with the contrast between his views and mine. In a nutshell, we both seem to believe that quantum mechanics has something to do with setting “contexts” and seeing what unrolls from that. Where we seem to disagree, however, is in what that has to do with “probability.”

The final two letters—the actual heart of this paper—were written to John Preskill and William Wootters, each in turn. These address various broader themes that I think best set the tone for my present research efforts.

1 28 June 2001, to Khrennikov, “Context Dependent Probability”

Khrennikovism 1: *It was nice to meet you in Växjö and discuss fundamental problems of quantum theory. Unfortunately, I have the impression that my presentation on Contextual Probabilistic Interpretation of quantum theory was not so clear for participants (conversations during lunches and dinners). I try to present my views as short and clear as possible.*

Thank you for valuing my opinion on your ideas; I am flattered. So I treated the problem in a conscientious manner: I downloaded and read three of your papers ([quant-ph/0103065](#), [quant-ph/0105059](#), and [quant-ph/0106073](#)).

I am indeed quite intrigued by the possibility that quantum mechanics may be nothing more than a calculus for comparing probabilities when the experimental context cannot be deleted from

the results it brings about. In vague philosophical terms, I think this is precisely the kind of idea Bohr, Heisenberg, and Pauli were bandying about in constructing their interpretation of quantum mechanics. It is certainly the kind of notion Bohr was trying to get at with his emphasis on “complementarity.” So I would welcome a more precise way (a mathematical way) of expressing the essence of all this. I myself have been attracted to this sort of thing for a long time: it is a large part of the thread connecting my “Notes on a Paulian Idea”²—that is, that the observer sets the context, and, in the words of Pauli, cannot be “detached” from what he finds. Also you can find discussions of it in Sections 4 and 8 of the large paper I was circulating at the conference, “Quantum Foundations in the Light of Quantum Information.”³ I say all this to make it clear that I am more than sympathetic to your program.

However, as much as I would like to tell you otherwise (because you are my friend), I do not see that your present formulation of the problem moves very far toward quantum mechanics in a convincing way. There are problems on at least two levels.

Maybe the most devastating and immediate is your move between Eqs. (5) and (6) of `quant-ph/0106073`. (I’ll focus on that paper for specificity since I did not see you make a stronger argument in either of the other two papers.) You write:

The perturbation term $\delta(\mathcal{S}, \mathcal{S}')$ depends on absolute magnitudes of probabilities. It would be natural to introduce normalized coefficient of the context transition . . .

The question anyone will ask is, “Why is this natural?” What compels the precise form of the normalization other than that it forces the equation to look of a more quantum mechanical form. Why did you choose the square root rather than the third root, say? Indeed, why not divide by the absolute value of δ , or the exponential of δ , or any other combination of functions one could pull out of a hat? To put it not so gently, it looks as if you built the desired answer in at the outset, with little justification otherwise.

The second level of my problem is that, even if you do get this far, how do you make the further step to vector space representations of quantum mechanics? Why are observables POVMs and not other exotic entities? What leads us to the starting point of Gleason’s theorem? Etc., etc.? I don’t see that you have enough structure to do that. But more importantly, until you have done that I would have to say that your theory remains fairly empty in making a connection to quantum mechanics. Too empty.

The way I view the problem presently is that, indeed, quantum theory is a theory of contextual probabilities. This much we agree on: within each context, quantum probabilities are nothing more than standard Kolmogorovian probabilities. But the contexts are set by the structure of the Positive Operator-Valued Measures: one experimental context, one POVM. The glue that pastes the POVMs together into a unified Hilbert space is Gleason’s “noncontextuality assumption”: where two POVMs overlap, the probability assignments for those outcomes must not depend upon the context. Putting those two ideas together, one derives the structure of the quantum state. The quantum state (uniquely) specifies a *compendium* of probabilities, one for each context. And thus there are transformation rules for deriving probabilities in one context from another. This has the flavor of your program. But getting to that starting point from more general considerations—as you would like to do (I think)—is the challenge I haven’t yet seen fulfilled.

I very much hope that I have not offended you with these comments. I greatly respect your program. But because of that I want much from it. I want it to stretch our understanding. John

²See C. A. Fuchs, “Notes on a Paulian Idea: Foundational, Historical, Anecdotal & Forward-Looking Thoughts on the Quantum (Selected Correspondence),” `quant-ph/0105039`.

³See C. A. Fuchs, “Quantum Foundations in the Light of Quantum Information,” `quant-ph/0106166`.

Wheeler used to say, “We must make as many mistakes as we can, as fast as we can, or we’ll never have a hope of gaining a true understanding!” I let that philosophy rule my research life. Thus I can only commend you for your exploration, and hold the strongest hope that something firm will come from it with a little more work and contemplation.

2 4 July 2001, to Khrennikov, “Invitation”

Khrennikovism 2: *Yes, this is very well! However, for me, the only bridge between “reality” and our subjective description is given by relative frequencies.*

But there other ways to make the bridge: this is what gambling situations (like the Dutch-book argument that Rüdiger Schack spoke about) ⁴ are about. They give a *nonfrequency operational* definition to probabilities. Subjective probabilities make their OBJECTIVE mark on the world by specifying how an agent should act when confronted with them.

3 4 July 2001, to Khrennikov, “Context Dependent Subjective Probability”

Khrennikovism 3: *P.S. But! How can you unify contextuality with subjective probability?*

I just don’t see this as a problem. In choosing one experiment over another, I choose one context over another. The experiment elicits the world to do something. To say that the world is indeterministic means simply that I cannot predict with certainty what it will do in response to my action. Instead, I say what I can in the form of a probability assignment. My probability assignment comes about from the information available to me (how the system reacted in other contexts, etc., etc.). Similarly for you, even though your information may not be the same as mine. The OBJECTIVE content of the probability assignment comes from the fact that *no one* can make *tighter* predictions for the outcomes of experiments than specified by the quantum mechanical laws. Or to say it still another way, it is the very existence of transformation *rules* from one context to another that expresses an objective content for the theory. Those rules apply to me as well as to you, even though our probability assignments *within* each context may be completely different (because they are subjective). But, if one of us follows the proper transformation rules—the quantum rules—for going to one context from another, while the other of us does not, then one of us will be able to take advantage of the other in a gambling match. The one of us that ignores the structure of the world will be bitten by it!

4 18 February 2002, to Preskill, “Psychology 101”

Let me reply to some of your points in a way that doesn’t reflect their original order.

Preskillism 1: *In the past I have sensed that you and I differ in how we regard ourselves. I believe that I am just another physical system governed by the same fundamental laws as any other system. You seem to think there is a fundamental distinction between yourself and the system you are observing. To me the Everett view is appealing because it turns away from this egocentrism.*

⁴See C. M. Caves, “Betting Probabilities and the Dutch Book,” at <http://info.phys.unm.edu/~caves/reports/reports.html>.

It's funny, but when I read this, my reaction went in two rather peculiar directions. First I thought, "I wonder if, in the end, the only thing the great quantum foundations struggles will leave behind is a few psychological observations? If so, what a shame." But secondly, I imagined Galileo hoisting me up to the top of the Leaning Tower of Pisa and dropping me off it along with his two famous stones. Even though I cursed and screamed the whole way down, I went "splat" at the same time that they went "thud."

Here's the psychological thought in a little more detail. One of the things that bugs me about the Everett view is what I consider *its* extreme egocentrism! Now, how can that be—both of us accusing the other's view as *the* egocentric view? I'll tell you what I think, trying to express the problem from both sides of the fence.

My side gets to go first. What I find egocentric about the Everett point of view is the way it purports to be a means for us little finite beings to get outside the universe and imagine what it is doing as a whole. And what is it doing as a whole? Something fantastic? Something almost undreamable?! Something inexpressible in the words of man?!?! Nope. It's conforming to a scheme some guy dreamed up in the 1950s.

This whole fantastic universe can be boiled down to something representable within one of its most insignificant components—the brain of man. Even toying with that idea, strikes me as an egocentrism beyond belief. The universe makes use of no principle that cannot already be stuffed into the head of an average PhD in physics? The chain of logic that leads to the truth of the four-color theorem (apparently) can't be stuffed into our heads, but the ultimate operating principle for all that "is" and "can be" can?

It's a funny thing: I don't think I've met anyone who would imagine that mathematics will ever come to an end. Or even that it *can* come to an end. There'll always be new axiom sets to play with, new formal structures to write down. But with physics it's a completely different story. People are always wanting to say, "Well we've finally gotten there." Or, "Even though we're not there, we're pretty damned close." It's OK, even condoned, to have Dreams of a Final Theory. From this point of view, all the mathematics yet to come is worthless as far as the essence of the universe goes; the wad was already shot.

You get the point. It's a psychological one, but it's one that I find overwhelmingly powerful. It is that anytime any of us ever has the chutzpah to say, "Here's an ultimate statement about reality," or even a potentially ultimate one, what we're really doing is painting the world in the image of man. We're saying that the measly concepts we've managed to develop up to this point in time fit the world in a way that none of our previous concepts have, that none in the future will ever do better, and, most importantly, we view this not as a statement about ourselves and the situation set by our present evolutionary and intellectual stage, but rather as a property of the universe itself.

Now let me start moving toward the other side of the fence. The question someone like me—someone who has these kinds of blasphemous thoughts—has to ask himself is, how can I ever hope to be a scientist in spite of all this? What can science and all the great achievements it has given rise to in the last 400 years be about if one chooses to suspend one's dreams of a final theory at the very outset? (Or, to tribute Johnny [Wheeler], how can one have law without law?)

I think the solution is in nothing other than holding firmly—absolutely firmly—to the belief that we, the scientific agents, are physical systems in essence and composition no different than much of the rest of the world. But if we do hold firmly to that—in a way that I do not see the Everettistas holding to it—we have to recognize that what we're doing in the game of science is swimming in the thick middle of things. We're swimming in this undulant sea, and doing our best to keep our heads above the water: All the concepts that arise in a physical theory must be interpreted to do with points of view we can construct from *within* the world.

That is to say, we have to loosen the idea that a physical law is a mirror image of what “is” in the world, and replace it with something that expresses instead how each of us can best cope with and hope to take advantage of the world exterior to ourselves. This, it seems to me, is something that by its very definition can be stuffed into the human brain. The current state of science is our presently best known means for survival. A scientific theory indeed, from this point of view, is yet another expression of Darwinian principles. Scientific theories evolve and survive because the survivors have a kind of staying power that none of the rest of the competition have. Not because they are part of the blueprint of the universe.

The situation of quantum mechanics—I become ever more convinced—illustrates this immersion of the scientific agent in the world more clearly than any physical theory contemplated to date. That is because it tells you you have to strain really hard and strip away most of the theory’s operational content, most of its workaday usefulness, to make sense of it as a reflection of “what is” (independent of the agent) and—importantly—you insist on doing that for all the terms in the theory.

I know you’re going to find the last sentence debatable, but that is what I see as the danger in the Everett point of view: You are able—or at least purportedly so—to view the universal state as a reflection of something, but at the cost of deleting all the concrete things it was meant to reflect in the first place. What I mean by this is, if we take any concrete situation in quantum mechanics—a system, a measuring device, and some kind of model for the beginning stages of a measurement—we can indeed construct a Church-of-the-Larger-Hilbert space description of it. I’ll grant you that. But try to go the other way around without any foreknowledge of the “measurement”: Start with the Church, and try to derive from it that a concrete measurement has taken place, and you encounter an embarrassment of riches. You don’t know how to identify the valid worlds, etc., etc. (And, if you ask me, invoking decoherence as a cure-all is little more than a statement of faith that some guy in Los Alamos has the all the answers to all the tough questions the rest of us are too lazy to work out.)

So, I myself am left with a view of quantum mechanics for which the main terms in the theory—the quantum states—express nothing more than the gambling commitments I’m willing to make at any moment. When I encounter various other pieces of the world, if I am rational—that is to say, Darwinian-optimal—I should use the stimulations those pieces give me to reevaluate my commitments. This is what quantum state change is about. The REALITY of the world I am dealing with is captured by two things in the present picture:

1. I posit systems with which I find myself having encounters, and
2. I am not able to see in a deterministic fashion the stimulations (call them measurement outcomes, if you like) those systems will give me—something comes into me from the outside that takes me by surprise.

OK, now let me put myself squarely in your pasture. You worry that having those main terms in the theory refer to *my* (or *your*, or Joe Buck’s)⁵ gambling commitments, is committing a kind of egocentrism. What respectable theory would refer to my particular vices, my desires, my bank account in making its most important statements?

This is going to surprise you now, but I agree with you wholeheartedly. Even enthusiastically so. Where I seem to disagree is that I do not find this a good reason to promote those vices, those commitments to an unearthly realm and call them “states of the universe” (or relative states therein). Instead, it seems to me to be a call to recognize them for what they are and to redouble our efforts for getting at the real nub of the matter.

⁵See pages 125 and 156 of [quant-ph/0105039](#).

Let me try to give you a way of thinking about this that you might respect. What was Einstein's greatest achievement in getting at general relativity? For the purposes of the present exposition, I would say it was in his recognizing that the "gravitational field" one feels in an accelerating elevator is just a coordinate effect—it is something that is induced purely with respect to the description of an observer. In this light, the program of trying to develop general relativity thus boiled down to trying to recognize all the things within gravitational and motional phenomena that should be viewed as consequences of our coordinate choices. Or to use a phrase I've come to like, it was in identifying all the things that can be viewed as "numerically additional" to the observer-free situation which come about purely by bringing the observer (scientific agent, coordinate system, etc.) onto the scene.

Now the point is, that was a really useful process. For in weeding out all the things that can be viewed as "merely" coordinate effects, the fruit left behind could be seen in a clear view for the first time: It was the Riemannian manifold that we call spacetime.

What I dream for in my foundational program for quantum mechanics is something just about like that. Weed out all the terms that have to do with gambling commitments (I used to call it information, knowledge, or belief), and what is left behind will play a role much like Einstein's manifold.

This much of the program, I hope and suspect you will understand even if you are not sympathetic to it. But, I don't know, you might be sympathetic to it. (Especially if I've done a good job above.) However, it is also true that you have rightly suspected some tendencies in me that go further. In particular, in opposition to the picture of general relativity, where reintroducing the coordinate system—i.e., reintroducing the observer—changes nothing about the manifold (it only tells us what kind of sensations the observer will pick up), I do not suspect the same of the quantum world. This is why I recommend to all my friends that they read William James's little article "The Sentiment of Rationality."⁶ It sort of sets the right mindset, even though it has nothing to do with quantum mechanics (other than in the efficacy of taking gambles) and goes much further on religion than I myself would go.

Anyway, here I suspect that reintroducing the observer will be more like introducing matter into pure spacetime, rather than simply gridding it off with a coordinate system. "Matter tells spacetime how to curve *when it is there*, and spacetime tells matter how to move *when it is there*." Observers, scientific agents, a necessary part of reality? No. But do they tend to change things once they are on the scene. Yes. Or at least that's the idea.

Does that mean that the scientific agent is something outside of physical law? Well, to give this an answer, you've got to go back and be very careful to use the picture of "physical law" that I built up at the beginning of the essay. What we are "governed" by, God only knows. He's the one, if anyone, who sits outside the physical universe and has a chance to look back at it whenever he pleases. Our task is to build up as good and solid a set of beliefs as we can from within it. In that way, we increase our survival power, and use our spare time to try to bring forth a few progeny of our own. (I used the word "governed," by the way, because you had used it above.)

If Galileo had dropped me from the tower, I feel pretty confident that I would have gone splat.

5 25 February 2002, to Wootters, "A Wonderful Life"

Thanks for the two notes, and wow, thanks for reading the James essay. Your questions were anything but naive. In fact, they were much needed. In trying to answer them, I think I significantly

⁶W. James, "The Sentiment of Rationality," in *The Writings of William James: A Comprehensive Edition*, edited with an introduction by J. J. McDermott (Modern Library, Random House, New York, 1967), pp. 317–345.

clarified—to myself even!—what I’m hoping to get at. Besides, I certainly don’t have a final stand yet; the whole point of view is in the process of formation and questions like yours really help.

I’ll do my best to reply to your questions below, and in the process I think I’ll finally compose what I’ve been wanting to say about your “private-world-within-entanglement” musings. At the end of the note, I’ll list some of the open questions on my mind. (These are likely to be the naive ones!)

Woottersism 1: *Of course I’m very sympathetic to the perspective you express in this paragraph ... but couldn’t one still argue that as a matter of methodology, the tactic of pretending that we can know the whole story has served science well? We make up a model of the world, and this model gives us something to shoot at. We hang on to the model until we have found an explicit flaw in it (other than the flaw of hubris). And then we move on to a new model.*

I find this an interesting question. On the one hand, I think this strategy does work well in advancing science. On the other hand, scientists (and others) are much too prone to accept as true the pragmatic lie that says we can fully understand the world.

Your note to John [Preskill] goes some way toward laying out an alternative methodology. You speak of science in Darwinian terms: the most successful theories survive. How then do we proceed as scientists? I suppose the answer is that we still make up theories and test them, but the theories are not tentative descriptions of the world. Rather, theories are schemes for making predictions. But you obviously also want to say that our theories tell us something about reality, even if they are not descriptions of reality. Moreover, our theories will tell us more about reality if we identify and remove from them those aspects that are subjective. So your view of science is not entirely operational. There is realism in the background.

Have I understood you correctly?

Yes there is certainly a kind of realism working in the back of my mind, if what you mean by “realism” is that one can imagine a world which never gives rise to man or sentience of any kind. This, from my view, would be a world without science, for there would be no scientific agents theorizing within it. This is what I mean by realism: That man is not a priori the be-all and end-all of the world. (The qualification “a priori” is important and I’ll come back to it later.)

A quick consequence of this view is that I believe I eschew all forms of idealism. Instead, I would say all our evidence for the reality of the world comes from without us, i.e., not from within us. We do not hold evidence for an independent world by holding some kind of transcendental knowledge. Nor do we hold it from the practical and technological successes of our past and present conceptions of the world’s essence. It is just the opposite. We believe in a world external to ourselves precisely because we find ourselves getting unpredictable kicks (from the world) all the time. If we could predict everything to the final T as Laplace had wanted us to, it seems to me, we might as well be living a dream.

To maybe put it in an overly poetic and not completely accurate way, the reality of the world is not in what we capture with our theories, but rather in all the stuff we don’t. To make this concrete, take quantum mechanics and consider setting up all the equipment necessary to prepare a system in a state Π and to measure some noncommuting observable H . (In a sense, all that equipment is just an extension of ourselves and not so very different in character from a prosthetic hand.) Which eigenstate of H we will end up getting as our outcome, we cannot say. We can draw up some subjective probabilities for the occurrence of the various possibilities, but that’s as far as we can go. (Or at least that’s what quantum mechanics tells us.) Thus, I would say, in such a quantum measurement we touch the reality of the world in the most essential of ways.

With that said, I now want to be very careful to distance this conception of reality, from what I'm seeking in the foundation game of quantum mechanics. Here's the way I originally put it to John [Preskill] the other day. Let me repeat a good bit of it so that it's at the top of your mind:

OK, now let me put myself squarely in your pasture. You worry that having those main terms in the theory refer to *my* (or *your*, or Joe Buck's) gambling commitments, is committing a kind of egocentrism. What respectable theory would refer to my particular vices, my desires, my bank account in making its most important statements?

This is going to surprise you now, but I agree with you wholeheartedly. Even enthusiastically so. Where I seem to disagree is that I do not find this a good reason to promote those vices, those commitments to an unearthly realm and call them "states of the universe" (or relative states therein). Instead, it seems to me to be a call to recognize them for what they are and to redouble our efforts for getting at the real nub of the matter. . . .

What I dream for in my foundational program for quantum mechanics is something just about like that. Weed out all the terms that have to do with gambling commitments (I used to call it information, knowledge, or belief), and what is left behind will play a role much like Einstein's manifold.

This much of the program, I hope and suspect you will understand even if you are not sympathetic to it. . . . However, it is also true that you have rightly suspected some tendencies in me that go further. In particular, in opposition to the picture of general relativity, where reintroducing the coordinate system—i.e., reintroducing the observer—changes nothing about the manifold (it only tells us what kind of sensations the observer will pick up), I do not suspect the same of the quantum world. . . .

Anyway, here I suspect that reintroducing the observer will be more like introducing matter into pure spacetime, rather than simply gridding it off with a coordinate system. "Matter tells spacetime how to curve *when it is there*, and spacetime tells matter how to move *when it is there*." Observers, scientific agents, a necessary part of reality? No. But do they tend to change things once they are on the scene. Yes. Or at least that's the idea.

From some of my choices of words, I think you probably got the impression that this thing—this structure within quantum mechanics—that I'm hoping to find at the end of the day is meant to be a model of "reality." Or at least our "current best guess" of what reality is. But no, that's not really what I want. And your questions helped make that much clearer to me. Remember, for me, the mark of reality is its indescribability.

What I'm asking for instead is something like what one finds in the old movie, *It's a Wonderful Life*. That is to say, in our scientific theories, we codify some fraction of what we know about manipulating the world and conditionally predicting the phenomena about us. However, suppose we wanted to get at a measure of our place in the world. How would we quantify it, or at least qualify it? That is, how might we ask how important our lives and agential actions are with respect to the theory we ourselves laid out?

Our only tool, of course, is the theory; for it defines the frame for optimal thinking (and imagination) at any given moment. We can only gauge our measure by deleting the free variable that is ourselves and seeing what is left behind. You surely remember what George Bailey found when his guardian angel granted his wish in *It's a Wonderful Life*. He found that his life mattered. So too is what I suspect we will find in quantum mechanics.

But all of that is the sort of thing I won't be able to say in a conference presentation for quite some time. It's the sort of thing that we discussed once before, in the context of some Jamesian quote.⁷ It's the underground reason for the philosophy.

At the level of convincing our peers, let me put it to you this way. Within quantum mechanics, there is an invariant piece which is common to all of us by the very fact of our accepting the theory. That is what we are in search of because in some sense—which need not pertain to a realistic conception of a theory's correspondence to nature—it is the core of the theory. It is the single part that we agree upon, even when we agree upon nothing else. In the direction I am seeking to explore, the quantum state is “numerically additional” to that core. (That is, the quantum state is a compendium of Bayesian “beliefs” or “gambling commitments” and is thus susceptible to the type of analysis James gives in his “Sentiment of Rationality.” Our particular choice of a quantum state is something extra that we carry into the world.)

I hope that clears up some of the mystery of my thoughts for you—it did for me. Given John's implicit acceptance of the idea that “a true theory is a mirror image of nature,” I should not have said in my note that I agreed with him “wholeheartedly.” I do not intend for *any* part of the formal structure of quantum mechanics to be a mirror image of nature (in the sense of a proposed final theory). However, I do not intend to give up the reality of our world either.

From my point of view, the only “true” reality that creeps into quantum mechanics is “in the differential”—i.e., in the changes we induce upon our (personal) quantum states for this and that due to any stimuli we give to or take from the outside world. That, however, is a pretty amorphous thing as theoretical entities go. It is little more than what might have been called in older language, the measurement “click.”

There is a temptation to go further—to say that the POVM element E_b associated with a measurement outcome b is itself an element of reality. But I think that has to be resisted at all costs. There are several arguments one can use to show that the *ascription* of a particular POVM to a measurement phenomenon is a subjective judgment at the same level of subjectivity as the quantum state itself. (In fact the two go hand in hand, one cannot support the subjectivity of the quantum state without also taking the subjectivity of the POVM.) Instead, one should view the (theoretical) ascription of a POVM to an actual measurement device as an attempt to set the significance and meaning of the “click” it elicits. Similarly for the Krausian quantum operation associated with the measurement: It describes the subjective judgment we use for updating our quantum-state assignment in the light of the “click.” (If you want more details about these arguments, I can forward you some of my old write-ups on the subject.)

⁷In particular I was thinking about this quote of William James:

The history of philosophy is to a great extent that of a certain clash of human temperaments. Undignified as such a treatment may seem to some of my colleagues, I shall have to take account of this clash and explain a good many of the divergencies of philosophies by it. Of whatever temperament a professional philosopher is, he tries, when philosophizing, to sink the fact of his temperament. Temperament is no conventionally recognized reason, so he urges impersonal reasons only for his conclusions. Yet his temperament really gives him a stronger bias than any of his more strictly objective premises. It loads the evidence for him one way or the other, making a more sentimental or more hard-hearted view of the universe, just as this fact or that principle would. He *trusts* his temperament. Wanting a universe that suits it, he believes in any representation of the universe that does suit it. He feels men of opposite temper to be out of key with the world's character, and in his heart considers them incompetent and ‘not in it,’ in the philosophic business, even though they may far excel him in dialectical ability.

Yet in the forum he can make no claim, on the bare ground of his temperament, to superior discernment or authority. There arises thus a certain insincerity in our philosophic discussions: the potentest of all our premises is never mentioned. I am sure it would contribute to clearness if in these lectures we should break this rule and mention it, and I accordingly feel free to do so.

So, you probably ask by now, “What does that leave for the core of the theory? Aren’t you throwing away absolutely everything?” And the answer is, “No, I don’t think so.” Let me give you an example of something which I think is left behind. Recall my favorite argument for why the quantum state cannot be an element of reality—it’s the Einstein argument I wrote about in Section 3 of my NATO paper. Once I posit a state for a bipartite system, even though by my own admission my actions are purely local, a measurement on one of the systems can toggle the quantum state of the other to a large range of possibilities. Thus, I say that the quantum state of the far-away system cannot be more than my information or the compendium of subjective judgments I’m willing to ascribe to that system.

Notice, however, that in positing the original state, I had to also implicitly posit a tensor-product space for the bipartite system. Let me ask you this: Once this tensor-product space is set, is there any way to toggle one of the factors from afar just as with the quantum state? As far as I can tell there is not. Thus I would say that the Hilbert space of the far-away system is a candidate for part of the theory’s core. Well, the Hilbert space—once the choice of a particular quantum state within it is excluded—really carries no substance beyond its dimensionality d . Thus, in a more refined way of speaking, what I really mean to say is that when I posit a quantum system, I am allowed to also posit a characteristic property of it. It is a property that can be captured by a single integer d .

There are some other things which I can argue will be “left behind” in such an analysis, but I don’t want to clutter this note too much. Mainly I presented the example above so that I could give you a clearer sense of how I want to draw a distinction between the rawest forms of “reality” (the surprises the world gives us) and the “core of a theory.”

It is the core of the theory (along with the theory as a whole) that I am starting to view in Darwinian terms. But don’t we have every right to posit that core as a property of the world itself, at least as long as that belief serves us well? This, as you point out, has been the predominant image of what science is about heretofore.

The only answer I can give you is “yes, we can” (just as indeed we have heretofore). So, your point is well-founded. What I am worried about is whether we *should* posit it so.⁸ You say that this view has guided science well in the past. But how do you know? In a world with a view that there is no ultimate law, how do you know that we would not be a thousand years more advanced if we had only better appreciated our role as the substratum of our theories? I think it boils down to the difference between an active and passive view of what existence is about. Or maybe the difference between a positive and a negative view.

To make this point, let me try to put things back into the context of regular Darwinian evolution. Consider the word “elephant.” Does it denote anything that exists in a kind of timeless sense, in a way that we usually think—or in my case, previously thought—of physical theories as existing? If the concept of an elephant is worthy of treating as a candidate for an element of reality, then so

⁸Here is the way I put it to Henry Folse when he asked, “Every attempt to sketch a conception of the universe from our best theories at any date in human history in effect commits such arrogance. Were the Newtonians of the end of the seventeenth century being “egocentric” to think that Sir Isaac had done nothing less than peer into the mind of the Divine and discerned God’s blueprints for the universe?”:

Yes. (In my opinion.) And you might interpret James and pragmatism in general as a reaction to that. However, I think in our modern age with quantum mechanics we have a motivation and opportunity in front of us that James did not have. Try to give quantum mechanics a naive realist interpretation—you can do it, or at least both Everett and Bohm tell us we can—and you find yourself contorting yourself beyond belief. It’s as if nature is telling us for the first time, “Please don’t interpret me in a naive realist fashion. I can’t stop you, but please don’t.”

Folse, by the way, points out that what I really mean here is Cartesian representational realism—that reality is as we represent it mathematically in our theories—rather than naive realism.

too will a theory's core.

Well, if we have bought into Darwinism in any serious way, then I would say, no, there is nothing particularly timeless about the concept of an elephant. There was once a chance that it might not even arise in the world. The "elephant" is merely a function of the selective pressures that cropped up in our world's particular history. And, ashes to ashes, dust to dust, the poor elephant may eventually disappear from the face of the universe, just like so many species that arose in the course of evolution only to be never discovered by a single archeologist.

But now, contrast the evolution of the elephant with the possible future evolution of the human species. The elephant was an accident pure and simple, from the strictly Darwinian view. But I would be hard pressed to apply pure Darwinism to the future of mankind. The birth of my oldest daughter, for instance was no accident. Her traits were selected based on personal visions that both her mother and I had for the future. Similarly, but not so excitingly, with the golden retriever, and all our other domesticated species. The key point is that in the present stage of evolutionary development, we have it within our power to move beyond strict Darwinism. This is what our industry of genetic engineering is all about.

However, we would have never gotten to this stage if we had not first realized that the concept of a species is not immutable. As strange—and as crazy and as scary—as it may sound, this is where my thoughts are starting to roam with physical theories. This does not mean, however, that we can have exactly what we want with our physical theories—that they themselves are little more than dreams. Just as the genetic engineer can make a million viruses that will never have a chance of surviving on their own, there is more to the story than our whims and fancies: There is the ever-present selective pressure from the outside. But that does not delete the genetic engineer's ability to make something that was never here before.

But now, I go far, far, far beyond what I needed to say to answer all your questions. Mainly, I just wanted to emphasize why I intentionally placed the words "a priori" in my definition of reality way above.

I fear now slightly that you're going to realize I'm one of the craziest people you've ever met! And, trust me, I'm not sure I really believe all that I said in the last three paragraphs. But it does strike me as a productive, or at least hopeful, train of thought that someone ought to explore. I guess I offer myself as the sacrifice.

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There. I think that's enough of my going around your questions in a rather wide way. Let me now zoom back to the center of one of them for purposes of a final emphasis.

Woottersism 2: *But you obviously also want to say that our theories tell us something about reality, even if they are not descriptions of reality.*

I hope you can glean from all the above that I do indeed believe our theories tell us something about reality. But that something is much like what the elephant tells us about reality. Its presence tells us something about the accumulated selective pressures that have arisen up to the present date. A theory to some extent is a statement of history. It is also a statement of our limitations with respect to all the pressures yet seen, or—more carefully—a statement of our limitations with respect to our imaginations for classifying all that we've yet seen. (I for instance, cannot jump off the leaning tower of Pisa unprotected and hope to live; you, for instance, cannot get into your car and hope to push on the accelerator until you are traveling beyond the speed of light.) Finally, to the extent that we the theory users are part of nature, the theory also tells us something about nature in that way.

But for any theory, there is always something outside of it. Or at least that's the idea I'm trying to build.

PS. Way above, I said I would finally say a few words about your “private-world-within-entanglement” musings. But somehow it didn't quite fit in with the flow of the rest of what I wanted to say. So, let me try to present the statement in isolation. From my point of view, the quantum state, and with it entanglement, never pierces into the quantum system for which we posit a parameter d (the “dimension”). Similarly for any bipartite system for which we posit two parameters d_1 and d_2 . The quantum state is only about what I'm willing to bet will be the consequences when I reach out and touch a system. Otherwise, indeed, a quantum system denotes a private world unto itself. And similarly with bipartite systems. We have very little right to say much of anything about the goings-on of their insides. (This part of the picture is something I've held firmly for a long time; it even shows up in my *Physics Today* article with Asher Peres.)

PPS. I also promised to end with some open questions. But I'm petered out now. And if you've gotten this far, you're probably exhausted too. So I'll just leave it for the future, depending upon how interesting you find the ideas above, or how much you think they're nonsense!

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