Anti-Fundamentalist Lessons for Scientific Representation from Scientific Metaphysics

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Abstract

Scientific metaphysics can inform discussions of scientific representation in a number of ways. For instance, even a relatively generic commitment to some minimal form of scientific realism suggests that the targets of scientific representations should serve as source material for one's scientifically-informed ontology. Historical connections between commitments to realism and commitments to reductive approaches in scientific metaphysics further inform a persistent strain of reductive approach to generating scientific representations. In this discussion, I examine two recent challenges to reductive scientific metaphysics from philosophers working across a variety of scientific domains and philosophical traditions: C. Kenneth Waters' "No General Structure Thesis" and Robert Batterman's account of scientific metaphysics built on many-body physics.

Each of these accounts has what I shall call "anti-fundamentalist" leanings: they reject the premise that fundamental physical theory is the appropriate or best source material for scientific metaphysics. Following Waters, I contrast these leanings with the methodological approach of contemporary structural realism. Additionally, both Waters' and Batterman's accounts foreground the role of scale in defining ontological categories, and both reject the reductionist ideal that the stuff at the smallest scale is the most fundamental, the most general, or the most real. I discuss the implications for scientific representation imparted by anti-fundamentalist approaches that emphasize the role of scale in building a scientifically-informed ontology.

1 Introduction

Contemplating scientific representation can naturally lead to speculation about the relation between the representation and the target, or represented, system.[1] How do representations manage to represent their targets? What can insights about the nature of representations reveal about the represented? What must the target system, and the world, be like in order for a representation to successfully represent?

This last question in particular connects investigation in scientific representation to investigation in scientific metaphysics. It is that connection that will be the subject of the remarks that follow. Regardless of whether one identifies as a scientific realist, anti-realist, structural realist, quietist, pluralist, or as some other more exotic flavor of metaphysical orientation, it is undeniable that one's beliefs about what counts as successful scientific theorizing and modeling will influence one's beliefs about what science is able to reveal about the ontological structure of the world. Equally undeniable is the banal observation that different answers to the question of what counts as successful representation will license different inferences about what scientific representations can reveal about the world is like.

Consider scientific realism. Many early presentations of scientific realism aimed to defend the truth of statements of scientific theory and the reality of unobservable objects postulated by those theories. The attention paid to the role of unobservables in justifying theoretical claims led many early realists to draw connections between realism and reductive approaches to inter-theory relations: it was atoms, not tables, whose reality early scientific realists were concerned with defending.

A frequent, though not universal, implication of this attention was that ontology could, and should, be read off the most "fundamental" scientific theories available. When applied to considerations of representation, such a view suggests that representations of unobservables should operate in a fashion analogous to representations of observables, and further that well-wrought representations of unobservables ought to, or at minimum can, serve as maps or guides to ontology. The result of such a chain of reasoning is an approach to representation and scientific metaphysics that suggests that one's ontology is best represented in the contents of our most fundamental physical theories.

This sketch is a caricature, to be sure, and it is one of an extreme version of fundamentalism about ontology. It is more common in the literature to find more moderate views that tolerate, or even embrace, theoretical objects from less fundamental theories. But the caricature is intended to gesture toward a pernicious intuition that persists even in those more moderate views in the literature, namely, that representing reality via scientific theories and models is best accomplished by a "reductionist strategy." I have borrowed this vocabulary from , who distinguish the reductionist strategy from reductionism as follows:

> *Reductionism* maintains that, in some sense to be explained, the higher level sciences in the hierarchy we have envisaged can be reduced to lower level (more basic) science, and that ultimately all can be reduced to physics. The *reductionist strategy* is more modest, recommending only that, when some objects of

[1]Many thanks to an anonymous reviewer and to Elay Shech for useful developmental comments on the thoughts that follow, and to Jennifer Jhun, Collin Rice, Chris Grimsley, Stephen Perry, Bob Batterman, and Ken Waters for productive discussions that led to the assembly of these thoughts.

> scientific study are composed of others, research on the higher-level objects might be aided by considering the constituents and what the scientific investigation of the constituents can tell us about them. (pp. 54–55)

Barker and Kitcher tolerate, and occasionally advocate for, the reductionist strategy while rejecting reductionism. My aim in what follows is stronger. I mean to articulate, and to recommend, an approach to scientific metaphysics that is actively anti-reductive. To put the point in Barker and Kitcher's terms, I mean to recommend that research on higher-level objects is sometimes hindered by considering the constituents of those objects and what the scientific investigation of the constituents can tell us about them. Ultimately, and somewhat counterintuitively, I think this anti-reductive strategy is compatible with certain reductive strategies (that "might" in Barker and Kitcher's definition does a fair amount of work for their view). However, the reductive, or fundamentalist, approach has had an extensive and, in my view, pernicious influence the development of scientific metaphysics in a way that the anti-reductive approach has not, and so my emphasis here will be on giving air time to the anti-reductive approach.

My aim in what follows is thus not to dismantle the fundamentalist intuition behind the reductive strategy definitively. Instead, it is simply to offer some evidence against it and to highlight some advantages of alternative routes; this is a project of suggestions. In assembling these suggestions, I draw on two recent accounts of scientific metaphysics from philosophers working across a variety of scientific domains and philosophical traditions. Each of these accounts has what I shall call "anti-fundamentalist" leanings: they reject the premise that fundamental physical theory is the appropriate or best source material for scientific metaphysics. These leanings also engender the use of anti-reductive strategies in articulating the ontology of a science.

The first account, from C. Kenneth Waters (Waters 2017; Waters 2018), draws on an analysis of the concept of a gene in order to develop what he calls the "No General Structure Thesis," which calls into question the association between generality and fundamentality in scientific metaphysics. Waters uses this account to critique the variant of scientific realism known as structural realism. Structural realism has historically drawn its notions of generality from fundamental physics, and Waters aims to show the limits of that strategy through an analysis of generality as conceived through the lens of biology.

The second account is most fully developed in Robert Batterman's recent monograph, *A Middle Way: A Non-Fundamental Approach to Many-Body Physics* (Batterman 2021). Therein, Batterman offers a further critique of fundamentality from within physics itself. He argues that physical theories from many-body physics, rather than fundamental physics, should be used as the source material for scientific metaphysics. I will emphasize in particular the use of "minimal model explanations" in Batterman's account, which builds on work he began with Collin Rice (Batterman and Rice 2014).

Both Waters' and Batterman's accounts foreground the role of scale in defining ontological categories, and both reject the reductionist ideal that the stuff at the smallest scale is the most fundamental, the most general, or the most real. Consequently, both reject the ideal that the stuff at the smallest scale should be taken as the basis of a scientifically-informed ontology. It bears noting that these are not the first anti-fundamentalist accounts of scientific metaphysics: Nancy Cartwright's (Cartwright 1999) "dappled world" view and

John Dupré's account of the disunity of science (Dupré 1995), for instance, may be seen as influential progenitors of both, and Michela Massimi's perspectival realism is a contemporary fellow traveler (Massimi 2018; Massimi 2019; Massimi 2022). I focus on Waters and Batterman here because they both emphasize a connection between structure, scale, and (non-)fundamentality that I believe plays an important role in subverting the reductionist intuition underlying much philosophical work on the connection between representation and realism.

A final prefatory remark: in Waters' and Batterman's rejections of fundamentalism, and in the analysis below, one may read implications both for the content of philosophical positions in the literature on scientific metaphysics and the method by which those positions are approached, articulated, and defended. Some philosophers endeavor to distinguish fundamentalism about the contents of an ontology from fundamentalism about the method of obtaining that ontology. It is my view that these two varieties of fundamentalism are more intimately interconnected than many such disambiguations tend to take into account, and I believe Waters' rejection of general structure in particular recognizes this interconnection. As such, the remarks that follow are "lumpy," that is, I do not make a special effort to identify the influence of one type of fundamentalism or another as I suggest reasons for rejecting both.

2 Fundamental Physics and Realism about Structure

In this section I review some tenets of the contemporary group of metaphysical positions that fall under the umbrella of "structural realism." Structural realism is hardly a pinnacle of fundamentalism in contemporary scientific metaphysics: it was developed in part as a response to certain dissatisfactions with ontologies that more fully embraced the reductive intuition I articulated above. So it might seem an unusual place to begin a discussion of fundamentalism today. However, by focusing on structural realism here, I will be able to accomplish two tasks. First, structural realism illustrates how the reductive strategy influences even moderately non-fundamentalist ontologies. Second, since Waters frames his own thesis in contradistinction to certain claims made by one formulation of structural realism, an introductory discussion of structural realism makes it easier to explicate Waters' views below. The goal in providing this review is, thus, to orient the reader sufficiently in order to (a) present Waters' critique in the next section and (b) establish the connection between reductive approaches to scientific metaphysics and accounts of scientific metaphysics drawn from so-called "fundamental" physics. This is not intended as a primer on structural realism nor a critical analysis of that family of views. [2]

John Worrall advanced his initial formulation of ontic structural realism in his (1989). The view he put forward then, and which he has defended since, came about as a conciliatory alternative to both scientific realism, the view that the objects posited by scientific theories exist, and scientific anti-realism, a collection of views that range from agnosticism about to denial of the existence of unobservable objects of scientific theory. The debate is often framed

[2] I thank an anonymous reviewer for pushing me to articulate more clearly the aim of this section. I note also that Penner and Nichols, this volume, offer a more accessible orientation to structural realism's place within scientific realism that readers are encouraged to consult.

in terms of the key arguments presented by each side, namely the no-miracles argument for realism and the pessimistic meta-induction to anti-realism.

The no-miracles argument urges that realism about the unobservable objects of scientific theory is the best explanation for the success of scientific enterprises, as it is the only explanation that does not make the success of science a miracle. Contrariwise, the pessimistic meta-induction argues (one might say, from hubris) that the vast majority of scientific claims made up to this point are no longer believed, so it is unlikely that current theories have gotten things right. Therefore, the present state of science gives us no reason to expect that the claims of our theories, such as about the objects that they posit, are true.

Both arguments are often given by way of examples from the history and current state of various sciences. A majority of these examples are physical. This is one of the ways in which naturalistic metaphysics has been historically tied to the physical sciences. For instance, Worrall cites the accuracy of quantum-theoretical calculations of the observed Lamb shift between the 2s and 2p energy levels of hydrogen as evidence toward the no-miracle argument, and the shift from Newtonian to Einsteinian conceptions of gravity as evidence toward the pessimistic meta-induction. Worrall's own structural realism is also demonstrated by way of physical examples, namely from the history of 19th century optics as it moves from Fresnel's to Maxwell's conception of the phenomena associated with the propagation of light.

Worrall recounts how first material particles, then waves, were posited to be responsible for the production of optical phenomena, with a few more flip-flops along the way. Additionally, the theoretical frameworks describing the movement of these phenomena changed alongside the phenomenological changes. He argues that despite all the changes, a set of mathematical relations persisted, and more generally that these relations are what is preserved over theory change. This is the foundational principle of structural realism, that mathematical or structural relations are the thing preserved over theory change. This approach is meant to reconcile the no-miracles argument with the pessimistic meta-induction. Satisfying the pessimistic meta-induction, we have no reason to expect that the particular phenomena posited by present scientific theories are real; while satisfying the no-miracles argument, we have a non-miraculous explanation for the success of science, namely that science has empirically discovered certain *structural relationships* that really are the stuff of the natural world — and so should be the stuff of ontology.

If the view stopped there, it might be compatible with Waters' and Batterman's own ontological attitudes. However, both in Worrall's original formulation and in the canonical development of ontic structural realism[3] in the work of Ladyman, Ross, and Spurrett, the views continue to develop by suggesting that fundamental physical theories are the ones that capture the most general structural relationships, and are therefore the best source material for scientific metaphysics. This line of reasoning is evident in Ladyman and Ross's (2007). Therein, Ladyman, Ross, and David Spurrett endorse a condition on scientific metaphysics that they call the Primacy of Physics Constraint, which states, "Special science hypotheses that conflict with fundamental physics, or such consensus as there is in fundamental physics, should be rejected for that reason alone. Fundamental physical hypotheses are not symmet-

[3]As noted at the outset of this section, the term "structural realism" denotes a family of philosophical positions rather than a single position. Ontic structural realism is one cluster of positions that contrasts with, e.g., epistemic structural realism.

rically hostage to the conclusions of the special sciences." (Ladyman and Ross 2007, p. 44) This is a contemporary philosophical justification of the grounding of scientific metaphysics in fundamental physics — and quite an explicit one, at that.[4]

The Primacy of Physics condition does not exclude "higher-level" physical phenomena from the ontology of physics, as I discuss below in Section 5. Indeed, Ladyman and Ross's attention to what Shech and McGivern have labeled as the "scale-relativity" of ontology (Shech and McGivern 2019) is one of its great strengths, in my view. I do not mean to suggest that the Ladyman–Ross–Spurrett account of structural realism endorses either reductionism or a deep fundamentalism. Rather, I believe that the Primacy of Physics constraint is an excellent example of how Barker and Kitcher's reductive strategy has been implemented in practice, and that as such, it illustrates the influence of the fundamentalist intuition behind the reductive strategy on the formulation of even relatively moderate views in contemporary scientific metaphysics.

In his work analyzing generality from the lens of biology, Waters aims to undo the association between generality and fundamental physics, and thereby to challenge the Primacy of Physics Constraint. I summarize this work in the next section.

3 Waters' No General Structure Thesis

Waters uses the term "traditional scientific metaphysics" (Waters 2017, p.85) to pick out views in which the results of scientific investigation are interpreted to inform metaphysical inquiry. He points out that most traditional scientific metaphysics uses fundamental physics, by which he means "the most basic theoretical results of physics," (Waters 2017, p. 84) as its source material, and that this preference appears to be connected to the supposed generality of fundamental physics. He contrasts this emphasis on "basic theoretical results" with the relatively smaller role that theoretical results from biology have played in traditional scientific metaphysics. In its most straightforward formulation, Waters' No General Structure Thesis (NGST) states: "the world lacks a general, overall structure that spans scales." (Waters 2017, p. 83) Of the four words titling the view, the one that receives the lion's share of Waters' attention is *general*. Waters is not interested in denying that the world has structure — indeed, he identifies many structures that scientific metaphysics suggests are in the world — but he is interested in denying that there is an overarching, general, or top-down structure of the world to be read off the results of science. Even more strongly, he asserts that taking the results of certain scientific investigations seriously implies that there is *not* general structure in the world.

Waters develops his view through an extended meditation on concepts of the gene. He offers a contrastive analysis comparing classical gene concepts with molecular gene concepts. For pre-1950s research in classical genetics, he argues, a central aim of investigation was to track stable causal relations. Even though many researchers believed the gene to have internal physical structure, tracking these relations did not require understanding or representation of the supposed internal physical structure of a gene. Instead, it required what

[4]This is, by the way, a variety of physicalism that Sandra Mitchell has lately referred to as "physicsism," (Mitchell 2009, p. 33) and which she, like Waters, opposes on both metaphysical and epistemological grounds.

Waters has long called "the difference principle," the idea that differences in genetic makeup cause differences in phenotype.

Waters' difference principle is an example of what Angela Potochnik has termed a "causal pattern" (Potochnik 2017), and it is a representation of a relationship between phenomena that both Potochnik and Waters (like Woodward before them in his (2003)) have striven to distinguish from *structural* relations. Using T.H. Morgan's own writings on the causal role of genes in development, Waters takes pains to highlight that the difference principle does not care about the internal physical makeup of a gene, and that "the structure of the world that geneticists were manipulating and investigating was not directly reflected in the structure of their concepts and theories." (Waters 2017, p. 91) The success of the classical gene concept despite its disregard of physical structure poses a problem for structural realism.

A structural realist might endeavor to salvage the primacy of physical structure through molecular gene concepts, which do appeal to notions of physical structure, such as of the physical makeup and sequencing of the nucleotides on a strand of DNA. But, in Waters' analysis, in order for the molecular gene concept to be flexible enough to be usable in scientific practice, there is no way to formulate the concept such that genes remain the fundamental units of heredity, development, or evolution. Re-centering structure shifts the concept *away* from fundamentality, rather than urging it closer. Yet again, this is a counterintuitive and troubling result for structural realism.

Ultimately, Waters (following the received view in contemporary philosophy of biology) holds that there is no such thing as *the* concept of a gene. However, the various gene concepts that there are are causal more than they are structural. Consequently, genes are not the fundamental structures of biology; further, biology is not the kind of thing that has fundamental structures. This analysis is used as empirical evidence against the idea that the world is arranged into fundamental, natural classes of structures that can be accessed via traditional scientific metaphysics. Rejecting the fundamentality of structure in biology further enables Waters to reject the generality of structure for traditional scientific metaphysics, that is, the idea that whatever the fundamental structural relationship of the physical world turns out to be, it spans across length scales and thereby guides the unfolding of the world from the very small to the very large. (Although he focuses on length scales, presumably there are analogous arguments to be made for time and energy scales.)

Waters offers a cartographical metaphor to characterize what he sees as the difference between structure and general structure: some cities have overall or general structure, where others do not. Cities with general structure — like Manhattan, Beijing, and Waters' own Calgary, Alberta — have street systems that make it easy to navigate from one part of town to another, using information about street layout and naming conventions. Cities lacking such structure — like Delhi, Cairo, and Pittsburgh, Pennsylvania — tend to be more difficult to navigate. Waters does not name or expand upon the type of structure that some cities have and others lack, other than to call it general. I will expand on this metaphor slightly, in order to develop a point about how structure interacts with scale in urban planning and beyond.

While there are a few strategies for street layout in urban planning, one of the most ancient and most common is the grid. The streets of Manhattan are famously laid out in a grid consisting of numbered avenues running north–south with the number increasing to the west, crosscut by east–west-running streets with the number increasing to the north. This allows for inductive projection from one's present street location to the location of nearby streets, and even to the location and distribution of streets in other parts of the city.

Pittsburgh, on the other hand, is a mess wrought by geography and time. Grid layout and street naming conventions vary by neighborhood. Main thoroughfares run sort-of parallel to the banks of the two rivers that converge around the city's downtown district, which means they often are angled at around 40° to each other. A road called Beechwood Boulevard snakes through multiple neighborhoods, varying from north–south to east–west and back again, while also overtaking blocks of other roads. Further, the hilly topography of the city makes certain roads appear to intersect on maps while one may be 100 yards higher than another. This topography also creates a system of cross-neighborhood shortcuts that might be likened to the warp pipes in Super Mario videogames. Unlike in Manhattan, in most areas of Pittsburgh, little can be induced about nearby neighborhoods or how to get to them from one's present street address.

While many Pittsburghers take pride in the convolutedness of their city's street network,[5] some might object that there are portions of the city, such as the Strip District, that do conform to a grid plan. Likewise, residents of Inwood in upper Manhattan, or those in its southern Financial District, might object that their portions of the city are not governed by a numbered grid. These exceptions illustrate (1) that street grids exist at a variety of scales and (2) that grids are not identical with Waters' notion of overall or general city structure. Manhattan happens to have general structure, which happens to be a grid. Pittsburgh lacks general structure, but employs grids in certain sectors. Other cities, like Paris and Washington, D.C., have large-scale wheel-and-spoke street networks that divide the city into wedge-shaped districts. Still others, like Beijing and Santiago and Houston, Texas, employ ring roads that enclose a mixture of wheel-and-spoke and grid networks, alongside geographically-constrained networks that look nothing like either grids or wheel-and-spokes.

The intention of meditating on this variety of layouts is to complicate Waters' metaphor by pressing on the question of which among these street networks count as having — and which count as lacking — general structure. I am quite sympathetic to Waters' intuition that cities whose street networks confer ease of navigation through layout and naming conventions are networks that can be said to have general or overall structure. However, street networks can be the size of a neighborhood or the size of a nation. The U.S. Interstate Highway system, while not a grid, aims to follow numbering conventions akin to those in Manhattan: east–west routes take even numbers, ascending from south to north, while north–south routes take odd numbers, ascending from west to east. I suspect Waters would concede that it has general structure; likewise, I expect he'd admit the same of Pittsburgh's Strip District or D.C.'s system of numbered and lettered streets, crisscrossed by diagonal avenues and sectioned into quadrants. Overall or general structure can (generally) be found, if one selects an appropriate scale or resolution to search for it.

This latter point is friendly to Waters, who ultimately concludes that "the world" lacks general structure *that spans scales*. It is possible to define a system by reference to a general structure that defines it only if the boundaries of the system are selected such that general structure applies to it. For Waters, it is an empirical result that the system defined as "the

[5] Indeed, there is even a Tumblr account devoted solely to "The Nonsensical Roads of Pittsburgh," https://pghroads.tumblr.com/

world" lacks general structure. Geographically, this seems true, although Waters' "world" is more one of biology than geography. An upshot of NGST is the ability to reconceive generality in terms of scale-dependent conceptions of reality.

His alternative articulates that attention should be paid to the length scales at which systems are investigated in order to assess the applicability of structural approaches to those systems. I agree. In fact, I think Waters does not go far enough in claiming only that general and scale-invariant notions of structure fail in biology. They fail in physics, as well. Batterman's work on the importance of mesoscale descriptions of phenomena in many-body physics illustrates this point. I summarize some of this work in the next section.

4 Minimal-Model Explanations and Mesoscale Metaphysics

Batterman and Rice (2014) contrast minimal model explanations with a class of theories of explanation that they call "common features accounts." Common features accounts, on their view, are theories of explanation in which a model explains "in virtue of meeting some 'accuracy' or 'correctness' conditions,"(Batterman and Rice 2014, p. 356) by which they mean that representational features of the model correlate with represented features of the system. They count mechanistic and causal or difference-making accounts of explanation among common-features accounts, as well as mapping accounts of the role of mathematics in scientific explanation.

Their minimal model explanations offer a different view of what makes a model explanatory. They argue that rather than pointing to a list of common features between the model and the target system as *justification* of explanatory efficacy, one must in addition be able to explain why heterogeneous details of the class of systems being modeled are irrelevant to an explanation of the class of systems. Their physical example comes from fluid dynamics and appeals to the renormalization group — a mathematical strategy for abstracting away from the details of a given represented system — to make their point.

In Batterman and Rice's (not uncontroversial) view,[6] the renormalization group does not represent a common feature among a class of systems being modeled, nor does it signify a definable structural relation between features of a system. Instead, it is a technique for eliminating degrees of freedom in computational models. It produces a set of fixed points characteristic of the system not by drawing structural relations among the elements, but by eliminating many structural details that are *irrelevant* to understanding the system's behavior. They argue that processes like this delimit the universality class to which a system or set of systems belong. This strategy is not limited to physics: they also illustrate how minimal models work in the modeling of biological populations via discussion of Fisher's sex ratios.

Minimal model explanations disentangle the notion of invariance from that of structure, and they assign explanatory priority to the former. I believe minimal model explanations can cut at structural realism in two ways. First, Batterman and Rice show that many common-features accounts appeal to *idealized* structural relationships to explain phenomena. The

[6]See (Batterman 2019) for a discussion of the controversy and a defense of the Batterman–Rice view.

role of idealization in such accounts calls into question the metaphysical underpinnings of those structural relationships. This is not a new point (Cartwright 1983, for instance, makes it). But what we can take away here is that in order to maintain a metaphysics grounded in structural relations (physical or otherwise), structural realists will need to provide an account that distinguishes genuine, ontological structural relations from the merely useful ones that nonetheless support much of scientific practice.

Waters' NGST points to the despair of accomplishing such a task by highlighting that the generality sought in scientific metaphysics is unlikely to be found in worldly structural relations. Minimal-model explanations suggest further reasons to question the defensibility of structural realism, both by showing that structural relations need't be accompanied by metaphysical ones (as in the mathematical structure of the renormalization group) and by appealing to features besides structural relations as the explanatory ones. Minimal model explanations show that the notion of structure — even in physics — is not so general as the structural realists need it to be.

There is an objection here for the structural realist: the physics from which the minimal-models account draws is not *fundamental* physics, so it is subject to the same metaphysical asymmetry as the special sciences. Batterman's recent work in scientific metaphysics (Batterman 2021) provides a rejoinder. His examination of many-body and condensed-matter physics considers a wide variety of physical systems and analyzes the role of those systems' mesoscale features (as opposed to macro- or microscale features) in explaining how those systems work and why certain mathematical models are appropriate representations of those systems. He concludes that minimal models capture "natural properties" of the systems they model by representing correlations between mesoscale features of the target systems. Further, he writes, "[i]t is this fact that justifies taking the mesoscale parameters as the most natural or most joint-carving with respect to the bulk behavior of many-body systems." (Batterman 2021, ch. 7.3)

Batterman's analysis shows that using the fundamental theories of physics as source material is the wrong starting point for getting metaphysics out of physics. Instead, examining mathematical models of many-body physical systems reveals the explanatory power and ontological naturalness of the mesoscale parameters that represent those systems. Like Waters' NGST, Batterman's middle-out approach produces a rejection of the ideal of a top-down, generalist account of the relations and relata that comprise a traditional scientifically-grounded ontology. In minimal-model explanations, ignoring the fundamental physics of the systems is what allows for unification of many systems under a single universality class. This is an ontological result grounded strict anti-reductive, anti-fundamentalist approaches, and it shows that in at least some cases, fundamentalism is incompatible with the ontology suggested by the representational contents of our best explanations of physical phenomena.

Waters, in particular, sees results like these as damning for structural realism, due to the fact that that view requires a top-down, generalist conception of "*the* structure" of the world (Waters 2017, p. 101) grounded in the "fundamental" science of physics. I agree strongly with the anti-reductive result, and I wish to emphasize the strides that can be made by recognizing and rejecting the influence of the reductive strategy on scientific ontologies. However, I believe some substance (or a structure representing it, anyway) is still left in structural realism after the exorcism of the fundamentalist spirit. In the next section, I consider what rejoinders might be available for structural realists and identify a difference in methodological attitude between Waters' and Batterman's work, on the one hand, and that of the structural realists, on the other.

5 Fundamentality and Conceptions of Scientific Metaphysics

Waters' NGST and Batterman's middle-out approach both suggest that there is no scale-invariant notion of general structure to be gleaned from traditional scientific metaphysics. Following Waters, I have framed these results as problematizing structural realism, especially Ladyman and Ross's canonical formulation of ontic structural realism due to their (Ladyman and Ross 2007). However, a bit more charity is due to the view, which will both offer an olive branch and provide a backdrop for some remarks on the role of scale in scientific metaphysics and scientific representation.

First, there is a reading of Ladyman, Ross, and Spurrett's view that may be able to accommodate Waters' NGST. Here is the view in their own words:

> All scientific disciplines except mathematics and, arguably, some parts of physics, study temporally and/or spatially bounded regions of spacetime. By this we mean that the data relevant to identifying real patterns are, for most disciplines, found only in some parts of the universe. Biology draws data only from regions in which natural selection has operated. Economists study the same region as biologists (Vorbeij 2005, Ross 2005)—since natural selection depends on competition created by scarcity—but at a different scale of resolution, since only significant aggregates of many biological events are relevant to economic generalization. All psychological measurement is confined to subregions of those examined by biologists and economists, namely, locations in the neighbourhoods of central nervous systems. Anthropologists and other ethologists study a tiny sliver of the universe: specific populations of organisms during the very recent history of one planet.
>
> Let us reflect on the epistemological and metaphysical implications of this institutional fact. What accounts for the specific selection of spacetime regions, at specific scales, to which disciplines are dedicated is obviously, to a very great extent, a function of practical human concerns. Scientific institutions organized by dolphins wouldn't devote more than 40 per cent of their total resources to studying human-specific diseases. There is no puzzle as to why far more scientific attention is lavished on the dry parts of the Earth's surface than on the waterlogged parts. To some extent this same consideration explains why more information is gathered about the Earth than about the Moon. Self-absorption and convenience, however, account only partly for the distribution of scientific activity. It is also important, in the third instance above, that the Earth is a great deal more complex than the Moon. . . . [T]here are far more real patterns to be discovered by isolating specific spacetime regions, and scales of resolution on those regions, and treating them as relatively encapsulated from other regions and scales, on Earth than on the Moon. This was true before life on Earth began, and is the main part of the explanation for why life did begin on the Earth but

> not on the Moon; but the extent to which the ratio of real patterns to possible physical measurements on Earth has increased relative to that on the Moon has been made staggeringly great by the progress of first biological, and then social and cultural, evolution. (Ladyman and Ross 2007, pp. 45–46)

I want to attend to two features of this view. First, there is no claim to scale-invariance as a working notion of generality; indeed, quite the opposite, as much of what they say in the first paragraph indexes the subjects of their ontology (that is, the "real patterns"[7]) to particular length scales. To the extent that this view leaves room for a real pattern that is identifiable as general structure, it would be one real pattern among many, and it would not be one that occupies center stage in most scientific theorizing. This is supported further by Ladyman and Ross's notion of scale-relative ontologies, which appears later in their monograph and which Ladyman in particular has further developed in more recent years. For instance, in 2018, Ladyman claimed that "ontology is scale-relative, in the sense that different energy levels and regimes, as well as different length and time scales, feature different emergent structures of causation and law." (Ladyman 2018, p. 103).

A thin notion of general structure is even recoverable from the cartographic metaphor: sure, it is easier to navigate Manhattan than Pittsburgh by using inferences about grids, road naming conventions, and city layout. But both Manhattan and Pittsburgh *have maps*. These maps are instances of real patterns just as much as the pattern of organs in a typical human or the pattern of electronic symmetries in ionized sodium, or the pattern of planets distributed throughout the solar system. On a thin reading of general structure, Pittsburgh's map is just as general as Manhattan's, because both describe street networks, even though Manhattan's street network could also be redescribed by a grid with labeled axes, and Pittsburgh's could not.

Viewing the Ladyman et al. claim as being about only a thin notion of general structure does, I believe, rescue the view from the letter of NGST, but not the spirit. This brings me to my second point. The description of how real patterns come to be limited in scope is noticeably top-down: it begins by invoking the image of all of spacetime, in order to point out that most real patterns apply to proper parts thereof. The examples — from biology, then economics, then psychology and anthropology — are offered in order to capture the intuition that patterns exist at more general, then more specific, scales of resolution, despite that the inclusion of anthropology seems to defy the Matryoshka-like "nesting" of scales developed in the first three examples.

This top-down perspective suggests a methodological approach to scientific metaphysics that is certainly incompatible with the methodological underpinnings of Waters' NGST and Batterman's middle-out approach. Ladyman et al.'s description of the complexity of the Earth relative to the Moon underwrites this methodology: they consider candidates for real patterns by beginning from the scale of planets, and work their way in; similarly, biological evolution begets social, which begets cultural. The asymmetric dependence of smaller-scoped patterns on larger-scoped ones, generated by the Primacy of Physics Constraint, further underscores this top-down methodological attitude: quantum and relativistic patterns are more reliably repeated across broader regions of spacetime, relative to condensed-matter patterns, let alone anthropological ones.

[7] A term due to Daniel Dennett (Dennett 1991)

Even though there may be an escape route for Ladyman et al. from the letter of NGST, I worry that the top-down methodological approach baked into their view is derived from the fundamentalist intuition underlying the reductive strategy. And I worry that that intuition continues to be counterproductive to theorizing about the connection between scientific realism and representation. Waters and Batterman both emphasize the fecundity of their alternative methodological attitudes. For Waters, a focus on biological complexity generates different types of ontological questions than a physics-centered approach, while for Batterman attention to the mesoscale descriptions of many-body systems redirects metaphysical inquiry toward a new understanding of what counts as a "natural" grouping of physical phenomena that does not rely on either bottom-up or top-down description. In the next section, I show how a top-down attitude toward scientific metaphysics may skew one's approach to scientific representation.

6 Anti-Fundamentalist Metaphysics as a Guide to Scientific Representation

An implication of Waters' and Batterman's views that is not explicitly addressed by either but is, I suspect, tacit in both, is that philosophers would do well to reject a part–whole approach to scientific metaphysics and should instead seek alternative logical and conceptual foundations for a scientifically-informed ontology. This implication bears directly on the connection between scientific metaphysics and scientific representation. Rejecting a part–whole conception of metaphysics means there is no ontological impetus to develop representations of scientific systems based in on part–whole models. This leaves room for approaches to modeling that emphasize other varieties of relation between the relata in a model. Massimi's perspectival realism is one such approach; my "conceptual strategies" account of how multiscale models come to represent nanoscale phenomena is another.

Massimi's project surveys a wide array of natural and social scientific practices in order to examine what types of metaphysical commitments are required in order to believe that reliable scientific knowledge is generated through contemporary scientific practices. Her central question is about what a realist commitment implies about the kinds of knowledge that is possible to obtain — and advisable to pursue — from scientific investigation. She contrasts this project with what she sees as the traditional realist project of "mapping the existence of the 'scientific zoo.' "(Massimi 2022, ch. 1) Massimi's approach emphasizes the role of the knower in answering her central question, and the resulting realism is built around the complex relations between knowers, known, and ways of knowing. Unsurprisingly, given these interests, Massimi's account emphasizes the role of representation in defining a scientifically-informed ontology. Her view is, I believe, a viable path forward for realism that also suggests new ways to connect realism and representation while avoiding part–whole approaches to scientific metaphysics.

Through a case study on a computer simulation of a nanoscale crack propagating in silicon, I have argued (Bursten 2018) that there are multiple types of techniques for stitching together the component models in a multiscale model. The case study contains three component models — a macroscale continuum model, a mesoscale classical rigid-body model, and a microscale quantum model — and two "handshaking" algorithms that bridge the macro to the meso, and the meso to the micro. She shows that the two handshaking algorithms are not strictly logically nor empirically dictated by the component models they aim to bridge: the macro-to-meso handshake involved the manipulation of non-representational features of the macro model in order to make a handshake between the two components possible, while the meso-to-micro handshake involved the construction of a fictional entity on which to perform computation. These are distinct conceptual strategies, and neither strategy can be redescribed in terms of part–whole relations between the different component models. Warrant for trusting a model to represent a system well derives from analysis of how these conceptual strategies function.

To put the point in terms of some of this essay's earlier discussions, each of the component models in my case are instances of real patterns at different spatial scales of resolution. What her analysis shows is that there is conceptual work to be done in order to build the modeling techniques that allow the model to "zoom out" or "zoom in." The resulting multiscale model does produce a top-down, overall description of the simulated system — namely, a Hamiltonian describing the distribution of energy in the system at a given instant — but modelers only come to formulate, and to trust, this top-down description by developing conceptual strategies to enable the construction of handshake algorithms. I also argue that it is not the case that the most zoomed-in model is the one that best or most truly represents the system.

Together, these features of my analysis suggest an approach to scientific modeling that further defies the reductionist intuition about representation. Like the accounts of Waters, Batterman, and Massimi, my analysis generates an anti-reductive account by offering an alternative to part–whole conceptions of systems of scientific interest. Further, Waters, Batterman, and I each explicitly emphasize the role of scale in limiting the scope of claims and inferences about systems of scientific interest. This is evidenced in Waters' opposition to general structure, Batterman's anchoring of natural categories in the mesoscale, and my attention to the conceptual strategies that stitch dynamics together across scales.

The point of bringing these accounts into friendly dialogue with one another has been to highlight some limitations in approaching scientific metaphysics from the top down — or, conversely, from the bottom up. Both directions of approach fall prey to what I have identified as the part–whole conception of metaphysics. I suspect that that conception is largely responsible for any lingering reductionist intuitions about how scientific representation works: when part–whole metaphysics is interrogated as a guide to representation, it will recommend parts and wholes, which can breed the reductionist intuition about representation that I identified above. I hope these alternative metaphysical starting points can generate alternative starting points for representation, as well.

While structural realism played a useful role as a foil to these accounts, I suspect that there are versions of a structural-realist approach to metaphysics that can avoid the pitfalls of top-down methodological approaches — Steven French's more recent developments of his own version of ontic structural realism (French 2014; French 2017), as well as Ladyman's more recent expansions of his views (Ladyman 2017), may avoid some of the critiques leveled here. Further, I suspect that what is necessary is, at least in part, increased and careful attention to the role of scale in delimiting, defining, and explaining the nature of various structures, which is to be found especially in Ladyman's more recent work. A gesture toward such a view can be seen in the thin notion of general structure articulated via cartography in the previous section. A more robust exploration of how scale-dependent notions of structure might reorient the methodology of structural realism is a project for another day.

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