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Fundamentality and Levels in Everettian Quantum Mechanics

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Abstract: Distinctions in fundamentality between different levels of description are central to the viability of contemporary decoherence-based Everettian quantum mechanics (EQM). This approach to quantum theory characteristically combines a determinate fundamental reality (one universal wavefunction) with an indeterminate emergent reality (multiple decoherent worlds). In this chapter I explore how the Everettian appeal to fundamentality and emergence can be understood within existing metaphysical frameworks, identify grounding and concept fundamentality as promising theoretical tools, and use them to characterize a system of explanatory levels (with associated laws of nature) for EQM. This Everettian level structure encompasses and extends the 'classical' levels structure. The 'classical' levels of physics, chemistry, biology, etc. are recovered, but they are emergent in character and potentially variable across Everett worlds. EQM invokes an additional fundamental level, not present in the classical levels picture, and a novel potential role for self-location in interlevel metaphysics. When given a modal realist interpretation, EQM also makes trouble for supervenience-based approaches to levels.

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1. Introduction

Quantum physics is dramatically different from classical physics, but it is an open question exactly how deep the differences run. Some approaches to quantum theory – such as Bohmian mechanics allied with a 'nomic' reading of the wavefunction (Miller 2014, Callender 2014, Esfeld 2014, Bhogal and Perry 2017) – retain a picture of fundamental reality which closely resembles a classical fundamental picture of particles or fields. The distinctive novelty of quantum theory is then located in how the fundamental stuff behaves, rather than in what there fundamentally is or in how the fundamental stuff grounds everything else. By contrast, Everettian quantum mechanics (EQM) revises both our view of fundamental reality and our view of how fundamental reality grounds the non-fundamental.

This chapter explores the distinctive role which the notion of fundamentality plays in EQM of the contemporary 'decoherence-based' variety, in which quantum theory is understood along scientific realist lines without any collapse of the wavefunction. Everettians including Saunders and Wallace have exploited techniques from decoherence theory (see Crull 2022) to argue that a space of approximately classical histories can be identified within a suitable, unitarily evolving, universal quantum state. As originally emphasized by Simon Saunders (1993, 1995, 1998), and subsequently by David Wallace (Wallace 2003, 2010), the emergence of the multiverse of Everett worlds from the universal quantum state has an imprecise and for-all-practical-purposes character. This feature even makes it into the title of Wallace's authoritative work on the Everett interpretation, *The Emergent Multiverse* (Wallace 2012); it is the source of some of the most philosophically interesting features of EQM.

Everettians give a highly unfamiliar picture of fundamental reality. It evolves deterministically and encompasses all of the different quantum possibilities rather than corresponding only to one quantum possibility among many. From this alien starting point, Everettians then reconceptualize ordinary scientific reasoning as correctly capturing truths about a non-fundamental subject-matter: the contents of our own Everett world. A distinction with respect to fundamentality between the fundamental quantum state and the emergent multiverse thus plays a central enabling role in the theory: it provides a principled basis for Everettians to use decoherence theory in modelling quantum measurement, it defuses demands for precise individuation criteria for worlds, and it aligns the high-level ontology of Everett worlds with higher-level ontology in science much more generally. If Everett worlds do not need to be seen as fundamental structure within the theory, and can instead be posited as higher-level explanatory structure, then adopting the many-worlds language and concepts for quantum theory is recast as a relatively conservative interpretive move rather than as a decidedly non-conservative revision of the fundamental physics. Saunders calls this point Wallace's 'killer observation' (Saunders 2010a). In my own recent work on the metaphysics of EQM (A. Wilson 2020a) I have likewise relied on the emergent nature of the Everett multiverse when developing accounts of modality, probability, causation, moral value, and related notions in the Everettian setting.

There is clear need for a serviceable notion of fundamentality if we are to make sense of the decoherence-only Everettian picture. Which accounts of fundamentality can measure up? I will suggest in section 2 that Everettians would do well to co-opt some existing account of fundamentality which is both flexible enough to accommodate their novel relative fundamentality claims while still capturing more familiar relative fundamentality relationships in established higher-level sciences. I commend to them the options of *grounding* and *concept fundamentality* in particular.

What consequences does EQM have for the metaphysics of levels? I will describe in section 3 how straightforward implementations of an Everettian system of levels extend orthodox views of levels in a way which is analogous to *conservative extension* of theories in logic and mathematics. A traditional ordering of scientific levels is then recovered, but as an emergent substructure of the overall levels structure rather than as fundamental – and moreover, as an emergent structure which emerges in a dynamical way and may be different across different regions of the multiverse.

What consequences does EQM have for the metaphysics of laws? I will suggest in section 4 that the system of Everettian levels here outlined is naturally paired with a multi-level law structure, such that the concept of law has a unified character (that of *modally strong generalization*) which plays out in different ways at different levels of the Everettian hierarchy. Even though laws of Everett worlds are all non-fundamental strictly speaking, we can still make sense of gradations of fundamentality amongst the laws of these worlds.

Finally, in section 5, I will argue that Everett-specific considerations tell against using the familiar notion of *supervenience* to capture a levels structure. The more flexible notions of grounding and of concept fundamentality are better suited to model a scenario where physical contingency itself is emergent. The arguments of section 5 draw on controversial premises about the interpretation of modality and probability in EQM, which I defend at some length in a recent book (A. Wilson 2020a). The arguments of section 2-4, however, rely only on assumptions which are common to most contemporary Everettians.

2. Frameworks for fundamentality in Everettian quantum theory

Why is an account of fundamentality in EQM needed? Wallace has after all provided an account of the emergent multiverse in terms of Dennett's notion of *real patterns* (Wallace 2003, 2010; Dennett 1991). From most metaphysicians' point of view, real patterns are intriguing but underdeveloped; more importantly, in their application to EQM they are embedded within the distinctive metaphysical view of science called *ontic structural realism* (OSR) which Wallace favours; see also Ladyman and Ross (2007). Wallace's specific application of OSR to the Everettian setting is directed at the ontology of decoherent worlds. The idea, roughly, is that Everett worlds are dynamically robust patterns in the fundamental quantum state.

It is not my intention here either to undermine OSR or to defend it; for a recent critical discussion, see Sider (2020). Instead, in this section I will offer schematic accounts of the emergent multiverse which do not presuppose OSR and which are congenial to a wider range of metaphysical views of science – including orthodox scientific realism, as well as more radically eliminative views of science. I hope that everything I say in what follows will be compatible with OSR, but one of the secondary messages of the chapter is that the full package of OSR is not compulsory for Everettians. So: how might we regiment the ontology of decoherence-based Everettian QM using the tools of contemporary metaphysics?

Supervenience is a natural place to start; it is familiar to philosophers from 40 years of disputes over the definition of physicalism in the philosophy of mind. Supervenience is modal correlation: the A-facts supervene on the B-facts iff there can be no difference in the A-facts without some difference in the B-facts. While this relationship can hold symmetrically, we can easily define a one-way notion: A *one-way supervenes* on B iff A supervenes on B and B does not supervene on A. One-way supervenience of all facts on the fundamental physical facts is close to a universal assumption within philosophy of physics, and it is typically presupposed in all discussions of Everettian QM (with the exceptions of outliers such as Albert and Loewer 1988). Supervenience can also provide a simple but effective system of levels characterized in modal terms: levels can be modelled as a partial order generated by the relation of one-way supervenience between subject-matters, with the microphysical level at the base of the supervenience ordering. A contemporary version of this approach is offered by List (2019).

Minimalist accounts of intertheoretic relations have often tried to do with nothing but a supervenience ordering; this was Lewis' considered approach, for example (Lewis 1994). But philosophical times change, and increasing dissatisfaction with supervenience as a level-connection relation has come to focus on its perceived explanatory limitations. The story is told (from a dissenting point of view) by Kovacs (2019); but a consensus in many areas of metaphysics has emerged that a notion distinct from supervenience is needed to account for the explanatory role of intertheoretic relations. The holding of that distinct relation would then explain one-way supervenience, but not vice versa. This explanatory objection to supervenience applies equally to its use in characterizing the emergence of the emergent Everettian multiverse, and I think it gives good reason to look beyond supervenience when explicating the Everettian worldview. However, there is an additional reason for Everettians in particular to avoid appeal to supervenience in the present context. Doing so would rule out one of the main prospective philosophical applications of EQM – to the metaphysics of modality - and complicate the project of making sense of objective probability in EQM. This additional reason is the focus of section 5.

In the remainder of this section I will show how the distinctively Everettian combination of a fundamental universal quantum state with an emergent multiverse of non-fundamental Everett worlds can be captured within two specific metaphysical frameworks for fundamentality: metaphysical grounding and concept fundamentality. Both these frameworks have the advantage that they do not presuppose any particular ontological or metaphysical account of the nature of physical reality; they can be applied to the physical facts regardless of what we may discover or hypothesize about their underlying nature.

The theory of metaphysical grounding (henceforth, just 'grounding') has proven a popular theoretical tool in recent metaphysics. Much of its appeal stems from its relative theoretical neutrality, which permits comparisons to be made different metaphysical approaches[1]; key discussions of the notion are Fine (2012), Rosen (2010), Schaffer (2009), Bennett (2017). Grounding permits a logically transparent account of interlevel relations which generalizes to any kind of subject-matter: facts at one level can ground facts at another, whatever peculiar kinds of properties or logical structures those facts might involve. This feature will be exploited in section 3 to relate the very metaphysically heterogenous kinds of levels which are combined into the decoherence-based EQM picture. Grounding is also assigned a constitutive link to explanation. In some approaches to grounding (e.g. Fine 2012), this link to explanation is assumed as basic, but in others (e.g. Dasgupta 2015, Schaffer 2017, A. Wilson 2018, 2020b) the explanatory element is linked to the presence of *mediating principles* which systematize the pattern of grounding relationships.

[1] There are limits to this theoretical neutrality; see A. Wilson (2019) for discussion.

The notion of grounding has been applied to physics in a number of recent works (e.g. Schaffer & Ismael 2020, Hicks MS). Without attempting a survey of these applications, what they typically have in common is the attempt to map a relationship in physics where there is an important asymmetry overlaid on certain background symmetric features. For example, in the context of Noether's theorem (Hicks' example), the existence of a suitable symmetry principle and the existence of a corresponding conservation law are interderivable in the presence of certain assumptions about the form of our dynamical theory. Despite this interderivability, consensus holds that symmetries are explanatorily prior to conservation laws. That judgment of explanatory priority can be captured by the idea that symmetries ground conservation principles in theories of the kind to which Noether's theorem applies.

For the applications to physics, the standard logical properties of ground – irreflexivity, transitivity, and anti-symmetry – are typically held fixed, although it has been suggested that anti-symmetry might be weakened to help model quantum entanglement (Calosi and Morganti forthcoming make a related move, though in the context of essential dependence rather than of grounding). We will not need to tweak any of the standard logical properties of ground for the Everettian application, although in section 3.2 I will argue that Everettians would do well to adopt a slightly non-standard approach to the distinction between partial and full grounds.

Grounding is not the only interlevel game in town. Another prominent approach to the fundamental in recent metaphysics is Ted Sider's generalization of Lewisian naturalness (Lewis 1983), into a more flexible notion of concept fundamentality (Sider 2011, 2020). Like grounding, concept fundamentality is a framework which is well suited to EQM. Not only properties and relations can correspond to fundamental concepts, but items of all grammatical categories. So we have the prospect that Ψ itself, the fundamental quantum state, is a perfectly fundamental concept. The Siderian notion of concept fundamentality is detached from any link to free recombination: there is no automatic presumption that if some particular items of vocabulary correctly capture some aspect of the structure of the world then all possible sentences which can be grammatically formed out of those items of vocabulary correspond to possible ways for the world to be. This keeps the door open to a characterization of the fundamental quantum state of the world in terms of fundamental concepts, and an account of the higher-level structure of Everett worlds and laws thereof in terms of a Sider-style *metaphysical semantics* (Sider 2011) specified in terms of the fundamental. A metaphysical semantics is, at a first pass, a specification of what it is for some facts to hold in terms of some other facts which are regarded as conceptually more fundamental.

The key difference between grounding theory and concept fundamentality, explored in Sider 2011, is that concept fundamentality and the associated notion of metaphysical semantics are naturally read as metaphysically deflationary with respect to the higher level facts: all that the higher-level facts amount to is a certain configuration (encoded by the metaphysical semantics) of the fundamental level. The concept-fundamentality picture can therefore be seen as a generalization of the often-caricatured nihilist metaphysician's view of the world as 'simples arranged tablewise' – now we have 'fundamentalia configured derivative-wise', where there is no restriction on the fundamentalia to be simples and no restriction on the configuration to be a spatiotemporal one, and where 'derivative-wise' is in principle specifiable using fundamental concepts. Grounding, on the other hand, is naturally interpreted as metaphysically inflationary: when something is grounded in the fundamental, it is not merely a redescription of the fundamental in non-fundamental terms but is something real in its own right, at least partly distinct from its grounds. This conception of ground is clearly articulated by Schaffer (2009). It ties ground closely to the notion of ontological levels; to the extent that the pattern of grounding relations forms a stratified structure, grounding brings with it ontological levels.

While the contrast I have just drawn between grounding and concept-fundamentality could of course be contested, it will serve for the purposes of this paper to illustrate the consequences of applying different conceptions of interlevel relations – as merely representational, or as metaphysically substantial – to the context of Everettian levels.

In this section I have suggested that both grounding and Siderian concept fundamentality are promising potential candidates for illuminating the levels structure of an Everettian worldview. In the next section, I explore their application to the Everettian scenario, and three distinct types of interlevel relationship which decoherence-based EQM encompasses.

3. Explanatory levels in Everettian quantum theory

3.1 The fundamental level and the multiverse level

The fundamental quantum state is a strange beast. There are two main ontological accounts offered by Everettians of this state: wavefunction realism and spacetime state realism. Fundamental reality according to wavefunction-realist EQM resides in configuration space rather than in three-dimensional space (Albert 1996; Albert and Ney 2013; Ney 2021). Spacetime state realism is unique to the Everettian scenario, and it involves positing an extraordinary amount of structure to a given spacetime region (Wallace and Timpson 2010).[2] In this chapter I will try to stay neutral on the ontology of the quantum state, and instead focus on some facts about it which are relatively uncontroversial among Everettians. It evolves deterministically according to the unitary/linear Schrödinger equation. It exhausts fundamental physical reality. And it gives rise to an emergent multiverse.

The metaphysics of the emergent multiverse is also a disputed matter which I will finesse so far as possible. Wallace's real pattern criterion has a strongly pragmatist streak: all that it takes for something to be real is that it be useful for someone to track it for some theoretical purpose or other. Wilson and Saunders have taken this pragmatist line of thought one step further, arguing that the best pattern to extract from the fundamental state is a pattern of diverging, or parallel, worlds – rather than the splitting worlds often envisaged by Everettians. Any pattern-based strategy of this kind is of course fraught with controversy: see Kent 2010, Maudlin 2010, and Hawthorne 2010 for a variety of critiques of the Everettian appeal to ontic structural realism. I will set all of these critiques aside here: if no account of high-level ontology as patterns in the low-level ontology can be sustained, then the version of decoherence-based Everett which this chapter considers is a non-starter.

If an Everettian approach to the ontology of decoherent worlds succeeds at least in broad outline, we are still left with a number of puzzles. The decoherence basis in which we obtain histories strongly peaked around approximately classical evolutions of macroscopic observables is itself only approximately defined. This immediately gives rise to a corresponding indeterminacy in the space of Everett worlds – both with respect to what each individual world is like, but also (at least if the state space of the cosmos is finite) with respect to how many of them there are. In A. Wilson (2020a) I call the former *indeterminacy of world nature* and the latter *indeterminacy of world number*. These indeterminacies are closely (and inversely) linked, since the more worlds there are the more determinate each individual world becomes, up to the (vaguely defined) point at which the worlds become so determinate that decoherence conditions cease to be satisfied and the worlds are no longer dynamically decoupled from each other. Quantum indeterminacy is a huge and difficult topic; for some recent discussions, see J. Wilson (2013), Wolff (2015), Calosi & Wilson (forthcoming).

[2] I have not seen any detailed discussion of the application of spacetime state realism to quantum gravity scenarios which lack fundamental spacetime. The simplest extension of the view would be to transfer what spacetime state realism says about spacetime over mutatis mutandis to whichever fundamental space hosts the fields posited by one's preferred theory of quantum gravity.

The presence of these unfamiliar forms of imprecision in the space of emergent quasi-classical worlds strongly suggests we are not dealing with a standard case of interlevel relations. This suggestion is substantiated by closer consideration of the metaphysical relationship which Everettians identify between the fundamental ontology and the individual worlds of an Everettian multiverse. Everett worlds are not parts of the fundamental object, the quantum state – rather, Everett worlds are parts of the multiverse, a complex derivative object identified as a distinctive kind of pattern in the fundamental object. The individual Everett worlds are indeterminate in nature, and their mereological fusion is likewise indeterminate, while the underlying fundamental quantum state remains determinate.

The Everettian picture of levels, then, incorporates a distinctive holism: the fundamental state is a single object, and multiplicity of Everett worlds is only found at the derivative level. The relationship here is not one of part/whole; there are no interesting mereological relations between fundamental elements as parts and Everett worlds as wholes, or vice versa.[3] Wallace instead says that the Everett worlds are 'instantiated by' the fundamental state. This observation rules out the application of some influential accounts of interlevel relationships which rely on mereological relations, such as that of Oppenheim and Putnam (1958). However, the flexibility of the two approaches which we have adopted for this chapter allows them to be applied immediately to the emergence of the emergent multiverse. Grounding applies straightforwardly: we obtain a real, grounded, imprecise multiverse. Metaphysical semantics also applies straightforwardly: we have a emergent multiverse language with an imprecise semantics in terms of the precise fundamental language.

3.2 The multiverse level and the Everett world level

The move from the multiverse level to the Everett world level is a quite different kind of shift from the move from the fundamental level to the multiverse level just discussed. There is no new vagueness introduced at the level of an individual Everett world, over and above the vagueness in world number and world nature already present at the multiverse level. What is introduced instead is the world-centric perspective: a given system being centred in one specific Everett world, and having a corresponding special relationship with other events centred in same world. The distinctive explanatory power of the world-centric perspective

[3] The parthood claim might be vindicated by loosening usual assumptions about mereology and its relation to space and time in the manner of Le Bihan (2018); Saunders (2010b) provides axioms for a mereology of state vectors which makes Everett worlds part of the universal quantum state.

derives from the dynamic decoupling of the worlds, such that they obey approximately classical equations of motion: systems located in one of the worlds have their causal interactions effectively limited to other systems located in the very same world.

It might seem peculiar (even misguided) to label the shift from the multiverse perspective to the Everett world perspective a shift in level. After all, we don't label the shift from considering the whole of my lawn to considering a quarter of the lawn a change in levels – and aren't individual Everett worlds just parts of the Everett multiverse in the same way that a quarter of my lawn is part of the lawn? But the analogy breaks down immediately: the shift from the multiverse perspective to the individual Everett world perspective is more like the relation between the lawn and my own location on the lawn. Facts about which world is ours are not to be found in the fundamental physics of EQM, or in a third-person-perspective description of the whole emergent multiverse. Rather, adopting the Everett world perspective requires adopting a perspective on the multiverse, a perspective from inside one individual world and one which is had in common with all one's worldmates.

What outcome of quantum processes you and I observe is a matter of which Everett world we are both in. The self-locating element of a fact about an outcome of a quantum process, in the Everettian picture, is not something which is in any way determined by the non-self-locating facts about the multiverse. Knowing all there is to know about the multiverse cannot tell us where we are in it, any more than a paper map (no matter how detailed) will tell me where in my environment I am currently located without further supplementation with, e.g., perceptual information. The case is familiar from what philosophers of language call 'essential indexicals' – expressions like 'here' and 'now' which cannot be replaced with the specific places or times they refer to without distortion of meaning. Just as I can know that someone is spilling sugar but not know that this person is myself (this example is from Perry 1979), subsequent to a Stern-Gerlach measurement I can know that there is an x-spin-up world and a x-spin-down world but not know which of these two worlds I am in. These self-locating contents are no mere curiosity: for many Everettians they provide the subject-matter for objective probabilities in EQM (Saunders and Wallace 2008; Saunders 2010b; Wallace 2012; A. Wilson 2013, 2020a, Sebens and Carroll 2018).

There is little by way of consensus in the broader metaphysics of perspectives about how to think about essentially self-locating facts, especially where these facts play important explanatory roles as they do in EQM. Some of the options on the table for understanding them include deflationary approaches, where perspectives are conceived as wholly representational; perspectives are just a mode of presentation of a non-perspectival reality. The options also include more inflationary approaches, including the prospect of perspectival facts (Giere 2006) or an irreducible fragmentation to reality (Fine 2005; Lipman 2015). But it's clear that Everettians need to give some sort of positive account of the nature of perspectives, given the unique explanatory role that perspectives on the multiverse play in their overall worldview – the role of accounting for our observations of specific outcomes of quantum processes.

Grounding can handle the relation between the multiverse and Everett world levels in a distinctive way, if we acknowledge the possibility of partial grounds which cannot be completed into any set of full grounds. The perspectival fact about the outcome of a quantum process is partially grounded in the multiverse, of course – the multiverse determines what the possible outcomes of that process are. But the perspectival fact also includes a self-locating element which is not grounded in the multiverse, and is incomplete without it; so the perspectival fact can be modelled as partially grounded (in the multiverse) without being wholly grounded in it. Which world is ours is, in grounding terms, a brute fact. See Leuenberger (2020) for more on partial grounds without any full ground, and Bader (2021) for the connection to bruteness (though neither envisage the Everettian application I am suggesting).

Concept fundamentality, and the associated metaphysical semantics, can also be brought to bear to account for the in-world perspective – and in a perhaps less unfamiliar way. What concept-fundamentalists should say, is that some of our concepts – not the wholly fundamental ones, but still relatively fundamental ones, through which we view all of the contingent goings-on that are the regular subject-matter of the sciences – are essentially self-locating/indexical in character. This approach is metaphysically more lightweight than the appeal to grounding, it is recognisably a descendant of Lewis' treatment of the semantics of centred content (Lewis 1979), and it still allows for a distinctive explanatory force to the Everett-world level facts, given that the concepts they involve are at least relatively concept-fundamental. Accordingly I think this approach is likely to appeal to many Everettians.

Some may wish, though, to avoid giving indexicality any role at all in the higher-level facts. It remains an option for Everettians to avoid bringing indexicality either into the grounding network or into fundamental concepts, and instead to make do with a purely representational account of indexicality. This would be to do without a distinct Everett world level altogether, locating special science levels as above the multiverse level without intermediaries, and would thereby avoid some of the more interesting features of the full levels hierarchy I have been describing. I leave it up to the reader to decide whether that would be a good thing.

3.3 The Everett world level and the special-science levels

The classical model of a multi-levelled science consists of a bottom level of fundamental physics, with additional levels corresponding (at least broadly, or perhaps in the ideal limit) to key explanatory disciplines like chemistry, biology, and psychology. I will assume three features will be had by any adequate account of these levels. First, the ordering of levels is partial rather than total: levels related 'horizontally' such as economics and geology need not stand in any direct dependence relation. Second, the dependence between levels is asymmetric at least for the most part: the higher level depends on the lower level in an 'upwards' fashion.[4] Third, dependence between levels is synchronic rather than diachronic. This latter feature is usually taken to rule out a causal understanding of interlevel relations, but it still leaves open a variety of possible views of the interlevel dependence relation: reduction (whether by definitional extension, model construction, or some other method), grounding, elimination of the higher level, identification of the higher-level as the lower level, composition, essential dependence – and various others.

How does the novel Everettian level structure relate to the familiar 'classical' level structure, of the special sciences overlaid on top of physics? It does so by approximating this structure within a limited domain, and extending it beyond that domain. The classical level structure is wholly embedded within the Everettian level picture, as an emergent substructure. The full hierarchy of Everettian levels, including the new fundamental level of the non-contingent quantum state, is therefore something like a *semi-conservative extension* of the structures of laws envisaged by previous theories of levels. The special science level and Everett world level, taken together, approximate previously envisaged systems of levels; but they should be understood by Everettians as a self-contained and largely autonomous subsystem within a deeper levels hierarchy.

The Everettian reconceptualization of classical levels as the higher levels within an enlarged level structure leaves most of their core features intact. That is only to be expected: a theory at the intersection of physics and metaphysics should not have substantive implications for chemistry, for biology, or for the relation between them.[5] The upshot is that, as with classical levels, we can use either grounding or concept fundamentality to model the

[4] Some acknowledge some higher to lower level 'downwards' dependence against a background of mostly upwards dependence: Gillett (2016) offers one such view.

[5] Why disciplines have this autonomy is an interesting question, raised by Fodor (1997) and discussed by Loewer (2009) and Strevens (2012). What matters for present purposes is that they have it.

Everettian's emergent quasi-classical levels. When grounding is applied to the Everettian context, there need be no in-principle distinction between how the Everettian multiverse depends on the fundamental level and how different scientific levels depend on one another within the emergent Everett worlds. The differences between these types of dependence will boil down to the character of the mediating principles linking the levels in each case. Likewise, there is no difficulty in principle in specifying a metaphysical semantics for (say) facts about the frequency of a sound in terms of the underlying facts about the underlying oscillations of the air molecules.

There is a very extensive discussion to be had about what non-fundamental laws there are and about how quantum mechanics underwrites and enables their operation. However, we will be able to mostly bypass that debate here, since the focus of this chapter is on Everettian quantum theory specifically, and there are few reasons to think that higher-level lawhood will play out differently depending on the interpretation of quantum mechanics that is chosen.[6]

The Everettian implementation of classical levels does, though, place some constraints on which interlevel relations can be involved to link levels. In particular, the global chance measure incorporated into Everettian quantum theory is distinctively antagonistic to the type of strong emergence in which the nomic behaviour of complex systems fails to supervene on the nomic behaviour of simpler subsystems. Probabilities for events at the micro-level – and, via physicalist supervenience, for all events – are fixed by the global chance measure. This apparently leaves no room for emergent laws at higher levels to have any further effect on those probabilities.[7]

Not all the features of the classical level structure are retained in the emergent levels of Everettian QM: in particular, there is likely to be physical contingency in the levels structure, with very different higher-level phenomena playing out in Everett worlds in different regions of the multiverse. This hypothesis is supported by the apparent extreme sensitivity of physical phenomena in our current cosmological epoch to the exact value of certain 'fine-tuned' cosmological parameters. If – as seems quite plausible – even one of these parameters takes its value as the result of a quantum-mechanical process, then there will be Everett worlds in

[6] One possible exception is the arrow of time, for which Albert (2000) floats a candidate explanation relying on distinctive features of the GRW theory; however, that explanation would render the arrow of time after all a fundamental phenomenon rather than a high-level phenomenon, so it need not detain us here.

[7] See Meacham (2014) for arguments of this general form.

which the parameter took on a different value, and in those Everett worlds there will be very different physical processes ordered into different sorts of levels structures. A potential candidate mechanism is a compactification process that generates a string landscape cosmology; see Susskind (2005).

The Everettian scenario of physically contingent levels contrasts with the classical picture, where levels structures are typically regarded as physically – perhaps even metaphysically – non-contingent. That is, typically any worlds with the same fundamental physical laws as ours (perhaps even any worlds with the same natural kinds as ours) are expected to also have the same levels structure. The emergent levels of Everettian QM confound this expectation.

Putting the pieces of this section together, we obtain the resulting structure of levels:

Special-science levels
The 'classical' levels of physics, chemistry, biology, etc. – emergent in character and potentially variable across Everett worlds.

↑

Everett world level
Akin to the 'fundamental physical level' of classical level pictures – although emergent in character.

↑

Multiverse level
No analogue in classical level pictures.

↑

Fundamental level
No analogue in classical level pictures.

4. Levels of laws in Everettian quantum theory

To fix the details of an Everettian multiverse, what is needed is a suitable initial quantum state evolving according to the unitary evolution described by the Schrödinger equation. The unitary evolution, and perhaps the initial quantum state too, are obvious candidates for being truly fundamental laws of physics in an Everettian scenario. In A. Wilson (2020a) I speculated that as cosmology progresses the initial quantum state of physical reality will turn out to be a precisely defined pure quantum state, most likely with a high or maximal level of symmetry; this assumption is in line with the expectations of Wallace (2012, forthcoming).

It is important for Everettians to mark the difference between the fundamental quantum state and the emergent multiverse. It is correspondingly important to mark the difference between *laws of the fundamental quantum reality* and *laws of individual Everett worlds*. The former are novel in character, without direct analogue amongst laws of classical physics. The latter resemble closely what have traditionally been regarded as fundamental physical laws: constraint laws, force laws, conservation laws, and the like. When contrasted with classical physics, the fundamental laws in a decoherence-based Everettian picture supplement the laws which we had previously regarded as physically fundamental rather than replacing those laws directly.

In A. Wilson (2020a), I offer a unified account of the fundamental and non-fundamental laws at work in the Everettian picture, making use of the notion of *modally strong generalization*: roughly, a generalization which is non-accidentally true. Laws of individual Everett worlds are true generalizations which hold across instances not only in the actual Everett world but also in other Everett worlds. (Fundamental laws are degenerately modally strong, since there is only one fundamental quantum state.) Each individual Everett world, on this account, comes equipped with a set of laws of its own, including both fundamental and non-fundamental laws.

Lawsets of individual Everett worlds are in some respects similar to the total lawsets envisaged in one-world interpretations of quantum and classical physics: they assign probabilities (including of 0 and 1) to various histories. But they are importantly dissimilar in other respects. The Schrödinger equation itself will not appear in the laws of individual Everett worlds; that law holds only of physical reality as a whole. Likewise, the initial quantum state of physical reality is not amongst the laws of any individual Everett world, even the fundamental laws of that world. The Schrödinger equation and the initial quantum state may of course still be used by physicists to predict and explain actual events – on the present proposal, it is not only laws of the actual world which can play that predictive and explanatory role.

This does not rule out a fundamental law of individual Everett worlds taking a boundary-condition form; (Chen forthcoming) highlights this possibility. One respect in which the lawsets of individual Everett worlds resemble lawsets of worlds in a one-world theory is that both kinds of lawset give rise to the problem of the arrow of time. From where, we may ask, does the evident temporal asymmetry of the actual world arise? Everettians, of course, can appeal to the initial quantum state and whatever symmetries it has, as an explanation of why the evolution of the universal quantum state is temporally asymmetric. But this account works at the fundamental level, as opposed to at the level of an individual Everett world.

Here I suggest that there is a role for a vague Past Hypothesis of each individual Everett world which specifies that world's macroscopic state at a suitable early time. Chen implements this idea as a constraint on an impure state's density matrix in an interpretation-neutral setting.[8] The resulting quantum Past Hypothesis has the curious feature of being a vague yet very general physical law. Chen suggests that we respond by positing vague fundamental laws, but the quantum modal realist can instead say that it shows that fundamental laws of individual Everett worlds can be vague even while the truly fundamental laws remain wholly precise. Then we would have an emergent vague Past Hypothesis holding within each Everett world as well as a fundamental precise initial pure quantum state of high symmetry: a boundary condition for the whole of physical reality.

Here then is a full proposed hierarchy of levels of laws for Everettian quantum theory:

Special-science levels
Laws: Topic-restricted generalizations over regions of Everett world space
↑
Everett world level
Laws: Topic-unrestricted generalizations over the whole of Everett world space.
↑
Multiverse level
Laws: Topic-unrestricted generalizations about the multiverse.
↑
Fundamental level
Laws: Topic-unrestricted generalizations about the universal quantum state.

5. Novel features of Everettian levels

Sections 3 and 4 sketched the application of grounding and concept fundamentality to the complex system of levels and laws which arise in decoherence-based EQM. But could more modest theoretical tools, in particular the more familiar and purely modal notion of *supervenience*, also do the trick? In this section I will argue that the answer is no: the distinctive nature of physical contingency in EQM precludes the exclusive use of supervenience in modelling Everettian levels.

[8] This would bring the Everett-world-level explanations of the source of probabilities and of the arrow of time much closer to the 'Mentaculus' picture of statistical mechanics associated with David Albert and Barry Loewer (Loewer 2020); Chen calls his alternative the Wentaculus (Chen forthcoming).

To make my case for the need to go beyond supervenience in modelling fundamentality in EQM, I will need to introduce some further assumptions about the interpretation of EQM – assumptions not shared by all Everettians. Up to this point I have tried to stay neutral on disputed features of decoherence-based EQM, but I now want to focus on the specific consequences of my preferred approach to probability in EQM: *quantum modal realism*. In a recent book (A. Wilson 2020a) I argued that EQM furnishes a powerful reductive account of objective contingency. To be possible is to occur in some Everett world; to be necessary is to occur at them all.

The core principles of quantum modal realism are:

Alignment: to be a metaphysically possible world is to be an Everett world. (ibid. p. 22)

Indexicality-of-actuality: Each Everett world is actual according to its own inhabitants, and only according to its own inhabitants. (ibid. p. 22)

Everett worlds then represent alternative possibilities – different ways things objectively could turn out – rather than representing different parts of one single, complicated, possibility.

Quantum modal realism renders supervenience hopeless as an account of interlevel dependence within EQM itself. If contingency is a matter of variation across the multiverse, then the fundamental quantum state itself is non-contingent. If the emergent multiverse supervenes on the fundamental state, then there is no possible difference in the emergent multiverse without some possible difference in the fundamental. Since a non-contingent fundamental quantum state cannot be different, nor can the emergent multiverse. And so we lose the one-way nature of the dependence relationship: the fundamental quantum state supervenes on the emergent multiverse and vice versa. This ought to be no surprise: when modality lives wholly inside an Everett multiverse, it can't also be used to characterise the emergence of that multiverse from something else.

What is needed for EQM, it emerges, is an interlevel relation which can hold compatibly with one-way supervenience – and which entails one-way supervenience in cases where there is any modal variation at all – but which can also hold non-trivially in the absence of modal variation. It is also desirable that this relation should be an explanatory relation: we want to be able to explain the higher levels, including the emergence of a multiverse, on the underlying fundamental quantum level. Both of these considerations point towards employing a more substantial metaphysical level-connector framework such as grounding or concept fundamentality. In each case, it is supposed that the holding of the relevant grounding relation or the relevant portion of the metaphysical semantics explains why any corresponding relation of one-way supervenience holds. More directly it is supposed that the holding of the ground facts (facts specified in terms of fundamental concepts), itself explains the holding of the grounded facts (facts specified in terms of less fundamental concepts). Hence the holding of these relations underwrites both the one-way supervenience between levels and the corresponding explanatory asymmetry.

Numerous other candidate relations other than grounding and concept fundamentality have of course been suggested in the literature. Several of the relations which J. Wilson (2014) calls 'small-g' grounding relations – relations of functional realization, set membership, determinate/determinable relations – are also intended to carry explanatory weight, and hence to be able to explain the holding of supervenience. What is required is that the notion in question should be able to hold in asymmetric patterns even in the presence of symmetric modal dependence – and realization, set membership and determinate/determinable relations all meet this condition. My argument accordingly does not tell against the application of these notions to EQM – it is only directed against those who would try to make do with nothing but supervenience.

6. Conclusion

An Everettian approach to quantum theory invokes a levels structure which extends previous conceptions of levels by including a level below the fundamental level of previous systems of laws. In extending systems of laws downwards in this way, the distinction between metaphysics and physics becomes blurred, and accordingly there is reason to look for explanatory relations between levels which are at home both in the contingent domain and in the noncontingent domain, and in both physics and metaphysics.

Grounding and Siderian concept fundamentality both offer potential metaphysical frameworks which can accommodate an Everettian level structure. As in other domains, these approaches differ in their implications for the metaphysics of the emergent worlds; concept fundamentality lends itself to a deflationary picture where Everett worlds are really just a manner of speaking about the fundamental level of the universal quantum state, while grounding lends itself to a more inflationary picture where Everett worlds are genuine, though grounded, emergent ingredients of reality.

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