THE METAPHYSICS OF PROBABILISTIC LAWS OF NATURE

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ABSTRACT

In this thesis I treat success in explicating probabilistic laws of nature (e.g., laws of radioactive decay) as a criterion of adequacy for a metaphysics of laws. I devote a chapter of analysis to each of the three best known theories of laws: the best systems analysis, contingent necessitation, and dispositional essentialism. I treat the problem of undermining that David Lewis identified in his theory of chance as a challenge that any metaphysical theory of probabilistic laws must overcome. I argue that dispositional essentialism explicates probabilistic laws while the other two theories fail to do so.

Lewis's best systems analysis explicates probabilistic laws only with a solution to the problem of undermining. Michael Thau's solution was met with Lewis's approval. I argue that Thau's solution is *ad hoc* and renders impossible the fit of best systems with probabilistic laws to indeterministic worlds.

Bas van Fraassen argued that David Armstrong's theory of contingent necessitation is totally incapable of explicating probabilistic laws of nature. I argue that Armstrong is able to respond to some of van Fraassen's arguments, but not to the extent of rehabilitating his theory. I also argue that Armstrong's theory of probabilistic laws suffers from the problem of undermining. This result adds to the widely held suspicion that Armstrong's theory is a version of a regularity theory of laws.

With propensities grounding probabilistic laws of nature, the problem of undermining does not arise for dispositional essentialism, because all nomically possible futures are compatible with the propensities instantiated in the world. I conclude that dispositional essentialism explicates probabilistic laws of nature better than Lewis's and Armstrong's theories do. Since probabilistic laws are ubiquitous in contemporary physics, I conclude that dispositional essentialism furnishes a better metaphysics of laws than Lewis's and Armstrong's theories do.

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Chapter 1: Introduction

This thesis is an investigation into the metaphysics of probabilistic laws of nature. The goal of the thesis is to determine which of today's three leading metaphysics of laws of nature best explicates probabilistic laws of nature. The metaphysics of laws that will be examined are David Lewis's best systems analysis of laws, David Armstrong's contingent necessitation theory of laws, and Alexander Bird's and Brian Ellis's dispositional essentialism. A number of philosophers have developed these metaphysical accounts of laws with respect to (deterministic) causal laws, *ceteris paribus* laws, and vacuous laws. In comparison very little has been done by way of an investigation into the metaphysics of probabilistic laws of nature.

Of the three metaphysics of laws to be explored here, more has been published about the best systems analysis of laws and probabilistic laws[1] than there has been about contingent necessitation and probabilistic laws and dispositional essentialism and probabilistic laws together. Of the latter two theories, some literature considers a contingent necessitation theory of probabilistic laws,[2] while scant little has been written in defence or critique of a dispositional essentialist account of probabilistic laws.[3] My hope for this dissertation is that it provides a step in the direction of correcting this imbalance by (1) offering a sustained comparative investigation into the metaphysics of probabilistic laws and (2) upholding a dispositional essentialist account of probabilistic laws.

1.1 The General Plan

It will be useful at the outset to have an overview of the structure of the thesis and its main argument. A good place to begin an investigation into the metaphysics of probabilistic laws of nature is an account of the mathematics and philosophical interpretations (or analyses) of probability. Chapter 2 gives "a briefer" on the probability calculus and provides expositions of the analyses of probability that are employed by our selected metaphysics: the frequency theory of probability, the subjective theory of probability, and the propensity theory of probability. Lewis's best systems analysis of laws uses the frequency and subjective theories of probability to explicate probabilistic laws of nature. Dispositional essentialism employs the propensity theory of probability, while Armstrong's contingent necessitation theory of laws proves to be exceptional by employing no standard analysis of probability in its explication of probabilistic laws. The frequency,

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[1] For example, Bigelow, Collins, Pargetter (1993), Black (1998), Briggs (2009), Earman and Roberts (2005), Hall (1994, 2004), Hoefer (1997), Ismael (2008), Lewis (1986, 1994), Loewer (2004), Thau (1994).

[2] Armstrong (1983, 1988b, 1997), Irzık (1991), van Fraassen (1987).

[3] Ellis (2001, pp. 130–2) defends such a position.

subjective, and propensity theories of probability do not exhaust the analyses of probability recognized by philosophers, but they are all that are required for our investigations here.[4]

The best systems analysis, contingent necessitation, and dispositional essentialism are each given a full chapter of exposition and critical assessment in Chapters 3, 4, and 5, respectively. Each chapter starts by reviewing the ontological and metaphysical commitments of a theory of laws, followed by an exposition of the metaphysical account of laws to which it is committed. Detailed accounts are given of how these metaphysics propose to explicate probabilistic laws of nature, and I adjudicate the major criticisms these theories face in the literature.

The main argument developed throughout the thesis is that dispositional essentialism better explicates probabilistic laws of nature than Lewis's best systems analysis and Armstrong's contingent necessitation theory. The criterion I use to determine whether a metaphysics of laws properly explicates probabilistic laws is its success in battling 'the big bad bug'. The big bad bug, also called the problem of undermining, first showed up as a problem for Lewis's Humean theory of objective chance. The full details of the problem of undermining and Lewis's response to it are given in Chapter 3, but I'll give a brief introduction to the problem here and my strategy to make use of it.

The problem of undermining was identified by Lewis for his Humean theory of objective chance, which takes chance to supervene on the global distribution of properties, i.e., the actual distribution of properties across all of space and time.[5] The frequencies of occurrences of properties in the global distribution of properties entail the probabilistic laws of nature for the actual world. The sum total of all the probabilistic laws of nature constitute a theory of chance T, which gives a maximal chance to actual history A coming to pass. But a theory of chance T also gives a small chance to an alternative history B coming to pass. If B were to come to pass, the theory of chance T *undermines* itself, since B would complete a global distribution of properties that would entail an alternative theory of chance T', one that gives B the maximal chance of coming to pass. So T seems to contradict itself by assigning probabilities to alternative futures. Lewis gives the problem of undermining proper expression as a contradiction that shows up in the Principal Principle, a principle of reason about how chance is related to credence.

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[4] The main interpretations of probability are the Classical, Logical, Frequency, Subjective, and Propensity theories of probability.

[5] Lewis says that Humean supervenience "is named in honor of the greater [sic] denier of necessary connections. It is the doctrine that all there is to the world is a vast mosaic of local matters of particular fact, just one little thing and then another" (1986a, p. ix). Further characterization and discussion of Humean supervenience and metaphysics is to be found in Chapter 3. Most of the technical terms in this chapter will be defined in the chapters ahead.

Michael Thau proposed a solution that Lewis endorsed, but I argue in Section 3.3.4 that the solution is ad hoc and leads to a new problem for Lewis. I argue that this new problem is just as worrisome for Lewis's theory of chance as was the problem of undermining, so that the best systems analysis appears to face a dilemma: accept Thau's solution only to face an undesirable consequence for its theory of probabilistic laws, or reject Thau's solution only to face the problem of undermining again.

The problem of undermining seems like a particularly good problem against which to test a metaphysics of probabilistic laws, since any theory of laws that suffers from the problem is a theory that entails a contradiction. So the big bad bug offers a stringent test for metaphysics of laws. With that test in place, I argue in Chapter 4 that a form of the big bad bug can be developed for Armstrong's metaphysics of probabilistic laws and conclude that contingent necessitation doesn't properly explicate probabilistic laws. In Chapter 5, fortune seems to turn. I argue that dispositional essentialism, which explicates probabilistic laws in terms of a propensity analysis of probability, does not succumb to the bug.[6] With the best systems analysis unable to properly formulate an argument against the problem of undermining, and with the problem lurking in contingent necessitation too, I conclude that dispositional essentialism shows promise explicating probabilistic laws of nature while the other two do not. Since probabilistic laws are so prevalent in today's physics, we should expect a metaphysics of laws of nature to explicate probabilistic laws, so my argument points to the conclusion in Chapter 6 that dispositional essentialism is a better metaphysics of laws than Lewis's and Armstrong's theories.

1.2 The Metaphysics of Laws

By a metaphysics of laws I understand a systematic metaphysical response to the question of what is to be a law of nature. Since it asks about the nature of the existence of laws, it is an ontological question that metaphysics is well positioned to answer, with its stock of metaphysical and ontological concepts ready at hand. Empirical science also studies laws, but it is not in a position to answer this question. Stephen Mumford gives us an account of why this is so: "Science merely notes what it can find empirically. It attempts to stick to the phenomenal facts. It can record the constant conjunctions, perhaps after conducting further tests to find corroboration of them.... [For science] there is no attempt to go beyond the phenomena to enter into metaphysics" (2004, p. 26). A metaphysics of laws of nature, on the other hand, may attempt "to go beyond the phenomena" and posit the existence of laws that underlay and explain the existence of constant conjunctions or regularities in nature.[7] This is certainly true for Armstrong's

[6] The details of these arguments are to be found in Chapters 4 and 5.
[7] Examples of regularities in nature are that water boils at 100^{o} C, that the planets trace elliptical orbits around the sun, and that bears hibernate in winter.

contingent necessitation theory of laws and the dispositional essentialists' theory. But a theory of laws may also give an account of laws as nothing more than the regularities identified by science. Lewis's best systems analysis of laws is considered a sophisticated version of this latter approach.

Metaphysical theories of laws characterize the existence or being of laws by drawing on a number of concepts and distinctions. Among the distinctions employed by our three metaphysics is the distinction between laws conceived as "deep features" of reality that underlie and explain empirical regularities and laws conceived as regularities with no metaphysical explainers underlying them. In the chapters ahead we'll see differences in opinion as to whether laws are necessary or contingent, and we'll see differences in opinion concerning the ontological status of other possible worlds.[8] Other distinctions might be mentioned, but these will suffice to show how the best systems analysis, contingent necessitation, and dispositional essentialism have between them interesting points of similarity and difference.

One way of addressing the ontology of laws is to argue that laws are a sort of deep feature of the world, parts of the fabric of reality that underlay regularities. David Armstrong's theory of laws takes this approach as does Alexander Bird's dispositional essentialism. This realism about laws contrasts with David Lewis's (best systems) regularity account of laws, which says there are no deep features of reality that explain regularities. For Lewis, laws just are (in a special sense) regularities in nature. While Armstrong and Bird share the view that laws underlie and explain the existence of regularities, their theories differ with respect to other metaphysical commitments about laws. For example, Armstrong is a categoricalist about the fundamental properties of the world, a position which allows him to argue for the contingency of laws of nature, i.e., the properties that are related by a law of nature need not have been so related by that law. Dispositional essentialists, on the other hand, argue for the existence of fundamental dispositional properties, a position that entails the necessity of laws, so that two properties that are lawfully related in the actual world could not have failed to have been so lawfully related. Like Armstrong, Lewis also gives a categoricalist account of fundamental properties and shares the view that laws are contingent. As we'll see in Chapter 4, there is room for a distinction to be made even here, as Armstrong thinks his contingent necessitation theory of laws provides a sense in which the laws of nature are necessary.

Differences between Armstrong and Lewis appear again with respect to the ontological status of other possible worlds. Our own world, the actual world, is one of an indefinite number of possible worlds. Lewis argues for the reality of all possible worlds, while Armstrong rejects the claim that worlds other than our

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[8] Our world, the actual world, is just one of indefinitely many possible worlds that are either real or not, i.e., they are real like our world (Lewis's modal realism) or abstract objects.

own are real.[9] As we'll see in the chapters on Lewis and Armstrong, different commitments about the ontological status of other possible worlds significantly shapes their respective theories of laws. Like Armstrong, dispositional essentialists tend to be anti-realists about the existence of other possible worlds.

Working with the metaphysical distinctions mentioned above we see we can go quite some way in stating similarities and differences between metaphysical thoeries of laws. The concepts that philosophers select from sets of distinctions like these uniquely shapes their metaphysics of laws. David Lewis argues that laws are regularities that figure in the best systematic accounts of the world. David Armstrong understands laws to be relations that contingently relate monadic properties. And dispositional essentialists take laws to be necessary relations between properties, grounded in the dispositional essences of causal properties (as we'll see in Chapter 5, there's some room for variation here). None of these distinct theories of laws is a view that was discovered by science; they are rather metaphysicians' proposed answers to the question: What is a law of nature?

This should do by way of a general introduction to the notion of the metaphysics of laws. We'll get a much better sense of the enterprise as we investigate the theories in the chapters ahead. We turn next to discuss the science of probabilistic laws of nature.

1.3 Probabilistic Laws of Nature

The kinds of probabilistic laws that this thesis will be concerned to explicate are the decay laws of radioactive elements, e.g., the laws – the half-lives – that govern[10] the decay of radium, uranium, polonium, and other naturally occurring radioisotopes. One reason for selecting these as paradigm examples of

[9] Armstrong defends naturalism, which he defines as "the view that nothing else exists except the single, spatio-temporal, world, the world studied by physics, chemistry, cosmology and so on" (1983, p. 82). Armstrong's naturalism will receive analysis in Section 4.1.1. Armstrong's theory of modality is a combinatorial theory of possibility, which he characterizes in his (1989) as a form of fictionalism: "I say that the (merely) possible worlds and possible states of affairs do not exist, although we can make ostensible or fictional reference to them" (1989, p. 49). Later he recants and argues against the fictionalist interpretation: "My attempt was misguided, as I now see it, and in the present [work] it is suggested that it is contingent states of affairs and constituents of states of affairs that are the suitable truthmakers for modal truths" (1997, p. 172). Armstrong's combinatorialism will be discussed in Section 4.2.3.

[10] In this thesis I (and others) often talk about how laws 'govern' nature. Stephen Mumford (2004) gives the governing conception of laws a technical sense and submits it to philosophical criticism. My own use of the term, however, is always intended to be a natural, pre-theoretical way of talking about laws and their relations to phenomena.

probabilistic laws of nature is that the decay laws satisfy the widely held belief of metaphysicians of science that the metaphysics of laws concerns fundamental laws of nature, which involve fundamental objects, properties, and events. Such fundamental laws are those discovered by physics and possibly chemistry too. Not all scientific laws are fundamental in this sense: the laws of biology, psychology, sociology, and geology, for example, are thought by some philosophers to be concerned with phenomena that are not physically fundamental. Many philosophers argue that such non-fundamental laws are reducible to, or can be analyzed in terms of, fundamental physical laws.[11] The theories of laws to be examined in this thesis all take the position that it is the fundamental laws of nature that require metaphysical explication, so I adopt this assumption for the work ahead. The decay laws will thus provide us with the examples of probabilistic laws we need, as they are fundamental laws that don't reduce to, or are entailed by laws that are more fundamental.

Another reason to use decay laws in our search for a metaphysical explication of probabilistic laws is that the decay laws may concern not just objects like uranium and radium atoms, but may extend to objects on an even smaller scale, the subatomic particles: "The majority of elementary particles are not stable and decay into other particles a certain time after their formation. Neither the lifetime of a single particle nor the products of its decay are fixed, but rather are statistical variables" (Ne'eman & Kirsh, 1986, p. 50). More recently it has been thought that every microphysical object in the universe has a real chance of decay according to a law of nature. Jim Lebans speculates as to what the universe might look like after 10, 000 trillion – yes, trillion – years of the expansion of space with nothing in it but isolated frozen stars and black holes:

> What happens after this? One theory is that stars and neutron stars will then start to break down, the atoms degrading through a process called proton decay and the matter slowly evaporating away as a feeble energy travelling through the nothingness. By 10^{38} years (1 followed by 38 zeros), this process will have finished and the only objects left in the universe will be black holes. Over the long, dark time that follows, even the black holes will start to break down, gradually leaking away their mass by emitting something called Hawking radiation. They will have evaporated away by 10^{200} years, and the universe will exist merely as empty space filled with weak radiation that can do nothing but maintain a temperature only infinitesimally greater than absolute zero. That's it, for all eternity: the Big Chill (2008, p. 29).

Will the universe end up looking like this in its old age? Who knows? Yet the possibility that every object in the universe is subject to a decay law speaks to the need to give decay laws a metaphysical account.

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[11] This principle of reduction is called the inter-theoretic reduction of the sciences.

Let me first briefly discuss deterministic laws of nature before discussing probabilistic laws. Coulomb's law is a causally deterministic law of nature (sometime simply called a 'causal law' in the metaphysics literature). Coulomb's law states that the force between two charged particles is directly proportional to their charges and inversely proportional to the square of the distance between them: $F = KQQ'/d^2$, where K is a constant explained by the first of Maxwell's equations, Q and Q' are the two charges of the two particles and d is the distance between them (Mumford, 2004, p. 2). This law is a deterministic law of nature because any two charged objects with these properties and distance d between them will react with a force equal to F. Deterministic laws are often characterized in terms of the predictions they offer. Provided that there are no complicating factors, the behaviour of any two charged particles is completely predictable under this law.

Another example of a deterministic law is Boyle's law. This law states that at a constant temperature for a fixed mass, the pressure and volume of an ideal gas are inversely proportional. Given in symbols, Boyle's law is $p \propto 1/V$, where p is the pressure and V is the volume. Boyle's law allows us to predict with certainty how a contained gas would behave under changes of pressure and volume at fixed temperatures. When a volume of gas is compressed its pressure is proportionally increased, and when its volume is expanded its pressure is proportionally decreased. In contrast, a probabilistic law does not allow us to predict with certainty how a particular object must behave. Rather, a probabilistic law gives us only a probability of more than 0 and less than 1 that an event of a certain kind will occur, for example, the probability that a particular radium atom will decay by a specified time can be calculated using the decay law for radium.

Single-case events, like the decay of a particular radium atom, cannot be predicted under a probabilistic law; what is predictable is that a definite fraction of atoms in a large sample will decay by a specified time.[12] The quantity of atoms in a sample of radioactive atoms that will decay by time t is calculated using the general radioactive decay law $N=N_0e^{-\lambda t}$, where N_0 is the number of atoms present at time 0, N is the number of atoms present at some later time t, λ is the decay constant, and e is the base of the natural logarithms. This is an exponential law that governs the decrease of the number of atoms over time, provided the number of atoms is large (*Int. Dic. Phys. El.*, 1961, p. 308). If the number of atoms is not large, the law may not apply. For example, if a sample of radium consists of just one atom, we cannot say that half the sample will decay by time t; at t, either the

[12] "A radioactive atom...is in an unstable condition. In any interval of time it will have a certain definite probability of disintegrating. Thus while individual atoms will decay at random, the over-all result for a large number of atoms is for a definite fraction of these to break up in any given interval of time" (Delaney, 1962, p. 45).

atom has decayed or it has not.[13] Provided the sample is large, if N is the number of radioactive atoms present, the law calculates the average number of atoms that will disintegrate by t to be λN. And since the decay law is a statistical law, the number of atoms which will disintegrate by t may not be exactly λN (*Int. Dic. Phys. El.*, 1961, p. 308). The law also cannot settle which atoms in the sample will decay by t, only that a certain average of them should decay by then.

λ is essentially independent of all the physical and chemical conditions that radioactive samples may be subject to, such as temperature and pressure (Delaney, 1962, p. 45). In the quote above it is called a decay constant, but it can also be described as "a proportionality constant characteristic of each radioactive species" (Overman, 1985, p. 1031). When a specific value for λ is given, the general law is applicable to a species of radioactive element, giving the average number of atoms that should decay by t. $N=N_0e^{-\lambda t}$ is thus valid for any single radioactive species and λ is equivalent to the half-life *T½* of a material, the time it takes for one-half of a sample of radioactive atoms to disintegrate.[14]

Radioactivity is a property of the unstable nuclei of radioactive atoms. Such atoms spontaneously decay, emitting radiation. There are three types of radioactive radiation: alpha (α), beta (β), and gamma (γ). Alpha rays are particles with a positive charge and were discovered in 1903 by Rutherford and Royds to be protons, the nuclei of helium atoms. Beta rays are also particles. They carry a negative charge and experiments proved them to be electrons. Gamma rays, unlike alpha and beta particles, have no mass, carry no electric charge, and were found to be electromagnetic radiation of very short wavelength (Ne'eman & Kirsh, 1986, p. 14).

Every emission of radioactive decay involves a spontaneous transmutation of one element into another. For example, when a uranium atom emits an alpha particle, the parent atom becomes an atom of thorium. "An atom of an element like thorium, uranium or actinium emits an alpha ray. Dying itself, another atom is born and it in turn decays with the emission of a beta ray. A cascade of similar changes follows until a stable element, lead, is reached" (McHenry, 1962, p. 68). Atoms of one element transmute into atoms of a different element because, in the event of alpha and beta radiation, the mass and charge of the atom are changed, sufficient for transmutation to occur. Gamma radiation, on the other hand, is not sufficient for transmutation of elements to occur: "Gamma radiation is emitted from certain nuclides after emission of alpha or beta particles, and carries off excess energy beyond that which can be stably retained by the new nucleus. Since gamma radiation has no mass or charge this does not alter the charge of the

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[13] Bas van Fraassen (1987) draws out the philosophical implications of applying the half-life laws to small samples. See Section 4.2.3 below.

[14] "Very often, instead of λ, an equivalent quantity, *the half-life*, denoted by *T½* is used. It is defined as the time taken for the activity [the number of decays by unit time] to fall to one half of its original value" (Reid, 1984, p. 23).

emitting nucleus, the mass of which is also almost unaltered" (Ne'eman & Kirsh, 1986, p. 15).

In the chapters ahead I will invoke the half-lives of radioactive elements as instances of probabilistic laws of nature, forgoing the need to make reference to $N=N_0e^{-\lambda t}$. The half-life of radium 226, for instance, is 1602 years. Thus it is a probabilistic law of nature that the half-life of radium is 1602 years. The half-life of beryllium 11 is 13.81 seconds, thus it is a probabilistic law of nature that the half-life of beryllium 11 is 13.81 seconds. Probabilistic laws of nature such as these are the laws whose metaphysical explication is examined in this thesis.

Some other examples of half-lives are Plutonium's half life at 24, 000 years and Neptunium's half life at 2.3 days. There is, in fact, an enormous range of half-lives that have been measured, from about 10^{-12} seconds to 10^{20} years (Harvey, 1991, p. 1020). But how are half-lives defined? For large samples of beryllium, for instance, the half-life is the time it takes for one-half of the atoms in a sample of beryllium to decay. Let's see what happens with a half-life at work. Beryllium's half-life is 13.81 seconds. Starting with a 20 gram sample of beryllium 11, after 13.81 seconds there'll be (approximately) 10 grams left. After another 13.81 seconds, 5 grams will be left, and so on. Since a half-life is a constant, it doesn't change as samples decrease in size. The decay rate of beryllium doesn't change, but as time passes and the sample becomes smaller, fewer and fewer decays take place.

This will have to do as an introduction to probabilistic laws of nature. We now turn to an exposition of the philosophical analyses of probability used by the metaphysics we will examine.

Chapter 2: Analyses of Probability

2.1 Introduction

Studies of probability fall into two branches: the mathematical and the philosophical or foundational. The mathematics of probability states the axioms, postulates, definitions, and theorems of probability theory and the theoretical apparatus required to measure probabilities. Mathematicians agree that probability is a well-advanced and well-established formal science. In contrast, there is little consensus on the philosophical issues concerning probability. Philosophical analyses of probability provide interpretations of the probability axioms; interpretations of probability try to answer the question of what the meanings of the axioms are or what domain we're talking about when we apply them.

This thesis focuses on the intersection of probability, metaphysics, and laws of nature to determine which metaphysics of laws of nature provides the best explication of probabilistic laws. Each of the metaphysical systems we'll examine makes use of a different interpretation of probability to provide for probabilistic laws of nature. Lewis's best systems theory of laws employs the limiting frequency interpretation, while Bird's dispositional essentialism appeals to the propensity theory of probability. We'll also see that Armstrong's theory of probabilistic laws is unusual, since laws of nature for him are undefined, primitive aspects of reality. I will thus be concerned to characterize the frequency and propensity interpretations in this chapter, but also the subjective analysis of probability, since Lewis uses it for single-case probabilities. I do not review the mathematics of probability beyond stating its axioms and some of their consequences.

Today's major interpretations of probability fall into two groups: epistemic theories and objective theories. Epistemic interpretations of probability generally take probability statements to be about degrees of belief of a particular statement. The main theories of epistemic probability are the subjective interpretation (e.g., Ramsey, 1926 and De Finetti, 1931), which assigns a probability measure to an individual who thinks that a certain event will occur, and the logical interpretation (e.g., Keynes, 1921), which attributes probability to the truth of a certain hypothesis given a certain body of evidence. Objective theories of probability take probabilities to be measurable features of the world. Examples of objective theories of probability are the frequency interpretation (e.g., von Mises, 1951), which identifies probability with the frequency with which an event occurs in a collection of events, and the propensity interpretation (e.g., Popper, 1951b), which attributes probability to a dispositional property of a system or object to produce a certain outcome.

Some analyses would seem to provide a better account of probability for single-case events than others. It seems, for example, the chance that a particular radium atom will decay within 1602 years (the half life of radium) is independent of what anyone may think about it. Hence one may think that chancy events, and the laws that describe or govern them, are strictly objective and independent of human knowledge and belief, and so that this thesis should restrict itself to the comparison and evaluation of the objective interpretations of probability and the metaphysics that incorporate them. But this would overlook the subjective interpretation of singular events. David Lewis (1986), for example, takes objective probabilities for single events to be gained through combining the subjective and frequency theories. So an analysis of subjective probability is required in addition to the objective interpretations.[15] We will be particularly interested to see how the analyses to be examined are amenable to single-case probabilities, like the chance of *this* particle decaying by time *t*. I will try to make clear that single-case probabilities can be introduced on the subjective and propensity interpretations of probability, but that the frequency interpretation faces difficulties here.

It should also be noted that the subjective, frequency, and propensity analyses do not exhaust the viable interpretations of probability. The logical theory of probability, for example, was one of the major theories of probability in the 20th Century. Keynes (1921) and Carnap (1951) were its main proponents.[16] Though interesting and deserving of attention, the logical analysis doesn't figure in any of the metaphysics of laws we'll investigate in this thesis, so there is no need to provide an exposition of it.[17] The same can be said for the classical interpretation of probability, so an exposition of it will not be given.[18]

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[15] On the subjective interpretation, probabilities are not objective in two senses. (1) Unlike the frequency and propensity interpretations, which take probabilities to be objective physical facts about the world, the subjective interpretation takes probabilities to be measures of degrees of belief of individual people. (2) Unlike the logical theory, for which probabilities are the same for all rational agents (because probabilities are objective evidential relations between propositions), the subjective theory allows for diverging initial probability assignments, regardless of what evidence shows. See Section 2.3.2.

[16] Carnap did not succeed in creating a logic of induction, because he was unable to find a non-arbitrary way of assigning prior probabilities to hypotheses antecedently of the collection of any evidence relevant to them.

[17] Roy Weatherford takes the basic ideas of the logical theory to be that (1) probabilities are determined a priori, not by purely empirical means, (2) probability is a logical relation between sentences, and (3) a probability is always relative to given evidence only (1982, p. 75).

[18] The chief proponent of the classical interpretation was Pierre-Simon de Laplace, born in 1749 and died in 1827. Laplace himself characterized the theory of chance to consist in "reducing all the events of the same kind to a certain number of cases equally possible, that is to say, to such as we may be equally undecided about in regard to their existence, and in determining the number of cases favorable to the event whose probability is sought. The ratio of this number to that of all the cases possible is the measure of this probability, which is thus

2.2 Some Formal Aspects of Probability

The mathematical formalization of probability captures our intuitive understanding of probability. In this section I discuss some of probability's formal aspects. These are particularly well illustrated by reference to gaming examples.

Probability can be defined by the ordered triple $<\Omega, F, P>$ called a 'probability space'. Ω is a non-empty set of total possible outcomes, i.e., of all possible elementary events or attributes. Often called 'the universal set', we'll follow von Mises and call it the 'attribute space'.[19] Elements or members of Ω are denoted by 'ω'. F is a field (or set) of subsets of Ω that always includes Ω itself as a member. F is closed under set union, intersection, difference, and complementation. P is a function from F to the real numbers between 0 and 1 (inclusive).

We can next state Kolmogorov's axioms (as presented in Hájek, 2008). These are

(1) (Non-negativity) $P(A) \geq 0$, for all $A \in F$[20]
(2) (Normalization) $P(\Omega) = 1$
(3) (Finite additivity) $P(A \cup B) = P(A) + P(B)$ for all $A, B \in F$ such that $A \cap B = \emptyset$.

Hájek says that axioms (1) and (2) serve to state that probabilities have maximal values, i.e., negative probabilities do not exist and unity (probability 1) is established by the attribute space. Axiom (3) requires some explanation. Let the intersection of sets A and B be the set denoted by $A \cap B$, and let the union of sets A and B be the set denoted by $A \cup B$. Set intersection consists of elements belonging to both A and B; set union consists of elements belonging to either A or B. Events A and B are mutually exclusive if $P(A \cap B) = 0$. For instance, the probability of rolling two and four on the single throw of a die is 0. If A and B are mutually exclusive, i.e., their intersection forms the null set, then the probability of their union $P(A \cup B) = P(A) + P(B)$. For example, the probability of throwing

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simply a fraction whose numerator is the number of favorable cases and whose denominator is the number of all the cases possible" (Laplace, 1951, pp. 6–7).

[19] The attribute space can be occupied by sentences or propositions too. For convenience, I proceed by referring to the probability of events and attributes.

[20] "If $P(A) = 0$, the ratio in the definition of conditional probability is undefined. There are, however, other technical developments that will allow us to define $P(B \mid A)$ when $P(A) = 0$. The simplest is simply to take conditional probability as a primitive, and to define unconditional probability as probability conditional on a tautology" (Hitchcock, 2008).

a two or four with the single throw of a die is 1/6 + 1/6 = 1/3. However, when the set Ω is infinitely large, "*F* can contain an infinite number of subsets of [Ω]. In this case, the additivity postulate here is usually extended to allow for denumerably infinite unions of subsets of *F*. If a collection of A_i's consists of sets, all of which have no members in common whenever $i \neq j$, then it is posited that $P(\cup_i A_i) = \Sigma_i P(A_i)$"(Sklar, 1993, p. 91).

A and B are independent events if P(A | B) = P(A). A and B are independent if the probability of A given B is identical to the unconditional probability of A. If A and B are independent, then the probability of their intersection P(A ∩ B) = P(A) × P(B). Let A stand for the event of rolling a two and B stand for the event of rolling a four. Since A and B are independent, the probability of rolling a two followed by a four is 1/6 × 1/6 = 1/36.[21]

Conditional probabilities take the form P(*m*/*n*), translated as "the probability of *m* given *n*". The conditional probability P(A | B) states the probability of an event A given that another event B has occurred; its formal definition is P(A | B) = P(A ∩ B) / P(B). The formula takes the joint probability of A and B and divides it by the probability of B. Suppose we want to calculate the probability of rolling a two given that an even side was rolled. Let A stand for the event of rolling a two and B for the event of rolling even. P(A) = 1/6 and P(B) = 3/6. We then find the intersection of A and B because we want the outcome from B that also appears in A. This would be the single event of rolling a two, the probability of which we already know is 1/6. We then divide by the probability of B, because B is our new sample space, i.e., A is a sub-set of B. Thus P(A | B) = 1/6 ÷ 3/6 = 1/3.[22]

The multiplication rule is used to calculate the probability of the intersection of sets A and B when A and B are not independent: P(A ∩ B) = P(A) × P(B | A) or P(B) × P(A | B). For instance, suppose we know the composition of a group of people is such that 55% are males. We also know that 66% of the males are bachelors. Let A designate the property of being a male and B designate

[21] Independence can be characterized in two ways. If the events in a sequence of trials are independent of other events of the trial, the sequence is called a "Bernoulli sequence" (Sklar, 1993, p. 92). A Bernoulli sequence is distinct from a Markov sequence: "In a Bernoulli sequence, no knowledge of other outcomes leads to a change of one's probability attributed to the outcome of a given trial. In a Markov sequence, knowing the outcome of what happened just before the specified trial may lead one to modify one's probability for a given trial, but knowledge of earlier past history is irrelevant" (Sklar, 1993, p. 92).

[22] Sklar introduces conditional probability by definition: "If $P(A) \neq 0$, then the probability of *B* given that *A*, the conditional probability of *B* on *A*, written *P(B/A)*, is just P(B ∩ A) / P(A). This can be understood intuitively as the relative probability of *B* to the condition of *A* being assumed to be the case" (1993, p. 92).

the property of being a bachelor. Being a bachelor is not independent of being a male. So if we want to know the probability of selecting a male who is a bachelor, we need to calculate $P(A \cap B)$: $.55 \times .66 = .363$.

Finally, if we know the probability of an event A, we can calculate the probability of its complement, i.e., the probability of A's not occurring, with the formula $P(A^C) = 1 - P(A)$.

These are some of the consequences that follow from Kolmogorov's axioms. Now let us turn to the task of expounding the analyses of probability.

2.3 Interpretations of Probability

2.3.1 The Frequency Theory

Frequency theorists advocate an interpretation of probability motivated by the need to give probability an empirical foundation that can be used in the sciences. By relating probabilities to observable phenomena, frequency theorists identify probabilities with the relative frequencies of events in reference classes, which can be expressed as ratios or proportions. By the frequency interpretation, probabilities conform to the axioms of probability theory either directly or indirectly from facts about proportions (Sklar, 1993, p. 111).

The frequency theory comes in two basic forms: finite frequentism and limiting relative frequentism. Both take probabilities to be measurable physical properties of the world (or of its parts), and both identify probabilities with relative frequencies.[23] Finite frequentism attributes probabilities to attributes in a finite reference class in a straightforward manner: "the probability of an attribute *A* in a finite reference class *B* is the relative frequency of actual occurrences of *A* within *B*" (Hájek, 2008). For example, if *A* is the attribute of rolling a six with a particular die, then the probability of rolling a six is the observed occurrences of six relative to the total number of actual rolls, *B*. If we throw the die twenty times with six occurring four times, then that die has a probability of rolling six equivalent to 4/20 = 1/5.

Probability is defined operationally for finite frequentism, since the probability of an event or attribute is measured by the actual results tallied in a measurement procedure, e.g., a sequence of experiments that produced a ratio of a favoured outcome *A* to the total number of actual outcomes *B*. This would make finite frequentism particularly attractive to strict empiricism and would complement the simple regularity theory of laws, since the latter identifies laws of

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[23] For comparison, on the classical view, probabilities and frequencies may diverge. According to the classicist, the principle of indifference and the space of all possible outcomes determines probabilities *a priori*, and these could be contradicted by any sequence of trials. The *a priori* probability of rolling a six on a fair die is 1/6, but it is possible that a limited trial of rolls yields six a frequency of 1/4.

nature with empirical regularities with no further conditions applied. (The simple regularity theory will be discussed more fully in Section 3.1.1.)

Hájek reviews a number of problems with finite frequencies. A coin never tossed, for example, would have no probability of landing heads (cf.: the coin would still have a diameter were its length never measured). More to the point, single-case probability is clearly problematic for this theory. Consider a coin tossed exactly once: it then has a probability of landing heads that is exactly 0 or 1. A peculiar result, especially since it's the same for any coin, whether bent, damaged, or newly minted. Hájek places the single-case objection within a sequence of related problems: the problem of the double-case fixes probabilities at 0, 1/2, and 1, and so on with the triple-case, etc. Hájek explains the problem to reside in the reference class of finite frequencies: "A finite reference class of size *n*, however large *n* is, can only produce relative frequencies at a certain level of 'grain', namely 1/*n*" (Hájek, 2008). Finite frequencies don't permit intermediate probabilities, but it is reasonable to think that probabilities intermediate to those given by finite frequencies of very small reference classes exist.

Further, Christopher Hitchcock says that the finite frequency interpretation rules out unrepresentative samples by definition:

> If a coin is fair, i.e., has a probability of 0.5 of landing heads when tossed, that should not be taken to rule out the possibility of it landing heads on six of the 10 occasions on which it is tossed. According to the finite frequency definition of probability, however, if the probability of heads is 0.5, then *by definition* the coin will land heads on exactly half of its tosses. Thus, while finite relative frequencies provide indispensable evidence for probability claims, probabilities cannot be identified with finite relative frequencies (2001, p. 12, 093).

The limiting relative frequency interpretation tries to solve some of the problems of the finite frequency theory by expanding reference classes to infinity (that is, infinite reference classes are infinite sequences of trials or infinitely many simultaneously existing objects) and identifying probabilities with the limiting relative frequencies of attributes in infinite reference classes. An immediate consequence is that the limiting frequency interpretation is able to provide more accurate probabilities where finite frequentism could not. Since it is impossible to actually generate infinite sequences of trials, infinite reference classes and limiting relative frequencies are mathematical idealizations. A limiting frequency involves the mathematical ideas of a convergence and a mathematical limit. This "leads to the idealization of an infinite sequence of trials in which the relative frequency of an outcome S converges to a limit" (Hacking, 2001, p. 145).

On the limiting frequency interpretation, actual empirical classes are conceived as sub-sets of infinite reference classes. But how exactly is the connection between the two conceived? Hájek says, "We are to identify probability with a *hypothetical* or *counterfactual* limiting relative frequency. We are to imagine hypothetical infinite extensions of an actual sequence of trials; probabilities are then what the limiting relative frequencies *would be* if the sequence were so extended" (Hájek, 2008).[24] The limiting frequency interpretation has thus drifted away from the empiricism that grounded finite frequentism. I'll come back to this point after a short exposition of von Mises's frequency theory.

Von Mises was the major proponent of the limiting relative frequency theory in the twentieth century. He was a scientifically minded philosopher and thought that probability was a study akin to the mathematical sciences: "The essentially new idea which appeared about 1919 (though it was to a certain extent anticipated by A. A. Cournot in France, John Venn in England, and Georg Helm in Germany) was to consider the theory of probability as a science of the same order as geometry or theoretical mechanics"[25] (1957, p. vii).

But von Mises also emphasizes the empirical dimensions of his theory, particularly evident in the notion of a collective. In the following he defines and gives an example of a collective: "[a collective] denotes a sequence of uniform events or processes which differ by certain observable attributes, say colours, numbers, or anything else.... All the peas grown by a botanist concerned with the problem of heredity may be considered as a collective, the attributes in which we are interested being the different colours of the flowers..." (1957, p. 12). Von Mises then goes on to state the central importance of the collective to the frequency interpretation: "The principle which underlies the whole of our treatment of the probability problem is that a collective must exist before we begin to speak of probability. The definition of probability which we shall give is only concerned with 'the probability of encountering a certain attribute in a given collective'" (1957, p. 12). Von Mises's maxim "First the collective—then the probability" perfectly summarizes his view. It should be noted that prior probabilities, such as those found in the classical and subjective theories of probability, are rendered meaningless on this view, since *a priori* assignments are made without reference to collectives.

There are two kinds of collectives in von Mises. An empirical collective is something that can be observed in the world, like a sequence of tosses of a coin at a particular time and place. A mathematical collective consists of an infinite sequence of events in the attribute space Ω (Gillies, 2000, p. 90). Von Mises's theory of probability links empirical collectives (of large sequences) to mathematical collectives to determine the limiting frequency of a select sub-set of attributes, F. Observed attributes in the collective are placed rationally in relation to the mass phenomena of the collective, and ratios are assigned to express objective properties of the collective. A. J. Ayer explains the strategy applied with

[24] "To say that the probability of heads in a toss of a certain coin is 0.5 is to say that if the coin were to be tossed an infinite number of times, the limiting relative frequency of heads *would be* 0.5" (Hitchcock, 2001, p. 12, 093).
[25] Von Mises published his first paper on the frequency theory in 1919.

limiting relative frequencies: "the reference class is represented as an infinite sequence of terms; it is assumed that at some point in the sequence the proportion of terms which have the property in question reaches a value from which it does not subsequently deviate by more than an arbitrarily small amount" (Ayer, 1964a, p. 199). However, the strategy is not without its problems, and we'll review one of those problems, the reference class problem, shortly.

On von Mises's approach, collectives, besides being foundational for probabilities, satisfy two conditions that Gillies calls the empirical laws of probability. The first is the Law of Stability of Statistical Frequencies. This law was known well before von Mises's time and was confirmed by gamblers in casinos and actuaries for insurance companies. Von Mises characterizes the law as follows: "It is essential for the theory of probability that experience has shown that in the game of dice, as in all the other mass phenomena which we have mentioned, the relative frequencies of certain attributes become more and more stable as the number of observations is increased" (von Mises, 1957, p. 12). Gillies makes the law more precise:

> Let A be an arbitrary attribute associated with a particular collective. If Ω is the attribute space of the collective, then A ⊆ Ω. Suppose that in the first *n* members of the collective A occurs *m*(A) times, then its relative frequency is *m*(A)/*n*. The Law of Stability of Statistical Frequencies is that as *n* increases *m*(A)/*n* gets closer and closer to a fixed value (2000, p. 92).[26]

A limited experiment of die rolling may show that the frequency of six is roughly estimated at 1/6. But in the long run, perhaps after a few thousand trials, the frequency of six should settle to a fixed value of (say) 1/6.[27] Gillies agrees that "there does indeed seem to be a rough empirical law of the kind" (2000, pp. 92–3), but criticizes von Mises's subsequent development of it (2000, pp. 93–5).

The second law is considered one of von Mises's greatest contributions to the study of probability. Gillies calls it the Law of Excluded Gambling Systems. Von Mises gives it two names, the Principle of the Impossibility of a Gambling System and the Principle of Randomness. Von Mises elucidates the Principle of Randomness with a pretty example. In some places in Europe, milestones mark

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[26] Hacking says Bernoulli's Theorem helps us to see how this is so. Bernoulli's theorem is a special case of the law of large numbers, and implies "the probability of large deviations if the relative frequency from *p* decreases as the number of trials increases" (Hacking, 2001, p. 194). It's not necessary to go into the details of the laws of large numbers here.

[27] See von Mises (1957, pp. 14–15) and Gillies (2000, p. 93) for examples. Supposedly the limiting relative frequency of the infinite collective, to which the empirical collective of observed experiments belongs, would also indicate a fixed value of 1/6 as trials go to infinity.

country roads with large stones at every mile and small stones at every tenth of a mile. Walking the road, a person could soon come to predict with complete accuracy the size of the next stone to appear given the stone previously observed. Yet a sequence of coin tosses gives no indication of what the next toss will be after observing heads or tails. The milestones exhibit a regularity that is absent from true empirical collectives. Central to the notion of an empirical collective, then, is that its elements are randomly ordered. The notion of randomness requires formulation: "Von Mises' ingenious idea is that we should relate randomness to the failure of gambling systems. A gambling system in, for example, roulette is something of the following kind: 'Bet on red after a run of three blacks', or 'Bet on every seventh go', etc." (Gillies, 2000, p. 95) But, as von Mises says,

> The authors of such systems have all, sooner or later, had the sad experience of finding out that no system is able to improve their chances of winning in the long run, i.e., to affect the relative frequencies with which different colours or numbers appear in a sequence selected from the total sequence of the game (1957, p. 25).[28]

A notable problem for the frequency theory arises from the way it assigns probabilities to single events. Ayer provides an example to illustrate:

> Suppose that I am seeking to determine the probability of my living to the age of 80: according to the frequency theory, in any of its versions, the answer depends upon the proportion of octogenarians existing in some class to which I belong. But now the problem is that I belong to an enormous number of such classes, and that the choice of one or other of them as my class of reference will make a great difference to the result. The measure of my probable lifespan will vary to a very great extent according as it is referred to the class of organisms in general, the class of all human beings, the class of male Europeans, the class of Englishmen, the class of professional philosophers, the class of university teachers born in England in the 20th century, the class of contemporary Englishmen who belong to such and such an income group, the class composed of the members of this income group who have attained the age of 50 in such and such a physical condition, and so on indefinitely. What reason can there be, within the terms of the frequency theory of probability, for basing the estimate of my chances of longevity on the ratio obtaining in any one of these classes rather than any other? (Ayer 1964a, p. 200)

The problem that Ayer describes is a matter of what property or properties members of a collective are grouped under, for the purpose of assessing or

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[28] Gillies (2000, pp. 105–09) discusses problems about formulating the empirical law in an exact mathematical axiom.

determining a probability. An event belongs to numerous classes, each of which assigns it different probabilities, and the frequency theory provides no reason for basing the probability on one class rather than another. Ayer says that the selection of a reference class in the example he gives may not be a matter of indifference. He should want to know the chance for living to the age of 80 for the members of the narrowest reference class to which he belongs. This suggests the following general principle: "The rule is that in order to estimate the probability that a particular individual possesses a given property, we are to choose as our class of reference, among those to which the individual belongs, the narrowest class in which the property occurs with an extrapolable frequency" (1964a, p. 202). This seems like a rational procedure for selecting among reference classes in cases like those concerning our health, but Ayer notes that there don't seem to be any grounds for accepting the principle in the terms of the frequency theory itself. He concludes that the principle of narrowing the reference class must be entirely arbitrary (1964a, p. 203).

Finally, the limiting relative frequency theory faces the same problem that the finite frequency theory did, namely, that it is unable to provide probabilities for single events, since for the limiting frequency interpretation probabilities are possible only in reference to properly defined collectives (von Mises, 1957, p. 28). If so, it makes no sense to ask what the probability of getting heads is on the next throw of *this* coin, or what the probability of decay is for *this* particle. Yet this would seem to be required of an interpretation of probability that is to be extended to the kinds of events described by probabilistic laws, like that of a particular uranium atom having a certain chance of decaying by time t. A frequency theorist may want to respond that, contrary to von Mises, we simply attribute to single events the probabilities that are assigned to the relevant reference classes (as Popper once did; see Section 2.3.3). This proposal for single-case probabilities may take the form of a subjective probability, where my belief that a toss of a coin will be heads is equivalent to the frequency with which heads appears. Having said that, let's turn to an examination of the subjective interpretation.

2.3.2 The Subjective Interpretation

The subjective interpretation of probability is an extremely well developed field of study. Frank Ramsey and Bruno de Finetti independently discovered subjectivism at about the same time, publishing their first results in 1926 and 1931, respectively.[29] It is unnecessary to individually expound Ramsey's and de Finetti's ideas here. Nor will I go into the complicated mathematical challenges subjectivism faces. (An excellent account can be found in Gillies 2000.) Instead, I

[29] For an excellent account of the history of the subjective interpretation, see Galavotti (2005).

will try to give a general overview of subjectivism about probabilities, with the specific aim of preparing for Chapter 3 on Lewis's theory of laws and chance.

Like the logical interpretation, the subjective interpretation of probability is an epistemic analysis of probability. Where the logical interpretation identifies probabilities as an objective relation holding between propositions (as hypothesis and evidence), the subjective interpretation identifies probabilities with partial beliefs, credence, or degrees of belief assigned by specific individuals at specific times. For example, after having read the weather report, Mr A believes there is a good chance of it raining that day. He assigns, say, a degree of belief of .8 that the proposition 'it will rain today' is true. At the same time, Ms B, a long time observer of cloud formations, assigns the same proposition a degree of belief of .6. On the subjective interpretation, people's probabilities are equally acceptable, so Mr C, who rarely reads a newspaper and cares little about the weather, arbitrarily assigns the proposition a degree of belief of .3. Given this information we can say that of the three Mr A expresses the highest degree of belief that it will rain today, Ms B expresses some degree of confidence that it will rain, and Mr C expresses the lowest degree of belief that it will rain today.

Now these people have expressed degrees of belief in a proposition based on different evidence: Mr A on the local weather report, Ms B on her experience observing the weather, and Mr C on whatever it was that arbitrarily influenced his decision at the time. However, the subjective interpretation allows for diverging initial probabilities based on the same evidence. Mr A, Ms B, and Mr C might each have assigned widely diverging probability values to the proposition in question after they each read the weather report. In such cases, the subjective interpretation treats each probability assignment as equally acceptable and the probability of rain receives many acceptable answers.

On Ramsey's account of subjective probability, we cannot suppose that degrees of belief are perceptible by their owners:

> Suppose that the degree of a belief is something perceptible by its owner, that beliefs differ in the intensity of a feeling by which they are accompanied, which might be called a belief-feeling or feeling of conviction, and that by the degree of belief we mean the intensity of this feeling. This view would be very inconvenient, for it is not easy to ascribe numbers to the intensities for feeling; but apart from this it seems to me observably false, for the beliefs which we hold most strongly are often accompanied by practically no feeling at all; no one feels strongly about things he takes for granted (1926, p. 71).

Gillies gives a nice example of a strongly held belief that is accompanied by no feeling at all: I, for instance, strongly believe that the bread I will eat for lunch will nourish me, but the belief (under normal circumstances) is accompanied by no feeling at all – it is simply a strong belief (2000, p. 54). Furthermore, my actions do not seem to be hindered by the lack of a belief feeling; I am just as likely to eat the bread based on my belief that it would nourish me as another person who shared my belief to the same degree as well as feeling strongly about it. If true, then it does not matter for the subjective interpretation that one believer might strongly believe that a probability of an event was (say) .8, and another believer also believe that the probability of the same event was .8, but without strong conviction or belief feeling.[30] What matters, according to Ramsey, is the extent to which we are prepared to act on a belief: "the degree of a belief is a causal property of it, which we can express vaguely as the extent to which we are prepared to act on it" (1926, p. 71). Ramsey and de Finetti think that degrees of belief can be measured by the lowest odds a person is willing to accept on a bet; it is unnecessary to pursue the details of this here—let it be merely acknowledged that subjectivists propose a non-introspective procedure of measuring degrees of belief.[31]

Moving on, the subjective interpretation does not rigidly commit us to our initial subjective probabilities; it allows us to change partial beliefs as we learn from experience. Formally the process is called 'conditionalization'. Lawrence Sklar provides a statement of the strategy involved:

> How should we modify our distribution of partial beliefs in the face of new evidence? The usual rule suggested is conditionalization. We have, at a time, not only probabilities for propositions, but conditional probabilities as well, the probability of *h* given *e*, whenever the probability of *e* is non-zero. Suppose we then observe *e* to be the case. Conditionalization suggests that we take as the new probability of *h* the old conditional probability it had relative to *e*. This rule has been nicely generalized by R. Jeffrey and others to handle cases where we don't go to *e* as a certainty, but instead take the evidence as merely modifying the older probability of *e*. Conditionalization is a conservative strategy. It makes the minimal changes in our subjective probability attributions consistent with what we have learned through the evidence, and it generates a new probability distribution as coherent as the one we started with (1993, p. 113).

To get clear on this passage we should say something about the notion of coherence. Coherence is a consistency-like constraint on the totality of an agent's degree of belief (Hitchcock, 2001, p. 12, 091). The example of a Dutch book will help explain. A Dutch book is a series of bets that guarantees a bettor a net loss no matter what the outcome is. Say I'm betting on the outcome of a coin toss. An example of a consistent bet would be to accept odds on heads 2:1, for whatever

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[30] Indeed, this shows that degrees of belief need not be accompanied by degrees of feeling, so that the degrees of belief are not degrees of feeling. It does not show that degrees of belief are not accessible to the believer.

[31] See Ramsey (1926), Jeffrey (1965), Gillies (2000), and Eriksson and Hájek (2007) for discussions.

reason I have. So I pay two units and the coin is tossed – if it lands heads, I gain one unit (2 + 1), but if it lands tails, I lose two. On a Dutch Book, however, I've accepted a set of bets where odds are, for instance, heads 2:1 and tails 2:1. So I pay four units and the coin is tossed – if it lands heads I gain one unit and lose two, and if it lands tails I gain one and lose two. A bookie is guaranteed to make money on me with odds like these. The problem with my bets is that they reflect incoherent degrees of belief about the coin tosses. The subjective interpretation takes coherence to be a requirement for subjective probabilities, be they absolute probabilities (e.g., P(A)) or conditional probabilities (e.g., P(A | B)). But since people's degrees of belief frequently violate the axioms of probability, e.g., my Dutch book, coherence is a normative requirement of subjectivism, meaning "If your subjective probabilities conform to the probability calculus, then no Dutch book can be made against you; your probability assignments are then said to be *coherent*. In a nutshell, conformity to the probability calculus is necessary and sufficient for coherence" (Hájek, 2008).

To return to conditionalization: conditionalization is a deliberative process that allows us to update our subjective probabilities in light of new evidence. The general schema for updating subjective probabilities is $P_2(A) = P_1(A \mid E)$, where P_2 is an updated degree of belief in A equivalent to P_1, the old degree of belief in A now conditional on evidence E. Lewis gives a simple example of conditionalizing on evidence:

> A certain coin is scheduled to be tossed at noon today. You are sure that this chosen coin is fair: it has a 50% chance of falling heads and a 50% chance of falling tails. You have no other relevant information. Consider the proposition that the coin tossed at noon today falls heads. To what degree would you now believe that proposition? Answer. 50%, of course.... [Now consider] it is afternoon and you have evidence that became available after the coin was tossed at noon. Maybe you know for certain that it fell heads; maybe some fairly reliable witness has told you that it fell heads; maybe the witness has told you that it fell heads in nine out of ten tosses of which the noon toss was one. You remain as sure as ever that the chance of heads, just before noon, was 50%. To what degree should you believe that the coin tossed at noon fell heads? Answer. Not 50%, but something not far short of 100% (1986, pp. 84–5).

Prior to the toss and on evidence that the coin is fair, we believe to degree 50% that the proposition 'the coin tossed at noon today falls heads' is true. When our evidence is updated with information that the toss did fall heads, our belief in the proposition is appropriately revised. Thus the subjective interpretation allows us to revise our subjective probabilities as observation updates evidence.

Lewis intends to give a subjectivist account of objective chance, by which objective single-case probabilities are gained subjectively. An interesting combination of elements goes into Lewis's account of chance. The single-case aspect of chance or propensity depends on a subjective probability (or credence) which is subject to the laws of mathematical probability, while the objective aspect of a propensity is grounded in objectively existing frequencies. Chance is given a special interpretation in Lewis and the Principal Principle plays a central role in it.

The Principal Principle is a theorem that links objective frequencies and subjective probabilities: Let *C* be any reasonable initial credence function;[32] let *t* be any time; let *x* be any real number in the unit interval; let *X* be the proposition that the chance (i.e., objective probability), at time *t*, of *A*'s holding equals *x*; let *E* be any evidential proposition compatible with *X* that is admissible at time *t* (Lewis, 1986a, p. 87). The Principal Principle (in its first formulation) states that $C(A \mid XE) = x$. This formula tells us that rational credence about chance should be equivalent to chances themselves.

One may wonder why *E* should be included in the formula at all, since the statement that subjective credence should correspond to beliefs about objective chances would seem to imply a formula "$C(A \mid X) = x$". The reason for the inclusion of *E* is that *E* contains evidence that bears on the value of *x* in proposition *X*. Without such evidence the value of *x* must be arbitrarily assigned; without *E*, *X* would fail to reflect objective chance, and subjective credence would fail to correspond to beliefs about objective chance. Thus conditionalizing on the available evidence is a necessary step in developing rational degrees of belief about objective chance. We can see *E*-type evidence and its relation to objective chance in an example of Ayer. Ayer elaborates some problems he detects in the logical theory of probability, but the example he uses to motivate the problematic contains an ancestor of the Principal Principle. Describing a punter who considers the odds on a horse named Eclipse, Ayer says:

> He is determined to be rational and so to bring his degrees of belief in the horse's victory into exact accordance with the objective probabilities. He assembles the evidence: h_1 that Eclipse will be ridden by the champion jockey; h_2 that the going will be hard; h_3 that Eclipse is suited by the distance; h_4 that it went lame after its last race; h_5 that it has previously beaten the more fancied of its competitors; h_6 that it has recently dropped in the betting, and so forth. Assume that he evaluates all the relevant evidence that he can acquire, or in other words, that, so far as his knowledge goes, he has not omitted any true proposition which, if it were conjoined with his other data, would make any difference to the resultant probability. So, taking *a* to be the proposition that Eclipse will win, he

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[32] That is, *C* obeys the axioms of probability: "I said: let *C* be any reasonable credence function. By that I meant, in part, that *C* was to be a probability distribution over (at least) the space whose points are possible worlds and whose regions (sets of worlds) are propositions. *C* is a non-negative, normalized, finitely additive measure defined on all propositions" (Lewis, 1986, pp. 87–8).

> decides that the probability of a on $h_1 = p_1$, $a/h_2 = p_2$, $a/h_3 = p_3$, $a/h_1h_2 = p_x$, $a/h_{1\text{-}4} = p_y$, ...; and finally that $a/h_{1\text{-}n}$, where $h_{1\text{-}n}$ represents the totality of the relevant evidence at his command, $= p_z$. How is he to place his bet? To common sense the answer is obvious. If his degree of belief in the proposition that Eclipse will win is to be rational, it must correspond to the probability p_z (1964a, p. 190).

Ayer develops problems with the 'common sense view' for the logical analysis of probability, and since the problems stem from that theory's assumption of necessary relations between propositions, we don't need to review the arguments here. The point of including this quote is to show the rationale for conditionizing on the evidence provided by proposition *E*: if our degrees of belief about the chances of future events are to be rational, they must correspond to our beliefs about objective chances, and our beliefs about objective chances are supported by evidence *E*.

We can see the elements of the Principal Principle at work in the coin-flipping example. The Principle tells us

> C_1(the coin tossed at noon today falls heads | *P*(the proposition will be true at noon) = .5 and the coin is fair) = .5,

where C_1 indicates our initial credence, *A* = the coin tossed at noon today falls heads, *X* = [P(the proposition will be true at noon) = .5] and *E* = the coin is fair. But if the content of *E* were changed, the value of *x* in *X* should change as well:

> C_2(the coin tossed at noon today falls heads | *P*(the proposition will be true at noon) = 1, plus evidence *E* to that effect) = 1.

Belief is updated in C_2 because *X* must now be the proposition that the chance at time *t* of *A*'s holding at noon is 1, since that is the only value of *x* that is compatible with proposition *E* that the coin lands heads at noon. Updating, then, is a logical consequence of the requirement that the propositions on which we conditionalize be compatible. We can show that degrees of belief cannot be rationally established on incompatible propositions. Consider the following incomplete statement:

> C_3(the coin tossed at noon today falls heads | *P*(the proposition will be true at noon) = .5 and the coin does in fact land heads).

What credence should we give to the proposition that the coin tossed at noon today falls heads? The conditioning proposition 'the coin does in fact land heads' is true, so warrants a probability value of 1, while the stand in for proposition *X* says the probability is .5. The conditioning statements form an inconsistent set of propositions, since at least one of them is false. (Proposition *X* is false, since 'the coin does in fact land heads' is true). Since an inconsistent set of propositions contains a contradiction and the probability of a contradiction is 0, we infer C_3 is 0 for 'the coin tossed at noon today falls heads'. Of course, in some circumstances we could arrive at the right value accidentally by means of conditioning on a contradiction. Take for example,

> C_4(the coin tossed at noon today falls heads | P(the proposition will be true at noon) = .5 and the coin in fact lands tails) = 0.

Since proposition E says that the coin tossed at noon today will not fall heads (because it in fact falls tails), we want a degree of belief of 0 in proposition A that the coin tossed at noon today falls heads; and indeed, that is what has been assigned to it. However, since A is conditional on X too, and X and E are inconsistent, the degree of belief has not come through rational consideration of evidence, but by way of the contradiction between X and E. So we arrive at the correct degree of belief accidentally.

This should suffice as an introduction to subjective probabilities. The feature that I have tried to make clear about the subjective theory is that it provides a way of connecting credence to observation. This is clear in the case of frequencies. If a coin shows heads 60 out of 100 tosses, we may believe that it has a .6 chance of landing heads on the next toss. If 1000 subsequent tosses show us that heads appears with a frequency approaching .5, we should adjust our belief about the chance of heads on the next toss. This finally brings us to the question of whether the subjective theory can provide for single-case probabilities. We saw that for the frequency theory, von Mises thought that the question of probabilities for single-cases is misdirected; probabilities belong only to collectives. The matter is different for the subjectivist: "It is easy to introduce singular probabilities on the subjective theory. All Mr Smith's friends could, for example, take bets on his dying before age 41, and hence introduce subjective probabilities for this event" (Gillies, 2000, p. 115). The subjective theory says that individual people assign probabilities to individual events, so the probabilities for those events are subjective in origin.

However, we may ask if the probabilities of singular events are objective properties of them, as Popper did for his interpretation of quantum mechanics (Gillies, 2000, p. 115). It seems unlikely that the chance of an objective event, like that of the radioactive decay of a particular particle, could depend on the subjective probability assigned by any particular person. Indeed, we might think that subjectivism is incapable of providing for cases like radioactive decay, since different people would be bound to submit different probabilities for such events. It seems that an account of single-case probability for the kinds of events about which this thesis is concerned points away from the subjective analysis of probability to an objectivist account, i.e., the frequency and propensity analyses. We saw at the end of the previous section that the frequency theory shows difficulty for single-case probabilities, but it seems they can be introduced with the help of subjective probability. Under the frequency interpretation, the objective probabilities of radioactive decay should be interpreted as frequencies: *n* out of *m* atoms will decay by time *t*. Probabilities for individual events could now be introduced subjectively, according to the degree of rational credence we should give to the belief that a particular atom will decay by time *t*. This is an interpretation that would work under Lewis's theory of objective chance. Its virtue is that frequencies constrain what we ought to believe about the probability of singular events. Nevertheless, there is room under this proposal for aberrant subjective probabilities – someone who didn't understand the meaning of frequency ratios might, if pressed, give an aberrant subjective probability due to frustration, confusion, or embarrassment, for example.

2.3.3 The Propensity Interpretation

Karl Popper was the first to give the propensity interpretation an explicit formulation.[33] Prior to that, Popper was an advocate of the frequency theory[34] and thought (contrary to von Mises) that he could provide for a single-case probability by simply equating it with the probability of the collective (Gillies, 2000, p. 115). However, in 1959 Popper devised a simple objection to his own frequency view. Gillies summarizes the objection as follows:

> Begin by considering two dice: one regular, and the other biased so that the probability of getting a particular face (say the 5) is 1/4. Now consider a sequence consisting almost entirely of throws of the biased die but with one or two throws of the regular die interspersed. Let us take one of these interspersed throws and ask what is the probability of getting a 5 on that throw. According to Popper's earlier suggestion this probability must be 1/4 because the throw is part of a collective for which prob(5) = 1/4. But this is an intuitive paradox, since it is surely much more reasonable to say that prob(5) = 1/6 for any throw of the regular die (2000, p. 115).

Popper suggests that to meet the problem the frequency theorist might modify the admissibility requirement placed on sequences:

> He will now say that an admissible sequence of events (a reference sequence, a 'collective') must always be a sequence of repeated experiments. Or more generally, he will say that admissible sequences must be either virtual or actual sequences which are *characterized by a set*

[33] Precursors to a propensity interpretation can be found in Peirce (1910), Kolmogorov (1933), and Braithwaite (1964).

[34] See for instance *The Logic of Scientific Discovery* (1934, Chapter VIII, pp. 146–214).

> *of generating conditions* – by a set of conditions whose repeated realization produces the elements of the sequences (1959b, p. 34).

Popper goes on to say, "Yet, if we look more closely at this apparently slight modification, then we find that it amounts to a transition from the frequency interpretation to the propensity interpretation" (1959b, p. 34). The modification involves a shift to the propensity interpretation because the generating conditions have to be imagined as being endowed "with a tendency or disposition, or propensity, to produce sequences whose frequencies are equal to the probabilities; which is precisely what the propensity interpretation asserts" (1959b, p. 35).

This is Popper's early propensity theory. It may be characterized by the repeatable generating conditions of an experiment, which in the long run produce sequences of events whose frequencies approach the probability determined by the propensity of the generating conditions. Since probabilities are connected to generating conditions, it now makes sense to say that a single event has an objective probability of occurring – it is the probability determined by the propensity inherent in the generating conditions.

Popper's later propensity theory (1990) identifies propensities not with the generating conditions of experiments, but with states of the universe. On this view, the probability of a uranium atom decaying by a certain time is the propensity of the state of the universe at a particular time to probabilistically cause it to decay. Propensities, for Popper, have thus gone from being a matter of the local arrangement of parts of generating conditions to the states of affairs of the universe. On this (rather peculiar) account of propensities, propensities might again be identical to generating conditions, e.g., the relations that obtain between the parts of the universe at a particular time, or properties that emerge from states of the universe. Either way, Popper's later account of propensities seems to be quite far from what dispositional essentialists propose for propensities that ground probabilistic laws, that properties intrinsic to the objects governed by probabilistic laws are the ground of those laws.

Moving on to Gillies, he proposes a theory of propensities that is not primarily concerned with providing probabilities for single-case events. 'Propensity theory' is to be extended to "any theory which tries to develop an objective, but non-frequency, interpretation of probability ... such an interpretation is needed for reasons which have nothing to do with the question of whether there are objective probabilities of single events" (2000, p. 114). Gillies adopts the view of Howson and Urbach (1989) that there are no objective probabilities for single events. According to Howson and Urbach, probabilities for single events are subjective probabilities, "which considerations of consistency nevertheless dictate must be set equal to the objective probabilities just when all you know about the single-case is that it is an instance of the relevant collective" (in Gillies 2000, p. 120). The objective probabilities that Howson and Urbach refer to are frequencies, which provide probabilities for collectives but not for the single-case. Gillies is persuaded by a series of arguments that he calls the 'reference class problem'.[35] The reference class problem for propensities says that the probability of a single event depends not on the event itself but on the description under which we place the event. Since we pick and chose our descriptions, we change the probabilities of an event as we change the description of it. If true, "then we are forced to consider the probabilities as attached to the conditions which describe the event rather than to the event itself" (Gillies, 2000, p. 119).

Following Howson and Urbach, Gillies thinks that the probabilities of single-case events have subjective origin, and that these are based on objective probabilities, i.e., frequencies. Suppose, for instance, that we have good statistical information about the probability of 40-year-old men surviving to the age of 41. Mr A may use this objective probability, *x*, to formulate the subjective probability, *x*, that a particular 40-year-old man will live to be 41. But this does not mean that a subjective probability picks out an objective probability in the individual, since Ms B might treat the same man as a member of a different reference class, e.g., the class of 40-year-old men who smoke two packs of cigarettes a day. Ms B has a different set of statistics about the proportion of men that make it to age 41, so produces a different subjective probability, *y*, that the man will make it to age 41. Gillies thus concludes,

> We can certainly introduce objective probabilities for events A which are the outcomes of some sets of repeatable conditions S. When, however, we want to introduce probabilities for single events, these probabilities, though sometimes objectively based, will nearly always fail to be fully objective because there will in most cases be a doubt about the way we should classify the event, and this will introduce a subjective element into the singular probability (2000, p. 120).[36]

(As he suggests, Gillies is open to some objective probabilities for single events in simple games of chance, like rolling dice or flipping coins; see Gillies (2000, pp. 123–4). For convenience I overlook this exception to his general view.)

It will have to be seen whether Gillies's argument against objective probabilities for singular events will affect the dispositional essentialists' appeal to dispositional properties. If the decay of a radium atom depends on its specific circumstances, then perhaps the point made by Gillies (and Howson and Urbach)

[35] "The reference class formulation is more natural in the context of the frequency theory where the problem first appeared. Although we are discussing the propensity theory, we will continue to use the traditional terminology and refer to this fundamental problem as *the reference class problem*" (Gillies, 2000, p. 119).

[36] Gillies overlooks the fact that the reference class problem is not just a problem for singular events. The probability that men in their 40s living to their 50s will shift if we add that all the men concerned lived in a radiation-affected area, for example.

can be directed against dispositional essentialists like Alexander Bird and Brian Ellis, who posit propensities as the basis of probabilistic behaviour. We'll take up this point in Chapter 5.

We will examine Gillies's propensity theory in Chapter 5 when dealing with 'Humphrey's Paradox', but it can be briefly characterized here. Gillies argues for a version of the propensity analysis in which objective probabilities for single events are abandoned.[37] For him, probabilities for single events are subjective probabilities. Gillies requires a modification of terminology to fit his conception of propensities: 'propensity theory' is to refer to 'an objective, but non-frequency, theory' of probability. His motivation for such a theory "is to develop a propensity theory of probability which can be used to provide an interpretation of the probabilities which appear in such natural sciences as physics and biology. For a theory of this kind, probability assignments should be testable by empirical data, and this makes it desirable that they should be associated with repeatable conditions" (2000, p. 128). Elsewhere he says, "I have a doubt whether single-case propensities give an appropriate analysis of the objective probabilities which appear in the natural sciences" (2000, p. 128).

Gillies, following Fetzer (1988), distinguishes between long-run propensities and single-case propensities. The distinction can also be found in Popper's 1959b paper on propensities; propensity theorists have tended to conceive probabilities either in terms of the single-case or in terms of repeatable conditions and long runs of trials. Popper himself in 1990 abandons the long-run conception for the single-case interpretation: "...propensities in physics are properties of *the whole physical situation* and sometimes of the particular way in which a situation changes" (1990, p. 17).[38] Gillies suggests that the change from identifying propensities with the repeatable generating conditions of a situation to total states of the universe reflects Popper's desire to have objective single event probabilities. As we saw, Howson and Urbach (1989) are skeptical that propensities conceived as involving repeatable conditions give the single event an objective probability of occurring. The later Popper seems to propose a situation that is decidedly *un*repeatable, the entire situation of the universe at a particular time. I think Popper regards these states to be the generating conditions of chance events, like particle decay; nonetheless they are not repeatable conditions.

Gillies's main objection is that Popper's later interpretation renders propensities metaphysical rather than scientific (Gillies, 2000, p. 128). Gillies's take on Popper's phrase "sequences whose frequencies are equal to the probabilities" is to interpret it as promoting a finite but very long sequence that would produce frequencies approximately equal to the probabilities. "This is because my aim is to make the propensity theory more scientific and empirical,

[37] Gillies gives a full defence of his propensity theory in (2000) Chapter 7.

[38] Miller also proposes a state-of-the-universe propensity theory: "Strictly, every propensity (absolute or conditional) must be referred to the complete situation of the universe (or the light-cone) at the time" (1994, pp. 185–6).

and it is obvious that infinite sequences of repetitions are not to be found in the empirical world" (2000, p. 116). Gillies' conception of propensities could prove a threat to dispositional essentialists, who think that science requires objective single-case probabilities and that the probabilistic laws associated with such events are explicated by objective single-case propensities.

2.4. Conclusion

This should do by way of an introduction to the analyses of probability we'll encounter in our investigations. Treating the explication of singular probabilities as a desirable feature for such analyses, we saw that von Mises's frequency theory is the least amenable to such cases, since single events on this theory have probabilities only in so far as they are members of a collective. The subjective theory fared better on singular events, assigning them subjective probabilities. However, it may be argued that the subjective analysis misplaces the origin of single-case probabilities, since objectively real processes like beta-decay happen with a probability independent of anyone's belief about it. This points in the direction of a theory that can provide objective single-case probabilities, which (objective) single-case propensity theories do. This indicates that dispositional essentialism is a scientific metaphysics that may accommodate objective single-case probabilities, since it posits the existence of propensities.

We will keep these points in mind as we work our way through the following chapters, in an attempt to determine which of the foremost scientific metaphysics solves the big bad bug, i.e., the problem of undermining.

Chapter 3: The Best Systems Analysis

This chapter analyzes David Lewis's best systems analysis of laws of nature and his attempt to solve the problem of objective chance – *the big bad bug* – a problem that he thought had the potential to undermine his entire metaphysics. The first part of the chapter investigates the best systems analysis of laws (BSA). I begin with the simple regularity theory of laws (SRT), the theory that BSA succeeds. John Carroll's and Alexander Bird's critiques of the simple regularity theory will provide the details of the simple regularity theory as well as an introduction to a basic distinction for theories of laws.[39] I then give an exposition of Lewis's best systems analysis. The second part of the chapter covers Lewis's metaphysics of modal realism. I discuss *possibilia* (possible worlds and possible objects) and how Lewis applies a possible worlds structure and set theory to an analysis of modality, properties, and propositions.

The third part of the chapter deals with Lewis's problem of undermining, also know as 'the big bad bug'. Lewis took chance to supervene on the global distribution of properties, the latter of which entails a theory of chance that assigns some high chance to actual history *A* coming to pass. But a theory of chance also assigns some small chance to alternative history *B* coming to pass. If *B* were to come to pass, the theory of chance undermines itself, since *B* entails an alternative theory of chance that assigns *B* the maximal chance of coming to pass. Lewis gave the problem of undermining proper expression as a contradiction that shows up in the Principal Principle, a principle of reason about how chance is related to credence. His initial attempts to eliminate the bug fail, but he warmly welcomes a solution by Michael Thau. In the final section of the chapter I argue that Thau's solution to the problem of undermining entails that best systems cannot be assigned to indeterministic worlds, a result that seems as problematic for BSA as the big bad bug.

3.1 The Best Systems Analysis of Laws

3.1.1 The Simple Regularity Theory

The simple regularity theory of laws is a product of strict empiricism.[40] Refusing to admit concepts or entities that cannot be traced back to experience, SRT is committed to minimalism about laws. On Bird's interpretation of the simple regularity theory, laws are expressed by true generalizations, e.g., 'all Fs are Gs', which expresses a regularity whose instances are Fs that are G. "The law, according to [SRT], is simply the regular occurrence of its instances" (Bird, 1998, p. 28). Further, since all of what we are aware of in experience are individual

[39] See as well Armstrong's 1983, Chapters 2, 3, and 4.

[40] Some mid-20th C. regularity theorists are Ayer (1964b), Braithwaite (1960), Hempel and Oppenheim (1948), Mackie (1974), Nagel (1961), and Popper (1959b).

objects, events, and properties, the laws, according to SRT, cannot involve necessary connections in nature, of which we have no direct empirical evidence.[41]

There are at least two ways to give a definition of SRT: one by a linguistic conception of laws, the other by an ontological conception of laws.[42] Alexander Bird, for instance, is committed to an ontological treatment of laws and interprets SRT ontologically. His general orientation on laws is that "Laws are things in the world…they are facts or are like them" (Bird, 1998, p. 26). Bird expresses realism about laws, whereby laws are taken to be real features of the world. Realism about laws influences Bird's interpretation of SRT: if laws are real features of the world, then on a simple regularity theory of laws, laws are identical with regularities (1998, p. 28).

John Carroll on the other hand is committed to a linguistic treatment of laws and interprets laws under the simple regularity theory to be (logically) contingently true general statements with unrestricted non-logical terms.[43] With Bird and Carroll we have two interpretations of SRT shaped by distinct general considerations about laws. That being the case, I will use SRT as preliminary to a discussion of the best systems analysis of laws and as an opportunity to present the differences between the linguistic and ontological treatments of laws.

Neither Bird nor Carroll thinks that SRT is a good theory of laws of nature.[44] Each offers numerous arguments against it, but we will examine just one of each of their arguments that will provide a nice contrast between the ontological and linguistic approaches.[45] Bird's formulation of SRT is as follows. (SRT): It is a law that Fs are Gs *if and only if* all Fs are Gs (1998, p. 28). But, as Bird argues, the statement is false since (1) there are regularities that are not laws, so being a regularity is not sufficient for being a law and (2) there are laws without corresponding regularities, so being a regularity is not necessary for being a law. An example of a law that fails to have a corresponding regularity is an uninstantiated law. An uninstantiated law concerns properties, events, or

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[41] According to strict empiricism, we will also have to consider electrons and other 'scientific objects' as unobservables.

[42] "Philosophers have understood 'is a law' as applying to a number of different kinds of entities: sentences, propositions, or certain nonrepresentational features of reality, i.e., whatever it is that makes a particular sentence or proposition express a law" (Loewer, 1996, p. 184).

[43] A *restricted* non-logical term would make essential reference to something restricted in time or place. 'Earth' would thus be a restricted non-logical term, whereas 'planet' would be an unrestricted non-logical term. Armstrong (1983) glosses 'unrestricted non-logical term' with the words 'cosmic', 'general', and 'non-local empirical term'.

[44] For early arguments against the simple regularity theory of laws of nature see William C. Kneale's (1950), (1961), and George Molnar's (1969).

[45] For thorough critiques of SRT, see Bird (1998, pp. 27–37), Carroll (1993, pp. 29–40), Armstrong (1983, pp. 11–52), and Mumford (2001, pp. 31–9).

individuals that fail to be instantiated in the actual world, hence the law fails to correspond to any actual regularity. Such a law may concern the behaviour of theoretical objects produced in high-energy experiments. Uninstantiated laws are laws since they are entailed by higher-order laws that are instantiated.

To show that being a regularity is insufficient for being a law, Bird asks us to consider the following:

(a) All persisting lumps of pure gold-195 have a mass less than 1,000 kg.
(b) All persisting lumps of pure uranium-235 have a mass of less than 1,000 kg.

Bird says that both (a) and (b) are true generalized statements, but only (b) expresses a law of nature. (a) expresses an accidental truth. It may be true that there are no lumps of gold whose mass is 1,000 kg or greater, but if someone thought it worth the time and money, he could build one to show its physical possibility. But 1,000 kg far exceeds the critical mass of uranium-235 (something less than a kilogram). Any such lump would cause its own chain reaction and self-destruct. According to Bird, this shows that "there can be two very similar looking regularities, one of which is a law and the other not" (1998, p. 28). Since we have here a regularity that is not a law, being a regularity is insufficient for being a law. Thus SRT is false.

According to Carroll, laws for SRT are true propositions with an essential feature that distinguishes them from true propositions that are not laws. Call this defining feature 'lawlikeness.' The SRT analysis of lawlikeness is that *P* is lawlike if and only if *P* is contingent, universally quantified, and has unrestricted non-logical terms (that is, the non-logical terms don't name a particular object, like Bob's pocket in "all the coins in Bob's pocket are nickels") (Carroll, 1993, p. 34). So *P* is a law for SRT if and only if *P* is true and lawlike.

Carroll asks us to consider the generalization that all gold spheres are less than ten metres in diameter. Since it is true, contingent, and has unrestricted non-logical terms, the statement is a law for SRT. However, since the statement fails to support counterfactuals, it is not a law: "All that prevents there being a gold sphere that big is the fact that no one has been curious enough and wealthy enough to have such a sphere produced" (1994, p. 34). The statement 'all gold spheres are less than ten meters in diameter' fails to be a law on the linguistic account because a ten metre diameter gold sphere is a real physical possibility, contrary to what the supposed SRT law says is possible. Thus the statement about gold spheres is true yet fails to be a law. According to Carroll, this counter-example shows that the SRT analysis of laws is too weak, since it would have us count as laws generalizations that are not laws (1993, p. 31). The SRT analysis of lawlikeness thus fails to identify the distinguishing feature of generalizations that are laws, since lawlikeness on this analysis captures generalizations that are accidentally true.

Both the linguistic and the ontological readings of SRT fail to provide a sufficient condition for what it is to be a law of nature. These approaches also show us that philosophers may think differently about what laws are. The distinction between linguistic and ontological analyses will be at constant work in this thesis. What Ellis means by 'law' is a certain kind of sentence made true by the dispositional properties instantiated in the world, while Armstrong takes it to refer to a necessitating (causal) feature of the world. As we will see, Lewis takes a law to express a proposition, which in turn is a set of possible worlds. Perhaps not too much should be made of this distinction, since philosophers are free to stipulate what they mean by 'law of nature'. But being clear on the distinction will help guard against basic mistakes, such as arguing a line of attack against Armstrong's metaphysics of laws that would be properly put against a linguistic interpretation.

3.1.2 The Best Systems Analysis

Lewis's best systems analysis is, as Armstrong puts it, a sophistication of the simple regularity theory of laws. Like SRT, BSA is motivated by empiricism. Lewis's basic metaphysical thesis is Humean supervenience, according to which "all there is to the world is a vast mosaic of local matters of particular fact, just one little thing and then another" (1986a, p. ix). According to Humean supervenience, "We have a geometry: a system of external relations of spatiotemporal distance between points. Maybe points of space-time itself, maybe point-sized bits of matter or aether or fields, maybe both. And at those points we have local qualities: perfectly natural intrinsic properties which need nothing bigger than a point at which to be instantiated" (1986a, p. ix). Everything else supervenes on the arrangements of these points. Under Humean supervenience, laws cannot be conceived as being real necessitating features of the world, like Armstrong's necessitation relation *N*, since laws will concern only the external relations that obtain between intrinsic qualities.

Lewis claims that Humean supervenience successfully deals with a host of metaphysical issues, including the nature of causation and the persistence of objects through time. Barry Loewer says that Lewis's defence of Humean supervenience is to support Physicalism, "that whatever happens in our world happens in virtue of physical happenings" (1996, p. 178). In the next section we will look closer at Humean supervenience and its role in Lewis's broader metaphysics of modal realism.

Lewis adapts F. P. Ramsey's 1928 theory of laws for his best systems analysis of laws. (Ramsey himself rejected his 1928 theory for another in 1929.) According to Ramsey, laws are "consequences of those propositions which we should take as axioms if we knew everything and organized it as simply as possible in a deductive system" (in Lewis, 1973, p. 73). According to Ramsey, laws are theorems that follow from the axioms of the simplest deductive system representing all that can be known about the world.[46] Since axioms entail themselves as theorems, Armstrong includes axioms as laws in deductive systems (Armstrong, 1983, p. 66). Lewis also takes the axioms of a best system to be laws, but dismisses Ramsey's reference to omniscience and introduces the conditions of simplicity, strength, and best balance:

> Whatever we may or may not ever come to know, there exist (as abstract objects) innumerable true deductive systems: deductively closed, axiomatizable sets of true sentences. Of these true deductive systems, some can be axiomatized more *simply* than others. Also, some of them have more *strength*, or *information content*, than others. The virtues of simplicity and strength tend to conflict. Simplicity without strength can be had from pure logic, strength without simplicity from (the deductive closure of) an almanac.... What we value in a deductive system is a properly balanced combination of simplicity and strength – as much of both as truth and our way of balancing permit (1973, p. 73).

Lewis then restates Ramsey's theory, giving us the best systems theory of laws:

> A contingent generalization is a law of nature if and only if it appears as a theorem (or axiom) in each of the true deductive systems that achieves a best combination of simplicity and strength. A generalization is a law at a world *i*, likewise, if and only if it appears as a theorem in each of the best deductive systems true at *i* (1973, p. 73).

Recall that Carroll entertained the claim under SRT that a statement is a law if and only if it is true, contingent, general, and uses non-logical terms that are unrestricted. The problem with this formulation was that it failed to distinguish contingent generalizations that are laws from accidentally true generalizations. The question was then which generalizations do we count as laws? Lewis refines SRT by adding the condition that a law belongs to all the best true deductive systems that capture the history of a world, those systems that achieve a best balance of simplicity and strength. The new condition is a relational or 'collective' property, as Lewis sometimes called it: a general proposition is a law if and only if it is a contingent unrestricted generalization that is a theorem or axiom of each of the true deductive systems of world *i* that meets the constraint of a best balance between simplicity and strength. True generalizations that fail to figure in such systems are accidentally true.

Deductive systems may exhibit simplicity and strength, and best systems achieve a best balance between these desiderata. Lewis admits that 'a best

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[46] Carroll (2004) lists the following as having deductive systems approaches to laws: Mill 1843 (1947), Ramsey 1928 (1978), Lewis (1973, –83, –86a, –94), Earman 1984, Loewer 1996.

combination of simplicity and strength' is vague, but he justifies it on the basis of the practice of science, which he thinks makes pragmatic decisions about such matters: "In science we have standards—vague ones, to be sure—for assessing the combinations of strength and simplicity offered by deductive systems. We trade off these virtues against each other and against probability of truth on the available evidence" (1973, p. 74). By this I understand Lewis to mean that there are no tested methods used by the sciences to produce best deductive systems (or theories), though pragmatic considerations are used to determine whether simplicity is to be sacrificed for strength or strength for simplicity. If a system or scientific theory requires added detail to explain or predict phenomena, then some sacrifice of simplicity is required. If details can be omitted from a system without weakening its explanatory and predictive success, then it can be simplified. So Lewis adopts pragmatic considerations to determine best balances of simplicity and strength.[47]

Lewis says that a generalization is a law at a world *i* if and only if it appears as a theorem in each of the best deductive systems true at *i*, leaving open the possibility that two or more systems could be tied for best (1983, p. 367). A law would then be a contingent generalization that appeared in each of the best systems. But in 1994 Lewis changed his mind, arguing that relative to some world, and on the condition that nature is kind, some particular deductive system will prove to be robustly best: "If nature is kind, the best system will be *robustly* best—so far ahead of its rivals that it will come out first under any standards of simplicity and strength and balance" (1994, p. 479).

The sense in which deductive systems are abstract objects needs to be clarified. Lewis says, "Abstract entities are abstractions from concrete entities. They result from somehow subtracting specificity, so that an incomplete description of the original concrete entity would be a complete description of the abstraction. This, I take it, is the historically and etymologically correct thing to mean if we talk of 'abstract entities.'" (1986b, pp. 84–5). By abstracting from the concrete individuals of our (concrete) world, we formulate various concepts about individuals, including the formulation of theoretical ideas, like 'economic man': "We purport to speak of the abstraction 'economic man'; but really we are speaking of ordinary men in an abstract way, confining ourselves to their economic activities" (1986b, p. 86). Deductive systems are thus abstract objects insofar as the content of their constituent sentences are abstractions from concrete

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[47] The best systems analysis of laws is modeled on the conception of the sciences being bodies of knowledge organized in deductive systems. This conception of science seems to express an idealization of science, much like that speculated by Richard Feynman: "Some day, when physics is complete and we know all the laws, we may be able to start with some axioms, and no doubt somebody will figure out a particular way of doing it so that everything else can be deduced. But while we do not know all the laws, we can use some to make guesses at theorems which extend beyond the proof" (1965, pp. 49–50).

objects. For example, Newton's law of gravitation may be an axiom of a best deductive system. It states in abstract terms that the force between two objects equals the product of their masses, multiplied by a gravitational constant, and divided by the square of the distance between them. Additionally, Lewis allows for particular facts to fit into best systems if they contribute enough to overall simplicity and strength. For example, certain particular facts about the Big Bang might be included in the best deductive system of our world (1983, p. 367). Perhaps particular facts are admissible under the condition of abstraction so long as they don't give complete or exhaustive descriptions of particular events or objects. Thus a deductive system will be a set of sentences expressing abstractions, whether they are laws expressing regularities or statements of particular fact.[48]

Let's now look at six things that Lewis thought BSA accomplished. The notion of a best system is at the basis for the first four accomplishments. (1) Generality is not sufficient to make a statement a law of nature, since there are statements that are general but accidentally true. BSA differentiates laws and accidental statements: "It explains why lawhood is not just a matter of the generality, syntactically or semantically defined, of a single sentence. It may happen that two true sentences are alike general, but one is a law of nature and the other is not. That can happen because the first does, and the second does not, fit together with other truths to make a best system" (1973, p. 74). Here BSA has a clear advantage over SRT. (2) "[BSA] explains why lawhood is a contingent property. A generalization may be true as a law at one world, and true but not as a law at another, because the first world but not the second provides other truths with which it makes a best system" (1973, p. 74). (3) "[BSA] therefore explains how we can know by exhausting the instances that a generalization—say, Bode's 'Law'—is true, but not yet know if it is a law" (1973, p. 74). We may know that a generalization is true but not yet know if it is a law, if we have yet to determine whether the generalization would contribute to the simplicity or strength of a best deductive system. Merely being a generalization, even one expressing the content of Bode's 'Law', is insufficient to make the statement a law. (4) BSA explains why being a law is different from being regarded as a law and different from being regarded as a law and also being true. Laws possess an objective relation that has them together with other true generalizations forming a best deductive system. For any number of psychological reasons, true generalizations might be

[48] Lewis is open to the possibility of treating particular facts as laws: "It is open that the best system might include truths about particular places or things, in which case there might be laws about these particulars. As an empirical matter, I do not suppose there are laws that essentially mention Smith's garden, the center of the earth or of the universe, or even the Big Bang. But such laws ought not to be excluded *a priori*" (1986, p. 123). The reference to Smith's garden is from Tooley (1977).

thought to be laws, e.g., they might be thought to fit into a best system, when in fact they don't.

The next two accomplishments concern simplicity and strength. (5) "[BSA] explains why we have reason to take the theorems of well-established scientific theories provisionally as laws. Our scientific theorizing is an attempt to approximate, as best we can, the true deductive systems with the best combination of simplicity and strength" (1973, p. 74). The argument seems to be that BSA in fact underwrites our actual scientific theorizing, because the sciences aim to provide true deductive systems with the best combination of simplicity and strength. Finally (6), "[BSA] explains why lawhood has seemed a rather vague and difficult concept: our standards of simplicity and strength, and of the proper balance between them, are only roughly fixed" (1973, p. 74).

Simplicity, strength, and balance are key notions in the best systems analysis of laws. A deductive system may be simple, that is, highly systematic, if it consists of only a very few axioms, but it might lack strength, i.e., it wouldn't be informative, if very little were entailed by it. Likewise, a deductive system might be highly informative if it is replete with details about the world, at the expense of simplicity. The best systems are those that strike the best balance between the competing demands of simplicity and strength (1994, p. 478). Frustratingly, Lewis only roughly fixes the standards of simplicity, strength, and balance, offering "no precise account of simplicity, informativeness, or the rules for balancing these desiderata" (Hall, 2004, p. 97).[49] The absence of such an account leaves Lewis open to the charge that our standards are not objective, but subjective and psychologistic, especially in the case when the simplicity of a system is in question.

Alexander Bird, for instance, says that what may seem simple to one person may not seem simple to another. Pursuing a different enquiry, Putnam expresses the same sentiment: "Regularities in what scientists take to be 'simple' and 'natural' may be a matter of psychology rather than methodology" (1970, p. 240). Lewis admits that "The worst problem about the best-system analysis is that when we ask where the standards of simplicity and strength and balance come from, the answer may well seem to be that they come from us" (1994, p. 479). The general worry for laws is that a true generalization may be a law because it contributes to the overall simplicity of a best system, yet if the simplicity of a deductive system is not an objective quality of it, but is subjectively determined, then it seems that a subjective component belongs to the laws, and that "conflicts with our intuition that laws are objective and independent of our perspective" (Bird, 1998, p. 40).

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[49] Cf.: "Though, undeniably, simplicity is highly prized in science, it is not easy to state clear criteria of simplicity in the relevant sense and to justify the preference given to simpler hypotheses and theories" (Hempel, 1966, p. 41). For a detailed study of simplicity in mathematics, logic, science, and psychology see Elliott Sober (1975).

However, Lewis says that the standards of simplicity, strength, and balance may *seem* to come from us—he does not concede that they do—because he denies that the standards are contingent: "what it is to be simple and strong is safely noncontingent" (1986a, p. xi). Standards that depend on the individual people employing them would be contingent standards. By denying that they are, Lewis asserts simplicity to be a necessary and objective feature of deductive systems, even if only roughly fixed. Hence, if the standards of simplicity and strength are objective, Bird's charge of subjectivity misses the target. A somewhat pedestrian observation can now be asserted in its place: while the standard of simplicity may be objective, it's possible some people will fail to recognize it. Yet it does not follow from the fact that some people may fail to recognize what is objectively simple that simplicity is subjective.[50]

Lewis takes simplicity to be a desideratum of best systems, where a system with fewer axioms is simpler than one with more. We may ask whether some of the laws that figure in a best system must themselves be simple,[51] since it's not unreasonable to suppose that any law that contributes to the simplicity of a best system does so in virtue of itself being simple.[52] The simplicity of laws, for example, may be a consequence of the form of laws: laws taking the form of differential equations may be considered to be especially simple: linear rather than nonlinear, first order rather than second order, etc. (Putnam, 1970, p. 239). I think it would be wrong to suppose that the best systems analysis places any requirement of simplicity on individual laws. I'll develop the point starting with a quote from Russell, who argues against taking the simplicity of laws as a postulate of scientific inference:

> It is customary to add to the postulate that there are natural laws the explicit or tacit proviso that they must be *simple*. This, however, is both vague and teleological. It is not clear what is meant by "simplicity," and there can be no a priori reason for expecting laws to be simple except benevolence on the part of Providence toward the men of science. It would

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[50] Carl Hempel makes the same point: "Any criteria of simplicity would have to be objective, of course; they could not just refer to intuitive appeal or to the ease with which a hypothesis or theory can be understood or remembered, etc., for these factors vary from person to person" (1966, p. 41).

[51] Hempel distinguishes between the simplicity (and complexity) attributed to theories and the basic assumptions (or axioms) they contain: "In the case of theories, the number of independent *basic assumptions* is sometimes suggested as an indicator of complexity. But assumptions can be combined and split up in many ways: there is no unambiguous way of counting them.... And even if we could agree on the count, different basic assumptions might in turn differ in complexity and would then have to be weighed rather than counted" (1966, p. 42).

[52] Cf.: If a department wants a balance of male and female faculty members, then some members will have to be male and some will have to be female.

> be fallacious to argue inductively that since the laws we have discovered are simple, therefore probably all laws are simple, for obviously a simple law is easier to discover than a complicated one. It is true that a number of laws that are approximately true are very simple, and no theory of scientific inference is satisfactory unless it accounts for this fact. But I do not think it should be accounted for by making simplicity a postulate (1948, pp. 478–9).

Russell argues that the claim that all laws of nature must be simple is false. Our immediate concern is not about whether all laws of a best system must be simple, but the weaker claim that some of the laws must be simple, on the supposition that a best system's simplicity is due in part to the simplicity of its laws. Let's see what Lewis might say about this quote.

Like Russell, Lewis admits that 'simplicity' is a vague or unclear term. For Russell, this is a reason against a requirement that laws be simple. But we shouldn't expect Lewis to conclude similarly, since for him the vagueness of 'simplicity' proves to be no hindrance in making simplicity a desideratum of deductive systems. Thus we might expect that for Lewis the problem of vagueness would not count against the requirement that laws themselves be simple.

While it's safe to say that Lewis doesn't believe in Providence, he could provide an a priori reason for expecting individual laws to be simple, if it were a requirement of best systems that they should be simple. And if there were such a requirement, Lewis could agree with Russell, without accepting his reasons, that induction is no reason to suppose that laws must be simple. However, BSA cannot legislate that any of the laws of a best system must be simple, since the simplicity of a best system may come through the inclusion of laws that are themselves complex. If so, the simplicity of deductive systems doesn't originate in the simplicity of individual laws. For instance, take Galileo's law of falling bodies, which Russell formulates as "the distance traversed by a body falling vertically is approximately proportional to the square of the time spent in falling." Russell notes that

> … Further observations suggested that the acceleration varies slightly with the latitude, and subsequent theory suggested that it also varies with the altitude. Thus the simple law turned out to be only approximate. Newton's gravitation substituted a more complicated law, and Einstein's, in turn, was very much more complicated than Newton's (1948, p. 479).

Russell's point is that laws cannot be required to be simple, since the history of science shows the simplicity characterizing most early discoveries has given way to more accurate but complex formulae. The point I want to make is that complex laws may contribute to the simplicity of best systems. The best system for the actual world probably contains Einstein's general theory of relativity, which reduces gravity to the curvature of space-time. While complex, the laws of general relativity afford the best system a degree of simplicity, since general relativity can be used to describe the movement of large objects anywhere in the universe, from those falling on Earth to galaxies caught in mutual gravitational attraction. The scope of the explanatory and predictive power of general relativity is remarkable.

On the other hand, Galileo's law of falling bodies is simple in comparison to general relativity, but it only concerns bodies that happen to fall on Earth. If this law were to figure in our world's best system, a great number of other laws would have to be included, like the 'law of falling bodies on the Moon', 'the law of falling bodies on Mercury', 'laws of falling bodies on any planets orbiting Alpha Centauri', etc., in addition to laws stating the movement of interplanetary, interstellar, and intergalactic objects, each of which, perhaps, is a simple law. But general relativity eliminates the need for this extensive catalogue. General relativity thus affords the best system tremendous simplicity, since it will have fewer axioms than a system that tries to incorporate Galileo's law. Thus the BSA cannot require that individual laws be simple (though they may be simple), since systematic simplicity may be gained by the inclusion of complex laws.[53]

Since our world is a world that is fundamentally indeterministic, under the criterion of strength the best system will provide probabilistic laws that entail the chances of chancy events. On the hypothesis that the world exhibits indeterministic patterns in the arrangement of its qualities, a system that failed to take chance into account would fail to be true at this world, as per Humean supervenience. Lewis thus adds to the criteria of best systems what he calls 'fit': some systems "will fit the actual course of history better than others. That is, the chance of that course of history will be higher according to some systems than according to others" (1994, p. 480). For Lewis, our best systems contain axioms or theorems that assign to the history of the world a high degree of probability of being realized. Unlike deterministic laws, which entail statements about occurrences, these probabilistic laws assign probabilities to possible future histories, but do not entail that any particular history will or will not come to be actual (Black, 1998, p. 76). We will come back to the criterion for fit in Section 3.3.6, where it will figure prominently in my argument against the validity of Michael Thau's solution to the problem of undermining.

[53] A different interpretation of the injunction that laws must be simple is the following: if law-statement 1 and law-statement 2 both state the same law, then the simpler of the two is preferred. This seems to be Putnam's (1970, pp. 239–40) interpretation of the simplicity of laws. This strategy may be of practical concern to scientists, but doesn't seem to bear on Lewis's metaphysics in any way: since law-statements 1 and 2 both refer to the same proposition, they pick out the same set of possible worlds, so the preference of one to the other leads to no refinement in systematic simplicity.

I mentioned that Lewis thought that if nature were kind it would place out front the best deductive system of the actual world. But in "New Work for a Theory of Universals" (1983), Lewis thinks he has found a way of significantly limiting the competition. If we limit our theory building to those laws that only relate perfectly natural properties, the theories whose laws relate unnatural properties will be eliminated as prospective candidates. A perfectly natural property is a universal identified by fundamental physics and which figures in fundamental physical laws. Unnatural properties are any gerrymandered Cambridge or 'gruesome' properties.[54] An indefinite number of deductive systems could be constructed with predicates naming such properties. But best deductive systems will employ a primitive vocabulary that identifies properties that are universals—perfectly natural properties related by laws[55] (Lewis, 1986a, p. 124). Thus the field of competition for best system is drastically reduced; only a system whose laws relate natural properties could be best.

It might seem odd that Lewis posits the existence of certain universals, given his thesis of Humean supervenience. We might think that Humean supervenience with a possible worlds structure and set theory could provide a nominalist analysis of universals, reducing properties to sets of objects over possible worlds. But Lewis argues that fundamental universals can work for him on a variety of topics, such as "duplication, supervenience, and divergent worlds; a minimal form of materialism; laws and causation; and the content of language and thought" (1983, p. 344). Lewis argues that universals can be given an analysis like that of non-natural properties, in terms of sets of possible objects: a fundamental natural property is the set of objects that possess the universal in question. And here Lewis thinks the nature of the universal is that of an entity that may be wholly present in different bearers in space and time, as does Armstrong (1978) and Russell (1948). There's no need to examine this in greater detail here (a discussion of universals pertaining to Armstrong can be found in chapter 4). Lewis thinks that identifying universals significantly reduces the field of deductive systems competing for best system, and we can note that Lewis and Armstrong share a belief in the existence of some universals and that both take laws to involve universals.

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[54] "Properties and relations that are not genuine qualities and connections may be called *Cambridge* properties and relations. Perhaps the most notorious Cambridge property in recent philosophical literature is the property grue, i.e., the property of being green if examined before *t* and blue otherwise. An example of a Cambridge relation would be the relation holding between *x* and *y* such that *x* is green and *y* is blue" (Bealer, 1982, p. 178). A discussion of 'grue' can be found in Goodman (1983, pp. 72–81).

[55] Lewis maintains that physics discovers laws and properties together (1983, p. 368).

One consequence of Humean supervenience on BSA is that laws designate arrangements of qualities not only in present and past history, but in future history too: "Like any regularity theory, the best-system analysis says that laws hold in virtue of patterns spread over all space and time" (Lewis, 1994, p. 479). Laws are true in virtue of the total arrangement of qualities in a world. The law 'All As are B' would be false if, in the future, there were a single A that failed to be a B. Hence laws hold in virtue of the global patterns of qualities in a world. Lewis has an eternalist or block view of the universe, according to which objects and times in the past and future are just as real as present objects and present times. We will see in Section 3.3.3 that eternalism is one of the aspects of Lewis's theory of chance that makes it susceptible to the problem of undermining. I will also argue in chapter 4 that Armstrong is an eternalist about past and future objects and properties. I will use this to Armstrong's disadvantage to argue that his own theory of contingent necessitation (with chance) suffers a case of the big bad bug.[56]

3.2 Modal Realism

3.2.1 Objects, Worlds, and Sets

In *Counterfactuals* (1973) and *On the Plurality of Worlds* (1986b), Lewis defends modal realism, the thesis that in addition to the actual world, infinitely many possible worlds exist: "absolutely *every* way that a world could possibly be is a way that some world *is*" (1986b, p. 2). What is actually the case is what happens in our world. But at some possible world Koala bears are carnivorous and at another the Andromeda Galaxy doesn't exist. Lewis believes in a plurality of possible worlds because of the theoretical benefits it brings to logic, philosophy of mind, science and metaphysics. A possible worlds structure with set theory allows Lewis to pursue an austere nominalism with respect to a variety of topics, including necessary and contingent propositions, de re and de dicto modality, meaning and counterfactuals.

A possible world is an object containing other possible objects. Objects in the actual world are, according to Humean supervenience, either fundamental qualities located at points in space and time, or objects that are constituted by such qualities. But Humean supervenience is only a contingent thesis. For example, chance in the actual world supervenes on the Humean arrangement of qualities, but at some possible world chance fails to supervene on other qualities because it is a fundamental property. Presumably, too, there are worlds where minds fail to supervene on anything else or where biological qualities do not supervene on chemical or physical qualities (Lewis, 1986a, p. x).

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[56] I won't review critiques of the best systems analysis of laws, but detailed analyses can be found in Armstrong (1983, pp. 60–73), Carroll (1993, pp. 45–55), and Mumford (2004, pp. 40–8).

In the actual world, qualities are the natural qualities that physics describes, or that some future physics will describe if physics should be improved. Natural qualities are thus universals. They are basic properties, the intrinsic properties of points. All other properties supervene on basic ones, and all non-basic relations supervene on the basic ones: "all else supervenes on the spatiotemporal arrangement of local qualities throughout all of history, past and present and future" (Lewis, 1994, p. 474).

Possible worlds are causally and spatio-temporally isolated from one another. We do not create worlds, but our languages, concepts, descriptions, and imaginary representations apply to worlds (Lewis, 1986b, p. 3). Possible worlds do not differ in degrees of existence; they exist in exactly the same way that the actual world exists, differing only with respect to the objects in them. The expression 'the actual world' is indexical like 'I' and 'here,' the referents of which depend on who utters them. When we talk about the actual world, we are talking about our world; when people in other possible worlds talk about the actual world, they refer to the worlds they happen to be in.

For Lewis, individuals are not transworld individuals; an actual individual exists in no other world than the actual world. But actual individuals do have possible world counterparts.[57] If x is an object in the actual world, then x's counterpart in world w is that object that is more similar to x under a counterpart relation than any other object in w.[58] If the only difference between the actual

[57] "The counterpart relation is our substitute for identity between things in different worlds. Where some would say that you are in several worlds, in which you have somewhat different properties and somewhat different things happen to you, I prefer to say that you are in the actual world and no other, but you have counterparts in several other worlds" (Lewis, 1968, p. 28). Kripke complains in his (1971 and 1981) that non-actual non-identical objects under Lewis's counterpart relation leave us incapable of asking what is possible for actual individuals. Kripke says we could not ask, for instance, what the *actual* Nixon might have done to avert the Watergate scandal; only what a possible man, sufficiently similar to Nixon, did do in the possible world in which he lives.

[58] "Exactly which counterpart relation is relevant, and so which individuals are relevant counterparts, is a matter that varies from token to token of a given type and is influenced to a large extent by the context in which the token is produced. In particular, it is a matter of context whether similarity in a given respect has any role at all in the selection of relevant counterparts, and where various kinds of similarity have such a role, it is also a matter of context what relative weight should be assigned to each in selecting relevant counterparts. Among such matters of context are the interests and intentions of speaker and audience, background information, spatiotemporal location of utterance and the choice of words used to refer to a relevant individual. Consequently, there is no settled answer, fixed once and for all, to the question of what is true about a given individual at a given

world and *w* happens to concern *x*, they are worlds that are very similar to each other. Other worlds may be more or less similar to the actual world depending on the individuals inhabiting them. A possible world containing no counterpart of the Andromeda Galaxy is more like our world than a world with fewer spatial dimensions. Worlds are similar in virtue of the counterpart relations between objects in worlds—world *a* may be similar to world *b* if the objects in *a* are in sufficiently many counterpart relations with the objects in world *b*. Worlds like *a* and *b* are discernible in virtue of difference of arrangement of their qualities.

3.2.2 Applications

Lewis explains modality in terms of possibilia with set theory. To begin this section, I give very brief accounts of Lewis's treatment of the terms 'actual', 'possible', 'necessity', 'impossibility', and 'contingency' (1986b, pp. 5–14). Something is *actual* if it is the case in our world. Something is *possible* if it might be the case—there is a possible world where it is the case. On Lewis's possible worlds model, modality is equivalent to quantification over possible worlds with restricting modifiers. *Possibility* is explicated as existential quantification over worlds with a restricting modifier within the scope of the existential quantifier. For example, possibly there are blue swans if and only if, for some world *w*, at *w* there are blue swans (1986b, p. 7). 'At *w*' restricts the scope of the existential quantifier, limiting it to world *w*. *Necessity* is explicated as universal quantification where the restricting modifier restricts the individuals to be considered: Necessarily all swans are birds if and only if, for any world *w*, quantifying only over parts of *w*, all swans are birds (1986b, p. 7). *Impossibility* is explicated as quantifying over no worlds, and *contingency* is explicated as something being the case in at least one world but not the case in another. A contingent property, for instance, is a property that belongs to an object in some possible world but does not belong to its counterpart in some other possible world.

Restricting modifiers play an important role for defining species of modality. 'Nomological necessity' is a form of modality restricted by those worlds that obey the same laws of nature as ours (Lewis, 1986b, p. 7). Nomological necessity is universal quantification over a proper sub-set of all possible worlds, since not all possible worlds obey the laws of the actual world. The access relations between worlds that are nomologically similar correspond to the modal system S4, in which worlds are reflexively and transitively accessible to each other. Modality *de re* indicates the essence and potentiality of things, and is understood as quantification over possible individuals restricted by counterpart relations (1986b, p. 8). Similarity between worlds or individuals seems to restrict

world. Representation de re is inconstant, and counterpart theory reflects this" (Divers, 2002, p. 123).

the scope of quantification. And since modal terms are defined by quantification over sets of possibilia, modality supervenes on sets of possibilia.

Possible worlds also bear on the analysis of properties. To illustrate, take nominalism under the thesis of Humean supervenience without the resource of a possible worlds structure. Property *F* would thus be analyzed as the set of all actual objects that exhibit *F*. But problems of coextension arise without a possible worlds structure. Take the properties creature with a heart and creature with a kidney. According to set theory and Humean supervenience, the property creature with a heart is the set of all the individuals that have hearts, and the property creature with a kidney is the set of all individuals that have kidneys. In the actual world, all and only creatures with hearts have kidneys, so that the extensions of these properties are identical. The property creature with a heart turns out to be identical to the property creature with a kidney – an unwelcomed result. But under modal realism we allow sets of individuals to range beyond the actual world to include possible world individuals. Now the problem of coextension is nearly resolved, since in some possible world creatures with hearts don't have kidneys. The set of all possible individuals that are creatures with hearts will be distinct from the set of all possible individuals that are creatures with kidneys. Nearly resolved, for Lewis recognizes problematic cases even for modal realism, for example, the property of triangularity may be necessarily coextensive with the property of trilaterality.

> Lewis also applies modal realism to an analysis of propositions.
> We may take sets of worlds to *be* propositions. A proposition *P* is true at a world *i* if and only if *i* belongs to the proposition—the set—*P*. There is a proposition for every set of worlds because the set itself is the proposition true at all and only the worlds in the set. For any sentence φ, let $[[\varphi]]$ be the set of worlds where φ is true. $[[\varphi]]$, being a set of worlds, is a proposition; call it the proposition *expressed* by the sentence φ. Then a sentence φ is true at a world *i* if and only if the proposition $[[\varphi]]$ expressed by φ is true at *i*; that is, if and only if *i* belongs to the proposition $[[\varphi]]$ (1973, pp. 46–7).

One may detect a circularity involved in this account of propositions, since the proposition *P* is the set of possible worlds where the proposition is true. As Loux says, "the notion we are attempting to explain appears in the explanation" (1998, p. 178). Loux provides a non-circular account of propositions under Lewis's and other possible worlds nominalists' proposals by clarifying what it means for a proposition, *p*, to be true in a given possible world, *W*:

> Is it not simply a matter of *W*'s being a world where it is the case that *p*? And is it not so that *W* is a world where it is the case that *p* if and only if *W* is a world of a certain sort? But what sort of world must *W* be to be a world where it is the case that *p*? Well, it must be what we might call a *p*-

> ish world. Now, we can understand possible worlds nominalists to be proposing that we take the idea of a *p*-ish world as basic. We could express the proposal by saying that it is an ontologically basic fact about a possible world that it is an [all swans are white]-ish world... But if we suppose that facts like [this] are irreducibly fundamental, then the claim that propositions are sets of possible worlds is noncircular. It is simply the claim that the proposition that all swans are white is the set of all and only those possible worlds that are [all swans are white]-ish worlds... Understood in these terms, the thesis that propositions are sets of worlds is just an extension of the possible worlds nominalists' treatment of properties...the idea that a property, *F-ness*, is a set theoretical entity whose ultimate members are things that are *F* or *F-ish*. The proposal that a proposition, *p*, is the set of possible worlds that are *p*-ish is simply the invitation to treat propositions as something like global properties that partition worlds rather than their inhabitants into sets accordingly as they meet or fail to meet certain descriptive conditions (1998, pp. 178–9).

How does Lewis's analysis of propositions bear on his theory of laws? On the best systems analysis of laws, a law of nature will be a set of possible worlds, since it is a proposition that is a theorem of a best system. If φ is a sentence expressing a law of a best system, then it expresses the proposition $[[\varphi]]$, a set of possible worlds. If proposition $[[\varphi]]$ is true in possible world *W*, then *W* is a world that belongs to the set of possible worlds that is the proposition $[[\varphi]]$. Put in Loux's terms, $[[\varphi]]$ is true at *W* if and only if *W* is a $[[\varphi]]$-ish world, a world whose global character exhibits the regularity described by $[[\varphi]]$. $[[\varphi]]$ itself is the set of all possible worlds that exhibits the character of being $[[\varphi]]$-ish. We may also consider best systems of laws to be sets of possible worlds, that is, super-sets of sets of possible worlds that are the axioms and theorems (propositions) of those systems.

3.3 The Problem of Chance

3.3.1 Credence and Chance

For Lewis, chance and credence are different kinds of probability. Chance is objective single-case probability, e.g., the .5 probability that a particular atom of tritium will decay within the next 12.26 years (1994, p. 475).[59] Credence concerns our subjective degrees of belief. Chance does not depend on people's beliefs about chances, whether those beliefs are warranted by total available evidence or by unrepresentative samples (1994, p. 475). Lewis's interpretation of chance, then, appears to be non-subjective. Yet chance and credence are connected in the following way:

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[59] Howson and Urbach (1989) have an alternative view, arguing that single-case probabilities are subjective, not objective. See also Gillies (2000).

> If a rational believer knew that the chance of decay was 50%, then almost no matter what else he might or might not know as well, he would believe to degree 50% that decay was going to occur. *Almost* no matter; because if he had reliable news from the future about whether decay would occur, then of course that news would legitimately affect his credence. This connection between chance and credence is an instance of what I call the *Principal Principle* (1994, pp. 475–6).

Objective chance constrains rational belief about chances. The Principal Principle is at the center of what will be Lewis's trouble with objective chance. But before elaborating on the Principal Principle and the problem of chance, we should look at two Humean theories of chance that Lewis rejects: symmetries and frequencies.

Symmetries may, as a principle of indifference, serve as chance-makers for chances. Lewis provides a humorous illustration:

> Suppose a drunkard is wandering through a maze of T-junctions, and at each junction we can find nothing that looks like a relevant difference between the case that he turns left and the case that he turns right. We could well understand if rational credence had to treat the cases alike, for lack of a relevant difference. If the symmetry is something that would, if known, constrain credence, then it is suitable to serve as a chancemaker. In short, Humean chances might be based on a principle of indifference (1994, p. 476).

The principle of indifference was coined by Keynes, but invented by Laplace (1951, first published in 1820). The principle states, "whenever there is no evidence favoring one possibility over another, they have the same probability" (Hájek, 2008). The principle of indifference is also found in the logical analysis of probability, like Keynes's (1921), giving the analysis an a priori basis for setting probability values. The reason Lewis calls symmetry a principle of indifference is that symmetries provide an a priori ground for why at each junction the drunkard has an equal chance of turning right as he does left.

However, a posteriori frequencies would seem to defeat symmetries. Suppose we had evidence that the drunkard turned right 90 percent of the time. This evidence places a new constraint on our beliefs such that we should believe to degree 90% that the drunkard will next turn right. So frequencies would seem to be the real chance-makers for chances: "A frequency is the right sort of thing to be a Humean chancemaker: it is a pattern in the spatiotemporal arrangement of qualities.... The simplest frequency analysis of single-case chance will just say that the chance of a given outcome in a given case equals the frequency of similar outcomes in all cases of exactly the same kind" (1994, p. 477). The simple frequency theory that Lewis considers would be an appropriate addition to the simple regularity theory for probabilistic laws.

Lewis thinks that the simple frequency theory works well enough when there are enormous classes of exact copies, like the abundance of tritium atoms. But not so for atoms of unobtainium^{346}, which is difficult to make and only two examples of it will ever exist. The first one had a lifetime of 4.8 microseconds, the second a lifetime of 6.1 microseconds. "So exactly half of all Un^{346} atoms decay in 4.8 microseconds. What does this frequency make true concerning the half-life of Un^{346}, in other words concerning the chance that an atom of it will decay in a given time? Next to nothing, I should think" (1994, p. 477). Why so? Because the sample is so small it would be unreasonable to suppose we could specify the decay time of Un^{346}.

Now consider isotope Un^{349}. Not a single instance of it has ever existed in all of space-time, but it is theoretically possible. "Its frequency of decay in a given time is undefined: 0/0. If there's any truth about its chance of decay, this undefined frequency cannot be the truthmaker" (1994: 477). If there is any truth of the chance of decay for Un^{349}, the truth-maker must be uninstantiated. So frequencies fail to provide us the chance of decay for classes of objects that are extremely rare or that don't exist but are theoretically possible. Lewis's solution to the unobtainium problems requires single-case chances to follow from general probabilistic laws of nature:

> There are general laws of radioactive decay that apply to all atoms. These laws yield the chance of decay in a given time, and hence the half-life, as a function of the nuclear structure of the atom in question. (Or rather, they would yield the chance but for the intractability of the required calculation.) Unobtainium atoms have their chances of decay not in virtue of decay frequencies for unobtainium, but rather in virtue of these general laws (1994, pp. 477–8).

Lewis conceives general laws of radioactive decay to be functional laws, whose arguments are substituted by magnitudes correlated with the nuclear structure of species of atoms: "the best system will contain a functional law whereby chance depends on the value of *M* in that particular case. [...] That's how we can get decay chances for Un^{346}, and even for Un^{349}, in virtue of chancemaking patterns that don't involve decay frequencies for unobtainium itself" (1994, p. 481). Accordingly, we could calculate the decay rate for a species of object irrespective of how many samples we have. These general probabilistic laws would be theorems or axioms of the best system of laws for a world.

For Lewis chance events themselves are not independent of each other. The laws of probability and total world history determine the chances. Chance thus seems to be a non-local or relational property of an event, a consequence of Lewis's Humean thesis: if chances are not fundamental features of the world, then they must supervene on the total arrangement of the qualities of the world. On Lewis's view, the probabilistic causal event sequence A causing B is not a local affair involving only A and B. Lewis requires A probabilistically causing B, or the chance that A will cause B, to be determined by probabilistic laws of nature and total states of affairs. Perhaps it would be better to say that the actual event of B following A is a local affair – it concerns just those states of affairs at a specific segment of space and time. But insofar as it is a chancy event, its chanciness supervenes on all Bs to have followed As in history. The chance of an event in the actual world supervenes on Humean qualities. This view of chance is very different from that which Armstrong and van Fraassen would advocate, by which the chance of decay of a particular atom does not depend on previous or future history of the world. For Lewis, the entire history of the world in conjunction with the probabilistic laws of nature provides the chances for future events and future histories. The laws of nature supervene on the arrangement of qualities of total world history, as does the truth of any true generalization.[60]

3.3.2 The Principal Principle

The Principal Principle is a general principle that is supposed to capture our intuitions about our knowledge of chances. It is also supposed to capture all we know about chance. The Principal Principle concerns chance, not frequency, and "it will incorporate the observation that certainty about chances – or conditionality on propositions about chances – makes for resilient degrees of belief about outcomes" (Lewis 1986a: 86). Our degrees of belief about future outcomes are conditional on certainty about propositions about chances. Beliefs about future outcomes are thus dependent on beliefs about chances.

Lewis's first formulation of the Principal Principle in "The Subjectivist's Guide to Objective Chance" (1986a, p. 86) is the special case where someone knows what the chances are: $C(A|XE) = x$. Let C be a reasonable credence function, t any time, $0 \leq x \leq 1$, X the proposition that the chance at t of A's holding equals x, E any proposition stating evidence that is compatible with X and is admissible at t, and A a statement that may be true at t. Suppose that A is the proposition that a certain coin tossed tomorrow at noon will land heads. Suppose also that E is the proposition that the coin and toss set-up are fair, and that X is the proposition that there is a 50% chance that the coin tossed tomorrow at noon will land heads up. Then our credence that A will be true at t is 50%, conditional on evidence E that the coin is fair and X that there is a 50% objective chance at t that the coin will land heads.

The Principal Principle is an instance of Bayes' Theorem, proven by use of the definition of conditional probability and substitution of equivalent statements. Since the Principal Principle is a statement of conditional probability, it can be defined using the standard definition for conditional probability:

[60] "We may be certain *a priori* that any contingent truth whatever is made true, somehow, by the pattern of instantiation of fundamental properties and relations by particular things. ...truth is supervenient on being" (Lewis 1994: 473).

$$\text{PP: } C(A \mid XE) = \frac{C(A\&XE)}{C(XE)}.$$

The conjunctive statement in the definiendum has the following equivalences:

$C(A\&XE) = C(A \mid XE)\, C(XE) = C(XE \mid A)\, C(A).$

Substituting the second equivalence for the conjunctive statement, we get Bayes' Theorem:

$$\text{PP: } C(A \mid XE) = \frac{C(XE \mid A)\, C(A)}{C(XE)}.$$

The proposition *E* is such that it may admit new evidence that on reflection would lead us to change the value of *x* in *X*. Under such circumstances, a rational agent's degree of belief that *A* will hold at *t* should also change accordingly, since it is measured by *x*. For instance, it may be discovered on close inspection that our coin is actually slightly off balance from center, *E'*. This would affect the value of *x* in *X*: perhaps *X'* states that there is a 53% chance that the coin will land heads at *t*. Thus our credence in *A* will be 53%. Any admissible proposition *E* may affect our belief in the present chances of *A*'s truth. Admissible propositions (typically about evidence) are admissible prior to or at *t*. They have direct bearing on the present chances that *A* will be true. Inadmissible evidence contains information about what happens after *t*, like the actual result of the toss of a coin. More will be said about admissibility and inadmissibility in the next section.

The Principle is given a more general formulation by Lewis, which itself undergoes revision in light of the solution to the problem of undermining. We'll see these changes in the Principal Principle as we deal with the problem of undermining and its solution.

3.3.3 The Big Bad Bug

For Lewis the problem of undermining is first expressed as a vague concern that chances undermine themselves. He then formulates a proper argument where the problem shows up as a contradiction in the Principal Principle. First I'll give an account of the problem as a feature of present chances to undermine themselves.

Lewis's setup (1994, p. 482) involves an argument with a number of assumptions peculiar to his metaphysics of laws. I've standardized it to make it clear:

1. Assumption: Probabilistic laws, plus present conditions to which those laws are applicable, give present chances.
2. Assumption: Probabilistic laws obtain in virtue of the fit of candidate systems to the whole of history.
3. If present chances are given by probabilistic laws, plus present conditions to which those laws are applicable, and if those laws obtain in virtue of the fit of candidate systems to the whole of history, then present chances supervene upon the whole of history, future as well as present and past. (Supplied)
4. Present chances supervene upon the whole of history (Humean supervenience). (1, 2, and 3)
5. If present chances supervene upon the whole of history, then different alternative future histories would determine different present chances. (Supplied)
6. Different alternative futures would determine different present chances. (4 and 5)
7. Assumption: The differences between alternative futures are differences in the outcomes of present or future chance events.
8. If different alternative futures determine different present chances and the differences between alternative futures are differences in the outcomes of present or future chance events, then each of these futures will have some non-zero present chance of coming about. (Supplied)
9. Each future has some non-zero present chance of coming about. (6, 7, and 8)

The conclusion is compatible with the general claim that an indeterministic world is one where non-actual futures have non-zero present chances of coming to pass.

Lewis then states in general terms the problem that alternative futures give present chances:

> Let *F* be some particular one of these alternative futures: one that determines different present chances than the actual future does. *F* will not come about, since it differs from the actual future. But there is some present chance of *F*. That is, there is some present chance that events would go in such a way as to complete a chancemaking pattern that would make the present chances different from what they actually are. The present chances *undermine* themselves (1994, p. 482).

Lewis provides an illustration. "There is some minute present chance that far more tritium atoms will exist in the future than have existed hitherto, and each one of them will decay in only a few minutes. If this unlikely future came to pass, presumably it would complete a chancemaking pattern on which the half-life of tritium would be very much less than 12.26 years" (1994, p. 482). Could future *F* come to pass given that present chances say it is unlikely? Lewis's answer is yes and no: yes, since there is a non-zero present chance of it; no, since *F*'s coming to pass contradicts the truth about present chances that favour actual future *A*: "If it [*F*] came to pass, the truth about present chances would be different. Although there is a certain chance that this future will come about, there is no chance that it will come about while still having the same present chance it actually has. It's not that if this future [*F*] came about, the truth about the present would change retrospectively. Rather, it would never have been what it actually is, and would always have been something different" (1994, p. 482).

Lewis characterizes the undermining in this example as no worse than peculiar. But undermining shows up much more seriously in the Principal Principle in the form of a contradiction. Lewis shows how the contradiction arises in a reformulation of the Principal Principle that does not involve knowledge, but conditioning: $C(A \mid E) = P(A)$. C is an initial credence function; A is a proposition that may be true at time t; E a proposition that conjoins a statement about total admissible evidence before t and a statement about the chance at time t that A holds; P is a probability function. The probability that A will be true at time t is a function of our rational degree of belief that A will hold given total admissible evidence (I explain this at the end of this section). Let A denote actual future history. A is conditional on E, providing a certain degree of belief that A will be true at t. And the probability that A will be true, $P(A)$, is equivalent to the value of our degree of belief that it will hold. Now what will the Principle $C(A \mid E) = P(A)$ have to say about our credence in alternative future F? $C(F \mid E) = 0$, because F is inconsistent with E. But then again, $C(F \mid E) \neq 0$, because F has a non-zero chance of coming to pass. Thus we have a contradiction. Lewis explains: "Our problem, where F is an unactualized future that would undermine the actual present chance given by E, is that $C(F/E) = 0$ because F and E are inconsistent, but $C(F/E) \neq 0$ by the Principal Principle because E specifies that F has non-zero chance of coming about" (1994, p. 485). Lewis suspects that the problem involves chance-making patterns that lie in the future (1986a, p. 130; 1994, p. 483) and that proposition E is inadmissible because it is based on actual chance-making patterns that exclude F and other alternative futures. His suspicion is correct, but it is Michael Thau who identifies the problem correctly.

Before working through the solution to undermining futures we need to say something about the concepts of admissibility and inadmissibility. But before doing that I want to address Lewis's point that chances are not determined by degrees of belief in the revised Principal Principle. For it certainly seems that in '$C(A \mid E) = P(A)$' the left-hand side of the equation, a statement about credence, sets the probability value for the right-hand side, a statement about the chance that A will be true at time t. Yet Lewis told us that this principle doesn't concern knowledge, but conditioning. I think the idea behind Lewis's claim is that $C(A \mid E)$ states that A is conditional on E. The information that E conveys is true, since it is a conjunction of statements that express probabilistic laws (which are true generalizations) and the history of the world up to time t. Thus proposition E supervenes on total world history, so is true. E also conveys the objective information of the present chances that *A* will be true at time *t*. This should constrain rational belief in *A* to degree *x*, which is also the probability that *A* will be true, *P(A)*. So the value of *P(A)* has its basis on *A* given *E* in $C(A \mid E)$. The rational agent should believe to degree *x* that *A* will be true and *A* has a probability *x* of being true. Both the value of credence placed in *A* and the probability that *A* will be true are based on the conditioning of *A* on *E*, so the revised Principal Principle concerns conditioning, not knowledge.

3.3.4 Admissibility

Admissibility is a key element of the Principal Principle: "The power of the Principal Principle depends entirely on how much is admissible" (Lewis, 1986, p. 92). Lewis doesn't give us a definition of admissibility. Rather, he suggests two sorts of information that are generally admissible. The first is historical information. "If a proposition is entirely about matters of particular fact at times no later than *t*, then as a rule that proposition is admissible at *t*" (1986a, p. 92).[61] Admissible propositions about a coin toss include any information about the structure of the coin, about previous tosses of coins just like it, and details about the set-up for the toss. And information that appears completely irrelevant to the outcome of the toss is also admissible. So a proposition about the history of the world up to and including *t* is an admissible proposition.

The second sort of admissible information is hypothetical information about chance in the form of history-to-chance conditionals. Such conditionals state how chance depends on history, but nothing about how history happens to turn out—they only state how chance depends on past history (Lewis, 1986, p. 96). The antecedent of such a conditional is a proposition about complete history up to a certain time, the consequent a proposition about chance at that time. A set of such conditionals constitutes a theory about how chance works. "It might be a miscellany of unrelated propositions about what the chances would be after various fully specified particular courses of events. Or it might be systematic, compressible into generalizations to the effect that after any course of history with property *J* there would follow a chance distribution with property *K*" (Lewis, 1986, p. 96).

Michael Thau argues to Lewis's satisfaction that the argument leading the Principal Principle to contradiction is unsound. Lewis thought that the admissibility of propositions is time dependent. Propositions are admissible at *t* if they are about events prior to *t*. Inadmissible propositions contain information about the outcome of chance events after *t* – they are inadmissible because they are about actual chancemaking patterns in the future arrangement of qualities.

[61] "A proposition is *about* a subject matter—about history up to a certain time, for instance—if and only if that proposition holds at both or neither of any two worlds that match perfectly with respect to that subject matter" (Lewis, 1986b, p. 93).

Thau, however, argues that admissibility and inadmissibility are not time-dependent notions. Rather, propositions are admissible or inadmissible relative to other propositions. For example, a proposition may contain information about a state of affairs prior to a coin-flip but nevertheless be inadmissible. This would be the case if one believed in temporally backward causation. If, say, "an outcome of heads determinately causes some event *E* to happen in the past, then information that *E* has occurred may be inadmissible" (Thau, 1994, p. 500). *E*'s inadmissibility is relative to the proposition believed to be true about backward causation. On the other hand, a proposition may be admissible even though it contains information about a future state of affairs. "Consider some event which will occur after the coin toss and suppose that it is not believed that there is any correlation between this event and the outcome of the toss. Then beliefs about this are admissible, even though it occurs in the future" (Thau, 1994, p. 500). So admissibility is a relation that holds between propositions – it is not a property belonging to a single proposition at a time (Thau, 1994, p. 500).

3.3.5 Thau's Solution

So how does the new condition for admissibility affect the argument from the Principal Principle? The special case of the Principal Principle was $C(A|E) = P(A)$. Proposition *E* is the conjunction of the proposition *T* stating for world *w* a total theory of chance[62] and the proposition *H* stating the complete history of world *w* up to time *t*. Lewis believed that *E* was admissible for any *A*, since *T* and *H* were admissible for any such proposition. Hence *E* is admissible with respect to alternative future *F*. And herein lies the problem, for *E* is not admissible with respect to any proposition whatever. *E* is in fact inadmissible vis-à-vis *F*, since *T* contains information that directly contradicts *F*: "If one has a *JC* view of chance

[62] Thau talks about a complete theory of chance rather than probabilistic laws, as Lewis sometimes does, for example, "Let T_w be the complete theory of chance for world *w*—a proposition giving all the probabilistic laws, and therefore all the true history-to-chance conditionals, that hold at *w*" (Lewis, 1994, p. 487). Bigelow, Collins, and Pargetter provide further clarification: "By a 'complete theory of chance', Lewis means a complete set of 'history-to-chance conditionals.' A history-to-chance conditional has as its antecedent a fully specific proposition about history up to some particular time *t*. This antecedent is a full and complete description of some possible initial segment of history. The consequent of a history-to-chance conditional is a proposition that fully specifies the chance distribution obtaining at time *t*. A history-to-chance conditional is a subjective conditional rather than a material conditional" (Bigelow et al., 1993, p. 445). Thau considers quantum mechanics to be an example of a theory of chance (1994, p. 492, fn. 1).

[a justified certainty view of chance[63]], then T_w itself provides direct evidence about the future, since on such a view accepting T_w forces one to rule out futures which would undermine belief in T_w. Hence, T_w cannot be admissible with respect to such futures"[64] (Thau, 1994, p. 500). Since T is inadmissible relative to F, E is inadmissible relative to F.

The contradiction is now blocked:

> Let F again be an undermining future. We then have: (i) $C(F/T_wH_w) = 0$, but (ii) $P_{tw}(F) = r > 0$. The special case of the Principal Principle in conjunction with (ii) does not yield that $C(F/T_wH_w) = r$, since on JC views of chance T_w is inadmissible with respect to any undermining future F (Thau, 1994, p. 500).

$C(F | T_wH_w) = 0$ because F undermines T, which states the chance for actual future history. Conditional on T_wH_w, we give zero credence to F. And $P_{tw}(F) = r > 0$ because of the theory of chance we have adopted: if the world is indeterministic, then there is a non-zero chance that in the future a history different from the actual history will come to pass. At this point Lewis would have said that if $P_{tw}(F) = r > 0$, then $C(F | T_wH_w) \neq 0$. Contradiction. But Thau shows us that T (and so Lewis's E) is not admissible relative to F, since T contains information that contradicts F, namely, that F has no chance of coming to pass. Thus our degree of belief in F, conditional on T_wH_w (i.e., E), is in fact zero; it was false to suppose $C(F | T_wH_w) \neq 0$. On the supposition that admissibility is relative to propositions, the contradiction is blocked.

Lewis takes three lessons from Thau. (1) Admissibility admits of degrees: "A proposition E may be imperfectly admissible because it reveals something or other about future history; and yet it may be very nearly admissible, because it reveals so little as to make a negligible impact on rational credence" (1994, p. 486).

(2) Degrees of admissibility are a relative matter: "The imperfectly admissible E may carry lots of inadmissible information that is relevant to whether B, but very little that is relevant to whether A" (1994, p. 486). This seems to be Thau's main point, that propositions are admissible relative to other propositions. For example, the blocking of the contradiction took T to be admissible relative to A, but inadmissible relative to F. T was inadmissible relative to F, since the former gave no chance of being true to the latter.

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[63] A justified certainty view of chance is "any view according to which certainty about complete world history can justify certainty about the chances" (Thau, 1994, p. 495). According to Thau, Lewis's theory is a species of JC. Thau also thinks that the problems that face Lewis's theory face all JC theories of chance.

[64] The subscripts in this quote refer to the actual world w. Sometimes I drop subscripts when the context is clear, e.g., 'T' would refer to the theory of chance for actual world w.

(3) Near-admissibility is good enough to preserve the Principal Principle: "If E specifies that the present chance of A is $P(A)$, and if E is nearly admissible relative to A, then the conclusion that $C(A/E) = P(A)$ will hold, if not exactly, at least to a very good approximation. If information about present chances is never perfectly admissible, then the Principal Principle never can apply strictly. But the Principle applied loosely will very often come very close, so our ordinary reasoning about chance and credence will be unimpaired" (1994, p. 486). The reason why information about present chances is never perfectly admissible is that E carries information about outcomes of future chance events. But E may be imperfectly but nearly admissible relative to some other proposition, because the information it carries may reveal so little about future chance events that its impact on credence is negligible. Lewis thinks the Principle affords credence values in most cases, and that is good enough. Only in some cases does the Principle fail to give us approximate values, like in the case of undermining: "And one of these applications that cannot be regained will be the one that figured in our reductio. If F is a future that would undermine the chances specified in E, then, relative to F, E is as inadmissible as it could possibly be. For E flatly contradicts F. Our use of the Principal Principle to conclude that $C(F/E)$ is non-zero was neither strictly nor loosely correct. Hence it no longer stands in the way of the correct conclusion that $C(F/E) = 0$" (1994, p. 486).

Lewis (1994, p. 487) thus corrects the Old Principal Principle to give us a new one:

(OP) $C(A \mid HT) = P(A)$
(NP) $C(A \mid HT) = P(A \mid T)$

Where the Old Principle conditionalized on the complete theory of chance T on just the left side of the equation, the New Principle conditionalizes on T on both sides. The consequences can be clearly shown in the case where F states an undermining future. For the Old Principle $P(F) \neq 0$, because, according to indeterminism, in the future there is a non-zero chance that an undermining future will come to pass. And $C(F \mid HT) = 0$ because HT entails the chance of the actual future coming to pass, contradicting F. Thus we have a contradiction: the values of the left and right-hand formulae are different.

The New Principal Principle solves the problem by making $P(A)$ conditional on T. Thus in the case of the chance of an undermining future F, $P(F \mid T) = 0$, because T is inadmissible relative to F. The contradiction is thus solved: $C(F \mid HT) = P(F \mid T)$. The Old Principle works approximately in most cases where imperfectly but very nearly admissible propositions have no appreciable effect on credence. But the Old Principle ends up in contradiction when alternative futures are under consideration. The New Principal Principle works exactly in this case, showing that relative to T_w no credence is to be given to alternative futures.

3.3.6 Inadmissibility without Undermining

I will now argue that on Thau's solution a theory of chance cannot be applied to actual world history. If so, then best systems with probabilistic laws won't fit indeterministic worlds and the best systems analysis fails to explicate probabilistic laws of nature.

Suppose that a proposition is *admissible* relative to another proposition only if it does not carry information about the outcome of future chance events; if it does carry such information, it's *inadmissible*. Thau seems to agree:

Statement 1 A proposition is inadmissible if it provides direct information about what the outcome of some chance event is (1994, p. 500).[65]

By statement 1 T is inadmissible with respect to alternative future F, as we saw in the New Principle. T provides information about what the outcome of the future is because it assigns a higher chance to the actual future coming to pass than to any alternative future. This is due to the fact that the actual future, along with present and past events, entails the theory of chance. But if we follow statement 1 to the letter, T is straightforwardly inadmissible relative to proposition H, where H states actual global history. If statement 1 is to be taken as the criterion of inadmissibility, the criterion of fit turns out to be adversely affected. Recall that Lewis says that some systems "will fit the actual course of history better than others. That is, the chance of that course of history will be higher according to some systems than according to others" (1994, p. 480). The fit of a best system to the history of the actual world would seem to take the general form '$P(H|T) = x$', where the probability of actual history H is conditional on the theory of chance T. The best system of the actual world assigns x a higher value than any of the competing systems; indeed, it will assign a value close to 0, but if nature is kind, all competing systems will place x much closer to zero.

If a proposition is inadmissible because it carries information about the outcome of chance events, then, I argue, 'T' in $P(H|T) = x$ is inadmissible relative to actual history H, since T says that H will come to pass. The theory of chance T "provides direct information about what the outcome of some chance event is", that is, direct information that actual world history will come to pass. Thus statement 1 seems to support the claim that T is inadmissible relative to H in $P(H|T) = x$, so that this formula is invalid, in the sense that T is undefined. If T is undefined, x has no value, and $P(H|T)$ fails to fit the world.

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[65] Alternatively: "A proposition is inadmissible with respect to another proposition if it provides direct enough evidence about it" (Thau, 1994, p. 500). But also Lewis: "Admissibility consists in keeping out of a forbidden subject matter—how chance processes turned out" (1986, p. 93).

However, Thau seems to give a second reason for why a proposition may be inadmissible, a reason that could block my argument based on statement 1. He says that *T* is inadmissible *because* of undermining:

Statement 2 [a] If one has a [justified certainty] view of chance, then *T* itself provides direct evidence about the future, since [b] on such a view accepting *T* forces one to rule out futures which would undermine belief in *T*. Hence, [c] *T* cannot be admissible with respect to such futures (1994, p. 500, with modification).

The structure of this argument is [b], therefore [a], therefore [c]. In this argument, [b] is the ground for [a]: the reason why *T* provides direct evidence about the future is that *T* is undermined by alternative futures. [b] is also the ultimate reason for [c], telling us that *T* is inadmissible because it is undermined by alternative futures. According to statement 2, *T* is inadmissible because of undermining, not because *T* carries direct evidence about the future. This clearly creates a problem for my argument that *T* is inadmissible relative to actual history *H* on the grounds that *T* carries direct evidence about the future. According to Thau, I need to show that undermining occurs in the case where *H* is conditioned on *T*. But I concede that there is no such phenomenon in that special case.

To defend my position I need to argue (i) that Thau would be wrong to identify undermining as the reason why *T* bears direct information about the future, and (ii) that Thau would be wrong to identify undermining as the chief reason why *T* is inadmissible. If successful, this will free statement 1 to give the reason why a proposition is inadmissible, namely, that it carries direct evidence of the future. This is the result I need in order to make the case that best systems fail to fit indeterministic worlds on Thau's solution to the big bad bug.

Let us first address argument (i), that Thau would be wrong to identify undermining as the reason why *T* bears direct information about the future. In statement (2) the sub-argument '[a] since [b]' says that undermining is the reason why the theory of chance bears direct information about the future. However, the phenomenon of undermining seems only to indicate a sufficient condition for *T*'s carrying direct evidence about the future. That is, if an alternative future undermines a theory of chance, then *T* surely bears information about the future outcome of chance processes. But the fact that the theory of chance carries such information doesn't depend on it being undermined by some alternative future. Rather, the theory of chance carries such information because it is entailed by the chance-making patterns in the arrangement of qualities, where chance-making patterns, to quote Lewis, "are just frequencies in large and uniform classes" (1994, p. 484). Thus frequencies entail that the theory of chance carries direct evidence about the future, not the phenomenon of undermining. Thus *T* carries banned information independent of undermining.

Now we turn to argument (ii), that Thau would be wrong to identify undermining as the chief reason why *T* is inadmissible. Thau's position here can be constructed from propositions [b] and [c], such that: [b] On a [justified credence] view of chance, accepting *T* forces one to rule out futures which would undermine belief in *T*. Therefore, [c] *T* cannot be admissible with respect to such futures. Such an argument would seem to be in trouble. We just argued above that the theory of chance comes to bear information about the outcomes of future chance processes by being entailed by chance-making patterns in the global properties. Since the theory of chance bears such information independently of undermining, *T* will be undermined when it conditions an alternative future *F*. Thus *T* is inadmissible relative to such a proposition. But the ultimate reason for *T*'s inadmissibility is not that undermining has occurred, but that the theory of chance bears information about the outcome of future chance processes—a precondition for the phenomenon of undermining. Thus undermining is not the ultimate reason for *T*'s inadmissibility; the ground of inadmissibility is that *T* carries direct evidence about the future, which makes possible the phenomenon of undermining.

I think we're now in a position to claim that statement 1 provides the correct condition for inadmissibility, that is, a proposition is inadmissible if it provides direct information about what the outcome of some chance event is. My argument that Thau's solution to the problem of undermining invalidates the criterion of fit would now seem to go through. If the fit of the best system to the actual world is represented by $P(H|T) = x$, then that formula is invalid on Thau's solution to undermining, since the theory of chance is inadmissible on the grounds that it provides direct information about the outcome of chance events. *T* cannot assign a chance to actual history *H* coming to pass since *T* provides direct information about the outcome of chance event *H*.

Thau might reply that my argument is mighty peculiar, since I would have it that *T* is inadmissible relative to proposition *H*, in a case where there's no undermining at all. I agree that the result is peculiar, but I think Thau's expectation for undermining is motivated by the original problematic, that of the big bad bug. According to my interpretation, Thau's solution to that problem now seems *ad hoc*. He set out to solve the problem of undermining by revising the admissibility conditions for propositions. By the new criteria we are supposed be able to rule out those alternative futures that undermined our belief in *T*. However, Thau seems to use the phenomenon of undermining as an indication of when proposition *T* is inadmissible. His solution thus appears to be the following: when undermining occurs, the theory of chance is inadmissible. And this seems to me to be a particularly ad hoc solution to the problem. If *T* is inadmissible because it contains information about the future, then *T* is inadmissible simpliciter.

3.4 Conclusion

My argument in the previous section is that the theory of chance may be inadmissible even when there is no undermining going on. *T* contains information about future chance history, and so is inadmissible by the criterion of statement 1;

and yet undermining does not result when we try to condition *H* on *T*. The result seems to be a rather difficult problem for best systems analysis with probabilistic laws. A deductive system for the actual, indeterministic world will be the best only if it fits the world. But on Thau's solution to the big bad bug, best systems cannot fit the world, since a theory of chance is inadmissible relative to actual world history. Generalizing, my argument is that on Thau's solution, best systems cannot fit indeterministic worlds. On Thau's solution, the best systems analysis fails for indeterministic worlds, so that best systems fail to explicate probabilistic laws of nature.

Chapter 4: Contingent Necessitation

In *What is a Law of Nature?* (1983) David Armstrong promotes a theory of laws according to which laws of nature are contingent relations of necessitation between universals. The metaphysics he develops uses deterministic causal laws as paradigmatic cases of laws of nature, but Armstrong thinks his metaphysics of laws also explicates laws of other sorts, including uninstantiated laws, functional laws, and probabilistic laws. This chapter examines Armstrong's general theory of laws and its specific application to probabilistic laws of nature.

The first part of this chapter begins with an exposition of Armstrong's metaphysical assumptions and the theory that laws of nature are contingent relations of necessitation. I then examine what some of Armstrong's critics have had to say about contingent necessitation, following a line of argument introduced by David Lewis and adapted by Bas van Fraassen and Alexander Bird. These critics doubt that the necessitation relation N provides a source of natural necessity that distinguishes Armstrong's theory from the regularity theory.

The second part of the chapter focuses on Armstrong's interpretation of probabilistic laws. It begins with a discussion of the failure of symmetry found between causal and probabilistic laws and Armstrong's solution to the problem. I then examine Armstrong's proposal that we treat probabilistic laws as laws that concern the probabilities of necessitation. Next, I examine van Fraassen's (1987) arguments against Armstrong's conception of probabilistic laws. I argue that Armstrong's (1988b) response to the arguments allows him to avoid abandoning the principle of instantiation, but at the expense of coming into conflict with his own metaphysical assumption of naturalism. I then argue that there are significant similarities between Armstrong's and Lewis's theories of laws, similarities that show that Armstrong's theory of probabilistic laws harbours the big bad bug. For this reason I conclude that Armstrong's metaphysics fails to explicate probabilistic laws of nature.

4.1 Armstrong's Metaphysics of Laws

4.1.1 Assumptions

In Chapter 1, Section 3 of his book, Armstrong identifies three assumptions that prove methodologically important to his project of developing a metaphysics for laws of nature: realism about laws of nature, realism about universals, and actualism about particulars, properties, and relations. Together these assumptions guide Armstrong's critique of the regularity view of laws and his argument that laws are relations of necessitation between universals. Armstrong states another assumption, the doctrine of naturalism, at Chapter 6, Section 2. Since both nominalism and realism may be naturalistic, naturalism serves as no ally in the argument against the regularity theory of laws of nature. However, the principles of realism and actualism that Armstrong employs appear to be specifications of his doctrine of naturalism, so we begin with it.

(1) Armstrong defines the doctrine of naturalism as "the view that nothing else exists except the single, spatio-temporal, world, the world studied by physics, chemistry, cosmology and so on" (1983, p. 82). Naturalism excludes Lewis's realism about possible worlds, as well as Fregean entities, Cartesian minds, God, a realm of numbers, and other non-spatial non-temporal objects (Armstrong, 1978 Vol. 1, pp. 127–28).

Armstrong's naturalism also gives him an Aristotelian account of universals. If universals exist, we must consider them to be features of our world, so that the existence of uninstantiated Platonic universals is excluded.[66] The basic ontological category for Armstrong is states of affairs. Individuals and universals (monadic and relational) are abstractions from states of affairs—abstractions not in the Platonic sense of being transcendent to the world, but in the sense that we abstract them from states of affairs.[67] Individuals and universals are thus elements of states of affairs, and cannot exist independent of states of affairs. If universal F is an element of only states of affairs ψ, then, counterfactually, if states of affairs ψ did not exist, and states of affairs φ to which F belongs as an element does not come to exist, universal F would not exist, since there would be no states of affairs from which to abstract F.

Both nominalists and realists about universals may be drawn to naturalism. Nominalists think that nothing but particular objects, property tropes, and events populate the spatio-temporal world. Armstrong's view on universals may be called 'naturalistic realism'; a position that he thinks excludes the existence of Platonic universals.[68] We'll see in assumption 3 below that Armstrong thinks the naturalist and realist views of universals imply the principle of instantiation, which also rules against Platonic universals.

Before examining the next assumption, realism about laws, we need to say something about naturalism and possible worlds. In Section 4.1.2, we'll see that Armstrong says that laws of nature involve a relation of contingent necessitation. Armstrong names the relation making free use of the notions of contingency and necessity, which contemporary modal logic defines by possible worlds semantics.

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[66] See Michael Tooley's (1987) for a version of Platonic realism that treats laws as contingent relations among universals. Tooley thinks that uninstantiated laws are better explained by a theory of uninstantiated universals than by a theory of instantiated universals (1987, p. 72 ff.).

[67] "We may think of an individual, such as a, as no more than an abstraction from all those states of affairs in which a figures, F an abstraction from all those states of affairs in which F figures, and similarly for relation R. By 'abstraction' is not meant that a, F and R are in any way other-worldly, still less 'mental' or unreal. What is meant is that, while by an act of selective attention they may be considered apart from the states of affairs in which they figure, they have no existence outside states of affairs" (Armstrong, 1986, p. 578).

[68] "Suppose, then, that one is a *Naturalist*, believing that the space-time world is all there is" (Armstrong 1986: 580).

Armstrong's naturalism takes there to be no worlds other than the actual world, yet he makes reference to possible worlds to expound his theory of laws. For Armstrong, possible worlds are constructed out of elements of the actual world. Armstrong's theory of possibility is a combinatorial theory of possibility, which denies the existence of possible states of affairs. However, we are able to construct possible states of affairs by the mental act of combining the actual simple individuals, properties, and relations, abstracted from the states of affairs to which they belong. Simple individuals are individuals without parts, where parts themselves are individuals. (A simple individual is thus a point-instance.)

> The simple individuals, properties and relations may be combined in *all* ways to yield possible atomic states of affairs, provided only that the form of atomic facts is respected. That is the combinatorial idea. Such possible atomic states of affairs may then be combined in *all* ways to yield possible molecular states of affairs. If such a possible molecular state of affairs is thought of as the totality of being, then it is a *possible world* (Armstrong, 1986, p. 579).

Possible worlds depend on actual states of affairs, and our ability to combine individuals, properties, and relations to create possible worlds. Suppose that *a* is F but not G. '*a* is F' is a true atomic statement. But possible atomic states of affairs are expressed by false atomic statements, e.g., '*a* is G'. '*a* is G' fails to refer to an actual state of affairs, but it does refer to a possible state of affairs, provided that G is a possible property able to be had by *a* (which it might not be, e.g., if G were the property 'is a round square'). Since possible states of affairs have no existence or subsistence, false atomic statements refer to only the recombination of actual elements.[69]

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[69] Armstrong (1986) also provides conditions on how possible worlds can be expanded to include non-actual elements (Lewis's so-called 'alien' properties and individuals), and contracted to exclude actual elements. A Naturalist-Combinatorial theory of possibility denies the possibility of genuinely alien universals for expanded worlds, since quiddities (property essences) have to be posited against the doctrine of naturalism. Armstrong considers alien individuals real possibilities, adopting a "weak-haecceitism" that shows individuals to be able to be "merely, barely, numerically different from each other" (1986, p. 584). Expanded possible worlds may thus include additional individuals, but exclude additional (simple) universals. Armstrong argues that a contracted world of fewer individuals is possible, since individuals need not have existed. He also argues for possible worlds with fewer universals, with the consequence that the accessibility relations between possible worlds will be non-symmetric. Thus combinatorially possible worlds form an S4 modal logic, where worlds are transitively and reflexively accessible to each other, and not an S5 modal logic, where worlds are transitively, reflectively, and symmetrically accessible to each other.

The foregoing provides a brief account of Armstrong's theory of possible worlds under the constraint of naturalism. Possible worlds are the results of combining (or recombining) the actual elements of the world, a point we shall keep in mind when considering the contingency and necessity in Armstrong's laws.

(2) A realist about laws of nature says that laws exist independently of the minds that attempt to grasp them (Armstrong, 1983, p. 7). On what basis does Armstrong think that laws of nature exist independent of minds? Briefly, Armstrong thinks that we posit the existence of a law as an inference to the best explanation. "The sort of observational evidence which we have makes it rational to postulate *laws* which underly [*sic*], and are in some sense distinct from, the observational evidence" (1983, p. 52). On the basis that independently existing laws explain the regularities we find in nature, Armstrong finds it reasonable to posit the independent existence of laws. Laws of nature also need to be distinguished from law-statements. In Armstrong's metaphysics, laws either exist or they do not, while law-statements may be true or false. If a law-statement is true, its truth-maker is a law of nature. We'll examine the metaphysical make-up of Armstrongian laws in section 4.1.2.

(3) Realism about universals includes Platonic and Aristotelian views of universals. Platonic universals are mind-independent, eternal properties that are separate from the spatial-temporal world. On this view, universals are real beings whose separation means that they need not be instantiated in spatio-temporal objects. In contrast, Aristotelian universals are mind-independent properties that exist *in re*. According to an Aristotelian view of universals, universal properties are real repeatable features of the world.[70] Armstrong adopts an Aristotelian approach to universals, a consequence of his naturalist assumption.

Armstrong advances 'the identity view' of universals, whereby properties and relations are universals (1978 Vol. I, p. 79). "Universals I take to be monadic, that is, properties, or else dyadic, triadic ... *n*-adic, that is, relations. Universals are governed by a Principle of Instantiation. A property must be a property of some real particular; a relation must hold between real particulars" (1983, p. 82). The principle of instantiation will be discussed shortly. Notice that Armstrong says that relations must hold between real particulars. The relation being taller than, symbolized '*R*', must obtain between two objects, say Ted and Sally, symbolized 'a' and 'b', respectively. *R* is a first-order dyadic relation that obtains between two particular objects, and should Ted be taller than Sally, we symbolize the state of affairs as *R*ab. For Armstrong's theory of laws some dyadic relations relate properties. This creates some awkwardness for terminology, since the relata of dyadic, triadic, etc. relations are typically particulars (e.g., see Copi's 1986 treatment of relations). Armstrong's solution is to treat universals as kinds of

[70] "Aristotle holds that for a universal to exist, there must exist at least one instance of it.... All property instances exist in subjects or substances. If there were no horses, then there would be no universal 'horse'" (Witt, 1989, p. 52).

particulars: objects like Ted and Sally are first-order particulars; first-order universals are second-order particulars; second-order universals are third-order particulars, etc. (1983, p. 89). With these equivalences in mind, we can talk about relations that relate properties, for example, a second-order dyadic relation that relates second-order particulars, monadic properties F and G.

The second-order relations pertinent to Armstrong's theory of laws causally determine what events follow what. For example, a dyadic relation R may externally relate monadic properties F and G, such that whenever F is instantiated, G will be too. The supposed causal connection between F and G isn't due to any intrinsic qualities of F and G, but rather in virtue of the external relation that determines that whenever an object is F, it will be G. Assumption (4) – actualism – will show that Armstrong needs relations to effect causation between things, because monadic properties under the assumption of actualism are intrinsically powerless.

Armstrong's realism about universals requires the principle of instantiation. To exist, a universal must have been instantiated in some particular in the past, present, or future. In principle, a universal is a repeatable entity, capable of being in the same particular at different times, in different particulars at the same time, and different particulars at different times. We shall see below that the principle of instantiation also requires laws to have been instantiated at some time or other. There's no place in Armstrong's ontology for uninstantiated universals or uninstantiated laws.[71]

As universals cannot exist without particulars, so particulars cannot exist without universals. Particulars are non-repeatable entities that instantiate universals,[72] and particulars and universals are elements abstracted from states of affairs. Armstrong introduces the notion of states of affairs to emphasize the mutual dependence that properties and particulars have to each other. Only instantiated universals exist, and objects must instantiate some universal or other.[73] Neither universals nor particulars exist separate from states of affairs.

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[71] One might wonder about the status of uninstantiated complex properties, all of whose constituent properties are instantiated, e.g., being a left-handed schoolteacher in Perth, Australia, when there are no left-handed schoolteachers in Perth, Australia. Since the constituent properties here are all instantiated, why isn't the complex property instantiated too? The answer must lie in the fact that the putative property is a conjunctive property that fails to have an instance. (Armstrong allows for conjunctive properties, but not disjunctive or negative properties.) So the property is putatively uninstantiated even though its constituent properties are instantiated.

[72] A particular is a non-repeatable entity. Numerically the same particular couldn't exist at different places at the same time, but it may exist at different points in space-time, such as having existed yesterday and existing today.

[73] This latter claim yields a principle of the rejection of bare particulars (Armstrong, 1978 Vol I, p. 113).

The simplest possible first-order state of affairs is an object that has just one monadic first-order property, e.g., that *a* is F, where '*a*' and 'F' respectively name an object and a universal. Such a state of affairs may not be physically possible, but logically there are no simpler states of affairs. Relations between particulars, e.g., that R*ab*, are also first-order states of affairs. We'll see shortly that Armstrong wishes us to take laws of nature to be simultaneously second-order states of affairs and dyadic universals. (First-order particulars and first-order states of affairs will be referred herein simply as 'particulars' and 'states of affairs'.)

(4) Actualism is the view that "we should not postulate any particulars except actual particulars, nor any properties and relations (universals) save actual, or categorical, properties and relations" (Armstrong, 1983, pp. 8–9). Armstrong states several consequences of assuming the truth of actualism. Actualism debars us from admitting into our ontology the merely logically possible and the merely physically possible. By debarring the merely physically possible, Armstrong debars postulating dispositions and powers, "where these are conceived of as properties over and above the categorical properties of objects" (1983, p. 9). Armstrong doesn't deny that there are statements that attribute dispositions and powers to objects, but the truth-makers for these statements are not objective dispositional properties, but actual, categorical properties. Actualism accommodates the principle of instantiation perfectly well, since actualism imposes no temporal conditions on the entities we postulate in our theories: actualism does not "debar us from thinking that both the future and past exist, or are real" (1983, p. 9). A universal might have been instantiated just once in the past and is no less real for having done so.

Actualism also debars the existence of negative properties (and negative relations and negative states of affairs). A negative property is a property that is the absence of a positive property; so if *a* lacked property P, *a* would have negative property *not being* P (or non-P). Armstrong gives four arguments against the existence of negative properties (1978 Vol. 2, pp. 23–9). One of these stems from an assumption that Armstrong employs regularly in his writings, that the sure sign of something's existence is its power to cause some change, i.e., if a property exists, then it should have a power (through a law of nature) to cause some effect. So what are the causal powers of negative properties? Since negative properties are mere absences, there are no causal powers associated with them—nothing comes from nothing (1978 Vol. 2, p. 25). However, we regularly use predicates of the form '~P'. How are we, then, to interpret the truth-conditions of true statements of the form '*a* is not P'? We need to provide truth-conditions referring only to individuals with positive properties.

Armstrong's proposal is to assign statements containing negative predicates a special correspondence condition, what he calls 'counter-correspondence'. Assume 'P*a*' is true. Armstrong says this statement corresponds "simply" to the state of affairs P*a*. However, 'P*a*' counter-corresponds to all the other states of affairs in which *a* happens to be an element, e.g., G*a*, F*a*, H*a*, etc. If the only correspondence that 'P*a*' finds to *a* are instances of counter-correspondence, then 'Pa' fails to simply correspond to a state of affairs P*a*. Thus counter-correspondence seems to be the failure of simple correspondence between a statement and the object which the statement is supposed to be about. Furthermore, '~P*a*' is entailed by the failed correspondence of 'Pa' to states of affairs G*a*, F*a*, H*a*, etc. Thus the correspondent of '~P*a*' is the actual properties of *a* to which 'P*a*' counter-corresponds: "We get a correspondent for '~P*a*' without postulating that *a* has the property, *not being P*. The positive properties do the job instead" (1978 Vol. 2, p. 27).

The reason for the excursion into the question of negative properties is that one of van Fraassen's arguments against Armstrong's theory of probabilistic laws can be blocked by appealing to Armstrong's truth-conditions for negative predicates. We'll examine this possibility in Section 4.2.3.

The four assumptions – naturalism, realism about laws, realism about universals, and actualism – together paint a picture of our world for which nothing exists except the spatial-temporal world, universals and laws of nature are real features of the world, and the actual properties of particulars are the analysans of dispositions and powers.

4.1.2 Contingent Necessitation

For Armstrong, 'All Fs are Gs' expresses a law of nature if and only if a relation of necessitation relates the universals F and G. Accordingly, a law is symbolized by 'N(F,G)', which may be read variously as "it is a law that being an F necessitates being a G," "being an F necessitates being a G," or "F-ness necessitates G-ness." Notice that N directly relates universal properties, not objects or propositions. The necessity that relates objects is in virtue of the properties they instantiate and the laws relating the properties. Thus *a*'s being F necessitates *a*'s being G in virtue of the fact that there is a law that N(F,G), such that *a* is necessarily G because *a* is F.

The law that N(F,G) is a contingently necessary relation between the properties F and G. F-ness necessitates G-ness, but not necessarily. By definition of 'contingency' and on combinatorial grounds, in some possible world F-ness does not necessitate G-ness. If in the actual world F-ness does necessitate G-ness, then in some other possible world, *w*, F may necessitate H. For Armstrong, laws of nature vary across possible worlds.[74] But given the identity of F in the actual world, it is accompanied or followed by G by physical necessity if it is a law that

[74] As they do for others, including David Lewis. We'll see in Chapter 5 that dispositional essentialists take the laws of nature to depend on the dispositional identity of properties, so that any two worlds identical with respect to the objects and properties they contain must have the same laws. Dispositional essentialism thus gains ontological economy over Armstrong's theory of laws, but at the expense of making the necessity of laws stronger than Armstrong's.

N(F,G). The laws of nature could have been different from what they actually are, since they are contingent. But given what laws there are, and given that they are relations between universals, every occurrence of F in the actual world is necessarily followed or accompanied by an occurrence of G, yet it is possible that a world with all the same monadic properties as the actual world obeys a completely different set of laws. Armstrong's account of laws raises questions about how merely accidental relations between properties are to be distinguished from lawlike relations between properties—an issue I address presently.

Armstrong says (1983, p. 85) that a law entails a uniformity, but a uniformity does not entail a law:

1. N(F,G) → (x) (Fx → Gx)
2. ~ [(x) (Fx → Gx) → N(F,G)].[75]

The second statement is supposed to be true since it is possible that regularities result from accidental circumstances. For Armstrong, true accidental generalizations do not imply laws of nature. As for the first statement, it seems to tell us that if it is a law of nature that F-ness necessitates G-ness, then for anything that is F, it is also G. But as we just saw, this seems to hold only for the actual world; the universal generalization is true for the actual world (and possible worlds for which N(F,G) is a law), but false for a possible world where F exists but does not necessitate G.

The claim of formula 1, that a law entails a uniformity, requires some explanation. Armstrong treats the law that N(F,G) both as the obtaining of a relation between universals and as a complex universal. As a complex universal, N(F,G) is a second-order state of affairs. For Armstrong, states of affairs obtain at more than one level. R*ab*, for example, is a state of affairs that involves the first-order particulars *a*, *b* and the first-order universal relation R. N(F,G) is a second-order state of affairs, involving second-order particulars (first-order universals) F and G and the second-order universal N. Armstrong's thought is that if the second-order state of affairs N(F,G) is a first-order universal, then "we could assimilate the relation between law and positive instantiation of the law to a particular case of that of a universal to its instances" (1983, p. 89). So Armstrong invites us to understand the entailment in 1 in terms of a first-order universal standing to its instances, according to the principle of instantiation. If laws of nature are complex first-order universals (with higher-order laws being complex higher-order universals), then, just as monadic universals require instances, so laws require instances. Armstrong treats the law N(F,G) as a second-order state of affairs and as a complex universal.[76] The consequence of this is that if a law is

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[75] The second statement is a paraphrase of the original that uses the arrow '→' with a slash through it, meaning 'does not entail'.

[76] "I propose that the state of affairs, the law, N(F,G) is a dyadic universal, that is, a relation, holding between states of affairs. Suppose that a particular object, a, is

instantiated in some object, it is fully instantiated in the object as a second-order state of affairs. Thus Armstrong thinks it follows that the instantiation of the law necessitates the instantiation of both its terms.

Armstrong conceives laws to be dyadic universals, relations of necessitation between first-order universals. If there is a law necessitating it, the presence of a first-order universal always brings along with it the presence of another. If N(F,G) is a law of nature, then the occurrence of F and G in an object is never accidental, since the (deterministic) law necessitating the co-occurrence is itself a universal. And the law N(F,G) is a complex universal, since it is a second-order state of affairs fully present in any object that bears its instance. This brings us back to formula 1: N(F,G) → (x) (Fx → Gx). Armstrong says, "It is clear that *if such a relation holds between the universals*, then it is automatic that *each* particular F determines that it is a G. *That is just the instantiation of the universal N(F,G) in particular cases*. The left-hand side of our formula represents the law, a state of affairs which is simultaneously a relation. The right-hand side of the formula represents the uniformity automatically resulting from the instantiations of this universal in its particulars" (1983, p. 97). So the law N(F,G) is supposed to entail (via the principle of instantiation) that all Fs are Gs. If there is such a law, then everything in the actual world that is an F is a G. But the reverse entailment in 2 does not follow, since it is possible that Fs are accidentally Gs.

This concludes my exposition of Armstrong's general theory of laws. Many philosophers are unhappy with Armstrong's account of the entailment condition stated in formula 1, that a law entails a uniformity. In the next section we'll review some of these complaints, starting with those of David Lewis.

4.1.3 Critiques of Contingent Necessitation

In this section I review critiques of Armstrong's general account of laws of nature by Lewis, van Fraassen, and Bird, but I begin by briefly inquiring into whether or not contingent necessitation might be identified as a version of the regularity theory of laws. While aspects of Armstrong's theory do resemble the regularity theory, the role of Armstrongian laws in counterfactual reasoning and explanation warns against identification.

We may begin by noting that Armstrong says that there may be in the actual world a law of physical or causal necessity that N(F,G), while in other possible worlds Fs and Gs are not related by N. Armstrong doesn't invoke other worlds to explain the necessity of the necessitating relation, though he does so to explain the sense in which they are contingent. In fact, 'N' in the law that N(F,G) appears to just mean that in the actual world, G always follows F. This is Russell's plan of defining 'necessity' in terms of a propositional function always

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F, and so, because of the law N(F,G), it, a, is also G. This state of affairs, an instantiation of the law, has the form Rab, where R = N(F,G), a = a's being F, and b = a's being G: (N(F,G)) (a's being F, a's being G)" (Armstrong, 1983, p. 90).

being true. For Russell (1918), the propositional function 'if *x* is F, *x* is G' is necessary when it is always true. And this seems to be what Armstrong means when he says that in the actual world F-ness necessitates G-ness. If this is how we are to read Armstrong, then his theory of laws reverts to the regularity theory, since on the Russell plan 'necessarily if *x* is F, *x* is G' is equivalent to the proposition '(x)(Fx → Gx)'. Equating a law of nature with a universal generalization is a regularity approach to laws, something that Armstrong will want to steer far from.

We can try to construct a possible worlds model for Armstrong's laws, one that will extend the meaning of 'necessity' beyond Russell's definition. This model will be a proper subset of all possible worlds (including the actual world) in which N(F,G) is instantiated. To say that in the actual world Fs physically necessitate Gs is just to say that in those worlds in the subset, however many Fs there are, Fs cause Gs.[77] This model entails a notion of necessity that is weaker than that of logical necessity, but it does not entail one that is stronger than Russell's notion of necessity. The proposal seems to simply increase the number of (possible) objects that constitute the truth of the proposition '(x)(Fx → Gx)'. On Russell's proposal, objects that are F are limited to the actual world. In the actual world, all Fs are G, so the propositional function 'if *x* is F, *x* is G' is always true in the actual world, entailing 'necessarily if *x* is F, *x* is G', i.e., (x)(Fx → Gx). On the suggested possible worlds model, we seem to merely repeat the procedure: any object F in the subset of possible worlds is an instance of '(x)(Fx → Gx)', since in those worlds Gs always follow Fs. So there is something of the appearance of a regularity account in this experiment.

However, Armstrongian laws perform successfully in areas where the regularity theory fails, indicating that Armstrong's theory of laws resists identification with, or reduction to the regularity theory.[78] Suppose on the regularity theory it is a law that (x) (Fx → Gx) and *a* is E but not F or G. If *a* were

[77] By 'necessitation' Armstrong means causation: "We transfer the notion of causing or necessitating from particular states of affairs to the 'realm' of universals" (1988b, p. 225); "The strong theory of laws says that laws are relations between properties.... singular causal processes are identical with the instantiation of strong laws ... only a strong theory of laws is capable of sustaining a probabilistic conception of causation" (Heathcote & Armstrong, 1991, p. 71); "I hold that a probabilistic law gives *the probability of a necessitation in the particular case*. Necessitation is just the same old relation found in any actual case of a (token) cause bringing about a (token) effect, whether governed by deterministic law, probabilistic law or no law at all" (Armstrong, 1988b, p. 226).

[78] Armstrong gives an account of a number of areas where the failure of the regularity theory contrasts with the success of his own theory of laws (1983, pp. 99–107). For purpose of this discussion I discuss only counterfactual support and explanation.

F, would *a* be G? No, not automatically. Since the counterfactual instance of *a* is not part of the regularity stated by the law, we are not licensed to infer that it will have property G, though it might G. But it has been supposed that one of the ways laws are distinguished from accidental generalizations is their role in counterfactual support (e.g., Goodman, 1983, pp. 17–27). Armstrong claims his conception of laws can provide that support: the law N(F,G) supports the counterfactual 'if *a* were F it would be G', since having instantiated the universal F, *a* also instantiates the universal N(F,G), necessitating the state of affairs *a*'s being G. Since the (second-order) universal N(F,G) is identical in all its instances, then, as would any object, *a* would be G as a consequence of instantiating F in a world where it is a law that N(F,G). Since there is no clear way in which a regularity theory is supposed to support counterfactuals, counterfactual support indicates why we should not suppose that Armstrong's metaphysics offers little more than a regularity theory in disguise.

Laws are also thought to provide explanations of why the world contains law-like regularities. Armstrongian laws fill the explanatory role since regularities are entailed by relations of contingent necessitation (see previous section). However, on the regularity theory, laws are not supposed to be anything over and above regularities, so the existence of regularities goes unexplained. (This is perhaps, a criticism best leveled against the simple regularity theory, since the best systems approach explains why some regularities are laws: they are those regularities that figure in best deductive systems.) Given, then, that Armstrong sees his theory of laws performing in ways that the regularity theory cannot, we shouldn't suppose that the former may be a version of the latter. This conclusion is underscored by the fact that Armstrong employs a metaphysical apparatus entirely alien to the regularity accounts of laws; much of that apparatus might have to be jettisoned to begin the task of identification.

Let's now turn to Lewis's critique of Armstrong's theory of laws. Lewis says that Armstrong's necessary connections N are unintelligible. Lewis's argument begins by noting that Armstrong requires a necessary connection between laws and constant conjunctions. "It is necessary – and necessary *simpliciter*, not just nomologically necessary – that if *N(F,G)* obtains, then *F* and *G* are constantly conjoined. There is a necessary connection between the second-order state of affairs *N(F,G)* and the first-order lawful regularity $\forall x(Fx \supset Gx)$; and likewise between the conjunctive state of affairs *N(F,G) & Fa* and its necessary consequence *Ga*." (1983, p. 365). The necessary connections described in the last sentence of the quote can be symbolized respectively as '$\Box(N(F,G) \supset \forall x(Fx \supset Gx))$' and '$\Box((N(F,G) \,\&\, Fa) \supset Ga)$.' In both statements, the major connective is the horseshoe falling within the scope of the necessity operator, so these are cases of strict implication. This suggests that we're supposed to take the relation between laws and constant conjunctions as logical entailment. Lewis doesn't say this explicitly, but it is suggested in the following complaint:

> Whatever *N* may be, I cannot see how it could be absolutely impossible to have *N*(*F*,*G*) and *Fa* without *Ga*. (Unless *N* just *is* constant conjunction, or constant conjunction plus something else, in which case Armstrong's theory turns into a form of the regularity theory he rejects.).... [But] *N* deserves the name of 'necessitation' only if, somehow, it really can enter into the requisite necessary connections. It can't enter into them just by bearing a name, any more than one can have mighty biceps just by being called 'Armstrong' (1983, p. 366).

I think we should interpret Lewis as doubting that laws and constant conjunctions are connected by logical necessity (necessity *simpliciter*), which would make it the case that in all possible worlds '$N(F,G) \supset \forall x(Fx \supset Gx)$' is true. Such would be anathema to Lewis's modal realism, since for him there is at least one world such that it is the case that *N(F,G)* obtains and something is *F* but not *G*. Of course, Armstrong doesn't think that *N(F,G)* is a law in every possible world, so the force of the meaning of *N* and 'necessitates' is supposed to be that states of affairs involving F nomologically imply states of affairs involving G, whenever the universal *N(F,G)* is instantiated. But surely the mere meaning of a word doesn't guarantee it—thus Lewis's quip that having the name 'Armstrong' doesn't guarantee one has mighty biceps.[79]

As we saw at the beginning of this section, there is a difficulty in understanding what the relation of necessitation is. Might there also be an empiricist challenge behind Lewis's comment? He suggests that *N(F,G)* doesn't pick out anything distinct from constant conjunctions. As Alexander Bird points out, "The necessitation of Gness by Fness *looks* just like the regularity of Fs being G" (1998, p. 52). The problem for Armstrong is that if he fails to convince us that *N* is distinct from, and adequately connected to, constant conjunctions, his theory of laws will be for naught.

Bas van Fraassen advances Lewis's concern somewhat. Van Fraassen observes that Dretske (1977), Tooley (1977), and Armstrong each make the same mistake of trying to explain how the statement Fness → Gness is related to the statement 'all Fs are Gs.'[80] Dretske says the relationship is 'valid', and Tooley

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[79] Jeremy Butterfield shares Lewis's skepticism: "I have the same difficulty here as Lewis. I do not understand what N could be, other than constant conjunction together with some conditions to block the converse entailment; but in that case, Armstrong's view becomes a version of the regularity theory.... Why cannot the constant conjunction of F and G act as, or determine, a first-order universal relating a's being F and a's being G?" (1985, p. 166).

[80] Michael Tooley (1977) and Fred Dretske (1977) also develop metaphysical positions that take laws of nature to be relations between universals. Tooley's commitment is somewhat guarded: "I am inclined to accept the contention that if the account of laws set out above is correct, there is reason to believe that Platonic realism, construed only as the doctrine that there are uninstantiated universals, in

says it follows by 'logical necessitation', but van Fraassen doubts that the connection between the law statement and the generalization can be established by logic: "The contention was that *It is a law that all Fs are Gs* entails, at least, that all *F*s are *G*s. This claim requires substantiating, and the first step is to equate the law statement with *Fness* → *Gness*. The second step is to claim that this relational statement entails that all *F*s are *G*s. But this claim seems no easier to establish by deductive logic than the former" (1987, p. 116).

Van Fraassen doubts the validity of both 'If it is a law that all Fs are G, then all Fs are Gs' and 'If *Fness* → *Gness*, then all Fs are Gs.' Dretske, Tooley, and Armstrong all seem to take the truth of the first to be evident. Why doesn't van Fraassen? He might think that the propositional function 'It is a law that...' serves like the propositional attitude 'John thinks that...' Propositional attitudes are non-truth preserving, e.g., the truth of 'John thinks that Istanbul is in Greece' does not entail the truth of 'Istanbul is in Greece.' If the propositional function 'It is a law that...' functions like a propositional attitude, then the truth of 'all Fs are Gs' does not follow from the statement 'It is a law that all Fs are Gs.' However, the subjective element implied by propositional attitudes is absent from our test case, so there is a strong disanalogy against this line of reasoning. Instead, 'It is a law that...' functions more like 'It is a fact that...', where the truth of 'Grass is green' is guaranteed by the truth of 'It is a fact that grass is green'. The problem seems to start with establishing the truth of 'It is a law that all Fs are Gs'. Van Fraassen says that Dretske, Tooley, and Armstrong offer the same form of solution: "*It is a law that all Fs are Gs* is true exactly if a certain singular statement *Fness* → *Gness* is true", and '*Fness* → *Gness*' is supposed to entail 'all Fs are G' (1987, p. 115). Van Fraassen asks for the rule of deduction that permits the inference, since we can't deductively infer a general statement from a singular statement, i.e., the statement 'the property F → the property G' does not entail that all Fs are G. But van Fraassen won't find any such formal rule of deduction that supports the entailment. Rather, Armstrong seems to be using "entails" in a way such that α entails β if and only if it is de dicto necessary that if α then β. Thus if the property F really does entail the property G, this will entail that all Fs are G.[81]

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not incoherent" (1977, p. 56). His (1987) gives a full defence of Platonic realism. Dretske is somewhat coy on the topic: "I expect to hear charges of Platonism. They would be premature. I have not argued that there are universal properties. I have been concerned to establish something weaker, something conditional in nature: viz., universal properties exist, and there exists a definite relationship between these universal properties, if there are any laws of nature" (1977, p. 34).

[81] If it is true that Armstrong's use of "entails" implies a de dicto necessary clause, then if the property F really does entail the property G, this would entail not only that all Fs are Gs, but also $\Box(\forall x)(Fx \rightarrow Gx)$. Thus if N(F,G) is instantiated in some world it will be a law in all worlds, clearly a result that Armstrong should find worrisome.

On the necessitation relation specifically, van Fraassen is in complete agreement with Lewis: "Armstrong used 'necessitates' instead of '→' which is a perspicuous reminder that the argument is meant to be valid. In commenting on this, David Lewis points out correctly that validity is no more guaranteed by the meaning of 'necessitates' here than someone is guaranteed to have mighty biceps by the meaning of 'Armstrong'" (1987, p. 116–17). Van Fraassen interprets Lewis to doubt that N connects with constant conjunctions by means of a logical relation or the meaning of the non-logical terms involved.

Alexander Bird's (1998) argument focuses on Lewis's claim that N might not be much different than a constant conjunction. Bird argues that the properties that Armstrong attributes to necessitation fail to distinguish the nomic necessitation view from the regularity view of laws. Armstrong attributed the following properties to necessitation: (1) the law N(F,G) entails that everything which is F is also G; (2) the reverse entailment does not follow; (3) since necessitation is a relation, it is a universal; (4) since necessitation is a universal, it has instances. According to Bird, the Ramsey-Lewis systematic account also satisfies (1)–(4) in the following way. Let the relation RL (for 'Ramsey-Lewis') be taken to hold between universals F and G if and only if it is a law that Fs are Gs.

> The requirements on RL are as follows: The properties F and G are RL related precisely when: (a) all Fs are Gs; (b) the [preceding] is an axiom or theorem of that axiomatic system which captures the complete history of the universe and is the maximal combination of strength and simplicity (1998, p. 53).

Bird goes on to argue that the RL relation does everything that necessitation was supposed to do according to properties (1)–(4). Taking (1)–(4) in turn,

> If F and G are RL related, then, by (a), all Fs are also Gs. (2) Because of (b) the reverse entailment does not follow. (3) The RL relation is a relation among properties. Hence it is a second-order relation. (4) We can regard "*a*'s being G because *a* is F" as an instance of the RL relation – when F and G are RL related, *a* is both F and G, and the capturing of the fact that *a* is G by the regularity that all Fs are Gs contributes to the systematization mentioned in (b) (1998, pp. 53–4).

(1) Relations N and RL both entail that everything that is an F is also a G. (2) The requirement of belonging to a best system blocks the reverse entailment. The regularity that Fs are Gs is not enough to ensure the RL relation between F and G. The relation is conferred only if the regularity belongs to a best system. (3) Both N and RL are relations among properties. (4) The law-statement that 'all Fs are Gs' is a universal generalization. Since it is a true statement, it has an instance

in any object that happens to be an F. Bird concludes that the relation N does not distinguish itself from relation RL by properties (1)–(4). According to Bird, Armstrong's failure to provide a satisfactory account of necessitation means that he also fails to show how (i) a law explains its instances; (ii) how particular facts can count as evidence for there being a law; and (iii) how it is possible for systematic (but accidental) regularities to diverge from the laws that there are.[82]

Let us turn from Armstrong's general account of laws to the case of probabilistic laws of nature. I don't think that the objections raised so far by Armstrong's critics will bear on his account of probabilistic laws – we will analyze specific critiques to that purpose. Let us note, however, that Armstrong's critics are genuinely concerned about precisely how a necessitation relation connects with regularities. Armstrong's consistent response is to remind the reader of how he conceives universals and laws to be instantiated in objects (e.g., 1988, p. 225). We will see shortly that the principle of instantiation comes under considerable strain when applied to probabilistic laws.

4.2 Armstrong on Probabilistic Laws

4.2.1 Symmetry and the Principle of Instantiation

A conspicuous feature of Armstrong's treatment of probabilistic laws is that he fits them into the schema he devised for causal laws. Under this interpretation, probabilistic laws are probabilities of necessitation. By the end of Section 4.2.3, we'll see that giving probabilistic laws the form as that of causal laws presents Armstrong with intractable problems.

Armstrong thinks that his metaphysics of laws provides more than just the foundation for deterministic laws. For probabilistic laws, Armstrong proposes to schematize an instance of a probabilistic law as ((Pr:P)(F,G))(*a*'s being F, *a*'s being G), "where ((Pr:P)(F,G)) gives the objective probability of an F being a G, a

[82] It may strike the reader that a further problem for Armstrong's theory of laws is that it rules out uninstantiated laws. Suppose that P is a property or complex of properties that is never instantiated in situation ψ. There may nevertheless be a law concerning the obtaining of states of affairs $P\psi$ (perhaps property Q is necessitated). But the principle of instantiation seems to rule out the possibility of uninstantiated laws. Armstrong's solution is to treat uninstantiated laws as a type of counterfactual statement. The following quote gives the general tenor of his view: "The view which I wish to put forward is that a statement of uninstantiated law should be construed as a counterfactual. Instances of the universal P_0 do not exist, that is, P_0 does not exist. Hence the $P_0 \rightarrow Q_0$ law does not exist. But if there were P_0s, that is, if P_0 existed, then P_0s would be governed by the law that P_0s are all Q_0s. Statements of uninstantiated law are really only statements about what laws would hold if, contrary to fact, certain universals were instantiated, that is, existed. I thus admit uninstantiated laws, but only as logically secondary cases of laws" (1983, p. 112).

probability holding in virtue of the universals F and G" (1983, p. 128). (Pr:P)(F,G) is analogous to N(F,G), a universal that obtains between F and G. So far so good: it appears that probabilistic laws can take the form of a causal law. However, for Armstrong, a causal law expresses a relation of necessitation in virtue of the universals F and G; a probabilistic law offers only a certain chance that some F will be G. For instance, the deterministic law that N(F,G) entails that one state of affairs, *a* is F, will be accompanied by another state of affairs, *a* is G. According to N(F,G), all Fs are G. But according to the probabilistic law that (Pr:P)(F,G), the state of affairs *a*'s being F may not be accompanied by the state of affairs *a*'s being G (1983, p. 129). Armstrong identifies this phenomenon as a "failure of symmetry" between deterministic and indeterministic laws, and proposes a solution to it before showing us how probabilistic laws may be understood as the probabilities of necessitation.

Armstrong first discounts two possible solutions to the failure of symmetry (1983, pp. 128–9). Both involve reformulating the structure of the relation obtaining probabilistically between F and G. The first suggestion is that probabilistic laws can be instantiated in two different kinds of situation:

(1) ((Pr:P)(F,G)) (*a*'s being F, *a*'s being G) and
(2) ((Pr:1–P)(F,G)) (*a*'s being F, *a*'s not being G).

Statement (1) gives the probability of *a*'s being G when it is F, while (2) has a negative state of affairs as one of its terms, giving the probability of *a*'s not being G when F. Armstrong supposes that the relation (Pr:1–P)(F,G) allows us to calculate the probability that some F is not G, for example, if P = 3/4, 1–P = 1/4. Armstrong rejects this proposal, since negative terms and negative states of affairs are rejected by actualism. However, it needs to be pointed out that the relation (Pr:1–P)(F,G) is not quite the one that Armstrong needs. For if (Pr:1–P)(F,G) = (Pr:1/4)(F,G), then (Pr:1/4)(F,G) would seem to be a relation that gives an F a 1/4 chance of being G. But this isn't the conclusion Armstrong wants. He wants to say, for example, that *a* has a 1/4 chance of not being G when F. When abstracted from particular states of affairs, like in (2) above, it is easy to see that (Pr:1–P)(F,G), has the same relata that (Pr:P)(F,G) does: they give distinct probabilities that an F will be G, 1/4 and 3/4 respectively, which together assures us that some *a* will be G when F. I suggest that we need to replace the second relatum of (Pr:1–P)(F,G) with the negative universal ~G: (Pr:1–P)(F,~G). This gives the probability of a molecular state of affairs having a negative atomic state of affairs, *a*'s being F, *a*'s not being G. Of course, given Armstrong's rejection of negative universals and states of affairs, this correction makes the solution no more acceptable than before.

The second solution posits within states of affairs certain chances or propensities. This would give us (N(F,H))(a's being F, a's being H), where H is a P-strength propensity to be a G. Armstrong thinks this formulation has the advantage of replacing probabilistic relations of the form (Pr:P)(F,G) with the old scheme N(F,G). But since propensities are not categorical properties, Armstrong rejects this suggestion too.[83]

Armstrong keeps the relation (Pr:P)(F,G) as the form of a probabilistic law, and proposes to deal with the failure of symmetry another way. He suggests that we "limit the instantiation of the universal ((Pr:P)(F,G)) to those cases where the particular which is F is also G. *Probabilistic laws are universals which are instantiated only in the cases where the probability is realized*" (1984, p. 129). This limitation of probabilistic laws is of instantiation applied to the specific case of probabilistic laws.

Armstrong argues that the principle of instantiation solves the problem that under a probabilistic law the state of affairs *a*'s being F might be instantiated without the state of affairs *a*'s being G. Under a law that relates F and G deterministically, this would be impossible, so the extensional inclusion of the instances of probabilistic laws and causal laws appears to fail to be symmetric. The principle of instantiation is supposed to show how symmetry is to be achieved. Armstrong proposes to limit a probabilistic law to just those cases in which the probability is realized, that is, limited to just those cases in which the law is instantiated. If the probabilistic law governing F and G is instantiated in *a*, *a* is both F and G. If a probabilistic law is limited to just those cases in which the probability is realized, thereby limiting the law's extensional inclusion, then for all cases in which the law is instantiated, all Fs are Gs, just as it is for N(F,G). Thus we have symmetry.

Armstrong believes that probabilistic laws are irreducibly probabilistic, e.g., "For a probabilistic law, there must be no such differentiating factor D which determines the outcome. The law must be *irreducibly* probabilistic" (1983, p. 30). Of course, given his actualism, Armstrong doesn't think that there can be irreducibly probabilistic properties. But probabilistic laws, which obtain between categorical properties, are irreducibly probabilistic when there is no deterministic relation, differentiating factor D that determines outcomes.

4.2.2 Probabilistic Laws as the Probabilities of Necessitation

Having argued for applying the principle of instantiation to probabilistic laws, Armstrong is in a position to further integrate probabilistic laws into his schema

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[83] The rejection of propensities follows from Armstrong's actualism, which "debars us from postulating such properties as dispositions and powers where these are conceived of as properties over and above the categorical properties of objects" (1983, pp. 8–9). Armstrong also thinks that laws explain dispositions, identifying dispositions "with the nomically relevant categorical properties of the disposed object" (1988a, p. 86). Since Armstrong takes laws of nature to be contingent, the identifications of dispositions will not hold across all possible worlds: "In Kripke's terms, to characterize the disposition *via* these [categorical] properties will not be to use a 'rigid designator'" (1988a, p. 86).

by arguing that probabilistic laws are probabilities of necessitation. By taking them to be probabilities of necessitation, Armstrong thinks that probabilistic laws involve necessitation.

> Let it be a law that Fs have a certain probability of being a G. Let *a* be F and be G, and let this state of affairs be an instantiation of the law. We have: (1) ((Pr:P)(F,G))(*a*'s being F, *a*'s being G). I should like to read this as saying that *a*'s being F *necessitates a*'s being G, a necessitation holding in virtue of the fact that universals F and G give a certain probability, P, of such a necessitation. Instead of formula (1) we might restore our relation N and write: ((N:P)(F,G))(*a*'s being F, *a*'s being G) where P is a number between 1 and 0, including infinitesimals (1983, pp. 131–2).

Some observations. First, the object said to instantiate the probabilistic law is both F and G, so the instantiation principle is at work. Second, Armstrong interprets the instantiation of a probabilistic law as a form of necessitation between states of affairs, e.g., *a*'s being F necessitates *a*'s being G. Hence we need to keep in mind that Armstrong understands 'necessitation' to mean causation, so that 'probability of necessitation' means probability of causation. Third, the necessitation holds in virtue of the fact that the universals F and G determine the probability of necessitation. Fourth, the probabilistic relation (Pr:P) is reinterpreted as a relation of the probability of necessitation, (N:P), whereby a certain instantiated universal has a real chance of necessitating a certain other universal.

According to the principle of instantiation, the probabilistic law (N:P)(F,G) is instantiated in all and only those cases in which F and G are instantiated. A state of affairs instantiating this law might be *a*'s being F and *a*'s being G. Generally, the instantiation of a law is an instance of causation, so we may rewrite '*a*'s being F and *a*'s being G' as '*a*'s being F caused *a*'s being G' or '*a*'s being F necessitates *a*'s being G.' Thus an instance of the probabilistic law (Pr:P)(F,G) turns out to be intrinsically the same as an instance of the causal law N(F,G): both involve a state of affairs such that *a*'s being F necessitates *a*'s being G. So how are we to understand the difference between the instance of a causal law and the instance of a probabilistic law? It must be in the difference between an instance of deterministic causation and an instance of probabilistic causation. The instantiation of N(F,G) in the state of affairs *a*'s being F and *a*'s being G is a case where Fness caused Gness to occur, as it always does. On the other hand, if the state of affairs *a*'s being F and *a*'s being G is an instance of the law that (N:P)(F,G) = 0.93, then we have an instance of probabilistic causation, so that in this particular state of affairs Fness caused Gness. However, it is not the case that Fs always cause Gs, since there are instances of F that are not instances of the law that (N:P)(F,G) = 0.93.

We may note at this point that Armstrong doesn't say which analysis of probability underwrites his theory of probabilistic laws. In fact, his ontological commitments admit none of the analyses examined in chapter 2. Given his realism about laws, the subjective interpretation of probability is ruled out, and given his commitment to actualism we rule out the existence of irreducible propensities and the propensity interpretation. And any frequency interpretation would be too much like the regularity conception of laws for Armstrong. This seems to leave us without an analysis of probability to ground probabilistic laws. I think Gürol Irzık provides the correct insight on this matter, that Armstrong's notion of probabilistic necessitation is an extension of the unanalyzed primitive of necessitation:

> Recall that according to Armstrong probabilistic laws are relations of probabilistic necessitations between universals. As we know, the notion of necessity is a primitive for Armstrong; he needs it to ground lawful relations. With probabilistic laws, we have a new universal, namely probabilistic necessity, which is also left unexplained. So it appears that this new property is also a primitive. But notice that there are two related but distinct issues here: understanding laws and interpreting probabilities. The problem of explicating probabilistic laws is inextricably bound up with the problem of interpreting the notion of probability. Armstrong glosses over this problem by relaxing deterministic necessitation to cover probabilistic laws. But because the former is left unexplained as a primitive, so is the latter. Armstrong has to tell us either what necessities are or what probabilities are. Since he does neither, his account remains doubly opaque (1991, pp. 216–17).

Irzık expresses further puzzlement about Armstrong discounting the propensity interpretation, since it's the one interpretation that could reasonably fit with his realism about laws. Irzık thinks a realist who admits propensities may go on to think of 'probabilistic necessities' along the lines of Giere (1979): propensities are weak natural necessities dressed up in the formal properties of the probability calculus and exploited for the purpose of explicating the notion of objective probability (1991, p. 217). But Armstrong staunchly rejects irreducible propensities on the grounds of actualism, so "it is not at all clear how Armstrong could meaningfully talk about probabilistic necessities while remaining a realist" (1991, p. 217).

4.2.3 Van Fraassen's Critique

Van Fraassen's critique of Armstrong's theory of probabilistic laws consists of seven arguments to the effect that Armstrong's theory of laws is "entirely incapable of explicating the concept of a probabilistic law of nature" (1987, p. 121). The general set up for the arguments is the following. (1) The law of radioactive decay, $N = Ie^{-At}$, is a test case for Armstrong's interpretation of probabilistic laws, where I is an initial amount of radium, e is Euler's number (a standard mathematical constant), A radium's decay constant, and N the amount remaining after time interval t.[84] (2) (Pr:P)(F,G) is the probabilistic law to be critiqued. (3) Van Fraassen recognizes the central role that the principle of instantiation plays in Armstrong's theory of probabilistic laws. The strategy of some of the arguments is to bring the probabilistic law and the principle of instantiation into conflict with each other. We'll review each of the arguments in turn.

Armstrong addresses van Fraassen's first five arguments collectively in his (1988b) response to van Fraassen. His answer there is to defend both his interpretation of probabilistic laws and the principle of instantiation. I will review his response after reviewing all five arguments. Until then I will comment on van Fraassen's arguments, highlighting the predicament they seem to put Armstrong in, and consider how he might respond to each argument individually.[85]

I. The first argument is based on real statistical distributions. Van Fraassen says that the real statistical distribution of radium, its actual mean decay time, should show a "good fit" with both the physical law $N = Ie^{-At}$ and the probabilistic law (Pr:P)(F,G). But van Fraassen raises a doubt about this: "We can divide the observed radium atoms into those which do and do not decay within one year. Those which do decay are such that their being radium atoms in a stable state bears ($Pr{:}e^{-A}$) (radium, decay within one year) to their decaying within one year. The other ones have no connection with that universal at all. Now how should one deduce anything about the proportions of these two classes or about the probabilities of different proportions?" (1987, p. 122)

The issue of universals and the problem of induction or projection indicate that it is Armstrong's probabilistic law, not the physical law that fails to show good fit with real statistical distributions. Van Fraassen's point is that the real statistical distribution of our radium samples fall into definite groups: those that have decayed and those that have yet to decay. But the probabilistic law applies only to the former group, because only those atoms instantiate (Pr:P)(F,G) – the atoms of the latter group are completely unconnected to the law since they fail to instantiate it. Thus the probabilistic law fails to connect with both groups and fails to tell us the proportions in which we should expect to find them. On the other hand, the proportions could be calculated according to the physical law $N = Ie^{-At}$. Thus the probabilistic law fails to show a good fit with actual statistical distributions, while a good fit is found for the physical law.

I think Armstrong has the resources to respond to argument I. Supposing he abandoned the principle of actualism, how would he be positioned? Armstrong might call upon the existence of negative properties (banned by actualism) to formulate his response, saying that Fs that are non-G are indirectly connected to

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[84] The general radioactive decay law was introduced in Section 1.3 as $N = N_0e^{-\lambda t}$.

[85] I haven't been able to find any commentary on van Fraassen and Armstrong's exhange. It is absent in Tooley's (1988) chapter on probabilistic laws, which may have been written before he became aware of it.

the law that (Pr:P)(F,G) by instantiating the concomitant law that (Pr:P)(F,~G). The probability value of this law could be calculated using Kolmogorov's first axiom of the probability calculus: 1 – (Pr:P)(F,G) = (Pr:P)(F,~G). But Armstrong is a committed defender of actualism, so we shouldn't expect him to follow an argument along these lines. Recall that in Section 4.1.1 we reviewed Armstrong's proposal for identifying the truth-makers of true statements containing negative predicates, so let's see if that proposal helps us to connect the law (Pr:P)(F,G) to instances of F that are non-G.

Though the probabilistic law (Pr:P)(F,G) may not be instantiated in instances of F that are not G, we may still be able to connect such instances to it by appeal to the notion of counter-correspondence. The law-statement '(Pr:P)(F,G)' corresponds simply (or directly) to the instances of the law that (Pr:P)(F,G), yet it fails to find the same correspondence to Fs that are not G. However, '(Pr:P)(F,G)' does counter-correspond to Fs that are H, Fs that are I, Fs that are J, etc. '(Pr:P)(F,G)' thus fails to simply correspond to any F that's non-G, but it nevertheless counter-corresponds with each such F. Thus we can provide truth-makers for the statement '(Pr:P)(F,~G)'. The correspondent of '(Pr:P)(F,~G)' is any and all states of affair that involve properties F and Φ, where Φ designates a monadic property other than G. It seems we can connect the law that (Pr:P)(F,G) to Fs that are non-G by means of the statement '(Pr:P)(F,~G)'. This is done via the counter-correspondence relation and without postulating negative properties, or the negative states of affairs that would instantiate a law with a negative term. Both the statements '(Pr:P)(F,G)' and '(Pr:P)(F,~G)' find truth-makers in actual properties in actual states of affairs, and using these statements we should be able to calculate the proportion of Fs that are G to those that are non-G using Kolmogorov's first axiom.

II. The first of van Fraassen's arguments is the only one from real statistical distributions. The remaining arguments focus on the issue of probability. The first of these takes together the probabilistic law and the principle of instantiation: the universal (Pr:P)(F,G) must have at least one instance of an F that is also G. To this van Fraassen says, "If it is a law that there is a probability of 3/4 of an individual F being a G, and there is only one F then it is a G" (1987, p. 122). The combination of the principle of instantiation, the probabilistic law, and the supposition that just one object is F turns an initial probability of 3/4 into 1. This simple model indicates a problem for Armstrong, one of shifting probability values for probabilistic laws.

A response to this argument that one may assume for Armstrong is to dispense with the principle of instantiation. It's an unlikely event that he would, but doing so would block the necessity of an F that is also a G, and so block the problem of shifting probability values. Suppose, then, that the principle of instantiation has been dropped, and there is only one F, and it happens to be non-G. We will need to call again on Armstrong's strategy for dealing with negative-appearing states of affairs. But notice that this time the law-statement '(Pr:P)(F,G)' finds no simple correspondence if the only F is non-G. So

'(Pr:P)(F,G)' will be false. But supposing that *a* is F and Φ, '(Pr:P)(F,G)' will counter-correspond to *a*'s being F and *a*'s being Φ, so that '(Pr:P)(F,~G)' will be true, corresponding to the actual state of affairs.

III. Van Fraassen demonstrates that the problem in II persists when the number of objects is increased. Suppose that there are two Fs, *a* and *b*: "the probability that both are G equals 9/16, the probability that *a* alone (or *b* alone) is G equals 3/16, and that neither is G equals 1/16"[86] (1987, p. 123). The principle of instantiation rules out the last case, so we must conditionalize on its negation. "This means dividing by 15/16, and we deduce, after a few steps: Given the law that there is a probability of 3/4 of an individual F being a G, and *a, b* are the two only [sic] Fs, then the probability that *a* is a G equals 4/5, and the probability that *a* is a G given that *b* is a G, is a bit less (namely, 3/4 again)" (1987, p. 123). Van Fraassen concludes, "If the law says probability *P*, and there are [finitely] n *F*s, then the probability that a given one will be *G* equals *P* divided by $(1\text{-}(1\text{-}P))^n$" (1987, p. 123). Van Fraassen's point is that the instantiation thesis leads us to deduce probability values different from those initially stated by laws. Shifting probability values for physical laws is a serious problem for any theory of laws, let alone Armstrong's. Again, we might recommend that he drop the instantiation thesis. But since Armstrong's general metaphysics is established on this principle, we can't expect him to do so.

IV. Van Fraassen shows that the instantiation thesis leads to paradoxical results for radioactive decay. Suppose that 'G' names the universal remaining stable for interval t (rather than decaying into radon within interval t). For every interval t, then, there must be a radium atom remaining stable. "This means that either there is one which never decays, or else there are infinitely many radium atoms.... The finitude of radium available entails that only the first alternative ... is possible. Hence we have deduced the existence of a radium atom which remains stable forever!" (1987, p. 123) Even if there is a radium atom that remains stable forever, its existence shouldn't be a consequence of a theory. Whether or not a particular radium atom does or does not decay should be a matter of empirical investigation, not determined a priori by the principle of instantiation.

V. Van Fraassen takes the next argument to be a consequence of the corollary quoted in III above, "the probability that *a* is a *G* given that *b* is a *G*, is a bit less (namely, 3/4 again)" (1987, p. 123). The probability that *a* is G is conditional on whether *b* is G. Van Fraassen interprets the corollary to mean that the decay rates of spatially-temporally separated atoms are not statistically independent: "given that some atoms decay the probability for any given other one decaying is less. This will be true regardless of how the atoms are separated in space and time; so we have here a correlation inexplicable by any causal model" (1987, p. 123). According to the corollary, an atom decaying at the time the universe was very young affects the decay rate of an atom existing when the

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86 9/16 (3/4 x 3/4), 3/16 (3/4 x 1/4), 1/16 (1/4 x 1/4).

universe is much older, but the causal connection is mysterious. Van Fraassen admits that atomic physics uses models with statistical correlations that are inexplicable by any causal explanation, but not in the case of decay rates of atoms separated in space and time. The result is at odds with Armstrong's general understanding of the instantiation of probabilistic laws. In the context of arguing against the regularity theory, Armstrong says, "But even if we are dealing with genuine infinite collections, the probability given by a probabilistic law cannot be identified with the limiting relative frequency of a random infinite sequence. For each instantiation of a law is an independent event, uninfluenced by the other instantiations of the law" (1983, p. 31). Again, the principle of instantiation appears to fail to serve him well.

It can be noted here that the problems Armstrong faces in the preceding arguments should not also affect Lewis's or the dispositional essentialists' theories of probabilistic laws. The reason is that van Fraassen's critique turns on the role that the principle of instantiation plays in Armstrong's theory of probabilistic laws, and Lewis's and the dispositionalists' accounts operate in the absence of such a principle. For Lewis, probabilities are identical with frequencies, so we don't get the problem we find in Armstrong of a divergence between the frequencies of an instantiated probabilistic law and the probability assigned by a law without the requirement of instantiation. The problem of instantiation is not required by dispositional essentialism too, since instances of probabilistic laws under this metaphysical approach involve the production of certain kinds of events by irreducible probabilistic dispositions or propensities. As we will see in the next chapter, the metaphysical analysis that dispositional essentialism brings to bear on probabilistic laws guards it against the kind of difficulties that Armstrong faces so far.

We now turn to Armstrong's response to van Fraassen's first five arguments. Armstrong identifies the problem that van Fraassen exploits as follows:

> The problem cases for me are those where the instances falling under the scope of the law are omnitemporally finite in number. As van Fraassen shows, given my analysis, given this finitude, *and given my demand that a genuine law be instantiated on at least one occasion*, the probable relative frequencies will fail to coincide with those which are most probable given the law but given it without a demand for its positive instantiation (1988b, p. 225).

The failing probable relative frequencies that Armstrong refers to are those cases in which a probabilistic law is instantiated relative to those cases in which it is not. For example, if it is a law that (N:P)(F,G), then it may be instantiated in x cases relative to the total number of objects F, y, so that the probable relative frequency of the law is $x : y$. However, as van Fraassen points out, the probable relative frequencies generated by the principle of instantiation fail to coincide with the probable relative frequencies of the law *without* the instantiation principle at work, e.g., the law $N = Ie^{-At}$ of atomic physics. We saw this in arguments II, III, IV, and V as the effect of the principle of instantiation driving up the initial probabilities stated by laws. Armstrong's response is to appeal to counterfactual statements and limiting relative frequencies in classes of infinite objects:

> In every irreducibly statistical law, the probability P gives us the probable limiting frequency *if the population is infinite*. The law embodies a conditional. In the case where the population is finite, the conditional is counterfactual. This conditional will demand that for any law it is not ruled out, it is nomically possible, that there should be an infinite number of instances falling within the scope of the law... If it is assumed that laws of nature are probabilistic relations of necessitation holding between universals, which is the view that van Fraassen is raising difficulties for, then it seems reasonable to assume the nomic possibility of an infinite number of instances falling under such a law (1988b, p. 226).

Armstrong raises the further point that his metaphysics of laws provides the truth-makers required for the counterfactuals in question, the actual nomic relations between actual universals: "Why should we not say that this state of affairs sets the probabilities for the infinite case, setting it as a limiting relative frequency, whether or not the relevant population is in fact infinite?" (1988b, p. 226)

Armstrong concedes van Fraassen's point that under the stricture of the principle of instantiation, relative frequencies in finite populations may not coincide with the relative frequency most probable under physical laws unrestricted by the principle. He then responds that we should find the match between probable relative frequencies not in finite cases, but in hypothetically infinite cases, where "the probable limiting frequency in the infinite case should diverge from the actual frequency in the finite case" (1988b, p. 226). The truth-makers for counterfactuals stating limiting relative frequencies are nomic relations between universals, i.e., probabilistic laws themselves. Armstrong's response thus represents a development of the picture of probabilistic laws that we are given in *What is a Law of Nature?* Is the response successful? On the one hand, offering up probabilistic laws of nature as the truth-makers of limiting relative frequencies seems to be well within Armstrong's purview for laws, since he intends laws to support counterfactuals: supposing it is a law that N(F,G) and *a* is not F, the law serves as the truth-maker for the counterfactual 'if *a* were F, *a* would be G'. In the case of a probabilistic law applied to the infinite case, the law (N:P)(F,G) is supposed to provide the counterfactual support that yields the limiting relative frequency equal to P. Furthermore, since on this proposal limiting relative frequencies belong only to possible classes of possible objects, we can interpret Armstrong to invoke, on grounds of combinatorialism, possible worlds that contain classes of infinite objects bearing the limiting relative frequencies desired.

The peculiar aspect of Armstrong's proposal is the invocation of possible worlds to explicate (actual) probabilistic laws of nature. Armstrong refers to merely possible worlds containing classes of infinite objects to show how the relative frequency of a probabilistic law coincides with the most probable relative frequency given by the law. But the desired limiting relative frequencies are merely possible, not actual frequencies. Thus Armstrong relies on merely possible properties, frequencies in the limit, to shore up his explication of probabilistic laws. This seems contrary to the spirit of naturalism. We recall that naturalism is the ontological thesis that nothing exists except the actual, spatio-temporal world, the world studied by the physical sciences (Armstrong, 1983, p. 82). Armstrong's theory of possibility is also naturalistic, according to which possibility is "subordinate" to actuality (1989, p. 6). The ontological subordination of the possible to the actual is also the theoretical basis of combinatorialism, which constructs possible worlds out of the elements of the actual world. So I find it odd that Armstrong, after emphasizing actual world chauvinism in many contexts, should rely on merely possible worlds, properties, and objects to save his explication of probabilistic laws in the actual world.

Armstrong anticipates the worry:

> It may be objected that the extension from the finite to the infinite case makes the truth of the counterfactual much more dubious. The merely possible particulars involved would presumably be *alien* particulars, ones belonging to the somewhat dubious 'outer sphere' of possibility. But to this, it seems, it may be replied that we are only required to *make sense* of the possibility that the value of P and the number of instantiations of a certain law should be at odds with each other in the way described by van Fraassen. It is not as if the objection is based on empirical data from physics or elsewhere. For the possible case, we have provided a possible truthmaker. That seems to be all that is required (1997, pp. 240–41).

Armstrong thinks he is justified in his response to van Fraassen, since he is using probabilistic laws as the truth-makers of counterfactual statements about infinite classes of objects. But the overall strategy seems contrary to the principle of naturalism, since Armstrong doesn't appeal to actual instances of the law to resolve the problem of shifting probability values. How are possible limiting relative frequencies, which are "subordinate" to actual relative frequencies, supposed to save Armstrong's account of actual probabilistic laws? Surely he won't assign hypothetical frequencies an ontological status that is superior to actual frequencies, a move that would align the instantiation of a probabilistic law with the law's most probable relative frequencies. Yet Armstrong nevertheless calls on limiting frequencies to save his account of probabilistic laws instantiated in the actual world. This seems inconsistent with the naturalistic thesis, especially when we place his solution here against his account of deterministic laws, which is done by reference to actual states of affairs alone. A new failure of symmetry thus seems to have been found. I suggested earlier that Armstrong might counter some of van Fraassen's arguments by dispensing with either the principle of instantiation or actualism. Armstrong's collective response to van Fraassen's arguments saves him from giving up these metaphysical principles, but at the expense, it seems, of entering into conflict with his own principle of naturalism.

Let's now address Van Fraassen's last two arguments, that the initial probabilities stated by laws might be false. An important assumption for the first argument is that "In an indeterministic universe, some individual events occur for no (sufficient) reason at all" (1987, p. 124). The assumption allows van Fraassen to entertain that there may be an object that is F and accidentally G.

Suppose (N:P)(F,G) is a law with P = 3/4. There are three sorts of Fs: those that are not G, those whose being F necessitates being G, and those that are accidentally G. "What," asks van Fraassen, "is the probability that a given F is of the second sort? Well, if P is the probability of necessitation, then the correct answer should be P. What is the probability that a given F is of the third sort? I do not know, but by hypothesis it is not negligible. So the overall probability that a given F is a G, is non-negligibly greater than 3/4" (1987, p. 125). On the supposition that there is a non-negligible probability that an F is accidentally G, we calculate the probability that any given F is G by adding the probability values for the second and third sorts of F. The result is a value slightly higher than the initial probability stated by the law. On the assumption employed here, probability values rise on Armstrong's model. To this Armstrong replies, "Let us suppose that there are in fact Fs that are Gs by absolute chance [i.e., by accident]. What has that got to do with the probabilistic law? The law gives a probability of Fs being Gs *as an instantiation of the F → G* law" (1988b, p. 227). Armstrong's point is that his account of probabilistic laws is not affected by occurrences of Fs that are accidentally Gs, since those are physical possibilities independent of the governance of laws. Armstrong seems to be on the right track with his response, since any theory of probability may be affected on the premise that there might be Fs that are accidentally Gs. So let's respond that in general, if F and G are only accidentally correlated, there will be no clear assignable probability of their correlation. The opacity of that probability will then attach to van Fraassen's third category of cases, in which Fs are Gs only accidentally.

VII. Van Fraassen considers a response to argument VI that doubts that probabilistic laws of nature leave open the possibility that the result occurring by law with a certain probability may also occur accidentally. For instance, could a radioactive isotope accidentally decay? Van Fraassen frames the response under the assumption that the meaning of a law is analytic, so that cases of accidental correlations could not occur: no Fs are G accidentally, since G-ness is necessitated by F-ness. He counters the response in the following argument:

> Let us again ask: what is the probability that in the case of a given F, its being F bears (N:P)(F,G) to its being G? On the supposition that it is a G, the answer is 1; on the supposition that it is not G, it is 0; but what is it

> without suppositions? We know what the right answer should be; but what is it? The point is this: by making it analytic that there can be no difference between real and apparent instances of the law, we have relegated (N:P)(F,G) to a purely explanatory role. It is what makes an F a G if it is, and whose absence accounts for a given F not being a G if it is not.... So we still need to know what is the probability of its presence, and this cannot be deduced from the meaning of "(N:P)" any more than God's existence can be deduced from the meaning of "God." It cannot be analytic that the objective probability, that an instance of (N:P)(F,G) will occur, equals P (1987, p. 125).

Van Fraassen assumes that the only way to rule out accidental cases of F being G is by fiat. This is a questionable assumption, since there may be other ways of ruling out accidental cases, which, if adopted, would guard against van Fraassen's argument. For instance, science might provide a good reason for why Fs cannot be accidentally G – perhaps the process of becoming a G is possible only by nomological connection to being an F. Indeed, Armstrong questions the supposed physical possibility of an F being G accidentally, when there's a law that connects F and G: "Might it not be nomically impossible that something should be a G except by instantiating the F → G law?" (1988b, pp. 226–27). Van Fraassen's argument is that we cannot discover objective probabilities merely by attending to the meaning of our words. His argument is thus similar to Lewis's comment that the meaning of 'N' in N(F,G) doesn't guarantee that all Fs are G anymore than being named "Armstrong" guarantees one has mighty biceps. Van Fraassen's argument suggests that he would be more accepting of a theory that linked objective probabilities to observable frequencies, which would allow him to ignore the distinction between Fs that are nomically G and Fs that are accidentally G. At any rate, I think that Armstrong can respond to the argument by objecting that the only way to rule out the possibility of the accidental case is by fiat.

In this section I have argued that Armstrong successfully responds to some of van Fraassen's arguments, namely, arguments VI and VII, and argument I, to which he can respond independently of his collective response to the first five arguments. However, I've argued that Armstrong's collective solution to the first five arguments brings him into a conflict with his own naturalistic thesis. The overall success of Armstrong's response to van Fraassen seems stuck on his proposal to use probabilistic laws as counterfactual support for infinite classes of objects. If I'm correct in my assessment, Armstrong faces a dilemma: in response to van Fraassen's first five arguments he must either give up the principle of instantiation or suffer a conflict with the principle of naturalism. Both principles are long-standing presuppositions of Armstrong's metaphysical analysis, but I suspect that he would prefer to bite the bullet on naturalism than to give up the principle of instantiation. If so, then he must slacken the claim to naturalism to permit a defence against van Fraassen, though the framework for his metaphysical enterprise warps somewhat as a result.

4.2.4 Armstrong and the Big Bad Bug

David Lewis leaves open the possibility that the big bad bug bites at theories of chance other than his own: "There are other theses about chance, weaker and less contentious than Humean supervenience itself, that are bitten by their own versions of the big bad bug"; "The big bad bug bites a range of different Humean analyses of chance. Simple frequentism falls in that range; so does the best-system analysis" (1994, pp. 473, 482). In this section I explore the question of whether Armstrong's theory of probabilistic laws suffers from the big bad bug or problem of undermining. This argument would be fairly straightforward if it were shown that Armstrong's theory of laws is a version of the regularity theory. I think this would force too much on Armstrong's theory, since (as Irzık notes) laws for him are supposed to be primitives. Nevertheless, I think that Armstrong's account of laws exhibits enough points of similarity with Lewis's account of laws to conclude that the big bad bug bites him too. But before I proceed to show this, we need to reflect again on the Principal Principle.

The Principal Principle, according to Lewis, is a principle of reason. As such, it is thought to have a status much like the law of non-contradiction: as it is irrational to ignore the law of non-contradiction, so it is irrational to ignore the Principal Principle. The Principal Principle tells us how chance is related to credence: credence about the outcome of chance processes should conform to our certainty about objective chances. If we are sure that a coin is fair, and no other information bears on the situation, the Principle tells us that our degree of belief that the coin will land heads when tossed at future time *t* should be 50%. It would be irrational to have any other degree of belief. The Principal Principle is thus independent of any particular theory of objective chance. But a theory of objective chance must be consistent with the Principal Principle, that is, the Principle ought not to show that a theory undermines itself. I argued in Chapter 3 that the problem of undermining remains for Lewis, despite Thau's efforts. If Armstrong's theory of probabilistic laws survives undermining, then some advantage over Lewis's theory would be indicated. By the same token, the test will have to be applied to the dispositional essentialist's theory of chance examined in the next chapter. Thus the theme developed in this thesis is that a necessary condition for a metaphysics of probabilistic laws is that the theory survives undermining when the Principal Principle is applied to it.

Let us begin our investigation of Armstrong by taking note of what Thau says about Humean theories of chance:

> Call any view according to which certainty about complete world history can justify certainty about the chances a *JC* (for justified certainty) view of chance. Obviously, any reductive analysis of chance will be a *JC* view of chance. Given that some *JC* view of chance is correct, there is no reason to think that Humeanism can force an agent who has complete knowledge of world history to be unreasonable in his assessment of what the chances

> are; that is, there is no reason to think the Humean gets the epistemology of chance wrong. Hence, if it is reasonable to be certain about the chances given knowledge about complete world history, it surely must be reasonable to be certain in just the way that a Humean would be, that is, to adopt a Humean epistemology. Thus, Lewis's worry applies to *any* acceptable *JC* view (1994, p. 495).

If it can be shown that Armstrong's theory of laws is suitably similar to the Humean's JC theory of chance, then Lewis's worry, the problem of undermining, ought to show up for Armstrong too. To show that Armstrong has (unwittingly) a JC view of chance, I will argue that a significant number of key elements in Armstrong's theory of laws are similar to key elements of Lewis's theory. Since the elements in Lewis's theory lead to undermining, the same or analogous elements in Armstrong's theory ought to lead to undermining.

Several elements of Lewis's theory contribute to the undermining we saw in Chapter 3. One of these is the Humean ontology of a regularity theory of laws, but since Armstrong's ontology is not a Humean one, we need to find other points of similarity between the two theories of laws. Lewis's block view of time contributes to the problem of undermining. The block view of time is "the doctrine that past, present and future are all equally real" (Dainton, 2001, p. 351). This view of time permits the existence of truth-makers for Humean laws of nature in the form of the global arrangement of qualities whose patterns extend partially in the future (as well as in the present and past). For Lewis, the global arrangement of qualities entails the probabilistic laws of best systems, laws which constitute the theory of chance T_w central to the phenomenon of undermining. Can we find the block view of time in Armstrong's metaphysics? I think we can. Recall that for Armstrong, actualism does not "debar us from thinking that both the future and the past exist, or are real" (1983, p. 9). As well, for Armstrong the past, present, and future instantiations of properties are fully real: "A universal exists if there was, is or will be particulars having that property or standing in that relation" (1978 Vol. 2, p. 9). A universal property F, while not at present instantiated, is nonetheless real if it will be instantiated in the future, or if it had been instantiated in the past. Armstrong believes that the future, with its propertied individuals, exists: "[A statement] requires some truth-maker, and that truth-maker cannot be something non-existent. (In passing, I believe that this shows that we should accept that the past and the future exist.)" (1983, p. 164) I think that we should elaborate the claims that the past and future are real and exist to say that the past and future, and the states of affairs obtaining at those times, are all equally real, since actualism does not provide the resources to say that one state of affairs is more real than another—under actualism, a state of affairs is actual simpliciter.

We can demonstrate that Armstrong has a block view of time. Suppose it's an Armstrongian law that F probabilistically necessitates G. Suppose also that Fs can be produced only at the CERN particle physics laboratory, and that it will produce exactly one instance of F at some future time. According to the instantiation thesis, if there is to be a future instance of the law, the properties F and G must exist sometime in the future. More specifically, if there are future instances of F and G, they must be time-indexed properties (to be explained shortly). If true, we have the block view of Armstrong's metaphysics that we're looking for. Someone might try to counter the argument by arguing that the future is open for Armstrong: properties F and G must exist some time in the future, but there are no specific times when they must be instantiated. But this defence presupposes an asymmetry between past and future instantiations of properties unjustified on Armstrongian grounds. Suppose M is a property that had just one occurrence in history, and it occurred sometime in the past. It is false to suppose that M existed at some time in the past, but at no time in particular. Since, for Armstrong, the past and the future are equally real, we cannot introduce ontological differences between past and future instantiations of properties. Thus future instances of F and G exist at particular future times, i.e., F is indexed (is related) to the time in the future when an F is produced at CERN, and the property G is indexed to the future time when the law that N(F,G) brings G about. So Armstrong is committed to a block view of the universe, whose patterns of properties could serve as the truth-maker for law-statements, including those about chance.

Establishing that Armstrong has a block view of time gets us part of the way to establish that Armstrong has a JC view of chance. While not a regularity theorist, Armstrong, like Lewis, is committed to a block view of time, in which we find patterns of properties (lying partially in the future) that are the truth-makers for laws, including the laws of chance. Let's see what further commonalities we can find.

Lewis's regularity theory is a best systems account of laws, and best systems provide the probabilistic laws for indeterministic worlds. Can we fashion something like a best systems account for Armstrong? Armstrong doesn't mention the criteria of simplicity, strength, fit, and best balance, but he often refers to what he calls 'total science', "the sum total of all enquiries into the nature of things" (1978 Vol. 2, p. 8).[87] I think it's a reasonable expectation to suppose that if we had a total science of the kind Armstrong has in mind, it would give us the probabilistic laws described by a best system. Since a best system has to meet criteria that a total science (probably) doesn't have to meet, we could expect a

[87] Armstrong raises the notion of a total science in the context of discovering properties and relations: "What properties and relations there are in the world is to be decided by total science, that is, the sum total of all enquiries into the nature of things" (1978 Vol. 2, p. 8). The call on total science to this task is a rejection of a priori theorizing about the ultimate constituents of the world: "In general, it is not for philosophers to say what the fundamental constituents of the world are. That question is to be settled *a posteriori*. It is a question for total science" (1989, p. ix).

best system to be a more frugal system of laws than Armstrong's total science. Nonetheless, a total science for the actual world will surely contain the irreducible probabilistic laws that the best system for the actual world has, since both the best science and the best system will state the irreducible laws that are true of our world. And this means that we can find in Armstrong's conception of science a theory of chance T_w that can be applied to the Principal Principle.

I think we've identified two important points of commonality between Armstrong's and Lewis's theories of laws: the instantiation of properties in the future and a science robust enough to catalogue all the laws of nature.[88] For Lewis, the instantiation of properties in individuals is given all at once (so to speak) in a block-view of time. The instantiation of these properties forms patterns, some of which are chance-making patterns that entail probabilistic laws that will figure in best systems. Best systems provide a theory of chance T_w, which assigns non-negligible chances to alternative futures coming to pass. Use the Principal Principle to condition alternative future F on theory of chance T_w and we get undermining.

A similar story can now be told about Armstrong. Armstrong subscribes to a block-view of time, as he takes the past, present, and future to be fully and equally real. His principle of actualism and the principle of instantiation imply that there are time-indexed instantiations of properties throughout time. It is possible that a finite number of instances of a probabilistic law lie entirely in the future and the properties that are related by that law are real and fully instantiated in future time. It seems that Armstrong must admit that there are patterns set in the global distribution of properties, irrespective of how he conceives the probabilistic relation that holds between properties instantiated under the governance of a probabilistic law. Armstrong himself would deny that his laws can be treated under the regularity theory and Irzık identifies Armstrongian laws as ontological primitives. However, we seem to be able to tell an alternative story of laws for Armstrong that has the hallmarks of the regularity theory and is consistent with his block-view of time and the principles of actualism and instantiation. These metaphysical assumptions commit Armstrong to the existence of patterns in the global distribution of properties. A good Humean will see that these patterns entail statements about frequencies that give us Humean laws of nature, some of which, of course, will be probabilistic laws. These law-statements will be included in the total science for our world. From total science we can fashion a theory of chance T_w, which will assign non-negligible objective chances to alternative futures F coming to pass. With the Principal Principle, the conditions are now ripe for undermining.

The most important element in this alternative account of Armstrong's probabilistic laws is that distributions of properties lying partially in the future serve as truth-makers for laws. For Lewis, it is unproblematic to say that chance

[88] We could also add that both Lewis (1983) and Armstrong believe that laws involve fundamentally intrinsic universals.

supervenes on the actual course of world history—he admits as much—and world history entails a theory of chance. Armstrong will deny that the same or similar account of laws can be found in his metaphysics, since probabilistic laws for him don't supervene on their instances. Rather, for Armstrong, laws are discovered by an inductive inference from observed regularities to theoretical entities (laws) that explain both the observed regularities and unobserved regularities. So observed frequencies of conjunctions of properties, perhaps with the theoretical apparatus of the appropriate science, provide the inductive basis to infer the existence of probabilistic laws of nature. But how are future distributions of properties supposed to bear on the law? For one, future observed frequencies confirm the law: "If the law holds, then the observation is *explained.* So the observation confirms the existence of the law" (Armstrong, 1983, p. 102). We might say about the unobserved instances at any time that they would have confirmed the law had they been observed. The observation of the relevant indeterministic patterns of properties in the world provides confirmation of probabilistic laws. But the instances do not entail the existence of the law, since for Armstrong the laws entail their regular instances. So patterns of properties that lie partially in the future are not supposed to entail the existence of laws for Armstrong.

But we have just found in his metaphysical commitments a picture of the world that is suspiciously like the one posited by Lewis, except that Armstrong adds primitive laws to his ontology. We may wonder, then, if Armstrong couldn't pare away primitive laws, leaving a distribution of properties that provides us with a Humean account of laws and chance. Armstrong qua Humean treats primitive laws as excess ontological baggage and finds that the block-view of time, actualism, and the principle of instantiation gives him some version of a regularity theory of laws. Let those laws be catalogued by total science and we have a theory of chance *T*. But now the threat of undermining draws near. Since a theory of chance assigns non-zero chances to alternative futures, we can expect that *T* will be undermined when it and an alternative future history are applied to the Principal Principle.

Armstrong would seem to have two responses at his disposal. Armstrong could say that even if an alternative future were actual, we could treat it as a segment of the infinite limiting frequency that yields a probability identical to the probability *T* assigns to the actual future coming to pass. When alternative future *F* is treated this way, *T* doesn't undermine itself, because *T* permits *F* as a segment of the limiting relative frequency that *T* entails (or with which it is compatible). The problem with this response is that it goes beyond the limits of Armstrong's naturalism. Just as in his response to van Fraassen, here Armstrong has to call upon possibilia to save his theory of laws, a theory that was supposed to be explained only in terms of actual elements of the actual world. Taking Armstrong's metaphysical assumptions into account, I don't find this response convincing.

Another response that seems available to Armstrong is to appeal to the primitiveness of laws. Here we anticipate the strategy behind the propensity response to the big bad bug, which I will propose on behalf of dispositional essentialism in Section 5.7. Without appealing to limiting relative frequencies, Armstrong could argue that since probabilistic laws are primitive, they are not entailed by frequencies and are compatible with alternative futures coming to be. But I am skeptical of this defence because of the ontology it implies. Just what are primitive laws supposed to do relative to actual patterns of properties that exist in the future? They seem superfluous: a Humean could argue that Armstrong has a block universe whose global distribution of properties wouldn't change if primitive laws were left out. Since the pattern remains, primitive laws don't explain it. The notion of primitive laws thus seems to be rendered explanatorily impotent by the notion of an actually existing global distribution of properties. The primitive laws defence thus seems a questionable strategy for dealing with the problem of undermining, for which actual patterns in global history plays a central role.

4.3 Conclusion

In this chapter I have argued that Armstrong meets success in responding to some of van Fraassen's arguments, but has to turn his back on naturalism to respond to the others. We shouldn't expect Armstrong to give up his principle of naturalism: it's one of his metaphysical assumptions and his combinatorial theory of possibility originates from it. Armstrong seems stuck with the fact he is at odds with his own principle, so his overall response to van Fraassen seems unsuccessful.

It also appears that the big bad bug lurks in Armstrong theory of laws. Revealing the bug required a Humean reading of laws to which Armstrong would strongly object. But it is a reading that readily suggests itself when we consider the picture of the world given by his metaphysical assumptions. I don't think that showing the bug to reside in his theory of laws proves that Armstrong has a regularity theory – he insists that contingent necessitation brings more theoretical benefits than regularity theories do. But I do think my argument adds to the long held suspicion that Armstrong doesn't succeed in giving us a theory of laws than is substantially different from a regularity theory. David Lewis thought that the bug infects all Humean theories of chance; the fact that it can be shown hiding in Armstrong's metaphysics doesn't help his defence.

Chapter 5: Dispositional Essentialism

In this chapter I examine a dispositional essentialist account of probabilistic laws and how it ought to respond to the problem of undermining. Dispositional essentialism grounds the existence of probabilistic laws in propensities, fundamental indeterministic dispositions exemplified by individuals subject to probabilistic laws. Surprisingly, recent books by dispositional essentialists provide very little investigation into how probabilistic laws fit into their general metaphysics. Alexander Bird (2007), for instance, omits a discussion of the propensity interpretation of probabilistic laws and Brian Ellis (2001, p. 131) dedicates just two paragraphs of substantial analysis to the issue.

Dispositional essentialists seem to have directed a great deal of their attention to how a dispositional account of fundamental properties affords a theory of causal necessity, i.e., a theory of causal processes instantiating deterministic laws, and have assumed that propensities will provide the foundation of probabilistic laws compatible with their general account of dispositional properties.[89] But with Humphreys's paradox – a challenge to the cogency of a propensity interpretation of probability – this assumption could be flatly wrong. Some investigation into the nature of propensities thus seems required if dispositional essentialism is to avail itself of propensities and pose a serious contender against Lewis's and Armstrong's theories of probabilistic laws.

The chapter has the following structure. The metaphysics of dispositional essentialism and its account of laws are developed over the course of Sections 5.1 to 5.4. Section 5.1 gives a brief introduction to the varieties of dispositional essentialism and contrasts them with the categorical and identity theories of properties. Section 5.2 examines the language we use in our ascriptions of dispositions, i.e., our dispositional terms and how conditional statements are related to dispositions, setting up a metaphysical analysis of dispositions in the next section. Section 5.3 examines Alexander Bird's (2007) metaphysical analysis of dispositions—the simple conditional analysis of dispositions. Section 5.4 turns to the analysis of laws and shows how dispositional essentialism conceives deterministic and probabilistic laws to be grounded in deterministic and probabilistic dispositions, respectively.

In Section 5.5 I introduce Humphrey's paradox, which poses the problem that the probability calculus might not provide the correct interpretation of objective chance, i.e., the probability calculus might not provide the correct interpretation of objective single-case probabilities. Without a solution to the

[89] With respect to recent philosophical history, explaining natural necessity by fundamental objective dispositions was the focus of Shoemaker's (1980) and Swoyer's (1982), works that dispositional essentialists frequently cite as inspiration for the development of dispositional essentialism. The same focus is found in Harré and Madden's (1975) work on causal powers. Mellor's (1971, 1995) works on propensity are an exception.

paradox, dispositional essentialists cannot appeal to propensities to explicate probabilistic laws of nature. In this section I argue that Donald Gillies's proposal does not provide an adequate solution. In Section 5.6 I put my support behind Christopher McCurdy's solution to the paradox. With the paradox solved, I turn to the chapter's main argument in Section 5.7. Here I argue that a theory of chance based on propensities instantiated in the world does not succumb to the big bad bug. This claim will be used in the final chapter to argue that dispositional essentialism explicates probabilistic laws better than either Lewis or Armstrong are able to do. In Section 5.8 I briefly address some issues concerning our knowledge of propensities. The chapter concludes in Section 5.9.

5.1 Varieties of Dispositional Essentialism

Alexander Bird (2007) endorses a dispositional essentialist account of laws of nature, arguing that laws are ontologically grounded in the fundamental natural properties of objects.[90] The fundamental natural properties of things are, for Bird, dispositional properties, so laws are grounded in the fundamental dispositions of things.[91] Bird advances a specific version of dispositional essentialism he calls Dispositional Monism, the view that all fundamental natural properties are dispositional in nature. Dispositional Monism is contrasted with Categorical Monism, which takes all fundamental properties to be categorical in nature (to be discussed shortly). Both Lewis's (1986c) and Armstrong's (2005) metaphysics fit the description of Categorical Monism. As Categorical Monism takes no dispositional property to be fundamental, it denies laws are grounded in fundamental dispositional properties; hence neither Lewis nor Armstrong is a dispositional essentialist.

Dispositional Monism is also contrasted with the Mixed View, which says that some of the fundamental properties of fundamental objects (i.e., atoms, sub-atomic particles) are categorical while others are dispositional. Ellis's scientific essentialism adopts a Mixed View approach to fundamental properties, since he

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[90] Accounts of dispositional essentialism can also be found in Ellis and Lierse (1994), Ellis (2001, 2002) and Anderson (1997).

[91] Bird characterizes the relation between laws and fundamental dispositions in a number of ways: (a) laws *spring from* properties (2007, p. 8); (b) laws are *reflections of* the essence of natural properties and kinds (p. 11); (c and d) fundamental properties *participate in* (or *generate*) the laws of nature (p. 13); (e) fundamental properties are the *supervenience basis for* laws (p. 15); (f) laws *flow from* natural properties (p. 18); (g) laws are (in a sense) *epiphenomenal*" (p. 47). In most of these, laws are not taken to be fundamental, but depend on the existence of fundamental properties. Ultimately Bird will argue for a conception of laws expressed by (e), whereby laws are properly understood to supervene on fundamental dispositional properties, or 'potencies'. See his 2007 Chapter 9, and Section 5.4 below.

thinks that some properties are irreducibly dispositional in nature, but that some properties, like spatio-temporal relations and structures, are irreducibly categorical (Ellis, 2001, p. 127).

Bird understands the distinction between categorical and dispositional properties to be modal:

> Essentially dispositional properties are ones that have the same dispositional character in all possible worlds;[92] that character is the property's *real* rather than merely nominal essence. Categorical properties, on the other hand, do not have their dispositional characters modally fixed, but may change their dispositional characters (and their causal and nomic behaviour more generally) across different worlds (2007, p. 44).[93]

We saw in Chapter 4 that Armstrong is a Categorical Monist: all fundamental (monadic) properties are categorical properties, and properties gain dispositions via the laws that relate them. Since laws relate properties only contingently, categorical properties may have different dispositions from world to world – their dispositional characters are variable. In contrast, dispositional properties are modally fixed for versions of dispositional essentialism, namely, Dispositional Monism and the Mixed View. This entails that the laws of nature are also modally fixed, or necessary, since for dispositional essentialism laws of nature involve the dispositional properties of things. We'll see later in this chapter why dispositional essentialists make these claims.

A fourth view regarding the ontological status of intrinsic fundamental properties that Bird finds implausible is the Identity Theory, defended by Martin

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[92] Bird suggests that essentially dispositional properties exist in all possible worlds, but it may be that dispositional property *P* fails to exist in some possible world *w*, so that *P* won't have the same dispositional property in unqualifiedly all possible worlds. If that were the case, then we should say instead that dispositional properties have the same dispositional character in all possible worlds in which the properties exist. Alternatively, we could say that dispositional properties have the same dispositional character in all worlds that have the actual laws of nature.

[93] Mumford (1998) argues a different modal distinction has traditionally been taken to be significant, that categorical properties are actual properties and dispositional properties are 'bare potentialities', i.e., possible properties identified with the manifestations of dispositions. Mumford, a realist about dispositions, argues that dispositions are in fact categorical, in so far as they are actual intrinsic properties of their bearers, e.g., a sugar cube is actually soluble even if it is never dissolved.

(1997), Martin and Heil (1999), and Heil (1998, 2004).[94] I'll review Heil's Identity Theory before examining Bird's argument. Heil claims that every intrinsic property of an object is both categorical and dispositional. He states the Identity Theory as follows (he calls categorical properties 'qualitative properties'):

> (IT) If *P* is an intrinsic property of a concrete object, *P* is simultaneously dispositional and qualitative; *P*'s dispositionality and qualitativity are not aspects or properties of *P*; *P*'s dispositionality, P_d, is *P*'s qualitativity, P_q, and each of these is *P*: $P_d = P_q = P$ (2004, p. 243).

Heil doesn't clarify what "aspects" of *P* might be, but by denying that *P*'s dispositionality and qualitativity are properties of *P*, he denies that dispositional and categorical properties are higher-order properties that must be grounded in properties that are ontologically more basic.[95] He continues, "This means, in effect, that every [intrinsic] property of a concrete spatio-temporal object is both qualitative and dispositional. A property's 'qualitativity' is strictly identical with its dispositionality, and these are strictly identical with the property itself" (2004, p. 243).

By 'strict identity' I take Heil to mean necessary identity, such that for any "two" entities *a* and *b*, if *a* is identical with *b* there is no world in which *a* is not *b*. A strict identity statement concerning *a* and *b* would also have to satisfy Leibniz's Law of the Indiscernibility of Identicals, such that it is necessarily true that 'if $a = b$, then every property of *a* is a property of *b*'. Heil's working example is the identity of the shape of a baseball and the power to roll. A baseball (this one) is spherical. We might suppose that sphericity is a purely qualitative property of the ball, but Heil claims that the baseball's sphericity affords it the power to roll, a power that it does not have in addition to being spherical.[96]

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94 Mumford (1998) also promotes an identity theory, taking dispositions to be identical with their causal bases, so that if categorical property or structure *b* is the causal basis of disposition *d*, $b = d$. Causal bases will be discussed in section 5.3.

95 For example, "A qualitative property, *Q*, might endow its bearers with the property of being fragile because *Q* itself possesses a certain property, □.... Here, a disposition is taken to be a higher-*order* property, a property possessed by a lower-order qualitative property" (Heil, 2004, p. 232).

96 It may be objected that that the power to roll is a multiply realizable property, capable of being associated with other qualitative properties, like cylindricality. If so, the power to roll cannot be strictly identical with sphericity. Might this not be the case with many, or even all, dispositions? Anticipating the challenge, Heil makes clear that dispositional predicates may be imprecise and used to refer to distinct but similar properties (2004, pp. 246–7). Thus the power to roll in a ball is specifically the power to rotate on each of its axes, while the power to roll in a cylinder is specifically the power to rotate on its single axis. The dispositions are

Bird finds the Identity Theory to be an implausible theory of properties, based on the modal distinction he makes between categorical and dispositional properties. Given the modal distinction, Bird disagrees with the Identity Theory that properties are at once categorical and dispositional: "Clearly no property may be categorical and have a dispositional essence at the same time.... Properties may be one or the other but not both" (2007, p. 44). I'll develop Bird's idea into an argument against the application of the Identity Theory to fundamental intrinsic properties, i.e., those properties that the metaphysics of laws of nature generally takes laws to involve.

According to Bird's modal distinction, dispositional properties are properties whose identities are determined by their dispositional essences, which are identical from world to world. Laws of nature that involve fundamental dispositional properties are thus necessary (a claim that will be substantiated in Section 5.4). This suggests that the Identity Theory might be a version of dispositional essentialism, since according to it every fundamental property is a dispositional property. Yet every fundamental property is also a categorical property, and categorical properties are individuated by the possession of primitive identities (quiddities). Categorical properties also have powers only contingently, as determined by contingent laws of nature. The problem with the application of the Identity Theory to some fundamental property P, then, is that the dispositionality of P entails that all P-laws of nature are necessary, while the categoricity of P entails that all P-laws are contingent. On the modal distinction of properties the Identity Theory is caught in contradiction with respect to the modal status of laws. Since the modal distinction is one that is central to metaphysical debates on the nature of laws, I conclude as well that the Identity Thesis doesn't offer an alternative theory of properties (or laws) that may be further developed here.

There are, then, two versions of dispositional essentialism: Dispositional Monism and the Mixed View. Each of these takes some fundamental properties of fundamental objects to be essentially dispositional, and each takes laws of nature to be grounded in fundamental dispositional properties. That being the case, in what follows I don't promote one version over the other, preferring instead to see how dispositional essentialism in general explicates probabilistic laws of nature. To do this, I examine the details of how Bird, and to a lesser extent Ellis and Anjan Chakravartty, conceive the relation between laws and dispositions. But the attention given to either author shouldn't be taken as an endorsement of his particular version of dispositional essentialism. I assume, therefore, that the results reached in this chapter regarding the explication of probabilistic laws can be made for dispositional essentialism generally, since both Dispositional Monism

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nevertheless similar enough to warrant reference to both by the predicate 'the power to roll'.

and the Mixed View ground laws of nature in fundamental dispositional properties.

5.2 Dispositional Terms and Conditionals

Alexander Bird says that dispositional properties have 'real essences' and not mere 'nominal essences' (2007, p. 44). The implication is that the essences of dispositional properties are fixed ontologically rather than selected or constructed for the purposes of linguistic performance. His analysis of dispositions is metaphysical, not a linguistic analysis of our dispositional locutions. A metaphysical analysis of the essences of dispositions should be an analysis of the discoverable but necessary character of dispositional properties, while a linguistic analysis of terms should inform us of their a priori linguistic equivalences. Bird gives a conditional analysis of dispositions and thoroughly examines the semantics of dispositional terms before doing so. So we should review the semantics of dispositional terms and discuss the link that dispositions are widely supposed to have to conditionals. Bird's account will serve us well here.

Bird identifies two general sorts of dispositional locution: overt and covert locutions (2007, p. 18). An example of an overt dispositional locution is saying of something that it is disposed to break when stressed; an example of a covert dispositional locution is saying that such-and-such is fragile:

> Overtly dispositional locutions are characterized by their reference to a characteristic *stimulus* and a characteristic *manifestation*. Thus if something is disposed to break when stressed, being stressed is the stimulus and breaking is the manifestation. Covertly or elliptically dispositional locutions do not refer explicitly to their characteristic stimuli and manifestations—they are frequently single words that in English have ending such as 'ile' or 'ible'—fragile, combustible, digestible (2007, p. 19).

Bird makes further distinctions among overt and covert locutions. There are two kinds of covert locutions: covert dispositional property names, taken to refer to dispositional properties, e.g., 'fragility', 'combustibility', and 'brittleness', and covert dispositional predicates that correspond to these property names, e.g., 'fragile', 'combustible', and 'brittle'. As well there are two sorts of overt dispositional locutions. Overt disposition property descriptions are "descriptions of properties of the form 'the disposition to M when S' where M is the description of a manifestation and S is a description of the stimulus condition, for example 'the disposition to break easily when stressed'" (2007, p. 19). Overt dispositional predicates are of the form 'is disposed to M when S'. Covert dispositional property names correspond to covert dispositional property predicates: something is fragile if and only if it possesses the property of fragility. And it is natural, says Bird, to take overt disposition property descriptions to correspond to overt disposition predicates: *x* possesses the disposition to M when S iff *x* is disposed to M when S (2007, p. 19).

Often there is a straightforward analysis of covert disposition names into overt disposition descriptions, and these descriptions may denote natural properties.[97] Bird shows that there are some reasons to think that analyses from the covert to the overt are not so straightforward, and his conclusion is cautionary – disposition terms may denote natural properties: "that they do so would be shown by their playing a role in some true scientific theory (this would be at best a sufficient condition, not a necessary one)" (2007, p. 20).

Bird's metaphysical analysis of dispositions uses counterfactual implication and overt disposition property predicates. If a covert dispositional locution is equivalent to an ascription of an overt dispositional predicate, a covert dispositional locution can be subjected to a counterfactual analysis. The upshot of this is that we may use either covert or overt dispositional predicates in our metaphysical analyses of dispositions. Let us then turn to Bird's metaphysical analysis of dispositions and the challenges his analysis finds in so-called 'finks' and 'antidotes'.

5.3 Conditional Analyses, Finks, and Antidotes

The simple conditional analysis (CA) is a metaphysical analysis of dispositions of the general form "*x* is disposed to manifest M in response to stimulus S iff were *x* to undergo S *x* would yield manifestation M" (Bird, 2007, p. 24).[98] CA places a biconditional between an ascription of an overt dispositional predicate and a subjunctive conditional statement. Let

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[97] Bird follows Lewis's (1983) distinction between natural and abundant properties. For Lewis, natural properties are universals that are discovered by science and figure in laws of nature, e.g., mass and charge. Universals, wholly present in their bearers, ground the objective resemblances and causal powers of their bearers. An abundant property is any class of objects other than those classes which happen to pick out natural properties. "The guiding idea, roughly, is that the world's universals should comprise a minimal basis for characterizing the world completely.... It is quite otherwise with properties. Any class of things, be it ever so gerrymandered and miscellaneous and indescribable in thought and language, and be it ever so superfluous in characterizing the world, is nevertheless a property. So there are properties in immense abundance" (Lewis, 1983, p. 346).

[98] Ellis also gives a version of the conditional analysis: "Objects have powers or essential natures whose existence entails the manifestation of the disposition when the appropriate conditions are realized" (2001, p. 141 fn. 23). My reason for examining Bird's work in this section rather than Ellis's is that Bird's is the more recent publication.

> '$D_{(S,M)}x$' abbreviate 'x is disposed to manifest M in response to stimulus S', and '□→' symbolize the subjunctive/counterfactual conditional, so that 'Sx□→ Mx' abbreviates 'if x were S it would be M'. Then the (simple) conditional analysis of dispositions may be symbolized: (CA) $D_{(S,M)}x \leftrightarrow (Sx \,\Box\!\!\rightarrow Mx)$ (2007, p. 24 with modification).

There seems to be no reason to require the dispositional locution to be an ascription of an overt dispositional predicate, since '$D_{(S,M)}x$' works fine to abbreviate the dispositional property ascription 'x has the disposition to manifest M in response to stimulate S'. So CA analyzes overt dispositional locutions as counterfactual conditionals. Bird then enquires whether CA is an adequate analysis of dispositions. He considers finkish dispositions and antidotes as counterexamples to the left-to-right implication CA→ and the right-to-left implication CA←. Counterexamples to CA would imply that dispositions cannot generally be given a conditional metaphysical analysis. For brevity's sake, I'll review only the problems that finks and antidotes provide CA→ to see how CA proposes to deal with them.

For CA→, finkish dispositions show a case where the antecedent '$D_{(S,M)}x$' is true and the consequent '$(Sx \,\Box\!\!\rightarrow Mx)$' is false. The possibility of finks depends on two characteristics of dispositional properties. First, dispositional properties seem to require time to manifest themselves.[99] A fragile glass must suffer stress fractures between the times of being struck and shattering. Second, many dispositions may be gained or lost. Food contaminated by botulism can lose the disposition to poison by cooking or irradiation. Together, these conditions provide an object with the opportunity to lose its disposition to manifest a property in the time delay between stimulation and when the manifestation would normally occur. A process that works this way to frustrate a disposition's manifestation is called a 'fink'.[100]

Imagine a sorcerer who can protect a fragile vase with a spell at the instant the vase is struck, preventing it from breaking. At the time when it was struck, the vase was fragile, yet it did not manifest the property of breaking when struck. So it was true that the vase had the disposition $D_{(S,M)}$ while the corresponding conditional was false. In this case, and in similar finkish set-ups, CA→ is false, entailing the falsity of the conditional analysis of dispositions.

David Lewis (1997) responded to the problem of finks by reforming the conditional analysis. The reformed conditional analysis (RCA) posits an intrinsic property as the causal basis of a disposition, which, jointly with stimulus

[99] As we will shortly see, Bird will argue that the fundamental natural dispositions do not require time to manifest their properties.

[100] Bird adds (2004, p. 25 fn. 23), "Although we talk of finkish dispositions, it is not the disposition itself that is finkish but its instantiation at a particular time"; i.e., the time between stimulus and manifestation.

properties, causes the occurrence of manifestation properties.[101] Bird gives a formal statement of Lewis's RCA:

> (RCA) Something *x* is disposed at time *t* to give manifestation M to stimulus S iff, for some intrinsic property B that *x* has at *t* and for some time *t'* after *t*, if *x* were to undergo stimulus S at time *t* and retain property B until time *t'*, S and *x*'s having of B would jointly be an *x*-complete cause of *x*'s giving response M. (An *x*-complete cause of *y* includes all the intrinsic properties of *x* which causally contribute to *y*'s occurrence.) (2007, p. 27)

t' is the time when the manifestation of M occurs in *x*. I suppose that an *x*-complete cause of *y* consists of the factors that are individually necessary and jointly sufficient to cause *y*. Bird doesn't comment further on the nature of intrinsic property B, but Lewis says that it is unlikely that such properties are dispositional (1997, p. 158)[102] and Prior, Pargetter, and Jackson (1982) and Prior (1985) take causal bases to be categorical properties.

Lewis and Bird think that RCA states the conditions under which finks are excluded. If RCA is a successful formulation of *x*'s disposition to manifest M in response to S, then a response to finks has been formulated on the postulation of intrinsic property B. But RCA seems to exclude finks in a trifling way, saying that if M occurs there was an *x*-complete cause of M. Indeed, if M occurs at *t'* finks of all sorts were excluded between *t* and *t'*. But what if M doesn't occur at *t'*? Then, assuming that stimulus S occurred, causal basis B must have been finkishly defeated. Thus RCA seems to claim that for any occurrence of M in *x* at *t'* (in response to stimulus conditions S), there was a causal basis B present in *x* at *t'*. But, if the stimulus conditions obtain and M wasn't manifested at *t'*, B was finkishly defeated between *t* and *t'*. Thus RCA invites the possibility of finks defeating the causal bases of the manifestations of dispositions. Following the strategy of RCA, we ought to posit an intrinsic property B' that serves to prevent the finkish defeat of causal basis B between *t* and *t'*. And now we seem to be at the start of an infinite regress assigning causal bases to causal bases.

RCA needs to be strengthened without positing causal bases beyond that of intrinsic property B. The only option I see for Lewis and Bird is to suppose that it's impossible for causal bases to be finkishly defeated when stimulus conditions are present. This move would take causal basis B to be a necessary property of any *x* that has the disposition to manifest M in response to S. Since S and *x*'s having of B would jointly be an *x*-complete cause of *x*'s manifesting M, finks are

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[101] The causal basis is the cause not of the disposition itself, but of the manifestation, which it does in conjunction with the stimulus conditions (Prior et al., 1982, p. 253).

[102] Lewis doesn't explain why he says this, but we can attribute it to his Humean point of view that fundamental dispositions are nowhere to be found in nature.

necessarily excluded on the supposition that x has B necessarily. However, I can't imagine Lewis signing on to this concession, given his allegiance to Humean metaphysics, which denies that necessary connections obtain between distinct existences. Bird, on the other hand, argues that there are necessary connections in nature (e.g., laws of nature), so he might accept this amendment to RCA. Nevertheless, I will argue at the end of this section that Bird is forced to reject RCA on grounds of his own ontological commitments.

Bird himself thinks that RCA may provide what is needed to foil finks, but argues that counterexamples to RCA are possible in the form of antidotes. Unlike finks, antidotes operate externally to dispositions. But like finks, an object subjected to an antidote may retain its disposition but fail to give rise to its characteristic manifestation property in response to characteristic stimulus conditions.

> Let object x possess disposition $D_{(S,M)}$. At time t it receives stimulus S and so in the normal course of things, at some later time t', x manifests M. An antidote to the above disposition would be something which, when applied before t' (and possibly before t), has the effect of breaking the causal chain leading to M, so that M does not in fact occur (2007, p. 27).

Antidotes thus change the extrinsic conditions normally required for the operation of a disposition, frustrating its manifestation. For example, a poisonous substance has the disposition to kill when ingested. But an antidote to the poison, administered before or after ingestion, might change a person's physiology (extrinsic to the poison itself) such that the poison fails to kill, i.e., the causal chain that leads to death by poisoning is broken. Bird considers antidotes to be counterexamples to both CA and RCA since, for example, in the case of the poison the disposition and the causal basis B remain throughout the process described. In the case of CA→ the antecedent $D_{(S,M)}x$ is true, but the consequent $Sx \Box\!\!\rightarrow Mx$ is false, since the poison's stimulus (ingestion) occurred, but the disposition failed to manifest in death. And antidotes show RCA to be false since the causal basis and the stimulus fail to be a jointly x-complete cause of x's giving response M.

Bird considers CA and RCA to be false because of finks and antidotes. Nevertheless, Bird goes on to use CA for an analysis of laws of nature. CA, when true, i.e., when finks and antidotes are not present, provides for the strict laws of nature. Laws of nature are associated with conditional analyses of dispositions. In cases when finks and antidotes are present, laws will include *ceteris paribus* clauses.[103] Indeed, Bird uses finks and antidotes as the ontological basis of *ceteris*

[103] *Ceteris paribus* clauses express qualifications of law-statements, e.g., other things being equal, all raptors have a hooked beak. The addition of *ceteris paribus* clauses to law-statements draws a distinction between strict generalizations, e.g., no signals travel faster than light, and *ceteris paribus* generalizations like the

paribus laws (2007, pp. 59–63). This motivates Bird to choose CA over RCA as a conditional analysis of dispositions, since he thinks RCA might solve the problem of finks, leaving an ontological basis that can't account for *ceteris paribus* laws.

Another motivation that may be behind Bird's preference of CA over RCA may stem from the fact that he takes dispositions to be the fundamental properties in nature. If Bird were to accept the truth of RCA, he would be committed to accepting causal bases of dispositions and forced to assert either that they are categorical properties or that they are dispositional properties. As noted earlier, Bird doesn't voice his position on the issue. Be that as it may, Bird couldn't follow Lewis by taking causal bases to be categorical in nature, since dispositional monism excludes categorical properties at the fundamental level. But nor could Bird posit there to be causal dispositional bases, since an infinite regress of such properties would then be generated. RCA thus offends Bird's ontological point of view.

Having reviewed how Bird conceives the metaphysical analysis of dispositions, let us see how Bird (and Ellis) argues that laws of nature are entailed by the dispositional properties of things.

5.4 Dispositional Essentialism and Laws of Nature

5.4.1 Deriving Laws from Potencies

Bird argues that dispositional essentialism and the simple conditional analysis of dispositions (CA) give us the laws of nature. The specific theses involved in deriving laws of nature are DE_P and $CA_\Box$. Dispositional essentialism (DE) is the claim that at least some sparse, or natural, fundamental properties have dispositional essences (2007, p. 45). Furthermore, "Dispositional essentialism, when applied to a particular property, says that that property has a *dispositional essence*. ...Essentially dispositional properties are ones that have the same dispositional character in all possible worlds" (2007, p. 44). Bird calls properties with dispositional essences 'potencies', symbolized by 'P'. Potencies are contrasted with properties that lack dispositional essences, e.g., the distance between any two points. DE_P thus says that for all possible worlds and for all *x*, if *x* has P, *x* is disposed to yield M in response to S:

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raptors-law: the former would be contradicted by a single counterexample, whereas the latter is consistent with a number of phenomena, like an injured raptor with no beak (Carroll, 2004, p. 9). Mark Lange's (1993) concern is that *ceteris paribus* laws are empty because they are consistent with indefinitely many exceptions, so that "other things being equal, all raptors have a hooked beak" just means "all raptors have a hooked beak provided that all raptors have a hooked beak." In other words, the law-statement is true when it is true, otherwise false. The concern arises for Bird too, who says that the simple conditional analysis provides for the strict laws of nature when finks and antidotes are absent.

$(DE_P)\ \Box(Px \rightarrow D_{(S,M)}x)$.

$CA_\Box$ is derived from taking CA to express a necessary equivalence between an object's disposition and its necessity to manifest property M when stimulated by property S, so that

$(CA_\Box)\ \Box(D_{(S,M)}x \leftrightarrow (Sx \Box\!\!\rightarrow Mx))$.

From DE_P and $CA_\Box$ it follows that

(I) $\Box(Px \rightarrow (Sx \Box\!\!\rightarrow Mx))$.

Consider now some world *w* where an *x* has a potency P and acquires stimulus S:

(II) $Px \ \& \ Sx$.

By (I) and (II) we derive

(III) Mx.

Discharging (II) gives us

(IV) $(Px \ \& \ Sx) \rightarrow Mx$.

And since *x* is an arbitrary object, we may generalize

(V) $\forall x((Px \ \& \ Sx) \rightarrow Mx)$.

Bird concludes that we have "a universal generalization derived from a claim about the essence of P, (DE_P), plus the general necessary truth, $(CA_\Box)$. Hence we have explained the truth of a generalization on the basis of the dispositional essence of a property. This is the core of the dispositional essentialist explanation of laws. Since the generalization is non-accidental it is a nomic generalization" (2007, p. 46).[104]

[104] Bird also thinks that the conditional analysis CA provides for *ceteris paribus* laws. Since (CA→) is false when finks or antidotes are present, Bird amends (V) to get (V*): $\forall x$(finks and antidotes to D are absent→((D*x* & S*x*)→M*x*)). "We may consider (V*) to be a version of (V) that admits exceptions—in this case the exceptions being instances of finks and antidotes. Laws that admit of exceptions are *ceteris paribus* laws, hence: (V**) $\forall x$(*ceteris paribus* ((D*x* & S*x*)→M*x*))" (2007, p. 60).

(V) says that for any object having potency P, were it to receive stimulus S it would manifest property M. For Bird, (V) expresses a law of nature, a nomic generalization derived from statements about a dispositional essence. But we may object that (V) looks too much like a law under the regularity theory, since it plainly states a relation of extensional inclusion, whereby the extensions of P and S are included in the extension of M. It may be objected that reference to actual extensions of properties cuts too close to the regularity theory for dispositional essentialism.

Bird can respond to this objection since he also defines a law as the essential relationships that obtain between the stimulus and manifestation properties characteristic of the essences of dispositional properties.[105] This suggests that (I): $\Box(Px \rightarrow (Sx \Box\!\!\rightarrow Mx))$ characterizes a law of nature, which describes the dispositional essence of a potency P. This interpretation is supported by Bird's final definition of a law of nature at the end of his book, where laws are said to supervene on the potencies of things. Laws are relative to a domain (e.g., fluids, electrical circuits) and are "the fundamental, general explanatory relationships between kinds, quantities, and qualities of that domain, that supervene upon the essential natures of those things" (2007, p. 201).[106] I take 'the kinds, quantities, and qualities of a domain' to refer to the stimulus and manifestation properties of a disposition, and 'the essential natures' of the things in a domain be given by the dispositional properties of things. Thus we can take (I): $\Box(Px \rightarrow (Sx \Box\!\!\rightarrow Mx))$ to express a law supervening on a potency or dispositional property of any object satisfying x.

By calling them "explanatory relationships", laws explain the existence of nomic regularities, so we really ought not to go along with Bird and take (V) to be an account of a law of nature, since the regularity described by the universal generalization is itself explained by a law of kind (I). Furthermore, since laws are grounded in potencies, a law of nature is not identified with a potency. The explanation of the existence of a regularity may then be equally well given by citing the realization of a law or the manifestation of the potency on which the law supervenes. Here the explanatory power of a law is inherited by the potency on which it depends: "Laws can explain in virtue of their being themselves explained by potencies" (2007, p. 197).[107]

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[105] See Bird (2007, p. 64) for his dual dispositionalist characterization of laws.

[106] Bird takes this account of laws to satisfy the following desiderata for laws: laws are general relationships; they are fundamental relationships; they are domain-relative; they supervene on potencies; they reflect the essential, not the accidental features of potencies and kinds (2007, p. 202).

[107] Bird believes that this view responds to objections about overdetermination, that if potencies explain regularities, laws can't as well: "This view simply rejects overdetermination worries for explanation. It permits the explanations we in fact employ to be genuine explanations despite not referring to fundamental

Dispositional essentialism argues for the necessity of laws. The necessity of a law of nature is entailed by the essential natures of the potencies on which the law supervenes. Dispositional essentialism thus entails the weak metaphysical necessity of laws, such that laws of nature hold in all possible worlds in which their grounding properties exist.[108] Laws hold in these worlds regardless of whether there also exist regularities that ontologically depend on laws. But Bird also thinks that dispositional essentialism is consistent with the stronger view that the laws of nature hold in all worlds without exception (2007, p. 50). Though it entails the weak necessity of laws, dispositional essentialism itself lacks the tools to decide between weak and strong metaphysical necessity. Thus Bird takes himself to be committed to the weak metaphysical necessity of laws.[109]

Brian Ellis also develops a dispositional essentialist theory of laws, arguing that dispositional properties give us laws of various kinds: global laws, compositional laws, causal (deterministic) laws, and stochastic laws. For Ellis, fundamental dispositional properties ground fundamental causal processes, and laws are descriptions of these processes. While agreeing about the existence of fundamental dispositional properties, Bird and Ellis differ about the ontological status of laws. Bird provides a realist or ontological account of laws, according to which laws are the essential relations that obtain between specific stimulus properties and manifestation properties, grounded by the identity of the disposition to which they belong. Ellis's approach to laws is instead linguistic: "Laws are not things that exist in the world; they are things that are true of the world" (2001, p. 128).[110] That which makes laws true are the natural dispositional properties that objects have. Natural dispositions are the truthmakers for laws of nature, so causal dispositions are the truthmakers for causally deterministic and stochastic laws:

> ...the natural kinds of processes that can occur are generally the displays of the basic dispositions of things, their causal powers, and so on. And to the extent this is the case, the laws of nature must be grounded directly in these properties rather than in any higher order relations of natural necessitation holding contingently between properties...The properties that are the truth-markers for the causal laws are the causal powers of

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properties" (2007, p. 197). For Bird, explaining a regularity by reference to a law but not the potency on which the law depends is a genuine explanation.

[108] "If properties have a dispositional essence then certain relations will hold of necessity between the relevant universals; these relations we may identify with the laws of nature. The necessity here is metaphysical" (Bird, 2007, p. 43).

[109] For his assessment of strong of metaphysical necessity, see Bird (2007, pp. 50–9).

[110] An unfortunate mode of expression – obviously sentences exist in the world. Ellis means to say that laws of nature do not themselves constitute a fundamental ontological category, as they do for Armstrong.

> things...fundamental dispositional properties of things are the truth-makers for the most fundamental causal laws that ultimately determine the ways in which things are disposed to behave, or with what probabilities they will be so disposed (2001, p. 217).

Anjan Chakravartty (2007) also defends a version of dispositional essentialism in the context of defending a version of scientific realism he calls 'semi-realism'. Like Bird and Ellis, Chakravartty endorses Sidney Shoemaker's thesis that the identity of a causal property is determined by the powers it confers on the things that have it. Chakravartty calls this the dispositional identity thesis (DIT) (2007, p. 123). Chakravartty assumes realism about dispositions and argues DIT entails certain conclusions as to what laws of nature are:

> To say that a particular has a certain causal property is to say that it is disposed to behave in certain ways in certain circumstances, and that all particulars having this same property are likewise so disposed. By circumstances I mean the presence and absence of other causal properties, both of the particular in question and of other particulars. Some of the processes elicited by these circumstances are experienced by us in the form of detected regularities. These regularities unfold in accordance with systems of laws which one attempts to describe using linguistic expressions, often in the form of mathematical formulae. Causal laws are relations between causal properties (2007, p. 122).

Chakravartty adopts an ontological account of laws. Since relations between causal properties are concrete causal relations, laws are causal relations between real dispositional properties. Thus laws, for Chakravartty, are grounded in the essential dispositionality of causal properties, as they are for Bird and Ellis. But like Bird, Chakravartty's consideration of causal properties and laws is confined to causally deterministic properties and the deterministic laws that they yield; his project doesn't extend to a dispositionalist account of probabilistic laws of nature.

Bird, Ellis, and Chakravartty share in common the conviction that laws are grounded in the fundamental dispositional properties of things. For Bird and Chakravartty, laws are general relationships between properties grounded in dispositions; for Ellis, law statements are true because they are descriptions of how things must behave given their essential natures. It's not necessary to defend any particular version of dispositional essentialism in this chapter – whether it is dispositional monism or the mixed view, or an ontological or linguistic conception of laws. All that is required here is a clear view of how dispositional essentialism in general proposes to ground laws in the fundamental dispositions of things,[111] which the exposition is this section was intended to provide.

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[111] Chakravartty may be an exception here: he grants the reality of dispositions but appears agnostic on whether some dispositions must be fundamental properties.

Let's now turn to probabilistic laws and the dispositionalist account of them.

5.4.2 Probabilistic Laws

We'll begin with Ellis's account of probabilistic laws. Let *t* be a time, δ a duration of time, C a kind of event or state of affairs for disposition D, and E an event that D manifests when in circumstances of kind C. Then,

> [t]he probability that a radium atom existing at *t* will have decayed by *t* + δ is, for any given frame of reference, a precisely specifiable function of δ, and this probability is independent of the circumstances in which the radium atom exists. Hence, we cannot even in principle eliminate this causally indeterminate disposition in favor of any more precisely defined dispositions that are causally determinate.
>
> Causally indeterminate dispositions such as these are *propensities*, and their laws of action are statistical laws. The statistical law follows from the fact that if anything *x* has a propensity ‹C,E› at *t*, then for any given value of δ, there must be an objective probability p(*x*,δ) that if *x* were to exist in circumstances of the kind C at *t*, then an E-type event would occur to *x* by *t* + δ. This is what we call the law of action of the propensity. Things having this propensity must behave according to this law (2001, p. 131).

There's a peculiarity in this formulation of the propensity account of probabilistic laws. It has to do with the placement of C, the circumstance in which one may find an object with a disposition. In the first paragraph Ellis says that the probability of a radium atom decaying by *t* + δ is independent of circumstances. This suggests that the propensity for radioactivity may be characterized without a characteristic stimulus event or condition, quite unlike the 'sure-fire' dispositions we've considered so far, like fragility. But in the second paragraph Ellis does characterize a propensity with reference to the conditions that the bearer of the propensity is in at *t*.

Why the discrepancy? One possibility is that the second paragraph provides a general account of how statistical laws relate to propensities, according to which stimulus events or states of affairs are generally characteristic of propensities, while in the first paragraph Ellis is giving the specific example of radium decay, the propensity for which C is irrelevant. This seems an unlikely

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This leaves open the possibility that essentially dispositional properties may be grounded in categorical properties. What makes Chakravartty's metaphysics a version of dispositional essentialism is the conviction causal properties are essentially dispositional and that laws of nature are causal relations grounded in causal properties.

interpretation, since it would juxtapose a general account of propensities with a counterexample. Perhaps C then is intended to be contextual, so that a certain probability is given when C_1 is a particular set of stimulus conditions for disposition D and a different probability is given for a different set of conditions for C_2. In the case of C_0, that of no stimulus conditions present at all, there is still a definite chance that the disposition will manifest itself in E by $t + \delta$. This would accord with the general fact about radioactive elements that they are materials that decay irrespective of their chemical and physical environments.[112] But it's not clear that Ellis is trying to make this distinction here: if he were, it would have made better sense to have left C absent in the second paragraph, giving a dispositionalist interpretation of the general law of radioactivity. Instead, he leaves C absent in his discussion about radium.

So what are we to make of Ellis's claim that radium has a probability to decay which "is independent of the circumstances in which the radium atom exists"? How does this square with the general claim that propensities are dispositions subject to conditions C? I don't think we should take his claim about radium to be a prescription to drop C from characterizing the propensity of radium to decay. Instead, Ellis seems to be asserting, through the example of a radium atom, that the disposition in question is irreducibly probabilistic.[113] Given the sentence that immediately follows it, this seems to be the right interpretation. What, then, are we to make of C in the second paragraph, if not a situation or event that determines a causal effect? Two answers seem to present themselves. First, a circumstance C may be an environmental condition that raises the probability of decay of a radioactive element without being sufficient for decay to occur.[114] Smoking, for example, raises the chance of a smoker to develop cancer, but is not sufficient to cause cancer, since a smoker may beat the odds and never develop cancer. Likewise, the environmental circumstances of some species of radioactive elements may raise their propensities to decay, without the circumstances deterministically triggering decay.

But what of those circumstances in which there are no factors that raise the probability of decay? Should we drop C to characterize propensities to decay independent of chemical and physical conditions? I don't think so. Since a

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[112] "Radioactive decay is spontaneous. It can occur even when the nucleus is totally isolated from external influences, although the presence of atomic electrons is sometimes required. Unlike most chemical reactions, the decay is not triggered by the absorption of energy from external sources. An unstable nucleus may live for billions of years before it suddenly and spontaneously disintegrates" (Harvey, 1991, p. 1021).

[113] Bird expresses the same thought: "Indeterminacy in the case of propensities is indeterminism—there being no prior state that causally necessitates the decay" (2007, p. 125).

[114] For an account of probabilistic causation by which a cause is neither sufficient nor necessary for its effect, see Mellor (1995).

propensity is a species of disposition, and dispositions are characterized, in part, by (stimulus) conditions C, we need to keep C to characterize a propensity, whatever circumstance it may be in. In the case of the propensity to decay of a radioactive element, I think we can capture its intrinsic propensity to decay by interpreting C as 'a state of affairs'. (Ellis explicitly states that C is a kind of event or state of affairs (2001, pp. 129–30).) Let *a* be an object. If *a is a radium atom* is a state of affairs that obtains, i.e., if it is a fact that *a* is a radium atom, then 'C' will stand for this fact in the formulation of the probability for radium decay. This way we save the placement of C and state the chance of decay for radium atoms by $t + \delta$, expressing the probabilistic causal relationship between being a radium atom and decay, independent of the circumstances in which an atom happens to exists.

Ellis's formulation of the law of the action of a propensity – the propensity interpretation of a fundamental probabilistic law – involves a reference to natural kinds of substances. A reference to a natural kind of substance summons the essential properties of the members of the kind, e.g., a propensity that confers on its bearers the disposition to behave in a certain way according to a certain probability. In general, Ellis's account of laws is rooted in an ontology that describes natural kind structures of substances, properties, and causal processes. Bird himself doesn't invoke natural kinds,[115] but he should find Ellis's interpretation of probabilistic laws acceptable since it is a realist account of probabilistic dispositions grounding probabilistic causation, and it explicates the law of action of propensities by a conditional statement probabilistically relating one property, e.g., being a radium atom, to another, radium decay. The conditional holds in virtue of real propensities that confer on their bearers probabilistic dispositions to behave in certain ways, e.g., radioactive decay. This account seems to satisfy Bird's account of dispositions (or potencies): "The nature of a potency is no more than its being a property whose essence is to be disposed to bring about a certain manifestation in response to a certain stimulus" (2007, p. 118). Of course, we saw that Ellis doesn't require environmental stimulus conditions for a fundamental propensity to generate a causal process, which is in keeping with the scientific notion of the spontaneous decay of radioactive substances. I suspect my interpretation of Ellis's 'C' as a state-of-affairs is one which Bird could easily accept.

So far we have been building up the ontology of dispositional essentialism and its account of probabilistic laws of nature so that we can see how dispositional essentialism might deal with the problem of undermining. We're not yet ready to turn to that question, since propensity theory faces a challenge in the form of a paradox. Humphreys's paradox poses the challenge that a propensity

[115] "I have not, primarily because the principal task is to account for the cement and motor of the universe (potencies and the laws that supervene on them). Natural kinds ought to be explicable in terms of that more fundamental ontology" (Bird, 2007, p. 8).

cannot at once be a measure of probability and a causal property of its bearer. Yet dispositional essentialists require propensities to have both of these features if propensities are to ground probabilistic laws. If the probability calculus does not apply to propensities or propensities are not causes, dispositional essentialism cannot posit the existence of objective indeterministic dispositions that ground probabilistic laws. So a solution to Humphreys's paradox is required if dispositional essentialism is to explicate probabilistic laws of nature. In the next two sections I explain the paradox and argue that Christopher McCurdy's solution (with minor adjustment) is preferable to the one proposed by Donald Gillies.

5.5 Humphreys's Paradox

Dispositional essentialists require fundamental propensities to ground fundamental probabilistic laws of nature. In this role, propensities provide an interpretation of the probability calculus and are the causal properties in virtue of which their bearers probabilistically display manifestation properties. Humphrey's paradox warns us against taking the probability calculus as the correct interpretation of objective chance or propensities. As such, the paradox casts doubt on the supposed relation of propensity to causality (Gillies, 2000, p. 129). If Humphreys's paradox were to go unsolved, dispositional essentialists like Brian Ellis and Alexander Bird would have a major problem at the core of their accounts of probabilistic laws, since the paradox casts doubt on whether probabilistic laws are grounded in fundamental probabilistic dispositions, as dispositional essentialists argue they are. So a solution that connects propensities to causation is required before posing the question of the big bad bug, since the latter will presuppose the causal powers of propensities. In this section I set out Humphreys's paradox and critique Donald Gillies's propensity solution to it.[116]

Some propensity theorists clearly express that propensities are closely related to causation. For instance, Karl Popper says that "causation is just a special case of propensity: the case of a propensity equal to 1" (1990, p. 20). Donald Gillies says that single-case propensities "can quite plausibly be considered as generalizations of causes. For example, a massive dose of cyanide will definitely cause death. A suitably small dose of cyanide might only give rise to a propensity of, say, 0.6 of dying. Here, propensity appears to be a certain kind of weakened form of causality" (2000, pp. 85–6). Humphreys's paradox identifies a problem with taking propensities so understood to be both causes and probabilities. Paul Humphreys first discussed the paradox in the 1970's, publishing his results in 1985. Some philosophers take the paradox to be a strong argument against the claim that propensities are probabilities.[117] Wesley C.

[116] See Section 2.3.3 for an introductory discussion of propensity theory and Gillies's theory in particular.

[117] There is some infelicity in calling propensities 'probabilities', as the title of Humphreys's (1995) paper does: "Why Propensities Cannot be Probabilities".

Salmon was the first to mention the paradox in publication, and the vividness of his example makes it an often quoted account of the paradox:

> As Paul W. Humphreys has pointed out in a private communication, there is an important limitation upon identifying propensities with probabilities, for we do not seem to have propensities to match up with "inverse" probabilities. Given suitable "direct" probabilities we can, for example, use Bayes's theorem to compute the probability of a particular cause of death. Suppose we are given a set of probabilities from which we can deduce that the probability that a certain person died as a result of being shot through the head is ¾. It would be strange, under these circumstances, to say that this corpse has a propensity (tendency?) of ¾ to have had its skull perforated by a bullet. Propensity can, I think, be a useful causal concept in the context of a probabilistic theory of causation, but if it is used in that way, it seems to inherit the temporal asymmetry of the causal relation (1979, pp. 213–14).

The paradox raises a dilemma for the propensity interpretation, one that centers on the question of whether or not propensities are symmetrical. On the one hand, propensities would seem to be asymmetrical since they are the causes of certain kinds of events. I'll give an example shortly, but generally causes and effects are temporally asymmetrical events. If A and B are events and A is the cause of B, then A is temporally prior to B and B cannot cause A. Causally related events are asymmetrically related, and we would expect propensities and their effects to be so as well. On the other hand, propensities would seem to need to be symmetrical since they are, on the propensity interpretation, probabilities. The probability calculus can be used on conditional probabilities to generate inverse or backward probabilities. For instance, if $P(A \mid B)$ is defined, Bayes' Theorem can

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Humphreys may be giving a real single-case interpretation of probability, characterized by Peter Milne as "a theory of probability…in which probabilities are assigned to the outcomes of a particular trial… The probabilities are real in that they are not only objective but also physical, located in the world" (1986, p. 130). The problem with this interpretation is that propensities seem rather to be properties that confer probabilities on possible single-case events – propensities are those properties in virtue of which there are single-case probabilities, which is not the same as saying that a propensity is a probability. It seems better to say that the probability calculus may be applied to certain things like frequencies, beliefs, propensities, etc., analogous to how fractions may be applied to things like pieces of pie. Pieces of pie are not fractions, but may exhibit features that allow fractions to be applied to them. At any rate, I'll defer to precedent and use 'propensities are probabilities' as shorthand for 'propensities are objective properties that interpret the probability calculus'.

be used with certain other probability values to calculate the value of P(B | A).[118] So if propensities are probabilities, propensities should be symmetrical. The dilemma for the propensity theory, then, is that if propensities are probabilities they are symmetrical, but if propensities are causes they are asymmetrical. So if propensities are probabilities they're not causes, and if they're causes they're not probabilities.

Grabbing one horn at the expense of the other can't solve the dilemma. One of the motivations to create the propensity interpretation is the need to provide a single-case account of probability that was applicable to quantum physics (e.g., Popper 1959b), and this approach requires propensities to be dispositions for probabilistic causation. So we want to be able to say that propensities are causal. But under the propensity interpretation we also want to say that propensities are probabilities. Propensities are both causal and probabilistic; no proper solution will come through a partial interpretation. As we will see, Gillies attempts just that by grabbing one horn at the expense of the other.

We need a good example of the paradox to work with. Earman and Salmon's (1992, p. 70) Frisbee example will do nicely. Here we imagine two machines that produce Frisbees. Machine 1 produces 800 per day with 1% defective; machine 2 produces 200 per day with 2% defective. At the end of the day the 1000 Frisbees are thrown into a bin from which we can randomly select samples. Let D = the selected Frisbee is defective, M = it was produced by machine 1, N = it was produced by machine 2. Some values are easily calculated: P(M) = 0.8, P(N) = 0.2, P(D | M) = 0.01, and P(D | N) = 0.02. Using Bayes' Theorem we calculate the value of the inverse of P(D | M), P(M | D):

$$P(M \mid D) = \frac{P(D \mid M)\,P(M)}{P(D \mid M)\,P(M) + P(D \mid N)\,P(N)} = \frac{0.01 \times 0.8}{0.01 \times 0.8 + 0.02 \times 0.2} = \frac{8}{12} = 2/3$$

P(M | D) is a measure of the propensity of an actual defective Frisbee drawn at the end of a particular day to have been made by machine 1. But "if we think of propensities as partial causes, this becomes the following. The drawing of a defective Frisbee in the evening is a partial cause of weight 2/3 of its having produced by machine 1 earlier in the day. Such a concept seems nonsense, because by the time the Frisbee is selected, it would either definitely have been produced by machine 1 or definitely not have been produced by that machine" (Gillies, 2000, p. 131).

118 "The value of a conditional probability is not determined by the value of its converse alone. But the value of a conditional probability can be calculated from the value of its converse, together with certain other probability values. The basis of this calculation is set forth in Bayes' theorem" (Skyrms, 1966, p. 134).

Gillies investigates how the long-run and single event propensity theories handle the paradox. According to Gillies, his own long-run propensity interpretation provides the best solution. He finds that the state-of-the-universe single event propensity theories of the later Popper and Miller do not fare well (2000, pp. 133–4)[119] but that Fetzer's nomically relevant single event propensities are able to resolve the paradox (2000, pp. 134–6). Concerning the latter, Gillies considers it a detraction that Fetzer introduces his own nonstandard axioms of probability; since the Kolmogorov axioms are widely accepted by probability theorists, a propensity interpretation should provide interpretations of them. Since Gillies's particular propensity theory does satisfy the standard probability axioms, he considers his solution to the paradox the best.

So how does Gillies solve the paradox? Since he gives a long-run interpretation of propensities, propensities are associated with sets of repeatable conditions S. Let A stand for an arbitrary event produced by S. $P(A \mid S) = p$ means that "there is a propensity if S were to be repeated a large number of times for A to appear with a relative frequency approximately equal to p" (2000, p. 131). Now as Gillies showed, on a causal reading of propensities inverse probabilities make no sense. But with propensities associated with repeatable conditions that produce finite frequencies, the causal implications of inverted probabilities are blocked. That is, it's nonsense to invert $P(A \mid S)$, since $P(S \mid A)$ would mean the occurrence of event A has the propensity to produce sets of repeatable conditions S.

The long-run interpretation now uses S to intervene on the problematic inverted conditional $P(M \mid D)$, and redefines it from a conditional probability about single events (D = the selected Frisbee is defective) to a conditional probability about a set of repeatable conditions $P(M \mid D\&S)$, where S is "the set of repeatable conditions specifying that the two machines produce their daily output of Frisbees, and that, in the evening, one of these Frisbees is selected at random and examined to see if it is defective" (Gillies, 2000, p. 132). D&S would accordingly be defined as the repetition of S and noting the result only if it is a member of D. Then

> The statement P(M/D&S) = 2/3 means the following. Suppose we repeat S each day, but only note those days in which the Frisbee selected is defective, then, relative to these conditions, there is a propensity that if they are instantiated a large number of times M will occur, i.e. the Frisbee will have been produced by machine 1, with a frequency approximately equal to 2/3 (2000, p. 132).

Gillies argues that no probability of the form $P(\_ \mid S)$ can be inverted. If A is an event and $P(A \mid S)$ is defined, then $P(S \mid A)$ makes no sense, since this would assume that sets of repeatable conditions can be produced by the occurrence of event A. So on the Frisbee example, there never was for Gillies a probability such

[119] See Chapter 2 for the long-run/single-case propensity distinction.

that P(D&S | M), even though on the causal interpretation of propensity we did have P(D | M), which could be immediately derived from given facts. Thus Gillies's concludes that S blocks the troublesome inverse of event-conditional probabilities.

The first thing that I would like to note about Gillies's long-run propensity theory is that it does attempt to preserve the relation between the notion of a propensity and causation. This seems to be evident in the fact that Gillies associates a propensity with repeatable conditions that produce relative frequencies approximately equal to the propensity. The preservation of the relation seems necessary for a solution to Humphreys's paradox, since the paradox casts doubt on the supposition that propensities are causal. Let us recall that in Section 2.3.3 we saw that Gillies rejects the notion of single-case propensities, arguing that we should explicate single-case probabilities subjectively. Gillies thinks that a virtue of the long-run theory is that it allows us to empirically verify propensity ascriptions when long-run frequencies produced by S approximately equal the propensity involved.

It's not obvious, however, that the long-run propensity theory excludes the existence of objective single-case propensities. For if a propensity is a power of repeatable conditions to produce frequencies, repeatable conditions S could surely be limited to a single trial, for instance, the production of just one Frisbee on a particular day. Here it seems that the propensity in S will produce a defective product with the same probability that would be reflected in the frequency of defective Frisbees it produced in the long run. Gillies's objection to single-case propensities is that they cannot be empirically verified, e.g., the production of a single Frisbee does not verify that the Frisbee making machine has a propensity *p* to produce defective Frisbees. (Though it may be that single-case propensities can be defined via frequencies, a possibility I'll consider in Section 5.8.) Nevertheless, that doesn't seem to negate the fact that the propensity at work in the production of finite frequencies is also the propensity at work in a single trial of production. So it doesn't follow from Gillies's verificationist criteria that objective single-case propensities don't exist and that single-case probabilities must be given account of by the subjective interpretation.

With that said, it's not clear that Gillies's long-run propensity theory offers something other than an alternative expression of the finite frequency theory. Gillies identifies propensities with repeatable sets of conditions that produce relative frequencies. But the only way a propensity can be ascribed to something is if the propensity were to produce a relative frequency approximately equal to the value of the propensity.[120] But it's not clear why a propensity must produce a long-run frequency equal to the propensity involved, for surely there is

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[120] I'm interpreting Gillies's statement "there is a propensity if S were to be repeated a large number of times for A to appear with a relative frequency approximately equal to p" with a biconditional, since he doesn't give us any other reason for believing that a propensity might exist.

some chance that the propensity $P(A \mid S) = p$ may produce a long-run frequency that is not approximately p. It may be that the possibility of the production of a long-run frequency not approximating the propensity involved is not a very likely course of events; but it is nevertheless a possibility that seems consistent with the notion of a propensity. (My propensity solution to the big bad bug in Section 5.7 will make critical use of this possibility.) So it seems that Gillies too closely associates propensities with long-term frequencies. And with this comes the charge against the frequency theory that objective single-case probabilities can only be subjectively defined, a view that Gillies defends. But this seems to be a particularly worrisome consequence, since subjective single-case probabilities seem to have little to do with the objective single-case probability that a radioactive atom is supposed to have to decay by some specified time. The best assumption to be made here, it seems to me, is to embrace the reality of objective single-case events, supplied neither by the subjective interpretation nor by the frequency theories. A propensity theory that is amenable to single-case events would fit the bill.

It also seems that Gillies doesn't provide a solution to Humphreys's paradox, since on his interpretation of propensities inverted probabilities are blocked. But mathematical probability tells us that conditional probabilities are invertible. It would seem that Gillies provides an interpretation of propensities that aren't probabilities – consequently he provides a solution that addresses the causal character of propensities without adequately addressing their probabilistic character (Berkovitz).

Finally, despite the fact that I have argued against a long-run theory of propensities, there are good reasons to think that propensities are connected to frequencies. D.H. Mellor, for example, conceives propensities to satisfy a frequency condition such that every chance (propensity) of fact P, $ch(P)=p$, that is a property of an earlier fact Q entails that "any collective of facts of a kind Q* with the property $ch(P)=p$ will have the limiting relative frequency $f_\infty(P^*)=p$" (1995, p. 44). Chances here are logically distinct from limiting relative frequencies—they are not identified with such frequencies but entail them. (I'll discuss Mellor's frequency condition again in Section 5.7.) Propensities are also causes of actual frequencies, whether or not the values of those frequencies are identical to the values of the propensities that produced them. In Section 5.7 I'll argue that actual frequencies are the epistemological base from which we may posit the existence of propensities. In this regard we can appreciate Gillies's attempt to give propensity theory an epistemological foundation in a long-run theory of propensities.

5.6 McCurdy's Solution

Christopher McCurdy's (1996) solution to Humphreys's paradox is based on a distinction between two sorts of events: the events in an event space Ω that are the possible outcomes of a process and the events that belong to the background conditions of a system that produces the events in the event space. Background conditions have a propensity to produce events in the event space, but there is no probability or propensity that background conditions will occur. Rather, background conditions B are the conditions on which a propensity function Pr(_ | B) is conditionalized. Background conditions have a propensity to produce certain outcomes, and we attribute the probability of outcomes only to the events in an event space that are possible outcomes of a system's processes.

McCurdy's solution also involves updating a system's propensity to produce future events as the system changes over time.[121] We'll see the effect of time and changes on propensities after some preliminary discussion. McCurdy presents his solution using Humphreys's example of an experimental arrangement. Quoting Humphreys (and putting time indices in subscripts):

> A source of spontaneously emitted photons allows the particles to impinge upon the mirror, but the system is so arranged that not all the photons emitted from the source hit the mirror, and it is sufficiently isolated that only the factors explicitly mentioned here are relevant. Let I_{t2} be the event of a photon impinging upon the mirror at time t_2, and let T_{t3} be the event of a photon being transmitted through the mirror at time t_3 later than t_2. Now consider the single-case conditional propensity $Pr_{t1}(. | .)$ where t_1 is earlier than t_2, and take these assignments of propensity values:
>
> i) $Pr_{t1}(T_{t3} | I_{t2}B_{t1}) = p > 0$
> ii) $1 > Pr_{t1}(I_{t2} | B_{t1}) = q > 0$
> iii) $Pr_{t1}(T_{t3} | {\sim}I_{t2}\, B_{t1}) = 0$
>
> where, to avoid concerns about maximal specificity, each propensity is conditioned on a complete set of background conditions B_{t1} which include the fact that a photon was emitted from the source at t_0, which is no later than t_1 (1985, p. 561).

Notice that i), ii), and iii) serve to describe the propensities of the photon experiment and all propensities are conditionalized on the set of background conditions B_{t1}.[122] i) states that there is a propensity at t_1 for a system satisfying conditions B_{t1} to produce a transmitted proton at t_3 given that it produced an impinging proton at t_2. iii) says that a proton cannot be transmitted at t_3 without an impinging proton at t_2. ii) says there is a non-trivial propensity (not 0 or 1) for the

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[121] Lewis (1983) and Mellor (1995) also note that the chance at t of a future event occurring at dt changes with any change in the physical conditions leading up to dt.

[122] "The background conditions typically include statements concerning the occurrence of certain events prior to t_1 such as 'a photon was emitted from the source at t_0'" (McCurdy, 1996, p. 108).

background conditions at t_1 to produce an impinging proton at t_2. i) and ii) respectively state non-trivial propensities for the production of transmitting and impinging protons, so describe an indeterministic system that produces events T and I.

If i) and its inverse conditional $Pr_{t1}(I_{t2} \mid T_{t3}B_{t1})$ are symmetric, then we should expect a non-trivial value for the inverse propensity consistent with the indeterminacy of the system. However, $Pr_{t1}(I_{t2} \mid T_{t3}B_{t1})$ and $Pr_{t1}(I_{t2} \mid {\sim}T_{t3}B_{t1})$ appear to be asymmetric to i), "since once the event T_{t3} or ${\sim}T_{t3}$ has been realized, there is no indeterminacy about the occurrence of the event I_{t2} – it has either occurred or not" (McCurdy, 1996, p. 107).[123] That is, $Pr_{t1}(I_{t2} \mid T_{t3}B_{t1}) = 1$ and $Pr_{t1}(I_{t2} \mid {\sim}T_{t3}B_{t1}) = 1$ or 0. So it would seem that the propensities of the photon experiment couldn't be probabilities, since conditional probabilities and their inverse conditionals are symmetric.

To deal with this problem, McCurdy notes that the assignment of 1 to the inverse propensity $Pr_{t1}(I_{t2} \mid T_{t3}B_{t1})$ may be based on mathematical calculation involving the relation between it and its conditional propensity. But we also know that the value of $Pr_{t1}(I_{t2} \mid T_{t3}B_{t1})$ must be 1, "since the description of the system indicates that the system is arranged in such a manner that if the system produces a photon that is transmitted at t_3, then the system must also produce a photon that impinges upon the mirror at t_2" (1996, p. 111). Notice that iii) $Pr_{t1}(T_{t3} \mid {\sim}I_{t2}B_{t1}) = 0$ is also a description of the physical system such that if the system produces a transmitted photon at t_3 the system could not have failed to produce an impinging proton at t_2. That being the case, then $Pr_{t1}({\sim}I_{t2} \mid T_{t3}B_{t1}) = 0$, since the system could not have failed to produce an impinging proton at t_2 given that a proton was transmitted at t_3. So the assignment of trivial values to $Pr_{t1}(I_{t2} \mid T_{t3}B_{t1})$ and $Pr_{t1}({\sim}I_{t2} \mid T_{t3}B_{t1})$, the inverses of i) and ii), respectively, can be explained by reference to the nature of the physical system we're dealing with.

Furthermore, consider the conditional propensities $Pr_{t1}({\sim}T_{t3} \mid I_{t2}B_{t1})$ and $Pr_{t1}({\sim}T_{t3} \mid {\sim}I_{t2}B_{t1})$. The first says that a system satisfying conditions B at t_1 has a propensity to not produce a transmitted proton given that an impinging proton was produced. Since $Pr_{t1}(T_{t3} \mid I_{t2}B_{t1}) = p > 0$, $Pr_{t1}({\sim}T_{t3} \mid I_{t2}B_{t1}) = 1 - p$. The inverse propensity of the first statement is $Pr_{t1}(I_{t2} \mid {\sim}T_{t3}B_{t1})$, that is, the propensity of the system to produce an impinging proton given that a proton failed to be transmitted, and is not assigned a value of 0 or 1, as Humphreys assumed. If $p < 1$, then $1 > Pr_{t1}(I_{t2} \mid {\sim}T_{t3}B_{t1}) > 0$, since the system is such that if a proton did not

[123] "The fact that the conditioning event occurs earlier than the conditioned event is inconsequential with respect to whether the inverse conditional propensities are physically meaningful or not. For any conditional propensity, inverses included, both the conditioning event and the conditioned event occur after the time at which the propensity function and the system are defined. Conditional and inverse conditional propensities are properties of systems to produce one future event given that the other future event is also produced (by the system)" (McCurdy, 1996, p. 109).

transmit at t_3, it is still possible that an impinging proton was produced. The second conditional states that there is propensity to not produce a transmitting proton at t_3 given that an impinging proton was not produced at t_2. Though clearly the value of this conditional is zero, the value of its inverse $Pr_{t1}(\sim I_{t2} \mid \sim T_{t3}B_{t1})$ is non-trivial, since a system satisfying conditions B at t_1 has a propensity to produce an impinging proton at t_2 whether or not it produced a transmitting proton at t_3. So if $p < 1$, then $1 > Pr_{t1}(\sim I_{t2} \mid \sim T_{t3}B_{t1}) > 0$.

Thus non-trivial propensities can be established for inverse propensities for the system defined by i) – iii), and in the case of inverse propensities that do equal one or zero, e.g., $Pr_{t1}(T_{t3} \mid \sim I_{t2}B_{t1})$, the reason is that trivial inverse propensities reflect the structure of the proton experiment, i.e., it is a necessary condition that if a proton is transmitted at t_3, a proton impinged the mirror at t_2. It follows that the trivial values of inverse conditionals do not imply deterministic systems and do not contradict the indeterminism assumed true for conditional propensities. Thus the propensities that describe indeterministic systems may entail trivial inverse probabilities.

McCurdy further argues that as propensities are updated to reflect the changes in systems over time, inverse conditionals may be blocked entirely. For example, if the event I_{t2} occurs at t_2 we can define a new propensity function Pr_{t2} that reflects the propensity of the system at t_2. "This function is conditioned on a set of background conditions B_{t2} which consists of the conditions expressed in B_{t1} as well as the additional condition that the event I_{t2} occurred at t_2" (1996, p. 112). Since I_{t2} is now part of the background conditions of the new propensity function and no longer a possible future event for that system, it is moved out of the original event space and Pr_{t2} is defined on a new event space, one that only has events $\sim T_{t3}$ and T_{t3} as possible outcomes.[124]

> Thus, as a system evolves over time, events are essentially removed from the event space and incorporated into the background conditions. Depending on which events actually occur, this creates a new propensity function that is defined at a different time, for a different system, and over a different σ–algebra of events [that is, over a different event space]. Consequently, inverse conditional propensities are susceptible to a propensity interpretation just in case both the conditioned event and the conditioning event are members of the Boolean σ–algebra defined on the event space. That is, *inverse conditional propensities, defined at some time t_i and defined for some system, are well-defined just in case: (1) both the conditioned event and the conditioning event occur after t_i and (2) the system is capable of producing those events* (1996, p. 113).

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[124] "The assignments made by the new propensity function are defined as follows: $Pr_{t2}(T_{t3} \mid B_{t2}) = Pr_{t1}(T_{t3} \mid I_{t2}B_{t1}) = p$, and $Pr_{t2}(\sim T_{t3} \mid B_{t2}) = Pr_{t1}(\sim T_{t3} \mid I_{t2}B_{t1}) = 1 - p$" (McCurdy, 1996, p. 112).

To summarize McCurdy's findings, problematic trivial inverse propensities are shown to be unproblematic by clarifying their triviality. Indeed, McCurdy shows that not all inverse conditionals have trivial propensities. And as we've just seen, in some cases inverses are blocked when systems are updated to reflect changing propensities. So Humphreys's paradox would seem to be dissolved by McCurdy. The solution in each case rests on a sharp distinction between the events in an event space and the events in the background conditions B at time t_i. However, as we questioned the placement of Gillies's repeatable conditions S in a conditional propensity, so we may question McCurdy's placement of background conditions B. For B, as it appears, e.g., in $\mathrm{Pr}_{t1}(T_{t3} \mid I_{t2}B_{t1})$, should also be inverted according to standard probability theory. Following Berkovitz, we should take such a condition out of the scope of the propensity function and place it in sub-scripts at the foot of the function, $\mathrm{Pr}_{t1B1}(T_{t3} \mid I_{t2})$, clearing the way for inversion.

Propensity theory, then, offers a viable interpretation of the probability calculus. Dispositional essentialism can thus posit propensities as the truthmakers of probabilistic laws of nature. Additionally, we saw in the previous section the problems in Gillies's long-run propensity theory and noted that a subjective account of single-case probabilities does not properly characterize the objective single-case probabilities of events governed by probabilistic laws of nature, like those concerning nuclear decay. Since a single-case propensity theory can provide the interpretation we need, we can now enquire into how dispositional essentialism fares against the problem of undermining. Does dispositional essentialism, like Lewis's and Armstrong's theories of probabilistic laws, succumb to the big bad bug?

5.7 A Propensity Response to the Big Bad Bug

Let's recall the big bad bug is the problem of undermining where a theory of chance T contradicts itself when it assigns chances to alternative futures of coming to pass. David Lewis worried that the problem of undermining infected his theory of chance, and that if left untreated it would cripple his entire Humean metaphysics. We saw in Chapter 3 that Lewis endorsed Michael Thau's proposed solution to the big bad bug, and I argued Thau's new criterion of admissibility creates a problem concerning the criterion of fit: best systems with probabilistic laws will not fit indeterministic worlds. I also argued in Chapter 4 that a version of the bug can be generated for Armstrong's theory of probabilistic laws.

In this section I will argue that undermining does not occur for a theory of propensities and dispositional essentialism. I'll argue that under the propensity interpretation of probability any nomically possible future[125] is compatible with a

[125] A nomically possible future for dispositional essentialism is any future course of events possible in virtue of the laws entailed by the fundamental dispositions of things.

theory of chance T_w, which gives a complete account of the laws of action of the propensities instantiated in our world. On the propensity interpretation there are no 'alternative futures' whose coming to pass would undermine T_w. I will thus introduce some new terms: on the propensity theory we substitute a future with the highest probability of coming to pass for an actual future, and substitute futures with lower probabilities of coming to pass for alternative futures. According to the metaphysics of probabilistic laws that I'm developing, there is no actual future and all possible futures are given relative probabilities of coming to pass by T_w. Thus any nomically possible future may come to pass, though the realization of some will be extremely unlikely, given the low probabilities that T_w assigns them. Even so, whichever nomically possible future does in fact comes to pass, none of them will contradict T_w. The future is open to any course of events that is nomically possible. Thus I reject Lewis's and Armstrong's actualism about the future, a consequence of the block theory of time they endorse. I endorse instead a position I'll call 'possibilism' about the future.

We have seen in this chapter that dispositional essentialists ground probabilistic laws in propensities—probabilistic dispositions instantiated in fundamental objects that display probabilistic behaviour. A theory of chance T_w for dispositional essentialism will concern the probabilistic laws of the actual world, a complete set of probabilistic law-statements[126] that describe the propensities of all natural kinds of objects, events, and processes to manifest properties characteristic of their propensities. T_w will include law-statements that state the probabilities of the behaviour of things independent of the environments that they happen to be in, as well as any derivative law-statements that factor in specific kinds of environments.

For Lewis, probabilistic laws are entailed by actual frequencies that exist, in part, in the future. Since a theory of chance is a summation of all actual probabilistic laws of nature, a theory of chance for Lewis is entailed by the global distribution of properties across all of time. The big bad bug arises for Lewis when the chance of an alternative future A coming to pass is conditioned on the theory of chance T, $P(A \mid T_w) = p$. T_w at present time assigns proposition A a certain probability of being true in the future; that is, T_w assigns alternative future A a certain probability of coming to pass. But if A were to come to pass, it would complete a distribution of properties that would assign it a higher chance of coming to pass. So T_w assigns A a definite probability p of coming to pass, but if A were come to pass, A's chance wouldn't be p, but some higher probability. Furthermore, a global history that includes alternative future A would form a distribution of properties whose frequencies would entail different probabilistic laws from the actual world, hence a theory of chance different from T_w. So T_w undermines itself.

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126 In this section I adopt Ellis's convention of treating laws as sentences which describe dispositions and how their bearers would behave in response to characteristic circumstances.

Part of the problem for Lewis is his commitment to actualism about the future, i.e., that the future exists. Actualism about the future, conjoined with the fixity of the past and present, implies a specific global distribution of properties, and the frequency interpretation of probability gives Lewis a theory of chance based on frequency distributions of properties. As long as his theory of chance depends on a global distribution of properties, the conditions for the infection of Lewis's metaphysics by the big bad bug seem set (notwithstanding Thau's proposed solution). I also argued that a version of the big bad bug affects Armstrong's theory of probabilistic laws, caused in part by his commitment to the block theory of time. In contrast, dispositional essentialists do not seem to commit themselves to a position on the ontological status of future events. This presents us with the opportunity of dispensing altogether with the troublesome ontology of actualism, though doing so would be better justified if motivated by or entailed by prior metaphysical commitments of dispositional essentialism. I believe such a commitment is found in the dispositional essentialists' posit of propensities.

Propensities are properties that are instantiated in individuals and are responsible for the probabilistic behaviour of their bearers. As such, propensities are the local probabilistic causes of the chancy behaviour of things that instantiate them. If Q is a propensity, a an object, and a instantiates Q, then the instance of Q is the local, intrinsic cause of the probabilistic behaviour of a characteristic of Q. For dispositional essentialism, probabilistic laws of nature describe the probabilities of behaviour that propensities confer on their bearers. By this scheme, probabilistic laws describe the local probabilistic causal properties of natural kinds of entities—laws do not depend on the non-local or global distributions of properties, as Lewis's Humean theory of laws does. Thus dispositional essentialism does not require the existence of an actual future for the existence of probabilistic laws. Since it does not require the existence of an actual future, let us suppose that dispositional essentialism is instead open to 'possibilism' about the future, by which I intend to convey the view that the future is now open to any nomically possible future coming to exist. Unlike actualism, possibilism does not take the future to be fixed by an actual portion of global history. Possibilism thus denies now the existence of an actual future, but asserts that some nomically possible future will come to exist.

However, possibilism about the future creates a problem for testing dispositional essentialism for the big bad bug, since if there is no actual future now, there is no sense in which there might be an alternative future that undermines a theory of chance. The notion of an alternative future conceptually depends on the notion of an actual future. Has the problem of undermining thus been dissolved for dispositional essentialism? Not quite. While it may be that for dispositional essentialism there is no actual future course of events, we can formulate analogues to actual and alternative futures. The theory of chance for dispositional essentialism describes the propensities instantiated by the objects of the world and will entail a possible future that is more likely to come to pass than other possible futures, while all other possible futures will be assigned probabilities such that they are less likely to come to pass relative to the most likely possible future and more or less likely to come to pass relative to each other.

With these analogues we can now answer the question of whether the problem of undermining arises for dispositional essentialism. The quick answer is it does not. The reason is that any possible future for the actual world is compatible with a theory of chance based on propensities. Dispositional essentialism's theory of chance tells us which possible future is most likely to come to pass. But if the most likely future does not come to pass, because some less likely course of events does, the theory of chance is not contradicted or undermined. Any future that is possible for the actual world is consistent with the propensity interpretation of probabilistic laws, though some futures are highly unlikely given the propensities instantiated in the world. For example, the theory of chance will have among its laws the half-life of radium 226, 1602 years; each radium atom has exactly a .5 probability of decaying within 1602 years. Though highly unlikely, it may be that each radium atom will take much longer to decay than what the law leads us to expect – perhaps in the future no radium decays in less than 10 000 years, whereas the law tells us 1/2 of all future samples will decay in 1602 years. It is unlikely that such a future will come to pass, but if it did it would not contradict the propensity of radium decay or the law that describes it. (And if a propensity were to give rise to an unlikely course of events, one whose frequency does not equal the value of the propensity, the propensity will nevertheless be a real property for the dispositional essentialist.)

The big bad bug does not afflict the propensity interpretation of probabilistic laws because any possible outcome for the actual world is consistent with the propensities involved. It is possible that no future radium atom decays in less than 10 000 years, even though every instance of radium instantiates the propensity to decay in 1602 with a .5 probability. This possibility is grounded in the locality of the propensity, the intrinsic cause of each radium atom to decay. The possibility of all future instances of radium taking more than 10 000 years to decay is grounded in the possibility that each instance of radium possesses this possibility in virtue of its propensity to decay. Hence, highly unlikely possible futures are nevertheless real possibilities in virtue of the propensity interpretation of probabilistic laws. Hence, unlikely possible futures do not undermine the theory of chance for dispositional essentialism.

Because propensities are the local, instantiated causes of probabilistic activity, a propensity theory of chance T does not carry direct information about the future. Lewis's theory of chance did carry direct information about the future, since a Humean theory of chance is based on distributions of properties that exist in part in the future. A propensity theory of chance is not based on global distributions of properties, so we dispositional essentialists are not hampered by an element that proves to cause trouble for Lewis.

The propensity solution to the problem of undermining discussed in this section does not contradict Mellor's frequency condition, introduced in Section

5.5. This is an important concession, since a propensity theorist may want the frequency condition to be a desideratum satisfied by his or her theory of chance, such that any particular propensity (chance) *ch*(P)=*p* entails a limiting relative frequency equal to *p*, i.e., the frequency with which P occurs in an infinite sequence of events Q will be *p*.[127] Mellor's frequency condition concerns infinite sequences of events entailed by chances, so the frequency condition is not threatened by the propensity solution to the problem of undermining, since the possible futures invoked by the solution will always concern finite classes of objects—there are only limited amounts of radium, polonium, etc. in the universe. If the actual world's future comes to pass with a (finite) series of events that are improbable according to the propensity theory of chance *T*, that series will contradict neither the theory of chance (as I have argued) nor the infinite limiting relative frequencies entailed by the propensities involved.

Let me explain further. Since a limiting relative frequency cannot be realized in a world of finite numbers of objects, a propensity *ch*(P)=*p* at once entails a limiting relative frequency equal to *p* and may give rise to an unlikely series of events in the real world. The limiting relative frequency will equal the propensity of which it is a consequence, but will not equal the frequency entailed by an unlikely future.[128] On the other hand, an unlikely possible future is consistent with the propensity which makes it possible. Thus the propensity theory provides a response to the big bad bug without challenging Mellor's frequency condition.

5.8 Propensities and Epistemology

Having argued for a propensity solution to the problem of undermining, I again need to make the point, as I did first in Section 5.5, that propensities and actual frequencies are not unconnected. As discussed in 5.5, propensities are causes of actual frequencies. But another connection to be found between propensities and actual frequencies is that observed actual frequencies provide the evidence on which we posit the existence of propensities. Actual frequencies thus provide the epistemological basis for knowing propensities. Mellor characterizes the epistemological relation between frequencies and propensities in terms of inferring a cause from its effect: "[The] propensity of any chance to yield frequencies close to itself means indeed that, for example, tossing many coins

[127] "Any collective of facts of a kind Q* with the property *ch*(P*)=*p* will have the limiting frequency f_∞(P*)=*p*" (Mellor, 1995, p. 44).

[128] The limiting relative frequency will not equal the frequency entailed by an unlikely future, because the value of the limiting relative frequency is equivalent to the value of propensity P and the value of an unlikely but nomically possible future may diverge wildly from P. The limiting relative frequency may, however, approximate to a very high degree the most likely possible future that is given by the theory of chance.

with the same chance $ch(H)=p$ of landing heads can *cause* the actual frequency $f(H)$ of heads to be close to p – thus making the inference from $f(H)\approx p$ to $ch(H)\approx p$ merely a special case of inferring a cause from its effect" (1995, p. 51).[129] It seems very likely that all our knowledge of propensities comes through knowledge of actual frequencies, whose values we attribute to the propensities from which they arose. Our knowledge of the laws that govern or describe the action of propensities will also depend on this epistemological connection.

But doesn't an acknowledgement of an epistemological bridge between actual frequencies and propensities amount to an endorsement of Gillies's long-run propensity theory, which I critiqued in Section 5.5? I don't think so. I agree with Gillies that some connection between propensities and frequencies is required if we are to have knowledge of propensities. But I disagree that a propensity theory must be a long-run theory. For without single-case propensities, Gillies has to call upon the subjective interpretation to give an account of single-case probabilities. But as I have stated throughout this thesis, subjective probabilities don't seem to be the right interpretation of the objective probability of decay that physics ascribes to individual radioactive atoms. If science is to be a guiding principle here, then we should posit single-case propensities to explain the existence of single-case objective probabilities. So I agree with Gillies that we need a bridge that links frequencies and our knowledge of the propensities that produce them, but unlike him I posit the instantiation of single-case objective propensities in fundamental substances like radioactive atoms.

Gillies's response would surely be to point out that I have opted for a metaphysical account of propensities, since the values of single-case propensities cannot be verified in scientific tests. He would also claim that his long-run theory is a scientific theory of propensities, since the values of long-run propensities can be verified in frequencies, as propensities are associated with sets of repeatable conditions (2000, p. 128). My response to the charge of endorsing a metaphysical rather than a scientific account of propensities is that I don't have any reservations about positing the existence of a metaphysical entity if there is good reason for doing so. Our best science says that an individual radioactive atom has an objective chance of decaying independent of whether other atoms of the same kind have or have not decayed.[130] Independent of my argument from the big bad

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[129] See Mellor (1995, pp. 70–3) for his causal theory of indirect perception that links our belief in the existence of propensities to our sensation of the effects of propensities, our senses and the effects of propensities, and the effects of propensities to propensities themselves.

[130] "A radioactive atom...is in an unstable condition. In any interval of time it will have a certain definite probability of disintegrating. Thus while individual atoms will decay at random, the over-all result for a large number of atoms is for a definite fraction of these to break up in any given interval of time" (*Encylopaedic Dictionary of Physics, Vol. 6*, 1962, p. 45).

bug, this seems to me a very good reason to posit the existence of single-case propensities.

But is knowledge of single-case propensities possible? This is an interesting epistemological question that deserves to be fully addressed, but about which here I will only make two comments to indicate direction for further enquiry. Contrary to Gillies, I think there is evidence that we do gain knowledge of single-case propensities through actual frequencies. First, Mellor's account of learning propensities through actual frequencies is amenable to single-case propensities, so the idea of epistemologically connecting actual frequencies and propensities is not new to philosophy. Second, physics attributes single-case chances based on observation. To use an historical example, Marie Curie recalls her experiments on uranium decay: "My experiments proved that the radiation of uranium compounds can be measured with precision under determined conditions, and that this radiation is an atomic property of the element of uranium" (Curie, 1923). Measurements such as Curie's were the basis on which the decay rate of uranium was calculated, and experiments on other kinds of radioactive elements lead to the discovery of other decay rates. Since radiation is an indeterministic event, Curie's comment that radiation is an atomic property of uranium implicitly endorses the single-case objective probability that a particular uranium atom will decay by a certain time. Other scientists make more explicit statements that individual atoms have single-case objective probabilities of decaying, e.g.:

> Our inability to predict the fate of any particular atom does not stem from a lack of data, but from the nature of the process. A *mathematical* analysis of the statistical phenomenon shows that the radioactive nucleus has no 'memory', and the probability that it will decay within the next second does not depend on the time elapsed since it was formed. A radon nucleus newly formed from radium has the same probability of disintegrating within the next second as one which is 200 hours 'old'. This shows that the disintegration is not the result of any hidden internal development but really a random occurrence (Ne'eman & Kirsh, 1986, p. 49).

In science we find such examples of the ascription of single-case objective probabilities based on observations of actual frequencies. Thus Gillies seems to be wrong to say that experimental work can only inform us of what long-run propensities are.

5.9 Conclusion

The main argument of this chapter is that dispositional essentialism fends off the big bad bug. To make the case I argued that dispositional essentialism should substitute possibilism for actualism about the future. A theory of chance T_w based on the fundamental propensities instantiated in the actual world assign a probability to every nomically possible future. If the possible future with the highest chance of coming to pass fails to do so, the theory of chance based on propensities would not be undermined by the coming to pass of another course of events, since the coming to be of a less likely future would complete a distribution of properties logically compatible with T_w.

T_w assigns a probability to each nomically possible future, and if a course of events with a low probability does comes to pass, its cause is found in the propensities involved. Since the propensity theory of chance is compatible with any nomically possible future to which it assigns a probability, the theory of chance for propensity theory does not undermine itself. Since dispositional essentialism endorses a propensity interpretation of chance and probabilistic laws, dispositional essentialism in turn does not suffer from the problem of undermining. In short, a dispositional essentialist account of probabilistic laws is not infected by the big bad bug.

Chapter 6: Conclusion

I have argued in this thesis that dispositional essentialism explicates probabilistic laws of nature better than either the best systems analysis or the contingent necessitation theory of laws do. To establish this I tested the theories against the problem of undermining. The problem of undermining points to incoherence among the elements of a metaphysics of laws. Manifesting itself in the form of a contradiction, the appearance of undermining indicates that a particular metaphysics entails a contradiction. Since no theory that entails a contradiction can provide an account of probabilistic laws, the problem of undermining can be used as a stringent test to determine whether a theory of laws does or does not explicate probabilistic laws of nature. If it can be shown that there is no undermining in a theory, or that an initial appearance of the bug can be strategically beaten, we have shown that the theory in question passes a stringent test that any such theory must pass if it is to explicate probabilistic laws. But if undermining is shown to be a problem, or if proposed solutions to undermining fail, we should conclude that the theory in question fails to explicate probabilistic laws. I argued that the problem of undermining does not arise for dispositional essentialism, that the bug is a threat to David Armstrong's contingent necessitation, and that Michael Thau's solution to the bug fails for David Lewis's best systems analysis.

With respect to Lewis's best systems analysis of laws, in Chapter 3 I argued that Michael Thau's solution to the problem of undermining is ad hoc and leads to a new problem for best systems with probabilistic laws. I argued that the theory of chance *T* for the actual world may be inadmissible even when no undermining occurs. Since *T* contains information about future chance history, it is inadmissible because it is a proposition that provides direct information about what the outcome of some chance event is. Thus *T* is inadmissible relative to actual history *H*, though no undermining occurs when we condition *H* on *T*. The result, I argued, is a difficult problem for best systems analysis with probabilistic laws. A deductive system for the actual, indeterministic world will be the best only if it fits the world. But on Thau's solution to the big bad bug, best systems cannot fit the world, since a theory of chance is inadmissible relative to actual world history. Generalizing, my argument is that on Thau's solution, best systems cannot fit indeterministic worlds. On Thau's solution, the best systems analysis fails for indeterministic worlds, so that best systems fail to explicate probabilistic laws of nature.

In Chapter 4, I argued that the big bad bug can also be shown to be a problem for Armstrong's contingent necessitation theory of laws. My argument here was to develop an analogy between Armstrong's and Lewis's theories of probabilistic laws of nature. I reasoned that if elements of Armstrong's theory of laws could be shown to be similar to the elements of the best systems analysis that contributed to undermining, then the bug lurks in Armstrong's metaphysics too. I argued that Armstrong's actualism about properties, his block theory of time, and his notion of a complete science form close analogies to the bug-related elements in Lewis's metaphysics and permitted an alternative regularity reading of Armstrong's metaphysics. Since those elements were sufficient to give rise to undermining in Lewis's theory of probabilistic laws, I reasoned that the analogues in Armstrong's theory of laws were sufficient to give rise to undermining too. I also argued that Armstrong meets moderate success in responding to van Fraassen's arguments against his interpretation of probabilistic laws. But in his response, Armstrong appeals to possibilia, contradicting his metaphysical assumption of naturalism. So it's not clear that Armstrong can respond to van Fraassen with a fully natuaralistic account of probabilistic laws. I concluded that contingent necessitation fails to explicate probabilistic laws of nature.

In Chapter 5, I argued that the problem of undermining does not show up for dispositional essentialism with its propensity account of probabilistic laws. I argued that dispositional essentialism should substitute possibilism for actualism about the future. A theory of chance *T* based on the fundamental propensities instantiated in the world assign a probability to every nomically possible future. If the possible future with the highest chance of coming to pass fails to do so, the theory of chance based on propensities would not be undermined by the coming to pass of another course of events, since the coming to be of a less likely future would complete a distribution of properties logically compatible with *T*. *T* assigns a probability to each nomically possible future, and if a course of events with a low probability does come to pass, its cause is found in the propensities involved. Since the propensity theory of chance is compatible with any nomically possible future to which it assigns a probability, the theory of chance for propensity theory does not undermine itself. Since dispositional essentialism endorses a propensity interpretation of chance and probabilistic laws, dispositional essentialism in turn does not suffer from the problem of undermining. In short, a dispositional essentialist account of probabilistic laws is not infected by the big bad bug.

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