

# Metaphysical and scientific accounts of emergence: Varieties of fundamentality and theoretical completeness.

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## Chapter summary

The concept of emergence figures prominently in contemporary science. It has roots in philosophical reflection on the nature of fundamentality and novelty that took place in the early decades of the Twentieth Century. While it is no longer necessary to offer philosophical defenses of the science of emergent properties, attention to basic metaphysical questions remains important for engineering and scientific purposes. Most importantly, this chapter argues for precision with respect to what scientists and engineers take to count as fundamental for the sake of their uses of the concept of emergence.

## 1 Introduction

Two defining characteristics; novelty and naturalness mark the concept of emergence. When emergent properties are first instantiated, they are said to be novel in some difficult to specify, but presumably non-trivial, sense. While every moment of natural history is new in the sense of being at least at a different time from what came before, the kind of novelty that is associated with emergent properties is understood to constitute a metaphysically significant difference. What might that significance amount to? Very roughly, we can say that if an emergent property appears, there is a new *kind* of entity or property on the scene. Not just more of the same. To claim that a property, say for example a property like transparency, liquidity, or consciousness, is emergent is to make a judgment about the way it relates to more fundamental features of the world. The emergent property or entity differs in kind from that which pre-existed it or is more fundamental than it. The first task of this paper is to explore what it might mean for emergent

properties to relate or fail to be related to more fundamental properties.

The discussion of emergent properties in scientific and philosophical research has emphasized discontinuities and differences between the emergent property and the prior or more fundamental properties from which it arises. However, emergent properties are not just discontinuous with what came before. They are also thought to be part of the natural order in some intelligible sense. According to most contemporary proponents, emergent properties are not unnaturally or supernaturally new (their appearance is not miraculous) but instead can be understood scientifically insofar as they are intelligibly connected with parts of the natural world and in particular with other properties that are prior or more fundamental.

The scientific problem of emergence involves understanding the relations between the emergent property and the more fundamental or prior properties. The practical payoff of this understanding is improved levels of prediction and control over those emergent properties and entities that concern us most.

## 2 To explain is not to eliminate

How could there be an intelligible connection between metaphysically distinct kinds? In one sense this is a question only a philosopher would bother asking. There are plenty of simple examples. Take Hilary Putnam's (1975, 295-98) famous example of the explanation for why a square peg fails to pass through a round hole. The rigidity of the pegs and the rigidity of the walls of the holes is dependent on their physical structure. However, the property of being able to pass through a hole of a particular size and shape is a different kind of property than the properties governing the physical constituents of the peg. Geometrical facts about the sizes of the cross section of the peg and the hole are sufficient to explain the facts about the peg's being able to pass through. An attempt to account for this higher-level property in terms of the physics governing the particles in the peg would result in an unexplanatory, albeit a true and very long, description of the particular case. The geometrical explanation, by contrast is simple, provides clear guidance for interaction in the system, and generalizes beyond this particular peg and hole to all pegs, all holes, and beyond.

The geometrical explanation explains many things at various scales, including why we have round manhole covers rather than square ones. Manhole covers have the property of not

falling dangerously on people working in the sewers below because of the circular (rather than, say, rectangular) shape of the covers. This is one example of how we can intelligibly connect distinct kinds of properties. The *microphysical properties* of this particular peg, its particular material instantiation, can be connected with the macro-level property of *passing through this particular hole* via a geometrical explanation. That geometrical explanation has the virtue of being applicable beyond this particular case. The property of being a hole, being able to pass through, having a particular stable shape in space, having the particular microphysics that this peg has, etc. are connected in the explanation in a way that satisfies our demand for explanation in this context perfectly.

Putnam intended this to be an example of a *non-reductive* explanation, since, he thought, the material constitution of the peg is almost completely irrelevant to the explanation of its fitting or failing to fit. His use of this example was meant to indicate the role of explanations that are not simply descriptions of physical microstates of systems. There is more going on in nature, he argued, than merely the microphysical.

Philosophers in the 1960s and 70s were very concerned with the distinction between what they saw as reductive and non-reductive explanation. They fixated on the distinction between reductionist and anti-reductionist explanations because of their concern for the ontological implications of explanations. For some, the *threat* of reductionism is that we are encouraged to believe that one kind of object simply does not exist insofar as it can be described in terms of some more basic kind of object. This is an ontological concern. Notice that it involves a judgment that is independent of the process of explanation: We might decide that the existence of certain kinds of explanation license ontologies with fewer things in them. Thus, given the fact that we can explain traffic jams on the highway in terms of the interactions of individual vehicles, we might be tempted to draw the ontological conclusion that there is no traffic jam. Notice that if one decided to take this strategy with respect to one's ontology, it is a step beyond what the explanation of the traffic jam by itself tells us. In fact, I would argue, one needs to justify the step from a successful reductive scientific explanation to the claim that because of this successful explanation we can therefore eliminate the thing that has been explained from our ontology. Furthermore, in paradigmatically reductionist explanations we see examples of intelligible relations being discovered between distinct kinds of properties. For example: subatomic particles are not the kinds of things that have properties like rigidity or wetness. A structural explanation of the subatomic constituents of a diamond goes some way

towards explaining why the diamond in the engagement ring is rigid. There is an intelligible relation between the macro-properties of the diamond and the micro-properties of its constituents that adverts to the structure of the diamond crystal. Properties like hardness or rigidity are manifest only on some scales and result from interactions of large numbers of molecules. There is simply no non-relational explanation of why diamond molecules give rise to hardness. These relations, like the geometrical properties of Putnam's pegs, are not built into their relata.

The concern among philosophers is inspired by the concern that giving an explanation is equivalent to explaining away. Philosophers sometimes argue, following Carnap and Quine, that "explication is elimination" in natural science as well as in mathematics. This is due to a mistaken conflation of kinds of explanations and the diverse theoretical goals motivating explanatory projects. Quine's arguments concerning eliminativism were drawn from purely mathematical contexts. He was moved, primarily by his understanding of the history of analysis in nineteenth century mathematics. The infinitesimal is a puzzling artifact of early calculus that, according to popular opinion) we no longer need to include in lessons to high school students thanks to the work of Weierstrass, Dedekind, and Cantor. As the story goes, Weierstrass gave us the means to eliminate the infinitesimal, Dedekind and Cantor helped to finish the job. Quine strongly approved of this story and built his account of explication as elimination upon it.<sup>1</sup> He proposed a view that began by individuating metaphysically puzzling notions in mathematics, like the infinitesimal or the ordered pair, via the mathematical roles that they play. Insofar as they are "*prima facie* useful to theory and, at the same time, troublesome" Quine recommended that we simply find other ways to perform their theoretical role. Once we find these other ways we can stop worrying about those concepts. Like the infinitesimal, they are eliminated (1960, 266).

The explanatory project that motivates complexity science or other studies of emergent properties is not the same as that which motivated Quine's approach to philosophical analysis. For Quine the method of philosophical analysis is to "fix on the particular functions of the unclear expression that make it worth troubling about, and then devise a substitute, clear and couched in terms of our liking that fills those functions" (1960, 258-9). By contrast, the goal of research in the natural sciences is the discovery of novel objects and relations in the world. The

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<sup>1</sup>Błaszczuk, Katz, and Sherry (2013) raise a number of credible objections to the standard histories of analysis that Quine relies upon. Their general line of criticism focusses on what they see as the unwarranted drive for

explanatory goal is understanding rather than the rearticulation, in more parsimonious terms, of functions that make the phenomenon worth troubling about.

In scientific and engineering research more generally, this kind of elimination is simply not a goal. Insofar as things like traffic jams or epidemics are troublesome, that trouble is not eliminated by defining ways that other, less troublesome things, cause delays and illness. A traffic jam or an epidemic is not a “troublesome” theoretical entity in Quine’s sense of being what he calls a “defective noun” that we wish to do without in the interest of ontological parsimony. Instead, the very goal of scientific investigation presupposes the reality of the object to be understood. If there were no epidemics or traffic jams they would not pose any real practical problem. Defining the hurricane away will not solve our hurricane-related challenges.

Emergentism was a view that was articulated prior to the rise of concerns about explanation, reduction, and elimination discussed above. Since the decline of so-called British Emergentism in the 1930s, philosophers have worried about the anti-scientific connotations of the term ‘emergence’ and have been concerned that emergentism involves an attachment to mystery, or at least the belief in limits to the power of scientific explanation. For the two most important figures in the British Emergentist tradition, Samuel Alexander and C.D. Broad, emergent properties resisted mechanistic or reductive explanation. They held somewhat different views on the nature of explanation.<sup>2</sup> However, the most important aspects of their views are the following: For Broad, nothing about the laws of physics would allow an ideal epistemic agent (what Broad called a mathematical archangel) to predict all aspects of emergent properties ahead of time. Broad mentioned the smell of a chemical compound as one of the properties that the archangel would have been unable to predict (1923 71). For Alexander, the appearance of emergent properties should be accepted as a brute fact, accepted, as he said “with natural piety” (See Alexander 1920 46-47). The emergentists saw the distinctive properties of, for example, the chemical, biological, or psychological levels as simply being brute facts. They argued that these distinctively non-physical aspects of reality, the smell of sulfur, the price of bread, the chemical properties of gold, the effects of crowds on individual psychology, the nature of life, consciousness, and countless other examples can be integrated intelligibly into our understanding of reality without being eliminated from our ontologies. In my view, the British Emergentists should be read as insisting that there are distinct kinds of properties or phenomena and that this distinctness cannot be explained away. At this point in the history of

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<sup>2</sup> See Symons 2017 for a detailed discussion of the view of explanation held by the British Emergentists.

science and philosophy we can have plenty of explanations that connect distinct kinds of phenomena or properties in ways that allow for understanding without assuming that such understanding entails eliminating one of these kinds.

### 3 Emergent properties and more fundamental properties

Fundamentality is the central conceptual component of discussions concerning the emergence. Most obviously, contemporary uses of the term 'emergence' vary according to their users' views of fundamentality. Varying positions with respect to emergence usually differ with respect to either (a) what their proponents take to be fundamental or (b) whether they see emergence as a purely epistemic matter. This is evident, for example, when we compare the divergent scientific and philosophical careers of the concept of emergence. In general, contemporary scientists talk relatively freely about emergent phenomena and properties while being non-committal (beyond gesturing approvingly to fundamental physics) about what counts as genuinely fundamental.<sup>3</sup> Instead, scientists tend to emphasize notions like predictability, surprise, and control. This is not to say that these epistemic *seeming* concepts are unrelated to metaphysical questions. As the philosopher of mathematics Alan Baker has pointed out, being a weakly emergent property does not entail any necessary relation to the epistemic or cognitive limitations of particular agents (2010, 2.3).<sup>4</sup> What Baker is pointing to is that weak emergence is an objective feature of certain kinds of systems in the same way that mathematical features of systems are independent of the epistemic and cognitive capacities of agents.

Since the middle of the 20<sup>th</sup> century most analytic philosophers have been more wary of the term 'emergence' than our colleagues in science and engineering. The most central feature of the resistance to the concept of emergence in the second half of the 20<sup>th</sup> century was been the philosophical community's attachment to the doctrine of physicalism. Physicalism is the view that physics provides us with our fundamental ontology. Ontology is our theory of what counts as real. The tendency among philosophers had been to see physics as our means of understanding the ultimate nature of being.

In recent decades, the grip of physicalism has loosened and, perhaps because of this,

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<sup>3</sup> See, for example the representative papers and articles from scientists in Bedau and Humphreys 2008.

<sup>4</sup> A weakly emergent sequence or pattern, for example, would be one that can be computed, but cannot be compressed informationally. Every step in the pattern or sequence must be cranked out by the simulation. There can be no shortcuts and no abbreviating recipes/algorithms. Bedau (1997) is the most well-articulated source for the idea of weak emergence.

philosophers are again engaging with the philosophical problem of emergence. However, because of our decades old practice of outsourcing fundamental ontology to physics, there had been relatively little philosophical engagement with the question of what counts as fundamental until very recently. Thus, philosophical debates concerning emergence have taken place in a context where physicalism dominated discussions.

While physicalism has dominated the conversation about emergence, the problem of emergence can be articulated independently of the kind of fundamental ontology one holds. This is good news since it means that it is possible to think about the concept of emergence without having settled all other metaphysical questions ahead of time. We can begin with a common sense account of emergence as the concept operates in philosophical and scientific discourse. Then we can proceed to get clearer on the implications of the concept of emergence for matters that concern us in scientific practice. Specifically, we are concerned with the relationship between emergent properties and the challenge of scientific modeling.

Philosophical usage of the term 'emergence' usually marks a single problem that can be stated very simply:

*Do genuinely novel entities or properties come into being over the course of natural history or are all facts determined by the basic facts so as to be explainable (at least in principle) in terms of those basic facts?*

While the question is easy to pose, providing a well-justified answer has proven to be a persistent conceptual challenge.<sup>5</sup> This question is of practical relevance to scientists and engineers in settings where we encounter complexity.<sup>6</sup> One reason that this is such a difficult problem involves the clash between ordinary common sense and what we can call scientifically informed common sense. Part One explains the conflict between these two ways of thinking.

Scientific interest in emergence is driven by the assumption that emergent properties and phenomena are real and relevant. For philosophers steeped in the doctrine of physicalism that assumption is precisely the point of contention. In the second half of the twentieth century most philosophers simply denied that there really are emergent properties. Until recently, philosophical reflection on emergence has focused on the challenge of understanding how one

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<sup>5</sup> For a detailed discussion of the conceptual problem see Kim 1999, Symons 2002, and the philosophical (rather than the scientific) papers collected in Humphreys and Bedau 2008.

<sup>6</sup> For a clear and helpful account of the meaning of the term 'complexity' see Mitchell 2009

can simultaneously believe that physics provides the fundamental and maximally general story concerning the nature of being while at the same time believing that emergent properties are genuinely real. Scientific investigation of the problem of emergence from the 1990s to the present has, for the most part, pragmatically sidestepped the metaphysical questions focusing instead on explaining or modeling relationships between putatively emergent properties and their predecessors.<sup>7</sup> While pragmatism might be a sensible strategy in short- to medium- term scientific research, it leaves the deeper and more basic philosophical questions unaddressed. In the sciences, as in philosophy in the late 20<sup>th</sup> century, the implicit attitude was to defer the deepest questions to the physicists.

## 4 Where does the philosophical problem of emergence come from?

Common sense is not free from ontological questions. In ordinary experience, we puzzle over the ontological status of holes, shadows, reflections, and the like, and as we try to organize the inventories of our lives we might wonder how to classify and count the objects that are of interest to us. Even in commercial contexts, considerable energy is expended thinking through ontological questions. The multinational oil company Shell, for example, was forced to develop its own ontological system in order to understand its own complex organization and to avoid inconsistency and waste.<sup>8</sup>

Common sense encourages us to believe in things like oil rigs, pipelines, dogs, minds, countries, and economies. We are inclined to think that a world without such things would have a smaller inventory of real objects than the actual world. If we imagine a scenario in which all dogs died yesterday, we tend to think that such a world would contain fewer things than actually are. Even though all the mass and energy that made up our dog will still be present in its corpse and local environment, we still believe that his death is a loss. In what sense is a dog something more than the sum of its mass and energy? Perhaps, we want to say, dog-like

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<sup>7</sup> Take for example Herbert Simon's position on the metaphysics of emergence. He argues that "By adopting this weak interpretation of emergence, we can adhere (and I will adhere) to reductionism in principle even though it is not easy (often not even computationally feasible) to infer rigorously the properties of the whole from knowledge of the properties of the parts. In this pragmatic way, we can build nearly independent theories for each successive level of complexity..." (1996, 27)

<sup>8</sup> Matthew West was one of the leading figures in the development of Shell's ontology. His work on the kinds of questions that it was necessary to answer as part to the management of the Shell's highly complex business demonstrate the direct role that philosophical ontology plays in the most hard-headed business contexts. See, for example West 2009; 2011



organization or structure is something real, over and above fundamental matter and energy. In ordinary life, it is natural for us to think of dogs as real. If pressed, we might qualify our view a bit, insisting instead that dog-patterns or dog information is real. But we also recognize the difficulty of grasping the ontological status of a dog-like arrangement of parts? Would the arrangement or pattern exist independently of our ways of knowing and thinking? Do dogs make a difference to the world over and above the difference that dog parts make? Is the dog the same as its fur? If so, which fur? Presumably not the fur that he has shed.

The reason we feel that we can dismiss questions like these is because we believe that the genuinely real stuff in the universe is the matter-energy that physics studies. Thus, in spite of ordinary common sense, we are hesitant to state categorically that the animals that veterinary science and zoology studies are as real as quarks and gluons. According to physicalists, physics is the science that tells us what exists; it is the source of (most of) our ontological commitments.<sup>9</sup> On this view, all the other sciences, from chemistry all the way up to psychology and economics derive what ontological legitimacy they have in virtue of the derivability of their ontologies from the fundamental physical story.

Recent decades have shown that it is extremely difficult to be fully committed to physicalism. Extreme versions of physicalism face three kinds of problem. The first, known as Hempel's dilemma, challenges the idea that our grasp of physics is good enough to serve as the source of our ontological commitments in the first place.<sup>10</sup> Hempel pointed out that we are certainly not committed to the ontology of the physics of the past since we believe that past physics contained numerous falsehoods. By induction, we can be reasonably sure that the physics of the present day is not perfect and that it will undergo correction. Thus, it would be unwise to look to present-day physics for our finished account of what exists. Presumably future physics, let's call it the ideal finished physics, contains the correct ontology. However, the problem with future physics is that we do not know what its ontology contains. It might be the case that future physics contains elements, like qualitative experience, for example, that current physicalists would reject. At the very least, it seems pointless for the physicalist to

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<sup>9</sup> Even the most die-hard physicalist will have a hard time avoiding ontological commitments to selves and sets. For example, Quine (1960) famously endorses an ontological commitment to sets. Precisely what is involved in ontological commitment can be understood in a variety of ways. The simplest way to understand the ontological commitment's that come with holding some theory is as the kinds of entities that are required in order for the sentences of a theory to be true. For an overview of the difficulties associated with this way of thinking about ontological commitment, see Rayo 2007.

<sup>10</sup> See Hempel 1969.

commit herself to the ontology of the ideal finished physics when she is unable to know what it is.<sup>11</sup>

The second problem for physicalism derives from the physicist's need for some kind of mathematics and the puzzle that the ontology of mathematics poses.<sup>12</sup> A third is the role of subjectivity, specifically, the challenge of reconciling conscious experience with the physicalist worldview. Most of us believe that our minds are real and that we and some other animals have conscious experiences. We can entertain a thought experiment wherein we imagine a possible world which features the kinds of brains and behavior that we have in the actual world, but whose inhabitants lack any qualitative experience accompanying their brains' processes and structures, we are inclined to say that these possible people are missing something that we regard as genuinely real.<sup>13</sup> But if consciousness - or more precisely the qualitative dimension of phenomenal experience - makes no difference in the causal economy of the physical world, how can we be so confident that it exists?<sup>14</sup> Either consciousness does make a causal difference somehow, or the idea of unique causal powers as a criterion for reality is incorrect, or we are simply deluded about our own conscious experience.

In the face of considerations like those sketched above, Daniel Stoljar concludes that it is not possible to formulate a coherent and non-trivial version of physicalism. "The bad news is that the skeptics about the formulation of physicalism are right: physicalism has no formulation on which it is both true and deserving of the name. The good news is that this does not have the catastrophic effects on philosophy that it is often portrayed as having in the literature" (2010, 9)

Our pragmatic impulse is to be inclusive when deciding what kinds of things are real. "Of course dogs are real!" says the exasperated voice of common sense. Even if we are not committed physicalists, in our ontological judgments, ordinary common sense is opposed by another kind of common sense. What we might call *scientifically-informed common sense* is not

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<sup>11</sup> It is possible to commit oneself to the answers provided by a process that one trusts. For example, I will buy roughly as many donuts as the number of people who RSVP for the breakfast meeting. However, the fact that one might be committed to believing the results of future scientific inquiry is independent of one's position with respect to current ontological disputes. One cannot preclude the possibility that physics will settle on an ontological framework that supports one's opponents.

<sup>12</sup> See Benacerraf 1965 for the classic presentation of the challenge of providing both a normal semantics for mathematical statements and a causal theory of mathematical knowledge.

<sup>13</sup> This is David Chalmers' famous zombie argument against the identification of conscious experience with brain states. (See his 1996)

<sup>14</sup> One answer here is that we are simply deluded about actually having conscious experiences. Daniel Dennett provides the most sophisticated account of what it could mean for subjects to tell themselves that they are conscious. (See his 1991)

precisely identical with physicalism, but they share a common deference to scientific practice. Rather than being a clearly articulated philosophical thesis, of the kind that physicalists hoped for, scientifically-informed common sense can be seen as a set of methodological commitments. It involves preference for reductive explanations, anti-supernaturalism, and some rough metaphysical commitments concerning causation and individuation that are drawn from conservation principles in physics. We can think of it as a disposition towards certain kinds of ontological commitments and explanations rather than a clearly defined philosophical position. A rough list of kinds of claims that scientifically-informed common sense endorses runs as follows:

- there are no non-physical causes
- the physical world is all there is (more or less... maybe (parts of) mathematics are real too)
- the current contents of the physical world are nothing more than a rearrangement of the stuff which existed during the big bang
- to be real means to make a real (and unique) causal difference to the way the world is

It is important to note that the notions of causation, completeness, and reality that undergird scientifically informed common sense are not defined or articulated in detail. These three interlocking concepts are not straightforwardly scientific in nature, but are, instead, metaphysical or at least conceptual. Currently, opposition to emergentism is not posed by physicalism per se, but rather by this more nebulous and poorly defined set of commitments that I am calling scientifically-informed common sense.

## 5 Incompleteness

While physicalism does not present a viable alternative to emergentism, this does not mean that emergentists can declare victory. The challenge to their view involves articulating the relationship between fundamental and emergent properties no matter what the account of fundamentality that we settle on.

What do we mean by fundamentality? We can begin with a sample of kinds of fundamentality relations that we might consider. Three familiar candidates are composition, governance and determination.<sup>15</sup> When we think about parts and composition, the fundamentals would be the basic micro-constituents and their possible composition relations. Let's call this Part-fundamentality, or P-fundamentality for short. Philosophical Atomism is the most familiar kind of P-fundamentality. For atomists, the basic components of nature have a fixed character. While atoms are not themselves subject to change, all change can be explained in terms of the changing relations among the atoms. On this view, atomic participation in new mereological sums explains everything.

Another kind of fundamentality concerns laws and governance. In this case, we list the laws that govern nature and specify their relative authority with respect to one another. Here, the fundamentals would be the laws that govern our system with maximal generality. Notice that maximally general laws need not be the laws governing the P-fundamental parts alone. If we did posit the maximally general laws as governing the P-fundamentals, those laws would be equivalent to what are sometimes called micro-governing laws. (Hutteman, 2004) However, there are other ways of understanding maximal generality that do not involve P-fundamentality at all. If we claim, for instance, that it is a law of nature that nothing travels faster than the speed of light, this law applies equally to Volkswagens as to quarks. Similarly, what Clifford Hooker has called basic and derived structural laws can be maximally general without being solely micro-governing, insofar as the scope of the quantifiers in these laws is not restricted to

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<sup>15</sup> For the purposes of this paper I will not discuss the currently popular notion that fundamentals stand in a *grounding* relation to other properties. This is because, as Jessica Wilson (2014) argues, the idea that there is a grounding relation that does something other than standard relations of composition, governance, determination, or perhaps reduction has not been established. More importantly, I think that no matter where one settles with respect to the grounding relation, the question of the relationship between fundamental and emergent properties will remain. This is a topic for another paper though!

the micro-constituents, but can include, for instance, the entire universe. (Hooker 2004) Let's call fundamentality that is concerned with governance, L- fundamentality.<sup>16</sup>

Given the varieties of fundamentalism and given that one's view of what counts as emergent will be relative to one's view of fundamentality, it is prudent to maintain a provisional stance with respect to what counts as emergent. In fact, we can allow our inventory of the factors determining the basic level to be discoverable a posteriori. We can make the case that our story about what counts as fundamental will change over time depending on the outcome of inquiry. Most obviously, we should leave room for a range of views about micro-determining factors. Micro-determination could take place in a variety of ways that we have not yet considered. By including a third, non-specific placeholder kind of fundamentality, (we can call it H-fundamentality) we preempt the objection that the present analysis does not allow for a posteriori discoveries with respect to micro-determination.

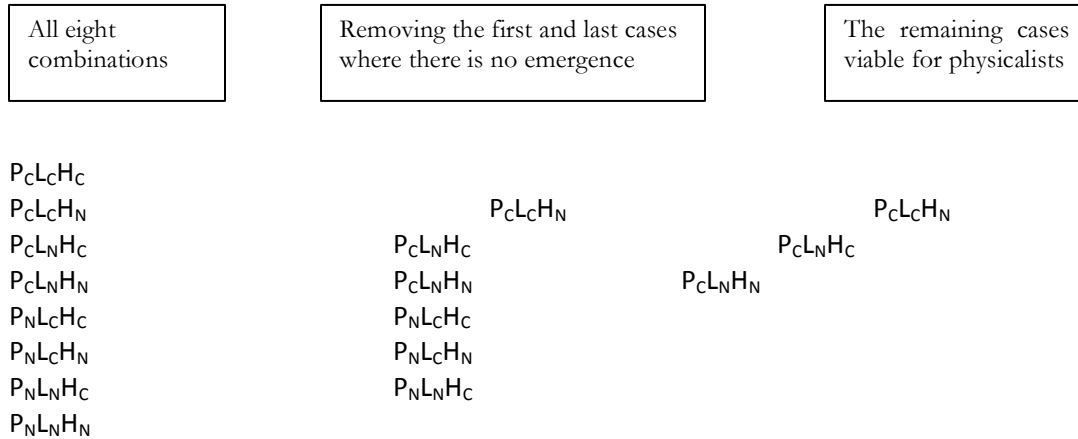
At this point, we can present the combinations of types of fundamentality along the following lines: We could let  $P_N$  stand for those properties that are novel with respect to the composition relation operating over the basic parts of our ontology. Let's let  $P_C$  stand for those properties that are not novel with respect to P-fundamentality. Let's let  $L_C$ ,  $L_N$ ,  $H_C$ , and  $H_N$  be defined in the same manner. We can see that with these three fundamentality predicates in place we can form combinations in a way that already has some useful expressive power. We could then begin to match positions with respect to emergence with the table of eight possible combinations of the three kinds of fundamentalism, as in the figure below. The first place on the table is equivalent to an eliminativist view where all novel features are denied. The denial of novelty in the first place would be an implausibly strong kind of anti-emergentism. This would reflect, for example, the position that Quine takes with respect to most ontological questions (see the discussion above). However, the last place on the table where  $P_N L_N H_N$  is also a denial of emergence since, while it embraces novelty, it denies naturalness, asserting the existence of properties with no connection to the fundamentals whatsoever.

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<sup>16</sup> Neither of these standard views captures the account of structural fundamentality that Sider has recently defended. I won't have time to discuss this in detail, but suffice to say that Sider sees structure as equivalent to nature's joints. The structural characteristics of nature, on his view, are accessible to us through common sense, mathematics, and physics. We could call his view S-fundamentality. Since Sider's account is new enough not to have figured in these debates, we can leave it out for now.

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Fig 1. Combinations of novelty and naturalness with respect to kinds of fundamental property



In the case of the remaining six spots on our table, each represents a combination of novelty and naturalness with respect to the three fundamentals listed. Note also that some of the combinations in a list like this will be either self-undermining or will be judged to be implausible metaphysical positions for some reason or another. So, for example, most contemporary physicalists will want to hold on to micro-constitution and will stick to the top half of the table. Given the three types of fundamentality presented here and given the usual physicalist qualms there will be only three options left for the emergentist; the second, third and fourth slots on the table.

From the remaining three slots on the table for example a  $P_{C_L}H_N$  property would be one that obeys micro laws, is constituted by micro-constituents but is determined by non-micro-level factors. For instance, when complexity theorists talk about emergence they often suggest that: “Systems with a higher-level of complexity emerge from lower-level entities in new structural configurations” here the usual reductionist composition relations and micro-governing laws are still in effect, and yet such phenomena are thought to be novel by virtue of their novel structural properties. Specifically the new structure is taken to be the factor that determines the appearance of the emergent property.

Of the remaining three accounts of ‘emergent’ properties, the first is that emergent properties obeys micro laws and are constituted by micro-constituents but are determined by factors other than those at the micro-level ( $P_{C_L}H_N$ ). The second is that laws of basic physics do not govern the emergent properties but those properties are determined by the micro-

constituents and micro factors ( $P_{CLNH_C}$ ). Finally, in the third case, an emergentist who is also a physicalist could assert that emergent properties are constituted by the microphysical constituents but are neither determined nor governed by microstructural laws or determiners ( $P_{CLNH_N}$ ).

This is an exercise in a kind of conceptual bookkeeping with respect to fundamentals that invites us to reconsider the problem of emergence in terms of clearly articulated accounts of what it is that we think metaphysical fundamentals are doing in our theories. If there are other candidate kinds of fundamentality or relations to fundamental properties, they could be added, generating a new table of positions along the lines described here.

Completeness is essential to arguments against the possibility of strongly emergent properties. There are a variety of ways one could imagine carving up the question of completeness for a metaphysical system. One might regard completeness as equivalent to capturing all true causal judgments, all facts more generally, all the right ways of carving up the world, the capturing grounding relations, and so on. At the very least, to determine completeness we need to decide on the relevant set of truths that we hope to capture and we need to specify as precisely as possible the set of objects, relations, laws, etc. that the metaphysical position proposes. This is an unwieldy *interpretive* task for most non-trivial metaphysical systems. However, as I have suggested elsewhere, for the purposes of understanding completeness we can treat metaphysical frameworks abstractly by recasting them as *generative fundamentals* (Symons 2015). Generative fundamentals are the set of total states of a world and the list of possible transformations on that set. They should be thought of as being a set of unexplained explainers. Elsewhere, I explain in detail how to think of a metaphysical framework in terms of generative fundamentals for the purpose of determining whether it is complete (Symons 2015).

From the anti-emergentist perspective, fundamental theories provide a total account of the behavior of a system. For example, Lewisians argue for the view that all facts (the entire actual factual landscape) are entailed by the most basic facts (1986, 15). On this view there exists a determination relation of some kind between the basic facts and all the other facts.

In these discussions, it is worth noting the burden that is being assigned to the fundamentals and how easily we can slip from a claim about supervenience or necessitation at an instant to the claim that all past, present, and future facts are packed into the facts about the fundamentals at any instant.

One way to understand the behavior of a system is to specify the possible states it can occupy and to provide some account of how the system changes from state to state. If the anti-emergentist is right, listing all the fundamental facts would suffice for generating such an account. With this in mind, we can reconsider the problem of emergence in terms of the relationship of the putatively emergent property to some specified set of states and transformations. Different kinds of fundamentality will result in different sets of states and transformations, whether a property is emergent will be determined relative to that set of states and transformations. A complete set of states and fundamentals will have no emergent properties associated with it.

When it comes to the problem of determining completeness, there are two significant challenges. First, there is the challenge of excluding the kinds of interactions between states and transformations that lead to truths about the system that are not derivable from the generative fundamentals. Prospects for finding a principled way to accomplish such an exclusion for metaphysical systems of sufficient complexity to be of interest are bleak.

One could simply define the space of relevant facts recursively in the following way:

- If a fact is fundamental, it is a true reachable fact.
- If a fact can be obtained from true reachable facts by means of the rules of the generative fundamentals, it is a true reachable fact.
- The set of true reachable facts is the smallest set of facts satisfying these conditions.

In any suitably interesting or complex set of generative fundamentals there will be at least one non-reachable fact. This is provably the case for arithmetical facts as Gödel's proof of the incompleteness of the system of *Principia Mathematica* demonstrated (1931). The anti-emergentist might decide to exclude facts about mathematics from his claims about the domain of reachable facts. At that point, one could imagine trying to exclude the possibility of genuinely novel properties using two general strategies. First, one could exclude unanticipated results of interaction by positing a system that anticipates (or claims to anticipate) all possible interactions ahead of time (the Leibnizian way) or by claiming that one's system does not have potentially problematic interactions between states of the system (the Humean way).<sup>17</sup> Both ways are

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<sup>17</sup> I discuss these alternatives in detail in (2015).



unattractive for reasons I discuss in Symons (2015). In that paper I argue that any approach that attempts to rule out the existence of emergence a priori is simply unscientific.

Unanticipated interactions are difficult to prevent completely without creating systems that are so trivially simple as to generate little to no insight. In Boschetti and Symons 2011 we attempt to demonstrate how even a trivially simple computational system can generate unanticipated and novel interactions.

In addition to preventing or anticipating interaction, the proponent of metaphysical completeness faces a stranger problem, namely the problem of transients. A transient is defined as a state or sequence of states or a subset of that sequence of states that has a first member.<sup>18</sup> This way of understanding transients is similar to the concept of transients as they appear in a Markov chain analysis. In a Markov chain if there is some non-zero probability that the system will never return to a state, we say that this state is transient. If a state is not transient, it is recurrent.<sup>19</sup> For any generative fundamentals,  $F$  the possibility of transients entails that  $F$  might have resulted from some other generative fundamentals  $F^*$ .<sup>20</sup>

There will be some cases where  $F^*$  is epistemically inaccessible from the perspective of agents in some system governed by  $F$ . More intuitively, for any system or universe that we imagine completely captured by some generative fundamentals, we cannot exclude the possibility that the set of fundamentals themselves are the result of some non-repeating process - a transient – that is not part of that set. One could imagine a simple series of states in some oscillating universe, for example, where the denizens live between a Big Bang and a Big Crunch. They might have developed a cosmological theory that correctly predicts all the truths of the future of their universe and perhaps does a good job retrodicting the past states of the universe as well. However, the apparent completeness of this account is threatened by the possibility of a transient that was part of the history of the universe, but not part of the cycle of bang and crunch into which their universe has settled.<sup>21</sup>

Properties in some system governed by  $F$  can be such that, relative to the successor or predecessor system, they can be called emergent. The kind of emergence exhibited by these systems can be called strongly emergent insofar as the novel system's generative fundamentals differ from the system that preceded it. In this sense, apparent completeness at the level of

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<sup>18</sup> Booth (1967)

<sup>19</sup> For an overview of Markov chains see Booth (1967).

<sup>20</sup> This section repeats some of the discussion of transients in Symons 2015

<sup>21</sup> See Symons 2015 for more elaboration on the relationship between emergence and the idea of incompleteness for generative fundamentals.

generative fundamentals governing the later system would not be sufficient to account for all the metaphysically basic features of reality. The purpose of the argument from transients is simply to note a limitation on attempts to use the completeness of some set of generative fundamentals as the basis for an argument against emergence.

At this point, the advocate of fundamentalist metaphysics might respond that one can opt for an *a posteriori* view of the fundamentals such that whatever this additional extra emergent something is, it can simply be added to the proposed list of fundamentals in order to ensure completeness.<sup>22</sup> As argued by Hempel (1969) and later by Symons (2015), an *ad hoc* strategy of adding to the list of fundamentals as required by new evidence is insufficient if one's goal is to defend something like physicalism or any other metaphysically complete account of the fundamentals against the possibility of emergence. Given the possibility of transients, one's metaphysics can fail with respect to the project of generating a complete list of fundamentals even when we allow our account of the fundamentals to be modified *a posteriori*. The possibility of an incomplete fundamental metaphysics turns out to be unavoidable and cannot be remedied by the addition of extra principles or categories. This is because, as we have seen even in cases where the present and future states of the natural world appear to have been completely captured by some set of fundamental principles, the possibility that these principles themselves are the result of the process of emergence cannot be excluded. Of course, what this means is that the possibility of emergent properties is simply an indication that the ambitions of theorists hoping for a fundamental theory can always be dashed.

## 6 Models, Emergence, and Fundamentality

As we have seen, emergent properties are not indicators of trouble with respect to scientific explanation. However, they run counter to the ambition of metaphysical fundamentalism. In the engineering and modeling context when we refer to emergent properties of systems we are often referring to those that were not originally intended as part of the functional characterization of the system. The unplanned behaviors of a system or the unintended uses to which these systems are put are referred to as emergent.<sup>23</sup> This is a straightforward analogue to the more abstract treatment of properties that are not (and perhaps could not be) anticipated

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<sup>22</sup> Or the fundamentals can be modified in some other way in order to ensure completeness.

<sup>23</sup> Following Crutchfield and Mitchell some computer scientists have proposed actively exploiting features of emergent computing via the use of genetic algorithms.

given what I called the generative fundamentals alone. Building on work by John Holland 1992 and others, Das, Mitchell, and Crutchfield (1994) define emergent computation as “the appearance in a system’s temporal behavior of information-processing capabilities that are neither explicitly represented in the system’s elementary components or their couplings nor in the system’s initial and boundary conditions.” There are a wide variety of accounts of emergence in the scientific literature. The key to all of them is the role of either limitations on the explanatory power of some existing system or the role of interactions as the source of novelty.

Scientific models are intended to provide guidance with respect to explanations and predictions of emergent properties or to offer possible interventions that would allow control over those properties. The relation between these models and the philosophical problem of emergence is multifaceted and challenging. As we have seen, our desire for theoretical completeness faces a set of hard limits. The fact that these limits characterize attempts to build complete systems in general is directly relevant to the engineering and modeling community. Discussions of novelty and emergence in complex systems science and computer science often take place in a way that obscures the central problem of defining the boundaries of the systems under consideration. In Boschetti and Symons 2011 we argue that the conceptual features of the problem of interaction can be characterized in a straightforward and non-question begging way. We argue that in scientific and engineering contexts the specification of system or model boundaries determines our commitments with respect to the nature of interaction and the possibility of genuinely novel causal powers for emergent properties.

The science of emergence involves understanding the role of system boundaries and interactions. Part of this task involves being explicit about what counts as fundamental in one’s model. With respect to what properties are the putatively emergent properties emergent? Properties that are called emergent will be understood as such relative to those features of the model taken to be fundamental and different scientific domains will understand this differently. The conceptual relationship between the emergent and the fundamental will be the same across different scientific domains, but they will vary with respect to what is taken to be fundamental and what is understood to count as a system boundary.

This paper discussed the limitations of one prominent account of ontological fundamentality; physicalism. We went on to provide a general characterization of fundamentality, explaining the challenges faced by the anti-emergentist versions of

fundamentalism. Anti-emergentist approaches must claim completeness, must block potentially novel interactions, and must make claims about epistemically inaccessible pasts. These are significant challenges for the anti-emergentist that force him into the unscientific position of having to exclude unwanted possibilities a priori. We concluded by asserting that scientific uses of the term emergence depend on stipulating as precisely as possible the nature of system boundaries and being as clear as possible about what one takes to be fundamental in the systems in question.

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