The Unity of Science and the Mentaculus

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Abstract

Among the most promising options for vindicating Oppenheim and Putnam's unity of science hypothesis is the 'Mentaculus' of Albert and Loewer. I assess whether this promise can be borne out. My focus is on whether the Mentaculus can deliver what Oppenheim and Putnam call the 'unity of laws': the reduction of special science laws to the laws of fundamental physics. I conclude that although the Mentaculus may support a fairly strong form of reductionism, it falls short of upholding the unity of laws.

1 Introduction

In 1958 Paul Oppenheim and Hilary Putnam had a beautiful dream: that 'all science may one day be reduced to microphysics' (p. 27). In the intervening years this dream—what they called the unity of science—has met with strong skepticism.[1] But some philosophers still keep the faith. This paper is an attempt to see whether that faith can be sustained.

Oppenheim and Putnam defended unity in two forms: the unity of language, the thesis that all scientific terms reduce to the terms of fundamental physics; and the unity of laws, the thesis that all scientific laws, including special science laws, reduce to the laws of fundamental physics. My focus will be on the thesis of the unity of laws.

What that thesis amounts to depends on what it is for some laws to reduce to others. Oppenheim and Putnam did not themselves give an explicit account of law reduction, but they appear to have understood it in terms of the reduction of one branch B_2 of science to another B_1,[2] which they say

> moves in the direction of *Unity of Laws*; for it 'reduces' the total number of scientific laws by making it possible, in principle, to dispense with the laws of B_2 and explain the relevant observations by using B_1. (pp. 6–7)

Evidently, for Oppenheim and Putnam the laws of a given special science will reduce to the laws of fundamental physics just in case the observations of the special science can all be explained by fundamental physics.

[1] Influential skeptics include Fodor ([1974]), Kitcher ([1984]), and Dupré ([1993]). Officially, the unity of science thesis is neutral on which is the science to which all others reduce. But for Oppenheim and Putnam, as for us, fundamental physics is the obvious bet.

[2] Such 'branch reduction' they understand along the lines of Kemeny and Oppenheim ([1956]).

But this implicit account of law reduction would seem to fall short in two ways. First, why stop at observations? After all, if we are truly to 'dispense with' the laws of some special science we will need to be able to explain not just certain observations but the laws themselves. And second, if we are really to reduce the special science laws to the laws of fundamental physics, as opposed to just the branch of fundamental physics, then it is the laws in particular to which our explanation should appeal. I therefore propose to depart somewhat from Oppenheim and Putnam's own understanding of the unity of laws. I will assume that the thesis should be understood in such a way that it entails that the laws of the special sciences are explainable in terms of the laws of fundamental physics.

But is such explanation possible? Among the most promising proposals in this connection is the 'Mentaculus' hypothesis developed and defended over the past few decades by David Albert ([2000], [2015]) and Barry Loewer ([1996], [2001], [2007], [2008], [2009], [2012a], [2012b], [2020]), according to which the universe comes equipped with a privileged probability distribution over its possible initial microstates. Loewer ([2020], p. 28) writes that the hypothesis 'provides a unified account of thermodynamics, the other arrows of time, special science laws, and the natures of the laws and probabilities that occur throughout the sciences'. In this paper, I assess the prospects of the Mentaculus for providing the kind of explanation required by the unity of laws. I conclude that although it may support a fairly strong form of reductionism, it does not support the unity of laws.

2 Two Reductionisms, Two Demons

Terminology first. To sidestep disputes about whether special science laws are really laws, I will follow Strevens ([2008]) in speaking of 'nomes', where a nome is any scientifically significant regularity. I will be pretty loose about which regularities count as scientifically significant; I merely insist that nomes must be counterfactually robust. That is, if it's a nome that all Fs are G, then on a wide range of counterfactual suppositions, it would still be the case that all Fs are G.

Can the Mentaculus hypothesis provide the kind of explanation of special science nomes ('nomes' for short) that the unity of laws requires? I will answer that question by evaluating how the hypothesis fares with respect to two reductionist theses, one strong and one weak.

> Austere Reductionism: All nomes may be explained in terms of the laws of fundamental physics.

> Ornate Reductionism: All nomes may be explained in terms of the laws of fundamental physics together with facts statable in fundamental physical terms.

The latter, of course, is weak only in comparison to the former.

Both theses entail that nomes can be explained without recourse to, in Loewer's ([2009], p. 221) words, 'kinds and laws that are metaphysically over and above the kinds and laws of physics'. And both appeal to philosophers with a taste for desert landscapes. But it is only austere reductionism that could vindicate the unity of laws as I understand it, since only austere reductionism ensures that the laws (or nomes) of the special sciences are explainable in terms of the laws of fundamental physics alone.

But why care about the unity of laws, anyway? For at least two reasons. First, it might be thought to have consequences for the explanatory power of special science theories. The unity of laws would mean that the nomes of the special sciences issue from what Carnap ([1955], p. 61) called 'one homogeneous system of laws for the whole of science'. Such an über-system would unify all scientific phenomena, from physics to biology to psychology. For philosophers who take a theory's explanatory power to derive from its unifying power (such as Kitcher [1981]), the unity of laws would mean that the special sciences possess a high degree of both.

Second, the unity of laws would render the nomological structure of the world freestanding in the following sense: all nomes would be explained by the fundamental laws alone, with no non-nomic facts mixed in. And this in turn might be thought to support the claim that nomes are not merely scientifically significant regularities but genuine laws. For example, suppose one held a 'governing' conception of law (Maudlin [2007]). Then it is not implausible to suppose that any nome that is explained solely by the fundamental laws will thereby inherit their governing capacity and thus their lawhood. Alternatively, suppose one held a Humean conception of law (Lewis [1973], pp. 72–5; Loewer [1996]) on which laws are good summaries of the mosaic of particular facts. Then one might argue that any nome that is explained solely by good summaries will itself be a good summary and so a law.

Which of our reductionist theses, if any, does the Mentaculus hypothesis support? Some of Loewer's remarks suggest an argument that it supports austere reductionism (and thus the unity of laws). In his ([2008], p. 159), he proposes that 'lawful special science regularities are grounded in PROB and the dynamical laws.' (PROB, a crucial component of the Mentaculus hypothesis, ensures the existence of a certain probability distribution over the possible initial microstates of the universe. More on PROB later.) For Loewer, PROB is a law; 'not a dynamical law', he explains, 'but a law about initial conditions' (p. 158). This suggests the following argument: all nomes may be explained in terms of PROB and the dynamical laws; PROB and the dynamical laws are laws of fundamental physics; so austere reductionism is true.[3]

Some of Loewer's other remarks, however, suggest that the explanation of some nomes may require an appeal to certain background conditions beyond PROB and the dynamical laws. In his ([2012a]), Loewer conjectures that

> All special science regularities and all causal relations can be obtained by conditionalization from the Mentaculus. [...] Consider, for example, Gresham's law [that 'bad money drives out good']. For it to apply, a great many conditions that involve the existence of human societies, economic exchanges, money, political structures, legal systems and so on must be obtained. Given a characterization of these conditions (which would be included in a characterization of the macro state of the Earth at some time in the past) and whatever *ceteris paribus* [conditions] are associated with the generalization the conditional probability on all these propositions and also that good and bad money are introduced into the economy the probability that good money is hoarded will be high. (p. 18)

This suggests the following argument: some nomes can be explained only by appeal to certain background conditions; even if these conditions can be explained by appeal to fundamental physical facts, they cannot be explained solely by appeal to fundamental physical laws; and so

[3] Austere reductionism is a claim about explanation, not about entailment. Loewer certainly does not think that PROB and the dynamical laws entail nomes like 'all ravens are black', for he is clear that he is concerned with the grounding of 'probabilistic regularities' (p. 159). But that leaves open the possibility that PROB and the dynamical laws might provide a probabilistic explanation of nomes—a possibility we will consider below.

even if ornate reductionism is true, austere reductionism is not.

I am not claiming that Loewer (or Albert) endorses either of the arguments I've just sketched, or that there is no way to reconcile the remarks quoted above. I call attention to them merely to suggest that the true reductionist force of the Mentaculus hypothesis is not immediately obvious. In what follows, I will argue that although the Mentaculus may be able to deliver ornate reductionism, it cannot deliver austere reductionism.

To do that, I will appeal to Laplace's demon, a hypothetical ideal reasoner with unlimited computational powers. I'll need two demons, one for each reductionist thesis. The austere demon knows only the laws of fundamental physics, presumed to be deterministic. (The indeterministic case must be left for another time.) The ornate demon is less constrained: it knows the laws of fundamental physics as well as the precise initial state of the universe, given in fundamental terms—for short, the initial microstate. Since the laws are deterministic, the ornate demon (but not the austere demon) can deduce the entire history of the universe, expressed in fundamental terms. So not only does it know the initial fundamental physical facts, it knows all the fundamental physical facts.

Borrowing a representational device from physics, we associate the microstate of the universe at each time with a set of numbers that determine it uniquely. For a classical mechanical universe, the mass of each particle together with its position and velocity along three orthogonal axes suffices to determine the microstate. Such a representation is also possible for a universe like ours, albeit with a different set of numbers. Now imagine an abstract space, each of whose dimensions corresponds to one of the numbers. Each possible microstate corresponds to a point in this space. As the universe changes over time, it traverses a path through the space. Call this path the universe's microtrajectory. The ornate demon, then, knows the universe's complete microtrajectory.

Let's allow, for the sake of getting the Mentaculus off the ground, that things in the ontologies of the special sciences, such as tectonic plates, bacteria, and GDP, depend somehow on things in the ontology of fundamental physics. And let's assume that what goes for things goes for facts too. For example, we'll assume that the fact that a certain economy is in recession depends on facts about things in the ontology of fundamental physics. I'll use 'realize' to refer to the dependence relation that holds between microstates and non-fundamental things or facts, and I'll say that a proposition p is true 'according to' a microtrajectory m if m passes through a microstate that realizes the fact that p (or that would realize that fact if m were the universe's actual microtrajectory).

The thought experiment of the two demons helps us evaluate our two reductionist theses. If there is a nome that the austere demon can't explain, then austere reductionism is false, and similarly for ornate reductionism.

Now for all I've said so far, there are nomes neither demon can explain. Take a representative nome from one of the special sciences: all ravens are black. Call this the raven nome. The demons can't explain this nome, for a very simple reason: they don't know what ravens are. The demons know only fundamental terms, and 'raven' is not among them.

They'll have more luck if we expand their vocabulary. Loewer ([2008]) envisions a 'souped-up' demon who possesses a 'translation manual' that connects the vocabularies of fundamental physics and the special sciences. For each state given in non-fundamental terms, the manual reveals which states given in fundamental terms realize it. Let a 'macrostate' be a state given in macroscopic terms; then the manual reveals which microstates realize a given macrostate. We'll allow our demons this manual.

There are two issues in the neighbourhood of my topic that I won't address in this paper. The first is *ceteris paribus* clauses. We typically think that the truth of a nome like 'the optic nerve transmits signals from the eye to the brain' is consistent with the existence of some optic nerves that do not transmit signals—damaged nerves, for instance. It is a very complicated matter precisely which apparent exceptions are consistent with the truth of the nome, and it's one that I will avoid here. Instead, I'll pretend that a nome of the form 'all Fs are G' requires that literally every F is G. The second issue is the vagueness of non-fundamental terms. One might think it is vague which microstates realize a given macrostate, but I'll make the simplifying assumption that macrostates are realized by precise sets of microstates.

Translation manual in hand, the demons can overcome the problem posed by the raven nome. They can translate any condition involving ravens into one given in purely fundamental terms. But that one obstacle has been removed does not show they can reach the goal. Can the demons explain why all ravens are black?

3 An Inadequate Explanation

A demon might think to offer a 'mad mechanist' explanation of the sort discussed by Kitcher ([1999], p. 198). Take the universe's complete microstate at the time of conception of the very first raven. Using first the fundamental laws and then the translation manual, deduce that the raven zygote will develop into a black raven. Repeat this procedure for all the ravens that ever have existed or ever will exist.

Since this explanation appeals to fundamental physical facts beyond the laws, it is available only to the ornate demon. By following this algorithm, that demon, it may seem, explains the raven nome. After all, the demon shows that, for each raven, the microstate of the universe at the time of its conception nomically necessitates its blackness.

But the mad mechanist explanation fails to show that the raven nome is, as Kitcher ([2001], p. 71) puts it, 'anything more than a gigantic coincidence'. After all, it appeals to extraordinarily specific facts about various microstates of the entire universe. For all the mad mechanist explanation says, it could be that if even one electron's position had been slightly different, there would have been some non-black ravens. It could even be that the truth of the raven nome depends on the universe occupying just its actual microtrajectory.

But if some fact is not a coincidence, then an adequate explanation of that fact must show that it's not. For example, suppose that at a distant airport, I run into an old friend whom I haven't seen for years. As it happens, we are both in town for the wedding of a mutual friend, so our meeting in the airport was no coincidence. Intuitively, an explanation of our meeting that neglected to mention the wedding would be inadequate, because it would leave open the possibility that the meeting was a coincidence.

The mad mechanist explanation is inadequate, then, because it fails to show that the raven nome is not a coincidence. What kind of explanation would show this?

An answer is suggested by the observation that coincidences are in some sense improbable. Consider a paradigm case: suppose I toss a coin five times, and coincidentally, on each toss it lands heads. How improbable! One way, and perhaps the only way, for an explanation of the raven nome to avoid Kitcher's coincidence objection would be for it to entail that the raven nome is sufficiently probable.

Perhaps the Mentaculus can help.

4 The Mentacular Explanation

4.1 The Mentaculus

According to the Mentaculus hypothesis, there exists a privileged probability distribution over the possible initial microstates of the universe. If the raven nome turns out to be probable according to this distribution, that might avoid Kitcher's objection.

But why think there is such a distribution? Albert and Loewer argue that positing it resolves a certain tension in the foundations of statistical mechanics.[4]

On the one hand, the laws of fundamental physics are temporally symmetric in the following sense. Define the configuration of a physical system to be a complete specification of the positions of all the particles in the system. Suppose a system is initially in a configuration c_0 and evolves in accordance with the laws to a final configuration c_n, passing through the configurations $c_1, \ldots, c_{n-1}$ in order along the way. Then the 'reverse' sequence of configurations, in which the system begins in c_n, passes through $c_{n-1}, \ldots, c_1$ in order, and ends up in c_0, is also physically possible.

On the other hand, many nomes are temporally asymmetric, including the nomes of statistical mechanics. Consider, for instance, the ice cube nome: all ice cubes in warm water melt. We see ice cubes melt in warm water all the time, and we never see ice cubes grow in warm water. But since the fundamental laws are temporally symmetric, if melting is physically possible, so is growing. Why then do we observe only the former?

The traditional resolution of this tension, dating to Boltzmann, is to posit a certain probability distribution over the possible initial microstates of the ice cube system. The distribution is

[4] My presentation here follows Albert ([2000]). Loewer has argued that positing this distribution can account for the temporal asymmetry of causation or causal influence ([2012b]) and for the probabilistic nature of special science laws ([2020]), but I will not discuss these arguments here.

uniform over the microstates that realize the initial macrostate of the system (an ice cube floating in warm water) and it is zero for all other microstates. One can show that this distribution entails that it is overwhelmingly probable that the system will evolve to one in which the ice cube melts. This result resolves the tension: it is because it is so probable that the ice cube will melt, and so improbable that it will grow, that we observe only melting and never growing.

But there is a problem. Although our probability distribution makes empirically adequate predictions about the future, its 'predictions' about the past are howlers. One can show that the distribution entails that it is overwhelmingly probable that the ice cube system is in a microstate that evolved from a system containing only warm water. In other words, it is overwhelmingly probable that the ice cube spontaneously formed in warm water. This clashes badly with our observations: we never see such spontaneous ice cube formation. Boltzmann's ingenious fix has been convicted by the tribunal of experience.

Albert and Loewer have proposed a solution. Instead of positing a probability distribution over the possible initial microstates of the ice cube system, they posit a distribution over the possible initial microstates of the universe as a whole. This solves the problem of incorrect predictions about the past, for now there is no longer any past to predict.

What does this ur-distribution look like? Just as the ice cube distribution was uniform over the possible initial microstates that realize an ice cube floating in warm water and zero for all other microstates, so the ur-distribution is uniform over the possible initial microstates that realize $M(0)$, the initial macrostate of the universe, and zero for all other microstates.

Let PROB be the proposition that such a probability distribution exists. Albert ([2000]) argues that our current best cosmological theories support what he calls the past hypothesis, the claim that $M(0)$ is a state of very low entropy. The past hypothesis fills out the content of PROB, so that PROB (together with the dynamical laws) is capable of delivering predictions about the future. And Albert and Loewer argue that these predictions are the right ones. For instance, they take PROB to have the consequence that it is overwhelmingly probable that an ice cube in warm water will melt. And more generally, they take it to provide a powerful explanation of why all the systems we observe obey the second law of thermodynamics, which states that isolated systems not in equilibrium increase in entropy over time.[5]

This is Albert and Loewer's proposed resolution of the statistical-mechanical tension. It has three ingredients: the fundamental dynamical laws, the past hypothesis, and PROB (the content of which depends on the past hypothesis). Albert and Loewer call this package of ingredients the Mentaculus.[6]

Focus on the third of these ingredients, PROB. It assigns a probability to every set of physically possible initial microstates. Given determinism, then, PROB induces a probability distribution $\mathcal{P}$ on every set of physically possible microtrajectories. $\mathcal{P}$ assigns a probability to every condition that is satisfied by a well-defined set of microtrajectories, and so it assigns probabilities to regularities like the ice cube nome.

How should we understand these probabilities? We can set aside two common interpretations of probability. First, we sometimes understand probabilities subjectively, as deriving simply from one's epistemic state. Might this subjective sort of probability be what's at work in PROB? Subjectivists about probability (such as Jeffrey [2004]) believe it must be, because for them there is no non-subjective kind of probability. But such subjectivism is quite implausible in this context. That ice cubes melt in warm water is a mind-independent fact about the world. It is very hard to see how it could be explained by facts about anyone's epistemic state.

Better to instead understand the probabilities of PROB as objective. But what is an objective probability? Perhaps the most natural way to understand objective probabilities is as propensities. If the probability that this atom will eject a β particle in the next five minutes is 0.6, then there is something about the atom itself, something like a causal tendency, that makes it eject a β particle with probability 0.6. But propensities also seem inadequate for understanding PROB. The problem is not only that it is very unclear what they are or how they influence events. It is that propensities are supposed to be things that influence events causally and so must be causally prior to the events they influence. But then how can there be propensities concerning possible initial microstates? The initial microstate, after all, is plausibly at the beginning of all

[5]These claims about the consequences of PROB are controversial. See Winsberg ([2004]), Frisch ([2010]), Callender ([2011]), and North ([2011]) for discussion.

[6]Perhaps the Mentaculus also includes the claim that the past hypothesis and PROB are themselves fundamental laws. I discuss this issue further below.

actual causal chains. If that's right, then it is not causally posterior to or produced by anything else, propensities included.

Loewer ([2004], [2012b]), inspired by the account of Lewis ([1994]), takes the probabilities of PROB to be objective in a different sense. Imagine a competition between different descriptions of a data set. Some descriptions are very informative, others very simple. Typically, a gain in simplicity means a loss in informativeness, and vice versa. The winner of the competition is the description(s) that best combines informativeness with simplicity.

Probabilistic descriptions can enter such a competition. Consider a typical sequence of one million coin tosses throughout which heads and tails are randomly distributed. Here are two competing descriptions of the sequence:

> Description A: The actual frequency of heads and tails is assigned a high probability by the binomial distribution with $n = 1$ million and $p = 0.5$.
>
> Description B: The actual sequence of heads and tails is assigned probability 0.99 by a certain probability distribution over all possible sequences of one million coin tosses.

Description B wins on informativeness, because it communicates more about the outcomes of individual tosses. Description A, by contrast, communicates almost nothing about individual tosses. (Nevertheless, it is still quite informative about more global properties of the sequence; for example, it entails that it is almost certain that about half the tosses are heads.) But Description A is so much simpler than Description B that it is clearly the overall winner. The probability distribution of Description A is given by a simple formula, while the distribution of Description B can be given only in terms of specific million-toss sequences and their probabilities. What Description A loses in informativeness, it more than makes up for in simplicity.

Suppose we hold such a competition among the members of a set of descriptions. Assuming the set has objective criteria for membership, and assuming we have objective notions of informativeness and simplicity, and assuming we have an objective measure of how well a description combines these, it is an objective matter which description is the winner. If a probabilistic description wins, its probabilities thereby acquire a kind of objectivity.

Consider now a grand competition among all descriptions of the entire history of the universe. Loewer suggests that PROB will be the winner—or among the winners. (The other winners will be the statements of the fundamental dynamical laws.) After all, PROB is quite informative. It assigns probabilities to every condition that is satisfied by a well-defined set of microtrajectories, and, as far as we can determine, these probabilities accord with our experience. It's not maximally informative, since it assigns the same probability to many microtrajectories—all those that realize the initial macrostate of the universe $M(0)$—but this very lack of informativeness considerably boosts its simplicity. If PROB is among the winners of this competition, then its probabilities are objective. Not only that, they are privileged. For PROB is one of the winners of a competition among the most global descriptions there are.

Weslake ([2014], p. 248), building on Callender ([2011]), has suggested that there is no reason to privilege the probabilities of PROB over those of a rival he calls PROB*. PROB* is stipulated to agree with PROB on 'the probabilities of all thermodynamic properties, but [to be] massively indeterminate with respect to the probabilities of all non-thermodynamic macroscopic properties'. And Weslake argues that PROB and PROB* 'have been equally well tested for the propositions on which they agree, and neither has been tested on any propositions on which they disagree'.

Maybe so. But Weslake's conclusion that there is no reason to prefer PROB to PROB* does not follow. There is such a reason—at least given Loewer's understanding of probability. After all, PROB is both simpler and more informative than PROB*. It is simpler, because it can be straightforwardly characterized as the distribution which is uniform over the microstates that realize $M(0)$ and zero for all other microstates, while PROB* would appear to admit of no non-'disjunctive' or non-'gerrymandered' characterization. And it is more informative, because it assigns probabilities not just to the sets of microtrajectories which satisfy thermodynamic conditions but to all well-defined sets of microtrajectories. There is thus reason to think that PROB will defeat PROB* in our grand competition and thereby ensure that its probabilities turn out to be the privileged ones.

Loewer himself is not content to say only that the probabilities of PROB are objective and privileged. He boldly endorses a modified version of David Lewis's ([1973], pp. 72–5) best system account of laws of nature, on which the laws are just the theorems of the deductive system which best combines the virtues of simple axiomatization and informativeness about the world. If Loewer is right that PROB is among the winners of the grand competition described above, then presumably his best system account will count it as a law of nature. And not just any law of nature: for Loewer PROB is among the fundamental laws.[7]

A philosopher in the Loewerian mould might instead offer a more modest take on PROB. Consider a slightly less grand competition among all probabilistic descriptions of the entire history of the universe. If PROB is the winner of this competition, then its probabilities are in a clear sense objective. They are also privileged, since PROB is the winner of a competition among the most global probabilistic descriptions there are. It is in this sense the best statistical summary of the world. But despite PROB's privileged status, this modest interpretation does not count it as a law of nature.

4.2 Two demons again

Could one or both of our demons explain the raven nome by appealing to the Mentaculus?

Take the ornate demon first. It knows the complete microtrajectory of the universe and so is able to offer the mad mechanist 'explanation' of Section 3: for each raven, the ornate demon can show that microstate of the universe at the time of its conception nomically necessitates its blackness. This much, we have seen, fails to show that the raven nome is not a coincidence. But by appealing to the Mentaculus the ornate demon can say more. Using the translation manual and its immense powers of calculation, it can hold the competition of probabilistic descriptions sketched in Section 4.1 and arrive at PROB. Again using the translation manual, it can obtain

[7]This, at least, is the view of Loewer ([2008], p. 157). Describing Albert's view, which he endorses, Loewer writes: 'His proposal then is that the fundamental laws of the universe are the dynamical laws (and whatever plays the role of the force laws) and a law that specifies a probability distribution (or density) over possible initial conditions that assigns a value 1 to [the past hypothesis] and is uniform over those micro-states that realize [the past hypothesis]'. The latter law is, of course, PROB. However, Loewer ([2020], p. 24) is open to the idea that the past hypothesis (and so by extension PROB) may not be 'a fundamental law. It may have an explanation in terms of fundamental dynamical laws'. But as long as PROB is explained solely in terms of fundamental laws it can be counted as fundamental for our purposes.

the set R of microtrajectories according to which the raven nome holds. Finally, it can show that $\mathcal{P}(R)$ is high, thus showing that the raven nome is probable and apparently dispelling the spectre of coincidence. It therefore seems the ornate demon can explain the raven nome.

Indeed, one might suspect that the mad mechanist component of this explanation is unnecessary. It is overkill, the thought goes, to show that each raven's blackness is nomically necessitated by the microstate of the universe at the time of its conception. All the ornate demon really needs is the second, Mentacular component of the explanation. It is enough simply to show that it is probable for all ravens to be black.

This thought creates a tantalizing prospect for the reductionist. The mad mechanist explanation is unavailable to the austere demon, because it relies on facts that demon is forbidden to know. But suppose we drop the mad mechanist explanation and explain the raven nome simply by pointing to its high probability. Is that explanation available to the austere demon?

Yes—provided that Loewer's bold interpretation of PROB is correct. If PROB is a law of fundamental physics, then the austere demon is allowed knowledge of it. So perhaps, with the help of the Mentaculus, even the austere demon can explain the raven nome.

Two immediate worries arise. First, Loewer's interpretation of PROB is controversial. Second, it's unclear whether showing only that the raven nome is probable is really enough to explain it. But set these worries aside. I'll argue below that there are more basic reasons to think that PROB, and the Mentaculus hypothesis that entails its truth, cannot deliver austere reductionism.

4.3 The background macrostate

But first, an admission: I've oversimplified something.

In Section 4.2, I suggested that one might be able to show that the raven nome is probable by showing that $\mathcal{P}(R)$ is high. But this strategy is hopeless, because it's plausible that $\mathcal{P}(R)$ is pretty low. After all, PROB entails that $\mathcal{P}$ is uniform over the possible initial microstates that realize $M(0)$, the initial macrostate of the universe, and zero for all other microstates. But, premise: most of the microtrajectories passing through possible initial microstates that realize $M(0)$ are not microtrajectories according to which the raven nome holds. And so $\mathcal{P}(R)$ is low.

Why believe the premise? Because raven blackness depends on many structures and systems being arranged just so: structures in ravens which produce their feathers and the melanin that renders those feathers black; the reproductive system of ravens, which transmits the phenotype of blackness from one generation of ravens to the next; the habitat of ravens, which contains the resources ravens need to grow and reproduce; … . This delicate arrangement is the result of an unimaginably complex process of evolution unfolding over billions of years (not to mention the process of star and planetary formation that preceded it). Given a small difference in even just the history of ravens' environment, or a past population bottleneck, ravens might well have turned out to be grey or spotted rather than black. All of which is to say that, as many philosophers have emphasized, the raven nome is highly contingent. Strevens ([2008], p. 1), for instance, writes, 'not only are [special science nomes] not entailed by the fundamental laws of physics, they require for their truth an antecedently quite improbable array of initial conditions'.[8] Even assuming determinism, the macroscopic features of the Big Bang did not on their own make this array of conditions likely to one day obtain. It is therefore plausible that most of the possible initial microstates which realize $M(0)$ do not lie on microtrajectories according to which the raven nome holds.[9]

Notwithstanding this point, however, there might still be a way to show that the raven nome is probable, at least in the sense required for explanation. Think back to my encounter at the airport. No one would think our meeting was probable *simpliciter*. The wedding might have been held in a different city or not at all. My friend and I might never have met. Airplanes might never have been invented! The meeting was probable only given certain background facts about the wedding, our relationship, air travel, and so on. But this may well be enough to explain it. Perhaps, then, we do not need to show that the raven nome is probable *simpliciter*. Perhaps we need only show it is probable given certain background facts.

Which background facts? One salient background fact is the universe's initial macrostate $M(0)$. But since $\mathcal{P}$ assigns probability 1 to this macrostate, and we have just argued that $\mathcal{P}(R)$ is low, we have argued that the raven nome is improbable given $M(0)$.

Gómez Sánchez ([2020]) has recently suggested that nomes like the raven nome will be prob-

[8]Others who have emphasized the contingency of nomes include Beatty ([1995]), Weber ([2005]), Rosenberg ([2006]), and Reutlinger ([2014]).

[9]Similar points are made by Weslake ([2014], p. 252) and Gómez Sánchez ([2020], p. 460).

able given what she calls '"crystallization conditions"—stable background conditions that—together with the laws—sustain the regularities that are crystallized within the [spacetime] region in question' (p. 461). This suggestion raises two questions. Is Gómez Sánchez correct that the raven nome is probable given the crystallization conditions? And if so, can these conditions properly figure in an explanation of the raven nome?

It is hard to answer these questions, because it is hard to know what exactly the crystallization conditions are. Gómez Sánchez provides a procedure for determining which regularities are what she calls 'crystallized' within a given spacetime region. The crystallized regularities are the axioms of the best system, where which system is 'best' is, in a way Gómez Sánchez spells out, relative to a spacetime region. But to know what the crystallization conditions are, given her characterization of them, we will need to know not just what the crystallized regularities are but what it is for a given condition to sustain a given crystallized regularity, and about that she says little (though her use of 'sustain' in two examples (p. 453, p. 454) suggests that she has in mind an explanatory relation of some kind). We will also need to know which spacetime region is 'in question', and that too is not completely clear.

Another possibility for what the background facts are is suggested by Loewer's discussion of Gresham's law, quoted in Section 2. Loewer observes that various background conditions must obtain in order for Gresham's law to hold and that these conditions follow from the past macrostate of Earth. One might therefore propose that, in order to explain the raven nome, it suffices to show it is probable given the past macrostate of Earth.

This macrostate, however, is at once too inclusive and not inclusive enough. It is too inclusive, because it contains a lot of irrelevant information: many aspects of Earth's past macrostate have nothing to do with why the raven nome holds. And it is not inclusive enough, because in general we will need to look beyond Earth to obtain the conditions that render a nome probable: think, for instance, of the nomes of lunar geology.

Which past macrostate we need depends on which nome we want to explain. If our target is the raven nome, we need a macrostate that includes information about ravens and their environment; if our target is a nome of bathymetry, we need a macrostate that includes information about the ocean floor. To say precisely which past macrostate is relevant to each nome would be a huge undertaking that is beyond the scope of this paper. For our purposes it is sufficient to note that in every case the relevant macrostate will be included in the macrostate of the universe as a whole at some past time. Even if this cosmic macrostate contains too much irrelevant information to properly figure in the explanation of, for instance, the raven nome, it will at least include a macrostate that does so figure.

But how far back in the past must we go? Not all the way to the Big Bang, for we have already argued that the raven nome is not probable given the universe's initial macrostate $M(0)$. But we must go back a considerable way. For suppose we use the macrostate of the universe five minutes ago. Then the blackness of ravens centuries ago will be explained in terms of the raven nome, which will in turn be explained by facts about the macrostate five minutes ago. But explanations (explanations of this kind, at least) should not explain facts about earlier times in terms of facts about later times. To avoid any such 'backwards' explanation, the past macrostate must be one that obtains no later than the appearance of the first ravens.

And since the macrostate must also include information about ravens and their environment, this strongly suggests that (bracketing the problem of irrelevance mentioned earlier) we should take the past macrostate to be the universe's macrostate at the time at which the first ravens appeared. (And in general, in order to explain a nome of the form 'all Fs are G', we should take the past macrostate to be the universe's macrostate at the time at which the first Fs appeared.)

Call this the 'background macrostate' of the raven nome. The demons must demonstrate that given that the world was in that macrostate, the raven nome is probable. This we may call the Mentacular demonstration of the raven nome. Such a demonstration is an essential part—perhaps even the only part—of a Mentacular nome explanation.

4.4 The Mentacular demonstration

Let's go through the Mentacular demonstration of the raven nome's probability. Its basic components are

1. the dynamical laws of fundamental physics,

2. PROB, and

3. the background macrostate.

Two further components are derived from these. The first is B, the set of microtrajectories passing through microstates that realize the background macrostate. To obtain B, the demons first use the translation manual to determine the set of microstates that realize the background macrostate. Then they apply the dynamical laws to deduce the microtrajectories that pass through each of these microstates and discard those microtrajectories that do not pass through these microstates at the time the background macrostate obtains. The remaining microtrajectories constitute the set B.

The other important component is R, the set of microtrajectories that realize the raven nome. As before, the demons use the translation manual to obtain the set R' of microstates in which all ravens are black. They then apply the dynamical laws to deduce the microtrajectories that pass through microstates in R'. The demons discard those microtrajectories that also pass through microstates outside R'. The remaining microtrajectories constitute the set R. According to these microtrajectories, all the ravens that ever have existed or ever will exist are black.

It is then straightforward for the demons to show that $\mathcal{P}(R \mid B)$ is high. Prob assigns probabilities to the sets of microtrajectories B and $R \cap B$, so the demons may calculate the probability of R given B using the familiar formula $\mathcal{P}(R \mid B) = \mathcal{P}(R \cap B)/\mathcal{P}(B)$.

What probability will the demons obtain? Since $\mathcal{P}$ is uniform over all microtrajectories compatible with the universe's initial macrostate $M(0)$, $\mathcal{P}(R \mid B)$ is equal to the proportion of $M(0)$-compatible microtrajectories in B that are also in R. But statistical-mechanical considerations give us reason to believe that most of the microtrajectories passing through the background macrostate are ones according to which the features of raven physiology responsible for blackness work normally. According to these microtrajectories, all ravens are black. It's plausible, then, that $\mathcal{P}(R \mid B)$ is sufficiently high.

5 Which Reductionism?

5.1 Taking stock

Now that the Mentacular demonstration has been detailed, it's clear that all three of the basic components are essential to it and hence to the Mentacular explanation of a nome.[10] The Mentacular demonstration, absent one of these components, simply can't be performed.

The first component, the dynamical laws, is available to both the austere and ornate demons. The second component, PROB, is certainly available to the ornate demon. And if we grant Loewer's bold interpretation of PROB as a law of fundamental physics, it is available to the austere demon as well. But the third component, the background macrostate, is available only to the ornate demon. Knowledge of the background macrostate requires knowledge of facts beyond the fundamental laws, and only the ornate demon is allowed such knowledge.

The ornate demon has access to all three of the basic components of the Mentacular demonstration. So given the Mentaculus hypothesis, ornate reductionism has a fighting chance of being true. We must leave for another time the important task of reaching a decisive verdict as to whether it really is true given the Mentaculus—and if it is, of developing the ornate demon's explanation in further detail (Sections 4.2–4.4 are a start).

In contrast to the ornate demon, the austere demon lacks access to the background macrostate. Since that is essential to the Mentacular demonstration, which is in turn essential to the Mentacular explanation of the raven nome, the austere demon cannot explain the raven nome. Austere reductionism is false given the Mentaculus hypothesis. And so the Mentaculus cannot deliver the unity of laws.[11]

[10] I call the explanation 'Mentacular' because it appeals to the Mentaculus; I do not claim that Albert or Loewer would endorse it. I do not know whether they would agree that showing only that the raven nome is probable is enough to explain it or whether they would agree with my proposal about what the background macrostate is. However, it is at least in keeping with their approach that the only nomological components of the explanation are the dynamical laws and (if Loewer is right about its status as a law) PROB.

[11] There is a variant of the Mentacular demonstration that is worth mentioning, if only to show that it too is available only to the ornate demon. Suppose that an account of counterfactuals in

But might it almost deliver it? Might it be that for the vast majority of nomes the background macrostate is of negligible explanatory importance? If so, then one might argue that the vast majority of nomes can be, if not entirely explained, then almost entirely explained in terms of the laws of fundamental physics. Although strictly speaking the Mentaculus would fail to deliver austere reductionism, it would deliver an austere almost-reductionism. And although strictly speaking it would fail to deliver the unity of laws, it could perhaps deliver the almost-unity of laws.

The notion of almost entire explainability is *prima facie* a coherent one. For example, suppose we want to explain why the baseball I threw had the precise trajectory it did. We naturally want to appeal to the properties of my throw: its speed, direction and so on. There are of course other influences on the ball's trajectory, such as the gravitational forces of distant stars. But these influences are so tiny that they are of negligible importance to the explanation. There is a sense in which the trajectory can be 'almost entirely' explained in terms of my throw. Although this case is only roughly analogous to the case of nome explanation, it supports taking seriously the idea that the Mentaculus almost delivers austere reductionism.

Further support for the idea may be given. Consider the following difference between the raven nome and the ice cube nome (all ice cubes in warm water melt). The 'essence of ravenhood', or what it is to be a raven, does not on its own nomically necessitate that all ravens are black. For as emphasized in Section 4.3, had evolution gone a different way, there would still have been ravens; it is just that they would have been grey instead of black. To explain why all ravens are black, one must bring in 'many' additional facts about the background macrostate,

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terms of PROB can be given, perhaps the account sketched in Loewer ([2007]). A demon might think to argue on the basis of this account that counterfactuals of the form 'if x were a raven it would be black' are probable, and so (assuming Weak Centring) that it is probable that all ravens are black. But any reasonable PROB-based account of counterfactuals will take the truth or probability of typical counterfactuals to depend in part on facts about the macro state at a time much later than the Big Bang (as indeed does Loewer's). The austere demon, however, is denied knowledge of such facts, and so this variant demonstration can be performed only by the ornate demon. I am grateful to an anonymous referee for suggesting this variant to me.

such as facts about the contingent physiology and environment of ravens. Contrast this with the ice cube nome. It seems that once you know what being an ice cube in warm water is, you know enough to conclude that it is nomically necessary (or highly probable) that all ice cubes in warm water melt. There are 'fewer' additional facts—perhaps none at all—that must be brought in from the background macrostate to explain the nome.

The background macrostate, then, seems to be more important to the explanations of some nomes than others. Might it be that the raven nome is atypical in its significant explanatory dependence on the background macrostate? Might it be that the vast majority of nomes are more like the ice cube nome, where the background macrostate seems to be of negligible explanatory importance? I will argue that the answer is 'no'. In order to do this, I'll first develop a device to measure more rigorously the explanatory importance of the background macrostate.

5.2 The conditional boost method

The basic idea is this. Let's suppose the probability of a given nome, according to PROB, is low. But suppose further that its probability conditional on the background macrostate is high. Conditionalizing on the background macrostate, then, changes the nome's probability from low to high. That, I suggest, is a good reason to take the background macrostate to be important to the explanation of the nome.

Before going on I must clarify something. There is more than one way to evaluate the probability of nomes of the form 'all Fs are G'. The most straightforward way is to take it to be the probability of the corresponding universal generalization $\forall x(Fx \to Gx)$. But consider the nome 'all ravens are black'. Any microtrajectory that lacks ravens altogether will vacuously satisfy the corresponding generalization $\forall x\,(\text{Raven}(x) \to \text{Black}(x))$. In view of the contingency of avian evolution, not to mention that of the formation of the solar system (Section 4.3), such raven-free microtrajectories presumably constitute the majority of the total set of possible $M(0)$-compatible microtrajectories. Since $\mathcal{P}$ is uniform over the possible $M(0)$-compatible microtrajectories, and zero for all other microtrajectories, $\mathcal{P}\,(\forall x\,(\text{Raven}(x) \to \text{Black}(x)))$ will turn out to be high. But then conditionalizing on the background macrostate cannot change the probability of the raven nome from low to high—it is already high! No matter how important the background macrostate may be to the raven nome's explanation, this method will judge it to be unimportant.

I therefore propose a different method of evaluation: take the probability of a nome of the form 'all Fs are G' to be the probability that $\forall x\,(Fx \to Gx)$ given that there are Fs (in symbols: $\mathcal{P}\,(\forall x\,(Fx \to Gx)\,|\,\exists x Fx)$). This solves the problem faced by the earlier, more straightforward method. In the case of the raven nome, for instance, conditionalizing on the fact that there are ravens prevents raven-free microtrajectories from driving up the nome's probability.

It's important to distinguish this type of conditionalization from the further conditionalization on the background macrostate, which we will use to measure that macrostate's explanatory importance. I hope no confusion will result from my continuing to refer to

$$\mathcal{P}\,(\forall x\,(Fx \to Gx)\,|\,\exists x Fx)$$

as the unconditional probability of 'all Fs are G'. This probability is distinct from the conditional probability of 'all Fs are G' given the background macrostate, which is

$$\mathcal{P}\,(\forall x\,(Fx \to Gx)\,|\,(\exists x Fx \cap B))\,.$$

I now want to suggest that the explanatory importance of the background macrostate is proportional to the difference between the conditional and unconditional probabilities, which we may call the 'conditional boost'. That is:

> Conditional Boost Method: The importance of the background macrostate B to the Mentacular explanation of the nome that all Fs are G is proportional to
>
> $$\mathcal{P}\,(\forall x\,(Fx \to Gx)\,|\,(\exists x Fx \cap B)) - \mathcal{P}\,(\forall x\,(Fx \to Gx)\,|\,\exists x Fx)\,.$$

When a nome's conditional boost is high, that means the nome's probability given the background macrostate is much higher than its probability not given this macrostate—its probability 'on its own'. And that seems to suggest that the background macrostate is a big part of why the nome holds.[12]

The conditional boost method is one measure of explanatory importance, but it is not the only one. For example, instead of the difference of these two probabilities, we might use their ratio, or the difference of their squares, or the ratio of their squares, and so on. There may even be measures that don't use conditionalization at all. For our purposes, however, the conditional boost method is as good as any other.

The conditional boost method bears some resemblance to statistical relevance accounts of explanation.[13] Like the conditional boost method, SR accounts understand explanatory importance in terms of probability boosts: for a factor to be important to an explanation is just for the probability of the explanandum to be higher given the presence of the factor. (Higher how? Different SR accounts give different answers.) There is a well-known objection to SR accounts which many have found convincing. But despite the conditional boost method's similarity to SR accounts, it is not subject to this objection.

Strevens ([2006]) presents the objection this way. Imagine someone fixes to the wheel of a car a very small bomb that will detonate with probability 0.5. If the bomb goes off, the tire will go flat. As it happens, the bomb does not go off, but the car drives over a nail, so the tire goes flat anyway. Intuitively, the undetonated bomb is totally unimportant to the explanation of the flat; only the nail is important. But on SR accounts, since the bomb increased the probability of the flat, it is judged to be important. SR accounts get this case wrong.

One might think this objection, slightly tweaked, spells doom for the conditional boost method as well. Consider a possible world, the 'fluke world', in which the Mentaculus hypothesis holds. The macrostate of the fluke world matches the macrostate of the actual world throughout history up until a short time after the first ravens appear, when Ray the raven is hatched. Ray's parents are perfectly normal, but due to an improbable just-so arrangement of fundamental particles, Ray's physiology is abnormal in certain ways. Among other things, he

[12] Might there be a case in which conditionalizing on the background macrostate lowers a nome's probability? If there are such cases, we should interpret the resulting negative value of the difference in same way we interpret a zero value: the background macrostate is not explanatorily important.

[13] Salmon ([1971]) is a classic SR account.

has no melanocytes (specialized cells which produce melanin, the pigment that colours raven feathers black). It is overwhelmingly improbable for a raven without melanocytes to be black, since melanocytes are an essential part of the normal mechanism for producing raven blackness. But due to a second improbable arrangement of fundamental particles, molecules of melanin form in his feathers without any assistance from melanocytes. So Ray ends up being black. And in fact, the fluke world is even more bizarre than I've said already: starting from Ray onward, all ravens improbably lack melanocytes but improbably form melanin anyway.

The objector might now suggest that in the fluke world, the background macrostate—in this case, the macrostate at the time the first ravens appeared—plays the role of Strevens's undetonated bomb. Conditionalizing on the background macrostate boosts the probability that all ravens are black. Yet the background macrostate seems hardly important at all to the explanation of why all ravens are black, since it has little to do with why Ray and all the ravens succeeding him are black. And so the conditional boost method, the objector says, gets this case wrong.

My reply is that the conditional boost method applies only to nomes. It's not a general method for measuring explanatory importance. And although we have been pretty loose about what counts as a nome, we did require nomes to be counterfactually robust. In the fluke world, the fact that all ravens are black is extremely counterfactually fragile. The blackness of most of the fluke world's ravens depends incredibly sensitively on the precise positions and momenta of all the particles in the ravens' backward light cone. Had even one electron been perturbed by a relatively small amount, the delicate arrangement of particles that made for raven blackness would have been destroyed. So in the fluke world, the conditional boost method does not apply to the fact that all ravens are black. The fluke world, then, presents no difficulty for this method.

5.3 The importance of the background macrostate

With the conditional boost method in place, we can now argue that for many if not most nomes, the background macrostate is quite explanatorily important.

Take the raven nome, for example. Its unconditional probability is

$$\mathcal{P}\left(\forall x\,(\text{Raven}(x) \rightarrow \text{Black}(x))\,|\,\exists x\text{Raven}(x)\right).$$

Since $\mathcal{P}$ is uniform over all the microtrajectories compatible with the universe's initial macrostate $M(0)$, and zero for all other microtrajectories, this unconditional probability is equal to the proportion of $M(0)$-compatible microtrajectories containing ravens according to which every raven is black. And reflection on the myriad contingencies involved in the evolutionary process that led to the existence of ravens, as well as those involved in the environmental conditions that make it possible for the blackness-producing mechanisms in ravens to function properly and for these mechanisms to be transmitted from one generation to the next (Section 4.3), makes it plausible that this proportion is low. Even given that there are ravens, there are just so many ways for them to fail to be black!

By contrast, the conditional probability of the raven nome is

$$\mathcal{P}\left(\forall x\,(\text{Raven}(x) \rightarrow \text{Black}(x))\,|\,(\exists x\text{Raven}(x) \cap B)\right)$$

where B is the background macrostate. And that is plausibly much higher than the unconditional probability. For conditionalizing on the background macrostate lets us ignore those microtrajectories according to which ravens possess a different physiology, or have a different environment, and so on. Once all these microtrajectories are thrown away, those that remain all contain what Strevens called the 'antecedently quite improbable array of initial conditions' that must be in place for the raven nome to hold. And the proportion of those microtrajectories according to which every raven is black is high.

According to the conditional boost method, the explanatory importance of the background macrostate is proportional to the conditional boost: the difference between the conditional and unconditional probabilities. Since this boost is high, we may conclude that the background macrostate is quite important to the raven nome's explanation.

The raven nome is not at all atypical in this regard. Ravens are the product of an evolutionary process, and the contingency of this process is an important part of why the raven nome has a high conditional boost. A similarly high boost can therefore be expected for the other nomes of biology, since these too concern the products of evolution. And the same goes for the nomes of empirical psychology and the social sciences. The conditional boost method will judge, in all of these cases, that the background macrostate is important to the explanation of these nomes.

The point, however, goes beyond the products of evolution. Consider the 'moon nome': each lunar orbit takes 27.32 days. This orbital period depends in part on the masses of the earth and the moon. But had the primordial collision that is thought to have led to the moon's formation occurred at a different angle, or with a different relative velocity, the masses of the earth and moon would have been different. It is therefore plausible that the unconditional probability of the moon nome is low. Yet once we conditionalize on the background macrostate, we bring in information about the primordial collision and thereby render the moon nome much more probable. The conditional boost, then, is high, and so the background macrostate is important to the moon nome's explanation.

Or consider geological nomes, such as nomes concerning the speeds of seismic waves. These speeds depend in part on the densities of various parts of the earth's structure. Had the process of the earth's formation been different, these densities would have been different, and so the unconditional probabilities of these nomes are plausibly low. But conditional on the background macrostate they are plausibly high, and so the background macrostate is important to their explanations.

Evidently, the truth of many nomes, across a range of sciences, depends on various structures and systems being arranged just so. In general, it is the background macrostate that provides information about this arrangement, and so conditionalizing on this macrostate will boost the probability of these nomes. The conditional boost method therefore judges the background macrostate to be explanatorily important.

Two classes of potential exceptions should be mentioned. One involves nomes involving functionally defined properties (if there are any such nomes). Some of these will be true by definition, and so will have an unconditional probability of 1 (and thus a conditional boost of 0). The nomes of folk psychology, for example, are sometimes thought to be members of this class. A more interesting class of potential exceptions involves the nomes of statistical mechanics. For example, if Albert and Loewer are right, then the ice cube nome (all ice cubes in warm water melt) is assigned a high probability by PROB. Its unconditional probability, then, is high, and so conditionalizing on some background macrostate does little to boost that probability further. The conditional boost method judges the background macrostate to be unimportant to these nomes' explanations.

If I am right, then on the Mentaculus hypothesis austere reductionism is not true. It's not even almost true. Many if not most nomes are not explainable solely in terms of the dynamical laws of fundamental physics together with PROB. Their explanations require—indeed, place significant weight on—the background macrostate. The Mentaculus may be able to deliver ornate reductionism, but austere reductionism, and the unity of laws, remains beyond its grasp.

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