Composite Observers, Empirical Adequacy, and the Combination Problem in Relational Quantum Mechanics: A Reply to Adlam

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ABSTRACT. Relational Quantum Mechanics posits that facts about the properties of physical systems are relative to other systems. As pointed out by Adlam in a recent manuscript, this gives rise to the question of the relationship between the facts that obtain relative to complex systems and the facts that obtain relative to their constituents. In this paper, I respond to Adlam's discussion of what she calls the Combination Problem. My starting point is a maximally permissive solution that I suggest should be our default view. Subsequently, I advance three main claims. First, I argue that Adlam's arguments in favour of a more restrictive approach is required are not compelling. Second, I argue that even if they were, she is wrong to claim that a 'tamed' version of RQM with postulated links between perspectives is in a better position to support such a restrictive approach. And third, I point out that the possibly most difficult aspect of the Combination Problem in fact pertains to the combination of quantum states and probabilities. While these issues do raise significant challenges for the permissive solution, I contend that they are likely to arise for any reasonable response to the Combination Problem. More tentatively, I propose a strategy to at least mitigate the difficulty that capitalises on the observer-dependence of relative quantum state assignments. Along the way, I address crucial foundational issues in Relational Quantum Mechanics, from cross-perspective communication to the link between relative facts and experiences to empirical adequacy.

1 Introduction

According to Relational Quantum Mechanics [1-2], facts about the dynamical properties of objects are observer-relative. The sense of 'observer' at stake, however, is a minimal one. According to official statements, any physical system – a galaxy, a dachshund, a fundamental particle – qualifies as a reference which facts can obtain relative to.

But galaxies, dachshunds, and particles are not simply different, unconnected systems on an equal footing. Galaxies contain dachshunds (at least some do), and particles compose (or constitute, or give rise to) both. This raises a question: What is the relationship between the relative facts of systems on different 'levels'? What is the relationship, that is, between the facts relative to some system and those relative to its parts, or constituents, or realizers? This is the Problem of Combination for Relational Quantum Mechanics, expounded by Adlam [3] in a recent manuscript and named after a similar issue that plagues panpsychism (cf. [4]).

In this paper, I react to Adlam's discussion of the Combination Problem. This is not only of interest and of itself. It also allows – indeed, requires – us to touch upon a number of conceptual key questions in the foundations of Relational Quantum Mechanics, and of relativist interpretations of quantum theory more broadly. These questions range from higher-order relativity to the experiences of situated agents to the nature of probability. Here, I approach them in a partly exploratory spirit: My primary aim is to get clearer on the Combination Problem and its interconnections to various other matters. More tentatively, I also propose some answers.

Adlam considers two distinct versions of Relational Quantum Mechanics currently on offer. I shall refer to the older one, which is thoroughly relativist in a sense to be made precise, as 'orthodox RQM' (RQM) [1-2]. I shall call the 'tamed' version with explicitly postulated cross-perspective links [5] 'RQM with Cross-Perspective Links' (RQM+).

My starting point will be a maximally permissive solution to the Combination Problem that I argue should be our default. According to this solution, any collection of atomic systems composes a potential reference system, and any relative fact that obtains relative to at least one constituent thereby obtains relative to any composite it partly constitutes.

Subsequently, I shall advance three main claims.

First, that Adlam's arguments to the effect that a more restrictive approach is needed are not compelling.

Second, that even if they were, her claim that RQM+ is in a better position to support this more restrictive approach than RQM is doubtful.

And third, that the possibly trickiest aspect of the Combination Problem is one that Adlam does not mention: namely, the combination of quantum states and interactional probabilities. This issue does turn out to raise significant difficulties for the permissive solution. However, I contend that these difficulties are likely to arise for any reasonable response to the Combination Problem, including Adlam's own.

More tentatively, I suggest a strategy to at least mitigate the problems of state and probability combination, capitalising on the fact that the quantum state of one system relative to another is itself an observer-relative notion in RQM.

I wish to note from the outset that my disagreement with Adlam mostly traces back to two key points of contention. As is fairly well known [6][7, p. 42], which facts obtain relative to an observer is itself an observer-dependent question in orthodox RQM. Adlam acknowledges this but maintains that there nonetheless is an important sense in which the facts of different observers in RQM fail to be systematically related. I disagree.

The second point pertains to the connection between relative facts and experiences. In a slogan, Adlam & Rovelli (and with them large parts of the literature) assume that accounting for the experiences of humans means ascertaining that the right kinds of facts obtain relative to them. I, in contrast, suggest we have good reason to consider it a matter of determining that humans are in the right bodily states relative to other observers. These two lines translate into different constraints of empirical adequacy on relativist interpretations, and hence different constraints on viable solutions to the Combination Problem.

My discussion thus is premised on the observer-dependence of both relational 'higher-order' facts and facts about the experiences of conscious creatures in orthodox RQM. I will neither develop a full defence of the tenability of views with these features here nor try to defuse every objection one might conceivably raise against them.[1] For the most part, I will simply put it to work in the specific context of the Combination Problem.

The structure of the paper is as follows. I describe and compare the two versions of Relational Quantum Mechanics, orthodox and tamed, in section 2. In section 3, I introduce the Combination Problem and the permissive view which I think we should adopt by default. Section 4 is dedicated to a critique of Adlam's arguments against the idea that any collection of particles qualifies as a reference system. The recurring issue of the relationships between the relative facts of different observers is picked up in section 5. Next, I sketch two competing conceptions of the link between relative facts and experiences, and discuss their implications for Adlam's worry that Relational Quantum Mechanics might stray into quasi-Everettian territory, in section 6. As it turns out in section 7, these considerations also cast doubt on the main constraint of empirical adequacy Adlam employs to rule out liberal solutions to the Combination Problem. In section 8, I introduce and discuss the two additional sub-problems of the combination of quantum states and probabilities. Section 9 summarises my conclusions.

[1] One important objection is that a view of this type undermines the possibility of science as a collective enterprise (cf. [8-10] for discussion). While some of the things I shall say clearly impact on this debate, I will not here address it directly.

2 RQM and RQM+

We shall be concerned with two versions of Relational Quantum Mechanics, which we can refer to as '*orthodox* RQM' (RQM) [1-2] and 'RQM with Cross-Perspective Links' (RQM+) [5]. Although they trade under the same name and, on superficial inspection, appear to disagree over the addition of a single postulate only, their differences do in fact run deep (cf. [11-12]).

We start with their commonalities. Both interpretations say that physical systems only acquire determinate dynamical properties when they interact with one another. The guiding intuition is that an observable of a system (say, the z-spin of an electron) stochastically takes on a well-defined value when the state of another 'witnessing' system depends on it. According to official doctrine, the properties thus actualised merely come into being for a single moment in time, so that a physical process is really a sequence of 'flash-like', instantaneous manifestations of properties of systems [13, p. 9]. Another point of agreement is that systems only have quantum states relative to each other, rather than absolutely. The precise status of quantum states, however, remains somewhat unclear. While at times it is said that they merely represent epistemic states [14, p. 2], and that the probabilities they encode are entirely subjective [15, p. 431], there is reason to think that Relational Quantum Mechanics can or even must make room for quantum states with more substantive ontic import as well as objective probabilities [cf. 16-19 for discussion].

Typically, the literature only considers interactions between two *disjoint* systems. Whether and how systems acquire properties relative to themselves, or relative to their own proper parts, or relative to composites they form part of, are open questions both in Relational Quantum Mechanics and beyond. Relatedly, it is notoriously difficult to find a generally applicable procedure by which observers can ascribe quantum states to themselves, or otherwise calculate probabilities for measurements performed on themselves. In this paper, I have nothing informative to say about these matters. I will restrict attention to mundane interactions that take place between disjoint systems, and predictions that do not require observers to model themselves. That is, I will rest content to address today's task *up to* the puzzles of quantum-mechanical self-description. If at any time we bump into them, I will take the liberty to throw my hands up and plead ignorant.

Neither RQM nor RQM+ assigns any special role to 'measurements' or conscious beings. Any interaction between any two systems – large or small, sentient or mindless – leads to the actualisation of properties. For ease of exposition, I shall continue to call reference systems 'observers', and say that they 'measure' some variable to express that they monitor it in an interaction such as to make it acquire a determinate value. I shall also call the values so acquired the 'outcomes' of interactions.

What the two interpretations differ greatly over is the degree to which they are relativist. The bold move characteristic of orthodox RQM is to deny the existence of any absolute facts about the outcomes of measurements or the dynamical properties of systems. Instead, it is assumed that such facts are invariably observer-relative. This places RQM firmly in the camp of 'quantum relativism'.[2] According to RQM, when two systems *S*, *S'* interact such that the state of some variable *O'* of *S'* depends on the value of some observable *O* of *S*, then *S* acquires a determinate *O*-property (*O* assumes some definite value) *relative to S'*. At the same time, though, *S* may possess no definite *O*-property relative to other reference systems.

An important, brain-twisting footnote all too often overlooked is that which properties one system has relative to another is itself considered an observer-relative question. This is because it is taken to be a dynamical property of the composite they constitute (cf. [1, 2, p. 15]). In other words, even which value observable *O* of *S* has *relative to S'* is a perspective-dependent affair. It is easy to see how this iterative construction gives rise to a regress of higher-order relativities [6]. The upshot is that no matter how many references are specified explicitly, there are no absolute facts (concerning relative state-dependent properties) to be recovered. It is relative facts all the way down.

This radical proposal invites a great number of difficult questions and stretches our ordinary conceptual ways to their limits. As with all thoroughly relativist positions, it is not obvious whether it can work. I will not here attempt an extended defence of its coherence (although I will say that I am not aware of any conclusive argument *against* its coherence, either). In this sense, my claim in the present paper is conditional: *if* orthodox RQM can be understood at all, and *insofar as* it does not fall prey to fatal prior problems, it can deal with the Combination Problem much better than Adlam acknowledges.

One worry that is routinely raised against relativist interpretations, and RQM in particular, is that they threaten to entail a multiplicity of mutually disconnected 'realities' relative to different observers (cf. [8-9, 12, 22, 24-25]). Indeed, much of what Adlam says about the Combination Problem rests on her conviction that in an important sense, there can be no systematic relationships between different observers in RQM [3, p. 3]. I have major reservations about this line of thought, and we shall come back to the point in due course.

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[2] Examples for other relativist interpretations in this sense include QBism [20], some Neo-Copenhagen views (cf. [21]), pragmatism [9], Dieks' perspectivalism [22], and Convivial Solipsism [23].

Concerns about cross-observer coherence and collaborative scientific confirmation motivated the development of RQM+. On the face of it, the new version of the interpretation is characterised by an additional axiom declaring that information can be shared:

> **Cross-Perspective Links (CPL)**
> In a scenario where some observer Alice measures a variable V of a system S, then provided that Alice does not undergo any interactions that destroy the information about V stored in Alice's physical variables, if Bob subsequently measures the physical variable representing Alice's information about the variable V, then Bob's measurement result will match Alice's measurement result. [5, p. 7]

Again, the scope of CPL is not supposed to be limited to human observers and 'measurements' in any loaded sense. CPL postulates that if some system A records the outcome of some interaction in a variable V, and if some other system B later interacts with A such that the value of V in turn is recorded in one of B's own variables, then the value which V assumes in this later interaction between A and B mirrors the outcome of A's earlier interaction. This is to ensure that one observer can reliably access information about an outcome previously realised relative to another.

As stated, CPL could well be a principle that holds *within* a perspective, that is, relative to a reference (cf. [10, p. 4]). In RQM+, however, CPL is supposed to provide an absolute coordination between the outcomes of different interactions involving different reference systems. More specifically, the vision is that there is some absolute fact about Alice's outcome, and some absolute fact about Bob's outcome, and an absolute fact to the effect that the two line up. Thus understood, the principle is incompatible with the iteration of relativity characteristic of RQM. Hence, RQM+ is much less relativist than its predecessor. In fact, it has been argued that it retains no clear reason to relativise outcomes or properties at all (cf. [12, p. 11-13; 26, p. 17f.]). If we follow this line of thought, the Combination Problem *qua* question about the relationship between different sets of relative facts may become obsolete in RQM+ (though cf. section 8).

3 The Combination Problem and its Default Solution

3.1 Two Problems and Two Preliminaries

If properties can be realized relative to any physical system, and if we follow Adlam in assuming an ontology of fundamental particles, then each particle will be associated with its own set of relative facts. But presumably, the world also contains more complex systems which the particles compose, or give rise to, or realize, such as molecules, guinea pigs, or Bobs. The Combination Problem for RQM(+) is to "offer some account of how the relative facts associated with individual fundamental particles are related to higher-level relative facts associated with beings like us" [3, p. 1].

Following Chalmers [4], Adlam distinguishes two aspects of this problem[3]:

SYSTEM COMBINATION[4]	How, and under which circumstances, do micro reference systems combine to form macro reference systems?
STRUCTURE COMBINATION	How are the facts relative to macro systems related to the facts relative to their micro constituents? Do macro systems 'inherit' relative facts from their constituents, and if so, how?

Here, what I mean when I say that a macro system 'inherits' a fact is that some fact obtains relative to a macro system *because*, or *in virtue of the fact that*, certain facts obtain relative to the particles that compose it. Possibly, not all facts relative to macro systems are of this type. A composite may interact with some system S such that its total quantum state but none of the reduced density matrices of its constituents depend on (get correlated with) a variable V of S. Taking this at face value, one might think that V acquires a determinate value relative to the composite but not relative to any of its parts. In this case, the macro fact would not be 'inherited' from micro facts.

It is worth pausing for two general observations.

First: One can broadly distinguish two possible attitudes towards inherited macro facts. One option is to conceive of them as additional physical structure over and above the micro facts they derive from. The other one is to go deflationist, regarding talk of inherited macro facts as mere coarse-grained summaries of (patterns of) micro facts.[5] Significant differences ensue from these different attitudes. If we take an anti-deflationist view, what we are doing when we try to answer the Combination Problem is searching an accurate

[3] Chalmers introduces a third subproblem for panpsychism, the question of Quality Combination. Like Adlam, I think that there is no analogous problem for RQM(+).

[4] Chalmers and Adlam speak of 'Subject Combination'. I choose a different name because not every reference system is a subject of experience, and to avoid the unwanted association of fact relativity with subjectivity.

[5] To repeat, this would not necessarily imply that all macro facts reduce to micro facts, because there could be uninherited macro facts.

description of the relationship between two equally real structures at different levels of reality. If we take a deflationist view, what we are doing is hunting for a higher-level, abbreviating terminology that allows us to neatly summarise lower-level facts, and in so doing fulfils any further requirements we impose on it.

This does not, however, necessarily mean that the problem loses all urgency for the deflationist. In particular, it may very well be that we find ourselves explicating how the theoretical structure of RQM(+) connects to the observations of situated agents partly in higher-level terms, viz., in terms of which (potentially inherited) facts obtain relative to composite systems. If so, then giving empirical content to the theory requires specifying which inherited facts obtain, whether we think of them as mere summaries of micro facts or not.

Second: If there were an agreed-upon, rigorous procedure to extract relative facts from the mathematical apparatus of quantum theory, this procedure would imply at least a partial answer to Structure Combination. There is, however, no such procedure yet in RQM(+). It is thus worth discussing the Combination Problem independently, keeping in mind that our provisional findings may be superseded once the interpretation is further mathematized. At the same time, the insights gained along the way might serve as guidelines for the development of a formal account. Interestingly, the deflationist should think that there necessarily is a certain conventional element to any such formal account, at least insofar as it applies to inherited macro facts.

3.2 The Default View

Let me describe what I think should be the default response to the Combination Problem in Relational Quantum Mechanics.

Consider System Combination first. Clearly, different ways of grouping particles together can be useful to very different degrees. They can render problems more or less tractable and mechanisms more or less perspicuous. It is tempting to think, however, that these are merely pragmatic considerations, and that it should not *in principle* matter much for the purposes of fundamental physics how we partition the world into composites. In this mindset, we might conjecture that *any* collection of particles, scattered about the universe as they may be, qualifies as a potential reference system.[6]

[6] We may have to make an exception for the collection of *all* particles, as it is not clear that there can be facts relative to the entire universe in RQM. But this will play no role in what follows.

This stance goes together well with the intuitive account of relative facts at the heart of RQM. As rehearsed, the story is that a variable A of a system S acquires a determinate value relative to another system S' when S and S' interact such that the resulting state of S' depends on the variable A (cf. [27, sect. 1.1]). Initially at least, this suggests that all that is required for facts to be realized relative to a collection of particles is that their joint dynamical state be describable in terms of a bunch of variables, and that they can be understood as interacting with other systems such as to depend on them dynamically. And there is a natural sense in which any interaction with a particle is an interaction with any collection which that particle is part of, so that any such collection can be understood as a possible interaction partner for other systems.

We can find some support for the liberal stance in the writings of those who advocate RQM. In Vidotto's view, the tensorial structure of quantum theory "indicates that [...] the manner in which we split the world into subsystems is largely arbitrary" [28, p. 301]. Combine this with the principle that "[a]ny system, irrespectively of its size, complexity or else, can play the role of the textbook's quantum mechanical observer" [27, sect. 1.3], and it follows that any collection of particles is a potential reference for facts.

By contrast, Rovelli has at least hinted at a more demanding attitude recently. "A 'system'", he says, "is any part of Nature that admits a somewhat compact description and whose dynamics can be considered as isolated within some approximation" [7, p. 13]. But again, notions like 'somewhat compactness' and 'isolation within some approximation', vague as they are, seem more likely to fall within the domain of pragmatics than to carry fundamental (meta-)physical significance.

There are other possibilities worth considering, for instance to identify systems with (maybe bounded and connected) spacetime regions (cf. [2, p. 1065]). The liberal principle of System Combination is thus certainly not forced on us. But I suggest we run with it until we hit a roadblock.

This leaves the question of Structure Combination. Staying close to the intuitive story about the realisation of relative properties in RQM(+), it remains to be clarified under which circumstances a dependence of the state of a particle on an external variable[7] implies a dependence of the global state of a collection it is part of on the same variable. If we look closely enough, the answer arguably is: under most if not all circumstances.[8] Moreover, it is

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[7] Recall that I bracket questions to do with the dynamical states of systems or their parts relative to themselves. Hence, I restrict attention to the relative values of variables that are external to all reference systems at issue.

[8] Perhaps one can concoct exceptions where indistinguishable particles in a collection swap dynamical properties contingent on the value of some external variable. It is doubtful, however, whether such cases really occur. In any case, they play no decisive role in what follows.

natural to assume that a variable possesses the *same* value relative to a particle and relative to any collection it is part of.

This leads us to the following working hypotheses:

- LIBERAL SYSTEM COMBINATION: Any collection of fundamental particles constitutes a composite reference system which facts can obtain relative to.
- LIBERAL STRUCTURE COMBINATION: If an external system has a determinate property *p* relative to at least one constituent of a composite system, then it has property *p* relative to the composite system.

Call this the *Liberal Package*. I suggest that it should be our default response to the Combination Problem, and that we should only deviate from it for good reason.

Adlam, it turns out, recommends a much more restrictive approach. The principles she proposes are the following (rephrased in my own words)[9]:

- CPL SYSTEM COMBINATION: Whenever systems S_i have all come to share a relative fact via interactions as described in the postulate CPL, there exists a composite observer S composed of the S_i.
- CPL STRUCTURE COMBINATION: The relative facts that a composite S inherits from its constituents S_i are exactly those which all the S_i have come to share via CPL-style interactions.

Call this the *CPL Package*. Our next task is to examine the arguments based on which Adlam favours this package.

4 Adlam on System Combination

The first objection raised by Adlam against overly permissible principles of System Combination is an argument from conceivability. The thought is that we can imagine a world in which all actual micro systems and their respective relative facts exist but there are no macro reference systems and macro facts. This, Adlam contends, "give[s] us reason to think that a collection of micro-observers will not *automatically* give rise to a macro-observer; some further component is needed" [3, p. 7] (original emphasis).

[9] The situation is a little more complicated than I make it here: Adlam's own view is that her package may well give way to a form of eliminativism about macro reference systems at the end of the day.

This argument is open to criticism along several lines. A deflationist for whom an inherited macro fact just *is* a certain pattern of micro facts would deny the conceivability of having one without the other. The non-deflationist might retort that "we should not expect the relation between micro-observers and macro-observers to be be [sic] revealed by appeal to a priori conceivability arguments" [3, p. 7]. Finally, the argument threatens to prove too much: we can use it to undermine just about *any* possible principle of System Combination. Take the CPL Package, for instance. Is it not conceivable that systems S_i have come to share a relative fact, and yet there is no macro observer they compose? So, these considerations seem to carry little force.

Adlam's second concern is that it is "hard to understand the meaning" [3, p. 8] of facts relative to arbitrary collections of scattered particles. "These particles cannot act jointly to perform anything that would look like a 'measurement'", she contends, "so relative facts associated with them cannot be understood as describing the outcomes of any possible measurements" (ibid.). Again, this cuts no ice against the deflationist. But independently of that, RQM(+)'s usual gloss on the acquisition of relative properties in terms of interactions and dependence works just fine for arbitrary composites. If S interacts with at least one of a collection of particles S', there is a natural sense in which it thereby interacts with S'. And such an interaction has the potential to impact on the overall dynamical state of S'.

Finally, Adlam argues that overly permissible principles of System Combination give rise to a 'problem of the many' (cf. [29]). For a start, she worries there is no unique collection of particles that would qualify as 'Alice' or 'Bob'. Now, it occurs to me that one can always ask which particles precisely constitute a complex creature and why. In this sense, a basic 'problem of the many' arises no matter what. We cannot even avoid it by denying the existence of all Alice- or Bob-like collections but one, inasmuch as we would then still have to provide a principled reason to privilege that one in particular. To this extent, the issue has little to do with RQM(+) and the attribution of relative facts to collections of particles.

But worse may be to come. Recall the widespread worry that the relative facts of different observers fail to be systematically connected in orthodox RQM. On this premise, Adlam expects that the myriads of Alice-like composites would have their own, totally unrelated sets of facts. Hence, she concludes, "we are starting to get into territory similar to the Everett interpretation, since in any measurement performed by an individual human being, all possible outcomes will probably be seen by at least some of her associated macro-observers" [3, p. 8].

Two assumptions underpin this concern: Firstly, the idea that completely different facts can be expected to obtain relative to different observers in RQM; and secondly, the notion that each Alice-like system is associated with its own subject of experience, whose perceptions correspond to its respective set of relative facts. I question both of them. Let us tackle the former first.

5 On Communication and Coherence

In this section, we shall investigate whether systematic relationships can be expected to exist between the relative facts of different observers in orthodox RQM. My discussion will crucially rely on the notion that the collection of facts relative to a particular observer is itself a perspective-dependent concept according to the interpretation.

There is a popular and apparently straightforward argument to the effect that different observers have completely unrelated sets of relative facts in RQM. It goes as follows.

Assume that Bob performs a repeatable measurement of some observable O on some system previously in a superposition with respect to O. RQM predicts that the system acquires a definite O-property relative to Bob.[10] But it also says that the quantum state of the system relative to *Alice* is *still* the superposition (or rather, an improper mixture) of O-eigenstates. Hence, if Alice measures O right after Bob did, she may register a completely different outcome. In fact, the outcomes of Bob's measurements have absolutely no influence on the probabilities of Alice's possible outcomes.

There is a closely connected and apparently straightforward argument to the effect that observers cannot communicate information in RQM. It goes as follows.

Assume again that Bob has performed the measurement on our system. This time, suppose that Alice would like to find out about his result. There are different ways in which she might go about this. But in any case, what Alice will do is engage in an interaction with some physical system or other, which as a result would acquire some property *relative to her*. And it looks like nothing in the theoretical structure of RQM would enforce any systematic connection between the facts relative to Bob and the properties he (or his computer or notebook) acquires relative to some *other* reference. Exemplarily for many, Lewis concludes that "it is easy to see that RQM [sic] property relativity prevents Alice from finding out Bob's measurement result by *any* means: whatever observation she makes will be an interaction between Alice and some other system, resulting in a property relative to Alice, and telling her nothing about properties relative to Bob" [12, p. 7] (original emphasis).

It thus appears like the world of RQM is one in which different observers not only have their own sets of facts that have nothing to do with each other but are also unable to

[10] I am here rather wilfully ignoring the complication that most systems of interest are not in the habit of revealing their properties to Bobs directly, but rather interact with some measurement device etc. first.

access information about each other's facts. If this were true, a principle like Liberal Structure Combination would immediately become very unattractive. For, if some observable had different values relative to different particles at the same time, Liberal Structure Combination would entail that it simultaneously possesses multiple inconsistent values relative to any composite containing both particles.

Fortunately, both apparently straightforward arguments are premature. To see this, recall that which facts obtain relative to Alice or relative to Bob is itself a reference-dependent question according to RQM. This already serves to dispel a naïve version of the worry that 'different observers have completely unrelated sets of relative facts in RQM': it is not like there are absolute facts about which sets of facts obtain relative to which observer, sets that, if placed side by side, would be found to differ wildly and unsystematically.

Once we do acknowledge that any analysis of the facts relative to Alice and/or those relative to Bob must be conducted from some perspective, the mathematics of quantum mechanics suggests a promising kind of coherence. For example, suppose that a third observer Charlie describes a sequence of events in which Bob performs a z-spin measurement on a spin-1/2 particle and informs Alice about the result. The quantum state Charlie would ascribe to the three systems at the end of the proceedings would approximately take the form (constants suppressed):

$$|\mathbf{up}\rangle_p\,|\text{'}\mathbf{up}\text{'}\rangle_B\,|\text{''}\mathbf{up}\text{''}\rangle_A + |\mathbf{down}\rangle_p\,|\text{'}\mathbf{down}\text{'}\rangle_B\,|\text{''}\mathbf{down}\text{''}\rangle_A,$$

where $|\text{'}\mathbf{up}\text{'}\rangle_B$ is Bob's state if he has seen the outcome 'up' (likewise for $|\text{'}\mathbf{down}\text{'}\rangle_B$), and $|\text{''}\mathbf{up}\text{''}\rangle_A$ is Alice's state if she has heard Bob report the outcome 'up' (likewise for $|\text{''}\mathbf{down}\text{''}\rangle_A$). The form of the state ensures that if Charlie would ask Bob and Alice about Bob's outcome, the answers that would materialize relative to him would line up.

If it is assumed[11] that these answers may, under the given circumstances, be interpreted as accurate reports of i) which property the particle acquired relative to Bob *relative to Charlie*, and ii) which properties Bob acquired relative to Alice *relative to Charlie*, it turns out there is a very systematic link indeed between Bob's and Alice's relative facts relative to Charlie. We seem to find, or are free to postulate, that CPL holds within *each* perspective (cf. [10, p. 4f.]). Moreover, a similar argument shows that the particle necessarily acquires the *same* spin relative to Bob and Alice, relative to Charlie, if they successively perform repeatable measurements.

[11] According to Ruyant, this assumption is best regarded as an "interpretational rule" which is "part of the universal claims" [30, p. 444] of RQM.

We can establish the same conclusion relative to Bob. Once Bob has completed his measurement, the particle will be in state $|\text{up}\rangle$ or state $|\text{down}\rangle$ relative to him. If Alice were to perform another z-spin measurement immediately afterward, the joint state of her and the particle relative to Bob would necessarily evolve into either $|\text{up}\rangle_p|\text{'up'}\rangle_A$ or $|\text{down}\rangle_p|\text{'down'}\rangle_A$, always in accordance with whichever state the particle was previously in relative to Bob.

Thus, there is a second sense in which the worry that 'different observers have completely unrelated sets of relative facts in RQM' is unfounded: if interpreted as a claim about the relationship between sets of relative facts as are relative to some reference, it is incorrect.[12]

Of course, this package of rejoinders is neither mine nor novel: It has long been espoused by Rovelli and collaborators (cf. [1, p. 1666; 15, p. 441; 31, p. 2-4]). Consequently, Adlam is fully aware of it. Nonetheless, she asserts that "in orthodox RQM there cannot be any systematic connections between the relative facts associated with different observers" [3, p. 3]. What she means by that is that there are no systematic connections *in an absolute sense.*[13]

Is that true? Well, it depends on what the 'absolute sense' is. In RQM, CPL supposedly hold relative to *each* perspective, and in this sense absolutely. We might even amend RQM with the novel postulate that CPL holds *independently* of any perspective, without revoking radical relativism about dynamical properties: for, perspective-independent facts about the *relationship* between the values of observables are arguably consistent with the absence of perspective-independent facts about the values themselves.[14] What is certainly correct, though, is that there are no connections between absolute facts about relative facts in RQM – trivially so, because there are no absolute facts about relative facts to begin with.

But we should be cautious not to draw false conclusions. In particular, we *cannot* infer that an observable can acquire entirely unrelated values relative to different observers.

[12] I admit there is a serious reason for scepticism about these rejoinders (which to my knowledge has not yet been pressed in print): They rely on a highly idealised toy model of interactions. In reality, the quantum state of particle + Alice + Bob would be something much messier than what we have supposed. For the rejoinders to go through, RQM hence owes us a much more rigorous, general account of the inferences Charlie may draw about Alice's or Bob's relative facts (relative to him) under various conditions. But while I am sympathetic to these criticisms, we should acknowledge that they apply equally to RQM+. What is at stake is an exact criterion for when information stored in a pointer is 'destroyed'. This is a notion that in CPL does crucial work for RQM+, too. And if it is fair to postulate CPL in an absolute sense (as in RQM+), it is equally fair to postulate it within each perspective (in RQM).

[13] I should note that Adlam has additional arguments, to do with the empirical confirmation of scientific theories, to regard connections in an absolute sense as indispensable [8]. I shall not engage with these arguments here.

[14] For the distinction between 'absoluteness' in the former and latter sense, cf. [32, p. 93].

As we have seen, this is not so – neither absolutely (because there are no absolute facts about an observer's facts at all) nor relative to any reference (by the above arguments). This also means that Liberal Structure Combination in no sense implies that an observable can simultaneously have multiple values relative to composites.

With this in mind, we return to the problem of the many Alices. To recall, the concern was that the various Alice-like collections would generically possess wildly different relative facts. However, we now have reason to think that this is not the case, even under a permissive principle like Liberal Structure Combination.

Suppose that there are multiple (mutually overlapping) Alice-like collections of particles, and label the particles that appear in at least one such collection the P_i. As usual, we must pick the perspective of an observer O to describe the physical situation. We require that O can describe the sequence of events without modelling themselves quantum-mechanically; in particular, we assume that the P_i neither perform disturbing measurements on O nor interference measurements on O and the systems O is entangled with in the relevant timespan. Moreover, we restrict attention to interactions between the P_i and systems external to the P_i. As remarked earlier, dropping these restrictions would raise difficult questions about the states or properties of systems relative to themselves, questions I wish to bracket for today's purposes.

Given these restrictions, the quantum state of the P_i plus any relevant external systems relative to O will display the desired coherence between the states of their respective pointer variables. If, for instance, several of the P_i measure the same external variable (either simultaneously or successively without intermediate disturbances), this variable takes on the same value relative to each of them, relative to O. Thus, the choice of which collection we identify with Alice affects which variables have definite values relative to her (relative to O) at a given time, but not *which* values they have if any.

More generally, whichever observables the P_i measure on external systems, their pointers will end up probabilistically correlated in the quantum state relative to O in just the manner predicted by ordinary quantum mechanics. Again, as long as we may regard this as indicative of the *facts* realised relative to the P_i, these will likewise be systematically related relative to O.

6 On Experience and the Many Alices

That the facts relative to various Alice-like collections would vary dramatically in RQM was one of two assumptions that fed into the threat of 'Everettianism'. The second was the notion that different Alice-like collections with different relative facts would translate into many Alices making different observations. We shall now turn attention to this second assumption.

To begin with, it is worth reflecting on an interesting remark Adlam makes early on in her paper to underline the urgency of the Combination Problem. "[I]n order to reproduce empirical results observed by human scientists", she says, "RQM must attribute relative facts to human-sized systems as well" [3, p. 3]. The remark is interesting because it reveals a certain conception of the connection between relative facts and observations that is otherwise left implicit in the literature. What Adlam assumes is that for some observer Alice to observe a certain fact, it is necessary that this fact obtain *relative to Alice*. Hence, she says that "we have direct access only to our own relative facts" [3, p. 5]. The idea is that the facts that obtain relative to Alice define her domain of possible experience. And since it is the observations of humans we must account for, it would follow that we need facts that obtain relative to humans.

This is a seductive idea, and one that is invited by the common practice of referring to an observer's relative facts as their *perspective*. I believe that it is widely taken for granted by both defenders and critics of relativist interpretations. But it is not inevitable and does not automatically follow from the relativisation of facts to systems.

In fact, we naturally arrive at a different conception if we take off from the naturalist assumption of a close correspondence between states of the body and states of mind. If you want to know which experiences Alice makes, then, shift attention from her facts to her bodily state. Recalling further that dynamical properties are supposed to be observer-relative, it is natural to hypothesize that Alice's experiential state is going to be determined by (or correspond to) her physical properties relative to various references in some way.

A particularly obvious suggestion is that Alice's mental state relative to some observer O stands in direct correspondence with the state of her body relative to O. Taking this thought seriously, we conclude that there are different reference-relative facts about which experiences Alice undergoes (if any) at a certain time. And just as no reference is privileged in describing the 'true' physical state of a body, so no reference can claim to provide the 'true' account of Alice's state of mind. Hence, an experience Alice has relative to Bob (viz., according to the facts that obtain relative to Bob) is no less real an experience than one she has relative to herself.[15]

There is no denying that the idea of observer-dependent facts about the experiences of particular observers takes getting used to. It also has certain odd consequences. For

[15] This is another point that is often overlooked in discussions about communication in relativist interpretations. My hunch is that this partially explains why an exchange of information between two observers *A* and *B* that occurs 'only' relative to some third reference *C* is not typically counted as an instance of genuine communication between *A* and *B*.

instance, introspection alone would not allow Alice to discern which observer (or which never-ending *sequence* of observers) she would be having this or that experience relative to. Moreover, it is not obvious how we ought to think of Alice's mental state relative to references which her body is in an indefinite state relative to. Novel challenges arise, for instance to do with empirical confirmation. I hope to provide a more comprehensive analysis of these elsewhere. But for the time being, let me make four points to justify taking the view seriously, at least if we take RQM seriously at all.

First, there is nothing *conceptually* more puzzling about the relativisation of experiences to sets of relative facts than there is about their relativisation to, say, 'branches' of an Everettian multiverse.

Second, this relativisation is all but *unavoidable* in RQM, given the unrestricted iteration of relativity, if one assumes any connection between physical and experiential facts. For instance, we cannot render facts about Alice's experiences absolute by postulating that they correspond to Alice's bodily state *relative to Alice*: if there even are such facts in RQM, they are again observer-dependent by the principle of higher-order relativity.[16]

Third, the conception I have sketched is only consequential from a naturalist perspective on the mind-body problem. Indeed, it follows automatically from the relativisation of bodily states plus the idea of direct correspondence between bodily and experiential states.

And fourth, even if we initially choose to measure an observer's experiences by their relative facts, we may in the end have no choice but to factor in their physical state, too. The reason is that a system's having a determinate property relative to a conscious observer cannot plausibly be a *sufficient* criterion for the observer to perceive it. Otherwise, I would have to have perceptions of all the particles that interact with various parts of my body all the time, and I can confidently report that I do not. Hence, additional information is needed to determine an observer's experiences beyond their relative facts, and this must plausibly be information about their physical make-up and dynamical state.

Much more would have to be said about the two competing conceptions of the relationship between relative facts and experiences, their merits and demerits. One thing I should emphasise is that their two core principles – an observer can only perceive what is the case relative to them, and what an observer perceives corresponds to their bodily state – are not inconsistent with one another. They can in principle both come out true in one and

[16] In [33], the author argues that any relativist interpretation of quantum mechanics is under high pressure to accept an unrestricted iteration of relativity. If this is right, it also follows that any relativist interpretation is under high pressure to make sense of observer-dependent facts about the experiences of particular observers.

the same theory.[17] Nonetheless, they can guide our thinking in different directions and place different constraints on the construction of a relativist interpretation.

Here is a first example: if we accept (something like) the second conception just outlined, we do *not* necessarily need facts that obtain relative to human-sized entities to account for the phenomena. Once we have humans in the right bodily states relative to some references, we have experiences. It does not *per se* matter which kinds of system these references are. They could be fundamental particles.[18]

The point is not that I want to propose we circumvent the Combination Problem by eliminating macro reference systems. Remarkably, this is an option which Adlam ultimately comes to recommend, in stark contrast to her earlier claim that facts relative to macro systems are indispensable.[19] And it is interesting to note that a crucial part of the thought process that leads her there is the realisation that relative facts should be disentangled from experience (cf. [3, p. 15f.]). However, I think it's clear that we do want to attribute relative facts to complex systems in RQM, if only derivatively. After all, we already do, and all the time, and we better try to understand what we are doing when we do. What we should be wary of, however, is the straightforward identification of what (macroscopic) observers observe with the facts that obtain relative to them.

This also has implications for the problem of the many Alices.

For a start, the mere existence of many Alice-like collections, each associated with a slightly different set of relative facts, does not entail the existence of many 'Alice minds' (who see slightly different realities). There is no need to count each reference system which is of the right constitution to be sentient as one subject of experience. To do so is somewhat natural when we identify the facts that obtain relative to such an observer with their perceptions. It is less compelling when we think of Alice's experiences (relative to an observer) as determined by her bodily state (relative to that observer). For, nobody would normally think that the blurriness of the boundaries of Alice's body would imply a multiplicity of many Alice minds.

Now, what can we say about the relationship between the experiences Alice has relative to different references?[20] One might worry that Alice generically is in totally different experiential states relative to different references, so that a form of proto-Everettianism comes in through the backdoor. But arguments much like those given in the previous section, if successful, would establish a high level of coherence regarding Alice's dynamical state

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[17] Indeed, I believe that this may well be the case in RQM at the end of the day.

[18] 'But it does not look like it is relative to some particle that we have our experiences!' – Well, what would it have looked like if it looked like we did?

[19] While Adlam wants to discard macro observers, she wants to retain 'macroscopic relative facts', without fully explaining what they are (if not facts relative to macro observers).

[20] Thanks to an anonymous referee for pressing this question.

across different perspectives. It is true that Alice's physical variables may possess certain values relative to some observers whilst having *no* definite values at all relative to others. But from any perspective, and modulo problems of self-description, the dynamical properties of her body would be the *same* relative to all references relative to which they would be definite at all. Correspondingly, it seems plausible that the properties of her experiential state would likewise be identical relative to all references relative to which they would be definite.

This is one example where the account we adopt of the connection between relative facts and experiences matters. It is not the only one, however. This connection also shapes what empirical adequacy requires of an interpretation, and in so doing demarcates the space of viable solutions to the question of Structure Combination.

7 On Empirical Adequacy and Structure Combination

The central consideration which Adlam employs as a constraint on acceptable principles of Structure Combination derives from the problem of the preferred basis.

We have noted that no agreed-upon mathematized procedure exists yet to derive the properties involved in interaction events in RQM(+). There are, however, two rough proposals for what such a procedure could look like. One is to identify the bases in which relative facts have been created between two systems A, B with the bases in which their joint quantum state assumes the form of a Schmidt bi-decomposition, $|\psi\rangle = \Sigma\ \alpha_i\ |\mathbf{A_i}\rangle|\mathbf{B_i}\rangle$. The other one is to read them off the variables that appear in the interaction Hamiltonian. Importantly for our purposes, neither of these procedures, as specified thus far, generally picks out a *unique* basis (cf. [19, p. 9-11; 24, p. 10-12; 34]). Absent additional considerations, it seems like multiple non-commuting observables may acquire determinate (relative) values in one and the same interaction in RQM(+).

While this would certainly go against the received wisdom, Adlam & Rovelli [5, p. 15-17] suggest it may be harmless. Their idea is that an interpretation does not need to establish a preferred basis for interactions between micro systems, provided it can explain why humans never attain precise simultaneous knowledge about the values of incompatible observables. In their view, the matter hinges on the facts that can be expected to obtain *relative to systems like us*: "[i]n order for RQM to be empirically successful", Adlam says, "it must be the case that macro-observers only possess relative facts about a given system in a single basis, since in our actual macroscopic experience we do not ever know incompatible facts about a single system at one time" [3, p. 6].

What we are looking at here is a proposal for a constraint on the empirical adequacy of RQM(+):

Incompatible Facts — RQM(+) is empirically inadequate if it entails that incompatible observables can be expected to simultaneously have definite values relative to human experimenters.

If it is true that incompatible observables can simultaneously be definite relative to fundamental particles, then Incompatible Facts rules out permissive principles like Liberal Structure Combination. By contrast, Adlam argues, a principle like CPL Structure Combination would conspire together with decoherence in just the right way to guarantee that unlike micro systems, macro systems only possess relative facts in one dynamically privileged basis.

Suppose for a moment that all this is correct, and that the CPL Package is the right solution for the Combination Problem. Then why should not RQM be able to embrace it just as well as RQM+, and reap the same benefits?

Adlam's reasoning on this point is involved. At core, though, it once again relies on the claim that there can be no systematic connections between the relative facts of different particles in RQM. This is why, in Adlam's opinion, RQM cannot harness a dynamical process like decoherence to explain how particles come to share facts in some privileged basis only [3, p. 13f.]. However, if what I have said is right, then CPL holds within each perspective in RQM. Hence, within each perspective, the CPL Package would have exactly the same implications for the relationships between the micro and the macro as it would (absolutely) in RQM+. By assumption, these are the right relationships. It follows that relative to each observer, micro and macro systems would be related in just the right way. Pending further argument, I conclude that if the CPL Package is the right solution for the Combination Problem, then RQM can adopt it just as well as RQM+.

Is it the right solution, though? There are at least two reasons for hesitation.

One, the proposal that we can do without a preferred basis in the micro realm is underdeveloped and faces significant obstacles. In particular, it is unclear which quantum state a system has relative to another which it possesses incompatible properties relative to, and what the probabilities are for future interactions between the two.

Two, Incompatible Facts itself is dubitable. This is so even if we take the facts relative to a sentient observer to circumscribe their experiences. For to justify Incompatible Facts, we need to presuppose not only that a fact's obtaining relative to an observer is *necessary* for that observer to perceive it. Rather, we would have to assume that the obtaining of incompatible facts relative to us humans would be *sufficient* for us to perceive and acquire knowledge about them (at least sometimes). It is not clear why that should be so.

If we take experiences to correspond to relative bodily states, even less reason remains to accept Incompatible Facts. But this is, of course, only one half of the story. While the alternative conception entitles us to reject one constraint, it forces another one upon us:

DISALLOWED STATES RQM(+) is empirically inadequate if it entails that humans can be expected to be in bodily states (relative to other observers) of possessing simultaneous knowledge of incompatible properties.[21]

This is just one aspect of a much more general challenge. Can it be understood how our apparently unified, continuous mental life emerges from the physical properties our bodies acquire, flash-like, relative to other systems? And can RQM(+) explain why we end up in the bodily states that correspond to the experiences we actually make in the circumstances in which we do?

The honest answer is that I have no idea. To make progress, it seems, we would not only have to settle for a sufficiently precise account of what determines the timings and bases of interactions. We would also have to clarify which properties systems possess relative to themselves (if any), venture at least schematic conjectures about the nature of the correspondence between bodily properties and experience, and take decoherence into account. I'm afraid that this task is for another day, and probably for another pay grade. But if what I have said is convincing, it is a task that RQM(+) will have to tackle in one way or other – and quite independently of the Combination Problem.

8 Quantum States and Probabilities: Two More Combination Problems

This concludes my critique of Adlam's arguments against the Liberal Package. Now, I shall describe a difficult aspect of Combination Problem which Adlam does not discuss: namely, the combination of quantum states and probabilities.[22]

According to RQM(+), a system S only has a quantum state (or density matrix) relative to another S'. This state is supposed to encode the probabilities for the possible outcomes of future 'measurements' on S by S'. In particular, we may assume that S has some

[21] Or perhaps relative to a *significant number* of other observers? This is a tricky epistemological question in its own right, because there is no obvious probability measure to avail ourselves of.
[22] Once more, I thank an anonymous referee for pushing me to say more about these problems than I did in a previous draft. I owe much of the material of this section to them.

quantum state relative to each fundamental particle, and that this state describes the outcome probabilities of their possible future interactions. This invites two new, interrelated questions:

State Combination	What is the relationship between the quantum state which a third system P has relative to i) a composite system S and ii) its constituents S_i?
Probability Combination	What is the relationship between the probability for a third system P to acquire a certain variable value upon measurement i) by a composite system S and ii) by its constituents S_i?

Note that these questions remain on the table even for a version of RQM+ in which facts about dynamical properties are absolute. Indeed, they are pertinent for any interpretation that relativises quantum states to observers which can be constituents of one another.

In RQM, relative quantum states are supposed to depend on relative facts [31, p. 4f.]. Similarly, in RQM+, they depend on the history of mutual interaction events between the target system and its observer. In both cases, however, there might be some wiggle room to determine how exactly the respective dependence is to be defined. I suggest we allow for the possibility that our answer to Structure Combination does not all by itself pin down answers to State and Probability Combination. In particular, we need not treat either direction of the eigenstate-eigenvalue link as sacrosanct.

It is easy to see how State and Probability Combination cause trouble for the Liberal Package. To illustrate, return to Alice, Bob, and their particle. Focus on a time t when Bob has just performed his z-spin measurement, but Alice has not become involved yet. At that time, what is the quantum state of the particle relative to the composite Alice+Bob?

According to the tenets of RQM(+), such a relative quantum state must encode the probabilities for future interaction outcomes between the particle and Alice+Bob. If, moreover, interacting with any one constituent (e. g., Alice or Bob) counts as interacting with Alice+Bob, the probabilities determined by the state would have to hold good *no matter* whether it's Alice or Bob that interacts with the particle next. But this conflicts with another official tenet of RQM(+), according to which the particle's quantum state is collapsed relative to Bob yet still a superposition (or improper mixture) of z-spin eigenstates relative to Alice.

One might take this trouble as indication that Liberal System Combination is too liberal, after all. If we would not regard Alice+Bob as a legitimate reference system, we presumably would not have to answer awkward questions about the quantum states of systems relative to it. Now, I do think that the combination of quantum states and probabilities is a formidable problem, and I do not claim to have a completely satisfactory solution to offer. But I would like to urge caution before that is counted against the Liberal Package.

The reason is that similar problems are bound to arise for almost any principle of System Combination. For instance, they also affect the CPL Package. As soon as two systems P_1, P_2 share information about the definite value of some observable on a third one P_3, CPL System Combination implies that there is a composite observer P_1+P_2. But this will not in general suffice to determine the quantum states of all physical systems relative to P_1+P_2. For one thing, the information shared between P_1 and P_2 about P_3 may not even suffice for the quantum state of P_3 relative to P_1 and P_2 to converge. Take, for instance, a case where P_1 and P_2 share information about the *position* of a particle but not about its spin. Or take a case where P_1 merely shares *coarse-grained* information about a previous measurement on P_3 with P_2.

For vividness, suppose this time that Bob measures the z-spin of a *spin-1* system initially in state $|\psi\rangle = \alpha|+1\rangle + \beta\,|0\rangle + \gamma\,|-1\rangle$, and subsequently informs Alice that the outcome was among +1 and 0. In this case, the state of the particle relative to Bob would be either $|+1\rangle$ or $|0\rangle$, whereas Alice would describe them jointly by means of the entangled state $|\psi\rangle = \frac{\alpha|+1\rangle|'+1'\rangle + \beta\,|0\rangle|'0'\rangle}{\sqrt{|\alpha|^2+|\beta|^2}}$. Nonetheless, the CPL Package says there is a composite observer Alice+Bob. We are thus in much the same jam as before when we assumed the Liberal Package.

What is more, we have not even begun to ask about the relative quantum states of systems *other* than those which P_1 and P_2 have shared information about. There is no reason to suppose that P_1 and P_2 would assign the same states to all systems just because they have communicated about, say, P_3. (Consider a case in which Bob has measured the z-spin of *two* uncorrelated particles in the lab and only told Alice about the outcome of one of these measurements. What is the quantum state of the other particle relative to Alice+Bob?) Hence, the CPL Package is just as vulnerable to problems of state and probability combination as the Liberal Package.

Another proposal hinted at by Rovelli is to identify reference systems with spacetime regions [2, p. 1065]. But this does not seem to help, either: in a sufficiently well-behaved spacetime, we can always find a bounded, connected region that includes Bob and Alice at coordinate time t, and it is still unclear what the quantum state of the particle (or its associated spacetime region) is supposed to be relative to such a region.

Other relativist interpretations restrict relative facts to observers or agents in a strong sense. But i), nobody knows how that strong sense is to be rigorously spelled out, ii), many find it incredible that high-level notions should play such a fundamental role in physics, and iii), this move would go completely against the spirit of RQM (cf. [1, 1644; 2, p. 1067]).

Upon recognition that even moderately permissive principles of System Combination seem to invite concerns of this kind, one might be tempted to adopt a maximally restrictive attitude. One might hold that multiple constituents form a bigger reference system only if *all* other systems have *identical* quantum states relative to all of them. But this position would in practice hardly be discernible from full-blooded irrealism about composite references. It is not clear at all – to me, at any rate – that even two fundamental particles could ever be expected to satisfy this criterion for any significant duration of time, not to mention bigger systems like Alices or Bobs. As an explanation of what we do when we refer relative facts to human experimenters, this proposal is a non-starter.

So, the problem of aggregated quantum states and probabilities is neither specific to the Liberal Package nor easily avoided by an obvious alternative principle of System Combination. Perhaps we should acknowledge the existence of composite reference systems which we do not yet know how to define relative states and probabilities for.

Even then, there remain two 'deflationary' moves to try and render the problem less urgent.

The first one is a maximally lightweight interpretation of quantum states and probabilities. Picture a view on which they are both so purely epistemic that even probability assignments of 0 or 1 have no ontic import. On such a view, confusion about appropriate probability assignments may remain lamentable, but it cannot cause problems for the ontology or metaphysics of a physical theory. Unfortunately, I concur with those who think that states and probabilities do and must play a more substantive role in Relational Quantum Mechanics [16-19], as I also concur with those who find subjective probabilities floating free from worldly constraints explanatorily wanting.

The second deflationist move is to simply accept that systems do not always have well-defined quantum states and interactional probabilities relative to all reference systems. But this leaves the hard work to be done: We would still have to detail under which circumstances which systems are in which well-defined states relative to which composites.

One particularly economical proposal is that quantum states and probabilities are well-defined only between pairs of particles. States and probabilities relative to composites would then be regarded as mere idealisations or approximations of great pragmatic value that work well in ordinary circumstances but do not have physical reality. In this case, it would be less problematic that we sometimes find ourselves at a loss for appropriate relative state assignments. Yet even then, the explanatory task would remain of connecting the relative states and probabilities relative to individual particles with those supposedly 'FAPP' states and probabilities that humans actually work with.

Moreover, such an approach would have to be premised on the reductionist hope that all phenomena can ultimately be accounted for in terms of facts relative to individual particles. Earlier, I have suggested that systems might sometimes interact with, and acquire uninherited properties relative to, composites 'directly'. The motivation for this thought was that quantum states of composites can change without changes to the reduced density matrices of their constituents. But if we take this possibility seriously, we need to be able to describe probabilities for systems to assume properties relative to composites. That is, which systems we define probabilities relative to should be dictated by the necessities of the theory in accounting for the physics, not by what we find natural to conceive of as wholes or easy to determine quantum states for.

To repeat, I do not claim to have a full solution for Quantum State and Probability Combination. Before I conclude, however, let me outline my best attempt to mitigate the problem. To this end, I shall have to tell a non-standard story about relative quantum states in RQM.

As usual, we note that in RQM, any physical situation ought to be described from some perspective O. And as usual, we rely on higher-order relativity, keeping in mind that there are no observer-independent facts about the states of systems relative to particular observers. Now, focus on an arbitrary target system S, and assume that it is in some quantum state $|\psi\rangle$ relative to O. The suggestion I would like to push is that for most purposes, we will get the desired results if we simply assume that *relative to O*, S is in state $|\psi\rangle$ relative to *all* reference systems.

I will once again revert to Alice and Bob for illustration. Suppose that Alice, Bob, and O (which may or may not be identical with Alice or Bob) agree that the particle to be measured is initially in state $|\psi\rangle = \alpha|\mathbf{0}\rangle + \beta|\mathbf{1}\rangle$. At the time of interest t when Bob has performed his z-spin measurement, O either has already acquired information about Bob's outcome or not. Suppose first that O has already acquired such information. In this case, the particle will be in state $|\mathbf{0}\rangle$ or state $|\mathbf{1}\rangle$ relative to O. For concreteness, suppose it is in state $|\mathbf{0}\rangle$. Now let us ask: *from the perspective of O*, what is the quantum state of the particle relative to Alice, Bob, and Alice+Bob?

Standard presentations of Relational Quantum Mechanics [1, 2] suggest that its state should be $|\mathbf{0}\rangle$ relative to Bob yet the reduced density matrix $\boldsymbol{\rho} = |\alpha|^2\, |\mathbf{0}\rangle\langle\mathbf{0}| + |\beta|^2\, |\mathbf{1}\rangle\langle\mathbf{1}|$ relative to Alice. Instead, I propose we assume that from the perspective of *O*, the particle is in state $|\mathbf{0}\rangle$ relative to each observer alike. In fact, I submit that the alternative, standard account of relative states is at odds with the equally standard account of cross-observer coherence rehearsed in section 5.

Cross-observer coherence requires that if *O* has performed a repeatable z-spin measurement on a particle, they can be certain that Alice would find the same z-spin upon subsequent measurement. The way to justify this in RQM is precisely to observe that *O* ascribes the state (say) $|\mathbf{0}\rangle$ to the particle, and would model its interaction with Alice such that their combined state would necessarily evolve to $|\boldsymbol{\psi}\rangle_{\mathrm{p+A}} = |\mathbf{0}\rangle_{\mathrm{p}}|\mathbf{'0'}\rangle_{\mathrm{A}}$. Hence, while my account may sound revisionary at first, RQM is in fact already committed to the claim that relative to *O*, the probability for a z-spin measurement *performed by Alice* on the particle at *t* to yield outcome '0' is 1. Insofar as the particle's quantum state relative to Alice is supposed to encode the probabilities for the outcomes of possible interactions between the two (rather than, say, Alice's state of information), this suggests that relative to *O*, the particle's state relative to Alice is $|\mathbf{0}\rangle$.

From the perspective of *O*, *anybody* who would competently measure the particle's z-spin at *t* would register the result '0'. Similarly, relative to *O*, anybody who would measure the particle's spin along an axis only slightly tilted away from the z-axis would *almost* certainly get to see the outcome '0'. In full generality: relative to *O*, the probabilities for measurements performed on the particle by no matter whom should be given by $P(a_i) = |\langle \mathbf{a_i} |\mathbf{0}\rangle|^2$. This is necessary for *O*'s perspective to be internally coherent. Hence, from the perspective of *O*, the state of the particle relative to any reference should be $|\mathbf{0}\rangle$.

This implies that the particle's quantum states relative to Alice and Bob are identical from the perspective of *O*. There is thus no obstacle to assuming that its quantum state relative to the composite Alice+Bob is the state $|\mathbf{0}\rangle$, too.

Of course, Alice would in fact describe the state of the particle by means of $\boldsymbol{\rho}$, and that is what quantum theory advises her to do. But from the perspective of *O*, this state assignment, while 'correct', is a product of incomplete information.

In a relativist interpretation like RQM, it might seem odd to assume that the particle's quantum state should be the same relative to each observer. It is important to realise, however, that this is *itself* supposed to be the case merely relative to a specific observer. The whole construction thus remains inherently perspectival.

Suppose instead that *O* has not yet acquired information about Bob's outcome or the particle's spin at *t*. In this case, the joint state of Bob+particle relative to *O* would be of the form $|\boldsymbol{\psi}\rangle_{\mathrm{p+B}} = \alpha\, |\mathbf{0}\rangle_{\mathrm{p}}|\mathbf{'0'}\rangle_{\mathrm{B}} + \beta\, |\mathbf{1}\rangle_{\mathrm{p}}|\mathbf{'1'}\rangle_{\mathrm{B}}$, and the particle would consequently be described by the reduced density matrix $\boldsymbol{\rho} = |\alpha|^2\, |\mathbf{0}\rangle\langle\mathbf{0}| + |\beta|^2\, |\mathbf{1}\rangle\langle\mathbf{1}|$. As before, I suggest we assume that relative to O, this is also the particle's state relative to any other observer, including Bob. Again, this may sound counterintuitive. For instance, it entails that relative to O, Bob would have a 50-50 chance of seeing the outcomes '0' or '1', respectively, if he immediately decided to measure the particle's z-spin again. But this becomes less dubious once we acknowledge that relative to O, there is at t no fact of the matter yet regarding *which* outcome Bob observed in his first measurement. Nonetheless, the outcomes of Bob's first and second measurements would agree, relative to O. And if it is accepted that the state of the particle relative to both Alice and Bob at t is $\boldsymbol{\rho}$, there is no obstacle anymore to assuming that this is also its state relative to their composite.

Contrary to appearances, then, it seems like we can tell a story about the state of the particle relative to Alice+Bob even in cases in which Alice and Bob play the roles of Wigner and his friend. To the extent that this story is convincing, it favours RQM over RQM+, for it relies on the higher-order relativity of quantum states.

However, this is not to deny that problems remain. In essence, what I have suggested is that the state of the particle collapses for everybody, including Alice, once it collapses relative to reference observer O. As far as I can tell, this account holds up well provided we exclude measurements performed on O from consideration. But of course, the core question that historically motivated the relativisation of quantum states in the first place is how it can be reconciled with the interference effects which Alice could presumably observe if she performed a suitable measurement on the system particle+Bob+O in its entirety. As we are now asking this question from O's perspective, we have reached the point where we run into the irks and quirks of quantum-mechanical self-description again.

9 Conclusions

Let us take stock.

I have started from two main points of disagreement with Adlam. One is that I do not think that observables can be expected to assume altogether unrelated values relative to different observers in RQM. The other is that I think we should focus on the relative bodily states of sentient creatures, more than their own sets of relative facts, to derive conclusions about their experiences. The first point means that RQM can implement Adlam's preferred solution to the Combination Problem, the CPL Package, just as well as RQM+ (or so I contend). The second point undermines the key constraint on the empirical adequacy of the interpretation which Adlam employs to rule out more liberal solutions. At the same time, it points towards a very significant challenge – in a slogan, the challenge of explaining why humans generically end up in the *right kinds* of (relative) bodily states.

Additionally, I have argued that the possibly most difficult part of the Combination Problem – the combination of quantum states and probabilities – has gone unnoticed in Adlam's discussion. As we have seen, it is not easy to restrict System Combination in such a way as to fully avoid these issues. While I have not offered a fully satisfactory solution, I have sketched a strategy to mitigate the problem in the context of RQM. Its core is a heterodox account of observer-dependent assignments of relative quantum states. However, the difficult problems of quantum-mechanical self-description and interference effects remain unresolved.

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