Modal Metaphysics and the Everett Interpretation

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Abstract

Recent work on probability in the Everett interpretation of quantum mechanics yields a decision-theoretic derivation of David Lewis' Principal Principle, and hence a general metaphysical theory of probability; part 1 is a discussion of this remarkable result. I defend the claim that the 'subjective uncertainty' principle is required for the derivation to succeed, arguing that it amounts to a theoretical identification of chance. In part 2, I generalize this account, and suggest that the Everett interpretation, in combination with a plausible view of natural laws, has the potential to provide a reductive theory of metaphysical modality. I defend the resulting naturalistic modal realism, and outline some of its implications for other parts of metaphysics.

1 - The Everettian theory of chance

a - Probability and the Everett interpretation

Since its inception nearly fifty years ago, the popularity of the Everett – or 'Many-Worlds' – interpretation of quantum mechanics has gradually increased. Once obscure and disreputable, it probably now attracts as much support as any other interpretation, among both theoretical physicists and philosophers of physics. This trend may reflect the general inadequacy of the other options on the table as much as the perceived advantages to be had from adopting Everett; however, in recent years some powerful positive results have been obtained from work on the interpretation. In particular, Wallace (2005b) and Saunders (2005) argue that within its context a general theory of probability can be formulated. I will discuss and defend their claim, and explore its consequences for modal metaphysics. Before looking at the result itself, a brief history of the interpretation's account of probability will put it into perspective.

The interpretation captured the imagination of many scientists when it was first proposed by Everett (1957), but his work was brief and itself open to multiple interpretations. He called it a 'Relative State' interpretation; the name 'Many-Worlds' was popularized by DeWitt & Graham (1973). However, their own presentation of the theory was tied closely to the metaphor of worlds 'splitting' discretely upon measurement, and they had trouble squaring this with the probabilities predicted by quantum mechanics. Roughly, their metaphor dictates that in an experiment with two possible outcomes, two distinct worlds are produced, and hence it suggests that the probabilities of each result should be equal. Of course, this is not so: a quantum experiment can be chosen so as to produce one result the vast majority of the time, and the other only rarely. In an attempt to disarm this kind of objection, Everett proved in his original paper that long-run limiting frequencies of results would tend towards the weightings given by quantum-mechanical squared-amplitudes. However, being only applicable in full generality to an infinite series of measurements, this result is widely thought inadequate. In consequence, serious criticism of the interpretation has often focused on its inability to account for probability[1].

The first rigorous response to this problem was due to Deutsch (1985), who introduced a continuous infinity of ‘worlds’ into every interaction; this resulted in a correct probability calculus, but at the cost of adding an infinite dollop of extra mathematical structure to the theory. A similar manoeuvre produced the influential 'Many-Minds' interpretation of Albert & Loewer (1988): in this case, the extra structure consisted of a continuous infinity of stochastically-evolving 'minds' (essentially, perspectives on reality). Both theories reproduce the probabilistic predictions of quantum mechanics, but do so by relying on additional dynamical structure introduced specifically for the purpose. For example, the original ‘Many-Minds’ theory saw probabilities as corresponding to the likelihood of *this particular mind* observing a particular result, and not directly to the likelihood of that result occurring. It is now usually accepted that the chief advantage of Everett lies in its promise to avoid auxiliary dynamics, and that the original 'Many-Minds' and 'Many-Worlds' theories do no better here than interpretations postulating wave collapse.

A far more promising approach to the Everett interpretation was inspired by technical progress in the physical theory of decoherence[2]. This gave proponents of Everett additional resources with which to reply to the ‘preferred basis problem’, historically the other major objection to ‘Many-Worlds’. Saunders and Vaidman, working independently, have recently argued[3] that decoherence can solve this problem completely: I will assume that this is correct. Wallace (2003) gives an elegant statement of a ‘decoherence-only’ version of the Everett interpretation; such an approach constitutes the background for the claims about probability to be discussed here. Of course, decoherence-only versions of the interpretation still run up against the same *prima facie* problem with probability mentioned earlier: in general, if all outcomes of a chancy situation really occur, then how does it make sense to talk about the probability of any particular outcome occurring at all?

In response, Saunders (1998) appealed to an analogy with Derek Parfit’s thought-experiments of

[1] A particularly clear version of this objection can be found in the introduction to Maudlin 1994.
[2] See Gell-Mann & Hartle 1990 and Zurek 1991
[3] See especially Saunders 1993, 1995, 1997, 1998 and Vaidman 1994, 1998

human fission. A person about to divide, amoeba-like, into two identical copies, might feel some confusion. Suppose he knows that two people will result, each of which will be indistinguishable from him, and that both will claim his identity: what should he expect to experience? Saunders argued firstly that it is a conceptual impossibility for any one person to be two people at once, and so it is impossible to expect to experience this or anything like it. The remaining options seem to be expecting no future experience – oblivion – or expecting an experience as of one or the other, with uncertainty about which. Oblivion is an implausible suggestion: if we do not expect oblivion in the case of a single 'descendent' (no branching) then why should the addition of an extra 'descendent' lead to it? The other options thus eliminated, Saunders suggested that, on the assumption of upcoming symmetric Everettian branching, the only plausible attitude to take is uncertainty about which possible future you will experience. Following recent work of Wallace, I will call this approach to branching *subjective uncertainty*[4].

The Parfittian splitting analogy was designed to reply to the 'incoherence problem' – it helps to make sense of probabilistic talk in the Everett interpretation. However, even if we accept Saunders' proposal, then the 'quantitative problem' remains. In an uncertain situation, why are we justified in identifying the subjective likelihood of a particular branch with its quantum-mechanical squared-amplitude? Saunders originally left this question unanswered, but noted in response that nobody had a very plausible constructive account of our probabilistic talk. There is no generally accepted metaphysical theory of probability, and it seemed unreasonable to ask an interpretation of quantum mechanics to provide one. All that is required, Saunders argued, is that we accept that an 'uncertain' attitude to branching makes correct sense of the physics, not that we can explain how it arises:

> 'Neither is it routinely required, of a physical theory, that a proof be given that we are entitled to interpret it in a particular way; it is anyway unclear what would count as such a proof.' (Saunders 1998)

[4] Wallace originally used the term 'subjective indeterminism'. I prefer this earlier formulation, as it emphasises the metaphysical implications of the view, but recent discussion (Wallace 2005a, Greaves 2004) has been conducted in terms of 'subjective uncertainty', and I have adopted their usage to prevent confusion.

Other interpretations of quantum mechanics tended to directly identify the squared-amplitudes with probabilities, and to do so without further explanation. Why should the Everett interpretation not do the same?

b - Objective chance and subjective uncertainty

Although Saunders' *tu quoque* argument, and his Parfittian fission analogy, serve to make the claims of the Everett interpretation about probability reasonably plausible, a completely satisfactory theory of probability would have to do more. It would have to systematically relate our use of probability talk to some feature of physical reality – objective chance - and justify the way in which it does so. It would have somehow to show how and why chance is relevant to our perceptions, judgments and actions. Specifically, there must be some good reason for us to use observed frequencies of results to judge what the chances are, and some good reason to adjust our beliefs about the future in line with what we believe the chances to be. David Papineau has called these the 'inferential link' and the 'decision-theoretic link' respectively[5]. Although these links are intuitively valid, it is not easy to find any agreed further justification for them.

Taking the inferential link first, a justification should explain why observed frequencies provide evidence for chances. There are, after all, some possible worlds in which observed frequencies are deeply anomalous, and thus provide misleading evidence. That such worlds are objectively improbable does not help us if we have not already established a relation between subjective likelihood and objective chance. Similarly, the decision-theoretic link appears impossible to justify independently. Why should we pay attention to chances when making decisions? Clearly, we can maximise the probability of a favourable outcome: however, what we are really after is not a high probability of the outcome, but that outcome itself. What exactly is it about chances that makes them relevant to the future, and hence to our decisions?

The philosophical 'problem of probability' comes down to a lack of justification for these two links. It has bothered philosophers of science for many years, but has perhaps been played down because

[5] Papineau 1996

we have such a good practical grasp of probabilities. The best-known formulation of the problem is due to David Lewis. In a well-known article, Lewis (1980) introduces the ‘Principal Principle’, which he claims manages to ‘capture all we know about chance’. The principle essentially states that a rational agent’s personal credences, or subjective degrees of belief, should be set equal to the chances inherent in a situation, on the idealisation that the agent has all admissible[6] knowledge. It combines Papineau’s inferential and decision-theoretic links into a full-scale *analysis* of probability. For Lewis, objective probability just is whatever can play the role of the objective chances in the Principal Principle. His subsequent work[7] on the subject was an attempt to construct entities capable of doing so, using only the austere materials of his underlying metaphysic of Humean Supervenience. Whether he succeeded is still a topic of active debate: however, what matters in the current context is that his conceptual analysis of probability is fairly widely accepted. Were we able to justify the Principal Principle, we would have a complete philosophical theory of probability.

But do we even need such a theory? In a completely deterministic world, ‘chances’ would always be either 0 or 1, so the Principal Principle would reduce to the truism (perhaps it could be called a rationality principle) that we should believe what we know to be true, and disbelieve what we know to be false. The assumption of physical determinism thus limits us to the use of epistemic probability, which can be accounted for by standard subjectivist accounts. So is the world according to Everettian quantum mechanics deterministic or indeterministic? Curiously, it is both. Everett’s original paper said that quantum mechanics was deterministic ‘from the point of view of the theory’, but indeterministic ‘from the point of view of an observer’. The question, in essence, is which point of view we should take when considering questions of metaphysics. Everett called it merely ‘a language problem’, but it divides the two main approaches to probability within the Everettian framework. We have already met subjective uncertainty (SU), associated with the work of Saunders and Wallace. An alternative approach, *objective determinism* (OD), has been implicit in the writings of Albert & Loewer, amongst others, and was explicitly defended by Greaves (2004).

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[6] Admissible knowledge does not pre-judge the outcome of chancy events in the present and future.
[7] In particular in his 1987 and 1994.

Objective determinism makes the ‘Gods-eye-view’ of branching events conceptually central, taking ‘the future’ to be the future-directed quantum state, rather than any particular branch within it. Greaves insists that this is the only reasonable position if we take the Everett interpretation seriously: after all, is it not committed to the physical reality of all outcomes? She argues that, as we know that all outcomes of a chance setup are part of the quantum state, we should regard the ‘real future’ as being a composite of these outcomes. Hence, having deciding to adopt Everett, we should care about this composite future just as we used to care about the single future we previously expected. This is to imply that our ‘newly-discovered’ status, as branching inhabitants of a multiverse, should directly override our previous belief that we have a unique future. In contrast with this, Saunders emphasises our own nature as ‘processes of a very special sort’, inherently limited to operate within a single branch of the wavefunction. We simply cannot *experience* more than one course of events, he argues, and a naturalistic metaphysics must reflect this limitation, however it arises.

We have already seen this point extended into an argument to make uncertainty in the face of branching plausible, by analogy with classical duplication of persons. While persuasive to many, this is not conclusive. It is perhaps unclear that the options considered exhaust the possible attitudes one could take to branching. Furthermore, the acceptability of Saunders’ own alternative has been called into question: Greaves has strongly urged an intuition which seems to point in the opposite direction. A corollary of the Everettian hypothesis is that the wave-function encodes all the physical facts there are, and the wave-function evolves deterministically. She asks how it is then possible to feel any uncertainty, given a complete knowledge of the wavefunction, and thus of the full range of branches. How can genuine uncertainty be reconciled with complete knowledge of how the quantum state evolves? How can an ideal epistemic position still leave any meaningful question unanswered?

This argument has a persuasive ring, but accepting it requires accepting a strictly tenseless approach to time, which is by no means the best option for an Everettian. Greaves tells us:

‘I assume eternalism as far as facts go – that is, I take it that facts, in whatever sense they

> exist at all, exist timelessly...' (Greaves 2004)

Eternalism is a natural enough approach in the context of a normal deterministic theory, but has some unwelcome consequences for quantum mechanics. Greaves accepts them:

> 'So I take it that, under a collapse interpretation of QM, there is ('already') a fact of the matter as to what the outcomes of future quantum experiments will be, no matter that that fact is unpredictable-in-principle from the present physical state of the universe; it is this that justifies my feeling uncertain under such an interpretation.' (Greaves, ibid.)

Furthermore, according to Greaves, this is the *only* possible justification for feeling uncertain. She puts forward explicitly a principle that:

> 'I can feel uncertain over P only if I think that there is a fact of the matter regarding P of which I am ignorant.' (Greaves, ibid.)

Greaves' insistence on eternalism has an epistemological twist. She is applying a maxim to the effect that:

> 'if there is no fact of the matter as to whether P holds, that is (invariably, I think!) because enquiring as to whether or not P holds is a bad question.' (Greaves, ibid.)

That is, the only proper subject-matter for our enquiries are facts which '('already')' have determinate values. This rules out any metaphysic under which the future is open and facts about it have indeterminate truth values. This approach has a respectable history, from Aristotle's ship-battle argument on, but Greaves considers it incoherent – or at least unable to deliver genuine uncertainty – for epistemological and metaphysical reasons which are essentially independent of the Everett interpretation. Hence, unless any tensed theory of time is rejected on independent grounds, Greaves' objection to subjective uncertainty is inconclusive. Of course, this is not in itself an objection to her own suggested attitude to branching, objective determinism, so we will need some way to compare both approaches on their merits.

We have seen that the two attitudes differ on which aspect of Everett's story to emphasise: the deterministic branching quantum state or the indeterministic experiences of an observer embedded within it. This difference of emphasis results in different mappings of our talk about the future onto the quantum state. Are we branching patterns within a branching multiverse, or classical individuals bound within a single universe? If we are to remain close to Everett's original intentions, the answer must be 'both, depending on your point of view'. The core of the interpretation is the idea that these two entities are to be identified, and their apparent differences explained as merely differences of perspective. We must then reformulate our question in a linguistic form: how, upon adopting the Everett interpretation, should we adjust our semantic policy in order to avoid contradiction or ambiguity? That is, which point of view should we adopt when reinterpreting our everyday language in the context of Everett – 'theory' or 'observer'? Wallace (2004) considers a version of this revised question from the perspective of philosophy of language, aiming to maximise interpretive charity towards a community who are embedded in an Everettian branching universe, but who use language just as we do.

On the objective-determinist approach, the future is an agglomerate of many branches, and all the facts about it can in principle be known. This lends itself very naturally to a tenseless analysis[8] of propositions in general, and in particular of future-directed ones; this kind of analysis seems to be an important motivation for most proponents of objective-determinism. However, Wallace argues that if we adopt this view it seems that we must ascribe widespread error to our linguistic community. Normal talk about the future takes it for granted that, in a chancy situation, only a single outcome actually occurs. 'The future', like 'the past', is taken to refer to a single course of events, set within a single and unified space and time. On the objective-determinist conception of branching in Everett, this is just a mistake: the future is *actually* a composite of myriad branching courses of events, all effectively causally isolated from each other. Adopting an objective-determinist version of Everett requires first that we accept that a large part of

[8] Such as that advocated by Mellor 1998

our everyday worldview is objectively wrong. For this reason, Greaves thinks that making coherent sense of probability in the Everett interpretation requires a new *rationality principle*, invoking a 'caring measure' over an agent's successors in different branches.

The subjective uncertainty approach does not require revisions of this sort. As it posits a genuine difference, at a given time, between the past and the future – the past is determinate, while the future is indeterminate – it necessitates some form of tensed analysis[9] of temporal language. This analysis would have to agree with our normal assertions that we have a unique future to look forward to, that this future is to a large extent unknown and unknowable, that the world only contains one instance of each of us, and that quantum measurements produce a single result. However, it sees these assertions as being made true by features of a branching quantum state rather than by features of a single classical phase-space point. Hence, despite Everett's radically new underlying physical ontology, subjective uncertainty recovers an adequate interpretation of our talk about the everyday world, and our own relationship to it. It solves the 'incoherence problem' by explaining how the process of branching fits into our pre-existing worldview, rather than by remodelling our conception of the actual world to fit in with what Everett tells us.

Intuitively, something of this sort is needed if the Everett interpretation is to be accepted as metaphysics, rather than as science-fiction. We have experiences of a single external world and of uncertainty about chancy events: these are important parts of a mature worldview and they must be respected by any general theory about reality[10]. If a theory as all-encompassing in scope as Everett is to 'save the appearances', then it must save all of the appearances, including, in particular, genuine uncertainty about the future. From a pragmatic perspective, it must be the case, if Everett is right, that conscious creatures undergoing branching are correct to take the subjective uncertainty viewpoint. After all, we do feel an inescapable uncertainty about chancy events, and if Everett is right we are, and always have been, undergoing constant branching, which in fact constituted those chancy events. Either the Everett

[9] Tensed accounts of time vary widely; all that is needed for these purposes is that future events are currently non-actual. An example view of this sort is given in Tooley 1997.

[10] A single external world is, in Kantian terms, a transcendental condition of experience, so its existence can be defended by transcendental arguments. The claim in Barrett 1999 that Everett is 'empirically incoherent' is one such argument; however, it has no force against subjective uncertainty.

interpretation is wrong – in which case further work on it is superfluous – or it is right – in which case the branching process is such that conscious creatures like us experience uncertainty before branching events. Either Everett is wrong, or subjective uncertainty is right. It seems to me that this argument, in combination with Wallace's related argument from interpretive charity, necessitates the subjective uncertainty approach to branching. For the rest of this paper, I will assume that SU is a coherent way to think about branching, and is the appropriate attitude to take to branching from a first-person perspective.

If we grant this much, then – at least from the perspective of an agent – Everettian quantum mechanics is an indeterministic theory. We will, after all, require an Everettian Principal Principle to make sense of probability. As mentioned above, we could choose to impose the Principle by fiat; this is effectively what is done in the case of dynamical collapse interpretations. But it is not a satisfactory approach; the Principal Principle has the status of an additional postulate of the theory, rather than being emergent from the physics. It is here that recent work by Wallace (2005a) has particular relevance. Generalizing a result originally due to Deutsch (1999), he applies decision theory to the circumstances of quantum-mechanical branching to prove a 'Quantum Representation Theorem' (also known as the Deutsch-Wallace theorem). This states that a rational agent who knows he lives in an Everettian universe ought to set his subjective probabilities equal to the quantum-mechanical branch weights, as and when he knows them. The basic starting points for its proof are a weighted branching universe[11], and some uncontentious axioms of rationality drawn from decision theory. The proof itself is non-trivial, and I will not try to reproduce it here: for economical accounts of how it proceeds and defences of all the major premises, see Wallace (2005a) and Saunders (2005).

In combination with the perspectival indeterminism of the subjective uncertainty viewpoint[12], the Deutsch-Wallace theorem becomes a quantum-mechanical version of the Principal Principle, with branch

[11] In the absence of a weighted branching universe, the symmetries exploited by the proof are broken; see Wallace 2005a for more details. This helps to explain why Deutsch's work has been criticised as question-begging, for example in Barnum et al 2000.

[12] Recent work by Wallace (2005a) suggests that OD may also be able to support the proof of a Quantum Representation Theorem. This would not, however, support a proof of an OD Principal Principle: according to OD the universe is completely deterministic, so that strictly speaking there are no objective probabilities at all. Instead, an OD proof of the Deutsch-Wallace theorem would justify the adoption of a certain 'caring measure' over future branches given by the Born Rule.

weights playing the role of objective chances. Thus, the proof of the theorem provides an independent motivation for the Principal Principle: it fulfils Lewis' criterion for a complete theory of objective probability, by establishing the right kind of connection between chance and our credences about the future.

c – Naturalizing chancemakers

This result might come as a surprise to those working in the foundations of probability. The Everettian theory of probability is robustly realist[13] about chances, and it has tended to be taken for granted that a realist account cannot possibly provide a justification for the Principal Principle. Max Black (1998), a realist himself, admits as much, but argues in his defence that reductionist accounts, like Lewis', are effectively in the same position. The Deutsch-Wallace theorem breaks this impasse by deriving a version of the Principle directly. How is this possible? I can do no better here than quote Wallace:

> 'Recall that historically symmetry has always rivalled frequency as a constraint on probabilities: we assign each face of the die probability 1/6, for instance, because (somehow) they are correctly regarded as being related by a somehow-relevant symmetry. But in the absence of branching, this argument falls foul of the observation that ultimately one event or the other must actually occur, breaking the symmetry…In a branching universe, on the other hand, no single outcome occurs. It is therefore possible that the symmetry constrains the probability without further ado.' (Wallace 2004)

David Lewis' highly-influential discussion of probability issues the following well-known challenge to any prospective realist about chance:

> 'Be my guest – posit all the primitive unHumean whatnots you like… but play fair in naming your whatnots. Don't call any alleged feature of reality chance unless you've

[13] 'Primitivist', in Lewis' tendentious terminology. This means only the (fairly weak) position that chances cannot be reduced to patterns of actual property-instantiations.

> already shown that you have something, knowledge of which could constrain rational credence…I can only agree that the whatnots deserve the name of chancemakers if I can already see, disregarding the names they allegedly deserve, how knowledge of them constrains rational credence in accordance with the Principal Principle.' (Lewis 1994)

Lewis knew full well that his metaphysic of Humean supervenience requires the nonexistence of any such 'unHumean chancemakers'. He gambled that nothing, in anyone's ontology, would turn out to be capable of playing this role in more than a nominal sense:

> 'I am prepared at this point to take the offensive against alleged unHumean lawmakers; I say there is no point believing in them, because they would be unfit for their work.' (Lewis 1994)

In resorting to these rhetorical questions, and putting the burden of proof on his opponents, Lewis shows that he has no positive argument for the incoherence of unHumean chancemakers. Indeed, in the same passage he admits that their non-existence is contingent; thus, his argument can be refuted by a single counterexample. The Everett interpretation introduces new and alien types of entity into our physical ontology, and some of its theoretical posits are, in fact, capable of playing the role of unHumean chancemakers: they are the weights of various outcome branches of a quantum interaction. The Deutsch-Wallace theorem provides just the demonstration that they constrain rational credence which Lewis demanded, but did not expect. By his own lights, if quantum weights exist at all then they can and should be legitimately interpreted as objective chances.

The proof of an Everettian Principal Principle requires the subjective uncertainty approach to branching, since only from this perspective can we treat Everett as genuinely indeterministic. In regarding future Everett branches as genuine alternative possibilities, and weights as their objective probabilities, subjective uncertainty carries certain theoretical commitments – in particular, an open future – which conflict directly with Lewis' metaphysic of Humean Supervenience. Of course, Humean metaphysics in general can be reconciled with any empirical data, and hence with any theory if construed only instrumentally; this flexibility is its greatest asset. But the price of compliance of the Everett interpretation with Humean doctrine would be to treat the entire quantum state as a single Humean world, evolving deterministically with an incomprehensibly enormous multiplicity of entities within it, rather than treating it as a set of distinct worlds, each evolving indeterministically and containing a reasonably familiar distribution of entities. In other words, reconciling Everett with Humean Supervenience requires that we construe Everett from an objective-determinist perspective. This undermines the subjective uncertainty derivation of the Principal Principle, and is objectionable on grounds of reduced interpretive charity and metaphysical orthodoxy, as discussed above.

However, the subjective uncertainty approach to Everettian branching, as advocated by Saunders and Wallace, is still committed to a strong but simple physicalistic supervenience thesis of its own: all facts supervene directly on structural relations within the quantum state. This form of supervenience is naturalistic, but certainly not Humean: according to SU, the quantum state comprises not only all actual, but also all physically possible, events. The idea that all facts might supervene on all actual and possible events is not implausible, or even without precedent: Sellars (1948) defended such a view, on purely metaphysical grounds. It manages to reconcile the two sources of probabilities, frequencies and symmetries: relative frequencies over actual and possible events just *are* probabilistic symmetries. It is also a natural analogue of a Leibnizian view of space, as composed of all actual and possible relations between objects. I would suggest the name of *Leibnizian Supervenience* for a form of supervenience claim appropriate to the subjective uncertainty approach to Everett. The most distinctive difference between our two forms of supervenience is their account of how probabilities supervene on the quantum state. On a Humean account (combined with Lewis' theory of chance), the probabilities all jointly supervene on the entire set of facts about all the branches: in the Leibnizian version, each probability supervenes individually on a quantum amplitude, one tiny fragment of the quantum state. This captures the 'propensity' aspect of our thought about objective probability in a way that Humean Supervenience cannot.

Perhaps surprisingly, Lewis admitted that the thesis of Humean Supervenience is itself contingent[14], despite being presupposed by his own analysis of contingency and necessity in terms of Humean combinatorics. That is, he accepted that future developments in physics might reveal that in fact, our world does, after all, contain some unHumean whatnots. If Everettian quantum mechanics were true, then it would fit the bill as such a development: the Deutsch-Wallace theorem constitutes a proof of the existence of real propensities, taking the form of the quantum weights of future branches, and playing the role of objective chances. I propose that this be seen as a *theoretical identification of chance*: a discovery of its true nature, analogously to paradigm examples like the discovery that heat is molecular motion, or that light is electromagnetic radiation. The concept of objective chance and the physical posit of quantum branch weightings derive from different historical considerations, but we nevertheless now have good scientific and philosophical reasons to believe that they have been one and the same all along.

This discovery would also constitute a naturalization of chance. This goal was the original motivation for Lewis' Humean theory of chance, but this theory unfortunately had the result that (strictly speaking) there were no such things[15]. However, the principle is sound: it is an important ongoing procedure to find natural explanations of all of our significant concepts, wherever they derive from. Chance then joins heat, light, sound, matter, planetary motion, life, and even (perhaps) mentality, whose essential natures have been revealed by scientific investigation. This trend seems inescapable, and the Everett interpretation is another step in the right direction.

It is true that chance is unlike many of these other successfully-naturalized concepts. It could be objected[16] that chance is part of our scientific framework – an abstract artifact of the scientific method rather than a natural phenomenon in its own right – and hence that it is not appropriate for the same treatment as the more concrete examples given above. My response to this is twofold. Firstly, a Quinean naturalistic view of scientific progress undermines the importance of this framework/theory distinction. On this view, as our theories and our capacities for making theories further adapt to the world around us, each evolves informed and enhanced by the other. The proper entities with which to populate a naturalistic

[14] In the introduction to Lewis 1987

[15] In their place, Lewis (1994) accepted some similar quantities defined by the 'New Principal Principle'.

[16] This would, however, be an objection to any approach to chance that adopted the Principal Principle.

worldview are just those that are presupposed by the explanations given by science. These do include objective chances, which bear causal-explanatory relations to other, more concrete, entities[17]. Secondly, in the context of Everettian quantum mechanics there is no scope for any sharp distinction between the form and the content of the theory. The wave-function, or quantum state, which is the central object of the theory, has amplitudes and hence branch weightings integrated into it directly. Accepting the physical reality of this state involves accepting the reality of a physical quantity which we can legitimately interpret as objective chance; this is exactly what is involved in a procedure of naturalization.

What worried Lewis most about propensities is that they seem to require a genuine, non-logical relation of necessitation between events. In the special case where a probability is one, an objective chance can completely determine a later event, which Humeans find unacceptable. Lewis puts it bluntly:

> ‘What prevents us having [a past] H without [a future] F, when they specify the character of wholly different parts of the world? This necessary connection between distinct existences is unintelligible.’ (Lewis 1987)

In naturalizing objective chance, the Everett interpretation also thereby provides a naturalistic account of this supposedly unintelligible power – of non-logical necessitation – as just being constituted by the universal validity of the unitary evolution of the quantum state. This is in tension, of course, with most metaphysical theories of laws of nature, under which non-logical or causal necessity is usually either dispensed with entirely (as in Humean accounts) or taken as a primitive metaphysical ‘necessitation relation’, as in the work of Armstrong. Effectively, the Everett interpretation contains its own account of laws: they are structural features of the quantum state which are invariant over all Everett branches. Everettian objective chance can then be seen as a quantitative form of *natural necessity*, grounded on the unitary evolution of the quantum state.

[17] An interesting feature of quantum mechanics is that the weights of branches cannot be measured or altered directly, even in principle; this is in fact an important ingredient in the proof of the Deutsch-Wallace theorem. Despite this, the weights are a crucial objective element in quantum mechanics, and a scientific realist is perfectly justified in positing their existence.

We are now faced with a parting of the ways when considering the Everett interpretation. The subjective uncertainty approach to branching requires that we treat future-directed branches as alternative future physical possibilities. As such it is committed to at least a limited form of modal realism; all physically possible worlds exist[18]. As a result, SU seems to contain within it not just a constructive theory of probability, but also an unusual constructive account of natural laws and natural possibility. Some might want to see this as a *reductio* of the whole line of thought: "It might be plausible at first, but taking it to its logical conclusion steadily undermines our modal metaphysics, and surely it is not the business of a mere interpretation of quantum mechanics to revise modal metaphysics. If it is itself to be acceptable, it must fit in with metaphysics, rather than *vice versa*." However, what assurance do we have of the truth of our current theories of modal metaphysics, historically a problematic subject? The epistemology of metaphysics is notoriously difficult, and naturalization seems one of very few viable options. Hence, it is worth carrying through any new implications of this approach to quantum mechanics, rather than attempting to force it into an existing mould, precisely because it promises new alternatives in a subject still lacking a consensus. The second part of this paper will consider the Everett interpretation as a constructive theory of modality in general, a role that it performs remarkably well.

[18] David Wallace has pointed out to me in correspondence that this argument requires that we allow inferences from 'x might have been going to happen' to 'possibly x'. If this principle of inference is rejected, then SU only implies a minimal future-directed form of physical modal realism.

2 - The Everett Interpretation as a theory of modality

a – Everettian modal realism

In naturalizing objective chance, the Everett interpretation provides a scientifically respectable account of a quantitative, non-logical, natural necessitation relation, deriving its force from the unitary evolution of the quantum state. Implicit in the subjective uncertainty approach to branching, on which this account rests, is a treatment of Everett branches as possible histories of the world, and of quantum amplitudes as determining the probabilities that one or another will become actual. When combined with an naturalistic supervenience claim – that all facts are made true by features of the quantum state alone – then the result is what I have called Leibnizian Supervenience: the supervenience of all facts on the set of actual and naturally possible events. This is equivalent to the claim that the quantum state, taken as describing a branching structure of worlds, is a *global truthmaker*[19].

Now, of the facts that it makes true, some are modal. Most obviously, facts about what is and is not naturally possible supervene on the set of all naturally possible events. This is already a promising result: the problem of truthmakers for modal truths is considered one of the most difficult challenges for metaphysics, and there have been several influential attempts to solve it in recent years. Amongst others, Plantinga (1974), Lewis (1986), Blackburn (1993), Chihara (1998), Peacocke (1999) and Armstrong (2004) have all taken the problem seriously, each offering a different systematic solution. But the Everett interpretation seems to contain a solution all of its own that is rather simpler than any of those currently on offer. That is to say, the interpretation comprises by itself a metaphysical theory of modality, through its claims about branching.

What is a metaphysical theory of modality? It is an answer to an ontological question: the question of what – if anything – makes propositions about possibility, actuality and necessity true. Traditionally, discussion has taken the form of a dispute over the ontological status of possible worlds, entities quantified

[19] See Armstrong 2004 for discussion of this notion.

over in important and accessible semantical formulations of modal logic. The battle-lines are drawn between *modal realism* and *modal nominalism*: those who believe that possible worlds are genuine entities of some sort, and those who believe they do not exist at all. Within the scope of modal realism, there is a further disagreement over what kind of entities the worlds are; whether they are concrete worlds of a kind with our own (e.g. Lewis (1986)), 'ersatz' linguistic or theoretical constructions (e.g. Adams (1974), Armstrong (2004)), or something else altogether. Among nominalists, most advocate the use of possible world semantics, somehow denuded of any ontological commitment (e.g. Chihara (1998), Forbes (1985)), while a few reject it altogether (e.g. Quine (1976)).

Under this classification, the type of Everett interpretation we have been discussing is clearly a version of modal realism, as it postulates physically real branches of the wavefunction as possible histories. Like Lewis' 'genuine modal realism', but unlike 'ersatz' versions, the subjective uncertainty viewpoint requires a distinction between reality and actuality, and like Lewis's theory it makes this distinction indexical. Each possible branch is physically real, but the branch in which we ourselves are located is (for us) especially interesting: it is (for us) the only one that is actual. Past discussions of Everett have, however, shrunk away from associating a real/actual distinction with the interpretation: Paul Tappenden (2000) is a good example.

Acknowledging Butterfield (1996), who had suggested that Everettian branching threatens to undermine our fragile conception of the continuant identity of objects, Tappenden notes that a consistent application of the Everett interpretation to talk about persistence of objects requires us to distinguish between different post-branching states of an object:

> 'if a Stern-Gerlach apparatus branches as a silver atom causally couples with the detector, then how are the subsequent detector states both part of the same object?' (Tappenden 2000)

He considers supplementing Everett's discussion of the subject with a real/actual distinction to perform the role of distinguishing between the subsequent states, but then rejects this idea, quoting one of Everett's very few explicit discussions of modality. In a well-known note, Everett asserts that:

> 'from the point of view of the theory all elements of a superposition (all 'branches') are 'actual', none any more 'real' than the rest.' (Everett 1957)

Tappenden takes this dictum at face value, remarking in addition that:

> 'all talk of possible worlds which has come out of modal logic post-dates Everett's proposal and has an entirely independent motivation. An outstanding difference between any proposed type of possible worlds and Everett's branches is that branches can have a common causal origin. So as it stands it does not look as though Everett's scheme can be assimilated to talk of possible worlds.' (Tappenden 2000)

He therefore rejects the use of a real-actual distinction to do the work required, in favour of a distinction between different *superslices* of an object. These are modal parts, analogous to temporal parts, and he names them according to the *superpositional dimension* along which they are arrayed. This idea, which Tappenden adapts from Lockwood[20], is just as far removed from Everett's original presentations of his view as a real/actual distinction. And, although picturesque, it assumes a form of objective-determinism, so is unable to account for probability in a fully general way.

As we have seen, Everett had only a vague understanding of how probability could be accommodated in his interpretation, and, as we have seen, it turns out that to make coherent sense of probability, we need subjective uncertainty. This carries with it a distinction between (physically real) alternative possible branches and the branch that we ourselves are in. It is clear from the above extract that Everett considered the words 'actual' and 'real' synonymous. This is exactly what one would expect: dictionaries usually treat them as largely equivalent, and the idea of distinguishing them indexically was

[20] See Lockwood 1989 and Lockwood 1996

only introduced into metaphysics, by Lewis, years after Everett was working. However, it is a natural way of expressing a metaphysical distinction that his interpretation requires for a consistent application to persistence and probability. Rather than using the clumsy terminology Everett proposes, contrasting 'real from the point of view of the theory' and 'real from the point of view of the observer', we can express the same distinction by opposing reality and actuality. From the point of view of the theory, all branches are on a par - call this reality. However, from the point of view of an observer one branch is picked out as consisting of the 'accessible' phenomena – the past and present – call this actuality. And, as observers, we take the point of view of observers, rather than that of the theory, in virtually every context. In this sense, adopting Everett under a subjective uncertainty reading involves positing a radically diverse reality, but retaining a familiar and sane actual world.

The Everettian picture is of a complex quantum reality with a branching structure of histories 'embedded' within it, and we have already seen that such a structure may be interpreted in terms of possible worlds in more than one way. We can either identify the entire branching structure with a single possible world, retaining Humean Supervenience at the price of objective determinism, or we can adopt subjective uncertainty and identify the branching structure with a collection of overlapping worlds. The physical ontology of the two approaches is the same: their semantics are different[21]. Taking the second alternative effectively results in a 'branching' version of modal realism that Lewis in fact explicitly describes[22], and even suggests there 'might be some reason' (viz. thinking of the future as indeterminate) to accept. Being able to solve the measurement problem without conflict with relativity, and to derive the Principal Principle from decision theory, are compelling additional reasons to do so.

Accepting this kind of Everettian modal realism also entitles us to most of the semantics that Lewis constructed for his own version, using analogous raw materials. But Everett branches are different sorts of thing from Lewisian possible worlds. Rather than concentrating on comparisons with modal realism on a case-by-case basis, we need to examine the conceptual relations with Lewis' theory, to clarify

[21] As this semantic difference leads to systematic disagreements about the nature of entities like 'the world' and 'the self', it arguably constitutes a metaphysical difference: Lewis, however, might deny this.
[22] See Lewis 1986 p.207

what the Everettian version can and can't do. According to Lewis:

> 'modal realism is the thesis that the world we are part of is but one of a plurality of worlds, and that we who inhabit this world are only a few out of all the inhabitants of all the worlds.' (Lewis 1986)

This is true of the Everett interpretation under a subjective uncertainty understanding of branching; however, it disagrees with Lewis about the nature of the worlds in question. As the kind of modality treated by Everett is objective chance, a posit of natural science, the Everett worlds must be identified with the naturally possible worlds. This on its own is a significant departure from Lewisian modal realism, and it is the reason why most have concluded the two theories cannot be reconciled.

Lewis' worlds are usually thought of as 'broadly logically possible', or 'metaphysically possible'[23]. They are obtained by a process of recombination of objects found within the actual world, or of objects which can be described by direct analogy with objects found in our world. Roughly speaking, they are the conceivable worlds: anything which can be described without an explicit or implicit contradiction can be found somewhere in one of them, including (according to Lewis) ghosts and unicorns. The Everett worlds, comprised only by processes compatible with quantum mechanics, are in general much more homely affairs. Their exact extent is still unknown: we have sufficiently little understanding of the early universe not to know whether values of physical constants or even the structure of physical laws were quantum-mechanically determined soon after the big bang. Then, there would be branches that diverged from our own before dynamical laws or physical constants were settled, which would consequently contain related but different physical processes. However, those that diverged more recently (the 'closer possible worlds') we can reasonably expect, from our knowledge of cosmology, to contain only broadly the same kind of emergent objects and processes as our own world: fields, matter, chemistry and so on.

Another important break with Lewis' approach, and also with that of others who advocate a

[23] To call them 'metaphysically possible' is however, rather contentious: as explained below, there is much debate about the nature of metaphysical possibility. Lewis does not claim a monopoly on the concept.

branching universe, such as McCall[24], is that Everett worlds are not in fact completely isolated from each other. The quantum state incorporates interference effects, or phase relations between the various superposed states of a subsystem. As a result, during 'branching events' different branches cannot be fully described in isolation from each other, leading to 'quantum interference' phenomena, as in the famous two-slit experiment. These interference effects, however, become negligible very quickly in all normal circumstances. This is ensured by decoherence, which results from the interaction of a system with its environment, and effectively guarantees that within incredibly short timescales (of the order of 10^{-23} seconds for a 1g object at room temperature[25]) branches can diverge so much that they no longer interfere to any detectable extent. Branching, then, is a continuous process with an effective duration of the decoherence time, rather than the discrete event envisaged by proponents of old-style Many-Worlds interpretations.

Observation of quantum effects requires that the system in question be 'protected' from interacting with its environment, to minimize the effects of decoherence. Certain experimental set-ups can in this way magnify quantum effects to be observable on a macroscopic scale. All worlds, as parts of the quantum state, interfere with the others to a greater or lesser extent; however, in the vast majority of cases this interference will be negligible except during the incredibly short branching process itself. The presence of other branches introduces non-zero terms into the physical equations describing the actual world, but decoherence and thermodynamic irreversibility ensure that, on the whole, these are negligible compared with the terms arising from processes *within* the actual world.

Does this mean that different Everett branches are causally isolated? Strong intuitions seem to point both ways. One the one hand, other branches correspond to other possible worlds, and presumably actual causal relations hold only between actual events; on the other hand, the presence of other worlds leads to non-zero terms in the physical equations which correctly describe the actual world. In this latter, microphysical, sense, other worlds make a real contribution to our own world: the only question is whether

[24] McCall (1994) argues for a branching model of the universe; like Lewis, he advocates his system for its philosophical utility, rather than on naturalistic grounds.
[25] Zurek 1991

this should be labeled a *causal* contribution. Given the intense controversy over the metaphysics of causation, no conclusive answer can be expected here. However, I would follow Ross & Spurrett[26] in distinguishing various different lines of thought which are often run together. In a first, 'scientific', sense, causation is closely linked to causal explanations in the special sciences; in a second, 'metaphysical', sense, it is the 'cement of the universe', relating distinct events together in a determinate fashion. A third, 'cognitive', sense corresponds to our 'folk' or 'Aristotelian' notion of causation, and is tied to the language of agency.

Other Everett worlds do not, in fact, feature in most of our causal explanations, except when we look at physical processes which can only be accounted for using quantum mechanics: hence, in most cases they do not make a causal contribution to the actual world in the first, scientific, sense. The third sense is derived from the archetype of agent causation, and Everett branches clearly could not be said to cause effects in this way. However, they do always have a miniscule but non-zero effect on the microphysics of the actual world; therefore, in the second, metaphysical, sense they *are* causally active. Ross & Spurrett propose to withdraw the name 'causation' from this notion of microphysical significance, on the grounds that it has too little in common with our 'folk' notion. However, this seems unnecessarily harsh, since it does capture the 'making a difference' aspect of our thought about causation, so a compromise is called for. Other worlds, we might say, are in general causally active (since they affect actual microphysics), but not usually causally relevant (since they do not feature in causal explanations).

An Everettian ontology gives primacy to the quantum state, which, in combination with dynamical laws, contains enough structure to describe a branching system of worlds. Worlds, and the physical objects within them, are not fundamental entities, but are instead thought of as structural entities, or patterns within the state. As such, they are broadly speaking emergent: they can be compared, metaphorically, to eddy currents in a stream of water. These are not ontologically prior to the substratum they are a pattern in, but they are nevertheless, in some contexts, explanatorily indispensable[27]. Worlds, taken in this way as physical

[26] See their 2004 and forthcoming.
[27] Wallace (2003) presents a strong defence of this approach to macroscopic ontology, which is based on ideas from Dennett 1991, and has significant overlap with ontic structural realism (Ladyman 1998).

objects, have interesting properties. Most significantly, of course, they undergo branching. A metaphor that is often used is of a world splitting into two. While evocative, this can lead to confusions: it invites misconceptions such as the idea that the mass-energy of the world is not conserved over time, and that the actual world undergoes a cataclysmic upheaval every time a spin measurement is made. Rather, the underlying quantum reality flows along in a relatively simple unitary evolution and what multiplies is a pattern within that reality. The actual world remains a single, continuous, emergent history.

It has been suggested[28] that we need some definite conditions for identity over time of worlds, which we can unambiguously extract from the quantum formalism alone. Here I follow Saunders and Wallace, who have both argued that this demand is unreasonable[29]. By their very nature, worlds are extended objects, unambiguously individuated for their (inevitably macroscopic) inhabitants. Any system capable of processing information at all - let alone framing the question of the individuation of a world - must itself be part of a decohering branch. The actual world will, for any given system, be individuated by causal relevance, just as we ourselves pick out 'the world' without a second thought. On any emergentist conception of mental phenomena, this kind of anthropocentricism is justified. By analogy, conscious perceptions are not ontologically primitive, and do not need to be explicitly encoded in basic physical theories. Precise-enough individuation and persistence of the actual world is guaranteed, by decoherence, from any world-bound perspective; when considering hypothetical scenarios, it can be assumed for any such perspective. Lewis appeals to a criterion of spatio-temporal isolation to demarcate his worlds, since he has no equivalent to decoherence: this is the 'outstanding difference' to which Tappenden (2000) refers.

The Everettian ontology is extraordinarily flexible. The basic elements are real and physical in nature: other possibilities make at least a minimal contribution to the physical equations describing the actual world. The basic elements are also naturalistic: the main motivation for believing in other Everett worlds comes from quantum mechanics. Thus, it offers a novel way of reconciling acceptance of genuine modal properties with naturalism. An apparent tension here has worried metaphysicians for some time. Alexander Bird expresses these worries clearly:

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[28] Bell (1987) initiated this line of criticism, which was pressed by Kent (1990).
[29] See Saunders 1993, 1995 and Wallace 2003

> 'it looks as if we are faced with a dilemma. If we accept modal properties we accept other possible worlds (viz. modal realism). But this seems to conflict with causal naturalism, which requires that we posit nothing beyond what is causally active.' (Bird, forthcoming)

The Everett interpretation slips between the horns of this dilemma by allowing that other possible worlds are in a real way causally active.

b – Criteria for a metaphysical theory of modality

So how does Everett compare with other current theories of modality? It is hard to answer this question directly, since there is no real consensus as to the relative merits of these contemporary theories. In the late twentieth century there was a lively debate over the metaphysical significance of the possible worlds semantics, in particular when applied to absolute, alethic, modality[30]. The problem was, in the words of Colin McGinn, that:

> 'how we choose to represent the truth conditions of modal sentences in a systematic semantic theory must reflect our considered conception of the nature of modal reality.' (McGinn 1981)

The simplest reality that could be reflected by possible worlds semantics is Lewis' notorious genuine modal realism. On this account, possible worlds are concrete entities exactly like our own world. Indeed, all that distinguishes the actual world from the merely possible worlds is an indexical: this world is ours, but all the other individuals in their worlds would say the same of theirs. Our modal discourse can then be analyzed as straightforward quantification over other worlds and otherworldly individuals.

[30] The modality of greatest metaphysical interest is alethic rather than epistemic or deontic: that is, it is independent of human knowledge or norms. Additionally, it is absolute rather than relative: it involves 'genuine', as opposed to 'hypothetical' possibility. Absolute alethic possibility is nowadays usually identified with metaphysical possibility, as outlined by Kripke (1972) and Putnam (1975).

Many find this ontology of causally isolated concrete worlds difficult to stomach: Lewis admitted freely that it was not intended to capture exactly the common-sense view, but to replace it. His arguments for modal realism were based entirely on the philosophical utility of the approach: on the number of difficult philosophical problems that could be resolved by swallowing the extra ontological commitment. These problems included the analysis of counterfactuals, of causation, of universals, and various others besides. By and large, his analyses are considered, if not entirely successful as they stand, then at least in principle viable. The general rejection of modal realism by the philosophical community rests instead on a feeling that any project of revisionary foundational metaphysics must be misplaced: however elegant a philosophical theory might be, it should not warrant radical ontological upheaval of this kind. From a naturalistic point of view, ontology is the job of the scientist, not the philosopher.

If modal realism is rejected then we need some other account of how modal discourse works. Lewis, however, reinforced his thesis of modal realism with a sustained critique of its rivals. At the root of his objections to modalism (the nominalist acceptance of modal operators as primitives of meaning) was the claim that it left modality itself primitive and unanalyzed, and thus mysterious:

> ‘to apply the results [of modal logic] you have to incur a commitment to some substantive analysis of modality…then we are doing metaphysics, not mathematics.’ (Lewis 1986)

For Lewis, to be substantive, a theory of modality ought be a constructive one: it must posit a basic ontology of individuals and properties, and show how modality can be analyzed in terms of them. His critique of actualism (the ‘ersatz’ thesis that possible worlds exist as parts of the actual world) in its various forms was primarily that its attempt at such an analysis is bound to fail[31].

[31] An anonymous referee has asked what distinguishes the Everettian theory of modality from a necessetarian naturalistic theory of modality based on – for example – classical statistical mechanics. A natural response to this is that Everett branches are real entities, while the micro-histories of classical statistical mechanics are linguistic ersatz entities, and hence are vulnerable to Lewis’ objections. However, certain alternative interpretations of quantum mechanics might also be able to ground an actualist ersatzism using physically real entities – the ‘tails’ of dynamical collapse theories, or Bohmian ‘empty waves’. A referee suggests that this approach could potentially avoid the problems that Lewis raises for ersatzism.

The kind of analysis Lewis advocates is certainly desirable. In Lewis' terms, his theory is qualitatively parsimonious: it reduces the number of fundamentally different kinds of things. Where the kind of thing avoided is as mysterious as primitive necessity, then this is indeed an advance. It is not eliminativism: it does not require that we stop using our standard modal language. Indeed, it would be a failure of a philosophical theory if it rendered our usual idioms untenable. Rather, a reductive analysis of modality would give a basic ontological grounding for those idioms and a rational justification for using them. A successful reduction of this sort is the first and most important advantage Lewis claims for modal realism. Thus, despite the prevalence of the 'incredulous stare' response, probably the most serious objection to genuine modal realism is that it does not after all provide this kind of reductive analysis. The problem that remains unanswered is, as Graham Forbes put it in a review of Lewis,

> 'the problem of what makes something possible or necessary.' (Forbes 1988)

Lewis' answer, 'because it is true in some or all possible worlds', is not completely satisfactory. The worlds are theoretical posits (albeit posited as concrete): which worlds are posited has, in the end, to be decided independently. Primitive modality has not been avoided after all. Hilary Putnam has urged this point directly:

> 'it is of course evident that one cannot explain the notion of possibility itself in terms of possible worlds.' (Putnam 1983)

This point can be put more forcefully by questioning the justification for plenitude: the necessary requirement on a modal realist's ontology that the worlds must exhaust genuine (or 'absolute') possibilities, but not include any impossibilities. It is clear that this condition must be met by modal realism, if it is to

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There are two points to note here. Firstly, such an ersatzism undermines the proof of the Deutsch-Wallace theorem, which requires a branching structure of worlds. The derivation of the Principal Principle and the functional identification of chance would thus be lacking from a 'quantum ersatzist' approach. Secondly, we have much better reasons to believe the Everett interpretation than the proposed actualist interpretations; not least that the latter have serious problems when generalised to the relativistic domain.

successfully analyze modality. However, it seems that this condition cannot be imposed without begging the question of what is and isn't a genuine possibility. Scott Shalkowski has argued that:

> 'if the modal realist's ontology meets these conditions, then a reduction of modality in terms of possible worlds and their constituents is circular.' (Shalkowski 1994)

However, this circularity can be escaped, as Chihara (1998) replies, if the worlds can be shown to satisfy the conditions as a result of some other stipulation, which could potentially be non-modal and inoffensive.

Lewis appears to have foreseen such an objection: his solution is a 'principle of recombination' according to which a mereological sum of parts of different possible worlds is itself a possible world. Thus every object has duplicates in other worlds, with identical intrinsic but different extrinsic properties.. Does this principle escape Shalkowski's objection? It certainly gives us a very large class of worlds, resulting from arbitrary reconfigurations of all the objects in the actual world. However, it isn't clear whether this class is large enough. Lewis raises - inconclusively - the prospect of 'alien' properties and individuals. Such things are not instantiated in our own world, so worlds containing them cannot be generated by recombination of this-worldly entities. This could be avoided if our world was 'maximally rich': if no properties or particulars were alien to it. However Lewis admits that on his account

> 'there is no reason to think we are privileged to inhabit such a world' (Lewis 1986)

Thus, an uncertainty remains as to the size of the class of Lewis' worlds. This uncertainty is exploited by Divers and Melia (2002), who have argued that the prospect of alien individuals is fatal to the analytic ambitions of Lewisian modal realism, since it cannot ensure a complete set of worlds.

An even more serious problem with the principle of recombination is that it appears to itself appeal to modal intuitions. Lewis' justification for proposing the principle is an appeal to the Humean denial of necessary connections between distinct existences, combined with an empiricist assumption that all existences are essentially distinct. However, these premises can be and often are denied. What is expressed is, at base, Lewis' intuition that:

> 'anything can coexist with anything else, at least provided they occupy different spatio-temporal positions.' (Lewis, ibid.)

This intuition is clearly itself a modal one: citing the authority of Hume does not make it any less so. As Chihara objects:

> 'how could anyone know any such thing?…It seems preposterous to suppose that anyone is in a position to know such general facts about other worlds' (Chihara 1998)

Lewis' reason for proposing the principle is, at root, his own modal intuitions, and for a genuine modal realist there is no guarantee that these do not outrun what is genuinely possible: modal reality is conceived of as entirely mind-independent. If there is, anywhere in any of the worlds, a necessary connection, then the principle fails and Lewis' account has included an impossibility as a genuine possibility. He must fall back on a bare assertion that the worlds which result from the application of the principle to all possible things (including those that we are unable to construct as they instantiate alien properties or individuals) meet precisely Shalkowski's criteria for the correct degree of plenitude. While we have no non-modal principle to justify this claim, we do not have a reductive analysis of modality.

A still more general objection to the possibility of a reductive account is due to Blackburn (1993) (he presents it as a version of the Euthyphro dilemma). We ask what it means for a fact A to be necessary: we require an explanation in terms of another fact B. Now, either B claims that something is the case, or that it must be the case: if the latter, then no progress has been made as we have simply explained one necessary truth by another, we have not explained the necessity itself. If the former, it could have been that B is not true: in this case, we have explained the necessary in terms of the contingent, which would seem to show that it was not necessary in the first place. Either the explanandum shares the modal status of the original, or it doesn't: either the explanation is unacceptable, or it goes against our intuitions about modal inferences. Considerations of this sort lead Blackburn to despair of any reductive analysis of modality. However, the argument is inconclusive. It doesn't show that a reductive explanation is actually impossible, only that it would lead to revision of some of our intuitions about the nature of modal inference. Were Lewis' account workable, it would indeed be revisionary of our intuitions: this would, however, surely be just a corollary of the success of the account. In recognition of this, many philosophers remain agnostic, though pessimistic, about the prospects for a reductive account.

The Everett interpretation promises to break this philosophical deadlock: it takes an entirely new approach to the analysis of modality, and seems to offer a solution at least for the case of natural possibility. Can it, however, count as a genuine reduction of the modal to the non-modal? It escapes Forbes' and Putnam's criticism: the nature of possibility is not taken to be explained by of the notion of possible worlds, but by the nature of physical structures described in those terms. The reason Putnam thought it was obvious that 'possible worlds' talk could not be a reduction of modality is that their very name presupposes a modal notion. According to this line of criticism, Lewis' modal realism is, at best, an (analytic) tautology. This cannot count against Everett: branches of the wavefunction are linked with possible worlds via a (synthetic) theoretical identification. This is what makes it possible to provide an argument for the Principal Principle, rather than having to assume it as a primitive principle of rationality, and it gives the interpretation a significant advantage over other naturalistic theories of modality.

I think that for the same reasons it also escapes Shalkowski's objection: what is a genuine possibility is defined by non-modal principles. An Everettian 'principle of plenitude' would state that, for every possibility, there is an Everett branch containing it. Once Everett branches are linked with possible worlds by a theoretical identification, then the principle follows trivially. If we found that something which we had intuitively thought possible did not in fact occur on any Everett branch, then we would be forced to conclude that it had never been a genuine possibility after all. The plausibility of this reply, of course, rests on there being a reasonably good match-up between what would normally be thought of as possible, and what Everettian modal realism counts as possible. Small deviations can be explained away as corrections to our pre-theoretical instincts; a systematic divergence would be more cause for concern, and might threaten our confidence in the original theoretical identification.

But there is in fact good reason to think that Everettian modal realism will match up well with our intuitions about natural possibility in general. What is and is not naturally possible is a question for investigation by natural science; and, assuming a broad physicalistic supervenience thesis, the results of natural science on a macroscopic scale will have to be consistent with the microphysics of the same situation[32]. Therefore, if biology correctly describes a certain set of possible outcomes to a process, and biological processes supervene on physical processes, then each biological outcome must correspond to a branch (or set of branches) of the wavefunction. Everettian plenitude follows from the ontological unity of nature, and the fact that all natural processes we know of are governed at the microscopic scale by quantum mechanics. As Everettian modal realism identifies possibilities on naturalistic grounds, it escapes Shalkowski's charge of circularity, giving us the prospect of genuine epistemic access to modal facts. The Everett interpretation makes substantive claims about modal reality; whatever its other merits as a theory of alethic modality, it is neither circular nor question-begging.

Against Blackburn's dilemma, we can choose the second horn, and accept that the explanation given for the necessity of a statement is of a highly unusual kind. Nobody denies that the Everettian ontology is radical, and its explanation of our experiences unique: however, the same is true of general relativity, and of its consequences for space and time. As an attempt to formalise our pre-theoretic intuitions about possibility, the Everett interpretation fails. However, it has the advantage over those intuitions, in that it appears to be true. And, accepting the interpretation, we can still explain how such intuitions arose: they are convenient approximations to genuine possibility, which happened to have selective advantages in the evolution of our species.

[32] In quantum-mechanical terms, plenitude is grounded by a combination of the sheer complexity of branching events, the incredibly short timescales of decoherence, the non-zero probabilities for very unlikely events and the propensity of macroscopic systems to display chaotically unpredictable behaviour. It is a important element of the Everett interpretation that this combination be enough to support all macroscopic indeterminism.

The kind of reduction that the Everettian theory of modality achieves for our concepts of possibility and necessity is not eliminative. It provides a real physical ontology that can act as a truthmaker for modal language, without claiming to provide a conceptual analysis of that language.. Nor should we remodel our modal language to make reference to decoherence conditions and consistent histories, any more than we should stop making reference to trees, and instead talk only of collections of atoms. Nevertheless, it is good to know what trees are made out of, and the same is true of possible worlds.

c - Natural possibility and logical possibility

As discussed above, perhaps the most significant difference between the Lewisian and Everettian versions of modal realism is that the Lewis worlds are the logically possible worlds, while the Everett worlds are the naturally possible worlds. That is, the types of modal realism differ as to which modality is held to have a concrete realization – logical or natural.

Following Kripke (1972) most philosophers take ‘metaphysical modality’ to be the modality at stake in our discourse about counterfactual possibilities, and to comprise ‘genuine’ possibility and necessity. Although it is not a bare logical truth that water is H_2O – no contradiction can be directly derived from assuming the contrary – we don’t wish to say that there is a possible world in which water is not H_2O. Kripke argued that theoretical identifications of this sort involved *a posteriori* necessity, metaphysical necessity.

Applying Kripkean forms of reasoning to natural phenomena has interesting and unexpected consequences. An argument due to Bird (2001) runs as follows. Imagine that salt doesn’t dissolve in water: for this to be true given the constitution of salt, Coulomb’s law would have to be different. However, were Coulomb’s law different, then salt would not exist at all, as it is held together by the same electromagnetic forces that allow it to dissolve in water; hence, in any world where salt exists it also dissolves in water. Necessarily, then, salt dissolves in water. This statement will have set alarm bells ringing, for something dissolving or not is a *prima facie* contingent matter. What is going on here? The argument exploits a feature of natural laws that Bird (2002) calls the 'down-and-up structure'. Laws of the kind 'salt dissolves in water' supervene on the underlying quantum-mechanical laws which determine chemistry, so any change in the higher-level law requires a modification to the underlying law. Even a very small modification to such a fundamental law would have large repercussions at the higher level, invariably going beyond the required higher-level change. The argument depends on the fact that at least some natural laws display this down-and-up structure; given the complexity of most natural systems, it seems likely that it is a pervasive feature.

Kripkean chonsiderations relating mainly to the individuation of natural properties have prompted Shoemaker (1980), Swoyer (1982) and Bird (forthcoming b), amongst others, to accept a general form of the thesis that the natural laws are necessary, known as *dispositional essentialism*. There is of course no space to defend a metaphysical thesis of this kind here, but accepting it does at least seem to be an open alternative, and to be a natural one for a proponent of Everett. Since dispositional essentialism implies that the laws of nature are metaphysically necessary[33], in combination with the Everett interpretation it allows for the direct identification of the naturally possible worlds – Everett branches – with the metaphysically possible worlds. This identification promises to allow for a naturalistic theory of metaphysical modality; but it conflicts with received opinion in denying the contingency of the laws of nature.

The assumption of contingency is enshrined in both of the prevalent modern views of laws: the neo-Humean account of them as a specially chosen group of true universal generalizations over actual phenomena, and the Armstrong-Dretske-Tooley account of relations between universals. However, both of these traditional accounts face well-known problems. According to the Humean analysis of laws, as true universal generalisations, they seek to describe relations between actual phenomena. However, this notoriously creates a problem of distinguishing between accidental and lawlike generalizations, which undermines the ability of the laws to ground counterfactuals. The universals account doesn't fare much better; a profound mystery surrounds the necessitation relation N(F,G) which connects two universals. The classic critique is by Lewis:

[33] In its 'strong necessitarian' variety; see Bird 2004.

> 'I say that *N* deserves the name of 'necessitation' only if, somehow, it really can enter into the requisite necessary connections. It can't enter into them just by bearing a name, any more than one can have mighty biceps just by being called 'Armstrong'.' (Lewis 1983)

Everettian modal realism can avoid both these problems. It incorporates the essence of Lewis' account, in that laws are universal generalizations which range over all possible worlds and are thus in principle capable of grounding counterfactuals. Furthermore, it incorporates the essence of Armstrong's account, an objective necessitation relation: however, it gives this relation a solid ontological grounding in quantum branch weights, answering Lewis' challenge.

Most objections against the necessitarian position I am defending rather beg the question by presupposing the reliability of the inference from conceivability to possibility: Sidelle (2002) admits as much but cites bare intuition, and traditional acceptance[34], to justify appeals to it. Fine (2002) suggests that conceivability evidence demonstrates that there is 'an intuitive distinction' between natural phenomena whose occurrence is metaphysically or naturally necessary: he cites the charge on an electron as a metaphysical necessity but the conservation of energy as 'at most' a natural necessity. This distinction is not, for me, particularly intuitive, but more significantly it is difficult to see how it can be reliably and sharply drawn. Sharp, though, it must surely be, if it is to do justice to our ascriptions of absolute possibility or impossibility. In standard language ascriptions of absolute possibility or necessity have categorical status: although a fact may have degrees of probability, we do not generally consider some possibilities to be more possible than others. A major advantage for any account of absolute modality, and a prerequisite for any reductive account, would be to have a well-defined boundary between what is and isn't possible, to within linguistic vagueness.

A problem with the route followed by Lewis, of treating broad logical necessity as absolute, is that it is not very well-defined: it is supposed to consist of narrow logical necessity combined with 'semantic

.[34] ''Tis an establish'd maxim in metaphysics, That whatever the mind clearly conceives includes the idea of possible existence, or in other words, that nothing we imagine is absolutely impossible.' (Hume 1739) truths', or a set of definitions of synonymy. How extensive, though, should this set be? For Lewis, it includes the definition that 'bachelor' means 'unmarried man', but not that 'donkey' means '*Equus Asinus*', as he asserts that some worlds contain talking donkeys. Many have been inclined to disagree on this point: there is clearly scope for disagreement about whether the essence of donkeyhood precludes the ability to talk or not. The exact extension of a set of worlds characterised by recombination therefore seems somewhat arbitrary. I would suggest that the only kinds of alethic modality which can escape this arbitrariness are narrow logical modality, as we have formal procedures to evaluate whether a set of statements is consistent, and natural modality, as we have the pronouncements of science and the reference case of nature through which we can evaluate the natural laws. A necessary condition for an absolute alethic modality ought to be that it is well-defined, so the only real contenders seem to be narrow logical necessity – lack of express contradiction – and full-scale natural necessity.

The modal realism implicit in Everett takes the second approach. The universal validity of the quantum state which it postulates grounds a form of natural necessity which is in no way parasitic on logical necessity. This in itself removes much of the motivation for holding logical necessity fundamental. The prevalence of contingentism about laws of nature has historically undermined natural necessity's claim to the role of genuine necessity. If laws of nature are contingent propositions, as is usually supposed, then an account of natural possibility is available in terms of logical possibility: what is naturally possible is just what is narrowly logically possible, given our contingent laws as premises. However, the Everett interpretation provides us with an equally simple, and in many ways more satisfactory, alternative account of natural possibility, which meshes neatly with dispositional essentialism.

d – Applications to metaphysics

True statements, including modal ones, are in general on the Everettian approach grounded in facts about structures within the quantum state. Alethic modal statements can be analyzed as expressing facts about a particular kind of structure, worlds. These worlds, as in modal realism, are to be thought of as possible histories, but they are now given a physical grounding by the branching wavefunction. The analysis of ascriptions of possibility and necessity follows directly, in line with modal realism. Something is genuinely alethically impossible *iff* it occurs in no Everett branches, genuinely alethically possible *iff* it occurs in some Everett branches, and genuinely alethically necessary *iff* it occurs in all Everett branches. Thus, it is impossible for there to be a married bachelor, as there are no objects in the entire range of Everett worlds that we would want to call by that name. It is possible for there to exist a 10-tonne sphere of gold, because plausibly in some Everett worlds the Earth's population assemble one as an offering to a deity. It is necessary that energy be conserved, as all Everett worlds evolve by macroscopic dynamical laws that conserve energy.

Modal statements about the future are dealt with very simply. Our actual world consists of the history up to the current time, and is open-ended: our future is not yet determined. On the other hand, the possible range of futures compatible with the world up to the current moment is determined: and to say that something might happen in the future is to say that it happens somewhere within the branching structure that starts from the current time. Modal statements about the past are dealt with in a similar way. To say that a certain tree could have been cut down as a sapling, we trace our history back through the branching structure to the time it was planted, and evaluate the possible futures available to it at the time. In some of those futures, it does get cut down, so in the future that is actual - our world - it is true that it might have been cut down.

This ontology can clearly support an analysis of counterfactual statements, since it has an ontology of counter-actual possible histories.. The obvious route to take is to ground our evaluation of counterfactuals in the set of Everett worlds which we would think of as relevant genuine possibilities. In evaluating the truth of a counterfactual we effectively 'trace back' through history to a time at which the occurrence or not of an antecedent event was still undetermined, and then evaluate the range of futures branching from that point, to see whether the antecedent and consequent are suitably well-correlated within them[35]. I think this scheme captures our intuitive methodology for dealing with counterfactuals. Consider

[35] As a result of the use of dynamical decoherence to solve the 'preferred basis problem', there is no exact way to count the number of worlds in which the consequent does or does not hold: see Saunders 2005 and Wallace 2005a. Rather, we will need evaluate the consequent according to the quantum weights, or relative

'if the president had pressed the button, the world would have been destroyed'[36]. In evaluating this judgment, we think back to the moment before the president made his final decision not to press the button, and consider[37] the range of possible futures resulting from that different decision. The correctness of the counterfactual will be grounded by the general properties of that range of futures; our knowledge of military procedure, basic engineering, chemistry and physics assures us that in the vast majority of these, the destruction of the world does indeed result. Extra evidence, such as the discovery that there is a crippling malfunction in the missile-launching system, would serve to restrict the range of relevant futures under consideration, and might alter our evaluation of the counterfactual.

An Everettian theory of modality also provides a naturalistic account of the counterpart relation: an object is a counterpart of another iff they share a common branching origin, and are connected to it through important persistence criteria such as spatio-temporal continuity and functional roles. This approach to individuation relies on a particular choice of basis - that is, a set of 'natural' physical quantities - which is picked out by decoherence. In particular, it assumes that decoherence will lead to effective localization of macroscopic objects. As such, it is only generally applicable to the individuation of 'medium-sized dry goods' - other criteria will be important to individuate other kinds of entity. For example, Parfit (1984) makes an excellent case that 'what matters' in the case of personal identity is psychological continuity. In general, though, such other sets of individuation criteria will reflect the purpose we design them to fulfil: they will not 'carve nature at its joints', but instead carve it according to a functional scheme. Decoherence, though, provides us with a set of natural physical properties which define, if anything does, the 'facts' of persistence and identity.

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probabilities, of the range of results. An anonymous referee, and some audiences, have questioned whether this represents a problem for an Everettian modal realism: it contrasts sharply with Lewis' model-theoretic conception of worlds, where the number of worlds is always a well-defined quantity. I believe that there is no fundamental problem here, since we have no pre-theoretical reason to think that the 'number of possible worlds' must be well-defined. In fact, there is some reason to think that this quantity is an artefact of Lewis' set-theoretic model: if it is possible for a given physical quantity to vary continuously, then it seems as natural to think of a continuum of possible worlds containing all values as of a discrete set of worlds containing each value. In the end, this simply represents another way in which the Everett interpretation diverges from Lewisian modal realism.

[36] This example is due to Fine 1975

[37] The consideration of the range of futures usually happens imaginatively, but may equally well occur by scientific modelling as in long-range weather forecasting.

An obvious consequence of taking natural possibility as fundamental is that hypothetical scenarios that are incompatible with physical laws cannot be counted as genuine possibilities. On the whole, this is no great objection to treating Everett as a theory of modality. Is, say, reliable faster-than-light information transfer *genuinely* possible? Lewis, Armstrong, and the like say yes; Shoemaker (1998), Bird (2004), and the Everettian account I am defending say no. However, it is unclear what could count as an argument for either side: it seems our intuitions on this subject are somewhat indeterminate. In such a situation, spoils to the victor: whichever modal metaphysic we choose to adopt carries with it a certain answer to this question.

One class of this kind of non-naturalistic hypothetical is worthy of particular attention: so-called counterlegal statements, such as ‘if gravity were an inverse-cube law, then the large-scale structure of the universe would be different’ or ‘if the charge on the electron were slightly larger, then atoms would be unstable’. These appear to make sense and to have definitely-evaluable truth-values, so they present a *prima facie* challenge to the analysis of counterfactuals outlined above. There are two obvious responses to this objection from the Everettian perspective: either we take the line that these counterfactuals, although sometimes useful, are strictly false, or we re-interpret them so they do not conflict with the universal validity of quantum mechanics. My preference is for this latter option. A supposed counterlegal statement is intelligible as a claim about theoretical models. On this meta-linguistic view, a scientist asserting a counterlegal is stating a truth about the physical theories in question, rather than about describing genuinely possible scenarios. This harmonizes with the actual epistemology of counterlegals: they are not tested for truth against some ‘naturally impossible possible world’, or by conceivability, but are invariably evaluated by considering how the predictions of the theory respond to a certain alteration within it. It makes much more sense to consider counterlegals as statements about physical theories than as about impossible worlds.

3 - Conclusion

Lewis presents his arguments for modal realism, taking broad logical modality as absolute, as a philosophical ‘inference to the best explanation’. This is a controversial methodology, and has not proven entirely successful: while his systematic metaphysics is respected (for the most part) as being consistent and comprehensive, most philosophers have been very reluctant to actually accept it. We just don’t trust philosophers to discover facts about the fundamental constitution of reality. Once we accept the necessity of laws of nature, a more naturalistic approach to modal ontology presents itself: we can take literally whichever respectable physical theories seem most believable and adapt our metaphysics and semantics to fit them. Rather than trying to identify the truth-conditions for modal statements *a priori*, we can examine what our physical theories make of the concepts of possibility and necessity, and in what they actually ground the modal status of events. The fundamental metaphysical necessary connections can then just be taken to be those that are described by our best scientific account of reality.

Here the Everett interpretation comes into play, providing just such an account. It does crucial work over and above a necessitarian form of modal realism: it provides a physical truthmaker for the otherwise extravagant metaphysical claims made by such an approach. Furthermore, as the interpretation derives from natural science, it has an epistemic authority that purely metaphysical theories of modality inevitably lack. Skyrms (1976) considers this a killer objection to Lewis’ modal realism: he argues simply but convincingly that Lewis gives ‘the wrong kind of argument to support realist conclusions’. The Everett interpretation, reinforced by the Deutsch-Wallace proof of the Born Rule and the consequent SU derivation of the Principal Principle, supports a naturalistic argument for realism about possibilia; this is surely the right kind, if any is.

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