# A THEORY OF LAWS OF NATURE, DISPOSITIONS, AND CHANCES

by

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# ABSTRACT OF THE DISSERTATION


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What are the fundamental properties of the world? What is chance? What are the laws of nature? These questions may seem isolated, but in my dissertation, *A Theory of Laws, Dispositions, and Chances*, I show how they are connected by developing a new account that unifies traditionally disparate elements. I defend the anti-Humean claim that there are some fundamental, modal features in the world—such as chance and dispositional properties. But, I also defend the Humean claim that the laws of nature merely *describe* the world, rather than *govern* it.

According to my view, which I call the *Propensity Best System Account* (PBSA), some of the fundamental properties are dispositional—these properties are called *potencies* if they are deterministic, and *propensities* if they are chancy. And the laws of nature systematize all of the possible distributions of those properties. The PBSA provides a new way of interpreting a probability measure over all of the possible initial states of the universe: as a fundamental chance that grounds all subsequent chances.

I argue that the PBSA accords well with scientific practice. Laws that systematize the distribution of properties suit the importance scientists place on simplicity and informativeness when they describe the regularities in the world. Potencies and propensities, which are necessarily connected to the behavior of the entities that instantiate them, are faithful to the scientific principle that the best way to learn about a system is by studying its characteristic behavior in different (stimulus) conditions.

The PBSA avoids many of the serious objections that face traditional, best system

accounts of the laws of nature and chance. For instance, the PBSA yields the right results for the laws of nature in both simple worlds and in improbable worlds. I argue that the PBSA is a promising theory of chance whether the dynamical laws of nature are deterministic or probabilistic and it can be formulated for consistency with classical mechanics or for consistency with quantum mechanics.

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# Chapter 1

# Introduction

In the late 1970's, Fred Dretske (1977), Michael Tooley (1977), and David Armstrong (1983) independently arrived at very similar accounts of laws of nature. They proposed that the laws of nature determine the course of events in the world. These authors were responding to a tradition, going back to John Stewart Mill, that held the laws were mere regularities. If the laws are regularities, they have no power to determine the course of events—indeed, the laws are *determined by* those very events. By contrast, if Dretske, Tooley, and Armstrong are right, the laws have important metaphysical work to do because they necessitate or determine the course of events. While there are well-known problems with the Dretske-Tooley-Armstrong accounts, they fuelled a resurgence of philosophical interest in the laws of nature.

Contemporary accounts of the laws come in a wide variety. One very recent account[1] derives the laws from our language, via counterfactuals. Another[2] takes the laws to be primitive, powerful, and unanalyzable. A third[3] identifies the laws with systematizations of patterns in the world. Nevertheless, all of these contemporary accounts accept Dretske,

[1]Lange (2009)
[2]Maudlin (2007)
[3]Loewer (2007), Loewer (2008), and Cohen and Callender (2009).

Tooley, and Armstrong's assumption about metaphysical power: if anything has the metaphysical power to determine the course of events, it is the laws of nature. The disagreement between these accounts is about whether or not the laws have that power.

In my dissertation, I argue that this assumption is mistaken. It is not the laws of nature that have the metaphysical power to determine the course of events, but the fundamental properties. It is not the law of universal gravitation that impels bodies to move closer together, but their masses. Since the metaphysical power traditionally thought to be held by the laws is instead held by the properties, the laws are best thought of as systematizations of all the possible ways such objects and properties can behave. Thus, the law of universal gravitation systematizes all of the possible ways massive bodies may move when they are near one another.

## 1.1 Powerful Properties

Such powerful properties are called *dispositional* because they do not float free of behavior. As a first pass, one can think of dispositional properties as entailing behavior. If an object has the dispositional property of fragility, then it will shatter if it is dropped. Of course, this admits of obvious counterexamples. When a fragile vase is dropped onto a pillow or dropped while securely wrapped inside a well-padded moving box, it may not shatter when dropped. These exceptions prompted a long and ultimately futile attempt at specifying necessary and sufficient conditions for dispositional properties.[4]

### 1.1.1 Bird's Account

One recent attempt is worth discussing in some detail because it concerns only fundamental, dispositional properties. This is Alexander Bird's (2007a) account of fundamental,

[4]See, for instance, Shoemaker (1980), Lewis (1997), Mumford (1998), and Bird (2007a).

dispositional properties, which he calls *potencies*. Bird argues that there is a necessary entailment between potencies and counterfactuals. Where $P$ is potency, $S$ is a stimulus condition, and $M$ is a manifestation:

(1) $\Box(\forall x)(Px \leftrightarrow (Sx \mathrel{\Box\!\!\rightarrow} Mx))$

According to Bird, it is necessary that if an object has a potency, then it would manifest its disposition in the stimulus conditions. The necessity operator in front of the formula in conjunction with an uncontentious reading of the counterfactual arrow when the antecedent is true—the consequent also must be true—entails that objects with potencies in stimulus conditions will always manifest their dispositional behavior. “Hence, in all possible worlds, any object that possesses $P$ is disposed to yield $M$ in response to $S$.”[5,6]

Bird claims that the biconditional equivalence holds without exception at the fundamental level because there are no finks (where the object loses the potency by entering the stimulus conditions) or antidotes (“last-minute” masks, where the object is prevented from exhibiting its manifestation, despite having the relevant disposition) for potencies.[7]

### 1.1.2 Objections to a Biconditional

Unfortunately, as formulated, the biconditional is not exceptionless, even at the fundamental level. To see this, consider a neo-Newtonian world with particles, fields, and forces. Suppose particle A has the potencies of mass and positive charge. If Bird is right,

[5] Bird (2007a, 45)

[6] There is a potential confusion lurking. If it is the potencies $P$ that have dispositional essences, then dispositions are properties that other properties (potencies) have. However, it is the objects that instantiate $P$ that are disposed to behave in a certain way. Thus, potencies have dispositional essences, and confer dispositional behavior to the particulars that instantiate them.

[7] Bird allows that at the non-fundamental levels, there are finks and antidotes, so a corresponding biconditional at the higher-level sciences, relating essential dispositions to counterfactual behavior, $(Dx \leftrightarrow \Box(Sx \mathrel{\Box\!\!\rightarrow} Mx))$, has exceptions. Bird argues that the exceptions to this biconditional yield non-fundamental *ceteris paribus* laws. Stephen Mumford, (1998, 88-92), disagrees, arguing that this biconditional is exceptionless when properly restricted to *ideal conditions*, but there is considerable debate about what constitutes ideal conditions and if they can be characterized non-circularly.

then the possession of each potency entails, and is entailed by, a corresponding counterfactual. Bird seems to suggest that the corresponding counterfactuals are:

(C1) If A were in a gravitational field, it would be deflected along the G-field.

(C2) If A were in an electric field, it would be deflected along the E-field.

But, in general, such counterfactuals admit of fink-, antidote-, and mask-counterexamples. For instance, (C2) could be false if A is a charged atom that is about to enter an experiment where it is first neutralized, and then sent into an electric field. While A currently has the potency of charge, it will lose it upon entering the experiment. Thus, the counterfactual is false, even though A currently has the disposition, demonstrating that fundamental potencies admit of finks.

Similarly, (C1) says nothing about whether or not A is *also* in an electric field, and (C2) says nothing about whether or not A is *also* in a gravitational field. And, if A is in *both* a gravitational field, *and* an electric field, it may not be deflected toward either. If the fields are configured in the right way, A may remain stationary or continue on its previous trajectory. Thus, the counterfactual is false, even though A has the disposition, demonstrating that fundamental potencies admit of antidotes as well. Indeed, Nancy Cartwright (1983) has argued that there are always interfering forces in fundamental physics.

Finally, we can easily imagine a particle for which the counterfactual (C1) is true, but for the wrong reason. For instance, a particle that had only the potency of charge might be deflected along a gravitational field, but only because it also happened to be in an electric field. Thus, fundamental potencies admit of masks.

We can partially fix these problems by adding a caveat that the potency is present while the object is in the stimulus conditions, we can avoid the fink counterexample. This is just David Lewis's (1997) solution to finks generally. However, the antidote counterexample is very difficult to deal with. The problem is that potencies rarely (if ever) act in isolation, and without a good theory of how forces compose, such biconditionals will always admit of counterexamples.

### 1.1.3 Potencies without Biconditionals

The fact that there is no adequate analysis of or biconditional for potencies does not mean there aren't any potencies. It just means that they do not act in isolation and are not reducible. A massive particle is not only responsive to gravitational fields, but also to electromagnetic fields, if it is charged. While I reject that potencies can be reduced to—or analyzed in terms of—simple counterfactual sentences, I agree with Bird that potencies nevertheless determine the course of events.

## 1.2 Fundamental Chance

But, of course, the world may not be wholly determined by the potencies, because it may turn out not to be wholly determined at all. The idea dates all the way back to Lucretius, but it has gained prominence since the results of quantum mechanics became well-known: some events may turn out to be *chancy*. If so, we will want a theory that accommodates those chances.

This accommodation can be made within my framework by modifying the potencies to include chancy dispositional properties, called *propensities*. Thus, some fundamental dispositions are sure-fire while others are not.

I argue that the chanciness of these potencies is fundamental and cannot be reduced to anything else. This runs contrary to the Humean theory of chance, according to which chance is nothing more than a mathematical measure that fits the pattern of events in the world. I argue that this kind of notion fails to account for some of the important features of chance. I go on to show how fundamental chance can meet this challenge.

I discuss two locations for chances: one at, or very near, the beginning of the universe, the other throughout space and time. Thus, it is possible (epistemically) that the only chances are located at the beginning of the universe. In such a case, the subsequent evolution of the universe is purely deterministic: propensities followed by potencies. I argue that my theory of fundamental chance can explain why the world may still seem chancy, and why non-trivial credences—beliefs that are not certain—are useful and reliable.

## 1.3 Fundamentality versus Parsimony

I postulate fundamental dispositional properties and fundamental chance—unified as propensities. While I also accept other fundamental features, such as positions in spacetime, these two are significant because my primary opponent, the Humean, rejects them. Indeed, the Humean argues that dispositional properties and chance can be derived from something more fundamental, namely the *Humean mosaic*, or the pattern of purely categorical (non-modal) properties throughout spacetime.

This raises a very deep and important question: when should we look for a reduction? and a corresponding question: when should we be happy to accept something into our fundamental ontology? The Humean's project is this: take the actual distribution of categorical properties in spacetime as fundamental, then reduce everything else to that distribution. If those properties get farther apart in space as one looks farther along in one direction of time, then we say "entropy is increasing." If one property always follows another, we call it a "law of nature." And, if one property follows another roughly 60% of the time, we say it has a "chance" of 60%. Opponents protest that "increasing" presupposes a direction of time; that the laws of nature and the chances *cause* the patterns we see.

Many take the situation to be a stalemate, with both sides claiming the intuitive higher ground. The Humeans claim that intuitions about parsimony or simplicity tell in favor of their theory. The anti-Humeans claim that intuitions about causation, governance, or production tell in favor of theirs.

The Humean often claims that the right theory has as few primitives as possible. For instance, if you postulate the existence of atoms that are arranged in a certain way, you don't also need to postulate the existence of a table. That table just comes along "for free" because a table is nothing over and above the atoms that are arranged in the right way. This suggests that if you can eliminate one thing by reducing it to another, you have made ontological progress.

On the other hand, many think that ontological progress is best achieved by identifying the *actual* fundamental bits of world. That this identification always lines up with considerations of parsimony requires further argument from the Humean.

I hope that my dissertation makes some progress in furthering the debate between the Humean and anti-Humean. I offer arguments against a purely Humean ontology. I argue that by including some anti-Humean elements, one need not accept counterintuitive conclusions. At the same time, I utilize many of the Humean motivations and innovations, including the emphasis on simplicity and informativeness in the laws of nature as well as the inherited probability functions underlying the special sciences. I think that both the anti-Humean and the Humean are partially wrong. I argue for a position that occupies the appealing middle ground between the two—hopefully retaining the best of both and the drawbacks of neither.

## 1.4 Outline of Dissertation

In the second chapter, I consider one of the foremost contemporary theories of the laws of nature: Marc Lange's (2009) account, according to which the laws depend on counterfactuals, which in turn, depend on primitive *counterfacts*.

I argue that such an account is too context sensitive to succeed. I offer two retreats available to Lange: 1) that the laws depend on counterfactual propositions, rather than counterfactual sentences and 2) that the laws depend on primitive *counterfacts*. I then argue that the first retreat fails because of certain nested counterfactual propositions and that the second retreat leaves him with a very implausible view.

In the third chapter, I explore the suggestion offered by Alexander Bird (2007a) that the fundamental properties are dispositional, rather than categorical. Bird calls these properties *potencies*. I then develop an account of the laws of nature, the *potency best system account*, PBSA. According to the PBSA, the laws are descriptive and systematize the possible distributions of potencies. I argue that my account avoids many of the problems that plague the standard best system accounts of laws.[8] I argue that a serious difficulty for the categorical best system, namely, that we have no guarantee the best system will match up with our physicists theory of everything, is less troubling for the dispositionalist. This is because of the tight connection between potencies and the behavior of particles that instantiate those potencies, and again between the behavior of particles and the theory of everything.

In the fourth chapter, I develop my account of fundamental chance. I argue that by taking chance as fundamental, one can avoid the problems that face reductive, particularly Humean, accounts of chance. I present five desiderata for a chance theory. I argue that the Humean account of chance cannot satisfy any of the desiderata completely. I then show how my own account can satisfy all of the desiderata. The five requirements for a good theory of chance are:

1. Chance events can happen and can fail to happen.

2. Chance is incompatible with determinism.

[8] See, for instance, (Lewis 1983), (Loewer 2007) and historically, Mill and Ramsey.

3. The past is no longer chancy.

4. Credences should match the chances.

5. Chance explains, metaphysically and epistemically.

The nature of inherited chance raises an important question of why we should have rational credences in a world that has initial chances, but subsequently deterministic evolution. I give a detailed response to this question within the framework of my chance theory.

In the fifth chapter, I combine each of these elements into a Propensity Best System Account of the laws of nature. I show how they naturally form a metaphysical ground for the world, and how they fit well with our best scientific practices.

# Chapter 2

# Do Counterfactuals Ground the Laws? A Critique of Lange

## 2.1 Introduction

There are two recent and promising accounts of the laws of nature. The first is the categorical best system account, developed most prominently by Barry Loewer.[1] The other is Marc Lange's (2009) account of counterfactually grounded laws. In this chapter, I argue against Lange's account. In chapters 3 and 4, I will argue against the categorical best system account in the process of defending my own positive account.

Most philosophers of science hold that the laws of nature play an important role in determining which counterfactuals are true. Marc Lange reverses this dependence, arguing that it is the truth of certain counterfactuals that determines which statements are laws. I argue that the context sensitivity of counterfactual sentences makes it impossible for them to determine the laws. Next, I argue that Lange's view cannot avoid additional counterexamples concerning nested counterfactuals. Finally, I argue that Lange's counterfacts, posited

[1] See Lewis (1983), Loewer (2007), Loewer (2008), and Cohen and Callender (2009).

as the ultimate ontological ground for the laws of nature, are unsuited to the role he demands of them.

## 2.2 Counterfactual Sentences and Context

One reason to think counterfactuals are closely bound up with the laws of nature is that the laws seem to hold 'no matter what' or 'come what may.'[2] Lange takes this to be an essential feature of the laws, and relies on it to ground the laws of nature. Lange's central principle **Nomic Preservation**[3] is as follows:

**(NP)** $m$ is a law if and only if in any conversational context, and for any $p$ that is relevant as a counterfactual antecedent in that context and logically consistent with all of the laws (taken together), the proposition expressed by "$p \mathrel{\Box\!\!\rightarrow} m$" is true. (Lange 2009, 15).[4]

Lange takes this principle to determine what the laws are at a world, $w$. Thus, consider a candidate collection of laws, $n = \{m_1, m_2, \dots\}$, at $w$. The basic idea of (NP) is that each member deserves to be in the collection if and only if every counterfactual is true that has a nomically contingent antecedent (relative to the candidate laws) and a nomically necessary consequent (again, relative to $n$) in every context of $w$. If so, then the collection $n$ has earned its status of lawhood, and statements $m_1$, $m_2$... are each laws of $w$. Lange's view is particularly striking because these counterfactuals are not merely epistmically or heuristically useful for *identifying* the laws of nature, they *ontologically ground* the laws of nature. And, according to Lange, the counterfactuals are, in turn, ontologically grounded

[2]This could be because the laws are *true* no matter what, or because the laws are *laws* no matter what. Lange defends the latter.

[3]While this early formulation differs slightly from later formulations, I use it because of its emphasis on context and its distinction between sentences and propositions (something that Lange elides in later formulations).

[4]Also, Lange requires that $p$ and $m$ both be **sub-nomic**: not containing any nomic terms such as "is a law" or "necessarily." For the purposes of this chapter, I need not say anything more about this requirement.

in primitive counterfacts.

### 2.2.1 Semantics and Context

According to a traditional semantic picture, sentence types in contexts express propositions. For example, the sentence,"You are wearing an orange shirt," in a context where Lee is the addressee, expresses the proposition that Lee is wearing an orange shirt. The very same sentence can express different propositions in different contexts. For example, the same sentence would express a proposition about Jones in a context where Jones is the addressee. A sentence in a context is true relative to a world, just in case the proposition expressed by the sentence in the context is true relative to that world.[5]

When we apply this standard picture to counterfactuals, we don't just need to interpret standard contextually sensitive terms, such as indexicals ("I," "you," "here," etc.), we also need to interpret "if" and "would have," which require *additional* context sensitivity. Recall the famous counterfactuals about what Caesar would have done in Korea. Depending on the context, either Caesar would have used the atom bomb or Caesar would have used catapults. There is a great deal of debate about how this added layer of counterfactual context sensitivity affects the propositions expressed by counterfactual sentences.[6] For Robert Stalnaker and David Lewis,[7] the counterfactual sentence, "If you had worn an orange shirt, gravity would have held," in a context where Jones is the addressee, expresses (very roughly) the proposition that the closest worlds in which Jones wears an orange shirt are worlds in which gravity holds. Whether such a proposition is true or false depends on

[5]There may be additional indices, such as times and places. Also, for the purposes of this chapter, I am putting aside recent proposed departures from this standard picture, such as non-indexical contextualism and relativism, according to which the truth values of propositions may still vary relative to contexts of assessment.

[6]It is worth keeping in mind that some philosophers, such as Dorothy Edgington (Edgington 2008), argue that counterfactual sentences do not express propositions at all.

[7]See Stalnaker (1968) and Lewis (1973). Note that their views differ in some important respects. For instance, Stalnaker thinks there is only one closest world, while Lewis thinks there can be many closest worlds. However those differences are not important for the purposes of this chapter.

what the closest orange-shirt worlds are like, as well as which worlds are closest for that context.[8] This is how they can accommodate our changing intuitions about what Caesar would have done in Korea. The context changes which worlds are closest: in one context, the catapult world is closer than the atom bomb, in others, vice versa.

Lange does not want to commit himself to a specific view of counterfactual semantics, but he does want to accommodate the fact that context can change the truth values of some counterfactual sentences. For reference, we have the counterfactual sentence:

(1) "If you had worn an orange shirt, gravity would have held."

which, in a context where Jones is the addressee, expresses the counterfactual proposition that:

(2) If Jones had worn an orange shirt, gravity would have held.

Since (1) has the form of (NP), Lange insists that it is true in *every* context, even if that context varies due to counterfactual considerations.[9] For instance, the truth-value of (1) should remain the same, even as the context shifts from the context of a physics classroom, to the context of an offhand conversation, to the context of a legal trial. But, sentences in different contexts can pick out different propositions, so we must proceed carefully. For instance, it is only because we have chosen a context where Jones is the addressee of sentence (1), that it expresses (2). In a different context, where Lee is the addressee, (1) expresses the different counterfactual proposition that:

(3) If *Lee* had worn an orange shirt, gravity would have held.

[8]There is a very interesting, but entirely separate, question about how to think of these worlds, e.g. concrete, spatio-temporally disconnected worlds, ways the actual world could have been, or maximal sets of consistent propositions. Conveniently, the Stalnaker/Lewis possible world semantics of counterfactuals does not depend on any particular ontological account of possible worlds, so we can bracket this issue.

[9]Technically, Lange insists that the *proposition* expressed by the sentence "$p \mathrel{\Box\!\!\rightarrow} m$," is true. But, on the standard picture, the proposition is true if and only if the sentence, in context, is true. Lange gives us no reason to reject the standard picture, so asking about the truth of sentences in contexts is equivalent to asking about the truth of the propositions they pick out. Of course, there is an entirely *different* view according to which it is the counterfactual *proposition* that we should care about—a view I will come to in the next section. But that is not Lange's view.

So far, Lange is right: the sentence (1) *is* true in the few contexts we've tested. It doesn't matter who the addressee of sentence (1) is. The sentence, in that context (as well as the corresponding proposition) is true. Surely, if Jones, Lee, Lopez, Cohen, or anyone else had worn an orange shirt, gravity would have held. Of course, there are many ways to vary the context, and below I argue that not all of them yield such favorable results.

### 2.2.2 The Problem

I argue that not all counterfactual sentences with law-statement consequents are true in every context, which is what Lange's (NP) requires. Lange (2009, 197) offers an example in which a patient is accidentally injected with a syringe that a male doctor mistakenly believes to contain arsenic. Assume, for the sake of the example, that there are "arsenic laws," which have as a consequence that if a normal human being takes arsenic, that person dies. Since the syringe does not, in fact, contain arsenic, the patient lives. The doctor, still believing the patient was injected with arsenic, is thrilled when the patient survives, and prepares to write up this surprising result for a journal. When the female nurse discovers that the patient was not actually injected with arsenic, she says,

(4) "If the doctor had given the patient arsenic, he would be famous for discovering that arsenic doesn't always kill human beings."

Prima facie, the counterfactual sentence (4) is a counterexample to (NP), since the sentence, in this context, is true, but the antecedent is logically consistent with all of the laws (of physiology, etc.) taken together, while the consequent is a violation of the laws. More technically, this counterexample has the form, $p \ \Box\!\!\rightarrow \sim m$, where $p$ is the contingent fact that the doctor injects the patient with arsenic, and $m$ is entailed by the arsenic laws. Lange's principle (NP) requires that $p \ \Box\!\!\rightarrow m$ is true in any context. But, if we posit that $p$ is contingent—not a vacuous antecedent, such as 'if squares were circles'—then $p \ \Box\!\!\rightarrow \sim m$ follows from (NP) and (4) is indeed a counterexample. Lange (2009, 24) agrees with the formal point, "we can demand not only that $p \,\Box\!\!\rightarrow m$, but also that $\sim (p \,\Box\!\!\rightarrow\sim m)$," But, Lange argues that sentence (4) is not a counterexample because, "in this conversational context, the counterfactual's antecedent is *implicitly* 'Had the syringe used to inject the patient been filled with arsenic *and the patient lived*,' which is logically inconsistent with the laws, so the truth of this counterfactual is no threat to NP." (Lange 2009, 197, italics added).

Thus, properly understood, (4) is really, or 'implicitly,'

(5) "If the doctor had given the patient arsenic *and the patient had lived*, then he would be famous for discovering that arsenic doesn't always kill human beings."

But, it's difficult to see what Lange could mean by this. Lange cannot have thought that the sentence (4) is really a different *sentence*, such as (5). While context can disambiguate lexical or structural features of sentences, as in, "visiting relatives can be annoying," it cannot change one clause such as "if the doctor had given the patient arsenic" into a radically different one that conjoins another clause, such as "if the doctor had given the patient arsenic and the patient had lived." And recall that the context sensitivity specific to counterfactuals, as in, "If Caesar had fought in Korea," allows a single sentence to designate different *propositions*, depending on the context of utterance. It does not allow one sentence to somehow be a different *sentence*. But what, then, are we to make of Lange's claim?

One option that suggests itself is that (4) *expresses the proposition* that:

(5*) If the doctor had given the patient arsenic *and the patient had lived*, then he would be famous for discovering that arsenic doesn't always kill human beings.

Indeed, this seems plausible. Semantic theories can be quite complicated, and propositions need not mirror the surface structure of the sentences that express them.[10] For

[10]This is especially clear once we clearly separate the goals of an adequate semantic theory from the goals of a truthmaker theory—what a sentence expresses need not be the same as the metaphysical state of affairs

instance, Lewis would argue that (5*) is a proposition involving possible worlds and their relations in modal space. Kratzer would argue that (5*) is a proposition involving a set of worlds restricted by the antecedent and other contextual factors. But these theories can be of no help to Lange, since, if (4) expresses the proposition (5*), then Lange has successfully explained *why* (4) is *true* in that context, which is just what his theory needs him to deny. Recall that it is a consequence of (NP) that any sentence of the form "$p \mathrel{\Box\!\!\rightarrow} \sim m$" is false. Therefore, if Lange is correct, (4) must be false. But, if (4) expresses the proposition (5*), then we have just shown it is *true*. After all, sentences that express true propositions are likewise true. Thus, Lange has not only given us a counterexample to his own theory, but he has also motivated the very interpretation of the counterexample that makes it a counterexample to his account.[11]

### 2.2.3 Two Possible Responses

In the face of these considerations, Lange could develop an error theory for this kind of problematic counterfactual. Rather than arguing that sentence (4) is 'implicitly' (5), Lange could bite the bullet and say that strictly speaking, (4) is false. We mistakenly believe it to be true because we have in mind a different counterfactual, namely, (5). Indeed, I find this solution most promising. However, Lange (personal communication) thinks this response has too high a cost and prefers to take our intuitions about the truth or falsity of such sentences at face value. But because a standard semantics does not include any notion of "implicitly," according to which (4) is 'implicitly' (5), appealing to such a notion won't help unless Lange can say more about it. Thus, this chapter could be read as an

*makes it true*.

[11]There is another worry about *which* clauses need to be 'implicitly' included in the antecedent. Lange (2009, 197-8, endnote 29) is able to answer the worry by offering the following test: if a counterfactual, $p \mathrel{\Box\!\!\rightarrow} m$, is true because $q$, then $q$ is 'implicitly' in the antecedent iff $p \mathrel{\Box\!\!\rightarrow} q$ is false. For example, It is because the patient survived that the doctor would have been famous had the injection contained arsenic. But, this counterfactual is false: "If the patient had been injected with arsenic, he would have survived," so the survival clause is 'implicit' in the original counterfactual. While this test tells us which clause is implicit, crucially, it does not tell us what "implicit" means.

invitation for Lange to motivate an interpretation of "implicitly" that is able do the work he envisions.[12]

Another way of responding to the above objection, is to give up on sentences altogether. Indeed, finicky linguistic items are an odd choice for grounding the laws of nature. John Carroll, (2011, 14), agrees, "On the face of it, [Lange's account] is troubling. What regularities are laws is tied to whether certain sentences are true in all contexts. This is startling; I find myself imagining Kip Thorne phoning Robert Stalnaker for a consult on the laws of quantum gravity!"

To keep the spirit of Lange's account, if not the letter, we could reformulate (NP) in terms of *propositions* rather than *sentences*:

**(NPP)** A *proposition* **m** is a law if and only if for any *proposition* **p** that is logically consistent with all of the laws (taken together), the counterfactual proposition $\mathbf{p} \mathrel{\Box\!\!\rightarrow} \mathbf{m}$ is true.

Lange can avoid the counterexample raised above by maintaining that the sentence (4) is true because it expresses the counterfactual proposition (5*), which has an antecedent *proposition* that is incompatible with the laws. Therefore, (5*) is no threat to (NPP).

By characterizing laws of nature in terms of propositions, Lange would avoid the objection raised above, but he would not escape a second objection that I raise for his view below.

## 2.3 Nested Counterfactuals

In this section, I will argue that another feature of Lange's account, namely, his theory of nested counterfactuals, admits of counterexamples as well.

[12] Lange (2009, 197, endnote 29) also uses the term "tacitly," which likewise requires elaboration.

Recall, Lange maintains that if $p$ is compatible with all of the laws taken together, and $m$ is a law, then $p \;\Box\!\!\rightarrow m$. While this guarantees that $m$ is counterfactually *true*, it does not guarantee that $m$ is counterfactually a *law*, which is a further requirement of Lange's. Since all laws obey the principle $p \;\Box\!\!\rightarrow m$, then if $m$ is counterfactually a *law*, it must be the case that $q \;\Box\!\!\rightarrow (p \;\Box\!\!\rightarrow m)$. For instance, if Jones had worn an orange shirt, gravity would have held. Additionally, Lange requires that if Jones had worn an orange shirt, then gravity would still have been a *law*, and wouldn't have held merely accidentally.

In order to secure this result by applying Lange's theory of counterfactually grounded laws, it must be true that if Jones had worn an orange shirt, then *if any other contingent thing had happened*, the law would still have held.[13] For that, Lange needs $m$ to *counterfactually* satisfy (NP) as well. This Lange achieves by nesting counterfactuals.

Thus, if $p$ and $q$ are each individually compatible with all of the laws taken together, and $m$ is a law, then $p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow m)$ must be true. In other words, if it were that p, then if it were that q, it would be that m. As discussed above where $p$ and $q$ are each possibly true (i.e. the antecedents are not vacuous), Lange's principle entails $\sim (p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow \sim m))$. It is this second formulation that I will argue against below.

Lange is at pains to emphasize that $p$ and $q$ need not be *jointly* compatible with the laws or even logically consistent with one another. "For example, consider the nested counterfactual 'Had the object been entirely made of rubber, then here's a counterfactual conditional that would have been true: had it been entirely made of copper, it would have been electrically conductive.'"(Lange 2009, 23) While this example may be favorable to Lange's theory, there are many other examples that are not. For example, recall

(5) If the doctor had given the patient arsenic and the patient had lived, then the doctor would be famous for discovering that arsenic doesn't always kill human beings.

[13] Of course, Lange need not require that laws are counterfactually *laws*. Many philosophers, such as Loewer (2007) and Hall (2010), think that laws need only be *true* at nomologically possible worlds. If Lange gave up this feature of his view, it would avoid the objections I raise in this section, but he would have to substantially modify other aspects of his account, the details of which would take us too far afield.

Lange is happy to concede that (5) is true. Since it has an antecedent that contradicts the 'arsenic laws,' it is no threat to his theory. But, suppose we modify it by turning it into the following nested counterfactual:[14]

(5') If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would be famous for discovering that arsenic doesn't always kill human beings.

(5') also seems true, and if so, it is a counterexample to (NP). To see this, note that it is compatible with the laws that the doctor gives the patient arsenic, it is compatible with the laws that the patient lives, and yet the consequent is contradicted by the arsenic laws. It is easy to design a formula for producing such counterexamples. Take $p$ and $q$ to be *jointly* though not *individually* incompatible with some law of nature ($m$). Then, in general, $p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow\sim m)$ will be true, and a counterexample to Lange's theory. Consider another example:

(6) If the earth were twice as massive, then if the moon's orbit were the same as it is now, gravity (as it is now) would not hold.

The above nested counterfactual seems true, but Lange's theory requires it to be false. To defend his theory, Lange must argue that despite appearances, (6) and all other nested counterfactuals of the form $p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow\sim m)$ are false.

Additionally, since $p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow m)$, the only way for Lange to deny that these are counterexamples, is to say that if $p$ were to hold, then if $q$ were to hold, then something about $p$ wouldn't hold (otherwise, if $p$ held, we would have a consequent that violated $m$). In general, when $p$ and $q$ are jointly incompatible with $m$, Lange has to say $p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow\sim p)$, a very counterintuitive result indeed! Thus, the following counterfactuals, though they seem false, according to Lange's account, must be true:

(7) If the doctor had given the patient arsenic, then if the patient had lived, then the

[14]Note that neither Lange nor I endorses the much stronger import/export principle, according to which $p \;\Box\!\!\rightarrow (q \;\Box\!\!\rightarrow m)$ is logically equivalent to $(p\&q) \;\Box\!\!\rightarrow m$.

doctor would not have given the patient arsenic.

(8) If the earth were twice as massive, then if the moon's orbit were the same as it is now, the earth would not be twice as massive.

And, Lange says just that, arguing that when you say, or think about, counterfactuals such as (5') or (6) with the right emphasis, they *do* sound false. Similarly, when you say, or think about, counterfactuals such as (8), they *do* sound true.[15] Thus, he asks us to consider the following alternative, but arguably equivalent formulations of (5') and (6):

(5") Suppose the doctor gave the patient arsenic, then here's a counterfactual that would be true: if the patient had lived, then the doctor would be famous for discovering that arsenic doesn't always kill human beings.

(6") Suppose the earth were twice as massive, then here's a counterfactual that would be true: if the moon's orbit were the same, gravity would not hold.

Lange (personal communication) claims that when we think carefully about these nested counterfactuals, they sound false. But what counts as 'thinking carefully?' One tempting option is to use the theoretical structure of the Stalnaker/Lewis semantics for counterfactuals, supplemented with an ordering on worlds, such as a closeness metric. On such an account, evaluating counterfactuals requires a kind of world-hopping tour. We begin at the actual world, then go to the closest first-antecendent world, for instance, the closest world where the doctor gives the patient arsenic. Next, we go to the closest second-antecedent world, *from the first-antecedent world*, namely, the closest world where the patient lives. Finally, we check whether the consequent is true or false in the final world, i.e. to see whether or not the doctor is famous for discovering that arsenic doesn't always kill human beings. It is arguable that, with the right closeness metric, a world where the doctor is mistaken about injecting arsenic is closer to the world where the doctor injects

[15] Since (7) is a *backtracking* counterfactual—the consequent occurs before the second antecedent—Lange argues it has no truth value. While I still consider this a cost of his view, since (7) sounds false, not truth-valueless, it will not be of any help with (8), which is not backtracking.

arsenic than a world where arsenic doesn't always kill human beings. Therefore, the whole nested counterfactual is false, and Lange's prediction is borne out.

But, there are two problems with this option. First, Lange (2009, 198) says that he does not want to commit himself to this picture. He claims that such talk is merely a "metaphor" and uses scare quotes when he says, "the 'metric' determining the 'closest possible world' where that antecedent obtains." And it would be a mistake to lean too heavily on a metaphor when evaluating the metaphysical plausibility of Lange's theory.

The second problem is that, though it is tempting to use the theoretical structure of a semantic theory to inform our intuitions about which counterfactual sentences are true, such a use misunderstands the point of a semantic theory, which is merely to *capture* common usage. A semantic theory should not be in the business of *determining* usage. Semantic theories are evaluated by how well they *predict* linguistic data; they should not *generate* linguistic data. Therefore, taking our pre-theoretic intuitions about such sentences seriously, and unless Lange can say more about what 'thinking carefully' amounts to in such cases, we have every reason to think that (5'), (6), (7), and (8) are counterexamples to (NP).

## 2.4 Counterfacts

If I am right and Lange's account cannot answer these objections, there is one final retreat available. We could give up on counterfactual sentences and counterfactual propositions in favor of ontologically primitive *counterfacts*. While Lange posits these entities as truthmakers for counterfactual propositions, the above counterexamples show that he must make a choice: either the counterfacts ground the counterfactuals, or they ground the laws, *but not both*. To see this, recall the true counterfactual:

(5') If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would be famous for discovering that arsenic doesn't always kill human beings.

Now, if counterfacts are truthmakers for counterfactuals, then the following counterfact obtains:

(9) [If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would be famous for discovering that arsenic doesn't always kill human beings.][16]

But, if the counterfacts are also grounding the *laws*, then the following counterfact obtains as well:

(10) [If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would NOT be famous for discovering that arsenic doesn't always kill human beings.]

But, (10), as a counterfact, makes true the following counterfactual:

(11) If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would NOT be famous for discovering that arsenic doesn't always kill human beings.

So (9) and (10) cannot both obtain or they would make true two contradictory counterfactuals, (5') and (11). Thus, if we are positing counterfacts to ground the laws of nature, they cannot also be truthmakers for counterfactual propositions. To avoid confusion, I will reserve the term "counterfact" and square brackets for the truthmakers of counterfactual propositions, and use the term "Lange-fact" and angle brackets for the ontological ground of the laws.

Once we have disconnected the Lange-facts from counterfactual sentences and propositions, we see that there can be no objections to the view based on our intuitions about counterfactual sentences or propositions. Thus, it doesn't matter that the following is true:

[16] I will use square brackets to distinguish counterfacts from other entities.

"If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would be famous for discovering that arsenic doesn't always kill human beings," because the following Lange-fact can still obtain: ⟨If the doctor had given the patient arsenic, then if the patient had lived, then the doctor would NOT be famous for discovering that arsenic doesn't always kill human beings⟩.

We can formulate a revised nomic preservation for the Lange-facts, according to which the laws are states of affairs that obtain in the world, $\mathbb{M}$, rather than law-statements or law-propositions.

**(NPC)** $\mathbb{M}$ is a law if and only if for any $\mathbb{P}$ that is possibly co-instantiated with all of the laws (taken together), the Lange-fact $\langle \mathbb{P} \mathrel{\Box\!\!\rightarrow} \mathbb{M} \rangle$ obtains.

As far as I can tell, such an account is clear and consistent. Nevertheless, we should strive for more than clarity and consistency when grounding the laws of nature. I have argued that Lange-facts bear no relation to counterfactual sentences or propositions, so we cannot use our "great confidence" in counterfactual facts to help us determine the Lange-facts, which makes them awfully mysterious. And, since the Lange-facts are primitive, there is no further story to tell about them. In the end, such a theory would be plausible only if the Lange-facts were simpler or more explanatory than the laws they were postulated to ground.

But, this does not seem to be the case. There are many unanswered questions about them.[17] For instance, is there a distinct Lange-fact for every possible co-instantiated state of affairs? Do the Lange-facts bear any logical relations to one another, and if so, what are they? Lange gestures toward answers to these questions. But much more needs to be said in order to make the Lange-facts stand on their own, since on this particular formulation, they are independent of the counterfactuals. Consequently, our only access to which Lange-facts obtain and which do not is via the laws of nature.

[17] For more on these questions, see Loewer (2011).

Lange rightly points out, “That we figure out which counterfactuals are true by consulting what we already know about the laws (among other things) does not at all support the idea that the truths about the laws are *ontologically* prior to the subjunctive truths.” (2009, 136, original emphasis). But, as I have argued, on this final view, the *only* access we could have to primitive Lange-facts is through the laws of nature making them an ontological extravagance. If the Lange-facts have no theoretical virtues, but add a significant ontological cost, we should not accept them.

## 2.5 Conclusion

In this chapter, I have argued that, because of context sensitivity, Lange cannot characterize his view of lawhood in terms of stable sets of counterfactual sentences. I have also argued that his account predicts the wrong results for many nested counterfactuals. I conclude that the laws of nature cannot depend on stable sets of counterfactuals, whether construed as sentences, the option he endorses, or alternatively, as propositions or primitive facts. While I agree with Lange that there are some important connections between laws and counterfactuals, I think he is wrong about what those connections are.

# Chapter 3

# Powerful Properties, Powerless Laws

## 3.1 Introduction

I have argued against one of the two best current theories of the laws of nature. Now, I turn my attention to the other: the Humean, categorical best system account. In this chapter, I will argue that this account has many virtues, but one crucial drawback—namely, the account's reliance on categorical properties. I will argue that this drawback leads to several problems for the account. I will go on to argue that these problems can be avoided if one replaces the categorical properties with dispositional properties. I also argue that there are independent reasons to prefer fundamental, dispositional properties to categorical properties.

In debates about the fundamental ontology and the laws of nature, two opposing metaphysical pictures loom large: the Humean picture and the anti-Humean picture. When it comes to the fundamental ontology—the most basic stuff out of which everything else is made—Humeans defend an austere fundamental ontology. They claim that, at bottom, the world is made up of only categorical (non-modal) properties distributed through spacetime. Anti-Humeans, on the other hand, defend a rich fundamental ontology. They claim that, at bottom, the world includes at least some modal entities. One example of a modal entity is a fundamental dispositional property, called a *potency*. I will have much more to say about potencies below. When it comes to the laws of nature, the most popular Humean account is the *Best System Account* (BSA). According to the BSA, laws are not fundamental, and they do not govern the world but merely systematize it. By contrast, according to several anti-Humean accounts, laws have metaphysical power because they govern the world.

I argue that the best scientific package is anti-Humean in its ontology, but Humean in its laws. This is because potencies and the best system account of laws complement each other surprisingly well. If there are potencies, then the BSA is the most plausible account of the laws of nature. Conversely, if the BSA is the correct theory of laws, then formulating the laws in terms of potencies rather than categorical properties avoids three serious objections: the mismatch objection, the impoverished world objection, and the metaphysical "oomph" objection. I argue that combining anti-Humean properties with Humean laws into a *Potency-Best System Account of Laws* is a powerful and science-friendly account—something that people on both sides should be able to appreciate.

## 3.2 The Categorical Best System Account

I will begin by presenting the traditional, categorical best system account of laws of nature, made famous by David Lewis,[1] which consists of two pieces. The first is a fundamental ontology of categorical properties and spatiotemporal relations, referred to by Lewis as the *Humean mosaic*.[2]

[1]This account is often called the 'MRL' account for its early proponents, Mill, Ramsey, and Lewis. The account is developed further and in different directions by various authors such as Barry Loewer (2007), Jonathan Cohen and Craig Callender (2009), and Helen Beebee (2000).

[2]The crucial idea behind a fundamental ontology is a metaphysical one: what is the minimum amount of stuff needed to guarantee the existence of the entire world? (A useful, much-used metaphor is to consider what God would have to create, in order to thereby create the entire universe.) For instance, suppose a table is nothing over and above atoms arranged table-wise. Then, the atoms are more fundamental than the table, and the existence of the atoms, along with their properties and relations, is sufficient for the table's existence. Thus, when the Humean postulates a fundamental ontology of purely categorical (non-modal) properties and

The second piece of Lewis's best system is a set of true statements that summarize and systematize the distribution of those properties and relations. These statements often take the form of universal generalizations, such as '$F = ma$'. Systematizations can be simple, informative, both, or neither. For instance, a long list of every property's instantiation—one mass at $(t_1, x_1, y_1, z_1)$, one charge at $(t_2, x_2, y_2, z_2)$, etc.—is informative but not very simple, while the single statement, "all instantiations of mass move closer together throughout time, all else equal," is simple, but not very informative. Then, Lewis postulates that the basic laws of nature are the axioms of the systematization that best balances simplicity and informativeness.[3,4]

Lewis adds the further constraint that the laws reference only the *perfectly natural* properties and relations. Perfect naturalness is a primitive feature of Lewis's theory and corresponds roughly to other authors' notions of universals, sparse properties, or elite properties.[5] Lewis has in mind properties like mass and charge when he talks of perfectly natural properties, though below, I will question whether he is justified in assuming that the properties of our basic physics match up with the perfectly natural properties. To see why naturalness is necessary, consider 'F,' the predicate which stands for the property applying to all and only objects at worlds where a given systematization holds. Then, the laws of the universe could be summarized by the axiom: '$(\forall x)Fx$.' Since this simple and (arguably) informative axiom would be 'best,' it also would trivialize the BSA. Therefore, Lewis stip-

relations in spacetime, she has to show how all the other features of the world, such as the laws of nature (but also tables, minds, causation, etc.) depend upon that ontology. There is a vast and fascinating literature on fundamentality and the related notion of ground, but the particular details will not be relevant here. For more, see Schaffer (2009).

[3]Throughout this chapter, I will refer to such *scientifically fundamental* laws as "basic laws," and I will reserve the term, "fundamental," for those things that are *ontologically* basic. Note that according to the best system account, the basic laws are not fundamental, because they supervene (or depend) on the fundamental Humean mosaic.

[4]Two caveats: First, if the world is chancy, then Lewis argues the best system will have to balance simplicity, informativeness and *fit*. In this chapter, I will bracket all issues relating to chance, treating the world as a deterministic system. I will take up chance in the next chapter. For more, see Lewis (1983, 1994) and Elga (2003). Second, Lewis tells us what to do if two or more theories tie for the best in balancing simplicity and informativeness, but these details will not be relevant here.

[5]See Lewis (1983) and Armstrong (1978).

ulates the perfect naturalness constraint, eliminating such an axiom from eligibility.

### 3.2.1 Science-Friendliness

In the scientific quest to discover the laws of nature, scientists routinely look for simple formulas that predict a wide range of phenomena. This emphasis on simplicity and informativeness is mirrored in the desiderata for the best system account, which lends the BSA additional credibility. According to Cohen and Callender (2009, 3),

> [The best system account] states that laws are the generalizations that result from a trade-off between the competing virtues of simplicity and informativeness. Scientists certainly see themselves as engaged in the project of finding such generalizations ... it is clear especially since Newton that scientists have sought general but simple principles applicable to systems with very general features. Virtually every science textbook contains frequent appeal to simple principles that cover a vast array of phenomena in the field. Even philosophers skeptical of laws recognize that scientific theorizing is a process of carefully balancing simplicity and strength (e.g., Cartwright, 1983, 144). And in many cases the result of this process is a set of fundamental principles [basic laws] that are taken to describe the essence of a theory.

But, as Lewis pointed out, simplicity and informativeness are only well-defined *relative* to a set of predicates. Since scientists do not have direct access to these perfectly natural properties, they postulate the existence of properties based on how well those properties systematize. What then, is the systematization *of*? Ned Hall articulates a popular way of thinking about the project that I endorse:

> The primary aim of physics—its first order of business, as it were—is to account for motions, or more generally for change of spatial configurations of things over time. Put another way, there is one Fundamental Why-Question for physics: Why are things located where they are, when they are?[6]

[6] Hall (2010, 29). It is not clear whether Hall endorses this way of thinking about physics, but his perspicuous presentation of the view is worth repeating here.

On this picture, particle trajectories through spacetime are the expananda, the phenomena to be predicted or captured by a theory. And, every theory makes reference to a certain set of properties. So, the question naturally arises: how do the properties referenced by these theories relate to Lewis's perfectly natural properties? I take up this question in the next section.

### 3.2.2 The Mismatch Objection

While the best system account is faithful to scientists' concern with simplicity and informativeness, its insistence on a fundamental ontology of perfectly natural, categorical properties makes it vulnerable to a 'mismatch' objection. This objection was raised by Bas van Fraassen and a version of it was acknowledged by Lewis himself.[7] Suppose, the argument goes, that our best scientists have arrived at a very simple, very informative final theory of everything (TOE). But, suppose further, that this theory is formulated in terms which reference properties that differ from Lewis's perfectly natural properties—call them "TOE" properties. We can easily imagine that in such a situation, the best system, i.e., the simplest, most informative system *restricted to terms that pick out perfectly natural properties*, is much less simple and/or much less informative than the TOE, which is not so restricted.

To see why, consider again Hall's characterization of the TOE: *The theory that summarizes, as simply and informatively as possible, the trajectories of particles*. In order to do that, scientists appeal to the properties that make for the best systematization, in this case, the TOE properties, and what they have straightforward access to is the trajectories:

[7] Bas van Fraassen (1989, 53), Lewis (2009). See also, Loewer (2007), Cohen and Callender (2009), and Hall (2010).

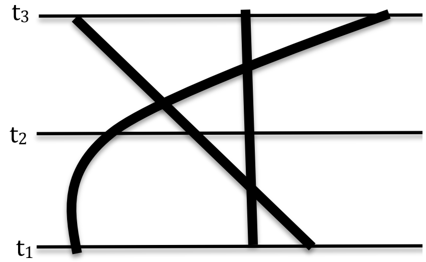


Figure 3.1: Trajectories of Particles Through Spacetime

But, if Lewis is right, then the real laws of nature do not systematize the trajectories, but rather, the distribution of perfectly natural properties in spacetime:

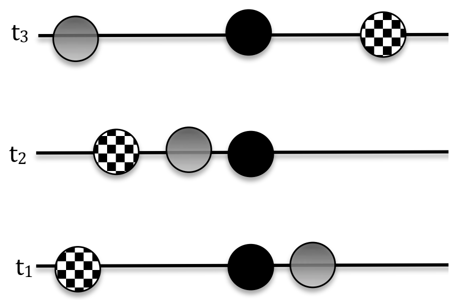


Figure 3.2: Distribution of Perfectly Natural Properties

Lewis hopes that the systematization of the perfectly natural properties matches up with the trajectories:

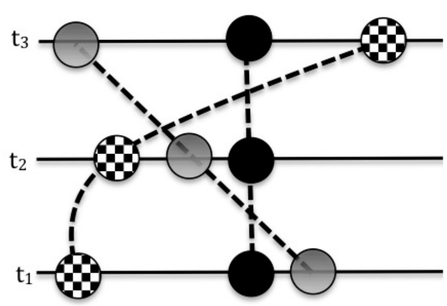


Figure 3.3: Trajectories that Correspond to the Perfectly Natural Properties

However, there is no guarantee—not even a probabilistic argument—that they match up in just the right way. Furthermore, two worlds with the very same particle trajectories, and thus the same TOE laws and TOE properties, on the Humean view, could have radically different distributions of categorical properties:

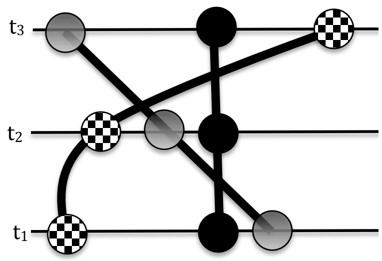


Figure 3.4: BSA—Best Case

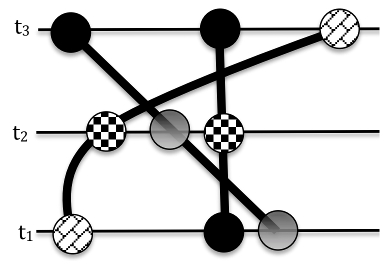


Figure 3.5: BSA—Worst Case

The BSA hopes for a "best case": a match between the TOE properties (which figure in scientists' theories of trajectories) and the perfectly natural properties (which figure in the BSA). But, as in the "worst case," mismatch is not only possible, but also undetectable. One pattern of trajectories is compatible with vastly many different distributions of categorical properties.

This is because categorical properties bear no necessary connections to the behavior of the objects that instantiate them. Thus, for every world in which the TOE does match the BSA, there are many, many more worlds in which it does not, and there is mismatch.

What is even worse for the Humean, is that when there is such a mismatch, it seems that the simple, informative TOE is a better candidate for the real laws of nature than the complicated, uninformative BSA. After all, on the Humean picture, the laws are supervenient entities, postulated to capture actual scientific practice in a way that is faithful to the Humean picture of the world. The introduction of perfect naturalness is merely a way to deal with the triviality objection. We then have two competing intuitions. On the one hand, it is plausible that the laws of nature systematize the distribution of the fundamental properties. On the other hand, it seems that the laws of nature should systematize particle trajectories as simply and informatively as possible. What the mismatch objection shows is that the Humean is not entitled to demand *both*. And, if our theory of laws is motivated by actual, scientific practice, we ought to prefer the TOE to the BSA—a serious strike against the categorical-BSA.

It is important to see why the mismatch objection isn't just a skeptical argument. Of course, there is no guarantee, and indeed, there should be no such guarantee, that our best science will describe the actual world perfectly. The world can always conspire against us to make good theories seem bad, and *vice versa*. However, this objection goes further by alleging that Lewis's best system gets things wrong, even granting perfect knowledge of the categorical base. This is because the distribution of perfectly natural properties might be quite complicated to systematize, as in figure 3.5, while a systematization of particle trajectories—even if that systematization is in terms of non-perfectly natural properties—could be very simple and informative. Since the Lewisian places so much importance on simplicity, informativeness, and science-friendliness, while de-emphasizing extraneous metaphysical commitments, by the Lewisian's own lights, the TOE properties begin to look like better candidates than the perfectly natural properties for formulating the laws of nature.

### 3.2.3 Impoverished Worlds Objection

One well-known objection to the best system account arises for laws of nature in impoverished worlds.[8] Consider, for example, a world in which there is only one particle, which happens to instantiate mass.[9] Such a particle will behave inertially for all time. Therefore, according to the BSA, there is one law at this world: all massive particles travel inertially for all time. But, intuitively, the law should say that massive particles attract other massive particles and behave inertially only in the absence of other massive particles. Counterfactuals lend support to this objection. If that particle were in the presence of one

[8]See, for example, Tooley (1977), Carroll (1994), and Beebee (2000).

[9]Here, and throughout the chapter, I use toy-physics examples. The behavior of Newtonian mass is easier to understand than quantum mechanics, though I have every reason to think my arguments work just as well with, e.g. Bohmian mechanics.

other particle which happened to be massive, it would not behave inertially.

Defenders of the BSA try to minimize the force of this objection by pointing out that our world is not impoverished.[10] And intuitions about worlds like ours matter more than our intuitions about other worlds. If the BSA gave the wrong result for the *actual* world, that would be a problem, but it only does so for other, exotic worlds. Another response is to distinguish between statements that are *laws in* other worlds and statements that are merely *true of* other worlds. The statements that systematize world $A$ give the laws that are *laws in* $A$. Statements that are laws of other worlds may be *true of* $A$, even if they are not *laws in* $A$. So, the Humean can say that the statement 'massive particles attract one another, all else equal' is *true of* the impoverished world, even though it is not a *law in* that world.

These responses help, but are far from satisfactory. While I care *more* about the laws at the actual world than at impoverished worlds, as a metaphysician, I care about the laws at impoverished worlds too. A good theory of lawhood should give the right results for what the laws are in *any* world. As for the *law in* / *true of* distinction, it is of no help with counterfactuals. The impoverished world will have many different, incompatible statements true of it, and if we relied on them for counterfactuals, they would yield different counterfactuals. But, surely there is a fact of the matter about what the massive particle would do, were it to encounter another massive particle. The Humean is not able to accommodate that fact with a straightforward appeal to the laws. I argue below that the dispositionalist can.

### 3.2.4 Metaphysical Oomph Objection

Some philosophers, such as Fred Dretske, Michael Tooley, David Armstrong, and Tim Maudlin, argue that the laws have very important metaphysical work to do, and the BSA is not equipped for such work. According to this objection, some parts of the world are

[10] See, for example, Loewer (2007) and Hall (2010).

fundamentally *powerful*.[11] The laws provide a kind of 'oomph' that governs, or produces the behavior of the particles in the world.

Other philosophers, such as Barry Loewer and Jenann Ismael (personal communication) think that intuitions about governance and production need not be taken seriously. One reason is because these notions are often obscure or mysterious. Thus, before I argue that the categorical-BSA is ill-equipped to account for governance or production, I would like to make these notions more precise. I suggest that metaphysical power is best thought of as *dynamic, metaphysical dependence*. There are many entities in the actual world and they are related by metaphysical dependence relations of various kinds that differ in interesting ways.[12] For instance,

- A mountain is related to the atoms that compose it by the metaphysical dependence relation of constitution—the mountain depends on the atoms.
- The truth of the proposition that it is raining is related to the fact that it is raining by the metaphysical dependence relation of truthmaking—the true proposition depends on the fact.
- A mind is related to a brain by the metaphysical dependence relation of realization—the mind depends on the brain.

If the world contains dynamic, metaphysical power, then governance and production are two additional kinds of metaphysical dependence—*dynamic* metaphysical dependence. They both relate entities or events at one time to entities or events at an earlier time. Governance does so via the laws, while production does so via dispositional properties.

**Governance:** The behavior of entities or events (at least partly) dynamically, metaphysically depends on the laws of nature.

[11] See Dretske (1977), (Tooley 1977), Armstrong (1983), and Maudlin (2007).
[12] For more on this, see Bennett (2009).

**Production:** The behavior of entities or events (at least partly) dynamically, metaphysically depends on properties.

The ontology of the categorical-BSA supports some metaphysical dependence relations. For instance, the laws of nature, as statements that systematize the distribution of properties in spacetime, metaphysically depend on the distribution of properties in spacetime. However, the ontology of the categorical-BSA does not support any kind of *dynamic* metaphysical dependence. This is because the fundamental base includes the entire Humean mosaic of categorical properties: past, present, and future, with no metaphysical dependence relations between states at different times. Thus, there is no governance or production on the categorical-BSA. Of course, from the laws and the state at a time, the Humean can *predict* the future states, but the laws are themselves metaphysically derived from those future states, so there can be no dynamic metaphysical dependence. This lack of powers should come as no surprise to the defender of the categorical-BSA, since the Humean mosaic is postulated with this requirement explicitly in mind.[13]

It is no use for the Humean to appeal to a theory of causation. Since Humean causation ultimately depends on the Humean mosaic,[14] it does not exhibit dynamic metaphysical dependence either. For the Humean, nothing short of the entire mosaic is sufficient to guarantee the entire mosaic. Arguably, a Humean account of causation could explain our experience of macroscopic 'oomph.' But Humean causation is a higher-order phenomenon, and does nothing to accommodate production (or governance) at the fundamental level. More importantly, the *experience* of production is different from the intuition that the world, fundamentally, is produced.

The intuition that there is production (or governance), fundamentally, in the world, is strong enough that any theory which denies it is biting a substantial bullet. Helen Beebee

[13]See Lewis (1983), Loewer (2007), Cohen and Callender (2009), Beebee (2000), Bird (2007a).

[14]Most Humean accounts of causation depend on the mosaic via counterfactuals. Thomas Blanchard has a particularly promising account of Humean causation.

(2000, 593) argues that even so, "the Ramsey-Lewis view does justice to enough of our intuitions about the laws of nature to be a viable alternative." That may be, but, I think that the defender of the BSA can do even better. By exchanging purely categorical properties for potencies, as I argue we should, the best system account of laws *can* accommodate our intuition that there is fundamental, metaphysical "oomph" in our world.

## 3.3 Potencies: Fundamental Dispositional Properties

Many philosophers[15] argue that the fundamental properties are *dispositional*. Dispositional properties are necessarily connected to the behavior of the objects that instantiate them. Take, for instance, the property of having mass. If mass is *categorical*, then massive objects in different possible worlds can behave very differently, attracting each other in some worlds (like ours), repelling each other in other worlds, and neither attracting nor repelling in still others. However, if mass is *dispositional*, then the property of having mass is necessarily connected to the behavior of the objects that instantiate it. Thus, any massive object, in any world, is disposed to attract other massive objects.[16]

In what follows, I will rely on Alexander Bird's (2007a) characterization of fundamental dispositional properties, as presented in *Nature's Metaphysics*, though my conclusions should generalize to many other dispositionalist accounts. My account of potency-BSA can be thought of as elaborating on Bird's suggestion that it is possible to derive universal generalizations from potencies.

Bird argues that the regularities of a best system account can be derived from potencies via the following entailment: $\Box(\forall x)(Px \leftrightarrow (Sx \,\Box\!\!\rightarrow Mx))$ entails $(\forall x)(Px \& Sx) \rightarrow$

[15]See, for example, Alexander Bird (2007a), Stephen Mumford (1998), Jonathan Jacobs (2011), and Brian Ellis and Caroline Lierse (1994).

[16]I will set aside the interesting and important debate about whether the categorical/dispositional distinction can be successfully drawn, or whether all properties must be both qualitative and dispositional. For more on this, see Jacobs (2011), Martin and Heil (1999), and Cross (2005).

$Mx$)), where $P$ is a potency, $S$ is a stimulus condition, and $M$ is a manifestation. Unfortunately, Bird does not elaborate on what it is that metaphysically grounds the biconditional. Additionally, as I argued in the introductory chapter, there is good reason to think the biconditional is false. While I do not rely on counterfactuals in deriving the laws of nature from possible distributions of potencies, nevertheless, I take my account to be very much in the same spirit as Bird's. I fill in the details of just what a potency best system account should look like, and why we should prefer it.

Since dispositions can exist at any level (fragile vases or massy electrons) and for a wide variety of properties, as gerrymandered as you like, Bird (2007a, 45) introduces a new term, *potency*, that is defined as follows:

**Potency:** A fundamental, sparse property with a dispositional essence.[17]

Potencies can be thought of as dispositional versions of Lewis's perfectly natural properties. They are fundamental, so they are not made up out of anything else—they are on the 'ground floor' of the world.[18] They are sparse, and as I will argue below, correspond to the scientific kinds that appear in our best physical theories. The dispositional essence of a potency is the necessary connection between the property and the behavior of objects that instantiate it.[19]

Three things to note. First, even though the potencies are metaphysically more fun-

[17]Though the arguments in this chapter wont depend on the answer, another interesting question is whether to treat the potencies of 1kg, 2kg, etc., as one (determinable) potency with infinitely many determinates, or as an infinite number of different potencies. I am inclined to agree with Jessica Wilson (2010), who argues that the fundamental properties are best thought of as determinables. Additionally, I will address only briefly the very complex issues of component forces.

[18]While some, e.g. G.K. Chesterton, have objected to the coherence of fundamental dispositions, the literature is full of excellent replies, and I need not repeat those arguments here. For a particularly nice reply, see Bird (2007b).

[19]Several defenders of dispositional properties have moved from talk of dispositions and stimulus conditions (situations) to *mutual manifestation partners*. Thus, rather than think of one instance of mass as the disposition and another instance of mass as the stimulus condition (situation), it is more accurate to think of both instantiations of mass as participating equally in the interaction. When two masses are near each other, they both manifest mutual repulsion. Singling out one as the disposition and the other as stimulus is merely an artifact of our particular interests. I think this is a promising idea and my conclusions in this chapter should carry over to such a picture.

damental than the behavior of the particles that instantiate them, the behavior of particles across worlds is sufficient to individuate potencies (i.e. no potencies have the same essential dispositions). Second, while this connection entails certain counterfactuals (how objects *would* behave), those counterfactuals depend upon the nature of the particles involved, how they are arranged, and what potencies they instantiate, so I reject any attempt to analyze potencies in terms of counterfactuals. The metaphysical direction of explanation runs the other way. Third, potencies are purely deterministic. I see no reason why propensities—stochastic dispositional properties—could not be integrated into the potency-BSA, but I leave that development for future work.

A potency's dispositional essence, plus the stimulus condition or external situation, determines the behavior of any particle instantiating it. I will turn to the question of *how* this determination works in section 4.4 below. Sometimes this behavior is the instantiation of a further potency, as when a moving charge induces a magnetic field, and sometimes the behavior is simply a modified trajectory through space(time).[20]

### 3.3.1 Potencies are Science-Friendly

Since potencies often do not exist in isolation, and are typically exposed to many stimulus conditions, it can be quite difficult to determine just how the particles that instantiate them will behave. Luckily, the effects of stimulus conditions get weaker with distance, and often can be shielded. Thus, while the gravitational contribution from Alpha Centauri has some effect on massive particles on earth, that effect is insignificant relative to the gravitational effect of the earth's mass. Similarly, because oppositely charged stimulus conditions have opposite effects on a charged particle, they can be used to shield one another. Scientists rely on these features to carefully construct experimental setups in which

[20] Alexander Bird offers some arguments for thinking spatiotemporal relations are also potencies, see Bird (2007a, chapter 7), but I doubt such a view could be metaphysically complete, so I assume that spatiotemporal relations are not potencies. For arguments that spatiotemporal relations cannot be potencies, see Ellis (2010).

a single potency's characteristic behavior can be observed.

To illustrate this phenomenon, consider a representative physics experiment, which measures gravitational attraction at very small distances.[21] In such an experiment, the physicists place two masses very close to each other and measure the force between them by how much they deflect the springs to which they are attached. Because the force of gravity is so weak, especially when compared to the electromagnetic forces, the biggest challenge of the experiment is to screen off as many outside effects as possible. Thus, the experiments are performed in a deep basement, in the dark, at night, and only during breaks in the traffic outside. This careful screening-off procedure is evidence that the physicists aim to discover the characteristic behavior (manifestation) of a specific *kind* of property (disposition). Cartwright (1999, 82) describes a similar process in the case of measuring charge,

> To say it is in [the electrons'] nature to experience a force . . . is to say at least that they would experience this force if only the right conditions occur for the power to exercise itself 'on its own', for instance, if they have very small masses so that gravitational effects are negligible.

By repeated applications of this procedure in different areas of fundamental physics, each potency can be ever more effectively isolated and its characteristic behavior in various conditions discovered. Why think these properties are dispositional rather than categorical? Scientists need only perform a relatively small number of experiments on a single kind of particle before they feel confident that they have captured its true nature (essential disposition). Only a few experiments need to be performed before scientists are persuaded they have captured the essential dispositions of the potencies. As Cartwright (1999, 85) argues:

> For example, we measure, successfully, we think, the charge or mass of an electron in a given experiment. Now we think we know the charge or mass of all electrons; we need not go on measuring hundreds of thousands. In so doing

[21] These details are from an experiment performed at the University of Colorado by Long et al. (2003).

> we are making what looks to be a kind of essentialist assumption: the charge or mass of a fundamental particle is not a variable quantity but is characteristic of the particle so long as it continues to be the kind of particle it is.

I argued above, in section 2.1, that when scientists formulate their systematic theories, they use simplicity and strength as standards for success. In this section, I gave reasons to think that when scientists investigate the nature of the fundamental properties, they look for dispositional essences, or what it is that things *do* in different situations. Thus, just as the best system account is a science-friendly account of the laws of nature, potencies constitute a science-friendly ontology.

## 3.4 Potency-Best System Account of Basic Laws

In this section, I combine potencies with the best system account of basic laws. I use Lewis's best system account of laws as a template, replacing his perfectly natural categorical properties with sparse, dispositional properties, i.e. with potencies. The other crucial difference is that I systematize the potencies in many possible worlds, not just one. More specifically:

**Potency-BSA** The basic laws of nature at $w$ are the axioms of the simplest, most informative, true systematization of all $w$-potency-distributions, where a $w$-potency-distribution is a possible distribution of only potencies appearing in $w$.[22]

For example, if a world, $w_1$, contains a possible distribution of the potency of mass, then the laws of $w_1$ must systematize all possible distributions of mass. Since the possible distributions of mass are determined by the potencies and not the laws, there is no threat of circularity. If another world, $w_2$ contains a possible distribution of the potencies of mass and charge, then the laws of $w_2$ must systematize all possible distributions of mass, all possible

[22]David Albert (2000) persuasively argues that a low-entropy restriction on possible initial distributions is necessary to recover the special science laws. But for the purposes of this chapter, I am concerned only with the basic laws of nature.

distributions of charge, and all possible distributions of both mass and charge. Thus, any systematization that fails to reference those potencies, fails to be an eligible candidate for lawhood. In the same way that Lewis's perfectly natural, categorical-BSA rules out a trivial best system, so does the potency-BSA—in this case '$(\forall x)Px$', where $P$ is the potency had by all and only objects satisfying a given systematization. And, as I will show below, this account does not succumb to the three objections discussed above.

### 3.4.1 Why systematize properties in *non-actual* worlds?

Recall that every Humean version of the BSA systematizes the properties of the actual world. But, with the introduction of potencies, properties that are primitively modal, there is no additional cost to include other possible distributions in our systematization. As discussed above, the initial distribution of potencies determines the later distributions (by *production*, which I discuss below). Because the laws include systematizations of all the ways in which initial configurations of dispositional properties can evolve, it allows us to characterize the laws of nature without including any actual, but accidental generalizations, and without omitting any non-actual, but lawful regularities.

Why can't the Humean do the same thing: systematize the distribution of properties in non-actual worlds? First, the Humean would need a way of characterizing the other worlds. Granting that, the Humean would need to identify the right set of worlds to systematize for the laws. Choosing only those worlds at which the laws of nature hold would be obviously circular since the systematization is meant to ground the laws, not the other way around. On the other hand, the Humean cannot systematize all of the worlds that instantiate the perfectly natural properties found in the actual world, as I do with potencies, because it would include too many worlds. Since the categorical properties are not connected to the behaviors of the particles that instantiate them, they can appear in vastly more combinations than potencies. Therefore, the laws would have to systematize worlds that differed in radical ways from each other. There would be no non-trivial regularities between such disparate worlds, and thus, no BSA laws. Therefore, the only reasonable option for the Humean is to systematize the distribution of properties in the actual world.

### 3.4.2 A Potency-BSA Matches our TOE

Let us return to the mismatch objection. Suppose, again, that our best scientists have arrived at a very simple, very informative final theory of everything (TOE) that correctly predicts as wide a range of empirical data as scientists can test. What are our reasons for thinking such a theory will match the potency-BSA?

Recall that potencies—primitive, sparse properties with unique dispositional essences—are necessarily connected to the behavior of the particles that instantiate them. So, almost any permutation of potencies will affect the trajectories of particles, unlike in the case of categorical properties, as we saw above. This is where the ontology of potencies and the best system account of laws complement each other so well. Since the scientists' TOE systematizes the trajectories of particles, and since the trajectories of particles are *produced by* the potencies, we have good reason to think that a simple, informative TOE will appeal to those potencies.

By positing an ontology of potencies, we've ruled out the vast majority of ways in which a best system could fail to match our TOE. However, there is still no guarantee (again, nor *should* there be) that the trajectories of the particles will yield enough information for scientists to uniquely identify every potency. For instance, if there are only a few potencies instantiated in only a few different kinds of situations, scientists would not be able to fully capture their modal profiles, and thus, their theory of everything would fall short of the best system.

However, there is reason to think that a complex world like ours is not impoverished in this way. Nature, it seems, eventually gets around to displaying all different kinds of behavior. And, if nature is not forthcoming, scientists perform experiments specifically designed to test for potencies in stimulus conditions that rarely occur on their own. For instance, scientists are able to perform experiments at very high energies which arose naturally only just after the big bang. Thus, aside from the unavoidable skeptical concerns, the defender of the potency-BSA need not worry that science fails to capture the genuine laws of nature.

Similarly, if we assume that potencies are simple, and not gruesome, there is good reason to think that a best system account, which systematizes only the actual distribution of potencies, would match the potency-BSA, which systematizes all possible distributions of potencies. This is because the world is complex, and includes a wide variety of different configurations of potencies over time. Thus, the simplest, most informative systematization of the actual distribution of potencies is going to have to include that variety. For the actual systematization to differ from the modal systematization, there would have to be some kind of interaction that was never actually instantiated, and that if systematized, would add complexity.

### 3.4.3 Impoverished Worlds and the Potency-BSA

Since the Potency-BSA systematizes the distribution of potencies in all possible worlds that contain the same potencies, an impoverished world will receive the same systematization as a complex world. Consider, again, a world with a single massive particle, traveling inertially for all time. The laws of this world will systematize not just this world, but all worlds that contain mass. Therefore, it will be a law that all massive particles attract each other, and NOT that they always travel inertially. Furthermore, even without developing a theory of how counterfactuals depend upon the potencies and laws, it is easy to see that *if* that single particle *were* near another massive particle, it *would* experience attraction toward that particle. Therefore, the potency-BSA laws are intuitively correct in impoverished worlds, and they yield the right counterfactuals for those worlds.[23] The potency-BSA, and not the traditional BSA, secures the intuitively correct result in impoverished worlds, whether or not inhabitants of those worlds know it.

### 3.4.4 Potencies do Metaphysical Work

There is a very deep and interesting question about just how it is that a potency produces its characteristic behavior. Many philosophers, such as Bird, avoid this metaphysical question by appealing to counterfactuals. But while counterfactuals can tell us *what* behavior results from a configuration of potencies, they cannot tell us *how* that behavior results. Nevertheless, Bird (2007a, 200) claims, "Mumford and I agree that the existence of regularities in nature, the truth of counterfactuals, and the possibility of explanation are explained by the potencies."

So, Bird claims that the potencies are explanatory, but he says very little to illuminate how this explanation is supposed to go. Stipulating a biconditional between potencies and counterfactuals does not tell us how it is that the potencies *explain* the behavior of particles—even if those counterfactuals can be used to derive regularities. Entailment falls short of metaphysical explanation. To see this, consider that Lewis's best system account of laws entails facts about how particles behave. Despite this, the laws do not (metaphysically) explain the behavior of particles, rather it is the distribution of properties that explains the laws.

I think the most promising solution is to appeal to *production*—dynamic, metaphysical dependence. According to my view, the fundamental ground includes spacetime and an

[23]Of course, scientists of such a world would be in a kind of skeptical scenario, and thus unlikley to *arrive at* the correct account of the laws. Analogously, if our world turns out to be impoverished, we would be in a similar, unfortunate situation. But, this is the correct result—the laws of nature are not guaranteed to be epistemically accessible.

initial arrangement of particles and potencies. And the subsequent behavior of the particles (further potency instantiations as well as trajectories through spacetime) is dynamically, metaphysically dependent upon that base. Since the potency-BSA systematizes those trajectories, the laws of nature are not fundamental, and do not govern, but rather depend upon the behavior of the particles and potencies. To summarize what (metaphysically) explains what: on my view, the subsequent behaviors of particles and subsequent potency instantiations are metaphysically, dynamically grounded in the initial distribution of particles and their potencies.[24]

If the fundamental properties are potencies, they can do the metaphysical heavy lifting many have thought had to be done by the laws of nature. The intuition about metaphysical "oomph" is that the behavior of particles in our universe is not primitive, but, rather is produced (or governed) in a systematic way. One option is to locate this power in *governing* laws of nature, which "push and pull" the particles around. But, if the fundamental properties turn out to be dispositional, rather than categorical, then the potencies are a natural place to locate metaphysical power as they *produce* the behavior.

Indeed, Bird (2007a, 46) takes potencies and powers to be the same thing, "potencies just are their dispositional powers." Bird (2007a) and Mumford (1998) agree that governing laws are superfluous with an ontology of potencies. Markus Schrenk (2012, 8) claims, "if nature equips properties with their own (causal) essences then what would be the point of a Lewisean best system analysis? Most causal roles and, thus, causal laws would anyway already be fixed by the properties' essences and, so, a best system competition would at best deliver exactly those already given laws and roles." But, while laws of nature are, indeed, fixed by dispositional essences, they are distinct from them. The difficulties that beset attempts to state dispositional essences do not beset similar attempts to state the laws of nature. For instance, even if the potencies are restricted to include only mass, there is a great

[24]Much more could be said about such a relation. For instance, each arrangement of particles and their potencies is probably best explained in terms of the previous (or in the limit) arrangement of particles and their potencies, perhaps just in the past light-cone of the arrangement in question.

deal of controversy as to what the dispositions are. Are masses simply disposed to attract one another, with perhaps, a meta-disposition for how those massive attractions add to or subtract from one another? Or are there separate dispositions for each particular possible mass-instantiation distribution? If, instead, the laws systematize the possible distributions of potencies throughout spacetime, there is the possibility of 'backsolving' to arrive at the potencies. And, it is likely that this is exactly what metaphysicians do when they discuss dispositions such as mass and charge. But, of course, the metaphysical direction of explanation need not point the same way as the epistemic one.

If the potencies bear the metaphysical responsibility for the behavior of particles, then the laws of nature are no longer needed for this role. This makes a best system account, which eschews just such a role, perfectly suited to a fundamental ontology of dispositional properties. Thus, we can reconcile the thought that 'oomph' is needed in the world while retaining the BSA and its tight connection to scientific practice.

## 3.5 Conclusion

In this chapter, I have argued that a best system account of laws and an ontology of fundamental dispositional properties are well-suited to each other. Physicists test for potencies, and formulate laws that systematize trajectories, while maximizing simplicity and strength. This makes an ontology of potencies and best system laws science-friendly. In addition, my potency-BSA can avoid three objections that plague the categorical-BSA. Because potencies are necessarily connected to the behavior of the particles that instantiate them, the potency-BSA avoids the mismatch objection. Because the potency-BSA systematizes all worlds with the relevant potencies, rather than just one, it avoids the impoverished worlds objection. Finally, I have argued that potencies can play the metaphysical role of production traditionally reserved for governing laws of nature. So it makes sense to think that the laws of nature are metaphysically inert, just as they are in a best system account. Thus, I hope to have shown that potencies and the best system account of laws complement each other nicely and make for a promising picture of the fundamental ontology and the laws of nature.

# Chapter 4

# Fundamental Chance

## 4.1 Introduction

In the previous chapter, I presented my account of fundamental properties and the laws of nature. I argued that the fundamental properties are potencies—fundamental, dispositional properties, and that the laws of nature are the simplest, most informative systematization of the possible distributions of those properties. But, potencies are deterministic. They do not admit of degrees or chance. Thus, the account is impoverished if, as seems (epistemically) likely, our world turns out to be chancy. In this chapter I present my theory of chance and argue that it has advantages over the best Humean theory of chance. I will go on to show how my theory of chance fits with my theory of laws and properties in the subsequent chapter.

David Albert (2000) and Barry Loewer (2004) have developed a bold and surprising new theory of how chances in the special sciences relate to fundamental physics. They give this theory a Humean interpretation, attempting to reduce all chances—including chances in physics—to the actual distribution of categorical properties in spacetime. In this chapter, I argue that their notion of chance fails to satisfy five central chance roles. I go on to argue for my own anti-Humean interpretation of the theory. My account posits metaphysically fundamental, irreducible chance. I show how fundamental chance gives rise to metaphysical, inherited chance—which includes all of the chances in the special sciences. With this machinery in place, I outline how conditional chance and a conservation principle recover all of the epistemic facts we should expect from a complete theory of chance.

## 4.2 Inherited Chance

Consider a coin flip in a classical, Newtonian world.[1] The coin can begin its toss in many different ways, depending on how it is flipped. Its speed can be fast or slow, it can spin quickly or slowly, and it can be flipped from high off the ground or close to the ground. A full specification of these initial conditions constitutes the system's microstate. And, if the dynamical evolution is deterministic, then each specific initial microstate evolves into a specific final microstate. Some of those final microstates are specific ways of landing heads, and some are ways of landing tails. Very tiny changes in the initial conditions can have a large effect on whether the coin ends up landing heads or tails. For instance, a coin that lands heads would have landed tails, if only it had been thrown with slightly more speed, or with a bit more rotation, or from a slightly higher point. The interesting fact about coin flips is that even though the outcome depends so sensitively on the initial conditions, roughly half of those initial conditions lead to outcomes in which the coin lands heads and half lead to outcomes in which the coin lands tails.[2]

Now, suppose that each possible initial coin microstate has the same *chance* of coming about.[3] And suppose the evolution is deterministic. Then, those chances propagate

[1]For clear presentations of examples like this, please see Albert (2000) and Michael Strevens (1999). This example is a simplified version of Boltzmann's original example of an expanding gas.

[2]Since there are continuum-many initial conditions, we cannot simply count, but must use a measure to compare them.

[3]Strictly speaking, because the possible initial microstates of a coin toss are continuous, each one will have a chance of zero. Thus, we must talk of measures, rather than finite chances. I will address this complication

through the deterministic evolution, with the result that each final microstate has the same chance. Since roughly half of the possible final microstates are heads and half are tails, it follows that the chance of heads is $\frac{1}{2}$ and the chance of tails is $\frac{1}{2}$. Furthermore, only a minuscule fraction of the final states are anything *other* than heads or tails, such as the coin landing on its side. Therefore, there is a very, very high chance that the coin will land on a face side, and a very, very low chance it will land on its edge.

Note that the hypothesis of equal chance is not an *a priori* claim or a claim of logical possibility. Rather, it is an empirical claim. As coin-scientists, we observe many coin tosses and begin to theorize about coin tosses in general. We make a hypothesis: each initial microstate has the same chance.[4]

The upshot of all this is that a simple assumption—that each initial state has the same chance—in conjunction with the dynamical laws of motion, yields the following:

- Chances for individual events—there is a chance of $\frac{1}{2}$ that the next coin toss lands heads.
- Chances for sequences of events—there is a chance of $\frac{1}{32}$ that the next five coin tosses all land heads.
- Generalizations for events—coins have a much, much higher chance of landing on their faces than on their edges.

Albert and Loewer's bold and surprising claim is that the entire universe is not relevantly different from such a coin. Thus, we ought to shift our attention to the ultimate initial conditions—those of the entire universe. So, suppose that each of the specific ways in which the universe could have begun has the same chance.[5] Again, the hypothesis is not

in more detail below.

[4]Again, this isn't quite right since the hypothesis assigns a measure that is more bell-shaped. This is because it is most likely that a coin is tossed between one and three feet in the air, and very unlikely that it is tossed only a couple of inches or ten feet in the air. Similar reasoning applies to its rotation, etc.

[5]If we use the simple mechanics of a classical Newtonian world, then those ways are represented by a continuous Lebesgue measure in phase space over microstates that are further restricted by a low-entropy

*a priori* or based on logical possibilities. Rather, it is an empirical hypothesis that is given support from the subsequent patterns we see in the actual world. Then each subsequent, deterministic evolution of those initial conditions has the same chance. If Albert and Loewer are right, then the familiar statistical patterns and generalizations at every level of scientific investigation can be derived, in principle, from this initial chance distribution over possible microstates.

## 4.3 Basic Chance: Humean vs Fundamental

It is important to note that this exciting proposal is *conditional*: *if* there is an initial chance distribution over states, and if the evolution of these states is deterministic, *then* that distribution yields a final chance distribution over states. If we want a complete account of chance, something must be said about the nature of those basic, initial chances. Albert and Loewer argue for a Humean interpretation, which they call **L-chance**. They claim that the basic, initial chances can be further reduced to the *subsequent* actual pattern of actual events. I will argue that such a reduction suffers from several counterexamples, and thus fails to satisfy five central chance roles. I will go on to argue for my own anti-Humean interpretation, according to which basic, initial chance is fundamental. I hope to show that my account better satisfies those chance roles.

### 4.3.1 Humean Chance

Albert and Loewer accept the metaphysical doctrine of Humeanism: all that exists, fundamentally, is the actual distribution of categorical (non-modal) properties in spacetime—the "Humean mosaic." Thus, everything else—including laws and chances—supervenes

condition. For more, see Albert (2000).

on, or reduces to the mosaic.[6] This contrasts sharply with other metaphysical pictures of the world, some of which hold that the laws and/or properties *determine* how the actual world turns out. Humeans think the world—past, present, and future—generates the laws and L-chances, while anti-Humeans think the laws and chances (at least partly) generate the world.

### Lewis on Chance

Albert and Loewer's theory of chance is an extension of David Lewis's account. According to Lewis (1983; 1994), chances are given by the laws of nature. And the laws of nature are "deductive systems that pertain not only to what happens in history, but also to what the chances are of various outcomes in various situations." (Lewis 1994, 480) In order for chances to reduce to the mosaic, the laws that include them must reduce to the mosaic. Lewis proposes that laws are merely statements that do a good job of systematizing the mosaic by balancing simplicity, strength, and fit. Lewis offers only a rough characterization of simplicity, strength, and fit, though others have done more to elucidate these notions.[7]

Simplicity has to do with linguistic length—short statements in the right language are better than long. Strength has to do with how much the laws cover—statements that say a lot about the world are better than statements that say only a little. Fit, for Lewis, is simply a numerical constraint: the higher the probability that the laws assign to the actual world, the better the fit. According to Lewis's account, "probabilistic laws" are just statements about the mosaic that include numbers between zero and one.

Lewis tells us to find the best balance between these virtues. For instance, it is easy to make a set of statements simpler by giving up on fit, as in the single statement, "Every

[6] I will not address the motivations for resisting fundamental, modal features or the alleged desirability of a Humean ontology in this chapter. See, for instance, Jessica Wilson, "What is Hume's Dictum and Why Believe it?"

[7] See, for instance, Loewer (2004).

event has a chance of $\frac{1}{2}$." Likewise, it is easy to make a set of statements stronger by giving up on simplicity, as in the set of statements that describes every event. One might wonder why we should care about simplicity, strength, and fit. Lewis's answer is that we should care about them because they yield the kinds of laws that appear in our best physics. He goes on to claim that these laws contain numbers that play most of the important chance roles—a claim I will dispute below.

The simplest Humean account of chance is actual frequentism, according to which the chance of, say, a die landing five-up is just the number of times it does land five-up divided by the number of times it is rolled. Actual frequentism counts as Humean because the statement, "One-sixth of all die rolls land five-up," can be reduced to the actual pattern of events. Lewis's proposal is more sophisticated than actual frequentism because the probabilistic laws are more complicated than simple ratios. Nevertheless, it is very much in the same spirit as actual frequentism.

### Chance as Systematization

Return to the example of the coin toss. Part of our scientific theory of coin tosses says that coins land heads about as often as they land tails and that they almost never land on their edges. It also says that these gross or macro facts depend so sensitively on the initial conditions of the toss, that gross or macro changes to those initial conditions do not affect the overall distributions. For instance, tossing it faster or slower does not affect the frequencies of various outcomes. It turns out that there is an incredibly simple and informative way to systematize this information about coin tosses, as well as all of the other statistical and general regularities in the world.

The systematization has three pieces:

**DDL** The Deterministic Dynamical Laws of Newtonian mechanics describe how any particular initial condition evolves throughout time.[8]

**PH** The Past Hypothesis constrains the initial conditions to a certain low-entropy subset of possible configurations.

**SP** The Statistical Postulate assigns a normalized, uniform measure to the region of mathematical space that represents those possible configurations.

It is tempting to interpret these three statements as metaphysically explanatory. Indeed, I will argue this is exactly how we *ought* to interpret **SP**. But for the Humean, **DDL**, **PH**, and **SP** concisely *summarize* what actually happens. It is fairly straightforward to see how **DDL** and **PH** could be descriptions, but **SP** requires a bit of explanation—especially since **SP** is where Albert and Loewer locate basic chance.

Note that we could have systematized the mosaic with **DDL**, **PH**, and instead of **SP**, a description of the exact initial microstate. This would have been maximally informative, as it would have entailed every fact about the actual mosaic. Unfortunately, it would have been prohibitively complicated. It is much simpler to use **SP**.

Technically, **SP** merely specifies a mathematical measure over a restricted possibility space—there is no explicit mention of chance. The measure assigns numbers to regions in the space that represent events. Thus, every event has an associated number between zero and one. The measure also assigns numbers to subsets and intersections of regions. This implies that every pair of events has an associated number between zero and one. For instance, the number associated with a coin toss that lands tails is just the measure of the space representing a tails-land, divided by the measure of the space representing a coin

[8]Of course, we know the laws are not Newtonian, but this simplification provides an easy way to see how the explanation would go if the world were Newtonian. Albert and Loewer make the plausible assumption that if the world evolves deterministically, this Newtonian systematization can be generalized to a more complex and accurate formulation.

toss: $\frac{1}{2}$.

Why do Albert and Loewer think these numbers are *chances*? They agree with David Lewis (1980) that chance is as chance does. They claim that these numbers in their theory satisfy more of the kinds of roles chance is supposed to play than any other theory does. I agree with their standard of success: a good theory of chance should be able to satisfy all of the important chance roles, but I disagree with their claim that no theory can do it better than theirs can.

## 4.4 Objections

In this section, I present five serious objections to Albert and Loewer's account of chance. First, a good theory of chance allows for the possibility of arbitrary divergence between chance and frequency, but Albert and Loewer's account does not. Second, chance is incompatible with determinism, but Albert and Loewer's account of chance is not. Third, past events are no longer chancy, but Albert and Loewer's theory allows for non-trivial chances—that is, chances that are other than one or zero—in both the future and the past. Fourth, Albert and Loewer's theory of chance does not always satisfy the Principal Principle. I argue that Ned Hall's replacement for the Principal Principle, called the *New Principle*, is unmotivated unless one has already accepted Humeanism about chance, making its justification circular. Finally, I argue that Albert and Loewer's notion of chance is merely epistemically explanatory but not metaphysically explanatory.

### 4.4.1 Chance Events can Happen

Suppose a certain die has a 17% chance of landing five-up if it is tossed. Does this mean that on the next toss the die is guaranteed not to land five-up? No. Does this mean that in the long run, assuming that each toss has the same chance, it is guaranteed to land five-up 17% of the time? No. But, this does mean that the die has a small *chance* of landing five-up on its next toss, and that the die has a very high *chance* of landing five-up roughly 17% of the time. And, there is a very, very small *chance* that the die will never land five-up, and an even smaller *chance* the die will always land five-up. These platitudes are central to our notion of chance and cannot be reduced to non-chancy notions. Otherwise, there would be a guarantee of one outcome or another—something that chancy processes, by their nature, just cannot do.

For instance, suppose that in the long run, the chancy die is guaranteed to land five-up 17% of the time. Then, it would be possible to derive a contradiction:

- On any given toss, this die might land five-up or it might not.
- The total number of times this die lands five-up will be 17% of all tosses.

It is easy to see how the two statements can contradict one another in the finite case. Suppose the die is tossed only one hundred times. Then, after the die has landed five-up seventeen times, it can no longer land five-up—it is guaranteed to land on some other side. But this means that the first statement is no longer true. Conversely, if the die has only landed five-up sixteen times by the ninety-ninth toss, it is guaranteed to land five-up on the hundredth toss, rendering the first statement false. In the infinite case, just apply the first statement to each toss at once: Can every toss land five-up? Not without rendering the second statement false.[9] Note that characterizing chance—as von Mises (1957) does—in terms of limiting frequencies within subsequences does not solve the problem because the requirement is that *any* toss may land five-up. This is ruled out by such a characterization.

The first statement—that on any given toss, this die might land five-up or it might not—captures one of the central roles of chance. A chance event can turn out more than

[9] Here I bracket zero fit issues which present further problems for the Humean. For more on these problems see Elga (2003).

one way, regardless of how other events have turned out. Bigelow, Collins, and Pargetter (1993) make this role precise with their Basic Chance Principle and argue, "anything that failed to satisfy the BCP would not deserve to be called chance."

**BCP** Suppose $x > 0$ and $Ch_t(A) = x$. Then A is true in at least one of those worlds w' that matches $w$ up to time $t$ and for which $Ch_t(A) = x$.[10]

Thus, holding the history and the (non-zero) chance that a particular event occurs fixed, there must be at least one world in which that event occurs.[11] And, as the example with the die shows, a converse basic chance principle must hold as well:[12]

**Converse BCP** Suppose $x < 1$ and $Ch_t(A) = x$. Then A is false in at least one of those worlds w' that matches $w$ up to time $t$ and for which $Ch_t(A) = x$.

Together, BCP and Converse BCP entail that any collection or sequence of chance events is possibly coinstantiated with those chances. To see why, take the first chance event, $A_1$, in world $w_1$, where $0 < Ch_t(A_1) = x < 1$. According to BCP, there is a world, call it $w_2$ in which $Ch_t(A_1) = x$ and $A_1$ occurs, and according to Converse BCP, there is another world, call it $w_3$, in which $Ch_t(A_1) = x$ and $A_1$ does not occur. Either $w_2$ or $w_3$ may be identical to $w_1$, but not both. Then, consider the next chance events, $A_2$, $A_3$, and so on. By exactly similar reasoning, for every combination of event occurrences and non-occurrences, there is a corresponding world that includes that combination of events, and that matches $w$ in the chances of those events.

So one chance distribution is compatible with many different patterns of events. Jenann Ismael (2011, 7) notes the flip side of this, "it is a fact about the logic of chance that

[10]Alan Hajek (2011) has offered compelling reasons to think that BCP holds when $x = 0$ in some cases involving infinity, such as the case of the infinite dartboard. While I agree with Hajek, the weaker version of BCP is sufficient for my purposes in this chapter.

[11]Strictly speaking, $A$ is the proposition that a particular event occurs, not the event itself. Thus, $A$ can be true or false. For ease of exposition, I will sometimes use '$A$' to refer to the event and sometimes to the proposition that the event occurs.

[12]I include the converse BCP for those who are disinclined to accept negative events. If one has no such qualms, one can substitute $\sim A$ for $A$ in BCP to achieve the same result.

the very same distribution of actual events is logically compatible with an unlimited number of inequivalent chance distributions." But the fact that one chance distribution is *logically compatible* with almost any pattern of events and *vice versa*, does not mean that any pairing of chance and pattern has the same chance. Whatever the actual pattern happens to be, according to some chance theories, that pattern has a high chance, and according to other chance theories the pattern has a low chance. Thus, while we cannot deduce the correct theory of chance from the actual pattern of events, we can say which theories of chance would make the given pattern most likely. Where chance is involved, this is the best we can do. Though Ismael and I disagree about the nature of chance, we agree about this: "The link between the actual pattern of events and the chances is irreducibly and irremediably probabilistic." (Ismael 2011, 7)

But, Albert and Loewer's theory of chance cannot accommodate BCP or CBCP. For them, chance systematizes the actual distributions of events, resulting in a close connection between chance and the actual frequencies of events. To see this, note that if the divergence between the two were too much, those chances would fail to fit the mosaic, and therefore would not *be* the chances of the world. Thus, Albert and Loewer's notion of chance fails to allow for the possibility of radical divergence between the chance and the frequencies. It is interesting to note that their sophisticated theory of chance does much better than actual frequentist views on this score. Some divergence *is* tolerated because of the power of **DDL**, **PH**, and **SP**. Together, they are so simple and informative, they can fail to fit some actual distributions and still count as the best systematization. But, the intuitive chance requirement is that there can be radical, even total, divergence—such divergence has a very, very low chance, but there is always that possibility—and Albert and Loewer's chance does not allow for it.

To see why, first we need to get clear on what it means to say that the frequency *cannot* diverge too far from the L-chance, and for this, we'll need modal notions. If an event has a positive chance, that event should be not only metaphysically possible, but also, as the BCP requires, *historically-nomologically-possible*: possible even in worlds that share our history and laws.

And, according to L-chance, frequencies that diverge radically from the L-chances are metaphysically possible—there are possible worlds in which the frequencies look nothing like actual frequencies, either because they do not ever match, or because they match for some time, then diverge. But, according to L-chance, if we hold the laws fixed, not every event with non-zero L-chance is possible. There are two ways to see this. We can demand that all events with positive L-chance be historically-nomologically possible, or we can consider long sequences as possible events and demand that they be nomologically possible. Thus, begin by looking at all the worlds that match ours in their laws and history. Then, suppose there is a positive L-chance that at every future time that gas is collected in the corner of a container, it stays there, rather than spreading out. Now, the defender of L-chance agrees there is a world that matches ours until the present time, and in which gasses do this. But such a world does not share our L-laws, or our L-chances.

There is an interesting detail worth mentioning here. The Humean cannot take the weaker position that such worlds are historically-nomologically possible because the actual laws are *true* in them, even if they aren't *laws* in them. This is a position that one sometimes finds the Humean adopting in other contexts to soften the force of certain counterexamples.[13] But, in the case of probabilistic laws, it's not clear what it would mean for the chances to be true of a world, without being chances of that world.

So, while events with very, very low L-chance can happen, they just can't happen in worlds that share our laws. Thus, according to L-chance, events with a low L-chance are nomologically *impossible*. So, L-chance cannot satisfy the chance desiderata that says that all events with positive chance are nomologically possible.

[13]See, for instance, Hall (2010).

### 4.4.2 Chance and Determinism

Chance is often contrasted with determinism. An event can be chancy or deterministic, but not both. Either an event is determined to happen or it is not. Lewis (1994, 480) offers a way of cashing this out in terms of the laws of nature: The laws "never say that *A* without also saying that *A* never had any chance of not coming about." If the world is deterministic, then the state of the world at one time, in conjunction with the laws, fixes the state of the world at all future times.[14][15] If, on the other hand, the world is chancy, then given BCP and the Converse BCP above, the state at one time does not fix the state at all future times.

So, is the world chancy or not? The Humean has no way of consistently answering this question. In principle, it is possible to derive the complete microstate at one time from the complete microstate at another time using **DDL**. And, according to the Humean picture, at every time the world has a specific, complete microstate. Thus, it seems all events are determined. But, on the other hand, the Humean *laws* never specify the entire microstate. Rather, **SP** gives a probability distribution over possible microstates. Thus, all events are assigned probabilities and thus have non-trivial L-chances. So, according to the Humean laws, the world is chancy. But, according to the Humean laws *plus* the Humean ontology of an entire microstate, the world is deterministic.

### 4.4.3 Chance and the Past

After a chance event occurs, it loses its non-trivial chanciness. The chance of any past event is one, if it occurred, or zero, if it did not. For instance, suppose Anita is trying to find her way to the center of a labyrinth by noon. As Lewis points out, the chance that

[14]The world may be deterministic toward the future, or the past or both, depending on the particular formulation of the laws of nature, though I focus on the future-directed determinism.

[15]Strictly speaking, Newtonian mechanics is not deterministic. For more, see John Norton's (2008) paper on the dome and space invaders. These unusual and surprising cases won't be relevant here.

she makes it to the center by noon changes as her position in the labyrinth at various times changes, until the event is past. Supposing she makes it to the center at 11:49, "then, and forevermore [her] chance of reaching it by noon is 100%." (Lewis 1980, 271)

But, the Humean takes the entire mosaic, past, present, and future, as fundamental, with L-chances supervening on the patterns of the mosaic. Thus, the L-chances do not depend on the present moment, and do not require past chances to be zero or one. The Humean theory of L-chance does allow for conditional chances. So, the unconditional L-chance of a future event differs from the L-chance of a future event *conditional* on some past or present facts. But, if the Humean conditionalizes on anything less than the entire microstate at a time, some future events will have non-trivial, conditional L-chances, but so too will some past events. And, if the Humean conditionalizes on an entire microstate at a time, then all chances, past and future will be one or zero. The Humean cannot maintain that the past is no longer chancy, except by giving up all future chances as well.

The Humean can soften this objection by pointing out that if the Humean conditionalizes on the present macrostate, *most* of the actual past macroevents we care about will have chances very close to one. But, not all of them. Adam Elga (2000) presents one such case. Suppose that the lost island of Atlantis actually existed. But, unfortunately, all of the macrotraces of the island have since disappeared. Thus, if we conditionalize on the present macrostate, it will be overwhelmingly likely that Atlantis never existed. Therefore, past events can receive chances less than one, even chances that are very, very close to zero. Furthermore, in addition to such 'Atlantis' type macro cases, the vast majority of actual past microstates do not receive chances of one either. Thus, according to the Humean, many, many past events are still chancy.

### 4.4.4 Chance and Credence

The Principal Principle says that in the absence of inadmissible evidence, one should have credence $x$ in $p$ if and only if the chance of $p$ is $x$. But, the defender of L-chance cannot accept the Principal Principle.

Consider a simple world that has a single coin which is tossed over and over one trillion times. Suppose the coin lands heads roughly half the time but in a way that we cannot systematize with a better balance of simplicity, informativeness, and fit than by saying the coin has L-chance $\frac{1}{2}$. Then, the L-chance of that particular sequence is $\frac{1}{2}^{1{,}000{,}000{,}000{,}000}$. Suppose further that after 500,000,000,000 tosses only $\frac{1}{4}$ have landed heads. By the very definition of L-chance, roughly $\frac{3}{4}$ of the remaining 500,000,000,000 tosses have to land heads.

But now the Humean faces a problem: the L-chance of the 500,000,000,001$^{st}$ toss is $\frac{1}{2}$ but an agent who knows the chances and who knows the outcomes of the first tosses and how many remain ought to have a credence of $\frac{3}{4}$, *not* $\frac{1}{2}$, in the coin landing heads on the next toss. Ned Hall and David Lewis argue for just such a modification in their *New Principle*. An agent's credence in event $A$ at time $t$, conditional on the history and the chance theory ought to be equal not to the chance of $A$, but the chance of $A$, conditional on the truth of the chance theory:

$$Cr_t(A|H_t\&T) = Ch(A|T)$$

Essentially, Hall is saying that one's credence in a chance event ought to accommodate the fact that one is a Humean about chance. This New Principle presupposes that chance works in the way the Humean thinks it does. Indeed, I agree that if we knew chances were Humean chances, then we *should* conform our credences to them in the modified way Hall suggests. This is simply because the Humean chances are shorthand for information about patterns that exist throughout the entire mosaic, past, present, and future.

But, the relevant question is not how to modify our credences given the truth of Humeanism. Rather, we have a pre-theoretic desideratum: one ought to set one's credence to the chance of an event. The Humean simply cannot recover this result. Two examples will help illustrate the situation.

First, suppose God tells you that the chance of each coin toss is $\frac{1}{2}$ and that there will be one-trillion coin tosses. What should your credence be in the 500,000,000,001$^{st}$ toss? The intuitive and pre-theoretic answer is that it should be $\frac{1}{2}$. Why? Because God told you that the chance of each toss is $\frac{1}{2}$ and it seems plausible that you should set your credence to the chances. If God *also* told you that chances are Humean systematizations of total patterns, then your credence should be $\frac{1}{4}$. Thus, we see how Hall's 'solution' is only a solution if one is *already* a Humean.

Consider a second example. Suppose our best scientists do some research on coins. They run a range of tests and conclude that coins tosses are independent and each has a chance of $\frac{1}{2}$. This independence means that previous tosses have no probabilistic effects on subsequent tosses. Then, you observe the 500,000,000,000 tosses, $\frac{1}{3}$ of which land tails. This knowledge should have no effect on your credence in the next toss because you know the tosses are independent. Nevertheless, the Humean thinks it *could* have such an effect. Essentially, the Humean embraces the "Gambler's Fallacy." The Humean thinks that the coin has to "make up for" its unlikely string of tails, or that landing heads is somehow "due." Of course, the Humean doesn't think the earlier tosses metaphysically produce or determine the compensating later tosses, just that your credences should behave as if they did. Thus, I hope to have shown that the Humean cannot fully accommodate the Principal Principle.

### 4.4.5 Chance and Explanation

Since Humean L-chances are ways of systematizing actual patterns of events, if one has information about the L-chances, then one has information about the systematization of the pattern. Note that a great deal of information is lost as one goes from the mosaic to the systematization. Specific facts about the locations of particular particles or individual property instantiation is lost due to the requirement of simplicity. The Humean laws of nature, which include the L-chances of events, are selected for simplicity, strength, and fit. Thus, specific facts are omitted because they add a tiny bit of strength at a large cost to simplicity. Nevertheless, because of the way that the Humean laws—and the L-chances—are derived, knowledge of the L-chances just is knowledge of those patterns. Thus, Albert and Loewer can account for epistemic explanation: knowledge of the chance yields knowledge of the world.[16]

But, by the same token, those L-chances *derive from* the actual patterns, so they cannot metaphysically explain the patterns of events. Metaphysical explanation runs in the same direction as metaphysical dependence and tells us *why* things are the way they are. By the Humean's stipulation, the entire mosaic is metaphysically fundamental and the L-chances can be reduced to the mosaic. So, it is the mosaic that metaphysically explains the L-chances, and not *vice versa*. Thus, when you consider several tosses of a chancy die, it is not the die's one-sixth chance of landing five-up that explains why the die tends to land five-up roughly one out of every six rolls. Rather, it is the fact that the die lands five-up roughly one out of every six rolls that explains why the die has a chance of one-sixth to land five-up.

[16]Marc Lange (2012) recently has argued that this kind of explanation is not genuine explanation because it does not match the direction of metaphysical explanation. While there is some sense in which the systematization provides information, it only does so *in virtue of* the thing it is providing information about—namely, the mosaic.

### 4.4.6 Humean Costs

I have argued that the Humean account of L-chance faces significant costs. It cannot satisfy five plausible chance desiderata. According to L-chance, unlikely events cannot occur (while holding fixed the past and the chance), L-chance and determinism are compatible, the past may be L-chancy, L-chance does not obey the Principal Principle, and L-chance does not metaphysically explain the patterns we see in the world. How seriously we should take these objections depends on how much we care about these chance desiderata and how fully a theory must meet them.

I think these desiderata are definitive of chance. If there were no other theory that could satisfy them, we might say so much the worse for chance. But, in the next section, I will present my own theory of chance and show how it can accommodate these chance desiderata. I think this gives my account some *prima facie* plausibility over the Humean rival of L-chance.

## 4.5 Fundamental (Anti-Humean) Chances

Return to the example of the die that has a basic, 17% chance of landing five-up. There are no guarantees about how its tosses will turn out. *Any* sequence of rolls is possible—though some collections of outcomes have a higher chance than others. Recall Ismael's (2011, 7) observation, "The link between the actual pattern of events and the chances is irreducibly and irremediably probabilistic." I take this at face value, and posit metaphysically fundamental chance. Because it cannot be reduced or analyzed, fundamental chance can only be elucidated by describing some of its features.

First, because fundamental chance can be represented by ratios of volumes in phase space, it can be represented by numbers that satisfy the probability axioms. Next, if each event, $A_i$, has a fundamental chance of 0.7 of occurring, that implies that any given instance, $A$ may occur, or may not occur, and has a higher chance of occurring than not occurring. It also implies that over a long period of time, the relative frequency of $A$'s to non-$A$'s that has the highest chance is seven to three.

Fundamental chance is also time-indexed and time-asymmetric. Consider our die. Before the die is rolled, the chance is 17%. After it is rolled, if it landed five-up, that chance goes to one, and zero otherwise.[17]

Furthermore, metaphysically fundamental chances can be inherited. Thus, imagine a fundamentally chancy die that I roll and then photograph. Before I roll the die, the photograph has an inherited chance of 17% of showing five-up. Thus, it is still metaphysically chancy whether or not the photograph will show five-up. But, after I roll the die and before I take the photograph, the inherited chance of showing five-up goes to one (if the die landed five-up) or zero (if it did not).

### 4.5.1 A Metaphor for the Universe

The universe and its evolution can be thought of as a fundamentally chancy, many-sided die tossed at the first instant.[18] The result of that die toss determines which chain of deterministic dominoes to set in motion.

[17]Since chances are time-indexed, they avoid the dilemma Jenann Ismael (2011) presents for primitivism about chance. She argues that chance cannot be totally independent of frequencies because then there could be non-trivial chances for past events. By making chances time-indexed, the chance of an event *before* the event's occurrence or non-occurrence is independent (insofar as a non-trivial chance is consistent with the occurrence or non-occurrence of the event), but *after* the event's occurrence or non-occurrence is not independent because it is one if the event occurred or zero if it did not.

[18]I use the example of a die because it is familiar and easy to understand. Of course, real dice are complex objects whose behavior is produced by the interaction of many different properties—they do not have fundamental chances.

Figure 4.1: A Chancy Die and Six Deterministic Domino Chains

To see how subsequent events inherit chances from the die, note that if each side of the die has the same chance,[19] then patterns that occur on most sequences will also have a high chance. For instance, if two-sixths of the domino chains include event $A$, then the inherited chance of $A$ is $\frac{1}{3}$.

Figure 4.2: Patterns in the Domino Chains

Thus, I can accept the story that Albert and Loewer give us for deriving subsequent chances from an initial chance distribution over possible states near the beginning of the universe. But, I do not agree that those initial chances can be further reduced to the pattern of events in the actual world. Rather, I hold that the initial chances are metaphysically fundamental and that they (in part) determine the metaphysical, inherited chances of subsequent events.

[19]In the uncountably infinite case we can only compare subsets of sides, so the chance of landing [0,1) is the same as landing [1,2), etc.

### 4.5.2 Classical Mechanics

The die and dominoes provide a useful image, but in the end, they are just metaphors. Therefore, consider again the simplistic case of classical mechanics. According to my view, there is an initial, fundamental, chance of different distributions of particles. Following the chance event, these distributions of particles evolve deterministically and classically throughout time. There will be some kinds of events and processes that occur in most of the possible futures, and others that occur in only a few (in the infinite case, we make this notion of "most" precise by using a measure). Before the chance process, each initial distribution has the same chance. These chances propagate throughout the deterministic evolution, with the consequence that each possible future has the same chance. Thus, the events and processes that occur in most of the possible futures have high inherited chances, while the events and processes that occur in only a few possible futures, have low inherited chances.

Consider the worlds that contain coins that are tossed. Suppose 99.99% of those tosses are coins that land on their faces, and not their edges. Suppose that 49.995% of those tosses are coins that land heads, and 49.995% that land tails. Then, there is a very high chance that flipped coins land on their faces, and not their edges. And, a flipped coin has the same chance of landing heads as tails. It is easy to see how to apply this reasoning to the generalizations and chances of the special (non-physics) sciences.

Note that while it is easy to see how to apply the reasoning *in the abstract*, it is impossible to apply it in practice. We simply lack the requisite knowledge (i.e. range of initial conditions) and computing power (i.e. calculating the evolution of $10^{80}$ particles). It is important to keep in mind that this project is just a way of providing a metaphysical foundation for the everyday facts we take for granted—especially if, as seems entirely (epistemically) possible, the world's evolution is deterministic. Namely, what are we to make of the probabilities that appear in the special sciences? Similarly, why is it rational to have non-trivial credences? I will return to these questions in the section on credence below.

### 4.5.3 What Are the Initial Chances?

We still need to say more about the ‘initial’ chance process. I see three different ways to do this. The first is to locate the chance event outside the universe. Thus, the initial configuration of our universe had a chance of being actual, and different configurations also had chances. This has the downside of preventing the chance process from being a physical process. Thus, it could not be law-governed or subsumed under dispositional properties. It has the upside of dovetailing nicely with some of the literature on fine tuning and the ‘likelihood’ of our actual world. Note that these chances cannot replace the chances appealed to in the debates on fine tuning. This is because the chances of this theory are only for initial conditions that are within the range of nomological possibilities. For other initial conditions—that, say, vary the constants in the laws of nature—other, more inclusive chance measures are needed. Even so, this chance measure could be subsumed without any trouble by such a theory.

The second and third options locate the chance event in the universe in different ways. One way to do this is to hypothesize that the universe began as a hot, dense collection of matter. This collection was too dense to be stable and exploded in a chance process with chances of ‘banging’ into different configurations. The outcome was one of an uncountably infinite number of possible configurations of particles. The details of such a process and the subsequent evolution undoubtedly would be very complicated and we will have to wait until we have a theory of quantum gravity to say anything more specific. Nevertheless, one often hears physicists talking about the early universe as being radically affected by early chance processes (though these quantum effects show up throughout time as well as at the beginning). This has the upshot of treating all chance processes as physical processes that exist within the universe. It also has the feature—a cost or benefit, depending on your perspective—that it is open to empirical refutation. Thus, as scientists make more progress on their research into the very early universe, this theory could be confirmed or disconfirmed.

The third way of locating the chance process in the physical world is to appeal to "bubble universes." Some physicists, such as Sean Carroll (2010), postulate that in the very far future, as our universe expands, quantum fluctuations can lead to a bit of spacetime becoming isolated as a kind of bubble. These bubbles will rapidly expand, in much the same way that we think our universe did thirteen billion years ago. Thus, there may not be a single, initial condition. Rather, our present universe may be the product of another universe's bubble progeny. In such a case, there would be general principles—likely involving both quantum mechanics and general relativity—that determined the chances of each bubble universe's 'initial' conditions. This has similar costs and benefits to the above possibility.

Note that the last two options involve taking a stand of the laws of nature and/or the fundamental properties. Thus, the universe could not be wholly Newtonian or Bohmian because, on this picture, the big bang is a chance process while Newtonian and Bohmian mechanics are purely deterministic. *Prima facie*, this does not seem to be a benefit or a cost, but merely something to make explicit.

## 4.6 Certainty Versus Chance = 1

There is an interesting caveat that is worth explicating.[20] As Alan Hajek (2011) has noted, there are many events that have a chance of zero, and yet may still occur. Conversely, there are some events that have a chance of one, and yet may not occur.

[20]Thanks to Tim Williamson and Boris Kment for helpful discussion on this point.

Consider an infinitely dense dartboard with values [0,3] and a dart-thrower. The chance that the dart lands exactly on the point 2 is zero, but so is every other number. And the dart must land somewhere. Hajek takes this, in conjunction with other, similar examples, as a good reason to modify the mathematical device we use to represent chances. For instance, it seems that the dart has a chance of $\frac{1}{2}$ of landing on the point 2, conditional on its landing on either 1 or 2.

The results we must accommodate from this example are the following:

- If something has a chance of zero, it is not certain that it will not occur (e.g. that the dart lands on the point 2).
- If something has a chance of one, it is not certain that it will occur (e.g. that the dart lands anywhere *but* the point 2).
- We should be able to make sense of chances that conditionalize on events that themselves have zero chance (e.g. on the dart landing on either point 1 or 2).

Luckily, my account offers a solution to these puzzles. Recall that the mathematical device we are using to represent chances is a measure over the set of worlds that comprise the nomological possibilities. To account for the first puzzle, we must distinguish between having a chance of zero and not occurring in any world. It is a well-known mathematical fact that if two dense sets differ with respect to a single point, they will nevertheless have the same measure. Thus, [0,3] has the same measure as (0,3], even though the first set includes an additional point: namely, 0. If we properly distinguish between a measure of zero and non-occurrence, we can make sense of the claim that landing on the point 0 is possible in the first set, though it has a chance of zero, while landing on zero is impossible in the second set.

To translate this into my metaphysical picture, we need to properly distinguish between events that occur in *some* world, even if those worlds have measure zero relative to the entire nomological space, and events that do not occur in *any* world. Once this is done, we can see how the non-occurrence of an event entails a chance of zero, but not *vice versa*.

We can make a similar accommodation for events that have a chance of one. If they occur in every nomologically possible world, then they are certain to occur. But, if there are some worlds in which they do not occur, they may fail to occur, even if the measure of the worlds in which it occurs is one. Thus certain events entail a chance of one, but not *vice versa*.

Finally, this picture lends itself to the conditionalizing that Hajek recommends. When a uniform measure over all the worlds is conditionalized on something that occurs in only a few worlds (and thus is possible, despite having a chance of zero), the resulting measure is still uniform over those remaining worlds. This achieves exactly the right result.[21]

## 4.7 Credence

On my account, once a metaphysically fundamental chance event has occurred, the chance of that event goes to one (or zero, if the event did not occur) for all time. It follows that since the chancy big bang has already occurred, and keeping with our assumption of Newtonian mechanics, there are no longer *any* non-trivial chances in our world—neither fundamental chances nor inherited chances. Indeed, there have been no non-trivial chances for roughly thirteen billion years.

And yet, probabilities are ubiquitous in science and our everyday lives. The solution is to provide a theory of credences that are *objectively justified by the metaphysical chances*. Many people in the literature have proposed some kind of objective epistemic chance or

[21] Note that I am not the only one who can take advantage of this nice mathematical feature. Indeed, anyone who utilizes a measure over worlds can appeal to it.

objective credence distribution. What my view does is offer a new metaphysical foundation for these credences.[22]

For instance, suppose someone is about to toss a genuinely chancy die with the chance of five-up equal to $\frac{1}{6}$. Your credence that the die will land five-up should be $\frac{1}{6}$. This is just David Lewis's Principal Principle—roughly, that one's initial credence in $A$ should equal the chance of $A$. Now, after she has tossed the die, the chance of the die landing five-up is either one (if it did land five-up) or zero (if it did not). However, after the toss but before she tells you how it turned out, your *credence* that the die landed five-up should still be $\frac{1}{6}$. This commonsense result suggests a way of modifying our credences in a world that is no longer metaphysically chancy.

### 4.7.1 Credence Preservation

In the face of ignorance, it can be rational to have credences that don't match the chances. I call this principle:

**Credence Preservation** If an event, $A$, has a metaphysical chance of $x$ before it's occurrence (or non-occurrence), then, after $A$ occurs (or does not occur), and in the absence of any new information, one ought to set one's initial credence in $A$ to $x$.

This is a modification of the Principal Principle because it tells an agent what to do if she knows the prior chance of $A$, but not the present chance of $A$. According to the Principal Principle, she ought to set her credence at $t$ in $A$ to the chance of $A$ at $t$, which is one (or zero). Ideally, she would so set her credence—to one (or zero)—but, she cannot do this because she is ignorant of the chance. Credence Preservation tells her what to do when she does not know the present chance of $A$ at $t$.

[22] My account is quite similar to Jonathan Schaffer's (2007) epistemic chance, though I offer a metaphysical ground for it that he does not accept.

Often we have some information about an event that nevertheless falls short of perfect knowledge. For instance, I might know that the die landed odd. In that case, my credence that the die landed five-up ought to go to $\frac{1}{3}$. This is just to say that credences need to be conditionalized on that new information (where $t_1$ is a time before the metaphysically chancy event and $t_2$ is some time after).

$$Cr_{t_2}(A) = Cr_{t_1}(A|E) = \frac{Cr_{t_2}(E|A)Cr_{t_1}(A)}{Cr_{t_1}(E)}$$

And, since one's credence in a chance event before it happens is equal to the chance of that event,

$$Cr_{t_2}(A) = \frac{Cr_{t_2}(E|A)Ch_{t_1}(A)}{Ch_{t_1}(E)}$$

In the case of the die roll, we get the right result. Conditionalizing the initial chance of five-up on knowledge of an odd outcome yields a credence of $\frac{1}{3}$:

$$Cr_{t_n}(5) = Cr_{t_0}(5|odd) = \frac{Cr_{t_n}(odd|5)Ch_{t_0}(5)}{Ch_{t_0}(odd)} = \frac{(1)(\frac{1}{6})}{\frac{1}{2}} = \frac{1}{3}$$

### 4.7.2 Limited Agents

We can illustrate this by considering epistemic agents of decreasing abilities. Thus, first consider an ideal epistemic agent with full knowledge of the metaphysical chances, full knowledge of her present state and with unlimited computing power. She ought to set her credence to the most recent metaphysical chance of the event. This will yield non-trivial chances if the event is chancy and in the future, and trivial (one or zero) chances if the event is in the past—this is just a simple application of the Principal Principle. If the evolution of the universe is deterministic with all chances at the big bang, then she will know every actual fact because all chances are one or zero. Such an agent would have no need for non-trivial credences.

Next, consider an epistemic agent with full knowledge of the initial metaphysical chances—but not the actual microstate—and with unlimited computing power. Then, she will know all of the conditional chances and the chances of the special sciences. She will know, for instance, that evenly weighted coins have a chance of $\frac{1}{2}$ of landing on one side when they are flipped. She will also know that gasses expand to fill their containers, that foxes eat chickens, and that traffic jams can form without any car accidents. If we grant such an agent some additional knowledge about the actual macrostate, then she will know that many events have chance of one or zero—those that she knows to have occurred or not occurred. This agent ought to use the Credence Preservation Principle introduced above.

Finally, consider an epistemic agent who has no knowledge of the initial metaphysical chances, no knowledge of the actual microstate, and finite computing power—an agent not unlike an average human being. What should such an agent do? Suppose the agent acquires some of the following information:

- The present macrostate (by direct experience and testimony from others)
- The past macro-history (by memory and testimony from others)
- The underlying microevolution (from scientific experiments in conjunction with above)
- The ways in which macrostates are grounded in microstates (as above)

Then, she would realize that macrostates are multiply realized by a variety of microstates. She would also realize that if the microstates had chances, then the corresponding macrostates would have chances as well. Her understanding of the microevolution would allow her to infer the connections between earlier microstate chances and later microstate chances and subsequently the connections between earlier macrostates and later macrostates. Thus, she could hypothesize an early chance distribution that would lead to the known frequencies and patterns. Then, she would know that the macrostate patterns she had observed were likely to continue into the future, even if she were unable to exactly calculate their underlying microstate chances.

### 4.7.3 Justification

Most people have no knowledge of these chances or the underlying microevolution. Are their predictions and beliefs unjustified? That depends on whether justification is external or not. Consider a very simple account of external justification: $S$ **is justified in her belief that** $p$ **iff her beliefs are produced by a reliable process.** Now, suppose that my account of microevolution and chance is correct. Then, before the big bang, it was highly likely that certain patterns would persist (that flipped coins would land fifty-fifty) and highly unlikely that patterns would cease (that flipped coins would one day always land on edge). Thus, it was highly likely that successful beings would be the ones that successfully latched onto these patterns and projected them into the future. Thus, the beliefs of these beings are produced by a process that is reliable, and their beliefs are externally justified.

Another example may help to motivate the idea that credences based on chances are more justified (externally) than credences that are not so based. Suppose you are given a very large stack of photos, each of which shows an image of two dice. As you go through the stack you begin to notice patterns. The die on the right side of the photo shows each face roughy one-sixth of the time, and similarly for the die on the left side of the photo—though the two don't seem to correlate with each other in any interesting way. You use these patterns to infer that the photos are of dice that, when they were rolled, had equal chances of landing on each side and that were independent of each other. You use this hypothesis to make predictions about future photos of the dice. For instance, you predict that each face of each die will continue to land up roughly one-sixth of the time. Note that you do all this *even though the chance events are no longer chancy*. After all, the dice were tossed and photographed before you were handed the stack of photos.

Now, imagine that you are handed a similar stack of images, but that in this case you are told (by a reliable, trustworthy source) that these images are *not* photos of chancy dice. Suppose that this stack of images has been around since the first moment of the universe, or that the stack has been around forever. In this case, what could justify any prediction about the cards you have not yet turned over? It seems you would have to postulate some uniformity principle that applied to stacks of images—perhaps that if a pattern exists in part of a stack of images, then that pattern will be present in the entire stack. Without such a postulate, and in the absence of information (or hypothesis) about how the stack of images came to be, there is nothing on which to base such a projection.

### 4.7.4 Objection

Barry Loewer (personal communication) has objected to this epistemic reasoning. He claims that we would be in the very same epistemic situation regardless of whether there was an early chance event or not. After all, the current microstate and all future events would be the same either way. But, I think that the the reasoning about the stack of images carries over to the case of the entire universe's evolution.

To see why, imagine that the entire universe popped into existence a moment ago, in exactly the same microstate that it actually had a moment ago. We would have internal states that were indistinguishable from our actual internal states. Nevertheless, we would not have *memories* or *evidence* of the past. Rather, we would be radically deceived about what we thought our memories were, and what we thought we had evidence for. Similarly, if there were no early chance event, even though it would seem the same to us, we would be deceived about the state of the world and our credences about dice, roulette wheels, and the weather would be unjustified.

It is tempting to say that agents in the world without chances yet with our credences would be *lucky* with respect to their beliefs and expectations about the future. Their experience would be radically misleading about the past. So predictions about the future that were based on those experiences would only match the future by the luckiest of coincidences. Unfortunately, such claims are difficult to make sense of. That is because luck presupposes chance. Why would it be lucky for the agent's predictions to be correct? Presumably it is because they could have popped into existence with *any beliefs whatsoever* about the past and the vast majority of those would not correlate in the right way with the future. But, note that this reasoning relies on a space of possible beliefs and the likelihood of each combination. There is no way to escape the need for chances.

This is why the initial chances are so crucial to our current epistemic situation. Even if we do not explicitly appeal to these chances (indeed, it is prohibitively complicated to do so in practice), their existence is what grounds the patterns and frequencies we experience on a daily basis. Thus, our credences and predictions are only justified, externally, if we accept the existence of an early chance distribution.

The logical structure of the argument is as follows: if the universe popped into existence without any chances, then none of our predictions would be epistemically justified. That is because these predictions are grounded in the metaphysical chances. But our predictions *are* epistemically justified. Therefore, we have reason to accept such a chance distribution.[23]

[23]It seems similar to the skeptical dilemma of standard epistemology. Our subjective experience would be indistinguishable if we were brains in vats, and all of our beliefs about the external world, memories, predictions, etc. would be (externally) unjustified. Therefore, if we want to maintain that they are justified, we must accept that we are not brains in vats.

### 4.7.5 Credences: Humean vs Fundamental

Let's take stock in the complex debate between this account and the Humean account of credence and chance. According to the Humean, chances systematize information about the entire mosaic. Thus, if we know the chances, we know information about the entire mosaic. If we take chance as fundamental in the way I have suggested, knowledge of the chances only gives us chancy information about the world. Therefore, at $t_0$, the fundamental account of chance is consistent with more worlds than the Humean account. This is because the fundamental account allows for unlikely worlds while the Humean account does not. Thus, if you wanted to know as much as possible about the world, it would be better to know the Humean chances than the fundamental chances.

But, recall that the Humean account of chance systematizes the entire mosaic—past, present, and future. Thus, having knowledge of the chances amounts to having knowledge of the future (though not always via the Principal Principle, as discussed above). So, at $t_0$, it's clear that we would prefer to have knowledge of the Humean chances, but this is just because it is also knowledge of the future. What, then, are we to make of our current situation?

We currently have some knowledge of the universe. This comes from our experiences, our memories, testimony, and the results of scientific experimentation. Unfortunately, we do not have knowledge of the future. Yet, we do think we have some knowledge of the chances. Thus, if we accept the Humean theory of chances, we have to believe that the systematization of the local spacetime region (the bit we have access to) is also a systematization of the entire mosaic of the universe. But, why should we think this? Here the Humean posits a brute assumption of uniformity: that the mosaic admits of a simple, informative systematization.

Since it is a brute assumption, we cannot ask what reasons there are for accepting it. But, we can ask whether the fundamental account has a similar assumption, and if so, which is more metaphysically plausible. According to my fundamental account, the chances are at the beginning of the universe and the evolution thereafter is deterministic, with one state producing the next. This could be done by the laws of nature, as Tim Maudlin (2007) argues, or by potencies, as I argue in chapter 2. It seems as though both accounts rely on a similar uniformity principle: the Humean account posits uniformity in the mosaic, the fundamental account posits uniformity in the laws or the propensities.

I think this comparison deserves closer scrutiny. While both accounts do require additional posits, not all posits are created equal. For one thing, the defender of the laws or propensities has some guarantees: since the laws or properties are necessarily connected to subsequent behavior and property distributions, there must be some temporal uniformity. Nevertheless, the anti-Humean still needs to rule out potencies or laws of nature that are complex and include odd features, such as 'masses are disposed to attract in proportion to the inverse square of their distance—unless there are exactly ten of them in exactly the right shape, then they are disposed to attract in proportion to the inverse cube of their distance.' Whether or not these assumptions are on a par is far from obvious. It would be interesting to see explicit argument either that both the Humean and anti-Humean assumptions amount to equal metaphysically committing posits, or that one has the metaphysical advantage.

## 4.8 Answering Objections

Recall that the Humean account of L-chance faces five objections. First, L-chance is incompatible with **BCP** and **CBCP**. Second, the non-trivial L-chances are in tension with the fact that the future microstate is entailed by the present microstate and the laws of nature. Third, L-chance cannot secure the fixity of the past while maintaining the openness of the future. Fourth, L-chances do not always obey the Principal Principle. And finally, L-chances do not metaphysically explain the patterns in the world. In this section, I show

how my account avoids these problems.

### 4.8.1 Chance Events Can Happen

My account of fundamental chance can accommodate BCP and Converse BCP because the initial chances are only connected *by chance* to how the actual world turns out—not by any guarantee. The strongest thing we can say is that some patterns have a high chance of occurring. But, of course, they still might not occur at all!

### 4.8.2 Chance and Determinism

No event can be both metaphysically chancy (at $t$) and metaphysically determined (at $t$). Assuming classical or Bohmian evolution, at the beginning of the universe, there is a chance event from which all subsequent events inherit their chances. After that chance event, the universe is forevermore deterministic. At no time is any event both chancy and deterministic.

Nevertheless, in the absence of perfect knowledge, it can be rational to have credences that do not match the chances, as I described above. The many systems we think of as chancy—coin flips, roulette wheels, etc.—are purely determinstic, but it is still rational to have non-trivial credences about them. These credences are justified by the metaphysical chances and are conditionalized on subsequent knowledge.

### 4.8.3 Chance and the Past

Fundamental chances are time-indexed and go to one (or zero) after they occur (or do not occur). Similarly, inherited chances go to one (or zero) after the fundamental chances they are derived from go to one (or zero). Thus, if the dynamical laws are deterministic, then right now, there are no non-trivial, metaphysical chances in our world. But, I hope to have explained why it seems as though the future is chancy—we are not omniscient, and we rely on those initial metaphysical chances implicitly when we update on our experience to arrive at rational credences for future events.

And, if the dynamical evolution is chancy, then right now there are lots of non-trivial metaphysical chances in our world. And, in such a case, our credences ought to be determined by the Principal Principle or, lacking perfect knowledge of the chances, by Credence Preservation.

### 4.8.4 Chance and Credence

It should be clear that if we have knowledge of the chances, we ought to set our credences to those chances. Thus, my account satisfies the Principal Principle. In the absence of perfect knowledge, we ought to use Credence Preservation—or, more likely, the practical shortcuts that evolution has provided us with. And the fundamental chances provide the metaphysical justification for those credences.

### 4.8.5 Chance and Explanation

As I argued above, fundamental chance explains, epistemically, via the Principal Principle and Credence Preservation. But how does it explain metaphysically?

In the simplest case, if there is no chance of a certain event, then that event cannot occur. Similarly, if an event has a certain chance, then that event must occur. I say “no chance” and “certain chance” rather than “chance = 0 (1)” because some events with a chance of zero may nevertheless occur (e.g. a dart hitting a point on an infinite dartboard) and some events with a chance of one may nevertheless fail to occur (e.g. a dart failing to hit all points but one on an infinite dartboard).[24] The sense of "must" and "cannot" are nomological. Of course, those events may still be *metaphysically* possible.

But, suppose an event has a 50% chance of occurring. The event will occur in at least one world and will fail to occur in at least one world.[25] But, this is true of any other chance (that is not certain and not impossible). Thus, if an event has a 0.001% chance of occurring, then the event will occur in at least one world and will fail to occur in at least one world. Note, again, that it is a purely empirical fact that each initial configuration is equally likely. It could have been (in the metaphysical sense) that some configurations were much more likely than others. In such a case, different patterns would have been more likely, and we would have used those to infer the different initial distribution. Thus, it is not the fact that half of the worlds contain event *A alone* that makes it true that event *A* has a chance of 50%. Rather, we must make the additional postulate that each initial configuration has the same chance. There is no way to escape the posit of fundamental chance.

So, what metaphysically explains the patterns that we see? The initial chance event made some patterns very, very likely, others very, very unlikely (and everywhere in between). Following that chance event, the universe's particular microstate, in conjunction with the deterministic evolution, produced the subsequent patterns. So, one chance event produced infinitely many microstates, which, in turn, produced the rest of the universe. It is a curious, but unavoidable fact that the initial chance event explains both the occurrence of *A* in some worlds as well as the non-occurrence of *A* in other worlds.

[24] See the above section on certainty versus chance for a more thorough explanation.
[25] This satisfies the BCP and CBPC.

## 4.9 Conclusion

I have argued against Albert and Loewer's Humean, reductive interpretation of basic chance and inherited chance. Their theory fails to satisfy the desiderata for chance. Their chance theory is the most sophisticated chance theory available. I have offered my own theory of fundamental, metaphysical chance in its place. We do not yet know whether the underlying dynamical laws of our world are chancy or deterministic. What my theory offers is a solid metaphysical ground for our non-trivial credences and the probabilities of our special sciences either way. Even if the only fundamental chance process was at the beginning of the universe, later events inherit their chances from that initial chance process. Even if those chances are now only zero or one, our non-trivial credences are metaphysically justified by those initial chances.

# Chapter 5

# A Unified Theory of Potencies, Laws of Nature, and Chances

## 5.1 Introduction

I have presented two chapters arguing for independent pieces of a picture that I will now unify. I take my arguments to stand on their own. If one is attracted to the best system account of laws, one should have reason to accept fundamental dispositional properties into one's ontology. Conversely, if one is attracted to fundamental, dispositional properties, one should have reason to accept a best system account of the laws of nature. Similarly, if one takes chance desiderata seriously, and if one takes the (epistemic) possibility of deterministic evolution seriously, then one should have reason to accept fundamental chance.

In the next few sections I hope to show how these two pieces fit together in a unified metaphysical picture of the world. While the pieces could be accepted on their own, I think the unified picture is promising and deserves a place among the competitors for the fundamental metaphysical picture of the world.

## 5.2 Potencies and Propensities

Suppose there are particles that can move throughout spacetime. Suppose further that these particles can instantiate different properties. If I am right about the existence of fundamental, dispositional properties or *potencies*, then the potencies determine how the particles move throughout spacetime as well as what other properties are instantiated by the particles.

Now, if I am right about fundamental chance, then chance must enter the world at the most basic, metaphysical level. Thus, while potencies are enough, ontologically speaking, to produce the patterns that exist throughout the world, they are not enough to make some patterns likely and others unlikely—chance is required as well. Therefore, I need an account that combines potencies and chances.

I think the most promising combination of potencies and chance is to modify the "sure-fire" nature of the potencies. If some of the fundamentally dispositional properties are chancy, then both features of production and chance have a place in the world. Following other authors, I will call fundamental, chancy, dispositional properties *propensities*. The term dates back to Karl Popper (1957) but my use is closer to Alexander Bird's (2007a). Then, potencies can then be thought of as propensities that are certain to manifest in their stimulus conditions.

If there are chances throughout spacetime, as in GRW quantum mechanics, then the propensities are of the wave function to collapse at a specific spacetime location. I agree with David Albert's (2000) suggestion that in such a case, there may not be any initial chances—dynamical chances of the fundamental quantum evolution could be sufficient to yield the chances of physics, the special sciences and our everyday reasoning.

But, of course, we also want to make metaphysical sense of the probabilities we appeal to in everyday situations even if the underlying evolution is purely deterministic. As

I outlined in the section above, in the deterministic case, the initial chances are the only propensities. One option is to hypothesize that the universe came into existence containing a hot, dense ball of matter. This object had the propensity to bang in various ways, resulting in different configurations, each of which subsequently evolves deterministically. The other option is to posit propensities of the fabric of spacetime to give rise to "bubble" universes that undergo subsequent, deterministic rapid expansion—except insofar as the new, bubble spacetime has the propensity to give rise to further "bubble" universes. Both of these options could be empirically confirmed or disconfirmed by cosmologists and physicists. Thus, there is room in our physical picture of the world for propensities—some of which are sure-fire, others of which are not—no matter whether the dynamical evolution is GRW quantum mechanics, Bohmian mechanics, or classical mechanics.

## 5.3 Laws of Nature

If there are fundamental potencies and propensities in the world, what are we to say of the laws of nature? I think that a systematizing account, similar to the Potency Best System Account I presented above, is the most promising. After all, there is still no need for governing laws of nature—the potencies and propensities do all the metaphysical work of production. They fully determine, via chance or certainty, the evolution of the world. At the same time, there is no need to give up on laws altogether.

We can modify the Potency-Best System Account that I defended above to include propensities. In fact, since potencies can now be thought of as sure fire propensities, the best system account of laws can be formulated purely in terms of propensities.

**Propensity-BSA** The basic laws of nature at *w* are the axioms of the simplest, most informative, true systematization of all *w*-propensity-distributions, where a *w*-propensity-distribution is a possible distribution of only propensities appearing in *w*. For any set of worlds that match up to $t$ and diverge thereafter, the systematization must also state the chance of each world.

Again, the systematization is a modal one—it systematizes all of the nomologically possible worlds. It does so by systematizing all of the possible distributions of properties. Since the properties are propensities that have their modal profiles necessarily, the possible distributions are all and only the nomologically possible distributions.

The added sentence about chances is unavoidable because chance is fundamental. The systematization of possible propensities would just yield the space of nomologically possible worlds, and not their chances. While it may turn out that each of those worlds is equally likely, it also may not—this is an empirical matter. Thus, it is important to explicitly state the additional requirement.

One interesting upshot of this view is that nomological possibility space is impoverished without chances. When we talk of spheres of possibility: logical, metaphysical, and nomological, we are just specifying possibilities. In order to really capture nomological space, we also must include the chances of each world. And, indeed this seems plausible when we think of the connection between the laws of nature and nomological space. The laws include chances—so should the worlds.

## 5.4 Conclusion

In this dissertation, I have argued against two of the most popular theories of the laws of nature: Marc Lange's account of counterfactually grounded laws, and David Albert and Barry Loewer's account of Humean laws and chance. I have presented and argued for my own theory of fundamental, dispositional properties, fundamental chance, and laws of nature that systematize those properties and chances. On my view, potencies are sure-fire propensities and the Propensity Best System Account of the laws of nature reference only the propensities and their chances.

This account is science-friendly because the Propensity Best System Account of the laws is highly likely to match up with the Theory of Everything that our scientists arrive at via systematizing particle trajectories. Also, it reflects the concern that scientists place on discovering the true *nature* of the fundamental properties—what they must do, or are likely to do, in different situations—by appealing to fundamentally dispositional properties. Finally, it does justice to the desiderata for a theory of chance. Crucially, it allows that unlikely events may nevertheless occur, and it explains the usefulness of non-trivial credences in a world that evolves deterministically from an initial chance event.

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