Levels of Fundamentality in the Metaphysics of Physics

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Abstract

Within physics there are two ways of establishing the relative fundamentality of one theory compared to another, via two senses of reduction: "inter-level" and "intra-level" (Crowther, 2018). The former is standardly recognised as roughly correlating with the chain of ontological dependence (i.e., the phenomena described by theories of macro-physics are typically supposed to be ontologically dependent on the entities/behaviour described by theories of micro-physics), and thus has been of interest to naturalised metaphysics. The latter, though, has not been considered interesting for metaphysics, because it is not thought to correlate either with ontological dependence, nor causal or dynamical dependence. I argue, however, that this is a mistake, and that actually, the intra-level relation does reflect ontological dependence (in the same sense as the inter-level relation) and thus should not be neglected by metaphysics of physics. This argument further supports the assertion that the same notion of fundamentality underlies both the inter- and intra-level claims of fundamentality in physics, and that this notion of relative fundamentality in physics correlates with that of metaphysics.

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1 Introduction

Recently, work has begun to explore the variety of different notions of fundamentality in (philosophy of) physics, as well as the connections between these and the different ideas of fundamentality in metaphysics.[1] The present paper aims to continue this work. I point out that there is a plausible notion of relative fundamentality in physics whose "hierarchy" tends to correlate with the one that is intuitively adopted by naturalised metaphysics in articulating its (standard, or roughly consensus) notion of relative fundamentality. Although not implied, we can—provisionally, and in the spirit of exploration—interpret this correlation as the two accounts of relative fundamentality essentially capturing the same relation. Doing so, however, we find some surprising results, both for the philosophy of physics, as well as for metaphysics of physics.

The structure of the paper is as follows: §2 presents a short statement of what is meant by "relative fundamentality" in metaphysics, remaining open as to whether it is to be defined in terms of *grounding* or *ontological dependence* relations (i.e., both types of relation are considered); §3 introduces the conception of relative fundamentality in physics which I argue most plausibly captures the asymmetric dependence that characterises such a relation; §4 explores the possibility of interpreting this conception of relative fundamentality in physics as capturing the same relation as the ideas of relative fundamentality in metaphysics; §5 discusses some implications of this interpretation, as well as two other possible interpretations of this idea of relative fundamentality, and §6 concludes.

2 Relative fundamentality in metaphysics

There are many different ways of characterising relative fundamentality in metaphysics, and many debates about the best way to do so. I take it, however, that there are two main approaches: one utilises *grounding*, and the other *ontological dependence* relations (remaining neutral as to whether or not grounding is a species of ontological dependence relation, or vice-versa). Grounding is supposed to be a relation between facts, while ontological dependence can hold between entities, properties, behaviours, events, or other relata.[2] So, fact M is more fundamental than fact L, if M grounds L. And entity/property/etc. M is more fundamental than entity/property/etc. L, if L is ontologically dependent upon M. If L—whether fact, or entity/property/etc.—is

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[1] Specifically: Morganti (2020a,b); an international workshop organised by Fabrice Correia, Claudio Calosi, and Benjamin Neeser, Geneva, 2018; symposia at the BSPS conference 2018, Oxford, and the PSA 2018, Pittsburgh. Also related are the dedicated attempts within naturalised metaphysics to genuinely explore the meaning, and implications of, particular physical theories for the metaphysics of fundamentality, or to apply the "tools" of metaphysics to better understand the ideas of fundamentality suggested by particular theories of physics, e.g., Le Bihan (2018); Le Bihan & Read (2018); McKenzie (2011, 2017).

[2] Although there are more differences between these two types of dependence relation than merely their differing relata. See, e.g., Calosi (2020); Kovacs (2018, 2019).

grounded in, or ontologically dependent on M, then M is said to be *ontologically prior* to the less-fundamental L. (Throughout this chapter, I use M to denote the *More* fundamental object (fact, or theory), and L to denote the *Less* fundamental object when considering relative fundamentality between two objects (facts, or theories)).

There are two key features of the grounding and ontological dependence relations that enable them to be used in defining relative fundamentality. First is the fact that they are asymmetric relations: crucial to any conception of relative fundamentality is that it capture the idea that there is a *hierarchical structure* to reality (Bliss & Priest, 2018; Tahko, 2018). Second is the fact that they are not purely modal relations (Fine, 2012). Thus, I take these two minimal conditions to characterise the metaphysics conception of relative fundamentality:[3]

RF in metaphysics:

i. *Asymmetry*: If fact/entity/event M is more fundamental than L, then it is not the case that L is more fundamental than M;

ii. *Non-modality*: The relation must state something more than simply "if M, then necessarily L".

3 Relative fundamentality in physics

Physicists (and philosophers of physics) recognise a huge variety of features of physical theories as being indicative of a theory's (or entity's) status as either fundamental, or relatively fundamental.[4] Here, I take it that there is one minimal condition for relative fundamentality in physics: that it is a relation of *asymmetric dependence*. The relevant sense of asymmetric dependence is demonstrated in physics through *derivability* (note, by being evidence of asymmetric dependence, derivability is supposed to be *demonstrative* of fundamentality, rather than *constitutive* of fundamentality).

RF in physics: Theory M is more fundamental than theory L if L is *derivable* from M, and M is not derivable from L. This demonstrates that L *asymmetrically depends* upon the physics described by M.

Here, M and L are physical theories, or parts of theories that are, were, or will be accepted by mainstream physics as approximately true. M and L are to be compared at a given time, in the form that each is accepted at that time.

Derivability is a standard way of obtaining the physicists' sense of reduction as domain subsumption, i.e., the demonstration that all the successful parts of the reduced theory, L, can (approximately and appropriately) be obtained from the reducing theory, M. The idea of asymmetric dependence, or relative fundamentality, is that the reduced

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[3] This is following a suggestion by Andreas Hüttemann.

[4] See, e.g., Cao (2003); Crowther (2019); Morganti (2020b).

theory is shown, via reduction, to be embedded within the reducing theory (and hence that the physics described by the reduced theory depends on that of the reducing theory (Crowther, 2020)).

The claim of relative fundamentality as demonstrated by derivability underlies two of the most popular conceptions of relative fundamentality in physics: (i) a more fundamental theory as one applicable at *shorter length scales* (M describes "smaller stuff" than L does); (ii) a more fundamental theory as one with a *broader domain*, or increased generality (M describes "more stuff" than L does). These two popular claims roughly correspond to what are typically distinguished as two different types of reduction in physics: (i) Reduction$_1$, and, (ii) Reduction$_2$. The distinction between two types of reduction was originally drawn by Nickles (1973).[5] *Reduction$_1$* is, roughly, the deduction of (corrected) parts of a higher-level theory from (parts of) a lower-level one, under some appropriate conditions, and is standardly exemplified by Nagel-Schaffner reduction (after Nagel (1961); Schaffner (1976)). *Reduction$_2$* is, roughly, various inter-theory relations between (parts of) a new theory and its "predecessor", under appropriate conditions, that serve heuristic and justificatory roles in theory-succession.

Wimsatt (1976; 2006) elaborates on Nickles' distinction, and relabels it as one between *explanatory* and *successional* reduction. Explanatory reduction, according to Wimsatt, is an *inter-level* relation, relating "levels of organisation" rather than theories (however, I will stick to speaking about theories in this chapter).[6] Its aim is to provide a *compositional*, *mechanistic* and *causal* explanation of some large-scale phenomena in terms of shorter-length scale behaviours (Wimsatt, 2006, §4); e.g., explaining the behaviour of gases as clouds of colliding molecules, or the behaviour of genes in terms of the action of DNA (2006, p. 449). Wimsatt is clear that explanatory reduction is no longer best exemplified by Nagel-Schaffner reduction, but that it is richly complex and greatly diverse in its approaches, especially in biology. Successional reduction, according to Wimsatt, does relate theories, and is supposed to be *intra-level*: holding between newer and older theories, and/or more exact and more approximate theories, and/or more- and less-general theories that apply "at the same compositional level". But this sense of intra-level reduction is supposed to also relate theories that are not level specific, such as in physics (Wimsatt, 2006, p. 450).

Here is how I use the terms in this chapter:

Reduction$_1$: "explanatory reduction" holds between two theories formulated at different levels, e.g., different energy/length scales. M and L describe different degrees of freedom. M and L are related by *coarse-graining procedures.* M may

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[5] This distinction has also been referred to as *explanatory* versus *successional* reduction (Wimsatt, 1976, 2006), *synchronic* versus *diachronic* reduction (Dizadji-Bahmani et al., 2010; Rosenberg, 2006; van Riel & Van Gulick, 2016), and *vertical* versus *horizontal* reduction (Robertson & Wilson, ming).

[6] Wimsatt (1976, p. 680) conceives of levels of organisation as "primarily characterized as local maxima of regularity and predictability in the phase space of different models of organization of matter".

be a “constructive theory” or constitutive theory, i.e., describing particles or mechanisms supposedly underlying the physics described by L.

Reduction$_2$: “successive reduction” holds between more general/less general, or more exact/more approximate theories at the same level. M and L may be overarching frameworks, or “principle theories”, not restricted to a certain level.[7] L is restricted in ways that are revealed and overcome by M (typically, the succeeding theory). M and L are related by the *weak field limit*.

These two notions tend to be exemplified together in physics, so that it is difficult to find “pure” examples of either reduction$_1$ or reduction$_2$. A standard example of reduction$_1$ is the theory (or framework) of thermodynamics as less fundamental than statistical mechanics. Thermodynamics, which describes macroscopic physical quantities, is taken to be (in principle) derivable from statistical mechanics, which represents the underlying mechanistic theory of particles—the microscopic constituents of the thermodynamic system. Statistical mechanics is seen as providing an explanation of thermodynamic behaviour via the reduction, which utilises coarse graining procedures.[8] Another example of reduction$_1$ is chiral perturbation theory as less fundamental than quantum chromodynamics (QCD). Chiral perturbation theory is an *effective field theory* constructed based on the symmetries of QCD, and allows us to study the low-energy dynamics of QCD. The two theories describe different degrees of freedom: chiral perturbation theory is a theory of hadrons, which are supposed to be composite particles of quarks and gluons. The “constituent” quarks and gluons are described by QCD at high-energy scales. A more general example is atomic theory as less fundamental than the standard model of quantum field theory, which describes the subatomic physics and provides the most fundamental description of matter.

In each case of reduction$_1$ the two theories apply at different length scales, or different levels, and they describe different degrees of freedom, with M being finer-grained, and L being coarser-grained. This conception of relative fundamentality has been heavily shaped by the development of the framework of effective field theory (EFT) and associated philosophy, especially in regards to discussion of emergence.[9] EFT is a toolbox for constructing macro theories valid at low energy scales from micro theories valid at high energy scales—e.g., the coarse-graining procedures. The resulting *effective* theories are not supposed to be fundamental, given their restricted domain of applicability. Nevertheless, they are extremely useful, being highly predictive and providing an understanding of the large-scale phenomena by being framed in the appropriate degrees of freedom for the length-scales at which they apply (Georgi, 1989).

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[7] Famously, the distinction between constructive theories and principle theories is from Einstein’s 1919 article “What is the Theory of Relativity” in *The Times*, (Einstein, 1954).

[8] This particular example has been heavily debated as to whether or not it represents Nagelian reduction, but for our purposes of illustrating reduction$_1$, which need not be strict Nagelian reduction, the example is apt.

[9] See, e.g., Crowther (2015); Castellani (2002); Bain (2013).

The high-energy M is more encompassing than L: in principle, it predicts everything that L does, but it also describes physics at energy scales where L does not apply.

Examples of reduction$_2$ include quantum electrodynamics as more fundamental than classical electrodynamics; special relativity as more fundamental than Newtonian mechanics; and quantum gravity as more fundamental than general relativity. These theories are *universal*: they are not supposed to be restricted to certain length scales. Yet, M replaces L as a more-encompassing theory; L is restricted in some ways that are revealed and overcome by M, through the relation of reduction that connects them. This is typically demonstrated using the weak field limit (amongst other relations). For example, classical mechanics was seen as a universal theory of motion, but after the development of special relativity, Newtonian mechanics was shown to be invalid for velocities comparable to the speed of light. Special relativity is a more general, more-encompassing theory, since it applies to everything that classical mechanics does, plus more. The dependence of classical mechanics on special relativity is shown through various relations that connect the theories, including the limiting relation of low velocities compared to the speed of light.

Reduction$_1$ is usually taken to be (potentially) ontologically interesting: the idea is that it is capable of providing a "mechanism", a nice physical story, or a part-whole explanation of the higher-level phenomena. The higher-level phenomena described by L is considered "real", and L is still retained as correct, as a "special science". Contrarily, reduction$_2$ is typically not thought to be ontologically significant; it is not thought to provide the same quality of explanation as "explanatory reduction". The older theory L is demoted as strictly false, but nevertheless may be considered "approximately correct" in its restricted domain. The parts of L that are retained from the older theory are those that are shown to be compatible with (yielding approximately the same results as) the newer theory, M, via the reduction (Crowther, 2020).

I find this difference in attitudes to be ill-founded—it seems to be based purely on the fact that reduction$_1$ involves the idea of levels, related through coarse-graining procedures, while reduction$_2$, does not. Otherwise, there are many parallels between these two types of reduction. Both types utilise various inter-theory relationships aimed at establishing that L is in principle derivable from M, and thus that M subsumes the domain of L; i.e., M describes everything that L does, plus more). In both cases, M explains the phenomena described by L by being consistent with L in the relevant domain; i.e., M explains the success of L by yielding the approximately the same results as L in the domain where L is known to be successful. This is true even in the case of inter-level "explanatory" reduction$_1$. The "lower-level" theories are more fundamental *not* because they provide a "mechanism" or part-whole explanation, etc., but because L is (in principle, approximately) derivable from M and have broader domain. This establishes that L asymmetrically depends upon M.

An objection might claim that, in reduction$_2$, L can not be of ontological significance because L is just a special case of M—the stuff described by L doesn't "really exist" and L is in principle dispensable given M, e.g., classical systems "are really just" quantum systems. But this same line of thought can be applied to the levels-picture of reduction$_1$, where it echoes *naive reductionism.* According to naive reductionism, any emergent physics, or phenomena described by special sciences doesn't "really exist", and the higher-level L theories are in principle dispensable. Not many people support such a naive reductionist attitude today, and to be clear, neither do I—but nor do I accept the analogous position in the non-levels case of reduction$_2$. In both cases, L theories continue to be used—not just because of practical necessity, but because they provide a useful description of physics that is appropriate to the domains in which we most often find ourselves. The less-fundamental theories impart an understanding of the phenomena, and the more-fundamental ones (in the absence of the connecting relations) do not (Crowther, 2015).

A more general objection might be that the idea of derivability between theories is not always ontologically significant, since it could instead be merely mathematical relations connecting the theories. This is, however, not true in the case of the physicists' sense of reduction in general. It is a requirement upon any new theory of physics that it appropriately connect with its predecessor (including a "higher level" theory) via this idea of reduction, which necessarily involves some reasonable physical interpretation. It is generally seen as a problem if no physical sense can be made of the relations connecting the theories (even if, as typical, these relations involve approximations, and L may be seen as in some sense an approximation of M). It should also be emphasised that these sorts of reductions are not typically just a single mathematical relation such as a limiting relation linking the theories, but instead involve establishing various types of connections ("correspondence relations", which are not all mathematical in nature) between the theories (Crowther, 2020). Finally, this chapter is concerned with the metaphysics of physics, and involves asking what our physical theories—in the form in which they are currently accepted—could tell us about the ontology of the world (objects and/or relations), so the spirit is a realist interpretation of our theories and the relations between them.

So, I argue that both reduction$_1$ and reduction$_2$ are means of establishing that L is derivable from M, and thus that M is more fundamental than L. In other words, the derivability demonstrates that L is asymmetrically dependent upon M. But what kind of dependence does derivability establish? Most straightforwardly, it captures modal dependence (but we will see later that there is also a notion of natural dependence and ontological dependence). Theory L is less fundamental than theory M if L depends upon M, but M is not necessary for L. If M holds in the world, then necessarily so does L. L is derivative: it holds in the world because M does. But it is possible that (or, we can imagine a world where) we have L without M (i.e., there may be other reasons why L obtains, other than M obtaining).

This is easier to understand by looking at the examples. Newtonian gravity is less fundamental than general relativity (GR). If GR holds in our world, then necessarily so does Newtonian gravity, since it is the weak field limit of this theory, it is "contained" within GR. Newtonian gravity is derivative, it holds in the world *because* GR does. However, it is possible that there be a world where Newtonian gravity holds, but GR does not—Newtonian gravity might, e.g., be the weak field limit of a *different* more-general gravitational theory (other than GR), or it may be that the world is *only* described by Newtonian gravity and there is no more-fundamental theory of gravity. This is true also with "inter-level" reduction. Atomic theory is less fundamental than the standard model of quantum field theory (QFT), and is derivative from it. If the standard model is true in our world, then necessarily so is atomic theory, since atomic theory is a low-energy limit of the standard model. But we can imagine a world where atomic theory is true, with a different more-fundamental theory "underlying" it. Another example is the current situation with respect to the theory of quantum gravity, which is supposed to be more fundamental than GR according to both senses of relative fundamentality described above. There are several different possible theories of quantum gravity from which GR could be derived, and in this sense GR is *multiply realisable*.[10] This is in spite of the fact that we believe there is only one correct theory of quantum gravity that holds in our world, and that it is by virtue of this that GR holds in our world.

4 Can we understand these relations as capturing the same idea?

If we understand relative fundamentality in physics as described above, we can speak of an hierarchy of more- and less- fundamental theories, which needn't be associated with "levels" in the sense of theories applicable at different energy or length scales. Instead, the levels are *levels of fundamentality*, distinguishing the derivative from its "basis". Next, notice that the hierarchy of facts described by the hierarchy of physical theories tends to correlate with the chain of grounding relations, where the grounded fact (to be explained) is less fundamental than the fact grounding it (the explanation). Some examples:

- facts about the existence and behaviour of atoms, as described by atomic theory, are grounded in facts about subatomic physics, as described by QFT;
- facts about thermodynamic systems are grounded in statistical-mechanical facts;
- facts about electric current, as described by electrodynamics, are grounded in facts about quantum fields, as described by QFT;
- facts about the behaviour of systems at familiar velocities, as described by classical mechanics, are grounded in relativistic facts, as described by special relativity;
- facts about classical systems, as described by classical mechanics, are grounded in facts about quantum systems, as described by quantum mechanics.

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[10] Cf. Crowther (2020); Jaksland (2019).

Plausibly, then, there is a sense in which the hierarchy of physical theories captures grounding relations (however uneven or "wobbly" the levels may be). This type of grounding relation is what Fine (2012) calls "natural grounding". This form of grounding is not as "strict" as what Fine (2012) calls "metaphysical grounding", which holds when the "the explanans or explanantia are *constitutive of* the explanandum, or that the the explanandum's holding *consists in nothing more than* the obtaining of the explanans or explanantia" (p. 37). The idea is that metaphysical grounding leaves no "explanatory gap" between the grounded fact and the fact doing the grounding. In the case of natural grounding, however, there may be a gap, such that the fact doing the grounding is not *constitutive of* the grounded fact. To see the difference, we can compare the examples of natural necessity in the list above, with Fine's (2012, p. 36) example of metaphysical necessity, as "the fact that the ball is red and round is grounded in the fact that it is red and the fact that it is round". Clearly, facts about atoms are further away from facts about subatomic particles, than the fact of "being red and round" is to "being red and being round".

Grounding relations are not purely modal claims, but express an explanatory or determinative connection between the two facts (Fine, 2012). Ontological, or metaphysical, grounding is the strongest form of connection, and is of special interest to metaphysics, while natural grounding is weaker, and of special interest to science (p. 36). One may thus object that the grounding relations described in the list above, correlating with the hierarchy of relative fundamentality in physics reflect merely natural dependence rather than ontological dependence, and that only the latter is of interest to metaphysics. However, recall that here we are not doing pure metaphysics—we are doing *metaphysics of physics*, exploring what our theories of physics, on a realist interpretation, tell us about the entities and relations that exist in the world.

In this spirit, I claim that the entities described by each level in the hierarchy of physical theories tends to correlate with the chain of ontological dependence:

- the existence and behaviour of atoms, as described by atomic theory, ontologically depends upon subatomic physics, as described by the standard model of QFT;
- thermodynamic systems ontologically depend upon statistical mechanical systems;
- an electric current, as described by electrodynamics, ontologically depends on quantum fields, as described by quantum electrodynamics;
- systems at familiar velocities, as described by classical mechanics, ontologically depend on relativistic systems, as described by relativity;
- classical systems, as described by classical mechanics, ontologically depend upon quantum systems, as described by quantum mechanics.

The first two examples on the list reflect the relation of reduction$_1$, and may be easier to intuitively accept than the others. Of course, atoms are different things than subatomic particles or quantum fields, and we naturally think, too, that an atom is something different than the subatomic particles or quantum fields that "underlie it" or "compose it"—even though the atom's existence and behaviour is reducible to that of the quantum fields, and so, in a sense, the atom is *nothing other than* these fields on a different level of description. Contrarily, it may not feel so natural to think of a given non-relativistic object (i.e., an object not under the conditions where relativity is necessary in order to describe it) as being a different thing than its relativistic self—we can speak of both, but it intuitively seems more like two different descriptions of the one object, rather than two different objects. However, the only relevant difference between the atomic/subatomic example, and the non-relativistic/relativistic example is that the first involves the idea of levels related through coarse-graining procedures, and the other does not. Without an independent reason for thinking this relation is special in imparting ontological significance,[11] we may consider all the examples on the list as on par in capturing ontological priority. Hence, we may plausibly claim that the relation of relative fundamentality in physics correlates with that of metaphysics.

5 Implications and interpretations

In this section, I discuss different ways in which we might interpret the metaphysics of §3 – §4: what does this striking conception of relative fundamentality tell us about what exists? The main implication seems to be that we can have levels of fundamentality (ontological priority) associated with hierarchies of theories related through the physicists' sense of reduction. Importantly, these levels are not universally defined: they are not associated with particular energy- or length scales (i.e., the levels are not "micro" versus "macro" theories), but hold between any two theories where one theory is supposed to subsume the domain of the other and to be responsible for the success of the other, as demonstrated by L being derivable from M. Accepting both the L and M theories (so long as the L theories continue to be used in physics), we apparently get a "rich ontology", which seems to admit both atoms plus subatomic particles, classical forces plus quantum fields, relativistic masses and non-relativistic masses, etc., as well as the reduction or grounding relations between them. But this is not the only interpretation. Following Le Bihan (2018), we can recognise three different possibilities: (1) the *derivative view*; (2) the *eliminativist view*; (3) the *reductionist view*.

The *derivative view* is the view just described, which implies the existence of levels of reality (again, as understood as levels of fundamentality). On this view, we accept the existence of everything at each level, we accept the existence of constitutive/building relations between entities at each level, and we accept relative fundamentality of the entities described by M compared to L (Le Bihan, 2018, §4). The entities of the L theories are real, but they are *derivatively real*: they are grounded in, or built from, the more fundamental ontology described by the corresponding M theories in each

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[11] Those who already find this relation to be important in understanding ontological emergence may have an argument here, however.

case. The main objection to this view is the ontological cost: we have a very rich ontology, with entities at all levels, as well as connecting relations that exist. Some other concerns with this view are expressed in Le Bihan (2018, pp. 82–83),

> The notion of ontological level is not very clear, at least not as much as the notion of descriptive level. What does it mean that behind levels of description (think for instance of the biological level or the chemical level) lie 'ontological levels'? One could argue that levels come for free and should not be interpreted too seriously. However, if ontological levels come for free, then these merely are levels of description: the notion of ontological level has no counterpart obtaining in the world. The derivative view thereby collapses into eliminativism.
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> But perhaps one may argue that this is not a genuine problem. After all, maybe the ontological cost is well motivated insofar as it offers an adequate characterization of the delicate situation we face in contemporary physics. Nonetheless, if it is possible to come up with a view that does not entail the existence of levels of reality and has the same power of explanation, it should be preferred over the derivative space view.

So, the rich ontology may be seen as a high cost of the view, and we may be concerned that interpreting our theories as capturing genuine ontological levels rather than just levels of description is an ontological burden we needn't bear if avoidable. Nevertheless, we are here interested in the idea of relative fundamentality in physics, and this derivative view is the option to choose if we want to talk about relative fundamentality and want to take physics seriously—the two alternative views do not feature relative fundamentality.

The next alternative is the *eliminativist view*, which holds that the derivative entities of L are not real, and that only the ontology described by the fundamental M theories exists. Thus, there is no relative fundamentality, or levels of reality. This view has a minimalist ontology, but has the consequence that much of what we take to be true in physics is literally false: there are no atoms, no thermodynamic systems, no classical or non-relativistic systems at all. This becomes more disturbing with the recognition that physicists do not consider our current theories as fundamental[12], and so according to this view we'd have reason to believe that *nothing* currently described by physics exists. Only the entities described by the (absolute) fundamental theory, F, exist: those of M and L do not. The idea is that M and L describe concepts rather than entities, and that these do not map neatly onto the entities of F.

This view departs from the naive realism of the derivative view, and so represents a more sophisticated option. In other words, it requires more work. If we are to adopt this view, we need to address questions such as how it is that physics is so successful if the entities it describes do not exist, and how the concepts described by physical

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[12] See Crowther (2019).

theories relate to the minimal ontology. If these questions are not seriously addressed, then adopting this view no longer counts as metaphysics of physics, but falls into pure metaphysics.

The third option is the *reductionist view*, according to which we accept the existence of derivative entities, but reject the existence of substantive constitutive/building relations between the "derivative" and "fundamental" entities—i.e., there are no levels of reality, no notion of relative fundamentality, and thus no genuine distinction between fundamental and derivative entities (understanding fundamentality as ontological priority). Instead, the derivative entities are (in a non-spatiotemporal sense) "within" the fundamental structures, and thus the view is consistent with a *reductionist ontology* (Le Bihan, 2018, p. 84). This is the view favoured by Le Bihan (2018) in regards to the relationship between the spatiotemporal ontology of general relativity (as theory L) and the non-spatiotemporal ontology of quantum gravity (as theory M). The idea is that there is a weak relation of composition between the ontology of M and that of L, but this does not establish relative fundamentality of the M entities compared to the L ones. This weak relation of composition is supposed to be a non-spatiotemporal form of mereology, e.g., the relation of *logical mereology* of Paul (2002).

This reductionist view is the option to take if we don't want to talk about relative fundamentality, but still want to take physics seriously. Adopting this view does require some work, however, e.g., in elaborating the composition relation and explaining how it relates to the inter-theory relations of physics.

6 Conclusion

I have argued that one way of understanding relative fundamentality in physics is as holding between two theories, M and L, where the more fundamental theory M has a broader domain than L, and L is derivable from M. This establishes that L asymmetrically depends upon the physics of M. Such a relation of relative fundamentality needn't be associated with micro and macro theories, but can also hold between theories that are not restricted to certain length scales—e.g, M may be a more general theory, more exact, or finer-grained than L. This chain of relative fundamentality can plausibly be seen as correlating with an idea of relative fundamentality in metaphysics: facts about the physics described by L are grounded in facts described by M. This can be understood plainly as expressing natural dependence, but I further speculated, based on the potential fruitfulness of doing so, that we can understand this as also capturing ontological dependence—i.e., that the existence and behaviour of the entities of L ontologically depend on those of M.

Viewing the physics of a less-fundamental theory as ontologically dependent on that described by a more-fundamental theory leads to some startling consequences for ontology, however. For instance, that classical systems ontologically depend upon quantum systems just as thermodynamic systems ontologically depend upon statistical mechanical systems, or as atoms depend on sub-atomic physics. While this seemed to commit us to a rich ontology including derivative as well as fundamental objects plus the dependence relations, I argued, following Le Bihan (2018), that there are two other possible interpretations. We are only committed to the rich ontology if we want to retain a notion of relative fundamentality.

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