Perfectly Grounded: Special Sciences and Fundamental Physics

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Abstract

I propose an account of special science properties which (i) respects their autonomy from fundamental physical properties, and yet (ii) implies that they reduce to fundamental physics. The account uses two metaphysical tools: grounding, and perfect naturalness. Roughly put, the account invokes grounding to reduce special science facts, and the account invokes perfect naturalness to characterize the autonomy of special science properties.

1 Introduction

How do theories of non-fundamental phenomena—economics, psychology, and gender; chemistry, biology, and sociology; and all the rest too—relate to theories of fundamental physics? What is the connection between the fundamental bits of the world—the particles or fields or whatever those bits might be—and the non-fundamental world with which we are all familiar? Or as it is put in the literature: what is the relationship between special sciences[1] and fundamental physics?

My main aim, in this paper, is to lay the foundations for an answer to this question. I will propose an attractive, explanatory, unified, and general account of the metaphysics of

[1] I follow Fodor (1974), Kim (1992), Loewer (2009), and many others, in using 'special sciences' in a very general sense: economic theories, psychological theories, feminist theories, and other such theories of the non-fundamental, count as special sciences in my sense of the phrase.

special science properties. The account—call it the 'Perfectly Grounded' account—invokes two well-known primitives from contemporary metaphysics: grounding, and perfect naturalness. It uses those primitives to formulate a series of principles which, taken together, describe the relationship between special science properties—like the economic property *is a recession*, or the psychological property *is a belief*, or the gender property *is a woman*—and the properties of fundamental physics.

As will become clear, the Perfectly Grounded account unifies two popular views of the relationship between fundamental physics and special sciences. According to one—call it 'Reduction'—special sciences reduce to fundamental physics (Albert, 2015; Gómez, 2020; Kim, 1992; Loewer, 2009). According to the other—call it 'Autonomy'—the special sciences are autonomous from fundamental physical science (Callender & Cohen, 2010; Cartwright, 1999; Fodor, 1974; 1997; Kitcher, 1984).

Philosophers generally assume that Reduction and Autonomy are mutually incompatible; or at least, in deep tension with one another. For if special sciences reduce to fundamental physics, then in what sense are the former autonomous from the latter? How can the special sciences be autonomous, if they ultimately reduce to fundamental physics? And if special sciences are autonomous from fundamental physical science, then in what sense do the former reduce to the latter? How can the special sciences reduce to anything, if they are truly autonomous?

As I will explain, the Perfectly Grounded account resolves the tension between Reduction and Autonomy. According to the Perfectly Grounded account, special sciences are grounded in—and so reduce to—fundamental physics. And according to the Perfectly Grounded account, special sciences are autonomous from fundamental physics insofar as special science properties are perfectly natural. So contrary to philosophical orthodoxy, Reduction and Autonomy need not be taken to conflict. They are compatible with one another.

In Section 2, I use grounding to describe exactly how special sciences reduce to fundamental physics. In Section 3, I use perfect naturalness to describe exactly how special science

properties are autonomous from fundamental physical properties. Together, these sections form the basis of the Perfectly Grounded account. In Section 4, I discuss the tension between Reduction and Autonomy in more detail, and I show how the Perfectly Grounded account can be used to resolve that tension. Finally, in Section 5, I discuss two other attractive features of the Perfectly Grounded account.

2 Grounding the Special Sciences

Grounding can be used to reduce special sciences to fundamental physics. In what follows, I explain how. To start, I discuss some characteristic features of grounding. Then I present a condition which describes how grounding connects fundamental physics to the special sciences. Basically, according to that condition, facts about special science properties are grounded in—and so reduce to—facts about fundamental physical properties.

By way of preparation, it is worth reviewing three characteristic features of grounding.[2] First, the generative feature: grounding is a relation of generation.[3] In particular, if one fact grounds another, then the former generates the latter.[4] The former, that is, explains why the latter obtains. For instance, take the scarlet ball. Since the ball's being scarlet grounds the ball's being red, it follows that the ball's being red is generated by—is explained by—the ball's being scarlet.

Second, the fundamentality feature: grounding relates more fundamental facts to less fundamental facts. That is, if one fact grounds another, then the former is more fundamental than the latter. For instance, again, take the scarlet ball. Since the ball's being scarlet grounds the ball's being red, it follows that the ball's being red is less fundamental than the

[2]For more discussion of these features, see (Correia & Skiles, 2019; Fine, 2012; Schaffer, 2016).

[3]In what follows, by 'grounds', I mean 'fully grounds'. So if something grounds something else, then the former is fully sufficient to generate the latter.

[4]In this paper, I follow Rosen (2010) in taking grounding to be a relation between facts. There are other approaches to grounding: some take it to be a sentential operator (Fine, 2012), while others take it to be a relation between entities (Schaffer, 2016). Those other approaches could be used instead of Rosen's, in the account to come. That account would just need to be rewritten in various ways.

ball's being scarlet.

Third, the multiplicity feature: many facts have multiple distinct grounds. In particular, if one fact grounds another fact, it does *not* follow that the former is necessary for the latter to obtain. For instance, take the scarlet ball once more. The fact that the ball is scarlet grounds the fact that the ball is red. But the former fact is not necessary for the latter fact. The ball could be red without being scarlet. For the ball could be crimson instead. And if it were, then that fact—namely, the ball's being crimson—would ground the ball's being red. So the fact that the ball is red has multiple possible grounds: the ball being scarlet, the ball being crimson, and so on.

Now for the condition which connects special sciences to fundamental physics. It says that facts about special science properties are grounded in facts about fundamental physical properties.

> Grounding Properties
>
> Let S be a special science property, and let a be an object. Suppose that a has S. Then for some fact f which can be expressed using only the predicates and terms of fundamental physics, the fact that a has S is grounded in the fact that f.[5]

In other words, special sciences are grounded in fundamental physics in the following sense: each fact of the form "Object a has special science property S" is grounded in a fact of the form "Thus-and-so fundamental physical items have such-and-such fundamental physical properties."

For example, consider the property *is a belief*. Let f_b be the fact that a particular psychological state has that property. Then according to Grounding Properties, f_b is grounded in some fact f about fundamental properties, particles, and fields. So f_b is generated by f: a psychological state's beliefhood is generated by fundamental particles and

[5]Other approaches to grounding support other accounts of a ground-theoretic connection between special science properties and fundamental physical properties. For example, suppose that grounding is a relation which can obtain between non-facts—such as properties—in addition to facts (Schaffer, 2016; Wilhelm, 2020). Then consider the following account: each special science property S is grounded in a plurality of fundamental physical properties P_1, P_2, and so on. In what follows, the difference between this account and Grounding Properties will be largely irrelevant; I focus on the latter simply because in various ways, it is simpler.

fields having thus-and-so fundamental properties. Moreover, f_b is less fundamental than f: a psychological state's beliefhood is less fundamental than facts about fundamental properties, particles, and fields. And finally, f may not be the only ground for f_b: the fact that a psychological state is a belief may be grounded in different fundamental physical facts at other, merely possible worlds.

Similarly for other special science properties, like *is a recession* and *is a woman*. Each economic fact of the form "Thus-and-so event is a recession" is grounded in a fact about fundamental physical particles and fundamental physical fields instantiating fundamental physical properties. Each gender-theoretic fact of the form "Such-and-such person is a woman" is grounded in facts about physical fundamentalia too. These economic facts and gender facts are generated by—and less fundamental than—the fundamental facts in which they are grounded. And in addition, these economic facts and gender facts may well be grounded in entirely different sorts of facts at other worlds.

Grounding Properties is a precisification of Reduction. For grounding provides a generative, explanatory, reductive connection between less fundamental phenomena and more fundamental phenomena. Grounded facts are a 'free lunch' (Schaffer, 2009): the grounded are nothing over and above the grounders. So if one fact grounds another, then the latter reduces to the former.

Note that Grounding Properties avoids a problem faced by other proposed reductions of special sciences to fundamental physics. To see the problem, consider the following precisification of Reduction: special science properties are identical to—and in that sense, reduce to—complicated fundamental physical properties (Fodor, 1974, p. 99).[6] This version of reductionism, call it 'Identity Reductionism', has trouble accommodating the fact that special science laws often admit of exceptions (Fodor, 1974, p. 110; Loewer, 2009, p. 224).

[6] A brief aside: accounts like these do not seem very 'reductive' to me. Relations of reduction are asymmetric: if one property reduces to another property, then the latter does not reduce to the former. But identity is a symmetric, not asymmetric, relation. So identifying special science properties with fundamental physical properties is incompatible, I think, with reducing the former to the latter.

For consider any special science law of the following form.

$$\text{All } S_1 \text{ states bring about } S_2 \text{ states.} \tag{S}$$

According to Identity Reductionism, the special science property of being an S_1 state is identical to some fundamental physical property; the property, say, of being a P_1 state. And according to Identity Reductionism, the special science property of being an S_2 state is identical to some fundamental physical property; the property, say, of being a P_2 state. So (S) is logically equivalent to the following generalization of fundamental physics.

$$\text{All } P_1 \text{ states bring about } P_2 \text{ states.} \tag{P}$$

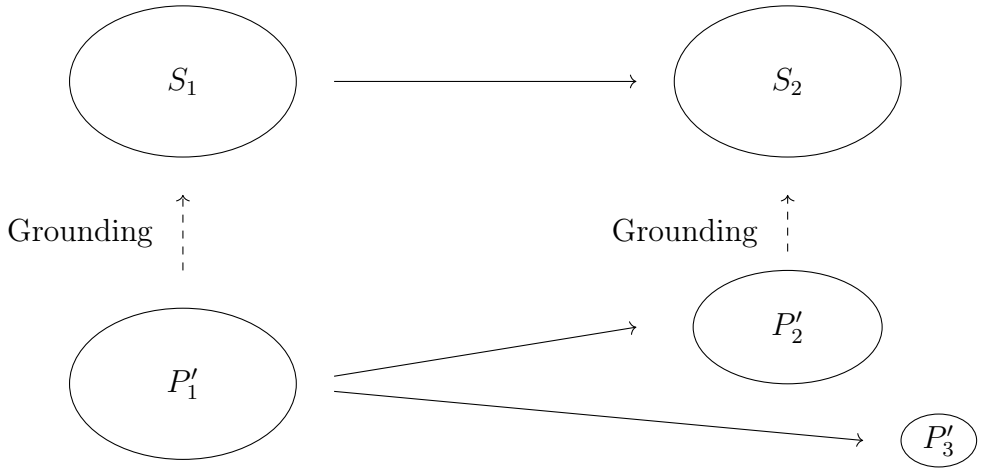
True generalizations of fundamental physics, like (P), do not admit of exceptions. But if (P) is exceptionless, then (S) is too, since (S) and (P) are logically equivalent. And that is the wrong result: special science laws almost always admit of exceptions.

Grounding Properties avoids this problem. For Grounding Properties simply says the following: for some fundamental physical properties P_1' and P_2', facts of the form "This is a P_1' state" ground facts of the form "This is an S_1 state," and facts of the form "This is a P_2' state" ground facts of the form "This is an S_2 state." Grounding Properties does not imply that the properties *is a P_1' state* and *is a P_2' state* are numerically identical to *is an S_1 state* and *is an S_2 state* respectively. Better still, when supplemented with a plausible principle concerning identity conditions for facts, Grounding Properties implies that these fundamental physical properties are distinct from their special science correlates.[7]

[7]To see why, note that grounding is typically taken to be irreflexive. So each fact of the form "This is a P_1 state" is distinct from each fact of the form "This is an S_1 state" which it grounds, and each fact of the form "This is a P_2 state" is distinct from each fact of the form "This is an S_2 state" which it grounds. Now consider the following plausible assumption about identity conditions for facts: if a fact of the form "Object a has property F" is distinct from a fact of the form "Object a has property G", then the property F is distinct from the property G. This assumption, along with the fact that 'This is a P_1 state" is distinct from "This is an S_1 state", implies that *is a P_1 state* is distinct from *is an S_1 state*. Similarly, this assumption—along with the fact that "This is a P_2 state" is distinct from "This is an S_2 state"—implies that *is a P_2 state* is distinct from *is an S_2 state*.

So Grounding Properties does not imply that (S) is logically equivalent to any generalization, like (P), of fundamental physics. And so Grounding Properties is perfectly compatible with (S) admitting of exceptions, even though generalizations of fundamental physics do not.

In fact, Grounding Properties can be used to explain how (S)—but no corresponding generalization of fundamental physics—could admit of exceptions. For consider the picture below.



In this picture, each ellipse represents a collection of facts of the form "This is thus-and-so type of state." The ellipse S_1, for instance, represents the collection of facts of the form "This is an S_1 state." The ellipse S_2 represents the collection of facts of the form "This is an S_2 state." The ellipse P_1' represents the collection of facts of the form "This is a P_1' state." The ellipse P_2' represents the collection of facts of the form "This is a P_2' state." And the ellipse P_3' represents the collection of facts of the form "This is a P_3' state", where P_3' states are (i) distinct from P_1' states and P_2' states, and (ii) brought about by certain sorts of P_1' states. Dashed arrows represent relations of grounding. The dashed arrow from the P_1' ellipse to the S_1 ellipse, for instance, represents the following: every fact of the form "This is a P_1' state" grounds a fact of the form "This is an S_1 state." The dashed arrow from the P_2' ellipse to the S_2 ellipse represents the following: every fact of the form "This is a P_2' state" grounds a

fact of the form "This is an S_2 state." And the *lack* of a dashed arrow from the P_3' ellipse to the S_2 ellipse represents the following: no fact of the form "This is a P_3' state" grounds a fact of the form "This is an S_2 state." Finally, the solid arrows represent nomological relations. The solid arrow from the S_1 ellipse to the S_2 ellipse represents (S). The solid arrow from the P_1' ellipse to the P_2' ellipse represents the following: under the influence of the fundamental physical laws, most P_1' states evolve into P_2' states. And the solid arrow from the P_1' ellipse to the P_3' ellipse represents the following: under the influence of the fundamental physical laws, a few P_1' states evolve into P_3' states.

So altogether, here is how Grounding Properties can be used to explain why (S) admits of exceptions. By Grounding Properties, each fact of the form "This is an S_1 state" is grounded in a fact of the form "This is a P_1' state." Most P_1' states evolve, under the influence of the fundamental physical laws, into P_2' states; and by Grounding Properties, each fact of the form "This is a P_2' state" grounds a fact of the form "This is an S_2 state." But some P_1' states evolve, under the influence of the fundamental physical laws, into P_3' states; and each fact of the form "This is a P_3' state" does *not* ground a fact of the form "This is an S_2 state." And this is how exceptions to (S) occur.

In other words, exceptions occur—to laws like (S)—whenever the following two things happen. First, an S_1 state obtains. Second, the fact that this S_1 state obtains is grounded in the obtaining of a particular sort of P_1' state: namely, one of the few P_1' states which evolve into a P_3' state. For when all that occurs, the S_1 state is not followed by an S_2 state, since the obtaining of the P_3' state does not ground the obtaining of any S_2 state.

To summarize: according to Grounding Properties, facts about special science properties are grounded in facts about fundamental physical properties. That is the sense in which special sciences reduce to fundamental physics. And that is compatible with special science laws admitting of exceptions.

3 Perfect Naturalness and Special Science Properties

Perfect naturalness can be used to capture the sense in which special sciences are autonomous from fundamental physics. In this section, I explain how. To start, I discuss some characteristic features of perfectly natural properties. Then I present three conditions which describe how special science properties are autonomous. According to the first, many special science properties are perfectly natural. According to the second, certain collections of those perfectly natural properties are, themselves, perfectly natural. And according to the third, those perfectly natural collections of perfectly natural properties are what the special sciences study.

Before presenting the three conditions, it is worth reviewing some characteristic features of perfectly natural properties. Five features will be particularly important in what follows.[8] First, perfectly natural properties make for genuine similarity among objects which share them, and for genuine dissimilarity among objects which differ over them. Objects which share most of their perfectly natural properties are extremely similar to one another, while objects which differ over most of their perfectly natural properties are not. Second, perfectly natural properties imbue their bearers with causal powers. The causal powers of various objects, that is, derive from those objects' perfectly natural properties. Third, and relatedly, perfectly natural properties are extremely explanatory. The best explanations for certain phenomena cite perfectly natural properties; less adequate explanations, in contrast, cite properties which are not perfectly natural. Fourth, perfectly natural properties are reference magnets for our terms. So predicates generally express perfectly natural properties rather than properties which are gerry-mandered and non-joint-carving. Fifth, perfectly natural properties are not definable in terms of other, more basic properties. In other words, definability always runs in the direction of more natural to less natural: perfectly natural

[8]For more discussion of these features, see (Dorr & Hawthorne, 2013; Lewis, 1983; Schaffer, 2004; Sider, 2011).

properties can be used to define other properties, but not the other way around.[9]

For example, the property of being negatively charged is perfectly natural, since it satisfies the five features listed above. Regarding the first: if two particles both have the property of being negatively charged, then they are genuinely similar in that regard. Regarding the second: the property of being negatively charged is causally efficacious, since particles with that property can causally influence other particles' trajectories. Regarding the third: the property of being negatively charged is explanatory, since the best explanations of certain electromagnetic phenomena cite that property. Regarding the fourth: the property of being negatively charged is a reference magnet for the predicate 'is negatively charged', since that is the property which that predicate expresses. Regarding the fifth: plausibly, the property of being negatively charged is basic and bottom-level, and so cannot be defined in terms of anything more basic than it. Because of all this, being negatively charged is, plausibly, a perfectly natural property.

Now for the first condition about special science properties. Basically, it says that there are more perfectly natural properties than just the properties of fundamental physics.

Natural Properties

Many special science properties are perfectly natural.

For instance, consider the property *is a belief*. As can be shown, this property satisfies the five features of perfectly natural properties listed above. Regarding the first: if two mental states both have the property *is a belief*, then they are genuinely similar in that regard. Regarding the second: *is a belief* is causally efficacious, since an agent's beliefs often cause that agent to perform various actions. Regarding the third: *is a belief* is explanatory, since the best explanations of various peoples' behaviors often cite the beliefs of the people involved. Regarding the fourth: *is a belief* is a reference magnet for the predicate 'is a belief', since *is a belief* is the property onto which that predicate latches. Regarding the fifth: among all

[9]Naturalness, according to standard accounts, comes in degrees (Dorr & Hawthorne, 2013; Sider, 2011). Given this degreed conception of naturalness, perfectly natural properties may be defined as properties whose degree of naturalness is maximal.

the different mental properties, *is a belief* is, arguably, basic and elementary; so plausibly, it cannot be defined in terms of any properties which are more basic than it. And since *is a belief* satisfies all five of these features, *is a belief* is, plausibly, perfectly natural.

The basic idea behind NATURAL PROPERTIES is this: the world has more joints than the joints of fundamental physics. Reality's joints span many, many different levels, from the fundamental level up through levels which get progressively less fundamental. And non-fundamental sciences carve at the world's non-fundamental joints. Psychological theories of mental phenomena carve at the joints, for instance. Similarly for economic theories, feminist theories, chemical theories, biological theories, sociological theories, and more.

One might object that the properties of special sciences, like *is a belief* or *is a recession*, do not satisfy the fifth feature of perfectly natural properties; so contrary to NATURAL PROPERTIES, those special science properties are not perfectly natural. For one might subscribe to the following version of Reduction: each special science property reduces to fundamental physical properties. And this version of Reduction, one might claim, is incompatible with NATURAL PROPERTIES. For this version of Reduction, one might claim, implies the following: the properties of fundamental physics, to which a given special science property reduces, can be used to define that special science property. So each special science property can be defined in terms of properties which are more basic than it. And so the properties of special sciences do not have the fifth feature of perfectly natural properties listed above. Therefore, special science properties are not perfectly natural; and therefore, NATURAL PROPERTIES does not hold.

For example, consider the property *is water*. This property figures in special science theories of geological phenomena; so it is a special science property. According to a standard version of physicalism (Kim, 1992; Lewis, 1999), *is water* reduces to the properties of fundamental physics. As a result, one might claim, those physical properties can be used to define *is water*. Perhaps *is water* can be defined in terms of properties about hydrogen and oxygen, for instance. So *is water* can be defined in terms of properties which are more basic than it.

And so *is a belief* does not have the fifth feature of perfectly natural properties listed above. Therefore, NATURAL PROPERTIES is false.

The problem with this objection is straightforward: even if this version of Reduction is true, it does not follow that fundamental physical properties can be used to *define* each special science property. One property may reduce to some others, even if the latter properties cannot be used to define the former property. For reduction and definition are very different from one another; and in particular, reduction is not sufficient for definition.

To see why, it helps to focus on specific approaches to reduction and definition. As in Section 2, I understand reduction in terms of grounding; see GROUNDING PROPERTIES. And following much of the recent literature, I understand definition in terms of essence (Correia & Skiles, 2019; Fine, 2015). In particular, say that one property can be defined in terms of some others just in case, roughly put, facts about the latter properties feature in the former property's essence.[10]

As many have argued, grounding and essence are importantly distinct (Correia & Skiles, 2019, pp. 648-662; Fine, 2012, pp. 79-80, Rosen, 2010, p. 131). In particular, one fact can be grounded in another, even if the latter does not feature in the essence of the former. For example, the fact 'Snow is white or snow is not white' is grounded in the fact 'Snow is white'. But even so, the fact 'Snow is white or snow is not white' does not include the fact 'Snow is white' in its essence: it is not essential to snow being either white or non-white that snow is white. Another example: the fact that the ball is scarlet grounds the fact that the ball is red. But even so, the latter fact's essence does not include the former fact; it is not essential to the ball's being red, in other words, that the ball is scarlet. So the grounds of something, and the essence of that something, come apart.

Likewise for reduction and definition. One property may reduce to some others, even

[10]Not much hangs on this particular characterization of how essence and definition relate. I adopt it simply for the sake of concreteness. For an alternative characterization, consider the following: one property can be defined in terms of some others just in case, roughly put, the latter properties feature in the former property's essence. Note that this characterization allows essences to include properties rather than just facts (Fine, 2012).

though the latter properties cannot be used to define the former. Just as grounding something is not sufficient for being in that something's essence, reducing to something is not sufficient for being definable in terms of that something.

For example, consider *is water* once more. That property may well reduce to the properties of fundamental physics. That is, facts about fundamental physical properties—about hydrogen and oxygen, say—may ground facts of the form "Thus-and-so liquid is water." But even so, plausibly, the essence of *is water* does not include such facts about hydrogen and oxygen. It is not essential to water, say, that hydrogen and oxygen compose it; perhaps water can be composed of XYZ too. So those fundamental physical properties cannot be used to define *is water*.

Therefore, contrary to the objection, Natural Properties and Reduction are perfectly compatible with one another. Many properties of special sciences—like *is water*, *is a belief*, and *is a recession*—can indeed satisfy the fifth feature of perfectly natural properties. Those properties may well reduce to properties which are more fundamental: facts of the form "Thus-and-so liquid is water" or "Such-and-such psychological state is a belief" may be grounded in facts involving the properties of fundamental physics. Nevertheless, the reducers cannot be used to define the reduced: for facts involving the properties of fundamental physics do not figure in the essences of properties like *is water* or *is a belief*.

Note that Natural Properties merely says that some special science properties are perfectly natural. Other special science properties might not be. For some special science properties—indeed, many of them—are definable in terms of others. The property of being married, for instance, may be definable in terms of legal properties which are more basic than it. And similarly for many other properties of the special sciences.

Before formulating the second condition that describes special science properties, I must present a preliminary definition. Some collections of perfectly natural properties are more natural than others. The properties in a more natural collection are well-suited for being grouped together, in a way that the properties in a less natural collection are not. For the

properties in a less natural collection, when taken together, form a fairly gerrymandered and arbitrary bunch; not so for the properties in a more natural collection. In addition, some of these collections are maximally natural. The properties in these collections are perfectly well-suited for being grouped together. Call these collections 'perfectly natural domains' of perfectly natural properties.

For instance, let $\mathcal{F}$ be the collection consisting of all and only the properties of fundamental physics: mass properties, charge properties, and so on. Let $\mathcal{F}^*$ be the collection consisting of all the properties in $\mathcal{F}$, along with the additional, economic property of being a recession. The properties in $\mathcal{F}$ form a more natural collection than the properties in $\mathcal{F}^*$. And plausibly, the properties in $\mathcal{F}$ are perfectly well-suited for being grouped together: after all, they can be used to completely characterize the fundamental level of the world. So $\mathcal{F}$ is a perfectly natural domain.

Think of perfectly natural domains like perfectly natural second-order properties. The perfectly natural domain $\mathcal{F}$, for instance, can be thought of as the perfectly natural property *is a property of fundamental physics*. So each perfectly natural domain is a perfectly natural second-order property: the perfectly natural second-order property of being one of the properties in that domain.[11]

Now for the second condition. Basically, it says that $\mathcal{F}$ is not the only perfectly natural domain.

Domains

Some perfectly natural domains contain only special science properties.

For example, let $\mathcal{M}$ be the collection of all and only the properties of the ideal theory of mental phenomena. Then plausibly, $\mathcal{M}$ is a perfectly natural domain. For the properties in $\mathcal{M}$ seem perfectly well-suited for being grouped together. They cohere with one another extremely well; they seem to belong in a group. Similarly for the collection $\mathcal{E}$ of all and only

[11]This view is compatible with Thompson's arguments against taking *is perfectly natural* to be, itself, a perfectly natural property (2016). For this view simply says that properties like *is a property of fundamental physics* are perfectly natural: it says nothing about the relative naturalness of *is perfectly natural* itself.

the properties of the ideal theory of economics; and similarly for the collection $\mathcal{G}$ of all and only the properties of the ideal gender theory.

The third condition describes, in more detail, these perfectly natural domains of non-fundamental properties. Basically, it says that each such domain consists of the properties of some special science.

THEORIES

True special scientific theories—that is, the theories that scientists actually and correctly endorse—describe facts about perfectly natural properties in some perfectly natural domain.

In other words, successful theories of a special science are theories of the perfectly natural properties that some perfectly natural domain contains.

The combination of DOMAINS and THEORIES is motivated by the following line of thought. In accord with NATURAL PROPERTIES, the world contains many more perfectly natural properties than just the properties of fundamental physics. But those properties—spanning many levels of reality—are not just some structureless heap. Those properties are more than a mere motley, a jumbled collection of joints. Rather, certain collections of those properties form highly organized, highly structured domains. Other collections of those properties do not. And each structured domain corresponds to the proper subject of study for some specific science. The perfectly natural domain consisting of fundamental physical properties, for instance, is the subject of fundamental physics. The perfectly natural domain consisting of all and only mental properties, for instance, is the proper subject of psychological theories of the mind. The perfectly natural domain consisting of all and only economic properties, for instance, is the proper subject of economic theories. The perfectly natural domain consisting of all and only the properties discussed in feminist theorizing, for instance, is the proper subject of gender theories. And so on.

Here is another way to put the point: it is not the case that any arbitrary collection of facts can be properly systematized by a special scientific theory whose predicates express

perfectly natural properties. Some gerrymandered collections of facts cannot be so systematized. But some collections of facts are special. Some collections contain all and only facts about certain perfectly natural properties which admit of such a systematization. These are the facts corresponding to perfectly natural domains of perfectly natural properties. And these are the facts that special science theories seek to describe.

The conditions Natural Properties, Domains, and Theories, jointly provide a precisification of Autonomy. The best psychological theories invoke the property *is a belief*, for instance, because (i) that property is perfectly natural, and (ii) that property figures in the perfectly natural domain that forms the proper subject of psychology. Similarly, the best economic theories invoke the property *is a recession*: that property is perfectly natural, and that property figures in the perfectly natural domain that forms the proper subject of economics. And the best gender theories invoke the property *is a woman*: for that property is perfectly natural too, and that property figures in the perfectly natural domain that forms the proper subject of gender theories. None of these theories invoke any properties of fundamental physics, because fundamental physical properties do not figure in any of the perfectly natural domains that these special sciences study. And none of these special science properties can be defined in terms of the properties of fundamental physics, because all of these special sciences are perfectly natural. So in that sense, special sciences are autonomous.

It is worth briefly comparing my view of perfectly natural properties—and how they sometimes come apart from fundamental properties—to the two conceptions of sparse properties discussed by Schaffer (2004, pp. 92-93). According to Scahffer's fundamental conception, the sparse properties are those invoked in fundamental physics. According to Scahffer's scientific conception, the sparse properties are those invoked throughout the sciences, special as well as fundamental. The two conceptions play different roles: fundamental sparse properties provide a minimum supervenience base for all other properties, while scientific sparse properties both (i) make for objective similarity, and (ii) imbue objects with causal powers (Schaffer, 2004, p. 94-95).

There are some similarities between Schaffer's approach and mine. On my approach, as on Schaffer's, the fundamental properties are those invoked in fundamental physics. In addition, on my approach, the non-fundamental perfectly natural properties are those properties which get invoked throughout the sciences; these properties are, in that sense, similar to Schaffer's sparse scientific properties.

Nevertheless, my approach extends—and so differs from—Schaffer's approach, in at least two respects. First, on my approach, non-fundamental perfectly natural properties do more than just (i) make for objective similarity, and (ii) imbue objects with causal powers. These properties also (iii) figure in the best explanations for special scientific phenomena, (iv) act as reference magnets for our terms, and (v) cannot be defined in terms of anything more basic. So on my approach, perfectly natural properties do more work than the scientific sparse properties that Schaffer discusses.[12]

Second, whereas my approach can be used to explain why only some clusters of perfectly natural properties are the proper subjects of special sciences, it is unclear whether Schaffer's approach—taken on its own—can. Here is the explanation which my approach supports: only some clusters of perfectly natural properties are the proper subjects of special sciences because (i) only some such clusters form perfectly natural domains, and (ii) those domains are the only proper subjects of the special sciences. In other words, there are no special sciences for certain collections of perfectly natural properties because those properties, taken together, do not form perfectly natural domains. It is unclear, however, whether Schaffer's approach—taken on its own—supports an explanation of this phenomenon concerning how perfectly natural properties tend to cluster. For Schaffer's approach does not say whether or not the sparse scientific properties cluster into perfectly natural domains.

Taken together, Grounding Properties, Natural Properties, Domains, and Theories, provide an account of the metaphysics of special sciences; call it the 'Perfectly Grounded' account of special science properties. According to the Perfectly Grounded ac-

[12]Similarly, on my approach, the fundamental properties do more than provide a minimum supervenience base: they provide a grounding base as well.

count, facts about special science properties are grounded in facts about fundamental physical properties. Nevertheless, many special science properties are perfectly natural, and cluster into perfectly natural domains; and those domains are what the special sciences study.[13]

4 Reduction and Autonomy

There is much to like about the Perfectly Grounded account. In this section, I discuss one of its most attractive features: it can be used to resolve the tension between Reduction and Autonomy. To start, I discuss Reduction and Autonomy in some detail. Then I discuss the tension between them. Finally, I show how Perfectly Grounded can be used to resolve that tension.

Roughly put, according to Reduction, facts about special science properties reduce to facts about fundamental physical properties. In some important sense or other, facts about fundamental physical properties generate facts about the properties of the special sciences. For instance, facts about *is a belief*, *is a recession*, and *is a woman*, all arise from facts about properties of the form *is a quantum field in thus-and-so state*.

Roughly put, according to Autonomy, special science properties are autonomous from fundamental physics properties. Special science properties—in special science theories—should not be replaced by fundamental physical properties with which they might be extensionally equivalent. For those extensionally equivalent properties of fundamental physics are not explanatory, of special science phenomena, in the way that special science properties are. Those extensionally equivalent properties of fundamental physics cannot, properly speaking, be used to define the corresponding special science properties. So it may be the case that

[13]Perfectly Grounded is compatible with the theories of autonomy, reduction, and multiple realizability proposed by Batterman (2000; 2018). On my preferred way of combining Batterman's views with Perfectly Grounded, facts about renormalization group flow explain why certain special science facts are grounded in fundamental physical facts. And facts about autonomy—like the fact that economics is an autonomous special science—are grounded in facts about renormalization groups and universality too. A full discussion of all this, however, is beyond the scope of the present paper; I am currently developing another paper which addresses this in detail.

properties like *is a belief*, *is a recession*, and *is a woman*, are extensionally equivalent to properties of the form *is a quantum field in thus-and-so state*. Even so, theories of psychology, economics, and gender, should not invoke those extensionally equivalent properties of quantum fields. Those theories should invoke *is a belief*, *is a recession*, and *is a woman*, instead.

Reduction and Autonomy are usually taken to be incompatible with one another. For instance, Fodor writes that given Reduction, each special science property is extensionally equivalent to a fundamental physical property which figures in good, lawful, special scientific theories (1974, p. 104). Those fundamental physical properties are indeed explanatory of special science phenomena. Therefore, given Reduction, Autonomy does not hold. Helleman and Thompson write that Reduction is committed to the following: each special science property can be explicitly defined in terms of fundamental physical properties (1975, p. 551). Given that Autonomy implies the opposite, of course, Reduction and Autonomy are incompatible. In fact, many philosophers write as if Autonomy is simply the negation of Reduction. Loewer, for instance, characterizes the autonomy of the special sciences in terms of those sciences' irreducibility to fundamental physics (2009, p. 221); so does Fodor (1997, p. 149) and Kim (1992, p. 17). So it is standard to simply assume that the reducibility of the special sciences precludes their autonomy, and vice versa.

But as Perfectly Grounded shows, we need not make that assumption. Reduction and Autonomy are, contrary to philosophical orthodoxy, compatible with one another. For according to Perfectly Grounded, special science facts are grounded in—and so reduce to—facts of fundamental physics. And according to Perfectly Grounded, special science properties are perfectly natural; so special science properties are autonomous from—and in particular, cannot be defined in terms of—fundamental physical properties. Note that there is no tension here. There is no incompatibility, that is, between (i) the claim that special science facts are grounded in fundamental physical facts, and (ii) the claim that special science properties are perfectly natural. Grounding is one thing, perfect naturalness is another.

Here is another way to put the point. The tension between Reduction and Autonomy can be characterized in terms of the following questions from Section 1.[14]

1. If special sciences reduce to fundamental physics, then in what sense is the former autonomous from the latter? How can the special sciences be autonomous, if they ultimately reduce to fundamental physical science?
2. If special sciences are autonomous from fundamental physics, then in what sense does the former reduce to the latter? How can the special sciences reduce to anything, if they are truly autonomous?

Perfectly Grounded can be used to answer these questions. Special sciences are autonomous from fundamental physics in the sense that special science properties (i) are perfectly natural—and so cannot be defined in terms of fundamental physical properties—and (ii) cluster into perfectly natural domains which special sciences study. Special sciences reduce to fundamental physics in the sense that special science facts are grounded in fundamental physical facts. That is how special sciences can both reduce to, and be autonomous from, fundamental physics.

5 Two More Features

In this section, I discuss two more attractive features of the Perfectly Grounded account. First, it can be used to account for one important way in which special scientific theorizing is valuable. Second, it can be used to solve a problem faced by interventionist accounts of explanation.

Regarding the first application: Perfectly Grounded can be used to account for one source of the value of special scientific theorizing. By way of preparation, it helps to recall that ideally, theories should invoke properties which (i) make for genuine similarity and

[14]Versions of these questions have been raised repeatedly in the literature. For instance, while wondering why there are so many true special science laws, Fodor (1997, p. 161) asks "why is there anything except physics?" Loewer asks the same question (2009, p. 218), as does Haug (2011, p. 1143).

dissimilarity, (ii) imbue objects with causal powers, (iii) support explanations of phenomena, (iv) act as reference magnets for those theories' terms, and (v) are the basic, indefinable, bottom-level properties from which other properties can be defined. As discussed in Section 3, perfectly natural properties do (i)–(v). So theories should invoke perfectly natural properties. It is better, in other words, for theories to invoke perfectly natural properties rather than properties which are gerrymandered and gruish.[15]

With that as background, here is the explanation of one way in which special scientific theories are valuable: they are valuable because they invoke perfectly natural properties. For according to Perfectly Grounded, may special scientific properties are perfectly natural. And as was just explained, perfectly natural properties are precisely the sorts of properties that theories should invoke. So special science theories are valuable insofar as they invoke properties like those.

Of course, there are other ways in which special science theories are valuable. For example, they are valuable because when it comes to explaining various special scientific phenomena, special science theories are much more tractable than extensionally equivalent theories of fundamental physics. It is much more tractable to explain the causes of recessions in economic terms, for instance, than to explain those causes solely in terms of fundamental physical particles, fields, and properties. It is much more tractable to explain human behavior in terms of beliefs and desires than to explain human behavior in fundamental physical terms. And that is another reason why special science theories are valuable.

None of this conflicts with the claim that special science theories are *also* valuable because they invoke perfectly natural properties. Special science theories are definitely valuable insofar as they are extremely tractable. My point here is simply that special science theories are valuable in another, more metaphysically loaded way: they invoke properties that make for similarity, are causally efficacious, support explanations, are reference magnets, and are definitionally basic. In short, special science theories are valuable because they invoke

[15]For arguments in support of this, see (Sider, 2011).

perfectly natural properties.

Regarding the second application: Perfectly Grounded can be used to solve a problem that arises for interventionist accounts of explanation. A complete description of these accounts is beyond the scope of this paper: the full interventionist framework uses variables, functions, structural equation models, and more. But put very roughly, interventionist accounts say the following: one proposition p explains another proposition q just in case the occurrence of p 'makes a difference' to the occurrence of q. 'Makes a difference' is defined in terms of counterfactuals: the occurrence of p makes a difference to the occurrence of q just in case (i) if p had occurred – as indeed it did – then q would have occurred – as indeed it did, and (ii) if p had not occurred, then q would not have occurred (Woodward, 2003, pp. 25-26; Woodward & Hitchcock, 2003, p. 2).[16] The truth conditions for these counterfactuals are given in terms of variables, functions, and other bits of formalism; for a detailed discussion, see (Pearl, 2009; Woodward, 2003).

Interventionist accounts are popular, in large part, because of how well they accommodate explanations in the special sciences. The interventionist framework—variables, functions, structural equation models, and so on—has been used to formulate successful special science theories of seagrass density in the ocean (Folmer et al., 2012), market innovation and internationalization (Hailem et al., 2014), smoking and socioeconomic status (Martinez et al, 2018), and more.[17] So interventionist accounts are attractive, in large part, because they provide the resources needed to describe explanations of special science phenomena.

But interventionist accounts face a problem: they struggle to provide clear criteria for when certain explanations are better than others. The literature on this is quite large and technical, so for the sake of brevity, I will not present it in full detail. But basically, the issue

[16]This account is called 'interventionist' because Woodward characterizes the truth conditions for these counterfactuals in terms of interventions. The counterfactual "If p had not occurred, then q would not have occurred" is true just in case intervening on p affects the occurrence of q. In other words, that counterfactual is true just in case it is possible to affect whether or not q occurs by intervening on p. The notion of an intervention is defined using variables, functions, structural equation models, and more.

[17]For a systematic overview of the use of this framework in various theories of social work, for instance, see (Guo et al., 2009).

comes to this. For any given proposition q—describing some special science phenomenon, say—interventionist accounts imply that q is explained by many different propositions: there is a proposition p_1 which explains q, there is a proposition p_2 which explains q, there is a proposition p_3 which explains q, and so on. Some of these explanations seem, intuitively, much better than the rest; for the rest invoke gerrymandered, arbitrary, intuitively unexplanatory properties. But as argued by Franklin-Hall, standard attempts to supplement interventionist accounts in order to capture this—that is, in order to classify these gerrymandered explanations as deficient—do not succeed (2016, pp. 561-565).[18] So interventionist accounts struggle to say what makes the non-gerrymandered explanations better than the gerrymandered ones.

Perfectly Grounded can help that. For according to Perfectly Grounded, many special science properties are perfectly natural. So here is what makes the non-gerrymandered explanations better than the gerrymandered ones: the properties invoked in the non-gerrymandered explanations are perfectly natural, and the properties invoked in the gerrymandered explanations are not. For any given proposition q, the best explanations of q are those that feature propositions which invoke perfectly natural properties; all other explanations of q are worse than those. So Perfectly Grounded can help interventionist accounts distinguish good explanations from bad ones.[19]

There is a general objection which one might have to all of this. One might dislike the use of abstract metaphysical tools—like grounding and perfect naturalness—for solving problems related to scientific theorizing. Those problems should be solved, one might claim, by using unobscure notions only: causation, counterfactuals, and so on. Grounding, and

[18] In particular, Franklin-Hall argues that it will not work to supplement interventionist accounts with either proportionality requirements (Woodward, 2008) or exhaustivity requirements on the variables used in the relevant structural equation models.

[19] A version of this solution is mentioned, briefly, by Franklin-Hall (2016, p. 574). As Franklin-Hall points out, many interventionists would not want to adopt this solution, because many interventionists do not want to rely on anything so metaphysically 'weighty' as perfect naturalness. For instance, Blanchard attempts to avoid Franklin-Hall's arguments by, among other things, proposing a new exhaustivity requirement (2020, p. 649). I am not convinced that this requirement will help interventionist accounts avoid the problem that Franklin-Hall raises: modifications of Franklin-Hall's examples seem to raise issues for the new exhaustivity requirement, just as they raised issues for the old one. So I suspect that in order to avoid the problems that Franklin-Hall raises, interventionists will need to invoke relative naturalness—or perhaps even perfect naturalness—in some way or other.

perfect naturalness, are too obscure.[20]

I disagree: grounding and perfect naturalness are no more obscure than causation or counterfactuals. For decades now, philosophers have contributed to developing theories of both grounding (Fine, 2012; Krämer, 2018; Schaffer, 2016) and perfect naturalness (Lewis, 1983; Sider, 2011). There are formalisms for both, for instance. There are clear, intuitive examples of grounding; and perfect naturalness admits of clear, intuitive examples too. Both grounding and perfect naturalness are taken to obey various principles: just recall the four characteristic features of grounding from Section 2, or the five characteristic features of perfect naturalness from Section 3. So theories of grounding and perfect naturalness are pretty far along. At this point, I think, we need not worry much about their potential obscurity.

6 Conclusion

To wrap up, here is a summary of the important notions, principles, and attractive features, of the Perfectly Grounded account of special science theories.

1. Important notions
   - The grounding relation
     (i) is generative, in that grounders generate—or explain—what they ground,
     (ii) relates more fundamental facts to less fundamental facts, and
     (iii) allows one fact to have many distinct grounds.
   - Perfectly natural properties
     (i) make for genuine similarity and dissimilarity,
     (ii) imbue their bearers with causal powers,
     (iii) are extremely explanatory,
     (iv) act as reference magnets for terms, and

[20] Concerns along these lines have been raised by Albert (2015), Cartwright (1999), Loewer (2009), Woodward (2003), and many others.

(v) cannot be defined in terms of anything more basic.

2. Principles
   - Grounding Properties: facts about special science properties are grounded in facts about fundamental physical properties.
   - Natural Properties: special science properties are perfectly natural.
   - Domains: some perfectly natural domains—like the domain consisting of all fundamental physical properties, or the domain consisting of all psychological properties—contain only perfectly natural properties.
     - Perfectly natural domain: a second-order property of properties. In particular, a cluster of properties forms a perfectly natural domain just in case the property *is a property in that cluster* is perfectly natural.
   - Theories: perfectly natural domains are what the special sciences study.
3. Attractive features
   - Avoids a problem, concerning exceptions to special science laws, which arises for many other reductions of special scientific theories.
   - Reconciles Reduction and Autonomy.
   - Accounts for the value of special scientific theorizing.
   - Solves a problem for interventionist accounts of explanation.

In short, Perfectly Grounded provides an attractive, explanatory, and unified account of special science properties. We would do well to endorse it.

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