No grounds for effective theories

Kerry McKenzie

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Abstract

In recent years there has been an 'explosion' of work in metaphysics aimed at articulating 'levels of reality' – a structural aspect of the world both suggested and investigated by the sciences. And in that context, the relation of grounding has emerged as the preferred relation with which to connect the levels. This paper argues that we cannot take grounding to be the relation that connects levels, insofar as those levels are described by effective quantum field theories. This is a problem for the grounding theorist, because effective field theory is taken to provide an explanation of why there seem to be levels in physics at all.

1 Introduction

It is by now a familiar idea that there has been 'explosion' of work in 'stratified metaphysics': that is, in metaphysical projects aimed at articulating the idea that reality comes parceled into a structure of 'layers' or 'levels'. And largely constitutive of these efforts has been the work that has gone into understanding the notion of 'ground'. Ground has after all emerged as the preferred candidate for the 'level connector' in metaphysics given the well-catalogued failures of purely modal conceptions, such as supervenience.[1] As such, there has been something of 'grounding revolution' afoot in contemporary metaphysics for over a decade now (*op cit*; (Kovacs 2017, p. 2927)). Part of the motivation for so much work on the grounding has been the recognition that many canonical metaphysical questions seem at their heart to be about ontological priority, and hence about what is more fundamental than what.[2] But a second and distinct motivation is that the world described by the sciences seems to come stratified into

[1] As Sider puts it, 'Metaphysics has always needed a "level-connector". One doesn't get far in metaphysics without some sort of distinction between fundamental and non-fundamental facts, or between more and less fundamental facts... So there's a niche for a metaphysical but nonmodal conception of the connection between levels. That niche has been filled by ground' (Sider 2020, pp. 747–78).

[2] By now the classic statement of this is probably (Schaffer 2009).

levels. As such, any metaphysics that aims to be adequate to the sciences ought to capture this fact, and this is seen as more work for ground to do. As Schaffer puts it, 'grounding is a notion that is extremely natural in the sciences, in considering the relation between levels. One need not be versed in an arcane metaphysics to think that the chemical depends on the physical' (Schaffer 2016, Sec. 4.4). There is thus motivation to study ground internal to metaphysics, but apparently also coming from the sciences.[3]

The purpose of this chapter is to pressurize this idea that the grounding relation can be regarded as the 'level-connector', insofar as the levels concern something described by the sciences.[4] My strategy will not be to problematize the idea that the sciences can faithfully be represented as describing a world that admits of some kind of levels structure, although this is a path that has been taken by others.[5] Rather, I will argue that while science does describe what we may regard as 'levels in nature', the relation of grounding cannot be taken to be that which links them together. The reason is that some core principles standardly taken to characterize grounding are incompatible with the relationship that exists between more and less fundamental *quantum field theories*. While such theories *prima facie* describe only a part of the hierarchy of levels – it having nothing direct to say about the relation between, say, proteins and living cells – this is nevertheless important for several reasons. The first is that if the argument is correct it implies that grounding is not the level-connector *simpliciter* since it does not have the generality that has been claimed for it. But a further and more fundamental reason is that it is arguably quantum field theory, and in particular the notion of 'effective field theories' (EFTs) that it sanctions, that supplies an explanation of *why* there are levels in physics at all – an assumption whose truth is by no means obvious. Since it is the effective field framework that gives a systematic physical explanation of the very existence of a levels structure, a metaphysics that aims to articulate the general nature of the 'level connector' has particular reason to be adequate to it.

The structure of my argument is as follows. In Section 2, I outline some of the reasons why the idea of 'levels in nature' is in certain respects a puzzling one. In Section 3, I outline why it is the emergence of the effective field theory concept offers an explanation of why there are levels in physics. In Section 4, I outline some of the properties standardly attributed to grounding and, by drawing on some classic literature within philosophy of science, argue that they are not compatible with the relation that connects successive effective field theories. Section 5 is a brief conclusion. Throughout, I will take a 'level' in physics to be the sort of thing that can be described by a theory, and to comprise 'a domain with its own set of entities, structures, and laws' (Rivat and Grinbaum 2020, p. 90). I will take grounding to be a worldly relation, and I will assume that relating 'levels' essentially involves relating the

[3]See (McKenzie 2022), Chapter 3 for further discussion of the two sources of inspiration for grounding.

[4]I will remain neutral here on whether it fares better in illuminating canonical questions in metaphysics: though see (McKenzie 2022, Chapter 3) for other reasons to think the relations involved in each context must be different.

[5](Potochnik 2017, Chapter 6) offers an extended critique of the notion of levels. Ladyman and Ross go so far as to say that 'contemporary science gives no interesting content' to the metaphor of 'levels of reality' (Ladyman and Ross 2007, p. 54) and even describe it as 'profoundly unscientific' (p. 4). I will not follow them here: see (Craver 2015) and[Havstad forthcoming] for what I take to be some compelling reasons why.

relevant laws.[6]

2 'Levels of nature' and the puzzle of quasi-autonomy

While some have used the concept of effective field theories to challenge the existence of a fundamental level (Cao and Schweber 1993), it will be easier to introduce the issue presuming that there is such a level and that QFT provides a description of it. What we are assuming, then, is that the basic principles of QFT furnish a theoretical description of whatever fundamental laws, properties, and objects the world contains. It is of course conceded at this point that we do not know what this specific quantum field theory is: even our most fundamental current theory, the Standard Model of particle physics, is regarded as merely an *effective* theory (see below) of an unknown but truly fundamental theory of quantum gravity.[7] We do believe, however, that we nevertheless know plenty of physics; indeed it is this physics that is largely guiding our investigations toward the elusive fundamental theory.

An immediate consequence of this situation is that the fundamental theory, while taken to *determine* the rest of physics, is nevertheless in some sense *distinct* from it. This is of course part of why it is we talk of different 'levels' in the first place: it is because the phenomena of the world seem to be largely sequesterable into different regimes – regimes that roughly correlate with size or spatial 'scale'. That is, some features manifest at cosmological scales; others at more mundane macroscopic scales; and other features seem to be manifest at microscopic scales alone. And while it is a basic presumption of the 'levels hierarchy' that these are in some way related, it is nevertheless implicit in scientific practice that each can be studied relatively independently of the others. Indeed, it is even conceded by practitioners that one usually does better by studying a certain level independently of the others. As one field theorist puts it:

> It is a basic fact of life that Nature comes to us in many scales. Galaxies, planets, aardvarks, molecules, atoms and nuclei are very different sizes, and are held together with very different binding energies. Happily enough, it is another fact of life that we don't need to understand what is going on at all scales at once in order to figure out how Nature works at a particular scale. Like good musicians, good physicists know which scales are relevant for which compositions (Burgess 2007, p. 330).

Given that human beings are not omniscient with respect to the subject matter of physics, were it not for this effective separation of scales then it seems 'physics as we know it would be impossible' (Van Kolck, Abu-Raddad and Cardamone 2002, p. 196). But while this may be a 'basic fact of life', there is in fact nothing obvious about why nature should be organizable in

[6]More on this in Section 5 below. I note for now that it is by this point quite standard to talk of non-fundamental laws as being 'grounded' in the more fundamental laws: see e.g. (Bhogal 2017).

[7]For a highly contemporary expression of this viewpoint, see (Weinberg 2021).

this way. For this levels picture assumes a certain *autonomy* between levels, such that upper levels may be meaningfully theorized largely without consideration of the more fundamental. However, there is nothing obvious in general about why a domain should be able to be successfully theorized in ignorance of the fundamental principles that govern it. And in the case of QFT it is in fact especially mysterious as to why it should be that less fundamental phenomena that lie within its scope should be describable independently of fundamental goings-on. QFT is after all a 'local' theory, meaning it studies interactions between fields at a point. But quantum uncertainty then requires that processes of arbitrarily high momenta must be included in the calculations of the probable outcomes of such interactions, whatever the fields involved (since the smaller the spatial domain considered, the larger the range of relevant momenta). Since it is in the short distance – equivalently, high-energy or high momenta – domain that we take fundamental processes to hold sway, it seems that low energy QFTs in principle *cannot* be understood without a grip on the fundamental theory.

It is therefore somewhat ironic that it is within QFT that we arguably find the most 'systematic and controlled' method for deriving the relations of relative autonomy between theories that allow us to stake out different 'levels' (Hartmann 2001, p. 268). It was the development of the concept of the *effective field theory* that paved the way for a nuanced understanding here. As Hartman puts it:

> It is not an easy task to make more precise what it means exactly that different levels of organisation are autonomous. However, within the programme of EFTs, the notion of quasi-autonomy can be given a precise meaning and the relation of one level of organisation to a deeper level can be studied (Hartmann 2001, p. 269).

My contention in this paper is that this relation between 'levels of organisation' is not the relation of grounding. To show why, I will first outline the basic features of how, at least in straightforward cases, the 'EFT programme' delivers a scientifically precise notion of a 'levels structure' and thus a clear sense to relative fundamentality – something that, as I hope to make clear, represents a real scientific and philosophical achievement.[8] Following that, I will defend the claim that the 'level connectors' used to map the levels structure so obtained do not have the features that are standardly taken to be essential to grounding.

3 The emergence of the 'effective field theory' concept

Our understanding of how the framework of QFT delivers back the notion of a 'hierarchy of levels' came via the attempt to understand the process of 'renormalization' that necessarily accompanies the extraction of predictions from interacting QFTs. As such, I will say just

[8] There are conditions under which some of the following statements do not hold. For example, turbulent systems do not exhibit the separation of scales required to get the EFT machinery running. But in such systems we might be hesitant to talk about levels at all. In any case, my argument only needs to apply to a part of the 'levels hierarchy' for it to have bite.

a little about this process and why the need for it arises.[9] To begin at the beginning: a QFT is a theory of the interactions of *fields* which respects the *principles of relativity* and the *principles of quantum mechanics*. Among the latter principles is the principle of *unitarity*, which requires that the probabilities of experimental outcomes, as computed by the Born rule, always sum to one. The interactions of these fields is typically given by a *Lagrangian*, which may be regarded here as interchangeable with a 'law of nature' – something that describes that way that the entities in the domain in question evolve and interact.[10] In many ways the simplest example of an interaction Lagrangian in QFT is so-called ϕ^4 theory, which describes the interactions of a scalar field $\phi(x)$ with itself via a quartic self-interaction term:

$$L = \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2}m^2\phi^2 - g\phi^4 \tag{1}$$

The g in this theory is the 'coupling constant' and represents the strength of the field's self-interactions. Field theorists will attempt to extract empirical predictions from this theory by calculating the scattering matrix (S-matrix) of the theory – a matrix whose elements give the *probabilities* corresponding for encounters between the particles described by the theory. It turns out that if g is large then there is no general method for extracting these amplitudes. However, assuming that the interaction coupling g is small – that is, < 1 in suitable units – the probabilities for obtaining a particular output state (such as the production of a certain particle) given a certain input state (paradigmatically some particles colliding with each other) may then be expressed as a series arranged in powers of g:

$$Prob(output, input) = \sum_{n=0}^{\infty} g^n \int_{E=0}^{E=\infty} F_n(E)dE \tag{2}$$

Here we don't need to worry too much about the functions F_n beyond that (i) they are functions of the energy and (ii) they are integrated over, with the range of integration unbounded from above. It is the fact that Minkowski space is continuous, and thus resolves into regions that are arbitrarily small, that accounts for why the range of integration is unbounded from above; and since (to repeat) this is a local theory it seems all of this infinite range must be taken into account in computing the amplitude. Unfortunately however – although not particularly surprisingly – what one finds is that these integrals generically *diverge*, leading to an egregious violation of unitarity and to mathematical nonsense. This 'ultraviolet catastrophe' for a long time made it look like something was remiss in the very foundations of the theory. Rather than give up on the QFT framework, however, what was developed was a means of 'taming' these infinities such that sensible predictions could be extracted from the theory. This arduous and initially perplexing process is known as the process of 'renormalization'.

[9] For a lucid presentation of the ideas behind renormalization see (Williams 2021).

[10] One gets from the Lagrangian to the familiar 'laws of temporal evolution' via the Euler-Lagrange equations. Note also that, while what one uses to compute is the law statement, in accordance with standard usage I'll refer to both law statements and the pattern in properties that they refer to as the 'laws'.

The initial idea behind renormalization was that these divergences were a manifestation that the Lagrangian used to compute amplitudes was somehow incorrect, or at least incomplete. As such, additional terms could be added to it to see if they helped to bring things under control. What was found was that in a certain class of theories – the 'renormalizable' theories – *finitely many* terms could be added to make the divergences disappear. Since as a general rule these terms have to have the same form as the original terms to cancel the infinities appropriately, renormalization in essence amounts to making a change in the value of the theory's coupling parameters (such as g), from a finite to an infinite value. Implausible as it may seem, if done correctly this succeeds in restoring finitude to the amplitudes and to the possibility of its making empirical predictions. Indeed renormalized QFTs such as QED have arguably resulted in the most accurate predictive successes of all time.

For all that, and while not entirely *ad hoc* from a physical point of view, the renormalization process seems to amount to a rather dark art mathematically speaking.[11] As such, it was for some time a source of some embarrassment among the physics community: Richard Feynman famously spoke of it as 'sweeping infinities under the rug'. But even aside from one's views about the legitimacy of the technique from a conceptual point of view, it is actually very surprising that such a procedure can even be made to work at the formal level. It is, after all, not unreasonable to presume *a priori* that the most energetic processes involved in an interaction make the most important contributions to it, and hence to the associated amplitude. As such, is very counter-intuitive that their contribution could be modeled in such a simple way as to modify the constants in it.[12]

It was the work of Kenneth Wilson is largely taken to have finally explicated why it is that renormalization works. What Wilson realized was that if we are to understand what is going on in in the process of renormalization then we have to explain why the high-energy contributions of the theory can be modeled as they are in that process. And in order to explain that, we need to understand the effects that the short-distance degrees of freedom have on the interaction amplitudes and other observable quantities. These observable quantities are ultimately determined by the theory's 'S-matrix', the elements of which may in turn be calculated from the *path integral*

$$Z = \int D\phi \exp -i \int \mathcal{L}(\phi, \partial_x \phi) d^4x \tag{3}$$

where $\mathcal{L}$ is the Lagrangian describing the interaction of the fields ϕ. The quantity $\int \mathcal{L}(\phi, \partial_x \phi) d^4x$ is known as the *action*, and the $D\phi$ indicates that we are integrating over all configurations of the field that have as their boundary conditions the given input and output states. What we are interested in is determining the effect that high-energy processes have on the low-energy interactions of this field. To see that, let us now divide the field into

[11] It is not entirely ad hoc because one can argue that measured charge of an electron partially results from the 'screening' effects of virtual particles. As one moves closer to the electron these effects decrease, and one is left with an unmeasurable 'bare charge' whose value, for all we know, could be infinite.

[12] Peskin and Schroeder (1995, p. 393.)

high and low energy components ϕ_H and ϕ_L respectively, where 'high' and 'low' is defined relative to a 'cut-off' energy scale Λ. Thus the ϕ_H are field oscillations of energy greater than Λ, and ϕ_L those with energy below it. The aim is now to express the path integral in these terms. Given the field variable separation, the path integral may now be written

$$Z = \int D\phi \exp -i \int \mathcal{L}(\phi, \partial_x \phi) d^4x = \int D\phi_L D\phi_H \exp -i \int \mathcal{L}(\phi_L, \partial_x \phi_L, \phi_H, \partial_x \phi_H) d^4x \quad (4)$$

We may write this in turn as

$$Z = \int D\phi_L \exp -i \int \mathcal{L}_{eff}(\phi_L, \partial_x \phi_L) d^4x \quad (5)$$

Here $\mathcal{L}_{eff}(\phi_L, \partial_x \phi_L) d^4x$ is known as the 'effective action', and is an expression involving low-energy modes only. It consists of the full Lagrangian with the higher-energy modes 'integrated out'. Now in essence, what this 'integrating out' process does is express the average of the effects of the high-energy modes on the low-energy sector of the theory. (To help make this intuitive, recall that according to the mean value theorem the average value of a function over an interval is equal to the integral of the function over that interval, divided by the interval length.) This expression thus abstracts away the differences between the individual high-energy contributions and incorporates only their net effect, as expressed in the low-energy modes. It is thus often referred to as a 'coarse-graining' of the full action $\int D\phi L(\phi)$. The question now is what the structure of this new effective action is.

The key result, which is general in scope, is that the integrating-out process generates *an infinite series of terms in the low-energy fields $\phi_L(x)$ in which every term consistent with the symmetry of the underlying theory is eventually included.*[13] Each new term comes accompanied with an undetermined constant g_i. The presence of these infinitely many undetermined parameters might raise the worry that the resultant 'theory' is predictively useless: after all, if we need to make infinitely many measurements just to determine the Lagrangian then we will never get around to using the Lagrangian to predict anything. But this worry turns out to be unfounded. For it turns out that the new couplings may, after a bit of work, be expressed in the form $g_i(E/\Lambda)^n$: that is, as functions of the energy divided by the value of the cut-off, raised to successively larger powers (see Bain 2013). A little more precisely, the new Lagrangian may be expanded in the form

$$\mathcal{L}_\Lambda = L_0(\phi_L, \partial_x \phi_L, g^*) + \sum_{n=1}^{\infty} g_n \Big(\frac{E}{\Lambda}\Big)^n O_n(\phi_L, \partial_x \phi_L) \quad (6)$$

where L_0 is the original Lagrangian, g^* a modified value of the original coupling parameter, and the sum is over infinitely many terms in the $\phi_L(x)$ and its derivatives.[14] These terms,

[13] Peskin and Schröder 1995, p. 399.

[14] The mass is shifted as well; but in QFT the mass is regarded as another coupling parameter so the general point holds.

suppressed by factors E/Λ, are said to be *non-renormalizable*.

The Lagrangian deduced via this process therefore possesses an infinite series of terms, each with its own undetermined coupling. However, it is not unworkable from an empirical point of view, for it may immediately be seen that at energies that are very low compared to Λ – or equivalently, when we are looking at spatial scales much larger than that corresponding to the cut-off – only a very few of the non-renormalizable terms will make an appreciable contribution to the amplitude.[15] Since all prediction and measurement is done to a finite degree of empirical accuracy, this means that *only finitely many will ever need to be incorporated into calculations*. Thus L_{eff} represents a perfectly workable theory from an empirical point of view. As one field theorist, Ben Gripaios, puts it:

> If each of these operators has an arbitrary coefficient, then we need to do infinitely many measurements before we can start to make predictions. This is not a theory! We find a way out of the impasse à la George Orwell, by declaring that 'all operators are equal, but some are more equal than others'. How? Since we are interested in the physics at large-distance scales, it may be that some operators are more important at large-distances than others. This is indeed the case...(Gripaios 2015a, p. 4)

It should be noted, however, that this effective Lagrangian is only appropriate to suitably low-energy processes. First and most obviously, since it simply has no variables for high-energy modes it cannot be applied to compute the results of high-energy scattering process. For another, however, as the energy approaches the cut-off Λ the influence of the previously suppressed terms grows, in the end almost certainly resulting in divergence and a violation of unitarity in addition to the loss of any predictive power.[16] Thus just from looking at equation (6) above, we can be confident that it is not valid beyond Λ, and as such that a new theory must take over.

While ϕ^4 is a simple example of a QFT, two important and general corollaries may be drawn from it.

1. We see the beginning of an explanation of sorts of the success of the renormalization procedure. For at low energies, one effect of high-energy processes here is simply to move the value of the couplings that featured in the initial Lagrangian.

2. We see that at low energies the effect of high-energy processes can be 'mocked up' by an infinite series of terms involving interactions of the low-energy fields. But only finitely many of these need to be considered if we are committed, as we always in fact are, to working to a finite experimental resolution.

[15]Greater energy is required to resolve small distances, meaning that energetic and spatial scales may thought of as inverse to one another.

[16]I can't say this in good conscience without noting that in some exceptional cases the series may 'saturate' and remain well-defined in the limit (see (Weinberg 1995, p. 523)). This is very much the exception and not the rule however.

While those are significant in themselves, the full significance of the latter point is further brought out when we consider theories with more than one field interacting. Consider for example a (toy) Lagrangian featuring two scalar fields $\Phi(x)$ and $\phi(x)$, the first heavy (mass M) and the second light (mass m), interacting as

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)^2 + \frac{1}{2}(\partial_\mu \Phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{1}{2}M^2\Phi^2 - \frac{1}{2}g\phi^2\Phi. \tag{7}$$

Suppose we are interested in processes involving energies $E << M$. At these energies particle quanta of the field Φ cannot even be produced, so we are not going to see them in our accelerator. (Suppose for example here Φ represents the Higgs boson and we are running our accelerator prior to 2012.) The energy scale M thus represents not just some scale we happen to be interested in, but rather a real 'joint in nature' where new ontologies can be produced and new effects manifest. Nevertheless, below this energy we can ask what effect this heavy field has on what we do see. To determine that, we do as we did before and 'integrate out' the heavy field from the theory as well as all field modes at or below the energy scale M to generate an effective Lagrangian L^M_{eff}. And to first order in perturbation theory, what we find is

$$\mathcal{L}^M_{eff} = \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2}m^2\phi^2 \ + c_0(\frac{g}{M})^2\phi^4 + ... \tag{8}$$

where the '...' refer to operators suppressed in powers of E/M (Kaplan 1995, Sec. 5.1)). What we find, then, is the light scalar field interacting as in ϕ^4 theory plus a string of non-renormalizable terms that will be negligible at low energies. Thus a theory that fundamentally involves two fields interacting as (7) can *look* at low energies like a theory with one field (self-)interacting via (8). Again, the theory is useless above the cut-off scale M, and indeed will generally violate unitarity as it approaches it. But at low energies it is perfectly predictive provided we are interested – as we always in fact are – in finite experimental accuracy. Unlike the previous example, however, what this gives is a glimpse of is how it is that the world can be fundamentally composed of a certain ontology evolving in accordance with a law of a certain structure and yet *look*, if we don't probe too carefully, as if it is composed of a different (in this case, smaller) ontology interacting via a law of a different structure.[17] As such, we get an explanation of why the physics can look significantly different from a structural point of view either side of a 'joint in nature', such as where a new particle or process comes into play.

Since the principal structural feature of laws that physicists are interested in is their symmetry structure we should say something explicit about how the process of 'integrating out' affects symmetry.[18] The answer here is well known, and it is that *the process of integrating*

[17]More complicated EFTs will permit the expression of the theory in fields taken to be bound states of the underlying ontology – for example, in chiral perturbation theory.

[18]For a review of how '[s]ymmetry considerations dominate modern fundamental physics', see (Brading, Castellani and Teh 2021).

out preserves symmetries. That is, the Lagrangian that is derived by this process will have all the same symmetries as the original. As van Kolck et al put it:

> The operators O_i [in (6) above] can in general be quite complicated. We can see, however, that... for an appropriate decomposition [into high and low energy fields], *they must possess all of the symmetries and transformation properties of the underlying high-energy theory.* Even if a particular symmetry is broken, it will manifest itself in the same way in the effective Lagrangian. (Kolck, Abu-Raddad and Cardamone 2002, p. 5).[19]

Nevertheless, if we neglect the effects of the non-renormalizable operators the low-energy theory can *look* like it has different symmetries from the original (see Section 4.1 Brading, Castellani and Teh 2021). Such symmetries arising from the neglect of small terms Weinberg termed "accidental'. And just as embellishing an already symmetric geometric figure will tend to reduce and not extend its symmetry, the low-energy theory will generally appear to have *more* symmetry than the underlying theory. An example described by Porter Williams is of an EFT which respects the symmetries of special relativity even though the theory from which it is derived is on a discrete spacetime which strongly violates those symmetries (Williams 2019). A further example, important in the search for grand unified theories, pertains to baryon number conservation. This conservation corresponds to a symmetry of the familiar (renormalizable) Standard Model Lagrangian, and has the consequence that the proton cannot decay. It may however be shown that this symmetry is violated by certain non-renormalizable term of 'dimension six' and above.[20] Their high dimensionality means they must be suppressed by a factor $(\frac{E}{\Lambda})^n$, with $n \geq 2$, and as such will make only a very small contribution at the energies at which we can currently test the Standard Model. Nevertheless, generic grand unified theories generically imply proton decay (such as $p \rightarrow K + \overline{\nu}$), since the symmetry that results in their conservation is now considered to be merely accidental (see e.g. Gripaios 2015b, p. 13).

What we see, then, is that QFT naturally invites the concept of hierarchies of nature in terms of a 'tower of effective field theories'. These are theories that are obtained through the process of 'integrating out' high-energy modes, and which therefore '(i) break down when pushed to scales beyond their limited domain of applicability and (ii) incorporate this inevitable breakdown into their mathematical framework' (Williams 2021). It is this outward manifestation of breakdown that justifies regarding EFTs as novel entrants into the conceptual landscape of physics – for this is not a feature exhibited by previous incarnations of non-fundamental theories. As Zinn-Justin puts it,

[19]Similarly, Ecker puts the matter thus: 'To model the effective field theory at low energies, we rely especially on the symmetries of the "fundamental" underlying theory, in addition to the usual axioms of quantum field theory embodied in an effective Lagrangian. This Lagrangian must contain *all* terms allowed by the symmetries of the fundamental theory for the given set of fields (Weinberg, 1979). This completeness guarantees that the effective theory is indeed the low–energy limit of the fundamental theory.' ((Ecker 1995, p. 2))

[20]Dimension 5 operators are also implicated but it is dimension 6 that are now thought to have the best chance of being realized.

> the main difference between [effective] quantum field theory and non-relativistic quantum mechanics or Newtonian mechanics [is that in the latter] the mathematics doesn't tell you that it is just an approximation. Mathematically it is a fine theory. You know just from empirical evidence that it is an approximation (Zinn-Justin 2009).

While this aspect of EFTs arguably represents something new in physics, it also gives us insight into the old problem of why it is that nature can look 'radically different' at different energetic or spatial scales, and why physics is possible prior to our possession of a fundamental theory (Kolck, Abu-Raddad and Cardamone 2002, p. 1). The simple answer is that 'the mathematical framework which we use to describe nature — quantum field theory — itself shares this basic feature of Nature: it automatically limits the role which smaller distance scales can play in the description of larger objects' (Burgess 2007, p. 330). But if this really is the explanation of the 'levels structure of theories' that physicists accept, then the theories, and the laws, that they regard as non-fundamental must be regarded as 'effective' laws generated from the more fundamental via the Wilsonian procedure. And indeed they are. For example, even the Standard Model of particle physics – our most fundamental theory to date – is regarded as an effective theory, and as such there are ongoing investigations looking for evidence of proton decay even though the corresponding terms are extremely small. It is not any empirical anomaly that leads us to invest in looking for such effects, but only our conviction that the Standard Model must be an effective theory.[21]

The fact that understanding levels in effective field theory terms gives us an explanation of why nature comes sequestered into 'levels' offers us an abductive justification for conceptualizing levels in this way. And the fact that physicists do conceptualize non-fundamental laws in this framework as effective versions of more fundamental laws suggests that we *must* understand at least some levels in this way if our metaphysics is to be extensionally adequate. But what I want to argue now that if we do understand 'levels of laws' in these terms then these levels cannot be thought of as connected by relations of grounding. Grounding's status as the generally applicable 'level connector', and thus one applicable to the order of nature, is for that reason thrown into doubt.

4 Effective field theories and grounding

To make this claim, it will of course be necessary to say something about how grounding is understood. As anyone familiar with the literature will be aware, what partly accounts for the fact that there has been an 'explosion' of literature on grounding is the fact that almost every assumption about it has been called into question by someone. However, there are some relatively fixed points in the debate, each of which has been described as a part of the 'orthodoxy' on grounding. These include the following principles.

[21] The JUNO, Hyper-Kamiokande, and DUNE detectors are currently all searching for the signatures of proton decay events.

1. Logic.[22] The logic of ground is a non-monotonic, strict partial order, always directed from what is less to what is more fundamental. Thus grounding is asymmetric, irreflexive, and transitive.

2. Objectivity.[23] Grounding links up worldly entities, and what objectivity implies is that those links are themselves parts of the world existing independently of our thinking. As such, the obtaining of grounding relations is an objective fact. As Maurin puts it, 'according to the "orthodoxy" grounding is a hierarchical dependence-relation that holds between worldly facts or states of affairs. More precisely, it is an objective and mind-independently obtaining hyperintensional and non-monotonic strict partial ordering relation'.[24]

3. Entailment.[25] Grounding is a relation of *determination*, such that the existence of a ground entails the existence of the grounded as a matter of metaphysical necessity.[26] Grounds are therefore *metaphysically sufficient conditions* of whatever is grounded in them, so that establishing that the grounds of some phenomenon are instantiated is enough to infer the instantiation of the grounded phenomenon as well.

More principles could be added to this list, but this will be enough for us to be getting along with.[27] My claim will be that the relation between successive EFTs cannot be regarded as a relation of grounding, insofar as grounding is governed by these principles. To be clear, some of the orthodox assumptions about grounding might find a happy home in the 'levels structure of theories' as conceived of within the EFT framework. In particular, the Logic requirement would seem to be satisfied.[28] The fact that successive EFTs may be defined via the same procedures checks off the transitivity requirement, and the fact that the process of 'integrating out' is 'lossy' means that the order so defined is asymmetric.[29] Rather than the Logic requirement, then, the problem for the orthodox understanding of grounding arises from a conflict between Objective and Entailment. And while the point I will make here is an old one – old, in any case, within the philosophy of science – it has to my knowledge yet to be raised in the context of the literature on grounding.

At the heart of the the argument is the fact that EFTs – and hence, we are assuming, non-fundamental laws of nature – are by their very nature 'intrinsically approximate' entities (Castellani 2002, p. 260). In particular, even in the energy range in which they are applicable

[22]Both Maurin (2019, 1574) and Rabin (2018, 38) describe these as 'grounding orthodoxy'.

[23]As (Bliss and Trogdon 2014, Sec. 2.1) put it, 'Grounding theorists routinely claim that grounding is fully objective.'

[24]Maurin 2019 1574.

[25]Skiles (2015) notes that this is 'orthodoxy', although he himself contests it; Bliss and Trogdon (2014, Section 5) call it the 'default' view . Likewise Cameron (2019) holds that it is 'widely held'.

[26]See e.g. Rosen 2010, 118, who calls this 'the entailment principle'.

[27]See e.g. Maurin *op cit.* for a discussion of the orthodoxy concerning grounding's relation to explanation.

[28]Or at the very least it does not raise new problems in addition to those raised below.

[29]I note also that (Butterfield 2011) has argued that this process constitutes a Nagelian bridge principle, relating the languages of the high and low energy theories. In 'integrating out', we are in a sense translating the high-energy contributions into the language of low-energy fields.

they are approximations to what is derived from more fundamental theories. This may be argued for in at least two ways.

1. The theories that physicists use and regard as non-fundamental are predictive, empirical theories. We regard QED, for example, as a highly predictively accurate theory, and also as an EFT. But we know that theories are only predictive if they have *finitely many* undetermined constants. What is derived by the process of 'integrating out', however, is a string of terms that is *infinitely long*. As such, if we want our theory of laws to be extensionally adequate – to have what we regard as laws of physics on each side of the relation – then the laws we take to define non-fundamental levels are necessarily approximations to what is derived from the more fundamental theory.

2. We take it that theories on different levels often have different symmetries. The whole motivation for regarding the world as structured into levels is that it appears 'radically different' on different scales, and one – and from a physics point of view, the prime – respect in which laws can differ is in terms of their symmetry structure. But we know that what is derived from a more fundamental theory must have the same symmetries as the original theory. Differences in symmetry can only arise by chopping off the Lagrangian at some point – resulting in at best an approximation of what the underlying theory entails for that scale.

It follows from that the laws that physicists regard as non-fundamental are *approximations* to what may be derived from more fundamental laws (and this even in the domain in which they apply): they are approximations to the infinitely long string of terms that is derived, all but a few terms being set to zero since they will negligible in the domain where the theory is applied. This, however, causes a familiar problem: and this is that what we take to be the non-fundamental laws are not *entailed* by those more fundamental laws. Indeed, they are generically *incompatible* with what those laws entail. This is a point familiar from some classic philosophy of science, mostly saliently in Feyerabend's critiques of Nagelian reduction and Hempel's deductive-nomological theory of explanation (see (Feyerabend 1962, pp. 46–7)); it is also core to Duhem's criticisms of inductivism as an adequate model of Newton's method (see (Duhem 1991, p. 193)). In either case, the basic point is that, in addition to Newtonian mechanics providing a more comprehensive description that that provided by his predecessors (taken to be Galileo and Kepler respectively), it *corrects* what each has to say about the systems each describes (in these cases, bodies falling at the surface of the earth and planets circumnavigating the sun). But given that Newton corrects these prior theories, it cannot be that it entails them: rather, it contradicts them. Exactly the same is the case here. Whatever the relationship between the laws on two levels, then, it cannot satisfy ENTAILMENT.

There is however a response that can be made here – one that which defenders of Nagelian reduction (including Nagel himself) were quick to point out in response to criticisms of Feyerabend and others. This is that they never actually intended strict deducibility as a requirement of successful reduction.[30] Rather, 'approximative reduction' – that is, derivation of an approximation to the theory that was to be reduced – is all that can and should be asked for. Nagel puts the idea as follows.

> It is undoubtedly the case that the laws derivable from Newtonian theory do not coincide exactly with some of the previously entertained hypotheses about the motions of bodies, though in other cases there may be such coincidence... Nevertheless, the initial hypotheses may be reasonably close approximations to the consequences entailed by the comprehensive theory, as is indeed the case with Galileo's law as well as with Kepler's third Law... But if this is so, it is correct to say that in homogeneous reductions the reduced laws are either derivable from the explanatory premises, or are good approximations to the laws derivable from the latter ("Issues in the logic of reductive explanations", p. 120)

It is clear that Nagel regards the fact that we can derive an approximation to what is strictly derivable as sufficient to save the core of his account: we have a close enough 'analogue' to the original to say that the spirit of the original proposal is preserved. Modern apologists for Nagel's account have followed him here.[31] Such a move is clearly relevant for our purposes, since it suggests we can, without much damage, make a mild alteration to the 'grounding orthodoxy' by relaxing the requirement of ENTAILMENT to something like 'APPROXIMATE ENTAILMENT' – a principle that demands only that the more fundamental laws entail an approximation to what physicists regard as the non-fundamental laws. This, however, was a move which Feyerabend himself anticipated. As he put it:

> The objection which has just been developed – so it is frequently pointed out – cannot be said to endanger the correct theory of explanation[32] since everybody would admit that explanation may be by approximation only. This is a curious remark indeed!... [T]he remark that we explain 'by approximation' is much too vague and general to be regarded as the statement of an alternative theory. As a matter of fact, it will turn out that the idea of approximation cannot any more be incorporated into a formal theory, since it contains elements which are essentially subjective (Feyerabend 1962, p. 48).

Feyerabend's objection here, then, is that if we weaken 'derivability' to mean 'approximate derivability' we (i) produce a theory which is so vague that cannot be stated, and (ii) sacrifice its objectivity. While I regard (i) as untrue – or at least, as unfair, given that vagueness

[30] Similar points apply to Hempel's theory of explanation.
[31] Frigg et al, Butterfield.
[32] Here he has in mind Nagel's account as well as Hempel's Deductive-Nomological model – models which he regarded to 'not differ in any essential respect' (Feyerabend 1966, p. 247).

permeates most of our theoretical notions – the objection in (ii) remains absolutely correct.[33] As such, while the modification of Entailment required to deal with the fact that what we regard as non-fundamental laws are 'intrinsically approximate' might save the spirit of that principle, it does so at the cost of sacrificing Objectivity – another central tenet of the orthodoxy on grounding.

To see this, let's start with the claim that 'approximation' is so 'vague and general' that to include in a theory of explanation is essentially to abandon one's ambition in providing a theory. Here defenders of Nagelian reduction have argued that while there may be no general philosophical theory that one can offer as to when two equations, or two theories – indeed, two anythings – are sufficiently similar to be regarded as 'approximations' of one another, we can still give content to the claim. It is just that the content is invariably going to be contextual. And in any empirical context, to say a successor theory approximates a precursor theory can be expected to at least involve the claim that the two theories are *approximately empirically equivalent* in the domain in which the old theory proved successful. Of course, what that means, and thus whether it is true, is going to depend on facts about the context of investigation. Once that context is specified, however, the truth value may be determined unambiguously.

So the problem afoot here is not 'vagueness'. Rather, the real problem is that by weakening Entailment to something like 'approximate entailment' steers us into the second horn of Feyerabend's dilemma, in that it implies a conflict with Objectivity. Feyerabend's own stated reasons for regarding approximation as inevitably involving 'elements which are essentially subjective' turn on considerations of theoretical incommensurability which are difficult to summarize, and probably in any case a bit dated. However, we can turn to a classic discussion by Duhem to see more clearly why the point stands. In this discussion, he first argues on broadly empiricist grounds that 'every physical law is an approximate law' (Duhem 1991, p. 171). From there, he writes:

> Such [an approximate] law [is] always provisional... It is provisional because it represents the facts to which it applies with an approximation that physicists today judge to be sufficient but will some day cease to judge to be satisfactory. Such a law is always relative; not because it is true for one physicist and false for another, but because the approximation it involves suffices for the use the first physicist wishes to make of it and does not suffice for the use the second wishes to make of it....
>
> The estimation of its value varies from one physicist to the next, depending on the means of observation at their disposal and the accuracy demanded by their investigations (Duhem 1991, p. 171).

[33] Thus while modern apologists for Nagel's account argue against the idea that the notion of 'approximation' between theories is devoid of content, holding that what that content is is nevertheless highly 'contextual' (see e.g. (Dizadji-Bahmani, Frigg and Hartmann 2010)). I agree; I hold further that those contexts involve 'subjective elements'.

What Duhem is pushing here is that whenever a law is regarded as in some way approximate, *whether it can be regarded as a law at all* is not only a 'contextual' matter but moreover one that *depends on the relevant interests.* Of course, we need not buy into Duhem's explicitly empiricist motivations for believing that all laws were necessarily approximate to take this conclusion seriously: all that is needed to generate the problem is that this is true of the non-fundamental laws corresponding to effective field theories. But such theories, as has been emphasized above, *are* inevitably and intrinsically approximate. And whether an EFT containing n terms and exhibiting symmetry S constitutes a good approximation to what can be strictly derived from the more fundamental theory is going to depend upon what we are interested in studying and the degree of accuracy with which we are interested in studying it. As such, Duhem's point applies here. It follows from this that the relata of the relation connecting successive EFTs are interest-dependent entities. Since I take it as uncontroversial that a relation can obtain in an interest-independent sense only if all of its relata obtain in that way, *the link between the laws given by effective theories cannot be identified with grounding.*[34]

It may help to flesh this out with an example already alluded to. As noted above, for the purposes of most particle physicists the Lagrangian of the Standard Model, applied at some energy scale E, where E is below Λ and hence in the range in which it is defined, is just the plain old renormalizable Lagrangian of the Standard Model – the one that can be found displayed on mugs and T-shirts in the CERN gift shop. But *for those interested* in studying proton decay, and experimentally well-positioned to do so, this is not the Lagrangian that it is appropriate: dimension 6 corrections to the Standard Model, of the form $O(E/\Lambda)^2$, must be included if such a phenomenon (should it exist) is to be accounted for. It is important to note that the issue here is not simply that 'different things happen at different levels' with levels parceled out at different energies or spatial scales – perhaps analogously to how we see different thermal phenomena, such as freezing or boiling, happening at different temperature scales. For we can hold the energy range – the 'scale' – fixed and *still* ask whether the higher-order terms can be neglected or not; and the answer will depend on our interests. To put the same point differently, we should not think it is at a scale 'beyond' the domain at which it is first appropriate to ascribe protons and the more familiar hadronic decays processes, at which proton decay kicks in. For the smallness of the higher-order terms corresponding to the decay of the proton simply translates (via cross-sections and decay rates) into the extreme *rareness* of the proton decay events, relative to other such decays. Thus if we will detect proton decay, we will do so in broadly the same sorts of detectors we use to see many other hadron decay events (a well-shielded chamber of fluid surrounded by array of detectors); we do not need a detector that probes to 'deeper' scales so much as just a particularly *capacious* such detector, kept track of for sufficiently many years.[35] Thus it seems to me that proton

[34] As (Bliss and Trogdon 2014, Sec. 2.1) note, given the variety of meanings associated with the word 'objective', there are a number of different ways in which grounding could fail to be objective. This way seems to correspond to the relata of the grounding relation being 'essentially connected to subjects', and thus to what they call the 'more "metaphysical" approach' to the failure of objectivity.

[35] As the Hyper-Kamiokande project webpage puts the matter: 'With the giant detector, data that would take 100 years to obtain with Super-Kamiokande can be obtained in about ten years with Hyper-Kamiokande. This makes it possible to measure rare phenomena of elementary particles and slight symmetry breaking that

decay happens at just the same 'scale' as more familiar hadron decay processes.[36] But it depends on one interests whether the corresponding terms, evaluated at that scale, may or may not be set to zero. As such, what law is 'approximately entailed' at a given energy by the more fundamental successor to the Standard Model is a function of the interests of the physicist, and Duhem's point stands.

To summarize the argument of this section. A core principle of the grounding orthodoxy is that the grounds entail what they ground. But the laws of nature that we take to be described by effective theories are not entailed by the more fundamental theory: rather, they contradict what is entailed. And if we modify ENTAILMENT to mean something like 'APPROXIMATE ENTAILMENT', as defenders of the Nagelian model think we should, then this modification is in contradiction with the idea that grounding relations satisfy OBJECTIVITY. For the very relata of the inter-theory relation are not objectively determined, even at a particular 'scale': on the contrary, what the laws at a given scale are is a function of the interests of the theorist. Again, since I take it as uncontroversial that a relation can only obtain in an interest-independent sense if all of its relata obtain in that way, it cannot be that the link between the laws described by effective theories is identifiable with grounding. And since I take a level to be 'a domain with its own set of entities, structures, and laws', levels themselves are not connected by relations of grounding either.

5 Responses

Today's physicists generally understand levels in terms of a tower of effective field theories, linked via Wilsonian methods; today's metaphysicians generally understand levels in terms of relations of grounding. I have argued that the relations of grounding do not correspond to the relations between levels in the physicists' sense. Given how pervasive is the belief in metaphysics that grounding is involved whenever one talks about a world structured into 'levels', I expect some pushback against the argument just given. While there are of course a number of objections that could be made to that argument, here I mention just three.

A first objection is that the argument just given applies only to laws of nature. But there are other relata of the hierarchy of nature – most saliently, that of more and less fundamental objects and that of more and less fundamental properties – that are not directly touched by the argument. A full response to this objection would have to say more that is explicit about how more and less fundamental ontology is to be understood in the EFT framework. Suffice to say here however that I am with Nagel when he writes that since the objects and properties described by our theories are just that – described by our theories – we need to understanding the relations between those through the prism those theories provide ((Nagel 1961, p. 270). Since laws are at the core of scientific theories and what we do with them, I

were previously invisible.' https://www-sk.icrr.u-tokyo.ac.jp/en/hk/about/research/

[36] If it is useful to make an analogy here, consider a very rare genetic condition that results in a very rare genetic transcription process. We wouldn't say that the rare transcription process took place on a different 'scale' from other such processes simply because it was rare.

do not think my argument will simply go away even if we do focus on a hierarchy different from the hierarchy of laws.

A second objection is that one could say that it is the entire infinite string of operators derived through Wilsonian methods that corresponds to a non-fundamental level, and what this is is not a function of anyone's interests. Thus, relations of grounding do obtain between levels after all. However, as noted above in Section 4, this string does not in fact correspond to anything that physicists call a 'law' (as the earlier quote from Gripaios puts it, 'this is not a theory!'). Moreover, this 'law' has the same symmetries as the underlying theory, and thus is not the law of any level with different symmetry structure than the fundamental theory. A level, by contrast, I am taking to be 'a domain with its own set of entities, structures, and laws'. For both these reasons, this infinitely-long string does not correspond to the law of a non-fundamental 'level', and so the relation between it and the fundamental theory is not the relation between levels that we are looking for.

A third and perhaps most important objection is that the argument over-generalizes. For it is not as though it is only the laws as they appear in the framework of effective theories that are both non-fundamental and approximate (see e.g. (Callender 2001)). Indeed, one can easily find the terms 'non-fundamental law' and 'approximate law' used interchangeably in the literature. As such, there is at best nothing new in this objection that the hierarchy of laws is not objective. And at worst, since approximation and idealization are utterly ubiquitous in scientific practice, practically nothing in science is going to come out as objective by my measure; who cares, then, that 'levels' and 'grounding' do not do so either.

In one sense I agree with this: I was after all explicit that I am going over old ground here. But for all that, I think that there is something both new and newly consequential for metaphysics here. After all, it is the EFT framework that is taken to *explain* why it is that Nature admits of something like a levels structure. Prior to EFTs, one was freer to understand that approximate character of non-fundamental laws in terms of something about human fallibility: something that, while revealing about humans, did not necessarily undermine the objective reality of non-fundamental laws. Now the situation is different. We find ourselves in a situation in which the 'hierarchy of levels' that is now not just *reported* but *explained* by physics turns out not to be fully specifiable in an interest-independent way, even if it also makes room for objective 'joints in nature' such as at particle masses. Thus it is not *wrong* for those working in 'stratified metaphysics' to take as their starting point ideas about a 'hierarchy in nature', which as I flagged at the outset is standard practice. The above should, however, give metaphysicians permission to think about levels in less commitedly realist terms. I suspect that talking in terms of 'grounding' is only going to hinder this endeavour, given the pervasiveness of the assumption that grounding obtains independently of us. For what seem to be fundamental reasons, this now does not seem to be fully apt.

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