ESSAY REVIEW:

David Wallace, *The Emergent Multiverse: Quantum Theory according to the Everett Interpretation*. Oxford University Press (2012), xvi+530 pp., $75.00

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We review and discuss the recent monograph by David Wallace on Everettian Quantum Mechanics. This book is a high point of two decades of work on Everett in both physics and philosophy. It is also a beautiful and welcome exemplar of a modern way of doing metaphysics. We discuss certain aspects more critically, and take the opportunity to sketch an alternative pragmatist approach to probability in Everett, to be fully developed elsewhere.

1. Introduction. The central interpretive problem in quantum mechanics is that if we take the formalism of quantum states evolving under the Schrödinger equation, and try to represent the measurement process by coupling a measuring instrument to a quantum mechanical system, in general the result does not represent a unique measurement outcome. One response to the problem is to deny that quantum mechanics is to be interpreted as a representation of reality, treating it instead as merely an algorithm for predicting results of measurements. Another is to add something to the formalism that picks out a result at the end. There are two ways to do this. One can supplement the quantum state with quantities that pick out a determinate result, or one can modify the dynamics to eliminate macroscopic superpositions. For many years it was widely believed that if one was not going to be an instrumentalist about quantum mechanics, she had to choose between these options. Everett (1957) found a way out of the dilemma. His idea was to take quantum mechanics at face value, treating the superposed state as an accurate representation of the total system after the experiment, and regarding all of the superposed outcomes as actual, existing together but in mutually (for the most part) inaccessible branches of the wave function, now conceived picturesquely as 'worlds'.

Within physics, after an initial period in which Everett was ignored, a 'many-worlds interpretation' had started to be vocally supported by a number of cosmologists (first and foremost Bryce DeWitt), and the development of decoherence was sometimes connected to Everettian ideas (but fully and explicitly only by Dieter Zeh). Within philosophy, it is fair to say

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that up to the 1990s the Everettian approach was viewed with suspicion, as an interpretation of quantum mechanics that combined the grief of ill-defined collapse upon measurement with the extravagance of not having the unobserved components just go away.

The turning point was the key role assigned to decoherence in Everett by Simon Saunders in the early 1990s, using the recently developed formalism of decoherent histories, and then by David Wallace, who developed the theme of emergence and the structural reading of Everett to its full potential. At the same time, within the physics community, Lev Vaidman started actively championing the many-worlds interpretation, bringing novel and pioneering insights to the field.[1] The second turning point was David Deutsch's decision-theoretic approach to probability, which was perfected by Wallace over the following years, and led in turn to the discussion of the epistemic problem by Hilary Greaves, again Wallace, and others.

Wallace's book is not only the culmination of these lines of research, but also completes the transformation from viewing Everett's approach as an 'interpretation' of quantum mechanics to viewing it as Everett himself did, as letting the formalism of quantum mechanics speak for itself (hence Wallace's preference for the term 'Everettian Quantum Mechanics', henceforth EQM). Wallace aims to present a rigorous version of EQM and defend it as a literal reading of what quantum mechanics tells us about the world. The project involves first showing that the bare formalism yields an emergent macroscopic multiplicity of decoherent quasi-classical histories corresponding to individual worlds and then show that this could be the correct account of the metaphysics of our world, i.e., a world that presents itself in our experience as a unique, indeterministically evolving quasi-classical history. And he manages to do his in a way that is neither a popularization or a technical books for specialists. It is a virtue of this book that it is a serious, science-driven book with major implications for metaphysics that doesn't patronize its audience and introduces all of the technical material needed to address the philosophical viability of its approach.

Needless to say, several voices have been opposing these lines of development. The most convenient source if one wishes to familiarize oneself also with the various criticisms of EQM is the volume *Many Worlds?* edited by Saunders, Jonathan Barrett, Adrian Kent, and Wallace (Saunders et al. 2010). Of these criticisms, the most vocal one of the ontological picture proposed by Wallace (and more generally of Wallace's broadly structuralist approach to metaphysics) is offered by Tim Maudlin. And even if one is sympathetic to Wallace's overall approach, there is scope for disagreement in spelling out the most perspicuous ways of exhibiting the structures present in the formalism (as Wallace correctly points out). Other criticisms (e.g. by David Albert, Kent, and Huw Price) focus mainly on the Deutsch–Wallace theorem, not so much on the

[1] His paper "On Schizophrenic Experiences of the Neutron" (Vaidman 1998) is still one of the clearest and best on the topic.

technical details, but on the claim that it embodies *rational* constraints on decision making. Finally, since avowedly Wallace is working in the spirit but not following the letter of Everett's approach, a further interesting complement is Jeffrey Barrett and Peter Byrne's edition of Everett's collected works (Barrett and Byrne 2012).[2]

2. Summary.

The book has three parts. The first defends the claim that unitary quantum mechanics yields a structure of branching quasi-classical worlds. The second argues that the weights—the squared amplitudes—of these branches are to be understood as giving the probabilities of the states of affairs they contain. These two parts comprise the exposition and defense of the theory, and the third turns to deriving consequences. In two Interludes and an Epilogue, Wallace debates a skeptic who voices some of the philosophical objections that have been lodged against the theory. Four technical appendices contain formal proofs of some results of the first two parts and a rigorous presentation of the decision theory required for the second.

As a whole, the book is admirably organized. Wallace provides frequent summaries, and a map of the logical relations between the parts of the book, with a number of fast tracks for readers with different interests and expertise. By picking and choosing one can read the book either as a philosophical treatise or as a piece of physics. As a whole, it is both. It constitutes the most comprehensive treatment of a theory that has been the focus of intense interest by very different groups of researchers.

Chapter 1 stakes a path through some familiar territory. Wallace makes a case for realism about the quantum state, arguing against the instrumentalism that is popular in philosophical discussions of quantum mechanics. The quantum formalism is introduced in this chapter, and Wallace formulates the measurement problem precisely. The difficulty is that we do not have a way of modeling measurement yielding a representation of a unique result. In practical terms we simply evolve the state forward and apply Born's Rule to the resulting state to calculate the probability of a given outcome. But if quantum mechanics is interpreted realistically, we need an explicit physical understanding of how measurement unfolds to transform a superposition into a single result with probabilities given by Born's Rule.

Wallace considers, and rejects, various traditional responses to the measurement problem, and introduces Everett's solution in the form of a physical postulate and a claim about the nature of the quantum state. The physical postulate is that the state of the universe is accurately represented by a unitarily evolving quantum state. The claim about the nature of the state is that it describes a multiplicity of approximately classical, approximately non-interacting parts, each of which

[2] Both books have been reviewed by one of us (Bacciagaluppi 2013a, 2013b), and Saunders et al.'s has been reviewed in this journal by Peter Lewis (2012).

appears to its inhabitants as a world punctuated by quantum events. The theory faces two challenges, which frame the discussion in the first two parts of the book. Part I is occupied with the task of making a convincing case that the quantum state describes a collection of quasi-classical worlds. Part II is devoted to making sense of probability in a deterministic branching universe.

Chapters 2 and 3 constitute Wallace's argument that the quantum state is correctly regarded as describing a collection of quasi-classical worlds. Worlds do not appear as fundamental elements in the formalism, nor are they explicitly definable in terms of such elements. They have the status rather of emergent entities. Building on work by Dennett, emergent entities are defined as patterns that play an essential explanatory and predictive role in the theories that posit them. Tigers serve as an illustrative example. Tigers play an essential role in zoology, and zoology cannot be *reduced* to physics. Instead physics *instantiates* zoology. Instantiation is a three-place relation between two theories and a domain. Theory A instantiates theory B over domain D iff there is a relatively simple map, *m*, from the possible histories of A within the domain D to histories of B such that if a history satisfies the laws (or 'dynamical constraints') of A, its image under *m* satisfies the laws ('constraints') of B. The details of the definition need to be tested against cases from other domains of science, but the guiding idea is clear enough, and is surely on the right track. With this definition in hand, all that Wallace needs to do in order to show that there are Everettian worlds is show that under certain conditions quantum mechanical superpositions instantiate multiple classical histories.

Chapter 3 provides a precise account of when and how this occurs. Wallace begins with the standard textbook account of the 'classical limit' of quantum mechanics, but rejects it because it fails for chaotic systems and relies on the unrealistic assumption of a classical system as isolated. He goes on to describe his preferred approach, according to which decoherence tends to transform delocalized states into mixtures of localized ones that evolve approximately classically. Since entanglement with the environment is inescapable for any macroscopic system, this will happen constantly and unavoidably.

This discussion provides a corrective to the often shallow understanding of decoherence in the philosophical literature, and includes excellent discussions of alternative approaches. Decoherence plays an essential role in the defense of EQM because it justifies the treatment of macroscopic degrees of freedom as dynamically isolated, explains why chaotic systems behave quasi-classically, and explains why even in situations like measurements, in which the dynamics is not even approximately classical, systems still *seem* to stay in quasi-classical states. It is a feature of this account of how Everettian branches emerge that the number of branches is not well-defined because, although one can choose a finer-grained set of histories, below a certain resolution interference terms becomes significant and the decohering structure disappears, so there is no *finest* grain. This plays an important role in Part II where it rules out certain otherwise natural treatments of probability.

With the conclusion of Part I, we move from Wallace's account of the ontology of EQM to his treatment of probability. This feature of the theory is often seen as an insurmountable stumbling block, and Wallace's work on the problem is well known.

Chapter 4 gives an informal overview of Wallace's solution. He begins with a discussion of classical probability and argues (rightly) that the philosophical understanding of the concept even in the classical case is a mess. He divides accounts of the nature of probability into frequentist and rationalist aacounts, and argues that frequentist accounts fail to state precisely the link between probability and relative frequency without running afoul of familiar objections. Wallace takes a rationalist route. For the rationalist, chances are whatever you are rationally compelled to set your credences to for purposes of decision. Any link to frequencies is derivative of rational constraints on decision. He then provides an informal sketch of an argument that the inhabitants of an Everettian world are rationally compelled to set their credence in an outcome equal to the weight of the branch containing it.

The argument is a symmetry argument that proceeds from a set of 'don't care about' premises to the conclusion that the Born probabilities are the only ones that can rationally guide decision. Since all outcomes are realized, what the proof shows is that if you don't use the Born probabilities to maximize your expected utility, you are being irrationally invidious, like the child who prefers one of two qualitatively indiscernible candies for no identifiable reason. Indeed, Wallace thinks that for the rationalist, probability makes *more* sense in the Everettian context than in a classical one. Classically, you assign a chance of 1/6 to each face of a die because of a dynamical symmetry of die throwing, but the symmetry argument ultimately fails, because something in the initial conditions breaks the symmetry, which is why only one outcome actually occurs. In an Everettian setting, *nothing* breaks the symmetry. Each outcome occurs in some branch and the Everettian agent is compelled to respect that symmetry in his credences.

Chapter 5 is the formal presentation of this decision-theoretic argument. Consider an agent betting on the outcome of an experiment and receiving a payoff known in advance. There are constraints that her preferences over these bets must obey on pain of irrationality. Classically, we can establish that her preferences must be represented by a probability measure and a utility assignment over the outcomes. Wallace shows that in the Everettian case, where the agent receives a payoff in each branch of the post-measurement state, a much stronger result can be proved. Instead of showing that the agent's preferences must be represented by *some* probability measure, they must be represented by the probabilities derived from the Born Rule.

The proof is well known, and has received a good deal of attention. The axioms divide into three classes: there are standard axioms of rationality, relatively benign axioms concerning the richness of the space of experimental outcomes, and then there are axioms specific to the Everettian setting. These are: (i) that an agent cares about macrostates, but not the microstates that realize them, (ii) that an agent doesn't care about branching itself, (iii) that an agent's preferences supervene on the physical state, and (iv) that an agent's preferences are robust across small perturbations of the state.

Wallace's defense of the axioms, in each case, is that agents violating them have decision strategies that depend in some way on artefacts of the model rather than on real features of the physical situation. The chapter ends by putting the axioms to work and showing how they are violated by various non-Born strategies.

Chapter 6 looks at statistical inference in EQM and argues that it presents no special difficulty. One might have thought that EQM trivializes statistical inference. Since every possible sequence of outcomes for any series of measurements actually occurs, there is no way that collecting statistical data (i.e., data about which sequences are observed) could count as confirmation for EQM. Wallace argues this is not so. Choose your favored theory of statistical inference, and Wallace shows you that according to that theory EQM can be confirmed by statistical data. Assume a classical statistical approach to hypothesis testing, rejecting hypotheses that have low likelihood (i.e., which assign a low probability to the data). It will turn out that EQM will assign itself a higher likelihood than rivals in branches whose aggregate weight (and hence probability) is very close to 1. Assume a Bayesian approach to inference. It turns out that agents who conditionalize on the data will take those data to confirm EQM in branches with aggregate weight close to 1. Taking a unified approach to the Born-Rule theorem of Chapter 5 and the statistical inference problem, Wallace proves, moreover, that a rational agent who is unsure of the truth of EQM will have preferences represented by a utility function and a probability function, where conditional on EQM being true the probability function is given by a density operator, and the agent's credence in EQM is updated according to standard Bayesian inference. This is his Everettian Epistemic Theorem.

Turning from Part II to Part III of the book, Wallace puts aside the task of defending EQM and derives consequences of accepting the theory.

Chapter 7 addresses how notions of uncertainty, possibility and identity appear from an Everettian perspective. Readers familiar with the philosophical literature on EQM will be surprised that the discussion of probability proceeds entirely without discussion of uncertainty, and that uncertainty doesn't appear until now. Although the two have been traditionally tied together, Wallace has argued that probability is properly understood by its role in decision and does not require a previous understanding of uncertainty. He looks in this chapter to see what EQM has to say about the epistemic lives of Everettian agents. He notes that if we interpret the claims of the inhabitants of an Everettian universe who say they are uncertain whether an event will occur as meaning "one will occur, I know not which", we will have to say that they are radically mistaken. He argues that we should instead interpret them as meaning that the event occurs in some but not all future branches. He is drawing here on a tradition in the philosophy of language according to which the interpretation of language is guided by a principle of charity that assigns meanings to terms in a way that maximizes truth over the sentences sincerely asserted by the community. Epistemic possibility is analyzed similarly. An Everettian who says that *p* is epistemically possible for him, means that *p* is not known by him to be false in all branches.

One might have thought that the Everettian faces a radical change at least when it comes to the diachronic identity of objects (including, in particular, persons). After all, if EQM is true, objects have multiple future continuants in different branches. There is no single future object that we can pick out as the unique continuant. This is sometimes put by saying that objects have a hydra-like rather than worm-like spatiotemporal structure. Wallace argues that a charitable interpretation is available here, too. He rejects the hydra view on the grounds that it conflicts with his analysis of uncertainty (since it would commit Everettian agents to the conclusion that they will certainly see all outcomes of every experiment). He adopts, instead, a Lewisian view, familiar in the philosophical literature, according to which an object is a complete space-time worm, indexed to a quasi-classical history. He notes the availability also of a stage view, according to which an object is a temporal stage of a Lewisian space-time worm. He is, however, inclined to think there is no fact of the matter about which is correct. If the task is simply to account for our linguistic behavior, there is nothing in our usage that rules between them.

Chapter 8 is Wallace's proposal for turning the abstract description of the quantum state, which mathematically is represented by a vector in Hilbert space, into something that gives us a better idea of the concrete reality that vector represents. His proposal (presented also in separate papers with Chris Timpson) is that the quantum state is the state of a four-dimensional space-time. Space-time can be divided into localized regions, which are treated as subsystems. The intrinsic properties of each subsystem are given by tracing over all other components of the global state. So the intrinsic properties of a localized region of space are represented by a density operator, and it turns out that the theory is local in the specific sense that the state of any region depends only on the state of some cross-section of its past light cone. The theory is not, however, separable, since the density operators of two subsystems do not determine the density operator of their union.

Chapter 9 takes on the much-discussed issue of the direction of time. The macroscopic branching process is patently not time-symmetric, since branching occurs in the future direction but not the past. Since the underlying microdynamical laws are time-symmetric, the Everettian has to identify the source of the asymmetry.

There is, of course, a familiar case of an emergent temporal asymmetry—viz., statistical mechanics. Existing accounts of the source of asymmetry in this case typically locate it either in the large volume of the equilibrium region of phase space or in the low entropy of the early universe. Wallace re-examines the issue, rejecting these accounts. He shows first how one constructs a formal theory in which an irreversible, stochastic dynamics for the macroscopic properties of systems emerges from a reversible deterministic underlying microdynamics. Then he shows that one could just as well construct a backward macrodynamics, which takes later states to earlier ones. Comparing the two theories, we see that the forward macrodynamics is empirically successful, whereas the backward macrodynamics is not. The reason for the difference, Wallace argues, is that simple microstates are predictable (both forwards and backwards), and only very gerrymandered microstates are not. Assuming a simple state in the remote past then explains observed behavior. This goes, he argues, for both the classical and the quantum case. If Wallace is right, irreversibility can be explained without appeal to a *low-entropy* past hypothesis, and this chapter provides a unified account of quantum and classical irreversibility, challenging the common wisdom on the issue.

Chapter 10, called "A Cornucopia of Everettian Consequences", is just that. It covers a number of additional topics including the possibility of predicting the future, quantum Russian roulette, the possibility of observing other branches, the quantum mechanics of time travel, and the status of mixed states. There is a good deal of extremely suggestive material in this chapter, indicating rich topics, only partially explored. Any one of these would make a good topic for a thesis.

3. Critical Engagement.

EQM provides an exciting field for philosophers working on quantum mechanics and its wider metaphysical relevance. Everettians have confronted problems about interpreting familiar concepts in an unfamiliar setting in a form that has forced soul-searching. The result is a creative response that involves rethinking a lot of things from the bottom up. That kind of rethinking is much in evidence in Wallace's book. Where Wallace finds the common wisdom unclear or unsuited to the Everett context, he dismisses it and rethinks the matter on his own. What follows are some general remarks on points we thought worth putting in a wider context or engaging with critically.

3.1 Emergence. The first example of fundamental rethinking is a reconception of the relationship between fundamental ontology and the manifest structure of the world. The relationship between the ontology of physics and the everyday world seemed relatively simple in the classical context. Big things were made up of little things, themselves localized in space and time. The cracks in this simple view were showing already in the phenomena that originally prompted talk of emergence in biology and complex systems, but it is much more obviously unworkable in the Everettian context, where the gap between the way things seem to the inhabitants of the universe and the way that the theory says they are is very large. Wallace was among the first to recognize the need for a reconception of this relationship, and to look to emergence as the proper account.[3] He makes a considerable contribution towards turning it into a workable explicit account. So conceived, emergence has general import quite outside the context of Everett. This is a nuanced explicit account of the relationship between fundamental and non-fundamental ontology, and a radical improvement on old and outmoded ideas of reduction, explicit definition and mereological composition.

According to the method for doing naturalistic metaphysics that Wallace advocates, we take our ontology from our best physical theories, interpreting them at face value**.** How do we find in the world described by the theory structures that correspond to things like tables, chairs, tigers and chipmunks? We first figure out what role they play in our epistemic and practical lives (how we learn about and interact with them), and then we find something in the base ontology that satisfies that role. This makes Wallace a functionalist about non-fundamental structures of all kinds. We see the method applied in Part I to identify structures that correspond (well enough) to worlds to warrant the description of EQM as a many-worlds theory. The emerging quasi-classical decoherent histories count as worlds *because they satisfy the 'world' role*. We see it applied in Part II of the book to the concept of probability.

This method quite generally is the strategy for 'interpreting' a fundamental theory. It turns the Ramsey/Lewis/Horwich method on its head. Instead of trying to implicitly define theoretical primitives in everyday or observational vocabulary, it treats the theory's basic concepts as ontological primitives and interprets everyday concepts in that ontological setting by identifying something that plays that role.

3.2 Probability. The second example of this rethinking is the discussion of probability. Common wisdom in the non-quantum setting is that we have probability only when we have indeterminism. The Everettian has to reject this link. Looking in the philosophical literature for an explicit account of what probability is even in the classical setting, Wallace finds it wanting. So he starts from scratch. What goes for tigers and worlds, goes also for probability. If chances are whatever justifiedly plays the role of probabilities in practical and epistemic reasoning, then with the decision-theoretic proof, which intends to show that the numbers derived from Born's Rule do just that, Wallace has shown that the Born probabilities *are* chances.

[3] See also Ladyman and Ross (2007).

We noted in Section 2 that Wallace is a rationalist about probability. He wants to establish that the use of Born probabilities in decision is not just a strategically good policy, but a policy that is rationally compelled, so that one would not just be making a pragmatic mistake if she failed to set her credences to the Born probabilities. She would be making a logical mistake. These rationalist leanings, however, are not a necessary part of EQM, and we want to suggest here that one could adopt a purely pragmatist view of probabilities. According to such a view the ontological content of the theory makes no use of probabilities. There is a story that relates the ontology to the evolution of observables along a family of decoherent histories. And probability is something that plays a role in the cognitive life of an agent whose experience is confined to sampling observables along such a history. In so doing, one would still be doing EQM, and this interpretation may have quite strong advantages. Here is how it might be developed.

Let us begin by looking at the kind of emergent probabilities in a classical setting that casinos, lotteries and insurance companies rely on, the probability that a roll of an ordinary pair of dice will come up sixes, that a quarter drawn from the general population will land heads if tossed, or that a person with BRCA1 gene will contract cancer. These probabilities are emergent in the sense of the previous subsection in that the fundamental ontological story is deterministic, and that probabilities are a theoretical construct useful in describing and predicting higher-level behavior. These kinds of probabilities are general in that they are defined for types rather than tokens, and their basic form is conditional. So, for example, we have the probability of heads in the toss of a coin under specified conditions. They aren't defined for any old reference class (the best known system for which there is a rigorous analysis is the coin toss), but only in those in which there is the right sort of 'randomness' so that any not too carefully chosen subset has a relative frequency that more or less matches the others. The dynamical underpinning of these probabilities, where they exist, varies from case to case.[4] They are of course related to frequencies, insofar as they may be inductively derived from stabilized relative frequencies, and insofar as they will be empirically successful in predicting them; but some of the complaints about frequentist accounts are inapplicable since this account doesn't aim for a content-preserving reduction of probability to frequency. There is no direct route from observed frequencies to probabilities. Theory is needed to prescribe reference classes. Whether I can apply probabilities derived from stabilized relative frequencies over the class of fair dice to generate expectations for the next roll of *this* pair, depends on whether this pair is fair. And 'fair' does not mean any pair that happens to exhibit certain regularities. It is a theoretical concept defined in terms of certain (fundamental, hence intrinsically non-probabilistic) structures, in particular dynamical symmetries. The theory contains a rule with certain physical structures as inputs, and

[4] See Hoefer (2007), Diaconis (1998), and Ismael (2009).

certain numbers (the probabilities) as outputs. The inputs are solidly objective,[5] but the outputs need not be reified.[6]

Let's call these general probabilities. They are quite familiar philosophically. Their existence is entirely compatible with determinism. Indeed, the deterministic dynamics will explain *how* they arise in many cases (although only for 'typical' initial conditions). They play a readily explicable role guiding belief where we are otherwise ignorant. The general probability of (*x*/*y*) gets transformed into the single-case probability that some particular *y* will be an *x*, and adopted as credence if all that one knows about the system or event in question is that it is a *y*. On this view, *general probabilities* are statistical probabilities grounded by a theory that has the right holistic fit with relative frequencies. Chances of the kind implicitly defined by the Principal Principle might be thought of as single-case probabilities extracted from general probabilities by conditionalizing on everything we generally think knowable about a system and deployed to set credence and to guide decision.[7] The recommended credences are, of course, only as good as our theories, but they function (more or less) as hedged predictions. This view makes general probabilities more basic than chances and so it is available even where the underlying dynamics is deterministic. It does not attempt to identify probability with frequency and so it doesn't fall afoul of the familiar objections to frequentist accounts (or other reductive accounts like Best Systems analysis) but rather treats chances as encoding inductive content of our theories in a form suited to guide credence in the face of ignorance.

Most of this goes over rather smoothly to the Everett case. If there are decoherent histories there are relative frequencies across macroscopic ensembles, so there are general probabilities of macroscopic events. These are the probabilities that feature in Wallace's account of statistical inference. They are well-enough defined to support the familiar probabilities that casinos and insurance agents rely on, as well as the probabilities of measurement results. We can say that the Born probability of *x* is a measure of the probability that a post-measurement branch will have an *x*-result. In the newer setting probability is not a measure of our ignorance of what the result will be, since all results will be realized. But it is none the worse for that. Ignorance about which of a set of possibilities gets actualized turns into distribution of belief over a set of downstream alternatives, all of which are actualized. And it still plays the same role in decision, but for pragmatic reasons. The Everettian agent walking into a casino is not betting on the singular

[5] Such a pragmatist interpretation is thus to be contrasted, as done in Bacciagaluppi (in press). with the radical subjectivist view of quantum states advocated in particular by Chris Fuchs.
[6] See Ismael (in press).
[7] See Ismael (2011) for a proposal along these lines. On a Lewisian view, laws and chances are the products of Best Systems theorizing, a process that takes information about local matters of particular fact as input and issues beliefs about chances, which then play the role defined by the Principal Principle. See Lewis (1986).

outcome of a chancy event, but choosing a betting policy in a universe in which all outcomes will be realized.

It is not hard to see in pragmatic terms how to justify a policy that tells him to bet evenly on the outcomes where the roulette wheel is fair, and in general according to the branch weight of the outcome. Indeed, we can reproduce the epistemic and practical situation of an Everettian agent as follows. As customary, we will suppose that the decisions are betting scenarios and suppose that the dollar is the measure of value and the same for everyone at all times. The Everettian agent knows roulette wheels are classically chaotic, so he knows that the quantum description is branching. We will suppose, moreover, that in the agent's branch we have stabilized relative frequencies for roulette wheels, where this is given precise content in terms of relative frequencies across randomly sampled subclasses. We now use those frequencies to introduce general probabilities of the form $pr(x/y)$ where x is a possible result and y is a generic description of the spin of a wheel. These probabilities are not treated as *representing* any kind of frequency, but are understood through their inferential role (the conditions and consequences of assignment). You are placing bets on a roulette wheel. You theorize that there is an equal general probability that an arbitrary spin will produce any particular result. You have no specific information about the outcome of a particular spin. You will be playing indefinitely long, you are certain that over the course of play all results will be realized, and you must bind yourself now in a single decision to a strategy that you must use throughout.

Is there a pragmatic justification for a strategy that assigns equal expectations to each result in the classical setting? If there is, then it equally supplies a pragmatic justification for the adoption of Born probabilities in the Everett setting. We can add relative frequencies that have any distribution whatsoever: one has the same pragmatic justification for adopting them as credences. We can add ignorance of what the stabilized relative frequencies are: now bets should be a mixture. We can allow that you might get lucky or unlucky. And we can tell any story that we need to tell (e.g., a Best Systems account) of how we form beliefs about the general probabilities, since the inference from observed frequencies to general probabilities is by no means direct.[8] What we have said here only links beliefs about general probabilities to credence.

Since Wallace has established in the discussion of statistical probability that branch weight and statistical probability go together (i.e., the branch weight of an x-result is (more or less) the statistical probability that a typical downstream descendant of the measurement will be observing x), someone who holds this view of probability has little problem making sense of its role in EQM: both decision and confirmation work fine and it all seems rather innocuous.

[8] Nor need it be conceived as a reduction. There is nothing to keep us from viewing the inference as ampliative.

Why then does Wallace work so hard to make sense of probabilities, offering the decision-theoretic proof? One possibility is pessimism about the prospects of a pragmatist account. He does consider a frequentist view, and rejects it on the grounds that it doesn't do a good job as an interpretation in the classical context, but remarks that it does at least as well in an Everett context as it does in the classical case. This pragmatist alternative is (among other things) a much more adequate relative frequency account of classical general probabilities. An Everettian might offer some such account of Born probabilities and be done with it.

Perhaps more plausibly, Wallace may think that the decision-theoretic proof is necessary whether one adopts a rationalist or a pragmatist account, in order to provide a theoretical underpinning of the Born probabilities. Although the proof of the Born Rule is formulated within the decision-theoretic framework, the mathematical core of the proof does not depend on it: as Wallace remarks, it 'establishes that *if* probability basically makes sense, and has the usual qualitative features, in unitary quantum mechanics, then quantitatively it is given by the Born rule' (155). Several critics have suggested that Wallace's decision-theoretic axioms fall short of being uniquely rationally compelling, but that does not mean they fail to lend the Born measure a significant degree of naturalness.

One may indeed feel that, without some argument such as the Deutsch–Wallace proof, the Born Rule is merely a phenomenological add-on to the theoretical structure of quantum mechanics, so that pragmatists may have an extremely good fit to observed frequencies but little theoretical underpinning for the Born Rule. However, while Wallace can point to the advantage of his proof as compared to classical symmetry arguments (no symmetry broken in the Everett case), it is not true that the Born Rule has little theoretical justification. As several commentators have pointed out, Gleason's theorem provides another natural way of justifying the Born Rule (perfectly acceptable as part of a pragmatic justification). And to do justice to Everett, he presents such a theoretical argument himself.

Wallace, in Section 4.6, appears to hold the common view that Everett's justification for the Born measure is based on the quantum law of large numbers (making Everett a species of frequentist). Instead, Everett justifies the Born measure as the unique function of branch weights that is *consistent over time*, in explicit analogy to the temporal conservation of the Liouville measure in classical mechanics, interpreted as a typicality measure.[9] Only after the Born measure has been thus justified is the law of large numbers applied in order to establish that typical memory sequences of observer systems display quantum statistics. Everett's derivation of the Born Rule is thus mathematically much closer to the Deutsch–Wallace proof than it seems: the crucial ingredient in both proofs is diachronic consistency, and one plugs it into one's favorite view of

[9] See Barrett and Byrne (2012, 123–130, 190–192, 261–264 and 294–295).

how measure-theoretic concepts are used (typicality measures for Everett, credence measures for Deutsch and Wallace).

In sum, the Deutsch–Wallace proof perhaps retains its interest as part of a pragmatic account of the Born probabilities, but rather less may be resting on it for establishing the intelligibility of probabilities in an Everett world. In either the classical or the Everett setting, probability emerges uniformly as a secondary or derived notion, and we can tell an intelligible story about the role it plays setting credences.

3.3 Uncertainty. Yet another example of rethinking occurs in the discussion of uncertainty, where Wallace challenges the common wisdom that accepting EQM would mean a radical overhaul in world-view. He focuses on three topics: uncertainty, possibility and personal identity. We were puzzled by the status of these analyses. One way of conceiving the task that the Everettian faces is that of reinterpreting familiar language against an unfamiliar metaphysics. In that capacity, he is likely to face choices about meaning that are made on pragmatic grounds, perhaps to preserve as much as possible of the old usage or to answer to new demands.

If this is the spirit in which Wallace is offering these analyses, they seem harmless enough, but we find it less plausible that they capture the content of the beliefs of pre-Everettian agents. Does he intend his semantics to capture the contents of language users' beliefs or is he just pointing out that our linguistic practices could be reinterpreted in an Everettian setting in a manner that kept them in place? Here is what he says:

> some advocates [of EQM…] have embraced the idea that so radical a theory ought to have comparably radical consequences for our everyday world-view. My purpose in this chapter is to defend a more conservative position: I will argue that the ways in which we use talk of uncertainty, identity, the future and so forth will remain fully justified in the event that we come to accept EQM as true. (259)

Does Wallace mean that our world-view isn't significantly altered, or that our ordinary ways of speaking can be preserved in the new setting? Consider the ancient medical practices that were justified by magical thinking. We might be able to rationalize the practices as justified from a scientific perspective, but surely we wouldn't be vindicating the beliefs of the ancient practitioners. We are happy to agree that we can make sense of the practical and epistemic behavior of agents in ways that are applicable irrespective of the move from a classical world to an Everettian one. We are not happy to say that the move would not involve significant reconfiguration of our world-view.

Part of the trouble is that the relationship between linguistic meaning and cognitive content associated with a term by the user is both complex and contested. Wallace draws on a tradition in philosophy of language holding that when we are interpreting speech, we are engaged in radical interpretation from a third-person point of view (Davidson 2001). The principle guiding the assignment of meanings to terms is charity: assign meanings that make most of the claims of users come out true. In the Everettian context, then, we are to think of ourselves as having the full multiverse in view, looking down at Everettian agents, and assigning meanings to their expressions. A principle of charity will have claims of uncertainty under branching meaning "happens in some branches and not in others". But even a defender of such a view about meaning should recognize a notion of content fine-grained enough to capture discriminations that we make from a first-person perspective. The way to see that there is a real and substantive difference between the pre-Everettian notion of uncertainty and the post-Everettian notion is to ask what an agent who underwent a conversion to EQM would say. Even if she continues to use the language of uncertainty, would she say that her subjective state of uncertainty has not changed? We think obviously not. We all know the difference between "one thing happens, I know not which" and "happens in one branch but not all". If I ask you whether Elm Street curves to the right or left at Tanner Park and you tell me you don't know, and if I find later that you know it has branches on both sides, I think you have lied to me.

Nothing really hangs on the issue for Wallace, because the task of making room for probability was treated in Part II with the decision-theoretic proof. The reason that issues about uncertainty became central in discussions of EQM was in part that they were closely tied to issues about probability. If there were something to be uncertain about, that would be the bearer of probability. Indexical uncertainty—or, self-locating uncertainty—presented itself as a natural candidate, but that only works in the "Vaidman window" in which a measurement has already taken place and an observer has not opened his eyes to view the result (Vaidman 1998). In that window, the agent can raise a question about a particular result that he can identify indexically, as *this* result, because at that stage he can distinguish that result by its relationship to his own location. The reason that this kind of self-locating uncertainty can't be transformed into uncertainty about the future is that it demands that self-directed thought about the future latches onto particular downstream descendants. If our future-directed uses of 'I' did have a well-defined subject, there would be uncertainty about what *I* will see—and statements about what I will see could be the bearers of probability. But because (at least on most standard readings of Everett) they do *not,* we cannot frame a question *at the pre-measurement stage* about the results in a branch in a way that leaves the outcome open. But Wallace doesn't need such bearers of probability, and he shouldn't be shy about acknowledging that EQM may do violence to some of our ordinary ways of thinking. The Copernican analogy to which Wallace repeatedly draws attention is apt here: Kepler and Tycho *mean* different things when they say the Sun rises in the East at dawn.

3.4. Space-time and the Quantum State. Wallace reiterates the view that the best way of doing metaphysics (or the metaphysics of our best physical theories) is by (i) taking our theories literally about the world and (ii) looking for perspicuous structures in our theories. He notes that to identify reality as a point in Hilbert space—although in a sense that may be the fundamental metaphysical picture—is not yet to tell us how this reality is structured. What he calls space-time state realism is supposed to make some of the structure of the quantum state explicit. At first it strikes one as trivial. If the state is real and if we assume some background space-time structure as in current quantum field theories, then it follows straightforwardly that what is real in a space-time region is the reduced density operator on that region, and that, although this ontology is localised (in the sense that it represents what is real in a region), it is non-separable, because the states of larger regions in general do not factorise into products of states on sub-regions. What is meant to be original in the proposal is that this particular way of analysing the structure of the universal quantum state is more perspicuous and helpful than others. To see this, we might consider the simpler case of non-relativistic quantum mechanics, and compare the result of writing down the quantum state in various representations. If we write it as a wave function on (the ’correct‘) configuration space, suddenly the Hamiltonian that generates the abstract evolution of the state takes on a familiar form, and it is this that gives meaning to the factorisation into subsystems, and meaning to the various operators as ‘position’, ‘momentum’, etc. Now do the same with space-time: we have the abstract state, and we find a representation of it as a state on space-time. Technically this might mean a state over a net of algebras of local observables (Haag), or a family of states over arbitrary hypersurfaces (Tomonaga–Schwinger). And suddenly we see dynamical structure manifesting itself, more specifically causal structure: dynamical influences propagating locally along the light-cones of a ‘branching space-time’. Not only is this choice of representation one that makes the (dynamical) microstructure explicit, but one might argue this is how space-time emerges from Hilbert space. Indeed, even though the quantum states in this representation are non-separable, the structure of how influences propagate between states on sub-regions is a structure of Minkowski light-cones. And Minkowski space-time arguably just is the causal structure of its light-cones. So, even though the way we have introduced space-time originally was as a mathematical background structure defining a representation of the quantum state, we now recognize the same mathematical structure in the physics.

As a way of making explicit structure encoded in an otherwise implicit way in the wave-function, space-time state realism is unobjectionable. But it is not particularly novel. We have known of the analysis of locality and non-separability of Section 8.5 since the classic discussions of nonlocality in the 1980s and 1990s. These apply to EQM because it just is standard quantum mechanics without collapse. (The novel question is rather whether the branching process should be thought of as local. In this regard, Wallace’s remarks on Everett and Bell’s theorem are indeed very helpful.) The analysis of Sections 8.6 and 8.7 points out how the effects of a decoherence interaction (of course) propagate along the forward light-cone, and how the non-separable structure of the state on a larger region leads to the subtle way in which the different local branchings intersect. But this analysis of branching was provided by Bacciagaluppi (2002). Nor does it provide a full analysis of the structure of reality according to EQM because it leaves space-time itself unanalyzed.[10]

3. 5. Plausibility. Perhaps the biggest *prima facie* challenge that the multiverse faces in winning over adherents is what many see as the intrinsic (im)plausibility of the view. Sometimes the challenge is expressed in terms of the distance from common sense, sometimes Ockham's razor is invoked, sometimes just incredulity.

In the Interludes where Wallace addresses his fictional (or composite) opponent, it is the philosophical questions that are mostly in play, and his strategy in answering them is repeatedly to point to episodes in the history of physics, revolutions that challenged the common sense of the day. The way that progression has worked is to expand our view of the universe in two ways: many of the structures at the forefront of experience and everyday thought turn out to be emergent from deeper structures, and many of them turn out to be parochial. And one can certainly make the case that the Everett view simply continues that progression along both fronts. It turns out that our view of reality is far more parochial than we imagined, limited not just to a small part of space and time, but to a single decoherent history. There is also a deeper way in which it arguably continues a progression seen in space-time theories. The development from Aristotelian through relativistic physics can be seen as successively restoring symmetries at the level of ontology that are broken in experience. Spatial isotropy is restored by relativizing the difference between up and down to a frame of reference defined by the observer's orientation, the difference between being at rest and travelling with constant velocity to a frame of reference defined by the observer's state of motion. In the Everett case, the symmetry-breaking transition that picks out one result as actual is replaced with branching, which relativizes the distinction between actual and not to a branch defined by the observer's location. The analogy isn't exact, but we agree with Wallace that the complaints that EQM violates Ockham's razor involve a misinterpretation of the principle. The right way of reading Ockham's razor as it actually figures validly in physics has less to do with reducing the size of the universe than with restoring symmetries.

[10] In this regard, Bacciagaluppi (2002) distinguishes further between the background spacetime introduced merely for the purpose of mathematical representation, and a concrete spacetime made up of decoherence events and the causal structures between them (i.e., of branchings that propagate along light-cones).

A lot of the debate surrounding EQM has revealed very different standards for rendering it intelligible that we live in the multiverse. Wallace's brand of naturalistic metaphysics gives complete authority to science, paying no heed to everyday 'intuitions' or judgments of intrinsic plausibility. This style of metaphysics contrasts sharply with 20th-century analytic metaphysics, which relies largely on a priori methods and where intuition and common sense play a role in choosing metaphysical frameworks. It also contrasts with the (so-called) primitive ontologists who typically hold that every theory, regardless of its prima facie ontology, must be about spatially localized building blocks evolving through time. The burden of argument for the authority of intuition and the justification for primitive ontology would seem to fall on the practitioners of these approaches. We think that the most important and urgent question in metaphysics right now is the choice between these methodologies, and that Wallace's book provides the best and most compelling example of what metaphysics is like performed in this new, scientific key.

4. Summary Assessment.

Wallace's book is tremendously valuable, full of rich insights, technical precision, and substantive philosophical contributions. There is little doubt that it is a major contribution to philosophy of physics, long awaited, and challenging various orthodoxies in the interpretation of quantum mechanics. But it should also be of interest to philosophers with no specific interest in quantum mechanics for a number of reasons: It contains a general re-examination of the relationship between the manifest image and fundamental ontology. It contains a probing examination of the nature of probability not just in a quantum context. It contains a re-examination of the source of temporal irreversibility. It raises in an interesting (and entirely novel) way the relationship between the description of the universe from the outside (no uncertainty, no indeterminism) and the description from the inside (uncertainty? indeterminism?). Perhaps most significantly, the book provides the most comprehensive and best exemplar of a new—and distinctly modern—way of doing metaphysics. On this way of doing metaphysics, one takes one's fundamental ontology from physical theories at face value and simply does the hermeneutic work of trying to understand the structures implicit in the formalism, connecting them with structures that are most readily manifest in our experience of the world, and seeing what needs to be done to accommodate old ideas (about ourselves and our place in nature) to a new world-view.

Those who know Wallace's work have grown accustomed to the combination of creativity and rigor, but it is hard not to be deeply impressed seeing a first-rate mind ranging so widely, with such mastery. The richness of the book and the philosophical interest of the material make it worthy of the attention of anybody interested in metaphysics. Wallace has a gift, moreover, for writing. The technical material is introduced with a light hand. The philosophical argumentation is clear and often compelling. The vision comes through powerfully and clearly. The book is challenging and rewarding at every step.

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