Where Blake Stands In Relation To Rovelli

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Recent conversations in the far-flung QBism discussion group nominally centered at UMB have prompted me to gather my thoughts about Rovelli's relational interpretation of quantum mechanics (RQM). I have included some topics that I think might fit well within a published critique of RQM, along with some ideas (particularly in the later sections) that are important to me but which I don't think philosophers of physics would find engaging.

I have been trying to make sense of Rovelli's "Relational Quantum Mechanics" for about fifteen years now, intermittently. In fact, I can point to the place where I first learned about it, a Wikipedia page written by a fan in 2006 [1] and since trimmed heavily on the grounds that it said many things not explicitly stated in the literature already. (As David Mermin once said, "Writing on Wikipedia is like writing on water.") For a few years after that, I was not particularly interested in quantum foundations, but after developing an interest, I have only been able to get so far towards understanding Rovellian RQM.

The general plan of this document is as follows. In §I, I comment on RQM's efforts at reconstructing quantum theory from physical principles. This leads us into §II, where we consider RQM's attempts at establishing a consistency condition between observers, and why this attempt flounders. Next, in §III, we investigate whether or not RQM really represents an advance over the views labeled "Copenhagen" when it comes time for wavefunctions to collapse. From there, in §IV we consider other difficulties that are brought about by RQM's interpretation of probability, which is at once insistent and imprecise. Finally, in §V, we look into what the RQM literature has had to say about QBism.

I. RECONSTRUCTION OF QUANTUM THEORY

I'd like to begin with the section of Rovelli's original paper [2] that might be the best suited to catch the attention of a researcher more interested in equations than in slinging words about: Rovelli's stab at reconstructing quantum theory from information-theoretic principles. This attempt has some appealing features but also a few things going against it, which can be illustrated by quoting the first two postulates that Rovelli proposes.

R1. "There is a maximum amount of relevant information that can be extracted from a system."

R2. "It is always possible to acquire new information about a system."

These have a little of the feel of Einstein's postulates for special relativity, in that they *seemingly* run the risk of contradicting each other [3]. However, in special relativity, resolving this dramatic tension required overhauling our notions of space and time, whereas it is possible to have **R1** and **R2** coexist in a much more mundane way. For example, the Spekkens toy model is a theory explicitly founded upon local hidden variables [4], and both **R1** and **R2** hold true in it.

Strangely, for a derivation motivated by a "relational" interpretation of quantum mechanics, there is nothing all that *strongly relational* about the postulates **R1** and **R2**. True, they refer to the information that one system might hold about another, but any statement in the theories of information or probability will be "about relations" in this sense. **R1** and **R2** neither lean upon nor imply the *relativity of physical facts* that RQM is supposed to endorse. In that sense, they are no more "relational" than the Central Limit Theorem. Laudisa and Rovelli say that RQM discards the assumption "that there are variables that take absolute values, namely values independent from any other systems" [5]. Yet **R1** and **R2**, both singly and in combination, are perfectly compatible with the existence of absolute physical quantities.

I will not dwell very long on the rest of Rovelli's derivation, as the other premises that he asserts are self-confessedly provisional. Two conceptual points do deserve examination, though, and will lead us into the next section. First, even granting all of the mathematical choices that Rovelli is willing to make in order to sketch how a future derivation might go, like the presumption of unitary matrices, some postulate is required to ensure that the derivation does not land in a subtheory of quantum mechanics that admits an easy classical emulation. For example, one can take the entirety of Rovelli's postulates and arrive at the theory of von Neumann measurements upon a single qubit, a theory for which Bell provided a perfectly satisfactory local-hidden-variable model [6]. Rovelli's stated premises would also be satisfied by the Spekkens toy theory of odd prime dimensions, which provides a local-hidden-variable emulation of qudit stabilizer states and operations [7]. Without something like a maximality assumption or a further additional postulate of nonclassical structure, it seems difficult to avoid these traps.

The other point of note is that Rovelli expresses the hope that his suggested third postulate could be derived from a consistency condition between observers. It is to that consistency condition that we now turn.

II. WHERE THINGS GET TRICKY: PERSPECTIVAL ENTOMOLOGY

The trouble with "consistency" in RQM is fundamental, and one way or another, the difficulty enters with every attempt to define what the consistency condition is supposed to be. For instance, Smerlak and Rovelli write, "It is one of the most remarkable features of quantum mechanics that indeed it automatically guarantees precisely the kind of consistency that we see in nature" [8]. They continue, setting up a scenario involving two observers and a spin system: "Let us illustrate this assuming that both A and B measure the spin in the same direction, say z, that is $n = n' = z$" [8]. Immediately, we have trouble: RQM is supposed to reject absolute states, absolute physical properties and everything like that. *Who gets to say, then, that these two directions are the same?*

In RQM, the quantum state of a system S with respect to another system S' is an expression of the relation between S and S'. The subject matter of quantum theory is taken to be "information" about such relations, how that "information" is constrained, how it may change and so forth. Any standard of consistency expressed in these terms *can only be* a consistency standard between informational relations, and by the basic edict to reject absolutes, the informational relations to which it applies *must* be tied to a specific observer. If we try to go beyond this, we introduce quantities that are not within the quantum formalism — say, the choice of direction intrinsic to observer B — and we end up saying that quantum theory is incomplete.

The pseudonymous author of the Wikipedia article — "Byrgenwulf" from South Africa — seems to have taken this and run with it. First, regarding the scenario of an observer O measuring a system S and being measured by O' in turn: "The interaction between O' and whatever he chooses to measure, be it the $S+O$ compound system or O and S individually, will be a *physical* interaction, a *quantum* interaction, and so a complete description of it can only be given by a further observer O''" [1]. It's turtles, all the way out. And on the subject of RQM's philosophical implications,

> Perhaps foremost among them is the nominalism implied by the absence of the observer-independent state of a system. A state, after all, is nothing but a compound of properties that a system possesses, and RQM implies that properties of a system are better ascribed to the relationship between the system and a particular observer. Thus properties do not inhere in the objects themselves, and exist as binary relations between objects, not unary relations as is the more typical view. [...] If all properties are relational, then what can be said of the objects they relate? Nothing: for any description is a property, which, in RQM, is a relation. This idea is perhaps unusual, but not new to philosophy. Heraclitus held a similar view, of a world constituted entirely of relations between relata of an indeterminate nature. The perspectivism advocated by Nietzsche, too, espouses a fundamentally relational reality, constituted of the myriad descriptions offered by individual observers, without the existence of an "absolute", underlying reality.

Thus, it is somewhat surprising that the primary literature on RQM backs away from this point. Indeed, taken at face value, Laudisa and Rovelli deny it [5]:

> [I]magine experimenter S' measures the spin of the electron S, and writes the value of this spin on a piece of paper. In principle, experimenter S'' can devise an experiment where she can detect an effect due to interference between the two branches where the spin of the electron (and the text) have one or the other value. But if S'' measures the spin and reads the piece of paper, she will find that experimenter S' has seen the same spin as herself.

The phrasing *has seen the same spin* erases the distinction between the sensory perception of S'' and the life experience of S'. In other words, it abandons Heraclitus and perspectivism, tumbling back towards the absolute.

Rovelli apparently found the question of inter-observer consistency important enough to include in his popularization of quantum foundations, *Helgoland* [9]. One passage nicely captures the problem we've confronted in this section:

> If I know that you have looked at the butterfly's wings, and you tell me that they were blue, I know that if I look at them I will see them as blue: this is what the theory predicts, *despite the fact that properties are relative.* The fragmentation of points of view, the multiplicity of perspectives opened up by the fact that properties are only relative, is repaired, made coherent, by this consistency, which is an intrinsic part of the grammar of the theory. This consistency is the basis of the intersubjectivity that grounds the objectivity of our communal vision of the world. The wings of the butterfly will always be the same color for all of us.

The trouble is that the last sentence does not follow from what went before it! It takes a wild leap from "each of us" to "all of us", staking out a claim that could only make sense for a super-observer to whom the regular laws of physics do not apply.

The perception of color has enough pitfalls in ordinary life, as evidenced by any married couple or anyone who remembers The Dress [10]. But let us try to set these aside, even if perhaps we ultimately shouldn't. Consider a straight-up classical scenario where internal consistency does not add up to intersubjective agreement. Alice sees Bob and a box, the latter labeled *Contents: One (1) Butterfly.* She fully expects that if Bob opens the box, he will say that the butterfly is blue, and that if she then looks into the box herself, she will also see that it is blue. Meanwhile, Bob sees Alice and the box. He fully expects that if Alice opens the box, she will say that the butterfly inside it is orange, and that if he then looks into the box himself, he will also see that it is orange. Relationalizing all the properties, to *color-as-seen-by-Alice* and *Alice's-voice-as-heard-by-Bob* and so forth, only gives a putative standard of consistency less to work with.

Interpreting quantum theory also means that we have to allow for multiple, mutually exclusive possible measurements upon each system. This is a little hard to give an intuitive example of, if we're talking butterflies. (Schrödinger's example back in the day was an exhausted student who might be asked either of two exam questions, but can only answer one before falling asleep [11].) To formulate a meaningful consistency condition, we must have a viable notion not just of when two observers get the same answer, but also of when they have asked the same question. Relationalizing everything doesn't make that easy, either!

III. REVENGE OF THE SHIFTY SPLIT

A commonplace criticism of "the Copenhagen interpretation" is that it leaves unspecified when the process of "measurement" takes over from unitary, Schrödingerian time evolution. According to this critique, subscribing to "the Copenhagen interpretation" is rather like saying that most of the time, gravity is an inverse-square law, but it stochastically switches to an inverse-cube dependence for brief moments. This would be, of course, a pathological feature for a theory to have. It is also rather disconnected from what Bohr actually wrote. To a Bohrian, there is not a sudden shift between different dynamical laws, but instead a contextual change in what language can be applied, in particular regarding when a system should be treated in functional or in structural terms [12]. Most likely, a Bohrian would say that in order to communicate the result of an experiment to another physicist, we would of course have to describe it unambiguously, and any sufficiently unambiguous description — "In natural language, potentially augmented by the concepts of classical physics," they might say — would necessarily fix any dividing line in place. (A Heisenbergian would instead have a different kind of dividing line in mind, and say that it *can* be shifted, but without operational consequence [12]. Still another species of Copenhagener, a Peresian, would agree with what the Bohrian said about languages, and then argue that we can move the quantum-classical "cut" under some conditions, never without consequence but sometimes with effects that are statistically negligible [13].) Everettian interpretations of quantum mechanics shunt the vagueness of the term "observer" over to the question of when wavefunction branches are "separate" [13]. RQM washes its hands of trying to define observers by declaring that any physical system can serve as one, which as we will see just transfers the load to the definition of *interaction.*

The primary literature on RQM carries forward the ahistorical idea [14] that "the" Copenhagen interpretation is well-defined and identifiable with what is found in "textbooks" [5]. It also opens the question of whether RQM actually manages to evade the critiques leveled at whatever the people out to "destroy the Copenhagen interpretation" imagine it to be. The *Stanford Encyclopedia* article by Laudisa and Rovelli has this to say:

> The history of a quantum particle, for instance, is neither a continuous line is spacetime (as in classical mechanics), nor a continuous wave function on spacetime. Rather, with respect to any other system it is a discrete set of interactions, each localized in spacetime.
>
> The flash ontology of RQM seems to raise a difficulty: what determines the *timing* for the events to happen? The problem is the difficulty of establishing a specific moment when say a measurement happens. The question is addressed in Rovelli (1998), observing that quantum mechanics itself does give a (probabilistic) prediction on when a measurement happens. This is because the meaning of the question whether or not a measurement has happened is to ascertain whether of not a pointer variable O_A in the observing system S has become properly correlated with the measured variable A of the system A. In turn, this is a physical question that makes sense because it can be posed empirically by measuring A and O_A and checking if they are consistent.

Here, we have the puzzling situation that what should be the most fundamental scenario, one system observing another, can only be said to make sense if we bring in a third party. Yet why should properties that exist relative to that third party be at all binding upon the first two systems? The joint state of the first two relative to the third is, by definition, not the quantum state of the second relative to the first. But it is the latter which changes "when a measurement happens".

Smerlak and Rovelli's 2007 paper "Relational EPR" [8] indicates that RQM finds the Heisenberg picture of time evolution "far more natural" than the Schrödinger. In a way, this is an invigorating move: It is tempting to wonder what attitudes physicists would find natural if we were taught all along that observables always change smoothly and unitarily, while states only ever change suddenly and stochastically. However, it does not seem obligatory. Whatever one does with the expectation values $\langle\psi|U_t^\dagger A U_t|\psi\rangle$, one must put the unitaries somewhere, and per the ethos of denying absolutes, none of the ingredients in that expression should be taken as intrinsic to the observed system. RQM says that at any moment t, there is a physically correct probability for each possible value that each variable could take upon actualization. So, the relative physical condition of the observer and the observed system must vary with t, regardless of which mathematical entity is chosen to stash that dependence in.

The term *flash ontology* suggests rather strongly that the "flashes" are ontological. Something is realized in the flash: A variable takes a physical value, even if only in relation to a single other system. This is at odds with the treatment in Rovelli's 1998 paper to which the *Stanford Encyclopedia* article refers [15]. In that paper, Rovelli declares,

> I am not claiming that there is an "element of reality" in the fact that a measurement has happened, or that, in general "measurement having happened or not" is an *objective property* of the coupled system.

Yet what are the "flashes" supposed to be, other than elements of relational reality? Moreover, the "time of measurement" calculated in the 1998 paper is not the time at which an observer O will have measured a system S (obtaining, one might guess, a "flash"). Instead, it is the time at which the joint state of the combined SO system, relative to a second observer O', will take a particular form. Using this as the means to define timing would mean that only an observer who does not experience the flash can have timing information about it. This is difficult to square with the idea that the state of system S relative to observer O is supposed to encapsulate the history of the interactions between them. Laudisa and Rovelli declare that any quantum state is "nothing more than a compendium of information" that is "determined entirely by a series of interactions: the interactions between the system and a second 'observing' system" [5]. In their view, a quantum state "codes the values of the variables of the first that have been actualised in interacting with the second" [5]. If this is the case, then the quantum state of S relative to O will change with each flash, except in the measure-zero set of circumstances where it was already an eigenstate of the observable whose value became actual in the flash. But RQM provides no way to predict, model or even define the times at which these changes occur: The only account of measurement timing it can offer is relative to a second observer O', who is not a party to the flashes between O and S. Consequently, RQM leaves the manner and mode of time evolution essentially underdetermined. The most basic criticism that anti-Copenhagenists aim at what they call "Copenhagen" hits RQM dead center.

IV. THE SENSE OF SHANNON

The relentless physicalization of probabilities in RQM causes other difficulties as well. For example, it makes the issue of locality harder to pin down. Suppose that the joint state of two systems S and S' relative to an observer O is maximally entangled. Then the realization of a variable of S immmediately implies a probability-1 prediction about the corresponding variable of S', and so *an aspect of the physical relation between S' and O must have changed.* Smerlak and Rovelli would have it that this is only a "subjective" change, analogous to a reader's information about a distant country changing when they read a newspaper article about it [8]. But this runs headlong into RQM's insistence that information is *factive,* always to be understood as objectively present within a physical relation [5]. Laudisa and Rovelli are insistent that RQM defines information "in the sense of Shannon", which they take to be a "definition of information that has no mentalistic, semantic, or cognitive aspects". Such a claim can only be as good as the presumption that the p_i in $-\sum_i p_i \log p_i$ have no such aspects. For Laudisa and Rovelli, "relative information" measures "the difference between the possible number of states of the combined system and the product of the number of states of the two systems". In other words, they declare objectivity at the cost of having all fundamental probability distributions be flat, so that Shannon's formula reduces to Hartley and Boltzmann's.

As best as I can tell, RQM's claims to objectivity rest entirely upon $p_i = 1/N \; \forall \; i$ being a satisfactory definition of probability.

The question of how to interpret probability theory, while manifestly of importance to quantum foundations, gets only a sketchy treatment in the RQM literature. In contrast, the primary literature on QBism covers the topic at length — perhaps exhaustively, if not persuasively.

V. RELATIONAL QUANTUM MECHANICS AND QBISM

Laudisa and Rovelli's *Stanford Encyclopedia* article on RQM states that papers by Fuchs in 2001 and 2002 [16, 17] are examples of QBism. They are not. A phase transition took place between those two papers, and another had to occur before QBism could be formulated [18]. Laudisa and Rovelli also write, "The emphasis on information in Rovelli (1996) influenced the birth of QBism (see Fuchs 1998: 3)." The latter paper [19] is not QBist either. Nor does it refer to Rovelli's 1996 paper on RQM. Fuchs began to think of quantum physics as being somehow information-theoretic during his undergrad years at UT Austin, thanks to the influence of John A. Wheeler, and he was writing about information theory in quantum foundations as early as 1992 [20], inspired by Braunstein and Caves [21, 22]. The 2002 paper [17] cites Rovelli's 1996 exposition of RQM to motivate the idea of reconstructing quantum theory from physical principles. However, it does not use the postulates **R1** and **R2**. Instead, it says a whole lot of things about "information-disturbance curves" and agreement among multiple agents — speculations that quite firmly date it to the pre-QBist era — and discusses the idea of a "standard quantum measurement", which *does* persist in QBism proper [18]. The most immediate and influential predecessor for that was the work of Hardy [23]. See the 6 March 2002 note "Poetry on Concrete" to Hardy in [24] for additional background. The conceptual influence of RQM upon QBism has been somewhat diffuse, and occasionally as an example of a thing to be more radical than. For example, as Fuchs wrote to Timpson in November 2006 [24]:

> Even a "relational" viewpoint on measurements (say like [the Ithaca Interpretation] or Rovelli, or what Spekkens desires) doesn't seem to be enough for me. There's something in my gut that says that anything weaker than the radical, Paulian direction [. . .] is ultimately inconsistent.

And to Brassard in October 2007 [24]:

> We didn't get a chance to get anywhere near this far, but I think if I had to put into a slogan what's going to be ultimately found and quantified in this research program of mine, it's this: That the ontic of quantum systems is that they are *catalysts*. That is their conceptual role. The thing that is intrinsic to quantum systems themselves (and the thing dimensionality is ultimately a quantification of) is that they bring about transformations in things external to them. Quantum systems are transformers. There is an element of [Ithacan] "correlation without correlata" in this idea, but it is a much more active thing, and it is careful to relegate quantum states to the epistemic (which [Ithaca] does not do). Also, it shares a small piece of similarity to Rovelli's relationalism, but ditto what I just said about [Ithaca].

I've written elsewhere about the rise and fall of the Ithaca proposal, which was more a set of desiderata than a full-blown interpretation [25].

Helgoland has this to say about QBism:

> The weakness of QBism, in my opinion—and this is the turning point in this whole discussion—is that QBism anchors reality to a subject of knowledge, an "I" that knows, as if it stood outside nature. Instead of seeing the observer as a part of the world, QBism sees the world reflected in the observer. In so doing,

> it leaves behind naive materialism but ends up falling into an implicit form of idealism. The crucial point that QBism disregards, I believe, is that *the observer himself can be observed.* We have no reason to doubt that every real observer is himself described by quantum theory.

This is a head-scratcher. I want to be kindly disposed towards it, but the more I look the wronger it grows. First, there's the big stuff, like the italicized part; we've said all along that one agent can apply quantum theory to another. And what's with that "stood outside nature" line? The most basic premise of our interpretation is that any agent is swimming in the thick of nature! It's hard to write a response to this when the bulk of "Hero's Handbook" [26] is a prefutation of it, to name only one of many pertinent writings.

The only one who is standing "outside nature" is the super-observer who can verify that everyone really does see the butterfly as blue!

But it's also the little things, like the words *knowledge* and *reflected* and *observer.* Of course, we jettison the last in favor of *agent,* with its more active connotations. But the other two also suggest a Quantum Bayesianism twenty years gone [18], a pre-QBist stage of understanding that had not yet traded talk of *knowledge* with that of belief, expectations, gambling commitments. To a QBist, a quantum state is not the kind of map that just tries to reflect the territory in miniature.

Also in *Helgoland,* we find the following:

> But while QBism is about the information of a subject, the relational understanding of quantum theory is about the structure of the world.

I won't speak for any other QBist, but for me, the hope that quantum theory will give us new lessons about the structure of the world is one of the things that gets me out of bed in the morning. But the deep lessons aren't in the bits of the mathematics that readily float to the surface.

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