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The miracles argument meets quantum mechanics: Toward a locavore philosophy of physics

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The miracles argument meets quantum mechanics: Toward a locavore philosophy of physics

(El argumento de los milagros se encuentra con la mecánica cuántica: hacia una filosofía de la física locavore)

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Abstract: It's a mistake to afflict upon on our best theories a single, uniform interpretation meant to apply in all circumstance. It's a mistake because it impedes the capacity of those theories to function as science. To refrain from the mistake is to adopt the *locavore hypothesis*: the same theory can merit different interpretations in different circumstances. Using quantum mechanics as an example, I argue for the locavore hypothesis, and examine its consequences not only for the scientific realism debate but also for our notion of scientific understanding.

Keywords: scientific realism, scientific understanding, quantum mechanics, interpretation, contextual empiricism.

Resumen: Es un error imponer a nuestras mejores teorías una interpretación única y uniforme, que deba ser aplicada en toda circunstancia. Es un error porque socava la capacidad de esas teorías de funcionar como ciencia. Evitar este error supone adoptar la hipótesis locavore: la misma teoría puede recibir interpretaciones diferentes en diferentes circunstancias. Recurriendo a la mecánica cuántica como ejemplo, defiendo la hipótesis locavore, y examino sus consecuencias no solo para el debate sobre realismo científico, sino también para nuestra noción de comprensión científica.

Palabras clave: realismo científico, comprensión científica, mecánica cuántica, interpretación, empiricismo contextualista.

Short summary: The Locavore view is an alternative to satellite-level views about scientific realism, scientific understanding, and the interpretation of physical theories. Close attention to concrete physical theories and their local practice motivates the Locavore view. Using quantum mechanics as an example, this essay develops and defends the Locavore view.

1. A curious juxtaposition

A juxtaposition between two modes of approach to philosophy of science sets the scene for this essay. Though hardly exhaustive and exclusive, the modes are influential and well-represented. One mode of approach is the *Balloonist*. Surveying science, which I imagine as a swamp, from lofty heights of abstraction, Balloonists ask sweeping questions of great generality, questions about the natures of scientific explanation and representation, about appropriate criteria of theoretical equivalence, about reduction and emergence, about realism and fundamentalism (to name a few). Another mode of approach is the *Frogperson*. Busying themselves in the lowbrow muck of actual, concrete physical theories, Frogpeople grapple with puzzles peculiar to those theories, puzzles about the nature of gauge symmetry or quantum nonlocality, the significance of Haag's theorem, and the cosmological constant problem (to name a few). The curious juxtaposition happens at the end of the working day, when Balloonists and Frogpeople meet at the the pub to discuss their labors—and begin to wonder whether they have, in fact, been investigating the same swamp.

The instance of the curious juxtaposition on which this essay focuses is the debate over scientific realism. To launch the balloon-level version of the debate, consider T, a highly successful theory of physics, and ask: what does T's success license us to believe about the physical world? Invoking the venerable Miracles Argument (Putnam, 1975), Balloon Realists answer: T's success licenses us to believe that the physical world is (very close to) the way T says it is. That is, T's success licenses us to believe that T, literally interpreted to describe a physical world existing independently of us, is approximately true.

The Miracles Argument (Schematic)

1. Theory T is successful.
2. T's truth is the best explanation of this success.

$\therefore$ T is (at least approximately) true.

Here "true" is construed non-pragmatically and non-epistemically—that is, in such a way that a mind- and practice- independent world is the standard of truth. For Balloon Realists, the license to believe that T is approximately true is *abductive*: T's extraordinary success cries out for explanation; the best explanation on offer is that the world is pretty much the way T says it is. Call this position *Balloon Realism*.

Meanwhile, down in the swamp, Frogpeople skirmish over *how* to interpret quantum mechanics (QM)—and skirmish so fiercely and persistently that the question, *what does QM say the world is like?*, remains unsettled. For Balloon Realists, the question is also unsettling. It's unsettling because answers available, answers in the form of *interpretations of QM*, invariably incorporate elements that clash with realist tenets. Interpretations on offer are ad hoc, or metaphysically profligate, or in tension with a theory (viz., the Special Theory of Relativity) it's easy to be a realist about. QM, it happens, is the most empirically successful theory in the history of physics, able to accommodate phenomena from the solid state technologies that run our smartphones to black hole evaporation. QM, that is, is the concrete physical theory best qualified to play the role of T in the high-level case for Balloon Realism just sketched. However and alas, with central questions of quantum interpretation both unsettled and unsettling, realists don't have a satisfying account of what to believe, when they believe QM. The very physical theory for which the premises of the Miracles Argument are most plausible is a theory that leaves the realists unable to execute that argument's conclusion—to believe something, concrete and specific, when they believe QM.

Here I'll try to make something of this curious, even scandalous, juxtaposition. §2 characterizes attitudes toward the interpretation of physical theories and the nature of scientific understanding that are implicated in and implicated by Balloon Realism. §3 analyses why the package of attitudes characteristic of Balloon Realism comes to grief when the Miracles Argument is deschematized by setting T equal to QM. §4 describes a Frogperson attitude toward the projects of interpretation and understanding, one (with apologies to Arthur Fine (1996a; see (Ruetsche, 2015) for the apology developed) I call the *Locavore Approach*. The Locavore Approach, §4 argues, makes better sense of the very datum central to Balloon Realism, the success of science, than Balloon Realism itself does.

2. *Belief*

Deschematizing the Miracles Argument by setting $T = QM$ places Balloon Realists in a predicament. Stripped of its hedging, the deschematized argument concludes: "QM is true." The predicament is *how* to believe that—*what to believe, when we believe that QM is true*? A name for an answer to this question is an *interpretation of QM*.

> To understand a scientific theory, we need to see how the world could possibly be the way that the theory says it is. An interpretation tells us that. (van Fraassen, 1991, pp. 336-337)

An interpretation of QM is what we believe when we believe QM. Interpretation appears crucial to understanding: grasping an interpretation of QM, we see what the world is like according to theory—and to see that is to understand the theory.

Interpretation mediates *understanding*, and is a *prerequisite* for belief. But you can interpret and understand a theory without believing it, just as you can understand falsehoods without believing them. For Balloon Realists, what motivates belief in a successful theory T is not the question of interpretation: What does T say the world is like? What motivates belief is a question of explanation: Why does T work as well as it does? The crux of the Miracles Argument is that the interpretive question and the explanatory question are different sides of the same coin: T works as well as it does *because* the world is the way T says it is.

So to understand QM, or to believe it, or to enact the conclusion of the deschematized ($T = QM$) Miracles Argument, realists need an *interpretation of QM*.

Unfortunately, as the Frogperson considerations advanced in the next section detail, the interpretations of QM on offer tend to be unpalatable to realists. Further analysis of the Miracles Argument will enable us to understand why. Start with the first premise: "Theory T is successful." Like human success, scientific success takes a lot of forms. Let's introduce the term of art "theoretical virtue" for a good-making feature of a scientific theory—a feature that conduces to and/or helps to constitute a scientific theory's success. Catalogs of theoretical virtues aren't hard to come by (Quine, 1955; Kuhn, 1977; Longino 1990 are classics), and typically include self-consistency, accuracy, scope, precision, consilience (predicting phenomena we didn't devise them to predict), parsimony, simplicity, elegance, unifying power, explanatory reach, consistency with other theories we're inclined to believe, fertility (serving as a springboard for successor theories), ... Cataloguers are wont to classify theoretical virtues under different headings: self-consistency is a logical virtue; accuracy, scope, and precision (insofar as all are dimensions of accurately describing empirical phenomena) are empirical virtues; simplicity, elegance, etc., are *superempirical* virtues.

Superempirical virtues have loomed large in balloon debates over scientific realism. A Balloon Anti-realist counter to the Miracles Argument is the Underdetermination Problem. Successful T, Balloon Anti-realists contend, has *observationally equivalent* rivals: theories that agree with T about what we can see, but disagree about what lies beneath. Underdetermination challenges Balloon Realists to justify believing in T *rather than* one of its observationally equivalent rivals. A brazen Balloon Realist response, a response we will revisit, casts underdetermination as a hollow bluff, and calls that bluff: "Give us a rival explanation and we'll consider whether it is sufficiently serious to threaten our confidence" (Kitcher, 1993, p. 154).

Concentrate for now on a more modest Balloon Realist response to the Underdetermination Problem, a response to which superempirical virtues are pivotal. The more modest response opens by observing that any basically decent theory describes observations accurately—that is, any basically decent theory exhibits *empirical* virtue. But, the more modest response hastens to add, really good theories possess a host of additional, *superempirical* virtues—simplicity, elegance, explanatory oomph, fertility, ... And these *super-empirical virtues*, the response concludes, break evidential ties between observationally equivalent rivals. The more virtues, including superempirical ones, constituting T's success, the more reason the Miracles Argument gives us to believe T. The more superempirically virtuous a theory is, the more the Miracles Argument favors belief in that theory over its observationally equivalent but merely empirically virtuous rivals. (Sider, 2020, pp. 17, 53-54, is a recent *identification* of scientific realism with the view that superempirical virtues have evidential heft).

Consider the role this modest response assigns superempirical virtues in light of our earlier moral, that an interpretation of T supplies the content of the conclusion of the Miracles Argument. Then it becomes clear that Balloon Realism has a silent partner: the presumption that there's what I'll call a *winning interpretation* of T. It would be a problem, for realists, if T manifests different virtues under different, and rival interpretations. If T did that, there wouldn't be one picture of the world (one interpretation of T, supplying the content of the conclusion of the Miracles Argument) whose truth would explain T's success (understood as T's possession of the whole range of theoretical virtues evinced by the first premise of the Miracles Argument). If T manifests different virtues under different, and rival, interpretations, that attenuates the abductive support the Miracles Argument presents for belief in T under any single one of those interpretations. But belief in T is belief in T under one of its interpretations. So abductive support for belief in T attenuates as well.

The presumption that T has a *winning interpretation* arrests the attenuation. A winning interpretation of T is one

- under which T is virtuous in all or most of the ways the Miracles Arguments's first premise claims (to maximize the abductive support the premises of Miracles Argument lend its conclusion); and

- that has no serious rivals (to neutralize underdetermination challenges)

T's winning interpretation is what the realist believes when she believes T. It's *the* interpretation of T the grasp of which constitutes *understanding* T. That the world is the way T's winning interpretation say it is, the Miracles Argument contends, is the best explanation of T's success.

To understand QM, or to believe it, or to enact the conclusion of the deschematized ($T = QM$) Miracles Argument, realists need a *winning* interpretation of QM. The curious juxtaposition—put more bluntly, the scandal that the best argument for realism, when deschematized using the best scientific theory we have, sputters—derives from the circumstance that there is, at present, no winning interpretation of QM. Or so I claim. The next section illustrates the claim. Adopting a Frogperson perspective on QM, an actual deschematized physical theory, that section documents QM's predilection to manifest different virtues under different, and rival, interpretations. Section 4 unveils a Frogperson position I call the Locavore Approach. That section make a case that, notwithstanding QM's lack of a winning interpretation, we have resources for some sort of making sense of QM. Urging the pursuit of that sort of making sense, the Locavore Approach provides a healthy alternative to Balloon Realism.

3. *Grief*

For present purposes, let's assume that quantum theories take the following form, which I will call *the Hilbert Space Template*:[1] they associate with a physical system a Hilbert space $\mathcal{H}$; self-adjoint elements of the algebra $\mathfrak{B}(\mathcal{H})$ of bounded operators on $\mathcal{H}$ correspond to physical magnitudes, aka observables, of the system; states of the system are normed, positive, countably additive,[2] linear maps $\omega : \mathfrak{B}(\mathcal{H}) \to \mathbb{C}$; provided $\mathcal{H}$ is of dimension three or greater, Gleason's theorem puts states into

[1] A template brilliantly limned by von Neumann in the early days of QM. For systems outside the scope of his 1932 uniqueness theorem, systems including quantum fields and quantum statistical systems in the thermodynamic limit, there are reasons to liberalize our conception of a quantum theory. The main morals of the present essay—a call for Frogperson/Locavore approaches to interpretation and understanding, and a reexamination of the question of scientific realism in light of those approaches—not only survive but thrive in the context of a more liberal conception of quantum theories. Or so (Ruetsche, 2011) contends.

[2] $\omega : \mathfrak{B}(\mathcal{H}) \to \mathbb{C}$ is countably additive just in case, for any countable set $\{P_i\}$ of pairwise orthogonal projection operators in $\mathfrak{B}(\mathcal{H})$, $\omega(\Sigma_i P_i) = \Sigma_i \omega(P_i)$

one-to-one correspondence with density operators (trace class operators of trace 1) on $\mathcal{H}$; $Tr(\rho A)$ is the expectation value assigned the observable A by the state corresponding to the density operator ρ. To subject this expectation value to experimental test, prepare a large ensemble of systems in the state ρ, perform A measurements on those systems, and compare the long-run experimental average of the outcomes to $Tr(\rho A)$. The Schrödinger equation conveys quantum dynamics. That equation casts the Hamiltonian (energy) observable H of an isolated system in the role of infinitesimal generator of that system's time evolution: if $\rho(0)$ is the system's state at time $t = 0$, its state at other times t is given by $\rho(t) = exp(-iHt)\rho(0)exp(iHt)$. To subject quantum dynamics to experimental test, prepare a large ensemble of systems with Hamiltonian H in the state $\rho(0)$ at time $t = 0$, and see if $\rho(t)$ reproduces expectation values of measurements performed on those systems at time t.

QM passes experimental tests with flying colors. For Balloon Realists, this prompts the search for a winning interpretation of QM, something to believe, when they believe QM, that explains why QM succeeds as well as it does. The Hilbert space framework just set out is a point of departure for interpretive efforts: it constrains them to make sense of the empirical success of quantum expectation value assignments and quantum dynamics. But it neither handcuffs nor determines the course of interpretive projects. An interpretation of QM has license to elaborate, revise, and reconceptualize the Hilbert Space Template. An interpretation that exercises this license is vindicated insofar as it succeeds in making sense of why the Hilbert Space Template works as well as it does.

The Hilbert Space Template comes with some physical content, in the form of an account of long run experimental averages for measurements performed on large ensembles of identically prepared systems. This illustrates the truism that physical theories fall into the hands of philosophers of physics *already partially—but provisionally— interpreted*. In QM's case, a variety of foundational considerations dramatize questions left unanswered by the Hilbert Space Template. These include *content-elaborating* questions such as

1. Where do quantum probabilities come from? Are they dynamic in origin? Do they reflect contingent ignorance or can they be eliminated in a successor theory that explains why the Hilbert Space Template works as well as it does?

2. What is an *individual* system represented by a Hilbert state ρ like? Does it have determinate properties? Which ones? What is the metaphysical status of those properties?

Views conventionally gathered under the heading of *interpretations of QM* are in the business of answering content-elaborating questions such as the foregoing—in fleshing out the partial picture of the quantum world afforded by the Hilbert Space Template. But, underscoring the fact that QM comes to us not only partially but also *provisionally* interpreted, it's fair interpretive game to *adjust* the Hilbert Space Template by developing revisionary answers to questions such as

(3) is the one-to-one correspondence between self adjoint elements of $\mathfrak{B}(\mathcal{H})$ and physical magnitudes apt? Are some magnitudes more fundamental than others? If so, is $\mathfrak{B}(\mathcal{H})$ *too rich* a structure to capture fundamental quantum phyics? Or might $\mathfrak{B}(\mathcal{H})$ be too poor a structure: might multiple, distinct physical magnitudes correspond to a self adjoint element of $\mathfrak{B}(\mathcal{H})$?

(4) What valuations on the collection of physical magnitudes correspond to physical states? What is the appropriate criterion of physical identity for states so understood?

(5) What forms of time development do physical states/magnitudes admit?

Questions (1) and (2), raised against the backdrop of the Hilbert Space Template, are adamantly content-elaborating—they're just not questions that Template settles. Questions (3)-(5), by contrast, have the potential to be content-revising or content-reconceptualizing questions: they can be (and are!) answered in ways that alter the Hilbert Space Template. Views conventionally gathered under the heading of "interpretations of QM" are in the business of seeking acceptable answers to the content-elaborating questions (1) and (2), a business many of them pursue by developing content-adjusting answers to (3) - (5).[3]

The history of attempts to interpret QM shows how risky it can be to give content-elaborating answers to (1) and (2) without giving content-adjusting answers to (3) - (5). Consider first approaches which offer non-revisionary answers to (3) and (4)—approaches, that is, that adhere to the Hilbert Space Template by associating physical magnitudes with self-adjoint elements of $\mathfrak{B}(\mathcal{H})$ (aka observables), and by identifying states of quantum systems with density operators on $\mathcal{H}$. Such approaches confront a version of (2) that asks: given a individual system in quantum state ρ, which system observables have determinate values? The model of classical physics, in which a system state defines an assignment of determinate values to system observables, makes it tempting to answer: they all do! (Note that the answer precipitates a partial answer to (1): quantum probabilities reflect contingent ignorance of the actual determinate values of quantum observables.) The Bell-Kochen-Specker argument reveals this answer to be fatally flawed: in Hilbert spaces of dimension 3 or greater, such a determinate value assignment, if it obeys prima facie reasonable constraints, is ruled out by Gleason's theorem. (See (Redhead, 1987) for details, and (Mermin, 1992) for an illuminating discussion of the B-K-S argument and the Bell Inequalities.) This is the Scylla threatening interpretations of QM: make too many observables determinate, and contradict the statistical predictions of the (tremendously empirically successful) Hilbert Space Template.

Textbooks have standardized a navigational maneuver that steers clear of Scylla. The maneuver, which unfolds in the scope of non-revisionary answers to (3) and (4), is to radically contract the realm of quantum fact. Rather than entertaining a determinate value for every observable pertaining to a system in a state ρ, textbooks typically assert that *only observables whose values* ρ *predicts with certainty are determinate*. If ρ assigns an observable A an expectation value different from one of A's eigenvalues, there's just no fact about what A's value is. This eerily cautious *eigenvector-eigenvalue link* delivers interpretations from Scylla's jaws. Alas, the eigenvector-eigenvalue link deposits interpretations in the roiling midst of the Charybdis of quantum interpretation, the notorious Measurement Problem.

This Measurement Problem is that the eigenvector-eigenvalue link, in conjunction with the non-revisionary answer to (5) that Schrödinger evolution is universal and exceptionless, in conjunction with the assumption that measurements are physical interactions governed by the laws of QM, issues in the unbearable conclusion that, almost always, measurement interactions leave instruments in states where the pointer observable—the observable whose value records the measurement's outcome—lacks a determinate value. Baldly put, measurements don't have outcomes. Given that the principle reason we're interested in interpreting QM is its uncanny capacity to accurately describe the statistics of measurement outcomes, an interpretation that denies the existence of those outcomes is unacceptable. The Charybdis threatening interpretations of QM is: make too few observables determinate, and don't say anything of empirical significance at all.

There are on offer a variety of interpretations of QM, many of which base strategies for navigating Scylla and Charybdis, on revisionary answers to (3)-(5). Constructing, assessing, and articulating these interpretation is a task for Frogpeople, navigating the mire of quantum theory. Herewith quick profiles of some contender interpretations (for more thorough introductions and references, see (Barrett, 2019)). Recall the predicament that befell the realist when we deschematized the Miracles Argument, by setting $T = QM$. The realist needs to find something to believe, when she believes QM,

[3] Note I'm not that interested in quibbling over where to draw the line here between QM and distinct theories whose truth would explain QM's success. As I'm understanding "interpretation of QM" here, it's something the Miracles Argument would give the Balloon Realist license to believe, on the basis QM's success: something that supplies the content of a realism that's supported by the Miracles Argument deschematized by setting $T = QM$.

something that's also the best explanation of QM's success, the winning interpretation, replete with theoretical virtue. With this in mind, the following profiles will foreground features that might give realists pause.

Contextual Hidden Variable Theory. The interpretation: The Bell-Kochen-Specker argument presupposes a non-revisionary answer to (1): quantum observables to stand in one-to-one correspondence with self-adjoint elements of $\mathfrak{B}(\mathcal{H})$. The B-K-S conclusion can be evaded by suspending this assumption, and associating as many distinct physical observables with a non-maximal observable A as A has distinct eigenbases ((Redhead, 1987) elaborates). The result is a *contextual hidden variable theory*. *What might give the realist pause*: Derided by Glymour as the "deOckhamization of QM," contextual hidden variable theories conspicuously lack superempirical virtues celebrated by realists: for instance, they're ad hoc and unparsimonious.

Textbook. The interpretation: The interpretation of QM most often encountered in textbooks offers non-revisionary answers to (1) and (2), and avoids No-Go results like B-K-S by adopting the eigenvector-eigenvalue link. This steers the interpretation straight toward the Measurement Problem. The textbook interpretation avoids the whirlpool by means of a revisionary answer to (5). According to textbooks, in the course of a measurement interaction, deterministic, continuous, reversible Schrödinger evolution is suspended in favor of a very different type of evolution, a collapse process which, discontinuously, indeterministically, and irreversibly delivers systems involved in measurement to states the eigenvector-eigenvalue link can understand as determinate outcome states. The collapse postulate interprets quantum expectation values in terms of a probability distribution over possible end-states of collapse. *What might give the realist pause*: The Measurement Problem is solved, in the sense that measurements have outcomes, and quantum probabilities are accounted for, but at a steep cost. Measurement collapse is a miracle in Hume's sense, a violation of the law of nature given by the Schrödinger equation. Entertaining two incompatible varieties of dynamics, the textbook approach owes us a criterion for when one sort of evolution applies and when the other. No precise criterion has been forthcoming. Ad hoc, unparsimoniously positing multiple sorts of state evolution, imprecise, the textbook interpretation lacks significant superempirical virtues.

Spontaneous Localization. The interpretation: Spontaneous localization schemes, the most prominent which is an approach due to Ghirardi, Rimini, and Weber (GRW), replace the Schrödinger equation with a stochastic dynamics tuned to mimic Schrödinger evolution for isolated systems and collapse for large systems. The hoped-for upshot is a single precise (and revisionary!) dynamics according to which microsystems, like electrons, almost always Schrödinger evolve, and macrosystems, like instruments, almost always undergo collapse. Hence measurements almost always have outcomes, obedient to quantum statistics. *What might give the realist pause*: Tuning the dynamics is risky and fiddly. Risky: being precise about what size systems are likely to suffer collapse, GRW exposes itself to disconfirmation through mesoscopic quantum interference experiments. (Although viewed in another light, this reveals the position to be falsifiable, a virtue!) Fiddly: to comport with its dynamics in an account of the quantum world, GRW needs revisionary answers to (1) and (2) as well. Finally GRW may not get along with other theories we hold dear: otherwise attractive and straightforward ways to make sense of the GRW proposal appear to require a privileged notion of distant simultaneity, which contravenes a central tenet of the Special Theory of Relativity.

Bohm. The interpretation: In the Bohm Theory, a particle is associated with a wave function $\psi(x)$, correlate to a pure Hilbert Space Template state, provided the Hilbert space in question consists of integrable functions of a configuration variable. The Bohm theory's central posit is that a particles always has, in addition to its wave function, a precise, determinate position. Bohmian particles follow deterministic trajectories defined by a dynamics in which their wave function Schrödinger evolves and their positions obey a guidance equation relating their velocities to the gradient of the imaginary part of their wave functions. A celebrated feature of Bohmian dynamics is its equivariance: given a swarm of particles sharing an initial wave function $\psi(x)$, if the initial positions of those particles are distributed according to standard quantum statistics extracted from $\psi(x)$, then at all other times, their positions are distributed according to standard quantum statistics extracted from the appropriate Schrödinger evolute of $\psi(x)$. Supposing measurement outcomes take the form of particles assuming determinate positions, the Bohm theory promises to explain why measurements have outcomes obedient to the quantum statistics. *What might give the realist pause*: because Bohmian mechanics appears back-engineered from standard QM, it strikes some as ad hoc (although see (Cushing, 1994) for a case that this is an artefact of the historical accident that standard QM came first). Bohmian mechanics' account of the origins of quantum probability (question (1)) is considerably less clear than its metaphysics (question (2)). Perhaps most distressing of all, Bohmian mechanics fails utterly to exhibit the theoretical virtue of cohering with other well-loved theories: Bohmian dynamics requires a special relativity defying absolute notion of distant simultaneity.

Many Xs. Aka Everett interpretations. The interpretation: These approaches aspire to offer non-revisionary answers to (3)-(5)—and to navigate between Scylla and Charybdis by positing some sort of multiverse or multiplicity (of minds, of worlds, of branches, ...) whose collective evolution the Schrödinger equation describes; within each element of the multiplicity, measurements have outcomes. *What might give the realist pause*: in their thoroughly modern form (Wallace, 2012), Everett approaches are avowedly imprecise (and accompanied by an argument that demands for precision are misguided). Like the Bohm theory, their account of quantum probability is highly subtle. Finally, they are metaphysically profligate.

Under the guidance of hardworking Frogpeople, we've curated a gallery of portraits of interpretations of QM—portraits that don't conceal their blemishes. Now that we've toured this gallery, let's revisit the balloon-level scientific realism debate. Recall the brash Balloon Realist response to the problem of underdetermination: to disparage putative examples of underdetermination as products of "logico-semantic trickery" (Laudan and Leplin, 1991, p. 463). Viewed from the perspective of the swamp—the perspective, that is, of serious groundlevel engagement with actual physical theories—the brash response rings with empty bravado. QM furnishes concrete serious, respected, and rival examples of *underdetermination of interpretation by theory*. Absent grounds for privileging one of these interpretations over its rivals as the appropriate one to believe, given QM's success, the realist confronts an underdetermination problem in full, concrete force.

More modest Balloon Realists would quell underdetermination worries by appealing to super empirical virtues (e.g. parsimony, fertility, consistency with other theories, ...) to break evidential ties between observationally equivalent rivals. But considering the situation from the perspective of the swamp suggests that there no single interpretation of QM at present on offer exhibits the full gamut of superempirical virtues Balloon Realists would employ as tie-breakers. This means that to rank interpretations on offer with respect to belief-worthiness, another ranking is needed: a ranking of super-empirical virtues, with respect to truth-worthiness. Put another way, to identify a winning interpretation, we need also to identify a *winning ranking* of superempirical virtues. One way to react to this is to begin to worry that any such ranking reveals more about the cognitive psychology of the ranker than it does about the disposition of the physical universe, and rethink the question of realism—for instance, along the lines sketched in §4. But a bold minority of observers, the minority who think they know what to believe, when they believe QM, react differently: they lean hard into a particular ranking.

Partisans of the Everett interpretation lean hard into the supermpirical virtue of consistency with other well-established theories, specifically the special theory of relativity. Of rival approaches, Wallace comments:

> The most important observation about [spontaneous localization and Bohm] is that they only really exist in the *non-relativistic domain*. (Wallace, 2012, p. 33)

Partisans of Bohmian mechanics, by contrast, lean hard into the superempirical virtue of metaphysical clarity afforded by what they call a *primitive ontology*, and present it as a sine qua non of successful theorizing:

> Arguably any physical theory with any pretense to *precision*, requires as part of its formulation a specification of the *"local beables," of "what exists out there,"* of what the theory is fundamentally about, which I would prefer to call the *primitive ontology* of the theory. (Goldstein, 1998, p. 9)

Neither offering nor illuminating a primitive ontology, Everett interpretations lack any "pretense to *precision*," as well as to the variety of explanatory oomph afforded by grounding accounts in a primitive ontology. Those who privilege precision and explanatory oomph (so understood) conclude:

> the cost exacted by those theories which retain Lorentz invariance is so high that *one might rationally prefer to reject Relativity* as the ultimate account of spacetime structure. (Maudlin, 2011, p. 202)

Everettians resist the suggestion that the only route to legitimate physics lies through a primitive ontology:

> Science is interested with *interesting structural properties* of systems, and does not hesitate at all in studying those properties just because they are instantiated "in the wrong way." (Wallace, 2012, p. 58)

Elsewhere I've suggested that Bohmian mechanics' commitment to its primitive ontology, as much as it clarifies its metaphysics, impedes its capacity to explain why quantum probabilities behave as they do (Ruetsche, 2023)—a possible instance of a more general pattern, that the better an approach copes with content-elaborating question (2), the question about the metaphysics of individual quantum systems, the more it struggles with content-elaborating questions (1), the question about the nature and origin of empirical quantum statistics.

Even among partisans who think QM has a winning interpretation, there are deep disagreements about what it takes to win—and no clear way to adjudicate those disagreements. What is more, any adjudication requires sacrificing some superempirical virtue, and thereby attenuating the abductive support Miracles Argument considerations give for belief in the interpretation. Frogperson engagement with the swamp has lead to a provisional finding: QM lacks a winning interpretation!

It's time to examine the assumptions that predisposed the Balloon Realist to expect there'd be one.

4. Relief

Balloon Realism aspires to make sense of T by devising an *interpretation* of T, an account of how the world could possibly be that *explains* why T succeeds as well as it does. Let s range over scientific successes and theoretical virtues credited to a theory T. Let i range over possible interpretations of T. Banking on a winning interpretation of T, the realist is also banking on the Cyclops hypothesis:

> (Cyclops) $(\exists i)(\forall s)$ i makes sense of s.

It's the single i posited by Cyclops, the winning interpretation, that the Realist believes when she accepts T as true.[4] It's the single Cyclops i, she asserts, that explains T's extraordinary success, an

[4] The $(\forall s)$ in (Cyclops) overstates things a bit: what the realist really needs is enough s for the Miracles Argument abduction to be plausible.

explanation, she contends, that gives us reason to believe T under that interpretation. The realist takes grasping the single Cyclops i to be constitutive of *understanding* T.

But there's an alternative to Balloon Realism. It's the *Locavore Approach*. The Locavore doubts that interesting theories have winning interpretations. But this doubt is consistent with valuing the pursuit of "local" projects of making sense, a pursuit condoned by Arthur Fine's Natural Ontological attitude. Local projects of making sense are swamp projects, projects for Frogpeople. So the Locavore Approach is inspired and informed by Frogperson considerations. Not all Frogpeople are Locavores, though—for one thing, not all of Frogpeople care about understanding, interpretation, or scientific realism! Those that do, I think, will find themselves drawn to the Locavore Approach.

I'll use a feature of Fine's Natural Ontological Attitude to explicate the Locavore's commitment to local projects of making sense, and to distinguish the Locavore's position from Balloon Realism. And then I'll give reasons to prefer the Locavore Approach.

Fine tells us that the Natural Ontological Attitude (NOA) "a pro-attitude" toward science (1996a). But what does "pro" mean here? Is NOA "a pro-attitude" in the sense that it is *for* science, like Superman is for truth, justice, and the American way? Or is NOA a pro-attitude the way a pro-noun is a pronoun and a pro-seminar is a pro-seminar: what it stands for, that is, its content, varies with its context of deployment? If NOA is pro-attitude in something like the way a pro-noun is a pronoun, we face a followup question: according to NOA, the content of science varies with the context in which we consider science. The followup question is: how to circumscribe these contexts?

This makes vivid a key contrast between Locavores and Balloon Realists. The contrast-eliciting question is: *with respect to what context* do we fix the content of our pro-attitude toward science? For Balloon Realists, the context is "the mature sciences." For the Locavore: the context is local bits of ongoing scientific practice — with different content-fixing strategies countenanced as appropriate to different contexts. Countenanced as well is the possibility of contexts to which *no* content-fixing strategies are appropriate.

Now we can distinguish a methodological commitment, which I'll call the *Locavore Strategy*, from a prediction about the outcome of pursuing that strategy, which I'll call the *Locavore Hypothesis*. The methodological commitment is, if undertaking to understand and articulate a physical theory like QM, to follow the

> *Locavore Strategy*: pursue local projects of making sense, Frogperson projects keyed to particular applications and contexts.

An impetus to pursue local projects of making sense is that commitment to a theory *in a form that fosters that theory's capacity to function as physics* often requires settling answers to at least some content-elaborating questions—it often requires, or at least is promoted by, localized pursuits of interpretive projects. The *Locavore Hypothesis* is not a methodological directive but a prediction about where following that directive will—or more to the point, won't!—lead.

> (Locavore) A single, overarching, unified account making sense of QM in its entirety will *not* emerge from local projects of making sense.

The Locavore Hypothesis (Locavore) entails that Cyclops hypothesis (Cyclops)is false.

There's an excellent methodological reason to adopt the Locavore Strategy. Consider two ways to approach the interpretation of a physical theory.

- answer the entire slate of content-elaborating and content-adjusting questions (questions that in QM's case include (1)-(5)), thoroughly, antecedent to *any* applications of the theory; use the answer to sustain *every* application of the theory.

- adapt your answers, as well as the list of questions they're answers to, to the problem at hand.

The former strategy seeks the Cyclops interpretation required by Realism. I'll call it the Cyclops strategy. The latter strategy is the Locavore's.

The Locavore's strategy has the *methodological advantage* that following it, one could support Realism, if Realism is tenable. For it could be that following the Locavore strategy in a wide variety of contexts and settings, we produce a collection of answers sufficiently uniform that they can be gathered under a single cyclops interpretation that makes sense of every theoretical success. But it could also be that the collection of locally-generated answers exhibits no such uniformity. And this is the outcome the Locavore hypothesis predicts. Following the Locavore strategy, it's possible to uncover evidence both for and against the hypotheses (Cyclops and Locavore) under consideration.

Anderson has a name for the methodological virtue the Locavore strategy exhibits: fruitfulness.

> One research design is more fruitful than another, with respect to a controversy, if it is more likely to uncover evidence supporting (or undermining) all, or a wider range of sides of the controversy. (2004, p. 20)

The Cyclops strategy, by contrast, is not fruitful: articulating an balloon interpretation in abstraction from swamp-level applications, details, and contexts, precludes the possibility that locally-generated answers to content-elaborating questions could differ, and differ significantly, in their specifics. That is, while the Cyclops strategy enables evidence for the Cyclops Hypothesis to register, it disables the uptake of considerations supporting the Locavore hypothesis. The fruitfulness of of the Locavore Strategy is its methodological advantage.

Which brings us to Locavore—the hypothesis that, following the Locavore strategy to construct a collection of locally-generated answers to scientifically appropriate content-elaborating questions, we'll produce a collection of answers insufficiently uniform to be collected under a single Cyclops interpretation. Brought home to QM, the Locavore hypothesis predicts that *QM lacks a winning interpretation*. But that's exactly the outcome we've just, in §3 observed! When it comes to QM, the underdetermination of interpretation by theory corroborates Locavore.

This essay will conclude by reconsidering questions of realism, interpretation, and understanding on the assumption that the Locavore Hypothesis is correct.

If realism's cyclops hypothesis fails, there is no "winning interpretation" of QM. According to the Balloon Realists, what it takes to understand a theory is to grasp its winning interpretation. If QM lacks a winning interpretation, does it follow that we don't understand QM? Not according to the Locavore. The Locavore is earnest that local projects of making sense are *projects of making sense*—they just don't fit together into a unique global univocal account that is *the* story we should take QM to be telling about the world. That doesn't render QM senseless. Rather, it underwrites a picture of scientific understanding less ambitious, but more nuanced than, the Balloon Realist's. The picture of scientific understanding the Locavore proposes applies to theories for which the cyclops hypothesis fails—theories that lack a winning interpretation. On the Locavore picture, what it is to understand such a theory is to learn how to navigate its "manifold of tenable interpretations" (van Fraassen, 1991, p. 481). What it takes to understand such a theory, that is, is to explore the range of interpretations it admits, and come to grips with different, even incompatible ways of making sense of it. To understand a theory is to learn the strengths and weaknesses of interpretations on offer. It is also to develop a feel for the contexts in which those strengths and weaknesses matter most.

On this picture, someone who understands a theory can't tell you what that theory means, period. She can't tell you, that is, what a Balloon Realist about the theory would believe, on the basis of the theory's success. But someone who understands a theory can make educated guesses, case by case and local context by local context, about which (alas, globally inadequate!) ways of thinking about the theory, which interpretations of the theory, are liable to promote the legitimate scientific aims appropriate to that case and that context. Here again, QM and its interpretations serve to illustrate the theme. In contexts where relativity matters, use interpretation of QM that play well with relativity. If you're designing an experiment, and it guides you in engineering a suitable apparatus to picture quantum particles as corpuscles following skittering Bohmian trajectories, do that. If you're a quantum cosmologist, the sort developing accounts of the quantum state of the universe in its entirety, work with an interpretation that makes sense of quantum states without appeal to external agency. Suppose you're trying to press physical theory forward— trying, that is, to find successor theories to QM. If you're an experimentalist, work with interpretations that indicate where the predictions of the standard Hilbert Space Template might break down—and look for that breakdown. If you're a theorist, work with any interpretation that suggests a way forward (as Bohmian mechanics suggests a particular way to pursue quantum gravity). If you're a physics teacher, exploit the fact that "interpretive latitude contributes to heuristic power" (Fine, 1996b, p. 250) to find approaches that click with your students—and thereby seed a future generation of physicist prepared to look for a way forward.

On the Locavore's picture of understanding, understanding a theory is an (inevitably incomplete) accomplishment more akin to understanding a person, or a work of art or literature, than it is to the Balloon Realism's grail of a single, complete, omni-adequate interpretation. Like interesting movies and interesting people, interesting scientific theories defy regimentation into a single overarching narrative. This semantic resourcefulness is part of what makes them interesting. And please note that interesting theories, like interesting people and interesting movies, put significant consistency demands on their interpreters. A semantically resourceful theory isn't one you can interpret however you want. It's one that sets its interpreters challenges without dictating how they meet those challenges. In the case of QM, a core challenge consists in making sense of successful empirical application of the Hilbert Space Template. Constrained to respect this empirical success, interpretations are permitted to alter the template only if they can do so without disrupting the empirical success; revisions are well-advised insofar as they underwrite satisfying answers to content-elaborating questions about quantum probability and the metaphysics of quantum systems. Semantically resourceful interpretations are interesting not only because they admit multiple competing interpretations but also because it takes creativity and rigor to formulate those interpretations.

For the Locavore, a theory's semantic resourcefulness is also part of what makes that theory a good piece of science.[5] To appreciate this, it helps to add a new virtue to the standard list of superempirical virtues. This new virtue, as befits the Locavore's natural swamp habitat, is *murkiness*—a virtue a theory manifests when it admits a variety of interpretations, none of them winning. A notorious passage from van Fraassen helps to explain why murkiness is a virtue. In the face of Balloon Realism's Miracles Argument contention that a theory's truth is the only scientifically legitimate explanation of its success, van Fraassen proposes a very different scientific explanation:

> I claim that the success of current scientific theories is no miracle. It is not even surprising to the scientific (Darwinist) mind. For any scientific theory is born into a life of fierce competition, a jungle red in tooth and claw. Only the successful theories survive—the ones which *in fact* latched on to actual regularities in nature. (van Fraassen, 1980, p. 40)

A theory exhibits the swamp virtue of murkiness (more kindly put: semantic resourcefulness) if it underdetermines its own interpretation. Extending van Fraassen's Darwinist analogy, a murky theory is something like a healthy breeding population. A murky theory has a shot at enough representational diversity to (under some interpretation or another) cope with the wide variety of pressures exerted by its scientific environment. Like a biological organism's survival, a scientific theory's success is a convoluted, chancy, and conditioned thing. Just as a genetically diverse population stands a better chance of surviving in a wide range of environments, so too a murky theory has the resources to meet a wide range of threats to its scientific survival, to compete successfully in the jungle red in tooth and

[5]For a similar claim more carefully developed and defended, see (Patton, 2015) on "modal resourcefulness."

claw. These swamp considerations reveal murkiness to be a good-making feature of scientific theory—a superempirical virtue, visible to Frogpeople but not from the balloon.

The Locavore's suggestions are bold, and liable to be met with resistance. One form this resistance might take is to suggest that focusing on QM lends the Locavore position an illicit credibility. The credibility is illicit because QM is a defective theory. To see that it's defective, just look at how interpretations on offer handle the content-adjusting and content-elaborating questions (1)-(5): (almost) all of them move to alter the content of QM. (Arguably, the Everett interpretation is an exception to this rule. But it requires an extraordinary amount of heavy philosophical lifting for the Everett interpretation to answer the content-elaborating questions without revising the Hilbert Space Template. Surely only a defective theory would require so much heavy philosophical lifting to make sense!) The almost universal move to alter QM's theoretical core might be evidence that something is rotten at that theoretical core. The resistor concludes: it's only because QM is a rotten theory that the cyclops hypothesis fails. It's only because QM is a rotten theory that it lacks a winning interpretation. The supposed virtue of murkiness is anything but.

The resistor is suggesting—and many realists of my acquaintance take this suggestion to heart—we simply wait for QM to go away. Once QM is deposed by a more sensible theory, one with a winning interpretation, the route to Balloon Realism is restored. Confronted with this hoped-for cyclops successor to QM, the Locavore position will lose all plausibility.

I'll close with the Locavore's response to this suggestion. It's two pronged. The first prong appeals to the Darwinian analogy already in play. That analogy presented murkiness as an *adaptation*, a feature conducive to the survival of theories that possess it. Sure enough, there's abundant inductive evidence that our favorite theories won't survive indefinitely—they'll be replaced by other theories even better at competing for scientific survival than they are. *But there's also good inductive reason to expect these successor theories to possess adaptations promoting survival.* And murkiness is just such an adaptation. Whatever succeeds QM, it's probably—not certainly, but probably—going to be murky too. The Locavore resists coding murkiness as a passing frailty of defective current theory. Instead, the Locavore codes murkiness as an adaptive feature we should expect to characterize science as mortals practice it.

The second prong of the Locavore's response to the resistant realist is to applaud them for recognizing that the scientific image is still under construction—but to hasten to add that this very circumstance is an additional reason to regard murkiness as a superempirical virtue. Entertaining a range of ways to apply and conceptualize a murky theory, we entertain as well a range of ways forward—that is, a range of ways to develop potential successor theories. And that stands to be a superior strategy for scientific progress than narrow adherence to a single interpretation we've declared the winner in order to sustain a stringent sense of understanding that might stand at cross-purposes with working physics.

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References

Barrett, J. (2019). *The conceptual foundations of quantum mechanics*. Oxford: Oxford University Press.

Cushing, J. T. (1994). *Quantum mechanics: historical contingency and the Copenhagen hegemony*. Chicago: University of Chicago Press.

Fine, A. (1996a). *The shaky game* (2^{nd} ed). Chicago: University of Chicago Press.

Fine, A. (1996b). On the interpretation of Bohmian mechanics. In J. Cushing, A. Fine, & S. Goldstein (Eds.), *Bohmian mechanics and quantum theory: An appraisal* (pp. 231-250). Dordrecht: Kluwer.

van Fraassen, B.C. (1980). *The scientific image*. Oxford: Oxford University Press.

van Fraassen, B.C. (1991). *Quantum mechanics: An empiricist view*. Oxford: Oxford University Press.

Goldstein, S. (1998). Quantum theory without observers. *Physics Today, 51*, 42-47

Kitcher, P. (1993). *The advancement of science: Science without legend, objectivity without illusions*. Oxford: Oxford University Press.

Kuhn, T. S. (1977). Objectivity, value judgment, and theory choice. In *The essential tension: Selected studies in scientific tradition and change* (pp. 320–39). Chicago: University of Chicago Press.

Laudan, L. and Leplin, J. (1991). Empirical equivalence and underdetermination. *The Journal of Philosophy, 88*, 449-472.

Longino, H. E. (2020). *Science as social knowledge*. Princeton: Princeton University Press.

Maudlin, T. (2010). Can the world be only wave function? In S. Saunders, J. Barrett, A. Kent, & D. Wallace (Eds.) *Many worlds?: Everett, quantum theory, and reality* (pp. 121-143). Oxford: Oxford University Press.

Mermin, N. D. (1993). Hidden variables and the two theorems of John Bell. *Reviews of Modern Physics, 65*, 803-815.

Patton, L. (2015). Methodological realism and modal resourcefulness: out of the web and into the mine. *Synthese, 192*, 3443-3462.

Putnam, H. (1975). *Mathematics, matter and method*. Cambridge: Cambridge University Press.

Quine, W. V. O. (1955). Posits and reality. In *The ways of paradox and other essays* (2nd ed) (pp. 246-254). Cambridge, MA: Harvard University Press.

Redhead, M. (1987). *Incompleteness, nonlocality, and realism: A prolegomenon to the philosophy of quantum mechanics*. Oxford: Oxford University Press.

Ruetsche, L. (2011). *Interpreting quantum theories: The art of the possible*. Oxford: Oxford University Press.

Ruetsche, L. (2015). *The shaky game* + 25, or: On locavoracity. *Synthese, 192*, 3425-3442.

Ruetsche, L. (2023). UnBorn: Probability in Bohmian mechanics. *Philosophy of Physics*.

Wallace, D. (2012). *Quantum mechanics and its emergent metaphysics*. Oxford: Oxford University Press.

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