ESSAYS ON CAUSATION, EXPLANATION, AND THE PAST HYPOTHESIS

By

CHRISTOPHER GREGORY WEAVER

A dissertation submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

In partial fulfillment of the requirements

For the degree of

Doctor of Philosophy

Graduate Program in Philosophy

Written under the direction of

Dr. Barry Loewer

And approved by

_____

_____

_____

_____

New Brunswick, New Jersey

May, 2015

ABSTRACT OF THE DISSERTATION

Essays on Causation, Explanation, and the Past Hypothesis

by CHRISTOPHER GREGORY WEAVER

Dissertation Director:
Dr. Barry Loewer

The essays in this collection begin with an introduction to the problem of the arrow of time, the necessity of the past hypothesis in the standard solution to that puzzle, and an appreciation of the special nature of the low-entropy state posited by the past hypothesis. Chapter 2 includes an explication and brief defense of several philosophical doctrines including an Aristotelian substance view of concrete particulars, logical monism, classical logic as the one true logic, necessitism, and that two-possibility claims afford *prima facie* epistemic justification. These doctrines build up a prolegomena that plays an essential role in my demolition of various reductive theses in Chapter 3. Chapter 3 knocks down both David Lewis's Humean supervenience thesis, and Theodore Sider's new fangled Humeanism. If either of these metaphysical worldviews are correct, the idea that causation is a fundamental relation in the world can never get off the ground. I end chapter 3 with a refutation of two direct arguments for the idea that causation reduces to physical history and natural nomicity. Having concluded that there is no good reason to endorse causal reductionism or a more general reductive thesis that would entail causal reductionism, I articulate and defend a novel account of causal *relata* and a new realist theory of deterministic causation. Both of these theories constitute the very heart and soul of the account of token physical explanation I defend in Chapter 5. The final substantial

chapter features an articulation of the two most complete attempts in quantum cosmology to explain the past hypothesis. I argue that neither explanation succeeds and conclude that given such failures and that there are certain other fine-tuned parameters, and constants, it is likely that there cannot be a scientific explanation of that hypothesis.

Acknowledgements

There are many people I am indebted to for their help and support over the past five years. First and foremost, I thank my Lord and Savior Jesus the Christ, who died a substitutionary death for my sins, was buried, and whom God raised from the dead (as *per* the ancient pre-Pauline creedal statement of 1 Cor. 15:3-8). Second, I thank my wonderful wife Christina Michelle Weaver. Without her continual encouragement I would not have been able to complete the project.

I also owe thanks to the following academic associates and colleagues for conversations, or comments, or helpful correspondence on or about various parts of these essays: Jonathan Schaffer, Tom Banks, David Albert, Anthony Aguirre, David Black, Eddy Keming Chen, Sean Carroll, Robin Collins, Shamik Dasgupta, Ned Hall, Matthew Johnson, John Norton, Don Page, Laurie Paul, Joshua Rasmussen, Daniel Rubio, Peter van Elswyk, Aron Wall, and Dean Zimmerman. I'd also like to thank audiences at the 2014 Eastern APA, the 2015 Central APA, the University of Illinois Urbana-Champaign, and Yale University for their comments, questions, and criticisms on and of portions of the project.

In addition to the above acknowledgments, I report that chapt. 3 is taken from my paper "Fundamental Causation". Large portions of chapt. 4 were also taken from "Fundamental Causation". Much of chapt. 6 incorporates material from my paper "On the Carroll-Chen Model" (Weaver (draft)). Other substantially smaller sections of material come from several of my other drafts and are cited appropriately.

To Barry Loewer, I say, *thank you for believing in me*.

Table of Contents

List of Illustrations

Chapter 1 Introduction

If one thought that time and its direction reduce to some reductive base in fundamental physical science one would encounter a perceived barrier *viz*., the fact that the underlying dynamical laws of fundamental physical theory do not privilege the past or the future. If those laws permit certain physical processes to be future-directed or oriented, then they also allow for those self-same processes to be past-directed or oriented. The dynamical laws are time-reversal invariant. As Roger Penrose stated,

> …the dynamical equations of classical and quantum mechanics are symmetrical under a reversal of the direction of time! As far as mathematics is concerned, one can just as well specify final conditions, at some remote future time, and evolve backwards in time. Mathematically, final conditions are just as good as initial ones for determining the evolution of a system.[1]

Even though the dynamical laws of our fundamental physical theories are time-reversal invariant, there appear to be macroscopic energetically isolated processes that are temporally irreversible. So the microphysics is such that it suggests temporal symmetry though macroscopic goings-on suggest temporal asymmetry. To make things worse, given an appropriately robust reductionist story in the background, macroscopic phenomena depend in some strong sense on underlying microphysical phenomena. We should now ask: "what could be the source of…[the]…widespread temporal bias in the" macroscopic "world, if the underlying" microphysical "laws are so even-handed?"[2] This is *the puzzle of the arrow of time*.

---

[1] Penrose (2005, p. 687). *Cf*. Feynman (1965, p. 52-3); Weyl (1949, pp. 203-204); Zee (2010, pp. 102-103); though there is some debate over how precisely to understand such invariance. The debate features Albert (2000, pp. 1-21) and Horwich (1987, pp. 15-57) on one side, with Malament (2004) and North (2008) on the other.

Some physicists (*e.g*., Tom Banks) would disagree with the claim that the laws of quantum mechanics are time-reversal invariant.

[2] Price (2004, p. 219).

There is a potential exception to the claim that the fundamental dynamical laws are time-reversal invariant. The CPT-theorem (rigorously proven in Lüders (1954)), states that all local Lorentz invariant field theories are invariant with respect to C-P-T (*i.e.*, charge conjugation, spatial parity, and time-reversal invariance) understood as a combined operation. One lesson this theorem teaches us is that if a field theory violates P-T, then the theory possesses either objective temporal handedness, or objective spatial handedness, or perhaps both (Arntzenius (2012, p. 200)).

In the context of weak interactions, there are *legitimate* instances of parity violation, and these violations imply in that context a further violation of time-reversal invariance or symmetry. We have experimentally confirmed a violation of time reversal invariance in B^0 meson systems. Weakly interacting systems are anomalous for this reason. I will have more to say about how to understand such systems in the context of discussing the arrow of time. For now, let's unashamedly affirm that the fundamental dynamical laws are time-reversal invariant, deliberately suppressing worries about weakly interacting systems for the purposes of deliberation. Why isn't the temporal handedness accounted for by the phenomenon of weakly interacting systems? Answer: That phenomenon does not occur frequently enough to serve as a proper reductive base for the pervasive temporal handedness we observe at the macroscopic level. North (2011, p. 315) indicates that this is the majority view on the matter.

But what about the second law of thermodynamics? Does not that law imply that energetically isolated systems almost never decrease in entropy, and that systems in non-equilibrium states always increase in entropy as time marches forward? Why isn't that law the source of macroscopic temporal handedness? The second law does not solve the

problem. Instead, it highlights how critical and weighty the puzzle of the arrow of time is, for that law is itself temporally asymmetric and yet the constituents of isolated systems which dance to that law are themselves governed by dynamical laws of motion that are temporally symmetric. So the question remains, whence the asymmetry of the second law? As Price put it, "[h]ow could symmetric underlying laws give rise to such a strikingly time-asymmetric range of phenomena as those described by the Second Law?"[3] This is, yet again, *the puzzle of the arrow of time*.

Looking to entropic increase involved in the attempt to solve the puzzle via the invocation of the second law looks promising. In fact, attempts to explain the second law by means of more fundamental happenings resides prominently in the history of the physics of thermodynamics and statistical mechanics.

Theoreticians looked to statistical mechanics (the theory which involves an application of fundamental dynamical equations of motion to systems of large particles) for the purposes of explaining the thermodynamic properties of complex systems. And so, again, it was hoped that one could account for the second law by paying heed to underlying mechanics.

Ludwig Boltzmann (1844-1906) tried to use his H-theorem to explain the second law.[4] He was attempting to provide a microphysical explanation of the tendency of isolated systems to evolve toward equilibrium states, and while in route, increase in entropy.[5] The theorem itself suggested that the entropy of (say a closed container featuring perfectly elastic walls that is filled with gas) always increases to equilibrium on

[3] Price (2002, p. 21).

[4] See Boltzmann (1965, pp. 131-141), ([1872] 2003, pp. 262-349). My reading is in line with Callender (2010, pp. 48-49); and Uffink (2008, sect. 3.1). Boltzmann's language was actually stronger. He said "[t]his [the H-theorem's derivation] provides an analytical proof of the Second Law in a way completely different from those attempted so far." (as quoted by Uffink (2008, sect. 3.1)).

[5] Brown, Myrvold, and Uffink (2009, p. 175).

account of the fact that the gas particles populating the system randomly collide with one another. I should add that here we are assuming Boltzmann's "thermodynamic" state-count theory of entropy as opposed to the Gibbsian approach to statistical mechanics which involves an information-theoretic conception of entropy.[6]

There are other temporally asymmetric explanations of the second law. For example, David Albert ((1994, p. 676), (2000, pp. 150-156)) has argued that a certain collapse mechanism (like the wave function of the GRW interpretation of quantum mechanics) may be enough to guarantee that entropy almost never decreases, but always pushes non-equilibrium systems towards equilibrium states. Both Boltzmann's *H*-theorem and Albert's exploratory appeal to GRW require two asymmetries, *viz*., (a) the asymmetry of the recommended mechanism and (b) the posit that entropy starts off low.[7] If it does not include (b), then if the system starts off in equilibrium, the mechanism will only ensure that the system stays in equilibrium. As Price (2004, p. 223 emphasis mine) highlighted, "[t]o get what we see, then, we need an *asymmetric 'boundary condition' which ensures that entropy is low in the past,* as well as an asymmetric mechanism to make it go up."

But we may not need a causal mechanism to ensure that entropy increases. In fact, David Albert has argued (2000) that increase in entropy may be nothing more than a

[6] See on this Ladyman, Presnell, and Short (2008). For criticisms of the information-theoretic approach, see Norton (2005). It seems that most theoreticians adopt the Bolzmannian interpretation of entropy and SM when discussing foundational issues. In fact, most physicists assume this interpretation as well, as D.A. Lavis remarked, "[w]hen confronted with the question of what is 'actually going on' in a gas of particles (say) when it is in equilibrium, or when it is coming to equilibrium, many physicists are quite prepared to desert the Gibbsian approach entirely and to embrace a Boltzmannian view". Lavis (2005, p. 246); Sean Carroll argues that Gibbsian entropy collapses into Boltzmann entropy, and that, therefore the latter conception is more primitive. See Carroll (2010, pp. 170-171)].

[7] Boltzmann's causal mechanism was itself temporally asymmetric. Samuel H. Burbury (1831-1911) would point out that the asymmetry is achieved not by honest toil but by "dishonest" gain. He noted that the H-theorem assumed "that the velocities of colliding particles are independent *before* they interact." Price (2002, p. 27) emphasis mine.

consequence of the geometry of phase space, a probability distribution over that space, and the past hypothesis, where the past hypothesis is the idea that (quoting Albert) "…the world first came into being in whatever particular low-entropy highly condensed big-bang sort of macrocondition it is that the normal inferential procedures of cosmology will eventually present to us."[8] Such an "Albertian" explanation of the second law represents the standard view in contemporary philosophy of physics. And so, in order to successfully account for the asymmetry of time it is thought that one should implore an explanation of the second law that requires the use of an initial condition described by the past hypothesis.

Recall Albert's statement of the past hypothesis. We should ask, what does contemporary cosmology say about such a "particular low-entropy highly condensed big bang state"? It says that our universe's initial low-entropy state corresponds to an extremely early state in our universe's evolutionary history in which matter is uniformly distributed across the available space. This may be shocking to those entrenched in orthodox Boltzmannian SM, for on that orthodoxy the picture just painted looks much like an equilibrium state and not one in which entropy is exceedingly low. As Robert Wald commented:

> The…claim that the entropy of the very early universe must have been extremely low might appear to blatantly contradict the 'standard model' of cosmology: there is overwhelmingly strong reason to believe that in the early universe matter was (very nearly) uniformly distributed and (very nearly) in thermal equilibrium at uniform temperature. Does not this correspond to a state of (very nearly) maximum entropy, not a state of low entropy?[9]

Wald's question is only perplexing because we have forgotten to consider gravity's role in the early universe (Wald himself notes this). Although the details are complex, the

[8] Albert (2000, p. 96).
[9] Wald (2006, p. 395).

majority view these days is that our universe's "early spatial uniformity represents the universe's extraordinarily low initial entropy"[10], and this is the case despite the fact that the early universe was in a thermal state with uniform temperature (what would have otherwise been judged to be an equilibrium state).[11]

Can one ground the past hypothesis itself in something else, something more fundamental? Is there an explanation of the universe's low-entropic state, and therefore is there an explanation of the arrow of time? Most cosmologists believe that there is, and there are number of proposals already on the table for examination, including attempts from cyclic and holographic cosmology, multiverse theories, and inflationary cosmology. Interestingly, Albert, Loewer, and Callender are more comfortable maintaining that the past hypothesis is a natural law.[12] Explanation, it is thought, stops somewhere. And it seems that non-dynamical laws of a form corresponding to the past hypothesis are not easily conceived of as legitimate *explananda*. Many, standing in a tradition that stretches back to Immanuel Kant, would insist that the range of explanation-types that are admissible—when seeking to explain the past hypothesis—have need of some earlier state of the world. With respect to the past hypothesis, such an earlier state may very well

[10] Penrose (2010, p. 76).

[11] Penrose (2005, pp. 706-707); Price (2004, pp. 227-228); and Wald (2006, p. 395). Although there are criticisms of this understanding of gravitational entropy (see, *e.g*., Earman (2006)), but as will become relevant later, the view adumbrated above is assumed by Sean Carroll and Jennifer Chen (see Carroll and Chen (2004, p. 4)) and explicitly endorsed by Carroll (see his (2010, pp. 295-299)).

[12] And here I have in mind the Mill-Ramsey-Lewis best-systems account (BSA) of natural laws. See Cartwright et. al. (2005), pp. 797-799; Earman (1984); Lewis (1973b, pp. 72-77), (1983), (1994, pp. 478-480); and Ramsey (1990, p. 150) for clear discussions of the view. On regarding the past hypothesis as a law in the BSA sense, see particularly Callendar (2004, pp. 207-209); and Loewer (2001, p. 619). For criticisms of the BSA see Armstrong (1983, pp. 70-71); Belot (2011, pp. 70-72); and van Fraassen (1989, pp. 48-51).

Roger Penrose (1989a, pp. 391-482) seems to regard something like the past hypothesis as law; it is just that he understands the initial low-entropy state in terms of weyl curvature, which vanishes as one approaches the beginning of the universe.

be unavailable, and so no proper *explanans* gets off the ground.[13] Still, the low-entropy state is quite special, unnatural and perhaps even highly improbable. Many would therefore conclude that it is in need of explanation. The present essays take up these and other issues. It seeks to say precisely what a scientific explanation is, and it tries to establish why it is that the low-entropy state *is* in need of an explanation. It then critically examines two of the most promising quantum cosmological models that try to solve the low-entropy problem. I conclude that there is probably currently no successful scientific explanation of the low-entropy state, and a realization and appreciation of the fact that the low-entropy state is one among many fined-tuned parameters, constants, and initial conditions suggests there can't be a scientific explanation of that state.

[13] See the comments in Sklar (1993, pp. 311-312).

Chapter 2 Philosophical Prolegomena

I will now articulate and defend important tenets of my more general philosophical worldview. These tenets play important roles in the argumentation of the present essay, and while a book could be devoted to each one of them, my hope is that the reader will find at least some motivation for regarding these tenets as at least *quasi*-plausible.[1]

2.1 Substances, Kinds, and Properties

The world is textured. According to one important philosophical tradition then, there are properties, characteristics, or attributes. These properties do not lend to the world its texture without an underlying *substance* in which to inhere. That is to say, the bundle theory of concrete particulars is false. ***If*** one understands that theory to be the claim that:

> (B1): a concrete particular *o* has a property *P* on account of the fact that *P* is a constituent of *o* and *o* is a concrete particular solely by virtue of being a complex entity built out of properties such as *P*,

then given that such constituency is understood in terms of set membership, the set {greyness, blackness} would itself be black. But obviously there is such a set, and obviously that set is not itself black (the objection is essentially McTaggart's ([1921] 1968, pp. 66-67); *cf*. van Cleve (1985, p. 96)). The objection would run even if (B1) were adjusted in such a way that the constituency involved was not understood in terms of set membership but mereological summation.

But suppose the bundle theory were (B2) below:

> (B2): A concrete particular *o* has properties P_1-P_n on account of the fact that P_1-P_n are consubstantiated or co-instantiated by *o*.

[1] I should admit upfront that scientific realism is an assumption of the entire work.

Characterization (B2) leaves the bundle theory susceptible to an objection in Loux (1978, p. 116). Should properties XYZ be co-instantiated at *t*, and then later Z fall out and be replaced by property D, the resulting co-instantiated complex *viz*., XYD would yield a completely new individual. Thus, there appears to be no sense in which *o* can persist through change. Given (B2) it follows that XY and Z are essential to *o*, if *o* just is the complex XYZ (as van Cleve (1985, p. 99) has noted, "…the bundle theorist's world…is…a Leibnizian one in which every individual has just the properties it does necessarily."). Such a radical kind of essentialism is clearly implausible.[2] I should add that I consider the new-fangled bundle theory discussed in sect. 3 of Van Cleve (1985) to be out of bounds for it only admits *Platonic properties* into its ontology as the "ultimate logical subjects" (p. 104). If I know anything, I know there are concrete objects. For if I know anything, there is a concrete object that knows (that formed a belief), and this newer bundle theory denies the very existence of the mental cause of events involving belief formation (see ibid. p. 105).[3]

There is no successful principled or scientifically motivated objection to the view that there are concrete objects understood as substances or individuals that transcend the properties which inhere in them or the relations they stand in.[4] This is because given a sufficiently realist view of the sciences coupled with the approximate truth of the general theory of relativity (GTR), there is at least one such object *viz*., space-time itself.[5]

---

[2] For other problems with the bundle theory see Armstrong (1978a, pp. 91-101); Loux (1978, pp. 116-119); and Zimmerman (1997).

[3] The bare substratum theory fares no better than bundle theory. For strong criticisms, see Bailey (2012).

[4] *Contra* French (2014, pp. 164-191).

[5] As Graham Nerlich indicated, "[i]n standard developments of GTR, the commitment to space-time looks straightforward" Nerlich (2003, p. 281). Arntzenius (2012, p. 17) stated, "[a]ccording to…[GTR]…space-time…is a single four-dimensional entity." In fact, a realist interpretation of our best physical theories, in general, suggests space-time substantivalism (see the comments in Pooley (2013, p.

According to GTR, space-time is a manifold over which one can define a Lorentz metric g_{ab}. Einstein's equation $G_{ab} \equiv R_{ab} - \frac{1}{2}Rg_{ab} = 8\pi T_{ab}$ specifies how the curvature of the Lorentz metric is related to the distribution of matter in the space-time manifold.[6] The metric tensor field g_{ab} fixes the metric properties of the manifold, and such structure (*i.e.*, the manifold's having metric properties) exists even in the absence of non-gravitational fields and particles.[7] This is important because "…Einstein ultimately [took] as the gravitational field the structure of space-time itself."[8] Thus, GTR implies that space-time is an object with certain properties. Einstein's equation specifies the nature of the relation properties stand in to space-time. Thus, if GTR is approximately true, then there exists an object that is above and beyond the properties and relations one associates with that object.[9] We should therefore refrain from dismissing the substance theory of concrete particulars on the basis of scientific considerations or arguments that suggest that we ought to give up on objects altogether. And given the falsity of both the bundle and bare

---

539); Sklar (1974, p. 214); *cf*. Weinstein (2001) who argues that substantivalism falls out of considerations having to do with quantum physics.)

[6] Wald (1984, p. 73). Einstein's equation is really six partial differential equations of the second order.

[7] See Arntzenius (2012, p. 173).

[8] Sklar (1974, p. 72).

[9] Space-time relationalists will object, but it is important to understand that in the context of GTR, substantivalism is the default position:

> …the theory [i.e., GTR] treats…spacetime as substantival in its surface presentation, just as do Newtonian, neo-Newtonian, and Minkowski spacetime theories. Any claim that the theory really affirms spacetime to exist solely as a set of relations among ordinary material things requires, as usual, an argument... Sklar (1974, p. 214)

Earman (1989, pp. 175-208) tried to rescue relationalism from the implications of GTR, but Arntzenius (2012, pp. 173-175) has responded convincingly. Even Huggett's (2006) regularity theory of relationalism is susceptible to the argument for substantivalism from GTR, for it has not been applied in the general relativistic context. Some relationialists who have tried to avoid the substantivalist implications of GTR admit, at the end of the day, that there exists a substantival object (see the comments in Pooley (2013, p. 578)).

substratum theories of concrete particular objects, it seems to me to be best to regard such objects as substances that exemplify universals or properties. Let me say more.

First, substances are typified by subjects that belong to kinds, and they are typified by subjects which are the paradigmatic bearers of properties. Such entities (as Eustachius a Sancto Paulo put it) "stretch out beneath" their accidents and so thereby substand.[10] They cannot themselves be exemplified by other substances for (quoting Aristotle) "it is common to every substance not to be in a subject".[11] And, furthermore, if substances failed to exist, absolutely no properties could be *instantiated*.[12]

Second, substances instantiate substance-kinds or individuative universals. As Loux put it, every "substance exemplifies a universal which guarantees its numerical diversity from every other substance".[13] Substances exemplify and thereby come to instantiate substance-kinds by belonging to those kinds.[14] Such kinds are not sets, for their members do not constitute their nature. Rather, kinds impart their natures to those objects that belong to them. Thus, kinds are prior to their members, and so from world to world, kinds may have distinct members though this is not true of sets.[15] Kinds "…to which concrete particulars belong represent unified ways of being that cannot be reduced to anything more basic."[16]

According to the above picture then, substances are fundamental bearers of properties. But what does this notion of 'bearing' amount to? Well, despite what some

---

[10] Summa I.1.3b.1.2, I:51. As quoted and cited in Pasnau (2011, p. 103). *Cf.* Aristotle (*Categories*, chapt. 5. (3a7), (4a10-11)). All references to Aristotle are taken from Aristotle (1984).

[11] Aristotle, *Categories* (3a7).

[12] These ideas appear to be in Aristotle's *Categories* (4 a10). I believe in abstract *possibilia*. There can therefore be worlds at which most of the properties that are instantiated come to be instantiated by *abstract* individuals.

[13] Loux (1978, p. 163).

[14] Loux (2006, p. 109).

[15] See Loux (1976).

[16] Quoting Loux (2006, p. 110).

realists about universals and properties maintain, I understand the connection between substances and properties as a relation. Many would now argue that I am susceptible to F.H. Bradley's infamous regress.[17] A property ϕ does not relate to its underlying substance α without both entities standing in a relation *R* of exemplification. But relations are typically thought to be properties, and substances stand in them by exemplifying them. But if, for example, α relates to ϕ via *R*, then in order for α to exemplify ϕ it must exemplify *R*. But now α will need to stand in a further exemplification relation *R**, in order to exemplify *R*, so as to exemplify ϕ. A regress is born—though I believe I can escape its clutches—for I would maintain that relations do not need to stand in a relation to their *relata* in order to relate those *relata*. As Moreland noted,

> …just as one does not need superglue to connect two objects to normal glue in order to tie them together with normal glue, so relations are the sort of things that do not need to be related to their relata before they can relate those relata to each other.[18]

It seems that Moreland's response only works if we are willing to give up on the thesis that relations are properties that relate to substances *via* exemplification. That is my view. Relations seem to me to belong to an altogether unique ontological category. Relations are not properties.

So I happily situate the present set of essays in that venerable philosophical tradition that is realist with respect to universals. I also gladly approve of that Aristotelian tradition, which upholds that concrete particulars are substances in which universals inhere by relating to them by exemplification.

---

[17] Bradley (1930, pp. 17-18).
[18] Moreland (2001, p. 116).

2.2 A Choice Logic

I am a necessitist.[19] I'm led to necessitism by an unflinching endorsement of classical quantified modal logic, and a rejection of Rudolf Carnap's ([1937] 1949) logical pluralist principle of tolerance (the thesis that many differing logics do not conflict in any way).[20] According to Carnap, the classical logician can embrace a non-classical logic in certain suitable contexts or spheres of inquiry and *vice versa* (see Beall and Restall (2006); *cf*. the comments in Field (2009, pp. 343-345)). While the defenders of pluralism have proven themselves resourceful, I cannot see how the classical logician can stay classical with respect to (say) the first-order calculus, and yet revert to a free logic in spheres of inquiry that have need of a *modal* first-order calculus. Quantified modal logic is assembled on a non-modal first-order logic. Free non-modal predicate logics (FFOL) have altogether different axiomatizations than classical first-order logic (CFOL). The difference in axiomatization produces differing lists of theorems. Surely when the free and classical logicians disagree about the theorems of first-order logic that disagreement is to be regarded as substantive, as Hartry Field stated, "[w]hen they disagree in their theorems (or at least, when one has theorems that the proponent of the other [logic] can be expected to disagree with), the dispute…seems a clearly factual one."[21] The theorems of FFOL and of CFOL cannot both be correct. In addition, and by consequence, the theorems of classical quantified modal logic (CQML) and free quantified modal logic (FQML) cannot both be correct. It would be inconsistent of one to embrace the theorems

[19] See Linsky and Zalta (1994), (1996); Parsons (1994); and Williamson (1990), (2000), (2002), (2013). For criticism, see Hayaki (2006) and Sider (2009).

[20] Carnap ([1937] 1949, p. xv).

[21] Field (2009, p. 358).

of CFOL and at the same time embrace the theorems of FQML, since the legitimacy of FQML rests squarely upon the legitimacy of FFOL.

The defender of a principle of tolerance in the context of classical and free modal logics has two promising lines of response. First, she can try to argue that the free logician's understanding of the connectives is fundamentally different and that on account of such a difference there is no real disagreement between the free and classical modal logicians. But this response fails. The two in fact have the *same* take on the meanings of the logical connectives. There is also no real disagreement about the meanings of the quantifiers. Free logicians merely restrict the quantifier rules (*e.g.*, universal instantiation and existential generalization) so as to avoid licensing undesirable inferences.[22]

The free logician may also try to escape a commitment to classical logic, even given certain considerations in its favor, by maintaining that CFOL and FFOL specify different and yet equally legitimate kinds of logical consequence.[23] Thus, neither is the one true logic. Both are applicable for different purposes. This is the second line of response, which like the first lacks plausibility. Validity amounts to truth-preservation across all *worlds*. An argument is valid, just in case, with respect to every situation under which the premises of the argument are true, the conclusion is also true.[24] The pluralist I have in mind (who is arguing in the spirit of Beall and Restall (2000), (2006)[25]) argues that varying and equally plausible accounts of logical consequence amount to a difference of how to precisely understand 'situation' in the aforementioned definition of validity.

[22] In Nolt's (2011, sect. 1.2) explication of the differences between free and classical predicate logic he never cites any differences having to do with how to understand the connectives or the quantifiers. He notes, what I have, that the quantifier rules are restricted in free logic.

[23] See Beall and Restall (2000).

[24] Priest (2001).

[25] For criticisms see Bueno and Shalkowski (2009, pp. 296-306).

Such a pluralist will agree that if the situations are complete and consistent possible worlds, then classical logic is appropriate (Beall and Restall (2000, p. 1)). However, if the situations are, for example, constructions of a mathematical sort and are therefore incomplete though consistent, then the logic is constructive.[26] With respect to free logic, however, what are such situations like? It is not immediately clear how they would differ from those that are indicative of classical logic. Pluralism of the Beall and Restall variety seems to imply that CFOL and FFOL are not really distinct logics.

Perhaps I'm being too hasty. The positive free logician can understand 'situation' in the above definition of validity in terms of worlds in which some singular term *t* fails to denote though at those worlds it's true that *t* has the property denoted by some predicate letter *F*.[27] This is because on every positive free logic *the principle of independence* (PI) holds.[28] (PI) states that entities may have properties even if those entities do not exist. The problem is that (PI) is necessarily false. Section 2.1 has already committed us to a particular understanding of the nexus that is outfitted with properties and those entities that exemplify them (the relationship of inherence). That nexus is a relation that is exemplification. But how can a property be related to that which does not exist? How can one have an obtaining two-place relation, to take a simple example, if one of the *relata* is missing? David Lewis was right, "[a] relation requires relata."[29] Do I believe that all instances of property exemplification involve concrete substances relating

[26] These examples show up in Bueno and Shalkowski (2009, p. 295) as well.

[27] What Beall and Restall (2000, p. 481) actually suggest is that the free logician might be able to understand 'situation' in terms of Phillip Bricker's (2001) world classes. A world class is nothing above and beyond a single possible world with causally isolated and detached spatio-temporal parts. If such classes are such that they can be completely empty, then one is dealing with a free logic. Since Bricker's approach requires the truth of possibilism, my response to the possibilist in the main text below will suffice as an objection to any appeal to possibilism for the purposes of escaping necessitism.

[28] Paśniczek (2001).

[29] Lewis (2004b, p. 281). O'Connor (2000, p. 48) remarked similarly, "the obtaining of any relation between two relata presupposes that each of the relata exists or obtains."

via exemplification to properties? No. But my theory of that relating holds for all such instances. A unified account of exemplification is a plus for any metaphysical worldview. And I'm not sure what it would mean to say that exemplification when involving *concreta* and *abstracta* (such as substances and universals) is a relation, but when it involves other types of entities it does not. So (PI) is necessarily false.

Carnap's principle of tolerance is false as well. If CFOL is better than FFOL and other non-classical logics, we should appropriate whatever consequences that fact implies. Before I explore these consequences, I should be more forthcoming about what CFOL is and why it is better than non-classical logics.

CFOL is that formal first-order language built on a classical propositional logic and outfitted with the classical quantifier rules or axioms.[30] In addition, CFOL abides by the following three principles:

> (Principle #1): Every well-formed formula's (*wff's*) truth-value on some interpretation $\mathcal{I}$ is completely fixed *via* the extension of the parts of that *wff* under $\mathcal{I}$.
> (Principle #2): There are only two truth-values, truth and falsehood.
> (Principle #3): Every *wff* has exactly one truth-value.[31]

Some non-intuitionist non-classical FOLs abide by (Principle #1), for such FOLs are compositional with respect to their semantics. And while some non-classical FOLs reject (Principle #2), almost all reject (Principle #3). Those non-classical FOLs which assert that some *wffs* under an interpretation are gappy entail that some *wffs* do not have a truth-value. Glut-laden non-classical first-order logics entail that there is a third truth-value (a truth-value glut) and so countenance *wffs,* which under an interpretation, possess truth-

[30] See Hughes and Cresswell (1996, pp. 241-242) and Hodges (2001, pp. 24-26)
[31] I have paraphrased these three principles from Grandy (2002, p. 531).

value gluts. FFOLs are non-classical in the sense that they all abandon the classical quantifier rules.

But why prefer classical logic? The reasons I would proffer are pragmatic. One cannot properly underwrite mathematical physics without classical logic.[32] By far, the most far reaching and substantive attempts to recapture certain spheres of applied mathematics for non-classical logic have come from intuitionists doing constructive mathematics. The problem is that their efforts come up short. Douglas S. Bridges—a foremost authority on constructive math—has remarked, "[i]t is clear that a constructive examination of the mathematical foundations of quantum physics does reveal substantial problems."[33] Let us look at some of the details.

First, consider linear Hermitian operators in non-relativistic and relativistic quantum mechanics (QM). Bounded Hermitian operators are at the very heart of QM's formalism, for in QM, the wavefunction represents the state of physical systems, and such states can necessitate that an observable take a certain expectation value. That observable is associated with a bounded linear Hermitian operator. And so bounded linear Hermitian operators represent observables and are associated with actual expectation values that are themselves linked to measurement outcomes. *Unbounded* linear Hermitian operators are extremely important as well. In fact, "most of the operators of interest in quantum physics are unbounded"[34] for they serve as mathematical representations of linear momentum, and position operators. Furthermore, unbounded

[32] Brian P. McLaughlin (1997, p. 219) has said, "…no one knows how to do calculus without classical logic, and no one knows how to do physics without calculus." This may be a bit of an overstatement. Constructive mathematicians have not only developed ways of "doing the calculus", but they have also gone beyond calculus to functional analysis (see Beeson (1985); Bishop (1967); and Bridges (1979)).

[33] Bridges (1981, p. 272).

[34] Prugovečki (1971, p. 180).

linear Hermitian operators correspond to the real physical quantities that are the momentums and positions of particles.[35] And since annihilation, creation, and Hamiltonian operators are functions of momentum and position operators, unbounded Hermitian operators are necessary for understanding the very dynamics of relativistic and non-relativistic QM.[36]

Both bounded and unbounded Hermitian operators are indispensable to an extremely useful theorem of linear algebra that plays an important role in QM. The spectral theorem, is what I have in mind, and it says that if an operator $\underline{A}$ is a normal (in that it commutes with its adjoints) operator defined over a finite Hilbert space $\mathcal{H}$, then $\mathcal{H}$ will feature an orthonormal basis of eigenvectors of $\underline{A}$.[37] With respect to all of the relevant operators, the spectral theorem generates a functional calculus, and it is needed to derive Stone's theorem which is itself important for proving the abstract Schrödinger equation.[38] Now what Geoffrey Hellman has shown in convincing fashion is that "the Spectral Theorem [cannot] be constructively *proved*," and *a fortiori* "it cannot even be constructively *stated*."[39] This is because (as I've already noted) constructivist mathematics seems constitutionally unable to handle unbounded linear operators of the Hermitian variety.[40]

---

[35] Weinberg (2013, p. 61).

[36] Hellman (1993, p. 240, p. 247. n. 5); Mahan (2009, p. 4); Weinberg (2013, p. 78).

[37] Palais (2008, p. 240); *cf*. Hellman (1993, p. 224); Redhead (1987, p. 13).

[38] Jauch (1968, pp. 151-159); Jordan (1969, pp. 96-99); following Hellman (1993, p. 226).

[39] Hellman (1993, p. 222) emphasis mine. He says elsewhere that unbounded "operators are not even legitimately recognizable as mathematical objects from a thoroughgoing constructivist standpoint" (Ibid.).

[40] Well, Hellman's proof pertains to unbounded linear operators that fall directly under the Pour-El and Richards theorem. Hellman (1997, p. 123). I should add here that Douglas Bridges (1995) attempted to refute Hellman's arguments, but I found Hellman's (1997) responses to the objections to be more than sufficient defeater defeaters for Bridges's worries.

There are further problems. Constructivist mathematics cannot underwrite the mathematical physics needed to do cosmology.[41] For example, on the standard model, the space-time continuum is ordered linearly (as are geodesics), but this is not so on constructivist mathematics. In addition, even if time, for example, is discrete and not dense, constructive mathematics understood in such a way that it conflicts with classical analysis entails that such analysis is ill-formed and without meaning. It is this latter consequence that smacks hard against space-time physics, for it is the consensus view among cosmologists and astrophysicists that both classical analysis and classical mathematical descriptions of the space-time manifold (that appears, for example, in the standard model) are at least meaningful and now mathematically well-understood (these points are due to Hellman (1998)).

Constructivist mathematics has a particular problem with establishing certain of the singularity theorems in cosmology. Hellman (1998) points out that while the constructivist mathematician may be able to establish more restricted singularity theorems they cannot prove the broader more far reaching theorems of Stephen Hawking and Roger Penrose.[42] This is an important methodological constraint, one that appears to count against going constructivist in one's mathematical physics.

There are, therefore, strong pragmatic considerations in favor of endorsing classical logic. But one might argue that I have not shown why one cannot be a logical

---

[41] Hellman (1998, pp. 428-432). The line of reasoning is also in Weyl (1949, p. 61), where he stated:

> "The propositions of theoretical physics, however, certainly lack that feature which Brouwer demands of the propositions of mathematics, namely that each should carry within itself its own intuitively comprehensible meaning. Rather, what is tested by confronting theoretical physics with experience is the system as a whole". Weyl (1949, p. 61)

[42] See Hawking and Penrose (1970).

pluralist (of the variety which goes in for Carnap's principle of tolerance) and maintain that intuitionism, and other non-classical logics (besides those that are free) should be adopted for certain spheres of inquiry, and that classical logic should be espoused for quite different domains of analysis, say mathematical physics. What piece of argumentation closes the door on such a maneuver?

Let logical monism be the idea that there is one true logic or one true conception of logical consequence, and that one cannot appropriate differing and conflicting logics for differing pursuits. My response will then run as follows: If logical monism is false, then there is no privileged logic with which to reason about formal object languages or logics in general. What choice logic does one use to conclude that logical pluralism is true, or that logical monism is false, or that such and such logics really do conflict (Beall and Restall, proponents of Carnap's principle of tolerance do believe that some logics conflict). How do you *resolve* such conflicts without a choice logic? It would seem that in order to avert the reasoning here you would have to endorse something like Gilbert Harman's (1986, p. 6) position, that there's a significant gap between cogent active reasoning and logic. One could reason plausibly to some conclusion without that reasoning being susceptible to the deliverances of a logic. But one can't simply say that and get away with it. The logical monist should pressure the pluralist into providing for her the logic-transcendent principled reasoning used to arrive at the relevant conclusion. If the pluralist cannot provide a description of the reasoning used, or if the reasoning used is rightly and accurately modeled by the choice inference rules of a logic, then the

pluralist is in real trouble.[43] I do believe that there is some distance between active reasoning and logic. The two should not be conflated. However, I'm very skeptical of the hypothesis that one can arrive at logical pluralism by some bit of persuasive and substantial reasoning that cannot be captured or modeled by a *bona fide* argument whose form is accurately represented by an inference peculiar to a logical system.

Logical pluralism is false. Classical logic is the one true logic. We must therefore brace ourselves for whatever consequences are bred. One such consequence is necessitism or (NNE) below:

(NNE): $\blacksquare\forall x\blacksquare\exists y(x = y)$

That is to say, necessarily for any *x*, necessarily there is at least a *y*, such that *x* is identical to *y*. In Williamson's (2013, p. 2) slogan, NNE says that "necessarily everything is necessarily something". That NNE follows from classical logic may strike one as a truly confounding claim. How can it be that classical considerations yield such a shocking truth?

There are several routes to NNE (or something near enough) from classical reasoning. A quick means to NNE by CFOL plus the rule of necessitation, given realism about propositions and abstract objects proceeds as follows:

(1) $(\forall x)(x = x)$ [Theorem]
(2) $(\forall x)((\forall y)\sim(x = y) \rightarrow \sim(x = x))$ [Theorem]

One might not see immediately how (2) is a theorem of classical FOL. Here is a tableaux proof of (2)'s theoremhood:

$\sim(\forall x)[(\forall y)\sim(x = y) \rightarrow \sim(x = x)]$
$(\exists x)\sim[(\forall y)\sim(x = y) \rightarrow \sim(x = x)]$

[43] This objection to pluralism was voiced by Baell and Restall (1999, pp. 6-7). The Harmanian response to the worry is also adopted by Baell and Restall with some modifications to Harman's original position.

$$\sim[(\forall y)\sim(a = y) \rightarrow \sim(a = a)]$$
$$(\forall y)\sim(a = y)$$
$$\sim\sim(a = a)$$
$$\sim(a = a)$$
$$X$$

The rest of the derivation proceeds as follows:

(3) $a = a$	[UI (1)]
(4) $\sim\sim(a = a)$	[DN (3)]
(5) $(\forall y)\sim(a = y) \rightarrow \sim(a = a)$	[UI (2)]
(6) $\sim(\forall y)\sim(a = y)$	[MT (4), (5)]
(7) $(\exists y)\sim\sim(a = y)$	[QN (6)]
(8) $(\exists y)(a = y)$	[DN (7)]
(9) $\blacksquare(\exists y)(a = y)$	[Rule of Necessitation (8)][44]

The derivation of (9) does not quite yield NNE, for it only says of the named object that it exists necessarily. We could of course substitute for the individual constant 'a' any constant standing for the proper name of any named object. Unnamed objects have abstract names (given realism about *abstracta*), as Williamson stated, "[a]nything unnamed and undemonstrated in natural languages still has a name in some abstract language…"[45] In addition, given that propositions are *abstracta*, there can be an abstract argument with the relevant abstract name for the heretofore unnamed object.[46] Thus, the derivation that is (1)-(9) constitutes evidence for necessitism given realism, classical logic, and an unrestricted rule of necessitation.[47]

Many philosophers believe that S5 is the system of modal logic that captures our intuitions about the nature of metaphysical necessity and possibility.[48] Interestingly, S5 classical (or) constant domain QML entails necessitism as a theorem. Here's the proof

[44] See Sider (2010, p. 251) for a similar derivation.
[45] Williamson (2013, p. 41)
[46] Williamson (2013, p. 41).
[47] The argument is Williamson's (2013).
[48] For arguments along these lines see Hale (2013, pp. 127-131).

(the complete and sound tableaux system in this case is from Priest (2008, pp. 6-11; 45-46; 266-277; 308-315; 350-352). It would correspond to an S5(NI) proof system):

$$\sim\blacksquare\forall x\blacksquare\exists y(x = y), 0$$
$$\blacklozenge\sim\forall x\blacksquare\exists y(x = y), 0$$
$$\sim\forall x\blacksquare\exists y(x = y), 1$$
$$\exists x\sim\blacksquare\exists y(x = y), 1$$
$$\sim\blacksquare\exists y(a = y), 1$$
$$\blacklozenge\sim\exists y(a = y), 1$$
$$\sim\exists y(a = y), 2$$
$$\forall y\sim(a = y), 2$$
$$\sim(a = a), 2$$
$$(a = a), 2$$
$$X$$

Therefore, $\vdash_{S5\,CQML}\blacksquare\forall x\blacksquare\exists y(x = y)$.[49]

In fact, NNE is a theorem on a much weaker system of modal logic. On the basis of classical commitments we can derive a particular instance of the converse Barcan formula (CBF) from the weakest normal QML (system K), and then with the CBF show that NNE is a theorem of K CQML.[50] Consider:

(10) $\blacksquare(\forall x)(\exists y)(x = y)$ [Theorem]

Here is a tableaux proof showing that $\vdash_{CK}\blacksquare(\forall x)(\exists y)(x = y)$:[51]

$$\sim\blacksquare(\forall x)(\exists y)(x = y), 0$$
$$\blacklozenge\sim(\forall x)(\exists y)(x = y), 0$$
$$0r1$$
$$\sim(\forall x)(\exists y)(x = y), 1$$
$$(\exists x)\sim(\exists y)(x = y), 1$$
$$\sim(\exists y)(a = y), 1$$
$$(\forall y)\sim(a = y), 1$$
$$\sim(a = a), 1$$
$$(a = a), 1$$

[49] "On the fixed domain interpretation, the sentence $\forall x\Box\exists y(x = y)$ (which reads 'everything exists necessarily') is valid". Garson (1991, p. 112)

[50] CBF: $\blacksquare\forall x\alpha \rightarrow \forall x\blacksquare\alpha$, where α is a formula in which *x* occurs as an unbound variable.

[51] The 'CK' stands for the constant domain K system of quantified modal logic. I adopt the CK tableaux system of Priest (2008).

X

(11) $\blacksquare(\forall x)(\exists y)(x = y)$ [Assumption]
(12) $(\forall x)(\exists y)(x = y)$ [Nec. Elim. (11)]
(13) $(\exists y)(v = y)$ [UI (12)]
(14) $\blacksquare(\exists y)(v = y)$ [Nec. Intro.]
(15) $(\forall x)\blacksquare\exists y(x = y)$ [UG (14)]
(16) $\blacksquare(\forall x)(\exists y)(x = y) \rightarrow (\forall x)\blacksquare(\exists y)(x = y)$ [CP (11)-(15)]
(17) $(\forall x)\blacksquare(\exists y)(x = y)$ [Modus Ponens (10), (16)]
(18) $\blacksquare(\forall x)\blacksquare(\exists y)(x = y)$ [Rule of Necessitation][52]

Of course, (18) is NNE. Thus, NNE follows from classical constant domain QML given just K (the weakest normal modal logic).

Let contingentism be the thesis that NNE is false. The contingentist will point out that the above proofs assume constant domain modal logics. According to such logics, the census of individuals does not change from world to world since the domain does not vary among accessible worlds. Are there not *classical varying* domain QMLs that provide an escape for the classical contingentist? No, there are not.[53] Every classical normal CQML validates the CBF.[54] Let me explain.

One fairly standard way of connecting normal *varying* domain QML with the classical quantifier rules involves adding in the increasing domains principle (also called the nested domain constraint). The increasing domains principle says that necessarily, if *w* is accessible from world *w**, then the domain of *w** is a subset of the domain of *w*. Adopting this principle appears to be the only way to preserve the normality of QML

[52] I'm sure there is an argument resembling something like the above in the literature somewhere.
[53] What about Kripke's (1963) system that did away with singular terms? Did he not show how one could keep the classical quantifier rules and yet work inside a varying domain QML? Kripke's 1963 system gave up on the rule of necessitation, not just constants and/or singular terms. If he had kept that rule in his system one could derive in it $\blacksquare(\exists y)(x = y)$ from the empty set of propositional parameters. See Garson (1991, p. 114)
[54] "The converse Barcan formula…is a Q1K-theorem." Schurz (2002, p. 464).

given varying domains and classical quantifier rules.[55] Interestingly, even these QMLs validate the CBF.[56] Ignore such validation. I happen to believe that classical logics that affirm the increasing domains principle are internally inconsistent due to an argument from Gerhard Schurz (2002). His objection may be paraphrased as follows: Suppose that 'h' names Han Solo, that all proper names are rigid designators, and that '@' picks out the actual world. Given contingentism, Han Solo will not be a member of the domain of @ (*i.e.*, h $\notin$ $D_{@}$, and so V(h) $\notin$ $D_{@}$).[57] Assume, however, that every entity that is a member of @'s domain has the monadic predicate F. Thus, (∀x)(Fx) holds at @. But notice that (Fh → (∃x)(Fx)) will not follow from (∀x)(Fx) even though the classical quantifier rules license such an inference. This is because in such a special case, Han Solo is not a member of the domain. What we should say is that ~Fh, and so therefore (∃x)~(Fx). But that existentially quantified sentence contradicts (∀x)(Fx). Thus, a varying domain QML seems to be incompatible with the classical quantifier rules. One could say that 'Fh' does not take a truth-value at all, but that would suggest a QML with truth-value gaps. Gappy logics are not classical (see Principle #3 above). They involve a denial of bivalence. Schurz's argument is sound.[58]

As a necessitist, I should point out that even given the nested domain constraint, varying domain classical QML implies a *constant domain* QML, so long as the following principle holds:

(19) $p \rightarrow \Box\Diamond p$ [Axiom B]

[55] Several authors have attempted to preserve the classical quantifier rules while embracing a varying domain QML *via* an appeal to the nested domain constraint (see Bowen (1979); Gabbay (1976); Hughes and Cresswell (1996); *cf.* the discussion in Schurz (2002)).

[56] Garson (1991, pp. 114-115).

[57] Where 'V' is the valuation function. Remember that we are trying to avoid necessitism here. So it is proper of us to say that *h* is not a member of the domain of the actual world.

[58] It seems that a version of this argument appeared in Garson (1991, p. 113 *cf.* p. 115).

i.e., so long as the accessibility relation of the logic is symmetric. This is a well-known result in the literature on quantified modal logic.[59] Since just about everyone believes that the correct modal logic for metaphysical necessity and possibility is at least as strong as S4, we are stuck with axiom B and so also a constant domain QML given classical commitments.[60]

It's clear then. Classical logic implies necessitism. Noted philosophical logicians have already realized this and have on that basis pushed for the adoption of a free modal logic:

> …the stipulations required in order to preserve the classical principles do not always sit well with our intuitions. Our conclusion, then, is that there is little reason to attempt to preserve the classical rules in formulating systems with the objectual interpretation and world-relative domains. The principles of free logic are much better suited to the task.[61]

I have already argued that positive free logic requires the principle of independence, and that that commitment yields its implausibility. But there are also negative and neutral free logics. Negative free logics imply that sentences featuring singular terms that fail to denote are false, while neutral free logics say of that such sentences are gappy. Gappy logics are non-classical on account of a denial of (Principle #3). They, like non-free but non-classical logics, cannot properly underwrite mathematical physics since they give up on the law of excluded middle.[62] We should therefore forgo on adopting neutral free logics.

Negative free modal logics have severe problems, for some such systems are crafted in such a way that there is only one domain (a domain of existing objects/entities)

---

[59] See Schurz (2002).

[60] Garson (1991, pp. 114-115) makes this point but with S5 in mind.

[61] Garson (1984, p. 261); see also the comments in Garson (1991, p. 111).

[62] See Hellman (1998, p. 441). There, Hellman notes how one cannot derive the more general theorems of space-time physics without the law of excluded middle.

and yet sentences involving modal predication to non-existent objects (objects not in the domain of the actual world) must be understood in such a way that they express falsehoods. So consider,

(20) ⧫Bh

where 'Bx' means '*x* is brave', and where '*h*' is once again Han Solo. Single domain negative free QMLs deliver the verdict that (20) is false since '*h*' fails to refer. However, the falsehood of (20) entails that it is impossible that Han Solo is brave, and that seems counter-intuitive. Consider now proposition (21):

(21) ⧫E!h

where 'E!x' means '*x* exists'. Again, the negative free modal logician must say of (21) that it is false. But that entails that *h* could not possibly exist! In fact, the following is appropriated as an axiom of single domain negative free quantified modal logic[63]:

(22) $(\forall x)(\sim E!x \rightarrow \blacksquare \sim E!x)$

Proposition (22) is clearly incredible if necessitism is false.

What of two domain negative free quantified modal logics?[64] I'm afraid such systems are underdeveloped. In fact, I cannot find a complete presentation of any such logic. Embracing free logic seems therefore to be an implausible way of avoiding necessitism.

2.2.1 Possibilism

Let me end my defense of necessitism with a brief word on possibilism, the idea that possible worlds are concrete causally isolated maximally consistent universes as

[63] See Schwarz (2011, p. 35). These results appear to be well known in the literature on negative free quantified modal logic. I'm not saying anything new here.

[64] See Bencivenga (2002, pp. 298-299) on the theme of two domains.

ontologically privileged as the actual world.[65] First, there's a real sense in which possibilism may be understood as an instance of necessitism, as Christopher Menzel wrote,

> …there is a somewhat weaker and more plausible version of necessitarianism to explore, viz., *possibilism*…it is assumed that the pool of objects generally, existing and otherwise, necessarily remains the same (though of course those fortunate enough to exist could vary in countless ways). …for the possibilist all things are in a sense necessary.[66]

For Lewis, possible worlds exist as "*maximal spatio-temporally interrelated whole*[s]".[67] Commitment to the existence of the contents of such worlds given how the worlds themselves are analyzed seems clear, as Michael Loux remarked:

> The actual world, Lewis tells us, is just one of the many total ways things might have been; and it is nothing more than myself 'and all my surroundings';[12] it is this thing we call the universe…. since each of the other possible worlds is a thing of the same kind, the other possible worlds are further concrete objects whose parts are further concrete objects entering into spatiotemporal relations…*all these concrete objects are fully real, fully existent. They are, so to speak, all really out there*.[68]

Second, one is forced into understanding Lewis's possible worlds or *possibilia* as existent objects, for each have properties, and as we have already learned from my discussion of the positive free logician's principle of independence; it is questionable to uphold that non-existent objects can stand in the exemplification relation since relations require *relata*. Lastly, while I would argue that possibilism just is a brand of necessitism, I must confess that I do not agree with the metaphysics of modality that theory entails. I

---

[65] See Lewis (1986b).

[66] Menzel (1991, p. 333). As Williamson remarked "…the best developed reductionist programme for modality is David Lewis's modal realism, which is an eccentric form of necessitism…" Williamson (2013, p. 390); *cf*. Bricker (2001, p. 24); Simons (2001, p. 50, specifically proposition (A1) there).

[67] Sider (2003b, p. 192) emphasis in the original; *cf*. Lewis (1986b, pp. 69-81).

[68] Loux (2006, pp. 167-168) emphasis mine.

find counterpart theory to be deeply problematic.[69] The criticisms that have generally convinced me to steer clear of possibilism come from Fara and Williamson (2005).

I will now forgo further discussion of modal metaphysics and push forward to my last setup section on the epistemology of modality.

2.3 Modal Epistemology

2.3.1 Two Possibility Claims

Just about every contemporary modal epistemology provides at least *prima facie* epistemic justification for belief in the following proposition[70]:

(23) Possibly, there is an omnicompotent being.

Following, to some extent, the discussion in Joshua Hoffman and Gary Rosenkrantz's (1980, p. 14) and (2012, sect. 3) work on omnipotence, I will adopt the following analysis of what I will call, "omnicompotence":

(24) $(\forall x)\{(x$ is omnicompotent) $\leftrightarrow (\forall s)[(s$ is a purely contingent event $\rightarrow \exists z(z$ is an ontological index and x has the categorical ability to causally produce s at $z]\}$

Talk of categorical ability may smack of agent causation, but my affirmation of (23) and (24) is not meant to commit me to such a theory, nor its possibility. We can understand such talk in terms of event causation with great ease and little elbow grease.[71]

Just as in the case of (23), a great many recommended paths to knowledge of metaphysical possibility yield *prima facie* epistemic justification for belief in:

---

[69] Lewis believed that the (possible) Alvin Plantinga, who was born in Antarctica is not identical to the actual Alvin Plantinga. He maintained that these two stand in a counterpart relation to one another, where that relation is analyzed in terms of resemblance. See Lewis (1986b, p. 112).

[70] I have in mind the theories of modal knowledge in Bealer (2002); Biggs (2011); Chalmers (2002); Geirrson (2005); Gregory (2004); Jenkins (2010); Peacocke (1997); Sosa (2000); Williamson (2007); and Yablo (1993). *Cf.* Tidman (1994).

[71] For my account of events and purely contingent events, see propositions (37) and (39) below.

(25) Possibly, there is a non-corporeal mind that formed a belief.

where the term 'formed' is indicative of mental causation.

Some will no doubt find (25) to be highly objectionable even given the presence of a metaphysical possibility operator. After all, do we not have good reasons for affirming physicalism?[72] If physicalism is true, it is necessarily true even if it is known *a posteriori*. I will forgo an in-depth discussion of the merits of physicalism and note here that if I'm right, that every plausible path to knowledge of metaphysical possibility yields justification for one's belief in (25), then the burden of proof is on the physicalist. They will have to provide independent substantiating evidence for the relevant doctrine. My reasoning below at least sets the default position to physicalism's falsehood.

2.4 The Prolegomena

All of the necessary philosophical pieces are in place. As I've said above, my theory of scientific explanation requires a novel non-reductionist theory of causation. In order to defeat reductionist views of causation, I will need to defeat both broad and narrow reductionist theses (*e.g.*, Humean supervenience, and specific arguments for causal reductionism). The equipment introduced and at least partially defended in this preparatory chapter will better enable me to dispense with such reductionisms and help facilitate a framework for my positive account causation and explanation.

[72] Physicalism is the view that every property-instance or instantiation of a property is metaphysically necessitated by the instantiation of a physical property.

Chapter 3 Against Causal Reductionism

Causal reductionism is the doctrine that obtaining causal relations are nothing above and beyond fundamental natural nomicity coupled with the world's unfolding history. It is the business of the present section to resist this attractive and popular thesis by setting up roadblocks on two important avenues to the demonstration of that thesis. The first avenue to be barricaded involves establishing a broader reductive doctrine, which entails that a great many entities reduce to an appropriately chosen sparse non-causal base. The second avenue to be obstructed suggests direct arguments for causal reductionism. Let me now take up the first task.

3.1 The Humean Supervenience Thesis

David Lewis's Humean supervenience thesis (HST) says that the world's fundamental structure consists of the arrangement of qualitative, intrinsic, categorical, and natural properties of space-time points (or perhaps some other suitable replacement[1]), and that all derivative structure supervenes on such fundamental structure which may include the spatio-temporal relations in which such qualitative entities stand. The fundamental subvenient base is "a vast mosaic of local matters of particular fact, just one little thing and then another…an arrangement of qualities. And that is all."[2] The qualities or properties involved are sets.[3] More specifically, a quality or property /*p*/ is the set of all of /*p*/'s instantiations.[4] This is class or set nominalism about properties.[5] Categorical

[1] The deliverances of physics determine whether or not the replacement is suitable.
[2] Lewis (1986a, p. ix.).
[3] Lewis (1986b, pp. 50-51. and see n. 37 on those pages as well); *cf*. Cross (2012, p. 141).
[4] Lewis (1986a, p. 50).
[5] See the discussions in Armstrong (1978a, pp. 28-43); Lewis (1986a, pp. 150-169); Moreland (2001, pp. 30-34); Rodriguez-Pereyra (2014, sect. 4.1). Lewis is also a set nominalist about relations. He identifies *n*-place relations with ordered *n*-tupled sets.

properties are non-dispositional properties involving absolutely *no modalities*[6], and for Lewis all fundamental properties are categorical (*i.e*., the HST implies categorical monism).[7] A qualitative property or a "suchness" is a non-haecceitic property (*i.e*., it is a property that is not an incommunicable property or thisness had only by its sole possessor).[8] An intrinsic property is one "…which things have [only] in virtue of the way they themselves are…"[9]

What about natural properties? Interestingly, Lewis does not provide an analysis of such properties.[10] He seems to treat such entities as basic, and uses only illustrative devices to shed light on what such properties are like. What we can infer from Lewis's remarks about them is that they are natural only in some degreed sense.[11] For the natural properties serving as the subvenient base for all else on the HST are *perfectly* natural in that they are not gruesome or gerrymandered in any way.[12] All natural properties are intrinsic, though not all intrinsic properties are natural, and in some way, natural properties (along with natural relations) are the very joints of nature in that they help constitute the deepest most primitive existing structure.

---

[6] See Armstrong (1968, pp. 85-88), (1973), (1996, pp. 16-17), (1997, pp. 80-83); Bird (2007, pp. 66-98); Choi and Fara (2014, sect. 2); Jackson (1977).

[7] See Bird (2007, p. 66) on categorical monism. Lewis may also be considered a categorical realist. Categorical realists believe that all fundamental properties are categorical, and that if there are dispositional properties, such properties supervene upon the fundamental ones. See the discussion in Ellis (2002, pp. 70-76).

[8] The idea of an haecceitic property may have come down to us from Duns Scotus (see Adams (1979, p. 7. specifically the sources cited in note 4); and Pasnau (2011, p. 99, p. 560)), though Peter King (2000, p. 169. n. 17) seems to disagree. He wrote that "…there is some question whether it [the term 'haecceity'] is Scotus's." King (1992, p. 73. n. 7).

[9] Lewis (1986a, p. 61).

[10] Well, he (Lewis, (1986b, pp. 74-75. n. 54)) flirts with three different views of naturalness, but says that he is "staying neutral between" the "three alternatives." See ibid.

[11] Lewis (1986a, pp. 60-61).

[12] Lewis (1986a, p. 60).

According to the HST, derivative structure *globally* supervenes on primitive structure[13], and we say that such derivative structure supervenes in the aforementioned sense on primitive structure if, and only if, any pair of worlds (at least one member of which is the actual world) that is indiscernible with respect to primitive structure is likewise "indiscernible with respect to" derivative structure.[14] Thus, all of reality not identical to some part (proper or improper) of the arrangement of the qualities of space-time points supervenes on that arrangement.

What of the modal status of the HST? The HST is at best a contingent truth. Thus, some possible worlds may differ with respect to higher-level structure even though they do not differ with respect to their local intrinsic and categorical qualities. Lewis's reason why he regards the HST as a contingent thesis is interesting however. He seems to generate that verdict on the HST because of the existence and instantiation of alien properties at distant possible worlds. A property is alien, if it is instantiated at some possible world, it fails to be instantiated at the actual world, and yet it also cannot be constructed out of properties instantiated at the actual world *via* some structural or conjunctive property or properties.[15]

One adopts the HST so as to afford a defense of physicalism, though not just any physicalism.[16] Lewis's HST entails a contingent *micro*physicalism, the thesis that "[a]ll

[13] Lewis said, "[a] supervenience thesis is a denial of independent variation….To say that so-and-so supervenes on such-and-such is to say that there can be no difference in respect of so-and-so without difference in respect of such-and-such." Lewis (1983, p. 358).

[14] Kim (1993a, p. 82). We might analyze indiscernibility *via* an appeal to similarity in which case global supervenience could be understood along something like the following lines, "[t]he degree to which any two worlds are similar in respect of" derivative structure "is matched by the degree to which they are similar in respect of" primitive structure. Kim (1993a, p. 89)

[15] Lewis (1986a, p. 91).

[16] Lewis said that he wanted to argue in favor of the HST for the purposes of resisting "philosophical arguments that there are more things in heaven and earth than physics has dreamt of." Lewis (1994, p. 474). *Cf*. the discussion in Loewer (1996, p. 103).

the facts metaphysically supervene on the microphysical facts."[17] Microphysicalism is stronger than a contingent physicalist thesis, since given such a view it need not be the case that all facts supervene on microphysical facts. Rather, such facts need only depend or globally supervene on *physical* facts whether they are micro or macro.[18]

3.1.1 Objections

If the HST is true, then causal facts reduce by supervenience to non-causal facts since all non-microphysical facts in general are subject to such reduction. General reductive theses entail the causal reductionist thesis. I will now provide several lines of reasoning which should serve as roadblocks for anyone on the path to causal reductionism by way of the HST.

3.1.1.1 Necessitism and the HST

Recall that the present work on causation is situated amidst several philosophical assumptions, *viz*., necessitism, and the thought that two specific possibility claims afford *prima facie* epistemic justification on leading modal epistemologies. The first of these assumptions straightforwardly entails the falsity of the HST. Let me explain how.

Lewis (1994, "The picture is inspired by classical physics." p. 474). This is strange since classical physics is non-separable (see Butterfield (2006)). For what it is worth classical physics is also non-local (think, for example, of Newtonian gravitation, (see Wallace (2012, p. 293))).

[17] Papineau (2008, p. 127).

[18] I should point out that I am assuming that Philip Pettit (1993) was wrong to define 'physical' in terms of being micro-physically determined, for if Pettit was right, the only respectable way to be a physicalist is to be a microphysicalist. This may seem fine, especially in light of one of the main arguments for physicalism:

(1) All known facts have been shown to supervene on microphysical facts.
(2) If (1), then physicalism is more than likely true.
(3) Therefore, physicalism is more than likely true.

If (1) is true, then the argument that is (1)-(3) supports microphysicalism not just physicalism. This is because proposition (1) is direct evidence for microphysicalism.

According to the HST, the subvenient base (the Humean mosaic) features extrinsic properties since spatio-temporal relations are nothing above and beyond extrinsic properties.[19] The subvenient set includes derivative structure that incorporates extrinsic properties. These are important qualifications for recall that Jaegwon Kim admitted that global supervenience entails strong supervenience when extrinsic properties show up in both the subvenient base and the supervening set. He said,

> Equivalence [between global supervenience and strong supervenience] seems to fail, through the failure of implication from global to strong supervenience, *only when* extrinsic properties are present in the supervenience set but disallowed from the subvenient base.[20]

What did Kim mean by strong supervenience? A-properties strongly supervene on B-properties, just in case "[f]or any possible worlds *w* and *w**, and for any *x* and *y*, if *x* in *w* is a *B*-twin of *y* in *w**, then *x* in *w* is an *A*-twin of *y* in *w**."[21] When applied to the HST, the idea would be that derivative structure strongly supervenes on primitive structure if, and only if, for any possible worlds *w* and *w**, and for any *x* and *y*, if *x* is the Humean mosaic at *w* and *y* is the Humean mosaic at *w** and *x* and *y* are identical, then *w* will feature the same derivative structure *w** features. And so by Kim's lights, necessarily, if derivative structure *globally* supervenes on the Humean mosaic, then such derivative structure also *strongly* supervenes on the Humean mosaic.[22] But of course, strong supervenience entails weak supervenience. Given that derivative structure strongly supervenes on the Humean mosaic it will follow that that structure also weakly supervenes on the Humean mosaic, where weak supervenience is understood as follows:

---

[19] This is not my view but appears to be a common assumption of adherents of the HST.

[20] Kim (1993c, p. 170) emphasis mine. The type of global supervenience Kim has in mind appears to be indiscernibility based global supervenience. This is the very same type of global supervenience Lewis adopted when characterizing the HST (*q.v.*, my discussion above).

[21] McLaughlin (1997, p. 210). *Cf.* Kim (1993c, p. 81).

[22] See the discussion in McLaughlin and Bennett (2014, sect. 4).

> (Weak Supervenience): For any possible world *w*, A-properties weakly supervene on B-properties at *w*, just in case, "B-twins in *w* are A-twins in w."[23]

Thus, by the transitivity of strict implication, the global supervenience of derivative structure on the Humean mosaic will entail that derivative structure weakly supervenes on the mosaic. And so if one can show that some bit of derivative structure fails to weakly supervene on the Humean mosaic, it will follow that global supervenience also fails.

Suppose that necessitism holds. If an individual P_1 is an abstract object that is possibly a human person, and O_1 is an abstract object that is possibly an ocean, and each object exists at the actual world @, both P_1 and O_1 would be similar or indiscernible with respect to their non-modal profiles at @ (they will have the same non-modal properties). However, the property /*is possibly a human person*/ would not weakly supervene on the non-modal, for O_1 does not have that property despite being non-modally similar to or indiscernible from P_1. In light of the fact that global supervenience entails weak supervenience, this result is bad news for the HST.[24]

3.1.1.2 Quantum Mechanics and the HST

"Humean supervenience" writes Lewis, "is named in honor of the greater 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*."[25] As I noted above, Humeans affirm that the physical state of the world is fixed by local and separable

[23] McLaughlin (1997, p. 210).

[24] My argument shares some affinities with that of Timothy Williamson's (2013, pp. 385-386).

[25] Lewis (1986a, p. ix) emphasis mine. John Hawthorne summarized the HST by stating that derivative facts supervene "on the global distribution of *freely recombinable fundamental properties*." Hawthorne (2006, p. 245). Hawthorne does not endorse the HST.

space-time points (with their qualities) and the spatio-temporal relations of those points.[26] The HST therefore entails that the fundamental physical state of the world is separable. However, if fundamental physics delivers to us an end-game fundamental physical theory that is non-separable, then the HST is false. Say that a fundamental physical theory is non-separable when,

> …given two regions A and B, a complete specification of the states of A and B separately fails to fix the state of the combined system A + B. That is, there are additional facts—nonlocal facts, if we take A and B to be spatially separated—about the combined system, in addition to the facts about the two individual systems.[27]

Many theoreticians have pointed out how the separability facet of the HST is untenable by reason of quantum physics.[28] The existence of entangled quantum states is an implication of every interpretation of quantum mechanics.[29] Entangled quantum states do not globally supervene on local matters of particular fact, "[t]hat is, the local properties of each particle separately do not determine the full quantum state and, specifically, do not determine how the evolutions of the particles are linked."[30] In fact, the non-separability of quantum mechanics was one reason why Einstein believed the theory to be incomplete.[31]

David Albert (1996) and Barry Loewer (1996, pp. 104-105) have proposed a means by which one can save the HST through the Bohmian interpretation of QM plus

---

[26] Lewis (1986b, p. 14); *cf.* the discussion in Maudlin (2007, p. 120) who characterized the separability of the view as follows, "The complete physical state of the world is determined by (supervenes on) the intrinsic physical state of each space-time point (or each pointlike object) and the spatio-temporal relations between those points." Maudlin (2007, p. 51).

[27] Wallace (2012, p. 293).

[28] See the discussions in Lewis (1986a, p. xi); Loewer (1996, pp. 103-105); and Maudlin (2007, pp. 61-64).

[29] Schrödinger (1935, p. 555) said that entanglement is the "…the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought".

[30] Loewer (1996, p. 104).

[31] See Einstein (1948); *cf.* Brown who remarked, "...[Einstein's] opposition to quantum theory was based on the fact that, if considered complete, the theory violates a principle of separability for spatially separated systems." Brown (2005, p. 187)

configuration space realism. The idea is that the 3*N* dimensional (configuration) space in which the quantum state of an *n*-particle system lives is the actual space in which we ourselves live and move and have our being. Values of the field (the wave function) in configuration space correspond to various properties of space-time points, and such properties represent the "amplitudes of the quantum state" itself.[32] The magical point or world particle dances in configuration space, and its dance fixes the motions and locations of ordinary particles which themselves determine the manifest image.[33] The maneuver has serious problems (see Arntzenius (2012, pp. 87-103) *inter alia*). However, we can ignore such difficulties for now and focus on an implication of a particular phenomenon of QM other than quantum entanglement that is thoroughly non-separable *viz*., the Aharonov-Bohm effect.[34] The effect says that a particle with a discernable charge can be subject to the influences of a vector potential in ways that are sensitive to measurements. Such measurable impact is left upon the relevant particle (detected by observations of the interference pattern on the sensitive screen in the two slit setup) even given a vanishing magnetic field along the entire path of the charged particle.[35]

Given the absence of a current flowing through the solenoid in the setup, the background screen will suggest the common interference pattern made manifest in two-slit experiments. Both the minima and maxima of the interference pattern shifts given the presence of the aforementioned current, for that current will yield a magnetic field within

[32] Loewer (1996, p. 104).
[33] Ibid. See also Albert (1996).
[34] Aharonov and Bohm (1959); Healey (2007, pp. 21-57); Wallace (2012, p. 294); Weinberg (2013, pp. 305-307). See specifically Weinberg (2013, p. 307. n. 2) for a list of sources that detail the various experimental situations in which the effect has been observed.
[35] Aharonov and Bohm (1959, p. 490).

the solenoid.[36] The interference patterns produced in the effect depend upon the values of the electromagnetic field within the solenoid (a region some distance away), "changing the current in the solenoid directly affects the spatially distant electrons."[37] The dependence is not itself accounted for by some spatio-temporally contiguous connection between the electrons and the values of the field in the solenoid (see Healey (2007, p. 48)). Aharonov and Bohm proved that this effect is a consequence of quantum mechanics by deriving it from the deterministic quantum mechanical equation of motion that is the Schrödinger equation.[38]

Aharonov, Bohm, and Feynman all argued that the effect the magnetic field has on the interference pattern is not non-local despite the fact that the relevant field is confined to a region within the solenoid.[39] They argued that a magnetic vector potential does the local explanatory work extending outside of the solenoid to do its work. Healey (2007, p. 25) has noted that such a vector potential "is gauge dependent", and that the potential's dynamical equations are indeterministic and not at all gauge covariant. In addition, Healy argued that realist interpretations of the vector potential entail a violation of the gauge symmetry of electromagnetism. Thus, such interpretations yield gauge invariance. There is therefore a privileged gauge for the vector field. But classical electromagnetism (with quantum particles in mind) "entails that no observation or experiment is capable of revealing that gauge."[40] Such a fact suggests a unique epistemic

[36] The amount by which the maxima and minima shifts is captured by the equation: $\Delta x = \frac{l\lambda}{2\pi d}\frac{|e|}{\hbar}\Phi$. $\lambda = h/p$, which is the de Broglie wavelength of all of the electrons with a momentum p and negative charge e that reside in the beam. Φ represents the magnetic flux residing in the beam. l amounts to the distance to the sensitive screen providing us readings. And d represents slit separation. Healey (2007); Healey (1997, p. 19)

[37] Healey (2007, p. 48).

[38] Healey (2007, pp. 23-25) provides a simpler version of the proof.

[39] Feynman (1965, p. 15-12).

[40] Healey (2007, p. 26).

isolation problem, and it cannot be overcome by a shift in formalism (*i.e.*, by a shift to fiber bundle formulations of electrodynamics). We should therefore not attempt to reassure ourselves of separability by appeal to the vector potential. Aharonov, Bohm, and Feynman were wrong. In fact, later on Aharonov (1984) would himself argue that the Aharonov-Bohm effect is "non-local" in a sense that entails non-separability.[41]

Nothing about Bohmian configuration space realism escapes the aforementioned non-separability. Following Healey (1997, pp. 37-38) I note that the Bohm-de Broglie interpretation of QM entails that the particles involved in the AB-effect always have determinate positions. Some of the quantum particles take the lower route while others the higher route relative to the solenoid. Various effects resulting from the electro-magnetic activity of the solenoid can reach out and touch quantum particles along either route in a local manner because the wave function (interpreted as a concrete physical object) is the one mediator between solenoid and particle. I may be too hasty here. Dürr, Goldstein, and Zanghi use a velocity field nomologically related to the (conditional) wave function to affect quantum particles.[42] Shifts in the electromagnetic current of the solenoid will result, therefore, in shifts in the relevant velocity field that in turn results in changes to the motion of the quantum particles (Healey (1997, p. 37)). This take on the matter yields *bona fide* non-separability (as Healey (1997, pp. 37-39) has shown), and the question, "how does electromagnetic phenomena act on the velocity field if such phenomena is confined to regions in which the solenoid is located?" becomes a troubling one for the proponent of the HST and Bohmian QM.

---

[41] See Aharonov's remarks in his (1984, p. 12). There are other attempted local and separable explanations of the relevant phenomena (see Holland (1993, p. 196); Mattingly (2006) who appeal to a quantum force), but Healey has shown that these purported local explanations fail.

[42] Dürr, Goldstein, and Zanghi (1992, p. 864).

3.1.1.3 The General Theory of Relativity and the HST

That there are a great many possible ways of correctly attributing topological structure to the space-time manifold is thoroughly compatible with GTR, though space-time's *local* topological structure must be the same as the topological structure of quadruples of the reals.[43] In GTR, one can determine the topological structure of the manifold by specifying that a certain group of subsets of space-time points are open sets.[44] It is therefore plausible to regard the property of /*being open*/ as a fundamental topological property of space-time points.[45] Importantly though, every *individual* space-time point has the compliment of such a property though some *non-singleton* sets of such points possess it. Thus, all space-time points are similar with respect to their topological natures, and so the topological structure of space-time in GTR does not globally supervene on the fundamental properties of space-time points. This is because *some non-singleton* sets of space-time points are open even though none of their elements are, while other sets of such points are closed.[46] The qualitative features of individual points in space-time do not determine the topological structure of sets of those points.

3.1.1.4 Quantum Gravity and the HST

3.1.1.4.1 Canonical Quantization and LQG

The leading canonical quantum gravity model (CQG), loop quantum gravity (LQG), violates separability (and not because of reasons having to do with quantum entanglement or the AB-effect). Following Rickles (2008), I note that according to canonical quantization of GTR, the one fundamental object is space, and GTR provides

[43] Arntzenius (2012, p. 45); Manchak (2013, p. 588)
[44] Arntzenius (2012, p. 45).
[45] See Arntzenius (2012) for objections to this maneuver.
[46] The argument was discovered by Arntzenius (2012, pp. 45-46).

the details about how that space evolves.[47] Such an understanding of GTR differs from the standard interpretation because that standard interpretation implies that space-time is static. Normally, according to CQGs space and time come apart, where the former evolves against the background of the latter. Such separation is obtained by the introduction of an approximate equivalence and a foliation:

(1) $\mathcal{M} \cong \mathbb{R} \times \sigma$

where σ is a 3D hypersurface that is compact, and where the foliation is:

(2) $\Im_t: \sigma \rightarrow (\sum_t \subset \mathcal{M})$

Every hypersurface $\sum_t$ amounts to a temporal instant, and the manifold then is an agglomeration of such instants understood as a one-parameter family. In the context of CQGs, there are a number of avenues from such an agglomeration to a *bona fide* manifold. The fact that there are such avenues amounts to the diffeomorphism gauge symmetry of GTR. The diffeomorphism constraint that is a vector field, the Hamiltonian constraint that is a scalar field, plus various gauge functions on the spatial manifold generate diffeomorphism gauge transformations.[48] Furthermore, these constraints and functions evolve space forward one space-like hypersurface at a time.[49] The entire theory remains generally covariant and so the laws hold for coordinate systems related by coordinate transformations that are both arbitrary and smooth.[50] CQGs, therefore, understand both the geometry of the manifold and the gravitational field in terms of the evolutions of various fields, which are defined over space-like hypersurfaces $\sum_i$ on an assumed foliation.

[47] I am following Rickles's discussion of CQGs. See Rickles (2008, pp. 323-327).
[48] Rickles (2008, p. 324); Sahlmann (2012, p. 189).
[49] In the present context, the Hamiltonian is a sum of the aforementioned constraints.
[50] I should add that if one says of spacetime that it is 3+1 dimensional, then the theory breaks general covariance.

Again, the leading and most popular CQG is loop quantum gravity.[51] Proponents of this approach maintain that GTR can be simplified, and that one can understand the theory in terms of gauge fields.[52] Quantum gauge fields can be understood in terms of loops. By analogy with electrodynamics, we can say that space-time geometry is encoded in electric fields of gravitational gauge fields. The loops appropriately related to such electric fields weave the very tapestry of space itself.[53] According to LQG then, the fundamental objects are networks of various interacting discrete loops.[54] Many proponents of LQG maintain that these fundamental networks are arrangements of spin networks.[55]

Spin networks do an amazing amount of work for LQG. They not only provide one with the means to solve the Wheeler-de Witt equation (see Jacobson and Smolin (1988)), but arrangements of such networks give rise to both the geometry of spacetime (Markopoulou (2004, p. 552)), and a fundamental orthonormal basis for the Hilbert space in LQG's theory of gravity.[56] Furthermore, the role of spin networks in LQG recommends that LQG is non-separable. The causal structure of space-time is not determined by the categorical and local qualitative properties of spacetime points and their spatio-temporal relations, nor by individual loops and spatial relations in which such loops stand. Let me explain.

---

[51] See Rovelli (2011a), (2011b); Smolin (2001, pp. 125-145), (2002), (2004a), (2004b, pp. 501-509).

[52] The insight is Ashtekar's (1986) who leaned on Sen (1981); *cf*. Smolin (2004b, p. 501).

[53] "…the loops of the quantized electric field do not live anywhere in space. Instead, their configuration defines space." Smolin (2004b, p. 503).

[54] Some of these loops are knotted, meaning that "…it is impossible, by smooth motions within ordinary Euclidean 3-space, to deform the loop into an ordinary circle, where it is not permitted to pass stretches of the loop through each other…" Penrose (2005, p. 944).

[55] A spin network is a "graph, whose edges are labelled by integers, that tell us how many elementary quanta of electric flux are running through the edge. This translates into quanta of areas, when the edge pierces a surface" Smolin (2004b, p. 504). The idea comes to us from Penrose (1971). Before the use of spin-networks theorists used multi-loop states. See Rovelli (2008, p. 28).

[56] There are theorems which establish each result. See Smolin (2004b).

On one interpretation of LQG, spin networks are types of causal sets, and so LQG in the quantum cosmology context has some similarities with quantum causal history (QCH) approaches.[57] Thus, LQG implies that the causal structure of the cosmos is determined by partially ordered and locally finite (in terms of both volume and entropy) sets. Such sets are regarded as events which one associates with Hilbert spaces with finitely many dimensions. The pluralities identified as events are "regarded as representing the fundamental building blocks of the universe at the Planck scale."[58] Notice that these building blocks are *pluralities* of loops.[59] Individual loops themselves do nothing to determine causal structure. Furthermore, some loops are joined in such a way that *they are not susceptible to separation even though they are in no way linked* (*e.g.*, Borromean rings).[60] The spatio-temporal relations of such loops do nothing to determine that self-same structure, for (again) spin networks of loops weave together space-time geometry itself. What is more, even on non-causal set approaches to LQG the very dynamics and evolution of quantum gravitational systems on LQG involve shifts from spin networks to spin networks. On orthodox LQG (without causal sets) quantum states are sets "of 'chunks', or quanta of space, which are represented by the nodes of the spin network, connected by surfaces, which are represented by the links of the spin

[57] Markopoulou and Smolin (1997) join "the loop representation formulation of the canonical theory [of gravity] to the causal set formulation of the path integral." (ibid., p. 409). See also Markopoulou (2004, pp. 551-556); Hawkins, Markopoulou, and Sahlmann (2003, p. 3840); Rovelli (2008, p. 35); and Smolin (2005, p. 19).

[58] Hawkins, Markopoulou, and Sahlmann (2003, p. 3840).

[59] In fact, one should understand a spin network state in terms of "a sum of loop states." Spin network states are quantum states (they are the very eigenstates of observables which help us get at volumes and areas via measurement) understood as pluralities of loop states. Quotations in this note come from Smolin (2005, p. 13).

[60] See Penrose (2005, p. 944).

networks."[61] Causal structure is therefore determined by interrelated systems of loops, not individual loops and their spatial-temporal relations.

3.1.1.4.2 String Theory

Arguably the leading quantum gravity paradigm is string theory.[62] String theories are perturbative manifold (or background) dependent quantum theories specified by a choice background $\mathcal{B}$ built out of the set $\{\mathcal{M}, g_{ab}, F, \varphi\}$ (where Φ is the dilaton, a massless scalar field which helps define perturbation expansion;[63] F is a plurality corresponding to generalized magnetic and electric fields, $\mathcal{M}$ is the background space-time manifold, and g_{ab} is the Lorentz metric).[64] Backgrounds are either consistent or inconsistent. Consistent backgrounds are those over which one may define a perturbative string theory.

I described string theories as perturbative because many of them include coupling constants that are dimensionless and that help one calculate the values of various "physical quantities as expansions in the small parameter."[65] The dimensionless or string coupling constant together with the string scale l_{string} help measure background fields and various aspects of the geometry of the background. Strings themselves are one dimensional (they possess lengths) filaments of energy that vibrate at various frequencies in $\mathcal{B}$. The frequencies at which strings vibrate correspond to an array of particles, and

---

[61] Rovelli (2008, p. 38).

[62] For a non-technical introduction to string theory see Greene (1999); and Greene (2004, pp. 327-412). For a more technical but brief primer/introduction see Bianchi (2012, pp. 141-144).

I do believe it is a bit of a misnomer to use the locution 'string theory', for the precise mathematical formalism of "string theory" is not yet known, nor has a complete conceptual framework emerged for understanding all of the details of the "theory".

[63] Becker, Becker, and Schwarz (2007, pp. 82-84).

[64] Smolin (2004b, pp. 510-511); Becker, Becker, and Schwarz (2007, p. 53). Another important background field for string theories which attempt to describe strings of the oriented *bosonic* variety is the two-form gauge field (see Ibid., 81).

[65] Becker, Becker, and Schwarz (2007, p. 8).

sometimes closed strings realize spin-2 particles (particles which spin twice the speed of a photon. Smolin (2004b, pp. 511-512) tells us that these strings amount to gravitational waves or gravitons, and these constitute the veritable heart of the quantum theory of gravity that string theory affords. As Smolin remarked: "The basic result that suggests that string theories are relevant for quantum gravity is that they provide in this way a unification of the gravitons with the particles and forces of the standard model of elementary particle physics."[66]

String theory also affords a great many dimensions, though it's an effective 2D field theory. These two dimensions lay against a 10D space, six of which require compactification. Such compactification breeds a 4D effective spacetime.[67]

Often enough the strings of string theory are coupled, and they are also built out of string bits, for they are not continuous but discrete complex entities.[68] According to some versions of string theory, open strings (strings which fail to form closed loops) attach themselves to p-branes (p-dimensional entities, that is, entities less than 10D). Interestingly, p-branes may be related to one another *via* strings that connect them.[69]

All of the above features of string theory and string theories imply that the most popular quantum gravity paradigm is fundamentally non-separable. Consider, for example, the non-separability implied by p-brane interaction. Suppose I specify both the state of a p-brane P1, and a different p-brane some distance away from P1 (call this other p-brane P2). Assume both branes are of the same dimension. String theory demands that open strings stretch out and connect these branes, constraining their movement. It now

---

[66] Smolin (2004b, p. 512).
[67] Weltman, Murugan, Ellis (2012, p. 424).
[68] See Smolin (2001, p. 165).
[69] Greene (2004, p. 390), and see figures 13.2(b) and (c) there.

follows that a specification or determination of the state of the complex system P1 + P2 is left under-determined by complete and separate specifications of the individual states P1 and P2. For those separate and individual specifications will say nothing about how the movements of P1 and P2 constrain one another. There is no physical freedom enjoyed by these states, they are linked by the open strings stretching out between them. String theory (if approximately correct) implies the real existence of fundamental non-separable states, and so it therefore also implies the falsity of the HST.[70]

3.1.2 Sider's New Fangled Humeanism

I have argued that it is an implication of our best logic and cutting edge science that the HST is false. There has emerged, however, a new fangled Humeanism in the work of Theodore Sider (2011). He maintains that causal, nomological, and modal structure are not fundamental features of reality (Sider (2011, p. 267)) for if they were, the ideology of our metaphysical theory (or book) of the world would be overly complex. In the interests of "ideological economy" (ibid.), it is best that we do without such notions. But what is the ideology of a metaphysical theory? Following Quine (1951), (1953), Sider (2011, pp. vii-viii) equates the ideology of a theory *T* with *T*'s primitive notions. Such primitive notions are those that are indispensable to *T*'s ideology. Sider (2011, p. viii, p. 13) argues that the primitive notions which belong to the ideology of *T* serve as part of *T*'s "representational content" (ibid.), and so, given *T*'s truth, that *T* has ideology **i** implies that the world has structure which comports to **i**. In this vein, Sider stated, "...the world according to an ideologically bloated theory has a vastly more complex structure than the world according to an ideologically leaner theory; such

[70] If one's string theory is bosonic and non-fermionic, then there are no p-branes. However, non-fermionic string theories are non-realistic.

complexity is not to be posited lightly."[71] Concern for ideological economy recommends theories with simple ideologies, while those ideologies help ensure desert landscape ontologies. For Sider, simplicity in both spheres is vital to proper metaphysical theorizing.

It is also important that the ideology of one's metaphysical theory be such that it is comprised of notions that carve reality at the joints. One should (quoting Sider) "regard as joint-carving the ideology that is indispensable to your best theory."[72] And one should (quoting again) "regard the ideology of our best theory—'best' by the usual criteria for theory choice, such as simplicity..."[73] Now, since the ideology of a theory *T* is *T*'s primitive notions, it follows that (for Sider) one should strive to craft one's metaphysical theory in such a way that its ideology consists of primitive notions that are indispensable to our best theories, where we get a fix on those theories by means of certain values which help us arbitrate, assess, and evaluate theories in general.

Sider's understanding of ideology and ideological economy is important for any sustained discussion of his views regarding modality, natural nomicity, and causation, since Sider (2011, pp. 21-22, p. 267) thinks of the world as a fundamentally acausal, anomic, and amodal place because of ideological economy considerations.[74] Thus, any metaphysical theory (or book) of the world incorporating ideology laden with causal, nomic, or modal notions is not at all well-ordered and proper, for it is unnecessarily bloated in its ideology and such ideological extravagance requires unnecessary structure which, if posited, would ruin hopes of a truly simple ontology.

---

[71] Sider (2011, p. viii)
[72] Ibid., p. 14.
[73] Ibid., p. 97.
[74] Ibid., p. 267.

Sider's new fangled Humeanism is false. Its attempt to rid the world of fundamental nomological structure fails. The attempt fails because one of our best theories does require (indispensably) nomological notions. Let me explain.

The notion of a configuration space is indispensable to the ideology of QM, and classical mechanics (CM). In CM, a mechanical system can consist of nothing above and beyond a particle of mass moving about a Euclidean 3D space. With respect to such a single particle system, the configuration space would be $\mathbb{R}^3$, and that space just is (quoting Laura Ruetsche) "the space of" the systems "*possible* configurations (a.k.a. positions)".[75] Hamiltonian mechanics has it that the state of the system I have in mind is fixed by the momentum and position of the system. In the formalism of Hamiltonian mechanics, canonical coordinates (that are both a momentum variable and position variable) are required for the purposes of serving as coordinates "for the phase space" "of *possible* states of the" entire "system".[76] "Possible states of a Hamiltonian system are elements of the phase space…appropriate to that system".[77] (quoting Ruesche) It's clear that in classical Hamiltonian mechanics, modal notions are required at the level of interpreting the formalism and defining or understanding both the configuration space, and phase space of a mechanical system.

Tim Maudlin (2003, p. 462) has pointed out that in order to even have an interpretation of QM, one's physical theory must be outfitted with both the notions of a wave function and a quantum state.[78] It just so happens that in QM, one defines the

[75] Ruetsche (2011, p. 30). Emphasis mine.
[76] Ibid., 31. Emphasis mine.
[77] Ibid. Emphasis mine.
[78] Maudlin (2003, p. 463).

former notion over a configuration space.[79] But configuration spaces are (as I noted above) collections of possible configurations of a system, and so QM indispensably bears modal notions at the level of its primitive ideology.

The modal notions inherent in QM and CM are natural modalities. Natural modalities are almost universally understood to be a consequence of natural nomicity.[80] If natural laws do not fix such possibilities I'm not sure what would. The presence of natural modal notions in the ideologies of our best physical theories therefore also suggests fundamental nomicity, since such possibilities are fixed by the content of natural laws. Notice also how understanding certain propositions as laws does real explanatory work. Crowning them with such a status removes puzzlement about why there are the natural possibilities there are. If these truths are not understood as laws, we would have no principled way to discern what's natural nomically possible and what is natural nomically impossible. But Sider tried to keep us from positing fundamental nomological structure by arguing that specifying certain truths as natural laws does no real explanatory work.[81] I believe I've therefore shown exactly why such an argument is implausible.

But what about causation? Is that notion indispensable to the ideology of any of our best theories? I believe so, and I will argue for such a conclusion in sect. 3.2.2. Importantly though, if the above argumentation is correct, and modal notions of the natural variety appear in the ideologies of quantum mechanics, and classical mechanics, then the case for fundamental causation will be significantly helped since most actual instances of obtaining causal relations are such that they are backed by natural nomicity.

---

[79] Maudlin (2002, p. 119). "The wavefunction of a system is…a complex-valued function on the configuration space, i.e. a function which assigns a complex number to each *possible* configuration" (quoting Maudlin (2003, p. 462) emphasis mine).

[80] Hall (manuscript, p. 2).

[81] See Sider (2011, p. 15). "Adding the notion of law to physical theory, for example, doesn't seem to enhance its explanatory power." Ibid.

And, as will become obvious when I present my anti-reductionist theory of causation, physical causation is wed to natural laws in a way detailed by Ned Hall's intrinsicness thesis. In addition, it seems that at least some of Sider's motivation for ridding the world of causal structure is attenuated, given the soundness of the above arguments, for Sider says that "[t]he case for fundamental causation is…strictly weaker than the case for fundamental laws of nature..."[82] But I have just argued that by Sider's own Quinian metametaphysic, the world is laden with nomological and modal structure. Thus, Sider's general new fangled Humean worldview is false, and the case for an anti-reductionist and fundamentalist theory of causation has been prepared.

3.2 Direct Arguments for Causal Reductionism

I have set up barriers to two broad paths to causal reductionism (*viz*., the HST and Sider's new fangled Humeanism). With respect to a defense of causal reductionism, my opponents still have options. Instead of seeking to move from a more general reductive thesis to causal reductionism, they can instead proffer a direct argument for causal reductionism. In my survey of the literature, I've come across two types of direct arguments. Following Schaffer's discussion (2008) I will call the first the methodological argument, and the second the argument from physics. I will now explain why I believe each argument is unsound.

3.2.1 The Methodological Argument

One direct argument for reductionism regarding causation proceeds as follows:

> (29) If proper theoretical principles materially imply the causal reductionist thesis, then normally or defeasibly, causal reductionism is true (*i.e*., causation is nothing above and beyond actual history in addition to natural nomicity).

[82] Sider (2011, p. 16).

(30) Proper theoretical principles do materially imply the causal reductionist thesis.
(31) Therefore, normally or defeasibly, causal reductionism is true.[83]

Notice that this argument rests upon the success of properly reducing natural nomicity to a non-causal base. I happen to believe that the only way to solve the problem of induction is through a realist theory of natural laws, a theory laden with causal notions. And so if one attempted to reduce causation to natural nomicity and actual history, such a reduction would fail since already hidden within natural lawhood is causation. Thus, causation cannot be nothing above and beyond history plus natural nomicity.[84]

Put the above response to one side, as proper substantiation of it would require a significant detour into the epistemology of induction. I would like to make use of one of the doctrines I defended in the prolegomena of this work, *viz*., proposition (25). I argued that on a very plausible contemporary modal epistemology one can acquire *prima facie* epistemic justification for one's belief that (25) is true.[85] I suggested that the same type of justification could be had by appeal to other contemporary theories of modal knowledge. Thus, until some consideration is provided in favor of (25)'s falsehood then we are well within our epistemic rights in affirming (25). But if that is right, then the reductionist who propounds premise (29) has a defeater for her belief that (29) is true, since such considerations mean that even in light of the relevant batch of sound theoretical principles we have good reason to insist that causal reductionism is false (and so we can grant that the antecedent of (29) is true though the consequent of (29) comes out false).

---

[83] I have paraphrased this argument from Schaffer (2008, p. 91).

[84] There is a firm realist tradition here in the literature on natural laws. See Armstrong (1997); Foster (1982-1983), (2001), and (2004); Tooley (1987) *inter alia*.

[85] The type of rebuttal I'm employing has some precedence. Chalmers used conceivability considerations to defeat scrutability versions of Humeanism (see Chalmers (2012, pp. 338-339)).

What about proposition (25) poses a problem for causal reductionism? Well, if the reductionist thesis holds with necessity then at every world causation is nothing above and beyond natural nomicity and history. However, if (25) really does hold, then there's a world at which a causal relation obtains and yet that relation cannot be understood in terms of such nomicity plus history since presumably an unembodied mind's relating causally to a mental event involving belief formation is not a relation backed by physical laws. It also does not involve "history" where that notion is clearly pregnant with the idea of repetition of physical goings-on. By the same token, if causal reductionism is a contingent truth holding only at those worlds which feature the same fundamental physical entities as ours, a close cousin of (25)'s would still problematic since the imagined possible world very well could be a physical duplicate of ours. Such a maneuver would involve transmuting (25) into (25*): Possibly, at a physical duplicate of the actual world an immaterial mind formed a belief. I see no reason why we cannot obtain *prima facie* epistemic justification for (25*) in much the same way we obtained it for belief in (25), or (23) for that matter.

3.2.2 A Russellian Motif

Channeling, to some degree, Bertrand Russell (1912-1913), Jonathan Schaffer (2008) insisted that there is no room for causation in well-ordered physical inquiry. Physics only requires natural laws and unfolding history. He remarked:

> …causation disappears from sophisticated physics. What one finds instead are differential equations (mathematical formulae expressing laws of temporal evolution). These equations make no mention of causation.[30] Of course, scientists may continue to speak in causal terms when popularizing their results, but the

> results themselves—the serious business of science—are generated independently.[86]

Considerations such as those in the quoted pericope above quite naturally yield an argument for causal reductionism. For Schaffer would add to the above claims that if sound physical inquiry can proceed without causation making use instead of natural nomicity and history solely, then causal reductionism is true. Therefore, causal reductionism *is* true.[87]

I find Schaffer's justification for the claim that praiseworthy physical inquiry does without causation to be problematic. While it may be true that with respect to *some* particular foundational physical theory T_P, absent from the formalism of T_P is the notion of a cause, that fact does nothing to motivate the claim that T_P should not be *interpreted* in such a way that it requires an appeal to the notion of causation. A predominate way of understanding the very structure of T_P involves demarcating between the formalism of that theory and the interpretation of that formalism. To take just one example, the syntactic view of the structure of physical theories suggests that T_p is built out of a formalism, a set of axiomatic interpretational postulates, and a collection of correspondence principles (French (2008, p. 270)). The formalism of T_p is a language that consists of both logical and non-logical terms. Some members of the set of non-logical terms are theoretical while others are observational. The interpretational postulates provide the theoretical terms and correlation rules which connect those terms to the

---

[86] Schaffer (2008, p. 92) italics mine. See also Hall (2011, p. 97); and Russell (1912-1913, p. 14), and the recent critical discussion in Frisch (2014, pp. 1-21). For other arguments in favor of causal reductionism, see Hitchcock (2007); and Norton (2007a), (2007b).

[87] Notice that this argument is not the following:

(1) Fundamental physical science consists of mathematical results that do not include causal terms.
(2) If (1), then causal reductionism is true.
(3) Therefore, causal reductionism is true.

empirical world by permitting the derivation of sentences laden with observational terms from sentences laden with theoretical terms. With respect to GTR, and a syntactical understanding of its structure, my suggestion will be that the proper set of interpretational postulates includes, in its constituent sentences laden with observational terms, both cause and effect.

If one were to insist that physical theories do not require an interpretation in the above sense because the underlying formalisms of those theories are somehow already "fully interpreted", I would respond by noting that this understanding of physical theories can be easily defeated. Consider Bohmian quantum mechanics. Here we have a formalism constituted by the Schrodinger equation expressed by (Eq.1)[88]:

(Eq. 1): $i\hbar \frac{\partial \psi}{\partial t} = H\psi$

where *H* is the Schrodinger Hamiltonian whose value is given by:

(Eq. 2): $H = -\sum_{k=1}^{N} \frac{\hbar^2}{2m_k} \nabla_k^2 + V$

Bohmian mechanics also requires a guidance equation expressed by (Eq. 3):

(Eq. 3): $\frac{dQ_k}{dt} = \frac{\hbar}{m_k} Im \frac{\psi^* \nabla_k \psi}{\psi^* \psi} (Q_1, \ldots, Q_N)$

(Eq. 1) tells the wave function how to dance, and that function is important because the entire state of a physical system constituted by N number of particles is given by it (on the assumptions that that function is understood in terms of $\psi(q,t)$, that q equals the configuration $Q = (Q_1, \ldots, Q_N) \in \mathbb{R}^{3N}$ with $(q_1,\ldots,q_N) \in \mathbb{R}^{3N}$, and that Q_K are the particle positions)). The wave function is said to affect "the behavior of the

[88] For a full explanation of equations (Eq.1)-(Eq.3) see Dürr, Goldstein, and Zanghì (1996). I follow the discussion in Goldstein and Zanghì (2013) in the above *per* (Eq.1)-(Eq.3).

configuration…of the particles."[89] But what exactly is the wave function? What is ψ? And furthermore, what is its ontological status, and how precisely does it "affect the behavior of the configuration"? Notice that what it does and how precisely it does it depends upon what precisely it is. For example, it cannot actually push particles around if it is nothing above and beyond a mathematical object, which figures in some description of the evolution of a system. If, on the other hand, the wave function is a concrete substance it can figure in causally potent events. (Eq. 1) and (Eq. 3), therefore require an interpretation that does not obviously fall out of a straightforward translation of the equation into English. In GTR, there are similar interpretational choices to be made.[90] I will now argue that with respect to GTR, the notion of causation shows up indispensably in the best *interpretation* of the underlying formalism of that theory.

3.2.2.1 The Gravitational Field as Cause[91]

Einstein's general theory of relativity rests atop four principles: the principle of relativity, the principle of general covariance, the principle of the finitude of the speed of light (c), and the principle of equivalence. The principle of relativity says that the laws of physics apply to all systems of reference no matter what type of motion they are

---

[89] Goldstein and Zanghì (2013, p. 96).

[90] For example, with respect to foundational issues in general relativity, both Carlo Rovelli (1997, pp. 193-195) and Harvey Brown (2005, pp. 150-177) argue that the gravitational field is just another matter field (like the electromagnetic field), and that gravitational effects are due to that matter field's influence. Such an interpretation of g_{mn}, the metric tensor that represents the gravitational field, is incompatible with the orthodox interpretation, which reduces (by identity) the gravitational field to spacetime curvature itself. For Rovelli and Brown, spacetime is an unobservable entity unable to causally influence anything.

[91] With respect to the discussion that ensues, it is my intent to be neutral about the question of whether or not the gravitational field represented by the Lorentz metric is to be reductively understood in terms of "just another matter field" (as Rovelli (1997, pp. 193-195) and Brown (2005, 150-177) maintain). If one does not like such a reductive strategy one can interpret my appeal to the gravitational field as an appeal to spacetime curvature itself. See the interesting discussion of these matters in Pooley (2013) for background.

In arguing that there's causation in physics, I follow an anti-reductionist tradition of argumentation seen in Lenzen (1932), (1954); Scriven (1975, p. 5) *inter alios*.

undergoing.[92] The principle of general covariance states that the correct theory of spacetime involves (a) no preferred system of coordinates, and (b) a coordinate free gravitational physics.[93] The principle of the finitude of c simply affirms that the speed of light is finite. And finally, the principle of equivalence (henceforth PE) says that with respect to an arbitrary spacetime point *p* in an arbitrary gravitational field, there exists a locally inertial coordinate system "in which *the effects of gravitation* are absent in a sufficiently small spacetime neighborhood of" *p*.[94] Or, (by Robert Wald's lights) what amounts to the same thing, "*all* bodies are *influenced* by gravity and, indeed, all bodies fall precisely the same way in a gravitational field."[95]

As is evidenced by the above statement, the PE is standardly characterized in causal terms.[96] In fact, Einstein himself understood the PE in causal terms. He wrote:

> Inertia and gravity are phenomena identical in nature. From this and from the special theory of relativity it follows necessarily that the symmetric 'fundamental tensor' (g_{mn}) determines the metric properties of space, the inertial behavior of bodies in this space, as well as the gravitational effects. We shall call the state of space which is described by this fundamental tensor the 'G-field.'[97]

Those characterizations of PE that do not include explicitly causal terms often note in subsequent discussion that the PE implies certain causal facts.[98]

Besides implying that observers in free fall do not feel gravitational effects, the PE suggests that gravitation is strongly related to spacetime curvature.[99] Einstein's field equations (henceforth EFEs) detail the relationship[100]:

---

[92] Einstein ([1923] 1952, p. 113); Mook and Vargish (1987, p. 139).

[93] Einstein ([1923] 1952, p. 117); Penrose (2005, p. 459). The principle helped Einstein discover the field equations. Rovelli (2004, p. 66).

[94] Weinberg (2008, p. 511) emphasis mine.

[95] Wald (1984, p. 8) emphasis mine.

[96] See Misner, Thorne, and Wheeler (1973, pp. 312-313); Weinberg (1972, p. 69).

[97] Einstein (2002, p. 33) emphasis mine.

[98] See *e.g.*, Carroll (2004, p. 50). Both the *deflection* of light and gravity's *effect* on time follow straightway from PE. Zee (2013, p. 280-287)

(**EFE**): $G_{ab} \equiv R_{ab} - \frac{1}{2}Rg_{ab} + \Lambda g_{ab} = 8\pi T_{ab}$

GTR adds to the above formalism geodesic equations of motion for particles.[101] These equations are the backbone of the geodesic principle (henceforth GP), the thesis that, due to gravitational influence, free particles (for example) traverse timelike geodesics understood as curves of the spacetime metric.[102]

The geodesic principle has traditionally been interpreted causally, since Einstein ([1923] 1952, p. 114, p. 120) and others affirmed that the means by which such objects find themselves in the aforementioned paths is through the determining causal influence of the gravitational field. A number of experts on relativity attest to my reading of Einstein on the matter:

Oliver Pooley:

> The idea that *affine structure plays a quasi-causal role in explaining the motions of bodies* figures significantly in Einstein's criticism of Newtonian mechanics and SR and in his subsequent understanding of GR. …the fact that it [Newtonian absolute space] acted without being acted upon was held up as problematic [by Einstein]; a 'defect' not shared by the spacetimes of GR (Einstein, 1922, 61-62).[103]

---

[99] Penrose (2005, p. 459).

[100] The EFE suggests that the gravitational field couples with matter and other sources of gravity. It specifies the relationship between the stress-energy tensor (T_{ab}) and the Riemann curvature (R). It also relates "spacetime geometry to matter distribution." Wald (1984, p. 68)

[101] I will be solely concerned with the geodesic equation of motion for free particles.

[102] Einstein (1922); Carroll (2004, p. 2); Einstein and Infeld (1949); Weinberg (1972, pp. 121-129); Zee (2013, pp. 302-311). It is interesting that some contemporary statements of the principle, mostly by philosophers, drop the "due to gravitational influence clause". But its important to note that *gravitating* bodies are those that follow geodesics. Einstein's original statement of the principle (what he called the "law of motion") included just such a qualification. He said that the principle "asserts that *a gravitating particle* moves in a geodesic line." (1922, p. 113 emphasis mine)

[103] Pooley (2013, p. 541) emphasis mine. Some think of the PE in such a way that it affirms that gravitation amounts to acceleration. Its important to understand, however, that acceleration is due to the influence of the gravitational field, as Einstein stated,

> "The system of reference K' is unaccelerated, but *the spacetime region in question is under the sway of a gravitational field, which generates the accelerated motion of the bodies* relatively to K'." Einstein ([1923] 1952, p. 114) emphasis mine.

Brown and Lehmkuhl:

> Several years after the development of his 1915 general theory of relativity (GR), Einstein began to stress that physical space, or rather the metric field, not only constitutes a fundamental, autonomous element of objective reality, *it plays a causal role in accounting for the inertial motion of bodies*. [The footnote on same page continued…] …in the beginning of the 1920s Einstein started to think of the metric field as (causally) determining things, rather than just being determined by the distribution of masses.[104]

Harvey Brown:

> …Einstein assumed that all test bodies would follow the grooves or ruts of space-time defined by curves that are straight, or equivalently that are of extremal length. *We have seen that during this period Einstein assigned a causal role to spacetime structure in precisely this sense: to nudge the particles along such privileged ruts*. This kind of action of space-time on matter *was taken to be primitive*…[105]

One can derive the geodesic equation of motion for free particles from the EFEs (given certain interpretational postulates),[106] though there may be some reason for believing that there is no true description of extended bodies in motion that is consistent with the EFEs.[107] In fact, Einstein and Grommer (1927) rejected attempts to derive the equations of motion from the EFEs that appealed to an energy-momentum tensor field T_{ab} description of matter.[108] And while Einstein did opt to understand matter in terms of singularities (as in Newtonian gravitation), such a characterization breeds rather absurd consequences, since on that interpretation geodesics of massive bodies do not reside in space-time (Earman (1995, p. 12); Tamir (2012, p. 142)).[109] There are other ways of understanding matter in the equations, and there are other types of attempted proofs

---

[104] Brown and Lehmkuhl (2013, p. 2) emphasis mine.

[105] Brown (2005, p. 161) emphasis mine.

[106] See Eddington (1923); Einstein (1922); Einstein and Grommer (1927); Einstein and Infeld (1949); Geroch and Jang (1975); Infeld and Schild (1949).

[107] Ehlers (1987, p. 61); Tavakol and Zalaletdinov (1997, pp. 312-314, p. 323, p. 325); Tamir (2012).

[108] See Einstein (1995, p. 311), and the excerpts from Einstein and Grommer (1927) quoted in Tamir (2012, p. 141).

[109] Infeld, who at one time (with Schlid) espoused the singularity approach to matter in deriving the geodesic principle, eventually turned his back on that approach (see Infeld (1954)).

which help one skirt around these issues though there are potential problems with all of these alternative approaches (for which see Tamir (2012); Tavakol and Zalaletdinov (1997)). Thus, it is at least not obvious that the geodesic principle follows from the EFEs.

Harvey Brown (2005, pp. 161-163) has attempted to conclude on the basis of the validity of derivations like those in Geroch and Jang (1975) that the geodesic equation of motion is not axiomatic (it follows from the EFEs), and that therefore the geodesic principle does not require an appeal to fundamental causal influence.[110] I note in response that even after Einstein admitted with Grommer (1927) that the geodesic equation could be derived from the EFEs, and even after a host of plausibility arguments and attempted derivations of the relevant dynamical truths from the EFEs were published, Einstein and the majority of other physicists continued to interpret the GP causally.[111] In fact, Robert Wald, recently confirmed the causal interpretation of the GP, in some recent personal correspondence. When discussing how precisely to interpret the GP *given issues about the argument from physics and causal reductionism in the background*, Wald remarked "[t]he metric and matter fields are coupled and undergo causal interactions", and both metric and matter "influence each other causally".[112] The mere fact that the geodesic equations follow from the EFEs does nothing to undermine a causal reading of those equations.

Brown may have been assuming that what is fundamental to a physical theory is that which can be closely read off of the axiomatic formalism of that theory (in this case, the EFEs). But if one goes in for such a view of fundamentality and physical theorizing it

[110] Brown actually appeals to the discussion in Misner, Thorne, and Wheeler (1973, p. 475).

[111] See, for example, Einstein and Infeld (1949), and Geroch's explicitly causal interpretation in (1978, p. 180) and (2013, p. 2, p. 65, p. 68); *cf.* Carroll (2004, p. 49). Carl Hoefer (2009, p. 702) says the causal interpretation is commonly accepted.

[112] Wald (personal correspondence, 12/18/2014).

ought to be essential to one's understanding of what's fundamental to that theory that everything that is derivative fall out of the true descriptions of the world's fundamental structure according to those axiomatic equations. God needed only to ensure that a general relativistic spacetime satisfied the axiomatic equations of GTR, and that certain initial conditions obtained. All other relativistic structure falls out by consequence of the creation of both fundamental structure and initial conditions. This view of the structure of a physical theory does not suit GTR well. The geodesic equations of motion for a free particle follow from the EFEs only if certain interpretational postulates are assumed to hold. For example, the distributional proofs of the geodesic equation use Einstein's generalized EFEs. However, the conservation principle $\nabla_a T^{ab} = 0$ does not follow from those equations, since the Bianchi identities are not true for all solutions to the generalized EFEs since those equations use distributional tensors (Tamir (2012, p. 144)). However, local energy-momentum conservation is an extremely important principle that does all types of explanatory work in GTR. One will need the conservation principle and a distributional form thereof to ensure the validity of otherwise unproblematic distributional proofs of the geodesic equation.

Add the further fact that the famous limit operation proof of Geroch and Jang (1975) also requires an interpretive postulate in the antecedent of the theorem. As originally stated the theorem used what's called the *weak energy condition* (*i.e.*, that the energy density of the relevant matter fields are non-negative).[113] But Weatherall (2011) proved that it actually requires the *strengthened dominant energy condition*. That condition subsumes the weak energy condition but adds that the four-momentum density of the relevant matter fields is a vector that is both timelike and everywhere future-

[113] See the discussion in Malament (2009); and Weatherall (2011).

directed (*cf*. Malament (2012, p. 144)). These energy conditions are all restrictions on the energy-momentum tensor in the EFEs *that do not follow from the EFEs* themselves. They are therefore interpretational postulates not part of the axiomatic equations. Importantly, the energy-momentum tensor depends on, *inter alia*, the metric g_{ab}. You cannot specify the distribution of matter without determining the metric. The two are intimately related, and one must account for that relationship when seeking to interpret and solve for T_{ab}.[114] But as I've argued above, g_{ab} is a causal entity, relating causally to matter distribution. Thus, causation enters both the best interpretation of the EFEs, and the interpretive postulates one needs to secure the geodesic equations of motion from the EFEs.[115]

There is another sense in which causation enters GTR through the activity of the gravitational field. Consider the fact that the gravitational field can come to possess ripples understood as gravitational waves or gravitational radiation. Some such waves exist when the background metric is curved or flat. These waves can causally influence electromagnetic fields.[116] Moreover, gravitational waves are emitted. They are produced, at least some of the time, by the interaction of the gravitational field and massive bodies in motion. Production and emission are of course causal notions. The formalism of all of the relevant dynamical interaction is well understood (see Wald (1984, pp. 78-88); Zee (2013, pp. 563-577)), and the detection of gravitational waves or radiation was a goal that now looks as if it has been attained (see Ade et. al. (2014)).

---

[114] Hawking and Ellis (1973, p. 61); Malament (2012, p. 160).

[115] GTR requires more interpretive principles than the above. To provide just one example, general relativistic spacetimes sometimes require smooth curves to serve as the images of the worldliness of massive particles. Principle: For any smooth curve x, x is timelike, just in case, x "*could be* the worldline of a point particle with positive mass" Malament (2012, p. 120) emphasis mine. Notice the explicit appeal to modality. Malament (2012, p. 121) notes that that appeal is absolutely essential.

[116] Grishchuk and Polnarev (1980, p. 395). Rueger (1998, p. 34) explicitly agrees with a causal interpretation of the activity of gravitational waves.

GTR gives us good reason for believing that causation shows up in the correct interpretation of the mathematical formalism of a highly successful physical theory. Appearance in the correct interpretation is enough to motivate realist replies to Schaffer's argument, for Schaffer's key premise suggests that the results of sound physical inquiry require natural laws and history (again no causation). On one reading of Schaffer's remarks regarding the results of physical science, such results are the formalisms alone. I disagree. GTR isn't just the Einstein equation. The results also include an accompanying interpretation, for only the two together constitute the theory. I do not know how to understand Einstein's equation as a result without some type of interpretation of that formalism. Nancy Cartwright made exactly this point in her response to Bas van Fraassen (1989):

> The scientific image of nature is no more devoid of cause and causings than is our everyday experience. The appearance to the contrary arises from looking only at science's abstract statements of law, and not how those are used to describe the world.[117]

No doubt the causal reductionist will question my interpretation of the formalism. She will ask, "is it not true that the presence of massive bodies interacts (perhaps causally) with the self-same field?" Is not the famous dictum of John A. Wheeler the claim that "spacetime tells matter how to move; matter tells spacetime how to curve"?[118] Does this not suggest that if there are real obtaining causal relations involved, then the gravitational field causes a material body to behave *x*-ly, while the material body's behaving *x*-ly causes the field to behave *y*-ly? Does this not breed a circle? Should we not prohibit such causal circles?

---

[117] Cartwright (1993, p. 426).
[118] As quoted by Wheeler and Ford (1998, p. 235), quoting John A. Wheeler.

I do not find these questions to be very troubling. With respect to the dynamics of the gravitational field and the GP, Wheeler's famous quip represents two different interpretations.

> Interpretation A: takes the gravitational field as primary and understands spacetime curvature as that which causally determines matter distribution.
>
> Interpretation B: takes matter as primary and understands material entities as the causes of spacetime curvature.

According to Robert Geroch, either interpretation is on the table, but *each is explicitly causal*:

> …from the standpoint of one particular interpretation of Einstein's equation, that in which the spacetime geometry is regarded as *determining the distribution of matter* (and therefore, in particular, *determining how particles must move). We may also see the same thing from the other interpretation, in which matter causes curvature* and thereby influences the space-time geometry.[119]

Elsewhere he stated:

> …Einstein's equation can be interpreted as requiring that '*matter cause curvature in space-time*,' and that it can also be interpreted as requiring that '*matter move in certain ways in response to curvature in space-time*.'[120]

We need not, therefore, commit ourselves to causal circles. In the context of the GP, we may choose between two primary causal movers, the matter fields or the gravitational field.[121]

Carl Hoefer (2009, pp. 703-704) has argued that if GTR implied that there are certain obtaining causal relations, or if its best interpretation requires the use of causal notions, the reductionist should not be worried, for GTR is not itself a *fundamental* physical theory. GTR's picture of the world is not the quantum mechanical picture of the

---

[119] Geroch (1978, p. 178).

[120] Ibid., p. 181.

[121] I do believe there is some reason for regarding the gravitational field's influence as primary since it is that field which may cause a decrease or increase in the energy-momentum of particles without itself having any localized energy-momentum density whatsoever. See Misner, Thorne, and Wheeler (1973, pp. 466-468); Rueger (1998, p. 34).

world. GTR will have to yield to QM in ways that would rub out any attempt to understand the causal activity of the gravitational field as fundamental physical activity. Look back to my characterization of Schaffer's argument for causal reductionism. Notice that one of the premises of the argument states that sound physical inquiry can proceed without causation making use instead of natural nomicity and history solely. That premise does not say that such inquiry must be peculiar to *fundamental* physical investigation solely. Obviously, sound physical inquiry is what physicists leaned on when developing GTR. And GTR is of course an extremely successful physical theory, and that is precisely why any quantum theory of gravity must recover its predictive success. Thus, Hoefer's complaint should not worry the realist about causation.

I should add to my response to Hoefer, the further fact that while both string theory and loop quantum gravity proponents maintain that GTR can be formulated entirely within the framework of QM, there are theories of quantum gravity (QG) that do not seek for such subsumption. A theory of QG needs to at least approximate GTR and QM in certain appropriate limits. The correct theory of QG may be one that is *more fundamental than both QM and GTR*. Lucian Hardy's causaloid approach to quantum gravity is like this. It attempts to incorporate QM and GTR as special cases. Important to Hardy's theory however is *fundamental* dynamical *causal structure*.[122] What is more, there are other takes on QG that promote causal structure to fundamental status. For example, causal set approaches to quantum gravity are approaches that, according to Dean Rickles, treat "*the causal structure of spacetime as fundamental*".[123] Furthermore, Aron C. Wall (2013) has recently proposed an explicitly *causal* theory of quantum

[122] Hardy (2007, pp. 3084-3085).
[123] Rickles (2008, p. 347. n. 124).

gravity. Hoefer's objection may therefore rest upon more than one false assumption. The correct framework for a truly quantum theory of gravity is far from settled.

The causal reductionist may still object: The dynamical laws of GTR are time reversal invariant. Therefore, any causal reading of those equations will imply the negation of the principle that necessarily, causes always temporally precede their effects. But surely that principle is true!

The principle that necessarily, causes always temporally precede their effects is false. Recall that in Newtonian mechanics gravitational interactions obtain instantaneously, and that the gravitational field has no dynamics in time. However, that field is commonly understood as an entity that acts on objects. But if its action does not obey time-governed dynamics, and its interactions are instantaneous, it looks as if simultaneous causation is an implication of Newtonian gravitation. Of course, this response assumes a causal interpretation of Newtonian gravitation, but that interpretation is at least not incoherent.[124]

Still, the reductionist will argue that my reading of the dynamical equations suggests that backwards causation is possible, since there will be a general relativistic spacetime at which the causes are the effects, and the effects the causes. I reply that: GTR does not preclude spacetimes with closed timelike curves (CTCs) or closed causal curves (CCCs). If GTR holds, then spacetimes with CTCs are naturally possible. But it is well known that if spacetimes with CTCs are naturally possible, then time travel is naturally possible. If, however, time travel is naturally possible, then (arguably) backward causation is naturally possible. But given the impossibility of backwards causation, it will

[124] Wald (1984, p. 8); Zee (2013, p. 146).

follow by the transitivity of material implication and *modus tollens* that GTR is false. Surely this demonstrates that a prohibition on backwards causation incurs too high a cost.

3.2.2.2 Domains of Influence in Cosmology

I have argued that a proper understanding of the gravitational field in GTR implies that causation is indispensable to a proper interpretation of GTR's formalism. There is, however, another sense in which causation enters sound physical inquiry and that is by way of a proper understanding of the formalism of the standard cosmological model (which of course subsumes the formalism of GTR). Note first that a relativistic spacetime is a pair (M, g_{ab}), where M is a manifold with four dimensions that is boundaryless, and both connected and smooth.[125] The Lorentz metric g_{ab} is pseudo-Riemannian, or Lorentz signature (1,3), and is both non-degenerate and smooth. I will also assume, that there lives on spacetime a continuous timelike vector field, and so spacetime is time-oriented.

It is known that given the above assumptions, spacetime points induce double light-cone structure (as they do in the Minkowski space of STR). It is, however, less well known that given the same assumptions the standard cosmological model associates with spacetime points domains of influence. Future and past domains of influence are represented in the standard formalism via the locutions '$J^+(p)$' and '$J^-(p)$', where p is a member of M. $J^+(p)$ represents p's causal future, while $J^-(p)$ represents p's causal past. $J^+(p)$ is that "region of space-time which can be **causally affected** by events in" p.[126]

[125] A manifold such as M, which fails to be the union of two open sets that are not null and are disjoint, is a connected manifold. M is smooth if there's a real-valued function f defined over M that is smooth. The function f is smooth, only if, $f \cdot \phi^{-1}$ just is C^{∞} for all charts or coordinate patches on M (where f is a mapping that takes one from a subset of M to R^n the set built out of n-tuples of the reals).

[126] Hawking and Ellis (1973, p. 183) emphasis mine.

"Physically," (quoting Robert Geroch) $J^-(p)$ "represents the collection of all events of space-time which can **affect** what happens at *p*."[127] GTR does not reduce the above causal influence talk to anything non-causal, despite the sometimes confused identification of causal influence structure with light-cone structure.[128] John D. Norton (no friend of causal realism), has recently emphasized the peril of such misidentification:

> It is standard in the physics literature to talk of the light cone structure as the causal structure of spacetime. That designation can be misleading. General relativity does not have a fully developed metaphysics of causation such as would be expected by a philosopher interested in the nature of causation. Rather, we should understand the causal structure of a spacetime in general relativity as laying out necessary conditions that must be satisfied by two events if they are to stand in some sort of causal relation. Just what that relation might be in all its detail can be filled in by your favorite account of causation.[129]

This is a telling excerpt for two reasons. First, it confesses to the real presence of a causal relation in GTR. Second, it states that one can insert one's favorite theory of causation so as to fill in the details about the precise kind of causation in play in GTR. The first admission is a welcomed confession, and when one realizes that the causal reductionist

---

[127] Geroch (2013, p. 123) emphasis mine; *cf*. Manchak (2013, p. 590).

[128] It is well known that gravitational lensing can lead to light cone structure collapse so that causal structure and light cone structure depart from one another. Moreover, light cone structure induced by vertex spacetime point p lives in tangent space V_p, while domains of influence J+(p), and J-(p) are both open subsets of the manifold M itself. They are not in V_p.

On (1/23/2015), theoretical physicist Don N. Page provided me with a mathematical proof of a counter-example to the claim that domain of influence structure is identical to light cone structure. The mistake of identifying causal structure in relativity with light cone structure is often committed by philosophers (see *e.g*., Frisch (2014, p. 16); Field (2003, p. 436) comes close to suggesting such identification). Causal structure is standardly regarded as more fundamental than light cone structure in GTR. Geroch wrote,

> "To summarize, the structure suggested by the question 'Can event *p* influence event *q*' is perhaps more fundamental than the manifold and metric structure which forms the basis for general relativity." Geroch (2013, p. 125)

[129] Norton (2015, p. 211). John Norton has recently informed me in correspondence (1/23/2015) that his papers (Norton 2007a, 2007b), written later than the passage quoted, develop a more overtly skeptical attitude to causation.

has no successful "favorite account of causation" to insert in the GTR context, the realist's position looks all the more attractive (*q.v.*, sect. 1.3 below).

The reductionist may respond at this point that all of the causal talk I've referenced can be removed without loss of explanatory power. Explicitly causal interpretations of all of the above are therefore problematic. I reply that: Domains of *causal* influence help determine the global *causal* structure of spacetime. Without such causal structure one cannot derive the spacetime singularity theorems that are necessary for describing and explaining features of the beginning of the universe (see Wald (1984, p. 188; pp. 237-242) who calls such domains a "crucial ingredient" in the proofs of the singularity theorems).

3.3 Causation after Reductionism

Causal reductionists will no doubt judge my appeal to GTR, and cosmology to be cheap and shallow. They will insist that the authorities I have invoked are merely describing matters with a particular gloss (at least in the GTR case that appealed to the gravitational field). Surely we can do without causal talk.

But again, in the absence of a truly successful reductive analysis or theory of causation, I do not see why we should believe that causal talk in the work of physicists should be understood as redundant and imprecise talk. One cannot dismiss such causal language without providing a worthy proxy or substitute for it. The appropriate substitute arrives at the end of a careful reductive analysis of causal facts and/or an ontological reduction of the causal relation. The problem is that after a great many years of trying, attempts to reductively analyze and/or ontologically reduce causation have pretty much

universally failed. As two foremost experts on the topic, L.A. Paul and Ned Hall concluded:

> After surveying the literature in some depth, we conclude that, as yet, there is no reasonably successful reduction of the causal relation. And correspondingly, there is no reasonably successful conceptual analysis of a philosophical causal concept. No extant approach seems able to incorporate all of our desiderata for the causal relation, nor to capture the wide range of our causal judgments and applications of our causal concept. Barring a fundamental change in approach, the prospects of a relatively simple, elegant and intuitively attractive, unified theory of causation, whether ontological reduction or conceptual analysis, are dim.[130]

Causal reductionism is not well motivated. Causal reductionists have failed to adequately reductively account for the metaphysics of the causal relation *via* some suitable reductive theory of the causal relation. They have also failed to reductively analyze causation. These failures are evidence for realism about causation. One would expect such failure were realism about causation correct.

Perhaps one can provide a local reduction of causal structure in GTR. After all, the problems with many reductive accounts rely on very unique and artificial cases of preemption, overdetermination and the like. Do such cases arise in GTR? The reductionist will bet that they do not. Thus, counterfactual dependence (or some similar reductive surrogate notion) may serve as a worthy proxy for general relativistic causation even if it cannot serve as a worthy proxy for causation wherever it is found in the actual world or in broadly logical space. But such a local reduction will not work. One can, on paper or with the mind's eye, craft general relativistic worlds at which cases of overdetermination, preemption, and the like occur though these cases involve matter fields and the gravitational field, or gravitational waves, or certain tidal forces. Such nomological possibilities will suggest an incompatibility between the local reductive

[130] Paul and Hall (2013, p. 249)

theory of causal structure and GTR itself. *A fortiori*, the problems with reductive theories of causation are not all revealed in artificial counter-examples or difficult cases. There are other problems with many of these theories.[131]

[131] See Tooley (2003), and Rueger's (1998) discussion.

Chapter 4 Fundamental Causation

"We cannot know the truth apart from the cause".
- Aristotle (*Metaphysic*s, book 2, chapt. 1, 993b)[1]

The indirect and direct arguments for causal reductionism do not succeed at knocking down the claim that causation is itself a fundamental obtaining relation. I will now articulate my anti-reductionist theory of that fundamental obtaining relation. That theory will serve as the backbone of my novel account of scientific explanation (for which see chapt. 5).

4.1 The *Relata* of Causation

Before I proceed to discuss my theory of the causal relation and what types of entities stand in that relation it will be important to disclose to the reader a certain bias. I do not believe that how we cognizers talk of events and causation reveals anything metaphysically deep about the causal relation or causal *relata* themselves. That is to say, in what follows I try to abide by Prior's dictum that one should not "substitute for questions about entities questions about sentences about entities."[2] I will therefore ignore the massive piles of literature that have sought to establish this or that theory of causal *relata* or causation by appeal to some theory of how we speak about events or causation (in English!). A number of philosophers would applaud this approach. Consider these comments from distinguished metaphysicians who have worked on the metaphysics of causation and causal *relata*:

Roderick Chisholm

> Many contemporary philosophers have developed theories about the nature of events on the basis of theories about the nature of what would be an adequate semantics for describing events. The present theory is not of this sort. I find it

[1] Kim (1993b, p. 34).
[2] Prior (1968) as cited by Chisholm (1990, p. 422).

> very difficult to see how such a linguistic approach could throw any light upon the nature of nonlinguistic things-unless the linguistic or semantic theory that is proposed is itself derived from prior considerations about the kinds of things there are.[3]

David Lewis

> There is no guarantee that events made for semantics are the same as the events that are causes and effects.[4]

And with respect to causation Bigelow and Pargetter remarked,

> It is important to recognize that there is a bridgeable but problematic swamp lying between the metaphysics and the semantics of causation. And in offering a metaphysics of causation we are not pretending to solve all the semantic problems…As far as semantics is concerned, this causal relation is primitive…Our task is metaphysical, not semantic.[5]

With the above admission out of the way, I will now attempt to show, *contra* several philosophers, that causation is in fact a relation.

4.1.1 Is Causation a Relation?

Causation is always an obtaining relation. Both Lewis (2004b, p. 281) and Mellor (1995) (2004) disagree. Lewis affirmed that the void, a veritable absence of everything situated somewhere in the space-time manifold, can causally produce effects.[6] But since the void is an absence of everything, it cannot afford causal *relata*. Thus, when the void brings about some effect, it does so without entailing the obtaining of a relation. Therefore, causation is not always an obtaining relation.

---

[3] Chisholm (1990, p. 422).
[4] Lewis (1986a, p. 241).
[5] Bigelow and Pargetter (1990a, p. 102); (1990b, pp. 278-279).
[6] He stated,

> "[a] relation requires relata. The void affords no causal relata: There's nothing there at all, so there's nothing for events to happen to, so the void is devoid of events. And even if we allow causal relata to belong to other categories, still there would be none of them in the void—because there's nothing at all in the void." Lewis (2004b, p. 281)

We can justifiably reject Lewis's position for the very similar reason that led him to deny that causation is always a relation. Since the void is not any thing or any entity, it cannot have the causal powers attributed to it. The possession of such powers will require the exemplification of properties. But as I have argued in my prolegomena, exemplification is a relation, a relation that requires *relata*. Thus, the Lewisian void cannot stand in relations and so cannot have causal powers.

Mellor's argument for the thesis under consideration is more complicated. He (2004, pp. 318-319) believes facts are causes and effects, and that there are plausible criteria for factual properties and relations. According to those criteria, causation is not a factual relation. Causation is therefore not a relation.

The criteria to which Mellor appeals are:

(EC#1): For any property or relation P, P is factual, just in case, P contributes to a concrete particular's possession of causal powers.

(EC#2): For any property or relation P, P is factual, just in case, P is featured in fundamental natural laws.

If the arguments for necessitism in sect. 2.2 are sound, then they serve as defeaters for EC#2, since their soundness would entail that there really are factual modal properties not at all featured in the natural laws (*e.g.*, the modal properties possessed by possible rivers, and possible oceans etc.).

What of (EC#1)? Again, considerations in sect. 2.2 provide ways of escape. *Abstracta* that exhibit modal properties such as *being possibly a river* play no significant causal role. Their (the *abstracta*) modal properties do not contribute to their causal powers since abstract objects are causally impotent and therefore do not possess causal powers. Mellor's reasons for rejecting an understanding of causation that would treat it as

an obtaining relation and that would understand cause and effect as *relata* are unpersuasive.

Do I have any arguments for regarding causation as an obtaining relation? None that would be independent of the reasons for affirming my non-reductionist theory of causation. It is perhaps worth pointing out that virtually every theory of causation, whether reductionist, anti-reductionist, or primitivist, regards causation as an obtaining relation. What I consider to be a common sense interpretation of our everyday encounters with causal phenomena seem to involve causes relating to effects by producing them, influencing them, or changing them in some way. I conclude then that those who would seek to move us off the sound foundation of understanding causation as a relation have a significant amount of work cut out for them. None of the arguments in the literature for anything like such an unorthodox view are at all convincing.

4.1.2 How Many Relata?

Causation is a relation. Fine. How many *relata* does it afford? It is the business of this subsection to tackle that question head on.

4.1.2.1 A Three or Four-Place Relation?

Arguably, explanations invite contrast.[7] Arguably, causal statements do as well.[8] Many theoreticians admit to a strong connection between counterfactuals and causation. Counterfactuals are context sensitive (*i.e.*, their truth-values are at least in part determined by the context in which they are affirmed). It is therefore not surprising that for many of these self-same theorists, causal statements are

[7] See on this Hitchcock (1996, p. 398), and van Fraassen (1980).

[8] See on this Hitchcock (1996), Maslen (2004), Northcott (2008), Schaffer (2005), and Weslake (draft).

likewise context sensitive. Exploring both the ways in which causal claims invite contrast, and the ways causal claims are context sensitive, has been the project of many of the adherents of contrastive theories of causation. Contrastive theories typically imply a rejection of the thesis that singular causation is a two-place relation. Instead, contrastive theorists multiply the *relata* of causation, sometimes insisting that the relation is four-placed, with contrast classes of events relating in some way to the actual cause, the actual effect, and/or to another contrast class.[9]

The best way to ensure that causation is not a ternary or quarternary relation would be by arguing that contrastive accounts of causation are fundamentally mistaken. Let me then take aim at those contrastivists who would insist that causation is a ternary relation, and that causal statements have truth conditions of the following form:

> (32) Event *c* rather than *c** caused event *e*, just in case, were *c** to occur over against *c*, then *e* would not have occurred.

A causal statement will hold so long as the occurrence of any contrastive event counterfactually implies that *e* fails to occur. The problem is that this is the case no matter what *c* is. Thus, *c* can be considerably removed from *e*, and yet *c* can be accurately described as *e*'s cause. Consider,

> (33) Obamacare's passing rather than Justin's exploding last week, caused Justin's car accident.

Notice that the causal statement that is (33) comes out true given (32), since the following counterfactual is true:

[9] The relating sometimes involves single members of distinct contrast classes.

(34) Were Justin to explode last week, Justin would not have had a car accident.

Some contrastivists (perhaps Northcott (2008, p. 121)) would no doubt claim that despite the fact that (33) comes out as an unintuitive truth, no one would assert it as true, since it would be altogether irrelevant in a great many contexts of utterance.[10] But this response amounts to bullet biting. It remains true that according to the account, Obamacare's being passed caused Justin's car accident.

Now consider the following contrastive theory:

(35) *c* rather than *c** caused *e* rather than *e** if, and only if, were *c** to occur *e** would have occurred.[11]

The account runs into trouble if, as Schaffer maintained, the causal relation is "differentially transitive" (ibid., 340) (meaning that if *c* rather than *c** caused *e* rather than *e**, and *e* rather than *e** caused *z* rather than *z**, then *c* rather than *c** caused *z* rather than *z**). Consider the following adjustment of an example from Paul and Hall (2013, pp. 227-228):

(36) Justin's placing a live grenade at the entry of the barracks at *t* over against hiding a live grenade in the bushes at the entry of the barracks at *t* caused Brandon to defuse the grenade at *t*+1 rather than not defusing it at *t*+1.

Claim (36) is true since had Justin hid the grenade in the bushes, Brandon would not have defused the grenade; but of course, Brandon's defusing the grenade rather than not defusing it caused Kevin (a soldier in the barracks) to survive rather than not survive.

[10] *Cf*. the discussion in Steglich-Petersen (2012, p. 122).
[11] Schaffer (2005, p. 329).

Thus, by differential transitivity, it follows that Justin's grenade placement caused Kevin's survival, *reductio ad absurdum*.[12]

4.1.3 What are the *Relata* of Causation?

I have established that causation is a relation. I have also argued that contrastive theories of causation do not provide one with good reasons for believing that the singular causal relation is formally ternary or quarternary. There appear to be no good reasons then for rejecting the, default (and somewhat orthodox) binary view of the relation. But even with such matters settled, there is still the substantive metaphysical issue of how precisely to regard the nature of causal *relata*.

4.1.3.1 Substances and Agents

Some have argued that individuals and/or substances can stand in causal relations.[13] Such a view is constitutionally unable to explain why effects occur at the indices they do. If a substance or individual brings about causal effects, then why don't all of the effects that causal substance is responsible for occur exactly when that substance comes into existence? There should exist some change in the features of the substance that explains why the substance involved brings about the relevant effect. But

---

[12] Schaffer may accept this result, but it seems clear that it is counter-intuitive. We should remember Lewis's advice:

> "When common sense delivers a firm and uncontroversial answer about a not-too-far-fetched case, theory had better agree. If an analysis of causation does not deliver the common-sense answer, that is bad trouble." Lewis (1986c, p. 194)

and Hall's rule:

> "If an analysis of causation does not deliver the common-sense answer, that is some evidence—defeasible, of course—that something of importance has been overlooked." Hall (2011, p. 100)

[13] Byerly (1979); Chisholm (1966); Reid (1969); Taylor (1966); *cf.* the discussion in Ehring (2009, p. 391).

if that's right, then fundamental causal *relata* are more event or state of affairs-like than individual or substance-like.

Clarke (1996, p. 201) argued that substances causally produce their effects on account of, or by virtue of their exemplifying a property at some index. But again, that suggests that substances stand in causal relations because of the deeper fact that the state of their exemplifying a property stands in a causal relation to the requisite effect. Thus, if one maintains that substances stand in causal relations and that they do so by virtue of the causal potency of certain states of those substances then any and every time a causal relation obtains that relation involves symmetric overdetermination.

One might argue that persons understood as agents can causally produce effects. Usually motivation for invoking agents as causes stems from a desire to defend libertarian accounts of free will. For example, Thomas Reid (1969, p. 65) maintained that when the determination of the will is causally related to a primitive and irreducible object that is the agent itself, further effects/actions causally related to volition are to be regarded as the free productions of that agent. In fact, Reid seemed to think that agents, and agents alone, are causally efficacious entities. He wrote: "I am not able to form any distinct conception of active power but such as I find in myself….But, if there is anything in an unthinking inanimate being that can be called active power, I know not what it is, and cannot reason about it."[14] The determination of volition, or the realization or exertion of causal power, amounts to (for Reid) the obtaining of a causal relation the *relata* of which involves the agent and will.[15]

[14] Letter to Lord Kames, Reid (1967, p. 59), as quoted by O'Connor (2000, p. 45).

[15] There is substantial disagreement in the agent causation literature over what it is precisely that the agent causally produces. See the summary discussion of this issue in O'Connor (2002, p. 348).

Reid's account of agent causation is susceptible to the same criticism I lodged against the object/substance view of causal *relata*. The agent's determination of its volition must involve the exercise of some power or categorical ability. There must exist some change in the person or agent that produced the relevant effect. If there is no such change, if there is no difference made manifest in the agent which issues forth in the effect, then there does not appear to be a way for the agent causal theorist to explain why it is that the effect occurred at the index it did rather than as soon as the agent began to exist.

For Reid, events amount to entities coming into existence or beginning to exist.[16] But as I will argue in sect. 4.2.6, there are very good reasons for believing in the universality of causation with respect to such events.[17] Since the state of affairs involving an agent's determining its volition begins to exist, such states qualify as events with accompanying causes. But if events of this kind have causes, then it is completely unclear how agents can freely determine their volitions while at the same time be accurately described as the fundamental sources of their determinations. It seems that the entire motivation for Reid's particular agent causal theory is nullified by his theory of events coupled with universal causal determinism.[18]

The accounts of Campbell (1957), Clarke (1993) (2003, pp. 186-191), O'Connor (2000), Swinburne (1997), and Taylor (1992) are all likewise committed to the idea that

---

[16] Reid (1969, p. 87).

[17] Reid *affirmed* universal causal determination. He stated,

> "If the meaning of the question be, was there a cause of the action? Undoubtedly there was: of every event there must be a cause, that had power sufficient to produce it, and that exerted that power for the purpose." Reid (1969, p. 625)

[18] *Cf.* the discussion in O'Connor (2000, p. 49).

agents relate causally to events in some fundamental and irreducible way. Their accounts are therefore inadequate for the same reasons Reid's was found wanting.

Before moving on, I should note that there is a cost of agent causation theories that is very rarely pointed out.[19] Every theory of agent causation presupposes that agents endure through time. Such a presupposition is incompatible with perdurantist accounts of time and persistence. This is because perdurantism entails that presently existing agents are mere temporal parts of four-dimensional wholes.[20] They are not wholly present at any one moment of time, as endurantism would demand. Perdurantism and endurantism are inconsistent.[21] Thus, theories of agent causation imply the truth of endurantism with respect to agents, and so also the falsity of perdurantism.

4.1.3.2 Events

4.1.3.2.1 Brand, Davidson, Lemmon, and Quine: Events as Concrete Particulars

W.V.O. Quine said that "[p]hysical objects…are not to be distinguished from events, or…processes. Each comprises simply the content, however heterogeneous, of some portion of space-time however disconnected or gerrymandered."[22] A physical object for Quine is one that is "the material content" of some region of space-time.[23] E.J. Lemmon (1967, p. 99) held a similar view. He said that, "…we may invoke a version of the identity of indiscernibles and identify events with *space-time zones*."[24] For Lemmon

[19] O'Connor (2002, p. 341).
[20] Lewis (1986b, p. 202); cf. the discussion in Sider (2001, pp. 68-73). For a defense of perdurantism see
[21] See Merricks (1994, p. 167).
[22] Quine (1960, p. 131).
[23] Quine (1985, p. 167).
[24] Lemmon (1967, p. 99).

then, two events are identical just in case they occur at the same time and at the same place.[25]

Quine and Lemmon were mistaken. Given space-time substantivalism, Quine's underlying theory of physical objects entails that space-time itself is not a physical object since space-time does not reside in a region of space-time. However, space-time is a physical object. Even if we leave Quine's theory of physical objects untouched we will find shelter from the above views by recalling Davidson's example of a spinning ball. The event that is the spinning of a ball does not appear to be identical to the event of the ball's heating up—though in actuality—the two events sometimes coincide with respect to spatio-temporal location.[26] And as Quine (1985, p. 167) pointed out, the event that is the ball's heating up transpires slowly while the event that is the ball's rotating transpires quickly. If the two events are really identical, how can that one event transpire both slowly and quickly?[27]

While still insisting that events are physical objects, Myles Brand (1977, pp. 333-334) attempted to ameliorate Lemmon's individuation conditions for events by positing that two events e_1 and e_2 are identical, just in case, necessarily, for any space-time region r, e_1 occurs within r if, and only if, e_2 occurs within r.[28] Notice that Brand's account of the individuation conditions of events is not susceptible to Davidson's spinning ball case since the ball may spin and yet fail to heat up.

Another view in the tradition of analyzing events in terms of physical objects is that of Donald Davidson's. He argued that events "are concrete occurrences" which are

---

[25] Ibid., 98-99.
[26] Davidson ([1980] 2001a, pp. 178-179).
[27] See also Cleland (1991, p. 229) for a similar counter-example.
[28] Brand (1977, p. 334) does add that locutions used to pick out events e_1 and e_2 be rigid.

themselves particulars that are located in space and time.[29] One individuates an event e by appeal to its effects and causes. Thus, e_1 and e_2 are identical just in case e_1 and e_2 produce the same effects and have the same causes. Davidson dismissed the idea that e_1 and e_2 could be without a cause since he was a staunch advocate of the universality of causation.

While the accounts of Brand and Davidson avoid the spinning ball counter-example, all of the aforementioned theories suffer from the following problem: I argued in sect. 2.3 that it is possible that a non-corporeal mind formed a belief. If that's right, then there could be an immaterial concrete object, which by participating in a causal *relatum* causally produces an event (the formation of a belief). If causal *relata* are events and there can be events—the individuals of which—fail to reside in regions of space-time, then events themselves cannot reside entirely in space-time. But Brand, Davidson, Lemmon, and Quine demand that we analyze events in such a way that they are physical spatio-temporal entities. Thus, if there could be mental causation of the type that involves immaterial minds, then the aforementioned accounts of causal *relata* are false.[30]

Readers intolerant of my appeal to the possibility of an immaterial mind for the purposes of criticizing theories of events would do well to remember that Brand (1977), Cleland (1991, p. 252. n. 11), Davidson (1985, p. 173), and Strawson (1959, pp. 59-86) all took seriously the possibility of there being events which do not feature as constituents physical objects (though the events themselves may be perfectly natural), with Cleland

[29] Ehring (2009, p. 388). See Davidson ([1980] 2001).

[30] It is worth highlighting that both Quine and Davidson admitted that their accounts of causal *relata* are problematic. At the end of the day, Quine (1985, p. 167) opted for the analysis of Jaegwon Kim, and Davidson (1985, p. 175) admitted defeat at the hands of Quine (1985).

Also, Davidson's account seems to be incompatible with an understanding of causation which treats that relation as formally transitive. See on this thought Ehring (1997, pp. 76-77); and Paul (2004, pp. 209-210).

and Strawson both taking seriously the possibility that there are events at worlds at which there is no spacetime manifold.

4.1.3.2.2 Goldman, Kim, Martin, and Wilson: Events as Property Exemplifications

A number of philosophers have argued that events are property exemplifications at times.[31] As Kim famously put the position:

> An event or state can be explained as a particular (substance) having a certain property, or more generally a certain number of particulars standing in a certain relation to one another.[32]
>
> We think of an event as a concrete object (or *n*-tuple of objects) exemplifying a property (or *n*-adic relation) at a time. In this sense of 'event', events include states, conditions, and the like, and not only events narrowly conceived as involving changes.[33]
>
> Events, therefore, turn out to be complexes of objects and properties, and also time points and segments, and they have something like a propositional structure; the event that consists in the exemplification of property P by an object x at time t bears a structural similarity to the sentence 'x has P at t'.[34]

Jaegwon Kim's account of events includes discernible identity conditions for them. According to those conditions, the event of I's having P at t, or the triple {I, P, t} is identical to another event I*'s having P*, at t*, or the triple {I*, P*, t*}, just in case, I = I*, P = P*, and t = t*.[35] Now let the event of I's having P at t, be E. It follows from Kim's identity conditions that E cannot have constituents other than P, I, and t, for if it did, E would not be identical to E. Thus, no matter what world you move to, if E occurs at that world E must feature I, P, and t (on the uncontroversial assumption that identity is a

[31] See also Goldman (1970); Martin (1969); Wilson (1974).
[32] Kim (1966, p. 231).
[33] Kim (1973c, p. 222).
[34] Ibid.
[35] Kim (1976, p. 161); *cf*. Simons (2003, p. 365, *cf*. p. 375).

necessary relation) as constituents. Thus, Kim's structured complex view of events entails that events have their constituents essentially.

Perhaps the move from Kim's view of events to essentialism for events is flawed. Assuming there are world-indexed properties (*e.g.*, Bubba's being the Master's champion in-@ the actual world), couldn't we say that E's having some other property F as a constituent at a possible world W amounts to nothing more than E's "being such that, if W had obtained", E "would…have"[36] had F as a constituent? But notice that by Kim's identity conditions for events, the event at W with F as a constituent is no longer E. That event (call it E_2) fails to be identical to E not by virtue of being located at a different world and thereby having different world-indexed properties (reminiscent of some objections to transworld individuals), but rather by having a different constituent. (We must distinguish between 'P', the property that is a constituent of an event, and properties the event itself exemplifies.) E_2's having the property of being such that it has F as a constituent entails that F is a constituent of E_2. But E_2's having that constituent entails that E_2 is not identical to E. So E simply cannot bear the property of being such that, if W had obtained, E would have had F as a constituent, for having F as a constituent yields straightway a distinct and different complex that is a Kimian event.

Cleland (1991, p. 230) has articulated what I consider to be a successful objection to Kim's account. Her key point is that Kim seemed to have required that the individuals featured as constituents of events are physical objects. She pointed how certain fluctuations in electromagnetic and gravitational fields do not appear to involve physical individual objects and yet should be correctly characterized as events. She also notes how

[36] Plantinga's wording in (2003, p. 150). I am not necessarily suggesting that Plantinga would advocate the above response.

P.F. Strawson's no space world countenances events without physical individuals and that that world seems perfectly metaphysically possible. With all of this I agree, though I believe that something like the property exemplification view remains mostly correct. Adjustments can be made so as to avoid this criticism (see sect. 4.1.4 below).

4.1.3.2.3 Chisholm (and Tooley): Events as States of Affairs

Earlier on, Chisholm sought to blur the line between events and propositions. There are, for example, negations of propositions, and since events recur, Chisholm thought that there are negations of events that occur when positive events fail to occur. Thus, if e recurs, then e occurs, and ~e occurs.[37] There are conjunctive propositions, and so there are also conjunctive events such that an event p occurs when event q occurs, and this results in event p & q's occurrence.[38] There are, however, some ways for events and propositions to come apart.[39] Events never succeed their negations unless something produces a change, or some entity ceases to exist or begins to exist. Every individual is such that during any differing moments of its existence it has "some properties at the one moment it does not have at the other…" (ibid., p. 17) Nothing can enjoy intermittent existence. These assumptions rule out the possibility of eternal recurrence.

Chisholm (1970, p. 20) maintained that events and propositions are both types of states of affairs. Propositions are essentially states such that either they or their negation fails to occur, and so they are "states of affairs which" are "necessarily such that either" they or their "negation always occurs."[40] Notice that the truth of a proposition is nothing

[37] Event ~e is not the event that it is not the case that e, but the event that not-e occurs.
[38] Chisholm (1970, p. 16).
[39] See the discussion in Chisholm (1970, p. 16).
[40] Chisholm (1970, p. 20), (1971, p. 179).

above and beyond that proposition's occurring.[41] Those *contingent* states of affairs for which it is possible that it and its negation occur are events.[42] And so, for the early Chisholm on events, there are also states of affairs, which obtain or occur and are neither events nor propositions (his example is "Jones' automobile being in his garage"[43]).

Later, Chisholm (1989, pp. 152-153) would amend his definition of events. While still understanding events to be states, they were no longer contingent states for which it is possible that they and their negation occurs. Rather, events became states which involve individuals (where sums or aggregates of individuals are themselves individuals) exemplifying properties, where the properties in question are (a) possessed contingently, (b) "temporally denumerable" and (c) such that individuals are the only types of entities that can bear them.[44] The (1989) account is noticeably similar to that of the property exemplification view just discussed.[45]

Once one passes on to Chisholm's mature corpus (1990, 1994, 1996) one sees a very specific property exemplification account that reduces events to states involving contingent substrates contingently exemplifying properties, where it is understood that substrates may be individuals *or* events themselves.[46] Like Kim, Chisholm is careful to note that one should never confuse the constituent or content property of an event with properties, which the events themselves exemplify. he (1990, pp. 422-423) also acknowledges what was shown above to be a consequence of the property-exemplification view, that events have their constituents essentially (*i.e.*, their properties

[41] See Chisholm (1970, p. 21) noting there that this view of truth was advocated by the likes of Bolzano, Meinong, and Husserl.

[42] Chisholm (1971, pp. 179-180).

[43] Chisholm (1971, p. 180).

[44] Chisholm (1989, p. 152).

[45] Chisholm (1989, p. 155. n. 2) points this out, citing Kim (1976). In fact, Chisholm's identity conditions for events are noticeably similar to those of Kim's (see Chisholm (1996, p. 78)).

[46] Chisholm (1990, p. 419); Chisholm (1994, p. 504); Chisholm (1996, p. 77).

and their substrates), though importantly Chisholm does not admit times into events as other advocates of the property exemplification view do.[47]

4.1.3.2.4 Lombard and Cleland: Events as Changes

Lawrence Lombard (1986, p. 178) has said that changes are movements of physical objects "at an interval of time in a quality space", and that causal *relata* just are such changes. The view has two problems. First, the theory privileges the physical. Mental causation of the kind I described in sect. 2.3 is perfectly metaphysically possible, and so causal *relata* cannot be properly reduced to changes in movements of physical objects in space. Second, as Cleland (1991, p. 232) notes, Lombard's theory cannot countenance "objectless events such as disembodied shrieks and flashes."

Following Aristotle (*Physics*, Book VI[48]), Carol Cleland (1991) has tried to revive the change theory of causal *relata* by enriching it with the metaphysics of existential conditions.[49] Existential conditions are those entities that undergo changes. They are non-recurring phases, or states, where phases are determinable properties, and states are determinate properties (the values of determinable properties).[50] Those existential conditions, which are events, are concrete phases. Concrete phases are themselves

---

[47] Michael Tooley (1987, pp. 252-254), (2003), (2009, p. 384) seems to go in for a state of affairs account of causal *relata* as well.

[48] Aristotle wrote,

> "With regard, however, to the actual subject of change—that is to say that in respect of which a thing changes—there is a difference to be observed. For in a process of change we may distinguish three terms—that which changes, that in which it changes, and the actual subject of change, e.g. the man, the time, and the fair complexion." (*Physics*, Book VI 236[b])

[49] Cleland (1991, pp. 232-242).

[50] Ibid., p. 233. Cleland (ibid.) assumes that "determinable properties are not" properly reducible "to determinate properties". We received the determinate/determinable distinction from Johnson (1921).

instances of phases (*i.e.*, they are determinable property instances or tropes).[51] More specifically, contingent determinate properties are borne by property instances of determinable properties. That is to say, changes are the determinate properties of concrete phases. Some such changes are repeatable and some are not. The former are generic whereas the latter are concrete.[52] While Cleland's treatment of generic changes is interesting, I will focus my attention exclusively on concrete changes since she defines events in terms of them.[53] We would do well then to present her formal definition of concrete changes:

> (**Concrete Changes**): "A concrete change R is a pair {x, y} such that x is the exemplification of a state s by a concrete phase CP at a time t and y is the exemplification of a state s' by a concrete phase CP' at a time t', where (i) t is earlier than t'; (ii) CP is the same concrete phase as CP', and (iii) s is not the same state as s'."[54]

Events can therefore be accurately described or represented as pairs {[concrete phase CP, initial state s, time t], [concrete phase CP, terminal state s', time t']}, where it is understood that the brackets denote a relation of exemplification, CP = CP, t' > t, and s ≠ s'.[55]

Cleland's account is truly brilliant, and its benefits are legion. The problem is that the account yields one particular strange result. Slightly adjusting a case from Ehring (1997, p. 87), note how an object o_1 can exemplify a determinable property F at a time t. On Cleland's metaphysic one would thereby have a concrete phase (call it CP*). That phase can itself exemplify a state or determinate property G, at t as well. Suppose though

---

[51] Cleland (1991, p. 235).
[52] Ibid., p. 238.
[53] Ibid., p. 245).
[54] Ibid., p. 238) I have changed Cleland's formatting.
[55] Ibid., p. 245).

that the underlying concrete phase continues to exemplify G at a time t' that is later than t. Now because the states of the concrete phase are the same, and because the concrete phase itself does not change as it persists from t to t', there fails to exist an appropriate pair of concrete phases exemplifying differing states and initial and terminal times. Thus, there can be no causal *relata* present in this imagined case, and so no causation. But as Ehring (1997, p. 87) would point out, CP* at t' would seem to have a cause *viz*., CP* at t, since CP* at t' counterfactually depends upon CP* at t, and these two phases at their respective times are probably lawfully related to one another. Thus, "[t]he presence of these fallible indicators signals a causal connection. Hence we ought to assimilate these cases to the causal realm."[56] If Ehring's judgment is correct, then we cannot maintain that concrete changes are the exclusive *relata* of the causal relation.[57]

4.1.3.2.5 Bennett and Ehring: Events as Tropes

Jonathan Bennett (1988, p. 88 *cf*. p. 90, p. 128, p. 156) has argued that causal *relata* are property instances or tropes at zones or regions of space-time.[58] There is, of course, much more to say about the account but there is no need to get into further details since the view delivers the verdict that it is impossible for there to be the type of mental causation adumbrated in sect. 2.4 above. If events just are tropes of regions of spacetime,

---

[56] Ehring (1997, p. 87).

[57] The objection here may require the falsity of certain perdurantist theories of persisting objects. It seems to me that such theories of persistence are not necessarily true if true (the physics of time could be very different), and so the above picture may very well be possible. If it is possible, then Cleland's account of causal *relata* remains too narrow.

[58] He seems to also (see Bennett (1988, p. 117)) think that property instances themselves are best understood as a zone's possessing a property. Thus, substances are not the sole entities that bear properties zones do. This supposition is incompatible with sect. 2.1 of the prolegomena above. I should add here that Ehring (1997, p. 85) is reluctant to judge Bennett's account as a truly trope theoretic one since the particularized properties themselves do not do the causing, instances of such properties do. If, however, tropes just are such instances, then it seems to me that the tropes do the causing.

The idea that tropes are causal *relata* goes back to Keith Campbell (if not further) who said, "…the terms of the *causal* relation are always tropes" Campbell (1990, p. 22 emphasis in the original). Cleland's (1987) work on tropes as causal *relata* also antedates Bennett's.

then a non-physical, non-corporeal mind's forming a belief cannot occur, since there cannot be a causally efficacious event of there being such a mind existing in some state which produces a belief. However, I've detailed precisely why we are justified in maintaining that such causation is possible, and so the account is flawed. Second, Cleland (1991, p. 245) has argued that Bennett's account precludes event occurrences at Strawson's no-space (or purely auditory) world. Once again the account says of what seems plainly possible, that it is impossible.[59]

Douglas Ehring (1997, pp. 71-115), (2009, pp. 389-390 and pp. 406-407) maintains that causal *relata* are property instances understood as persisting tropes. He said, "causal relatum…consist in a 'trope at a time', the existence or presence of an enduring trope at a time and location."[60] Ehring motivates his account of causal *relata* by way of his persistence theory of causation. There appear to me to be four problems with Ehring's theory. First, if the theory holds, then tropes can endure through time, and so the theory is true only if perdurantist theories of persistence are false.[61] Second, Ehring's underlying theory of tropes is at odds with the metaphysics of substances and universals explicated in sect. 2.1 above. Third, Ehring's theory of causation is squarely within the reductionist camp even if it involves a singularist element (*viz*., trope persistence). I have already sought to undermine motivating reasons for believing that causal facts reduce to

[59] In fact, she would go on to say that Bennett's account is not "able to countenance Cartesian mental occurrences as events." Cleland (1991, pp. 245-246).

[60] Ehring (2009, p. 407).

[61] Ehring remarked,

> "…tropes do not have temporal parts, and their persistence from t to t' consists in their existing wholly at t and t'. This position has similarities to nonrelational views of physical object identity over time, according to which physical objects do not have temporal stages (are not four-dimensional space-time worms) and are wholly present at each moment of their existence." (1997, p. 100)

Despite the fact that the above seems to improperly mix worm-theoretic accounts of perdurance with stage theoretic accounts, its clear that Ehring's enduring tropes are incompatible with either conception.

non-causal facts, and so Ehring's theory is in that sense deficient. Lastly, Ehring's theory of causal *relata* includes no substantial statement of the identity conditions for events, and that which Ehring does say about the nature of such *relata* seems to preclude the very possibility of there being the event that is the world cup championship match, or the superbowl, or the Master's tournament. As Helen Beebee has stated, "…Ehring's view that tropes are causal relata runs counter to the strong intuition that causes and effects are generally, or at least often, multi-featured events like parties, wars and chess championships."[62]

4.1.3.2.6 Lewis: Events *as Sets* of Space-Time Regions

According to David Lewis (1986a, 1986b) events just are properties of regions of space-time. But properties are classes for Lewis, and so events are sets of space-time regions.[63] The proper parts of events exist in sub-regions of the spatiotemporal region at which the events themselves occur. The relationships between events and their constituents are mereological and entire events may be mereological proper parts of others. Events also stand in logical relations. One event e_1 can imply another event e_2 in that necessarily if e_1 occurs at region R, e_2 occurs at region R.[64] No event ever recurs in two separated expanses of the actual world, and every event "occurs if and where and when there is a region that is a member of it".[65] Lewis also maintained that events have

[62] Beebee (1998, p. 183).

[63] He said, "I propose to identify an event with the set of spacetime regions where it occurs." Lewis (1986b, p. 84, cf. p. 95).

[64] Lewis (1986a, p. 255).

[65] Lewis (1986a, p. 245).

essences, and that these are merely conditions which some expanses of the actual world satisfy so as to ensure that the relevant events occur there.[66]

There are three problems with Lewis's account. First, (and again) it requires class nominalism, but class nominalism is false (see my objections in sect. 4.1.3.5 below). Second, the view predicates events ("predicates" because events are properties) to spacetime regions solely. Events only ever inhere in physical spacetime regions. But once again it is perfectly possible that there be an immaterial mind that formed a belief. This objection is particularly forceful since Lewis never provides any arguments for his theory of events.[67] Third, the view treats events as *abstracta*. Lewis seemed to be aware of this. Note his remarks in (1986a, p. 84):

> Is it true that sets or universals cannot enter into causal interaction? Why shouldn't we say that something causes a set of effects? Or that a set of causes, acting jointly, causes something? Or that positive charge causes effects of a characteristic kind whenever it is instantiated? Many authors have proposed to identify an event—the very thing that most surely can cause and be caused—with one or another sort of set….Must any identification be rejected, regardless of the economies it may afford, just because sets are supposed to be 'abstract'?

The above excerpt should give anyone pause. Abstract objects do not stand in causal relations. Lewis agrees, but seems to be willing to give up the almost obvious truth that sets are *abstracta*.[68] I believe Lewis owes us a story about why it is that sets aren't abstract, for one would have thought that if any entities are of that category sets are.

---

[66] Lewis (1986a, p. 247). I should add a little known point. Lewis believed that all events have causes (ibid., p. 242).

[67] In neither Lewis (1986a) nor (1986b) does Lewis provide supporting argumentation for his view of events. He seems think that its merits hang on how well it gets along with a counterfactual theory of causation (which incidently was refuted by Schaffer (2000)).

[68] As Rosen in the SEP admitted, "[t]o strike a theme that will recur, it is widely supposed that sets and classes are abstract entities—even the impure sets whose urelements are concrete objects." Rosen (2012, sect. 3).

4.1.3.3 Facts

4.1.3.3.1 Koons and Facts

Leaning on Barwise and Perry (1983), Robert Koons (2000, pp. 31-43) has adumbrated a theory of causal *relata* understood as "worldy"-facts. Koons-style facts not only obey a three-valued non-classical logic but they also obey the axioms of classical extensional mereology (CEM) (ibid., 37).[69] I described Koons's facts as "worldy" because they are not true propositions, but rather obtaining concrete states which serve as the truth-makers for true propositions. Because facts obey the axioms of CEM there exists a sum of all facts (he calls this "the world", I will call it the "world-fact"). The world-fact serves as the truth or falsity maker of every proposition. In addition, because CEM is relevant to an evaluation of facts, the world-fact has proper parts. These proper parts when considered do not make true or false every proposition when they are considered *in toto*. Koons believes this is precisely why a proper logic of facts must be three-valued (admitting gluts). (Notice that the core of the theory drives Koons to embrace a non-classical logic of facts.)

Situations or worldy-facts are states of affairs. They involve individuals having properties and/or standing in relations. Koons' theory of causal *relata* is therefore unable to afford events that do not feature individuals (Cleland's shrieks and flashes). Moreover, because the heart of the theory commits one to a three-valued logic of facts, the view commits one to a type of logical pluralism (at best), for while a proper logic of

[69] Koons is not alone in understanding causal *relata* along these lines. Bo Rode Meinertsen (2000, pp. 173-175) distinguished between I-facts and S-facts, understanding the former in terms of true propositions (abstract objects), and the latter in terms of truth-makers for true propositions (citing Armstrong (1997)). Meinertsen maintained that some S-facts amount to events that can therefore stand in causal relations. Likewise, Mackie (1980, p. 265) urged that there were two types of causes, explanatory and productive. He understood the former types of causes to be fact-like. Unfortunately both authors failed to explore in great detail the fundamental metaphysical nature of such entities (though Meinersten (2000, p. 175) flirts with a property instance metaphysic of S-facts).

propositions maybe classical, a certain sphere of inquiry (*viz*., that which concerns itself with facts) requires an altogether different logic. But, I have argued in sect. 2.2 above that logical pluralisms of this variety are false. Agreeing with Priest, logical monism is preferable. Lastly, Koons' theory of facts holds only if truth-maker theory holds. Why? Well, Koons' motivation for affirming a three-valued logic of facts just is the admission that proper parts of the world-fact fail to make true or false a distinctive set of propositions, though the world-fact makes true or false every proposition. There are, however, well-known difficulties with truth-maker theory.[70]

4.1.3.4 Values of Variables

4.1.3.4.1 Woodward

James Woodward (2003, pp. 38-45) insists that the *relata* of causation are the values of certain variables.[71] With respect to type causation, the relationship between variables and their values is the same relationship that holds between determinables and determinates. Values themselves are therefore property-types exemplified by "individuals or units" (ibid., p 39) in circumstances or situations.[72]

Now the variable talk helps Woodward provide an interesting non-reductive account of type-causation understood in terms of the manipulation of variables. This chapter is concerned, however, with singular physical explanation and singular token causation. Fortunately, Woodward has an account of singular token causation that also attempts to use the values of variables as the *relata* of such a relation. The aforementioned account of the metaphysics of the values of variables then applies *mutatis mutandis* to Woodward's account of singular token causation (for which see ibid., p. 84).

---

[70] See Merricks (2007).
[71] The view is espoused by Eagle (2007, p. 165) as well.
[72] Others adhere to an account like this. See, *e.g*., Spirtes, Glymour, and Scheines (2000).

For Woodward, singular token causation involves a relating of the actual or real values of variables in some circumstance. Thus, it seems that with respect to obtaining causal relations, what is related are individuals exemplifying properties in circumstances where such property exemplifications are understood as the values of variables. The variable talk is pragmatically and theoretically useful talk since it helps one speak at more general levels about both token and type causation.[73] Since I have already discussed the property exemplification account of causal *relata* I will say no more about variable theories.

4.1.3.5 Property Instances: Paul

According to L.A. Paul (2004, 2007) property instances understood as "thing-property pairs such that the property is had by the thing" are ***the*** *relata* of causation.[74] Understanding property instances in such a way that they become the *relata* of the causal relation suggests that they bear a certain affinity to property-exemplifications except that they need not involve individuals (since Paul (2004, p. 212) maintains that the property instance that is "being performed with the left hand" is an event itself). Property instances are admittedly spatio-temporal,[75] and while Paul does not commit to any one view of such instances, she is open to understanding them in terms of (a) tropes, (b) exemplifications of universals, or (c) collections of concrete particulars.[76] Notice that

[73] Ehring (2009, p. 392) also observes that the actual value of variables account reduces to some other account of causal *relata*.

[74] Paul (2004, p. 213). *Cf.* Paul (2007, p. 280 "[i]n Paul 2000, I argue that it is best to take property instances as ***the*** causal relata." emphasis mine).

[75] "Aspects [Paul's name for property instances] are things that correspond one to one with thing-property pairs such that the property is had by the thing; so aspects are in an important sense part of the spatiotemporal world." Paul (2000, p. 213).

[76] Paul (2004, p. 213).

because property instances are spatio-temporal, the universals referenced in position (b) must be immanent.[77]

Paul believes that her account surpasses that of Kim's (1973a etc.) since it does not succumb to counter-examples involving transitivity. Vanessa drafts her paper by writing only with her left hand, and her paper is then accepted for publication by a famous journal. She does this because she was injured in an unfortunate skiing accident. This causal chain involves Vanessa's being injured in a skiing accident, Vanessa's composing her paper with her left hand, and Vanessa's publishing her paper. Given Kim's view of events as property exemplifications, the skiing accident is a cause of Vanessa's publishing her paper *since the latter event counterfactually depends on the former*.[78] On Paul's account, however, the skiing accident causes an instance of the property of "being performed with the left hand" (ibid.), though that latter property instance does not causally produce Vanessa's publication event.

What the above example shows is that Kim's analysis of events is incompatible with counterfactual theories of causation, given that the causal relation is itself transitive.[79] This is important because the theory on which Paul's counter-example relies is a counterfactual theory. Proponents of the property-exemplification view who are realists about causation need not necessarily worry too much about her specific objection. Still, what is wrong with broadening one's view of what can serve as proper causal *relata* to include property instances? Well, suppose that property instances are tropes, where tropes are thought of as particularized properties bearing primitive resemblance relations

[77] Armstrong, at least at one time (see his 1997), argued that universal's are physically located where they are instantiated.

[78] The example is from Paul (2004).

[79] See Kim (1973b), (1974), and Lewis admits this in (1986b, p. 242; *cf.* pp. 249-250 citing Ken Kress for some of the points made there).

to other tropes (so as to account for similarities between particulars).[80] On such a supposition, my coffee mugs being red amounts to it's having a red trope (say red_1). My coffee mug is partially similar to my pencil holder, since each object has a trope that stands in a fundamental resemblance relation (my pencil holder has red_2). Thus, the similarity of the two objects is explained by the possession of resembling tropes.[81] Notice that the trope theorist is explaining the similarity of the two objects—the redness of tropes red_1 and red_2 if you will—by way of a fundamental resemblance relation. Such a maneuver is very much akin to one made by the resemblance nominalist, for consider the following excerpt from Armstrong (1978, p. 44):

> Consider a number of things which 'have the same property'. It follows that they all resemble each other, in some degree at least. The resemblance may appear to flow from this common property. But we [speaking from the perspective of the nominalist for deliberation purposes] can instead try taking the resemblance as primitive and analyse 'the common property' in terms of the resemblance which the particulars bear to each other. The foundation of our sortings and classifyings will then be found in 'the similitudes of things'.

Notice that the resemblance nominalist who does not believe in tropes, explains similarity among particulars not by shared properties or universals, but by a primitive resemblance relation. The realist who grants the trope theorist the existence of tropes will ask the trope theorist how she accounts for the similarities of tropes. In response, the trope theorists will insist that red_1's being similar to red_2 (for example) is explained by a primitive resemblance relation, just as the resemblance nominalist would account for the fact that my mug is partially similar to my pencil holder by appeal to a primitive resemblance relation. Thus, at the level of tropes, the trope theorist is susceptible to exactly the same

[80] As in Williams (1953).
[81] ibid.

criticisms the resemblance nominalist is susceptible to though at the level of concrete particulars.[82,83]

My objection to trope theory was aimed at a hypothesis that is not outfitted with bundle theory. For if objects just are bundles of tropes, then it will be very natural to explain the fact that my mug is similar to my pencil holder *via* the similarity of the tropes they possess, since my mug and my pencil holder just are bundles of tropes. A trope theory of this kind will just collapse into resemblance nominalism, for this kind of trope theory is only committed to the existence of tropes, and so resemblance relations will only obtain with tropes as their *relata*.[84] But now trope theory becomes susceptible to two different classes of objections, *viz*., those against resemblance nominalism and those against bundle theory (for which *q.v*. chapt 1 above).

Suppose that property instances are collections or sets of individuals. On that supposition, a radical essentialism is born. Sets have their members essentially. My mug's being red amounts to it's being a member of the collection of red things. But my mug could have failed to exist, and at the world at which every other red thing exists save my mug, nothing would really have redness, for that unique set would fail to exist.

Second, consider the fact that if property instances are sets of particulars, then the following principle holds:

g is F iff g is a member of the class or set of F-particulars.

The class or set to which g belongs must be an abstract object of some sort, for it cannot be the mereological sum of the members of the respective class (as Armstrong (1978, pp.

---

[82] Tropes are not concrete. See Maurin (2014).

[83] For damaging criticisms of resemblance nominalism see particularly Armstrong (1978, pp. 49-57).

[84] This is precisely what Keith Campbell did.

29-30) made clear).[85] If you do not believe in abstract objects, then the ontological commitment here is a cost. But more importantly two classes are identical, just in case, their members are identical. But if that's right, then class nominalism faces a well-known problem of companionship, for it is perfectly metaphysically possible that there be two distinct properties that are necessarily coextensive, *a fortiori*, there actually are distinct necessarily coextensive properties. Consider Derek Parfit's (2011b, p. 297) example of the property of /*being the positive square root of*/ four, and the property of /*being the only even prime number*/. These two properties are clearly necessarily coextensive though they are also clearly not identical.[86] Following Moreland (2001, p. 31), we note how with respect to closed geometric figures, the property of being trilateral is necessarily coextensive with the property of being triangular, though the two are distinct properties. If one were to fiercely insist that necessary coextensionality of properties yields the identity of those two properties, then (as Shafer-Landau pointed out (2003, p. 91)) the property of being identical and the property of being necessarily coextensive would come

---

[85] Here is an argument for just such a conclusion that leans on Armstrong (1978a, pp. 29-30):

(1): If class nominalism is true, then both (a) ζ is a fleet iff $\zeta \in$ the class {fleets} and (b) μ is a ship iff $\mu \in$ the class {ships}. [Premise]

(2): The mereological sum of all fleets is identical to the mereological sum of all ships. [Premise]

(3): Assume class nominalism, and that both (c) the class {fleets} is identical to the mereological sum of all fleets and (d) the class {ships} is identical to the mereological sum of all ships. [Assumption]

(4): Therefore, the class {fleets} is identical to the class {ships}. [(2) and (3(c),(d)) by the substitution of identicals]

(5): Therefore, ζ is a fleet iff $\zeta \in$ {fleets} and μ is a ship iff $\mu \in$ {ships}. [(1), (3) by simplification and modus ponens]

(6): Therefore, ζ is a fleet iff $\zeta \in$ {ships}. [by (4), (5) by simplification and substitution of identicals]

(7): Therefore, if class nominalism is true, and (c) and (d) hold, then ζ is fleet iff $\zeta \in$ {ships}. [(3)-(6) by Conditional Proof]

The conclusion that is (7) clearly illustrates the absurdity of combining class nominalism with the thesis that classes are identical to the mereological sums of their members.

[86] He said, "[b]eing the only even prime number cannot be the *same* as being—or be *what it is* to be—the positive square root of 4" Parfit (2011b, p. 297) emphasis in the original.

out identical. But that's clearly absurd. As Shafer-Landau stated, "[i]t seems that we are referring to different features when we assert the existence of an identity relation, as opposed to one of necessary coextension."[87] Moreover, one's insistence on such a relationship between coextensionality and identity entails that if there were properties which everything necessarily had, then those properties would be identical (this is Majors' (2005, p. 488) point). Thus, the property of being self-identical, and the property of being a member of one's own singleton set would be identical. The property having one's own haecceity, and the property of existing would be identical as well. These results count as costs.

If property instances are exemplifications of immanent (physical) universals and property instances are the sole *relata* of causation, then all obtaining causal relations involve causes that are spatiotemporal events. However, I showed in sect. 2.3 that it is perfectly possible that there be an unembodied mind that mentally causes the formation of a belief. Thus, property instances understood as exemplifications of immanent universals cannot the *relata* of the causal relation.

4.1.4 A New Account of Events

A proper account of the *relata* of causation must afford the possibility of non-physical substances. It must also anticipate certain desiderata we have on obtaining causal relations. It should therefore allow for the possibility that two states which differ only with respect to the times at which they obtain stand in causal relations though there has been no substantial change to their contents at these times. One's account should avoid the explosion of event reality so as not to incur the cost or charge of ontological

[87] Shafer-Landau (2003, p. 91).

extravagance, and it should not be so narrow so as to be of no use to the sciences. I therefore offer the following analysis of events:

> (37) Necessarily, for any *x*, *x* is an event, just in case, *x* is the state of a substance or mereological fusion of two or more substances contingently exemplifying a universal or standing in a relation at a time or interval of times.[88]

The above is indebted to property exemplification, fact (in the truth-maker sense), concrete states of affairs, change, and property instance theories of events. However, I think (37) outperforms the aforementioned theories. Again, consider the fact that there could be an immaterial mind that formed a belief. If that is a real possibility, then immaterial substances can participate in causal *relata*. But (again) if that's right, then Paul's (2004), (2007) property instance account is false since she understands such entities to be essentially spatio-temporal.[89] (37) allows for there to be events involving non-physical individuals. Second, the view allows for the possibility that there are two distinct events at different times though the same substance exemplifies the same universal at those respective times. There can therefore be causation between static events (*contra* Cleland (1991) and Lombard (1986) *cf*. the argument in Ehring (1997)). Third, the account that is (37) allows for there to be supposed individualless events such as Peter Strawson's (1959, pp. 59-86) shrieks and flashes (*cf*. Cleland (1991, p. 231)). My account is therefore consistent with Strawson's no-space or purely auditory world though the accounts of Chisholm (1990), Kim (1976), and Martin (1969) are not. This may not be obvious, so let me say more. Consider the fact that (4) presupposes an Aristotelian

---

[88] If you do not like mereological fusions then substitute for (ii), (ii*) 'arrangement of substances'.

[89] Paul (2000, p. 213).

The above consideration would also entail the falsehood of the accounts of Brand (1977), Davidson ([1980] 2001), Lemmon (1967), and Quine (1985) since such views imply that events are physical concrete particulars.

substance theory of *concreta* which entails that concrete objects fall under or belong to various kinds. Because the world includes artefacts, one should be open to including in one's ontology artefactual kinds (see Loux (1978, p. 161)). "[I]t is" therefore "plausible to assume that there is a substance-kind for every ordinary object" (ibid.). While shrieks and flashes are produced and do not at all belong to *natural* kinds, it seems difficult to resist the fact that they are legitimate objects since such entities bear properties and so fall under kind universals. Moreover, flashes and shrieks have natures and these seem to essentially involve photons (in the case of flashes) and waves (in the case of shrieks). Such entities are objects

Add to the above list of benefits and advantages the further fact that my account makes room for both temporally and spatially scattered events, such as parades, or major league baseball games that are delayed midway for two days, and other sorts of interesting entities. The account does this by allowing some of the constituents of events to be mereologically fused substances or arrangements of such substances that fail to be spatiotemporally contiguous with one another.

4.1.4.1 Omissions[90]

I have surveyed much of the literature on causal *relata*, and rejected what has heretofore been proffered. I have also advanced and defended a new theory of causal *relata* that belongs in the property exemplification tradition. My new theory has a great many advantages and avoids all of the perils of its competitors. But the acute reader familiar with the causation literature will ask, does (37) preclude the possibility that omissions are sometimes causes? Not necessarily, for that will depend on one's precise

[90] Most of this sub-section is taken from my discussion of omissions in my unpublished essay "The Contingent Cosmos as Necessarily Caused or Necessarily Uncaused".

theory of omissions. On some accounts (37) is completely consistent with understanding omissions as causes, but on others it is not. Consider, for example, the negative events view according to which a negative event (and so an omission) exists, just in case, "some corresponding positive" event does "not exist"[91]. On that view, (37) rules out the possibility that omissions are causes, since the non-existence of an event does not entail the existence of an event as circumscribed by (37). Fortunately, the negative events view of omissions is multiply flawed, for if there really is such a thing as causation by omission (by negative events), then the view is inconsistent with an assumption I consider to be above reproach, *viz.,* that counterfactual dependence is at least most of the time a good guide to "causal connectivity" (as Schaffer would put it).[92] Assume that Gardner's failing to water the lawn caused the lawn to die (causation by omission). The corresponding positive event that failed to occur in this case is Gardner's watering the lawn, but not just that. Kevin Durant watering the lawn (call this event K) is likewise an event that failed to occur, and its true that were K not to have occurred, the lawn would have died. Thus, not-K is a cause of the lawn's dying. Obviously we can generalize to other highly unintuitive events. One might respond to the objection on offer by noting how there are (as it turns out) rather strange causal truths. I think it's best to reflect upon whether or not accepting strangeness in this case is really biting the unintuitive bullet.[93]

There is another objection to the purely negative events view that has been promulgated by D.H. Mellor:

---

[91] Quoting Mellor (1995, p. 133). Mellor should have said, "some corresponding positive event does not *occur*". This view was criticized by Mellor (1995, p. 133-134) himself, along with Menzies (1989, pp. 66-67), and Persson (2002, p. 136). David Lewis put the above view of omissions this way, "[a]n omission consists of the nonoccurrence of any event of a certain sort. To suppose away the omission is, exactly, to suppose that some event of the given sort does occur." Lewis (1986c, p. 189).

[92] Though I think all counterfactual theories of causation are false, I, like Ehring (1997), would still maintain that such dependence is often a good guide to causal connectivity.

[93] See Dowe (2000, pp. 126-127); *cf.* Ehring (2009, pp. 396-398).

> Suppose instead that 'Don does not die' is made true by a single [purely] negative event, Don's survival, which exists just when Don is not dying. To make 'Don does not die' entail both 'Don does not die quickly' and 'Don does not die slowly', Don's survival will have to be both quick and slow; but it cannot be both, so it does not exist.[94]

Responses to the above objection from Edgington (1997, p. 422), and Noordhof (1998, p. 858) fail, as Persson (2002, pp. 135-136) has made clear.

Perhaps omissions are disjunctive events. Gardner's failing to water the lawn is nothing above and beyond the disjunctive state of Gardner's reading Theodore Sider's *Writing the Book of the World*, or watching television, or going to the movies, or…etc. This theory is clearly inconsistent with (37) since some of the disjuncts of a disjunctive event are not actual obtaining bits of the world, and so the entire disjunctive "event" cannot itself be regarded as one that involves a substance exemplifying properties or standing in relations at a time. Second, if the disjunctive account holds, then as with the negative events view, one cannot assume that counterfactual dependence is sometimes a good guide to causal connectivity. If there are disjunctive events, then a great many effects will counterfactually depend on not just some particular positive event *e* that is intuitively its cause, but on any and every disjunctive event which features *e* as a disjunct. All events, if they are caused events, would be grossly overdetermined. This is a strange consequence that we should try to avoid.[95]

Lastly, some theoreticians seem to treat negative events as nothing above and beyond the corresponding positive events, which occur in their stead.[96] Lewis (2004b, p.

---

[94] Mellor (1995, p. 133-134); *cf*. Ehring (2009, p. 397), and Menzies (1989, pp. 66-67).

[95] See Ehring's (2009, p. 397) discussion of disjunctive events.

[96] Interestingly, David Armstrong seemed to have held this view in his (1978b) text on universals. He stated:

> "However, when we reflect a little on such cases, we are very ready to admit that the actual causal processes involved proceed solely in virtue of the (positive)

282, and see n. 12 on page 289) responded to such a view by invoking the void, a maximal absence (where a maximal absence is an absence of everything, even spacetime itself). For Lewis, there can be no corresponding positive event to which we can reduce the void, for that positive event would need to involve the mereological sum of everything and that sum's having the totality property of /*being all that exists*/. Call the above event an "ersatz void" (following Lewis (2004b, p. 289. n. 12)). Now Lewis thinks that such an ersatz void cannot serve as that to which the void is reduced for it does not walk like a void, or quack like a void in two very important ways (quoting Lewis):

> This ersatz void is as wrong as it can be in its effects (and causes): It causes what objects cause, not what the void unassisted by objects causes. And it is as wrong as it can be in its location, by being exactly where the void isn't.[97]

Thus, with respect to the void, there simply does not appear to be any corresponding positive event that occurs in its stead. If one was not convinced by my response to Lewis's appropriation of the void above, then Lewis's void refutes this account of omissions.

Add to Lewis's objection the following worry: the account implies a very strong reduction, *viz*., that the Gardner's failing to water the plant just is_{identity} his reading Sider's *Writing the Book of the World*. But that reduction is clearly wrong since even given that the Gardner was reading Sider's text it may very well still be true that had the Gardner

---

> properties of the situation. To say that the lack of water caused his death reflects not a metaphysic of the causal efficacy of absences but merely ignorance. Certain (positive) processes were going on in his body, processes which, in the absence of water, resulted in a physiological condition in virtue of which the predicate 'dead' applied to his body." (Armstrong 1978b, p. 44)

See also Noordhof (1998, p. 858), and Schaffer (2005, pp. 329-332); *cf*. the discussion in Ehring (2009, p. 397) and Paul and Hall (2013, pp. 180-182).

[97] Lewis (2004b, p. 289. n. 12)

not read Sider's text, he still would have failed to water the plant.[98] As Phil Dowe (2000, p. 127) would point out, there are "innumerable ways that the" Gardner "could have failed to" water the plant.[99] The Gardner's failing to water the plant is therefore not *identical* to the event of the Gardner's reading Sider's text.[100] Therefore, it is not the case that negative events are nothing above and beyond positive events occurring in their stead.

4.2 The Formal Nature of Singular Causation

4.2.1 Asymmetry

4.2.1.1 Asymmetry without Temporal Asymmetry

Causation is formally asymmetric. For any event *x*, and for any event *y*, necessarily, if *y* caused *x*, then it is not the case that *x* caused *y*. Attempts to ground causal asymmetry in the asymmetry of time, (a somewhat Humean strategy) are doomed to fail since simultaneous causation seems not only perfectly metaphysically possible (*e.g.*, when the side of a perfectly rigid seesaw ascends downward simultaneously causing the opposite side to ascend upward (from Ehring (1997)), see Carroll (1994, pp. 141-147); Carroll (2009, pp. 286-287); and *cf*. Taylor (1966, pp. 35-40) for other cases), but natural nomically possible.[101]

There is a would-be case of simultaneous causation that vexes me greatly, for not only would its real metaphysical possibility imply the falsity of Hume's dictum—that necessarily, causes always temporally precede their effects—but it would also show that

---

[98] Notice that this response runs even if the positive and negative events under discussion are non-compossible.

[99] The same worry is echoed in Paul and Hall (2013, p. 180) though they find it to be "far from decisive."

[100] You might escape this worry by appeal to multiple realization, but I'm unclear on how exactly the details of that response would go.

[101] My opinion on the matter seems to be in agreement with a growing consensus. Daniel M. Hausman noted, "[m]any philosophers, myself included, have been dissatisfied with the stipulation that causes precede their effects." Hausman (1998, p. 44).

causation is not formally asymmetric.[102] The example suggests that there could be two wooden boards that stand up in such a way that each leans against the other. It is imagined that each individual board causes the other's "upright position", and that such causation occurs simultaneously (Fair (1979, pp. 230-231)).[103] While I would agree that the modal epistemologies I mentioned in chapt. 2 provide *prima facie* epistemic justification for one's belief that the board leaning case is one of simultaneous and reciprocal or symmetric or mutual causation, that justification is defeated by the following objection: Given the transitivity of causation (see sect. 4.2.4 below), plus the fact that board a's position causes board b's position, and board b's position likewise causes board a's position, it will follow that board a's position causes board a's position, and *mutatis mutandis* in the case of causation and b's position.[104] And so embracing the real possibility of such a case and the transitivity of causation entails that events can cause themselves.[105] But if events can cause themselves, then not a few theories of causation will yield:

(38) All events cause themselves.

Let me proffer one instructive example. Give attention to what Ned Hall calls the "[c]rude sufficient condition account"[106] of causation[107]:

> (Crude Sufficient Condition Account of Causation or CSC): For any world *w*, event *c*, and event *e*, *c* is a *bona fide* cause of *e* at a possible world *w*, just in case,

[102] Price and Weslake (2009, p. 415) identify the thesis that causation is temporally asymmetric as "Hume's view".

[103] See the discussions in Pollock (1976, p. 173)

[104] The argument is from Frankel (1986, p. 362).

[105] Attempts to dodge this objection by restricting transitivity to cases involving differing events are question-begging. Frankel was right, "[i]f x is a genuine cause of y, and y is a genuine cause of x, it seems ad hoc to deny that x is in some sense a cause of itself." ibid., 362. Elsewhere he remarked, "…most who allow mutual causation vehemently reject self-causation…" ibid., 363.

[106] Hall (2004b, p. 266).

[107] And here take some material from my paper "Yet Another New Cosmological Argument".

> both *c* and *e* occur in *w*, and for any possible world *w** with the same laws as *w* and in which *c* occurs, *e* occurs.[108]

If causation can be mutual, then given (CSC) above, every event causes itself. For that *e* occurs at all worlds *w** which have the same laws as *w*, is entailed by the fact that *w** is a group of worlds at which *c* occurs, since *c* = *e*. The kind of reasoning I've employed here can be easily extended to other analyses of causation, though not all. The reason why it cannot be extended to all accounts is because some are such that they constitutionally preclude reflexive causation (think for example, about transfer or process theories of causation).[109] It seems that we are stuck with (38). But it is absurd to think that all events cause themselves. So it seems that we must either (a) resist reading the standing wooden pieces case as a case of simultaneous and symmetric causation, or (b) resist the judgment that such a case is genuinely possible.[110] I'm proposing that one choose (b), though I am open to (a).

4.2.2 Temporal Asymmetry?

There does exist a staunch tradition in the literature on the asymmetry of causation that has sought to (c) ground that asymmetry in the asymmetry of time, and then to (d) further ground the asymmetry of time in the arrow of entropic increase, and then to (e) still further ground the arrow of entropic increase in the past hypothesis (the thesis that our universe began in an extremely low-entropy state).[111] David Lewis (1979)

---

[108] Paraphrased from Hall (2004b, p. 266).

[109] Also, my claim isn't that every possible theory of causation is incompatible with reflexive or symmetric causation. One could cook up a contrived or *ad hoc* theory, which allowed for such a possibility.

[110] It seems to me that a very similar argument will rule out partial reflexive causation, where the idea is that some event *c* together with an event *e* causally produces *c* itself. If such a relation could obtain, then it seems that a great many theories of causation will entail that every event which has a cause, will with that cause partially cause itself.

[111] For step (e) one may also need a probability distribution over the initial conditions of the cosmos. See Albert (2000), (2015); Kutach (2001), (2002), (2007); and Loewer (2007), (2012, p. 124).

defended (c), and although at one point he was unsure about (d)[112], he would eventually endorse that reductive strategy as well.[113] It is generally agreed that Adam Elga (2000) showed why Lewis's (1979) thesis regarding the asymmetry of counterfactual dependence and overdetermination is false as stated, and that one should therefore vie for something like (d) above.[114] Although the history is important, it has been adequately summarized in not a few places, and since Lewis's (1979) account is almost universally rejected, I will pass on to those approaches thought to be the best ways of explaining causal asymmetry *via* temporal asymmetry.

Again, Albert (2000), Loewer (2007), (2012) and Kutach (2007) seem to go in for (c)-(e). But as we shall see in sect. 4.2.6 below, causation is qualifiedly universal, and since obtaining causal relations usually underwrite and back explanations even scientific explanations, there should be an explanation the universe's initial low-entropy state. When we reflect upon the fact that the leading candidate scientific explanations fail, and that the special nature of the low-entropy state is one of many other special and equally unnatural conditions for a life permitting universe (see chapt. 7) we should discern that the explanation may not be scientific, and that the arrow of time's ground is not to be found in the physical sciences but in metaphysics. The attempt to ground the asymmetry of causation in the asymmetry of the arrow of entropic increase is usually motivated by a

---

[112] Lewis said, "I regret that I do not know how to connect the several asymmetries I have discussed and the famous asymmetry of entropy." Lewis (1979, p. 475).

[113] That is, according to personal correspondence referenced by Hartry Field,

> "My own view is that while it would be hard to find an acceptable statistical account of the directional asymmetry based on an asymmetry of near-determination, still bringing in statistical macro-laws in one way or another is the way we need to go, for there simply is no directional asymmetry independent of them. (*Lewis informs me that this is now his view as well*.)" Field (2003, p. 458) emphasis mine.

[114] See also the comments in Field (2003, pp. 456-457); Price and Weslake (2009, p. 422). David Albert voiced an objection similar to Elga's.

philosophical worldview, *viz*., physicalism. But since the most plausible way to relate the causal arrow to the arrow of time involves a further relating of the arrow of time to the past hypothesis, and since that hypothesis is neither brute nor scientifically explained (as I will argue in chapt. 6), the motivating worldview may have to be abandoned, in which case one wonders if there really is any good reason or remaining motivation to ground causal asymmetry in some physical reductive base at all.

4.2.3 Hyperrealism and Causal Direction

I have written into my account of causation formal asymmetry that cannot be reduced to temporal asymmetry. My account is now susceptible to an epistemological objection in that it "threatens to make [causal direction] both *epistemologically inaccessible* and *practically irrelevant*."[115] As Price and Weslake would go on to confess:

> …if the causal direction is detached from physics, then presumably the world could have had the same physics, with an oppositely directed causal arrow—in which case, apparently, we have no way of knowing whether our ordinary ascriptions of the terms 'cause' and 'effect' are correct or back to front.[116]

But this objection is quite poor. It presupposes that the choice way—the only way—we come to reliably know about the direction of causal structure is through formal physical inquiry. But subject relative scientism of this sort is false, especially when knowledge of causal structure is in view. If we come to learn and know about anything from the mother's knee it is that certain causal relations obtain with specific events being the causes of specific effects.[117] As David Danks remarked,

> We are clearly 'causal cognizers', as we easily and automatically (try to) learn the causal structure of the world, use causal knowledge to make decisions and

[115] Price and Weslake (2009, p. 417).
[116] Price and Weslake (2009, pp. 417-418).
[117] In fact, Strevens (2013) argues that from a very young age we are able to read off of the causal structure of the world reliable probability judgments through equidynamic thinking.

> predictions, generate explanations using our beliefs about the causal structure of the world, and use causal knowledge in many other ways.[118]

How precisely we acquire such knowledge is a matter that can be settled by an appropriate theory of the epistemology of causation. But it is important to first realize both the skeptical nature of Price and Weslake's objection and the Moorean nature of my response. Worries like the above, and much discussed misgivings about whether we are really Doppelgängers who have conscious experiences in reversed temporal order are skeptical worries[119], worries on par with egocentric predicaments.[120] There is no reason why we cannot meet such scenarios with the datum that we have causal knowledge from a very early age. That datum can be explained by the following piece of supplemental reasoning: Cognizers like us perceptually behold obtaining causal relations (following Armstrong (1988, p. 225), (1997, pp. 213-215); Cartwright (1993, pp. 426-427); Ducasse (1968, pp. 25-28); Fales (1990); Locke ([1690] 1975 II.xxi.4); Mumford and Anjum (2011, pp. 196-202); Reid ([1788] 1983 Essay 4.chapt. 2); and Siegel (2009)).[121]

Suppose someone walks up to you and pushes your forehead back with great force. Would you not in such a circumstance perceptually experience an obtaining causal relation? Notice that I'm not interested in the question of whether or not you perceived the relation that is causation (some connection). Relations are universals and therefore *abstracta*. Rather, I'm interested in whether or not you perceived an *obtaining* relation, a concrete state of affairs, and it seems to me that when someone walks up to you and pushes your forehead back, you can as a result perceptually experience a concrete state of

---

[118] Danks (2009, p. 447).

[119] See, *e.g.*, the discussions in Maudlin (2002, pp. 272-273); Price (1996, pp. 14-15), (2011, pp. 297-301); and Williams (1951, pp. 468-469).

[120] See Audi (2011, pp. 342-343).

[121] Hume's objections to experiencing obtaining causal relations have been refuted by Fales (1990, pp. 16-25).

affairs, and you can on that basis form a perceptual belief *viz*., that your head was caused to move backward. Present within the larger experience are three constituents, (i) a sensuous experience, (ii) a non-sensuous experience, (iii) and the act of belief formation.[122] Constituents (i) and (iii) are clear enough, and in order to appreciate (ii) one should first understand that it is connected to (iii) in that it involves "a certain felt attractiveness or naturalness, a sort of perceived fittingness" in that forming the perceptual belief that the push caused one's head to fling backward "feels like the *right* belief in those circumstances."[123] It would be difficult for one to form the belief that one was floating in a swimming pool, or that one's feet were being sprayed by a water gun in such circumstances.

The detractor of perceptually beholding obtaining causal relations may at this point ask *why* I believe that my perceptual experience presents me with an obtaining causal relation. But notice that such a question's meaning is ambiguous in this context.[124] Is the question a request that I give one reasons for believing that present in my experience is an obtaining causal relation? Or is the question requesting that I report on why it is that there's a cause in my perceptual experience as opposed to something else? Both of these queries are red herrings. I should insist that cognizers can and do perceptually behold obtaining causal relations and thereby form perceptual beliefs about such relations in a foundational way, a way that affords non-inferential epistemic justification or warrant.[125] I simply find myself believing that the lightning strike caused

[122] As in Plantinga (1993b, p. 92), (1988, p. 38).
[123] Plantinga (1993b, p. 92) but *cf*. the discussion of memory in ibid., pp. 58-61.
[124] And here I follow Plantinga (1993, pp. 94-95).
[125] See Bergmann (2006, pp. 184-197); Plantinga (1993b, pp. 93-98). I'm relying upon a foundationalist architecture of knowledge not unlike that defended by Alston (1976) and countless others.

the explosion, or that the push caused the fall, or that the initial falling domino caused the second's fall. I believe these propositions on the basis of my perceptual experience, and the justification or warrant-contributor in each case just is, at least in part, the perceptual experience itself. As Plantinga noted,

> My having that sort of experience in those circumstances helps confer warrant upon the belief in question; it does not acquire its warrant by being believed on the basis of propositions reporting that experience.[126]

So long as my belief formation in the relevant circumstances arose on account of properly functioning cognitive faculties in a congenial epistemic environment, an environment suited for those faculties, an environment conducive to true beliefs, and so long as my belief has no actual mental state defeaters for it in my noetic structure, it seems perfectly plausible to maintain that my belief enjoys warrant or epistemic justification.[127] This is proper functionalism about warrant. Whether we find ourselves in such an environment is a separate issue, one that need not be settled in order for us to know that some specific causal relation obtains (*i.e.*, externalism is true).

There is another route to my desired destination. One need not be a proper functionalist about warrant to get there. One can be justified in believing that a certain causal relation obtains in the virtue foundational way (Sosa (2007, pp. 44-69), (2009, pp. 154-177), (2011, pp. 74-90)).[128] A belief *b* enjoys virtue foundational justification when its foundational justification issues forth from *b*'s being formed in a way that manifests "a certain epistemic competence" (in this case a perceptual epistemic competence) "one that

---

The argument here may also rely on the supposition that perceptual experiences of the external world do not involve propositional content. But this supposition has been defended at length with great sophistication in Burge (2010, see specifically the comments at pp. 537-547).

[126] Plantinga (1993b, p. 95). And here I rely also upon the success of an argument given in Alston (1991, pp. 102-145).

[127] Plantinga (1993b, pp. 3-47).

[128] Sosa's theory of the manifestation of perceptual epistemic competence assumes that perceptual experiences of the external world essentially include or involve propositional contents. Sosa (2011, p. 75)

is not constituted by" basing *b* "on some other conscious state/reason for which" one formed *b*.[129] The epistemic competencies are specific types of abilities, where abilities are dispositions. These dispositions can be partnered with sets or collections of conditionals with "triggering antecedents and manifesting consequents".[130] But more specifically, perceptual epistemic competencies involve the ability to judge falsehood from truth in a sphere or venue appropriate for perceptual epistemic competence.[131] Sosa's account is famously externalist, and so cognizers need not demonstrate that their beliefs were formed in the relevant competence manifesting ways in order for those beliefs to enjoy virtue foundational justification, and I see no reason why cognizers like us cannot believe on the basis of perceptual experience that some causal relation obtains and claim to be manifesting the aforementioned perceptual epistemic competence. The mere report that we could be in some skeptical scenario in which causal structure is radically different (the effect is the cause, and the cause the effect) does nothing to defeat that claim and such a scenario itself can be met by the virtue epistemologist's response to skepticism in general.[132]

We can and do come to know about causal structure irrespective of causal direction's detachment from physics. Skeptical scenarios can be dealt with by appeal to sound traditional epistemology.[133]

4.2.4 Transitivity

[129] Sosa (2007, p. 51).
[130] Sosa (2011, p. 80).
[131] ibid., 82.
[132] I take the above considerations to be such that they rule out the type of error theoretic responses to perceiving causation discussed in Beebee (2003).
[133] I should point out that reductionists themselves find epistemological worries like the above problematic. See, for example, Schaffer (2008, p. 90).

Causation is transitive such that $\forall x \forall y \forall z \blacksquare [(Rxy \,\&\, Ryz) \rightarrow Rxz]$ (where 'R' denotes the causal relation and where the variables x, y, and z range over events). Most theorists writing on causation regard that relation as formally transitive (see Cartwright (2007, p. 192[134]); Ehring (1987, p. 325), (1997, p. 82); Hall (2000), (2004a[135]); Irzik (1996, p. 252); Koons (2000, p. 46); Lewis (1973a, p. 563)[136]; Rosenberg (1992, p. 308); Schaffer (2009, p. 376) *inter alios*).[137] In fact, it seems that only until rather recently has the transitivity of causation come under heavy fire.[138] Such recent detraction from transitivity is mostly due to a number of difficult cases thought to be counter-examples to transitivity. I, however, agree with Hall (2004a), that at the end of the day, these cases do not show that causation is not formally transitive. In what follows below, I examine the cases articulating precisely why they fail to serve as worries for the proponent of the transitivity of causation.

Here are a group of the best cases I could find in the literature:

(Case #1): "…a boulder is dislodged, and begins rolling ominously toward Hiker. Before it reaches him, Hiker sees the boulder and ducks. The boulder sails harmlessly over his head with nary a centimeter to spare. Hiker survives his ordeal."[139] The idea is that the

[134] She states that the relation is "functionally transitive". Cartwright (2007, p. 192).

[135] There are nuances with Hall. He thinks there are two different types of causation. One of these types ("the central kind" (2004a, p. 182)) is transitive, the other is not.

[136] Though I should point out that Lewis differentiates between causal dependence and the causal relation. He thinks that while the causal relation is transitive, causal dependence is not.

[137] "Many believe, however, that singular causation is transitive." Hitchcock (1995, p. 276) "That causation is, necessarily, a *transitive* relation on events seems to many a bedrock datum, one of the few indisputable a priori insights we have into the workings of the concept." Hall (2004a, p. 181) emphasis in the original.

[138] L.A. Paul remarked,

> "[o]ne obvious potential problem is that *R* is transitive, so if causation is the relation *R* then causation must also be transitive. Many, including Lewis, welcome this result, since they believe that the causal relation is transitive, *but in recent years* the transitivity of the causal relation has become controversial." Paul (2009, p. 159 emphasis mine)

[139] Hitchcock (2001, p. 276) who attributes the case to an early draft of Hall's paper "Two Concepts of Causation".

> boulder's dislodgement causes Hiker to duck. Hiker's ducking causes the prevention of his being struck by the boulder, which in turn causes his survival. If causation is transitive, then the boulder's dislodgement causes Hiker's survival. That seems odd.

(Case #2): James places an armed fused bomb outside of Julie's apartment, but as Henry passes by he defuses the bomb and as a result, Julie survives. The idea is plainly that James' bomb placement causes Henry's diffusing, which in turn causes the prevention of an explosion, which in turn causes Julie's survival. But if causation is transitive, then James's bomb placement causes Julie's survival, and that seems like an unintuitive result.[140]

(Case #3): "My dog bites off my right forefinger. Next day I have occasion to detonate a bomb. I do it the only way I can, by pressing the button with my left forefinger; if the dog-bite had not occurred, I would have pressed the button with my right forefinger. The bomb duly explodes. It seems clear that my pressing the button with my left forefinger was caused by the dog-bite, and that it caused the explosion; yet the dog-bite was not a cause of the explosion."[141]

There are other similar cases in the literature (*e.g.*, Kvart (1991); Hall (2004a, pp. 183-184) etc.), but they all seem to have the same underlying structure.[142] How should the proponent of the transitivity of causation respond?

I believe one can defend the transitivity of causation against such cases by appropriating a proper metaphysics of prevention, for preventions involve the causation of a negative event (the failure of some event's obtaining). However, I am very stubborn about proper causal *relata*. My theory of causal *relata* and its supporting arguments prohibits obtaining causal relations involving negative events. We can therefore avoid all these potential counter-examples by simply rejecting the thesis that negative events are effects. There are therefore no instances of causation by prevention. This may strike some

[140] This case is due to Hartry Field, according to the report in Paul and Hall (2013, p. 215).
[141] McDermott (1995, p. 531).
[142] Paul and Hall (2013, p. xi, pp. 82-87, p. 198, p. 216) have done us a great service by illustrating the precise structure of these counter-examples *via* neuron diagrams.

as counterintuitive but it is really just the cost of insisting that the *relata* of causation are events defined in terms of (37).

4.2.5 Irreflexivity

Causation is irreflexive, such that $\forall x \blacksquare \sim (Rxx)$ (where 'R' denotes the causal relation). I have already argued that causation is asymmetric. I said that the case of the slanting boards involved symmetric or mutual causation, and that if causation is also transitive, then it will follow that some events can cause themselves. I considered that result to be a *reductio* for the slanting board case (or at least interpreting that case in such a way that it involves symmetric or mutual causation), since not a few theories of causation will imply that all events cause themselves, if causation can be reflexive. So the work has already been done, the main argument has already been articulated. In addition, if my reasons for regarding causation as formally asymmetric and transitive are right, then irreflexivity follows by logical consequence. Thus, causation is irreflexive.

4.2.6 Universality

Not a few philosophers and scientists have affirmed that causation is universal, that every event has a cause (*e.g.*, Aristotle, *Physics*; Donald Davidson (according to correspondence cited by Brand (1977, p. 332)); Kant ([1788] 1998, B232-B256); Koons (2000); Laplace ([1825] 1995, p. 2); Lewis (1986a, p. 242); Pruss (2006)). I believe that when causation relates what I call *purely contingent events*, that relation is universal (*i.e.*, every *purely contingent event* has a cause). What is a purely contingent event?

> (39) Necessarily, for any *x*, *x* is a *purely contingent event*, just in case, *x* is an event that occurs, and every substance or mereological

> fusion of two or more substances that is a constituent of *x* is contingently concrete.[143]

Purely *contingent events* are different from ***merely*** *contingent events*. An event may be *merely* contingent and yet fail to be *purely* contingent by having as a constituent a necessarily existing, necessarily concrete substance. Purely contingent events only ever involve *contingently concrete substances* or fusions of such substances. Fusions of contingently concrete substances are themselves contingent given the following plausible principle:

> (40) Necessarily, for any entity *x*, if there are some *ys*, such that *x* is substrate-composed solely of the *ys*, and the *ys* are purely contingent, then *x* is purely contingent.

where what it means for *x* to be substrate-composed of the *ys* is for the *ys* to be those substances, which fuse together to yield the *x* which has the *ys* as proper parts (and it is understood that the *ys* exhaust all of the constituent substances which build up *x*).

But how does one show that all purely contingent events have causes? Here is an argument:

> (41) All successful causal explanations are backed by obtaining causal relations such that for any contingently true proposition that merely reports on the occurrence of a purely contingent event *x* (without logical redundancy) there is a true proposition which (among other things) reports on the occurrence of at least one distinct event *y* and the fact that *y* is a or the cause of *x*.[144]
>
> [Premise]

---

[143] *Cf.* Chisholm (1990, p. 419 see definition D11) and Koons (2000). Notice that this thesis is about those events, which actually occur. It is not intended to report on those purely contingent events that may occur at distant metaphysically possible worlds but which fail to occur at the actual world. Given necessitism, a purely contingent event may fail to occur on account of the fact that its constituent substances fail to be concrete.

I should note here that Hall is the first to use the locution 'purely contingent fact' in his (2004b, p. 261).

[144] I defend this premise in sect. ?.? below.

(42) All contingent truths that merely report on the occurrence of purely contingent events (without logical redundancy) could be causally explained. [Premise]
(43) If (42), then all contingent truths that merely report on the occurrence of purely contingent events are causally explained. [Premise]
(44) If (41) and all contingent truths that merely report on the occurrence of purely contingent events (without logical redundancy) are causally explained, then all purely contingent events have causes. [Premise]
(45) Therefore, all purely contingent events have causes. [Conclusion]

Premise (41) suggests that obtaining causal relations back causal explanations, and that supposition follows on not a few theories of causal and scientific explanation.[145] Premise (42) is sufficiently substantiated by the justification for proposition (23) provided in chapt. 2. That leaves premise (43). Call those contingent truths without logical redundancies that merely report on the occurrence of some purely contingent event '*reporters*'. How can one move from the mere possibility that reporters could be causally explained to the claim that all reporters actually are explained? There's a proof for such a maneuver.[146] Here is our interpretation for that proof:

> [Exy: *x* causally explains *y*; 'â' and 'ô' are pseudo-names (see the natural deduction system of classical first-order logic developed by Gustason and Ulrich (1989)[147]); with respect to the *y*s and *z*s the domain is restricted to propositions, although when [x] is a part of a quantifier, that quantifier ranges over a reporter. Variables in brackets are reporters. *x*s (without brackets) range over propositions.]

[145] See Salmon (1984); Strevens (2008); van Fraassen (1980, p. 124); and Woodward (2003, pp. 209-220) who seems to go in for the "backing" idea with respect to singular event causal explanation. In fact, Strevens (2007, p. 237) remarked, "[t]he core of Woodward's account of singular event explanation is the account of singular event causation…". This is *contra* Lewis (1986d) and Skow (2013).

[146] And here I'm indebted to Church (2009); Fitch (1963); Gale and Pruss (2002, p. 90); Kvanvig (2006, pp. 12-14); and Oppy (2000, pp. 347-348).

[147] Pseudo-names are used for the purposes of referring "to a thing of a certain sort" though we "do not know or care *which* thing of that sort it is." Gustason and Ulrich (1989, p. 215) I do not make strict use of their proof-system here, for my derivation requires a formal language able to handle modal operators which have as their arguments existentially quantified expressions (I'm using quantified modal logic). The use of pseudo-names is clear enough in the derivation and can be easily appropriated by slightly adjusting standard quantified modal logic proof systems.

So long as causal explanation (represented by the predicate letter 'E' below) can be understood as a relation that satisfies the following two principles, then that proof can go through:

> (Principle #1): The relation *E* is distributive, such that necessarily, if some proposition causally explains the conjunctive fact [[x] & [y]], then that proposition causally explains [x], and that proposition causally explains [y].
>
> (Principle #2): The relation *E* is factive, such that necessarily, if some proposition causally explains [x], then [x] is true.

Here is the proof:

(46) ∀x([x] → ♦∃y(Ey[x]))	[Premise]
(47) [[â] & ~∃z(Ez[â])] → ♦∃y(Ey[[â] & ~∃z(Ez[â])])	[UI (46)]
(48) ∃y(Ey[[â] & ~∃z(Ez[â])])	[Assumption]
(49) Eô[[â] & ~∃z(Ez[â])]	[EI (48)]
(50) Eô[â] & Eô[~∃z(Ez[â])]	[Principle #1, (49)]
(51) Eô[â] & ~∃z(Ez[â])	[Principle #2, (50)]
(52) Eô[â]	[Simp. (51)]
(53) ~∃z(Ez[â]) & Eô[â]	[Comm. (52)]
(54) ~∃z(Ez[â])	[Simp. (53)]
(55) ∀z(~Ez[â])	[QN (54)]
(56) ~Eô[â]	[UI (55)]
(57) Eô[â] & ~Eô[â]	[Conj. (52), (56)]
(58) ~∃y(Ey[[â] & ~∃z(Ez[â])])	[CP (48)-(57) and *Reductio*]
(59) ■~∃y(Ey[[â] & ~∃z(Ez[â])])	[Rule of Nec. (58)]
(60) ~♦∃y(Ey[[â] & ~∃z(Ez[â])])	[Duality of the Modal Operators and DN (59)]
(61) ~[[â] & ~∃z(Ez[â])]	[MT (47), (60)]
(62) ~[â] v ~~∃z(Ez[â])	[DeM (61)]
(63) [â] → ∃z(Ez[â])	[Impl. and DN (62)]
(64) ∀[x]([x] → ∃z(Ez[x])	[UG (63)[148]]

[148] The Gustason and Ulrich deductive system does not allow one to apply universal generalization to a line in which there appears a pseudo-name that was used in some earlier line of the deduction that was arrived at by means of existential instantiation. The only pseudo-name that appears in line (63) is [â]. That pseudo-name does "appear" at line (49), 'Rô[[â] & ~∃z(Rz[â])]'. I include scare quotes around 'appear' because the relevant fact there is the conjunctive fact: [[â] & ~∃z(Rz[â])]. For all intents and purposes, that fact is being named and referenced with the outer most brackets (*i.e.*, I'm naming a particular conjunctive fact). Thus, [â] does not "occur" in line (49) in the way that Gustason and Ulrich have in mind *per* their proviso on applying universal generalization. (See Gustason and Ulrich (1989, p. 226)).

where proposition (64) says that for any reporter [x], if [x] holds, then there is at least one proposition z, such that z causally explains [x]. We can infer (64) from (63) by UG because [â] is an arbitrary reporter, not an arbitrary proposition. If it stood for an arbitrary proposition we could infer $\forall \mathbf{x}([x] \rightarrow \exists z(Ez[x])$. But that is not the case here.

The derivation shows that if all reporters could be causally explained, then every reporter has a causal explanation. Many may find the initial universal instantiation step on proposition (46) to be objectionable. The worry is that propositions that report on how reporters lack causal explanations are not such that they themselves could be causally explained. Premise (46) is therefore false.[149]

The objection is easily rebutted once a clarifying point is made regarding its essential content. Note first that what the objection dismisses is the possibility that a proposition about some reporters' failing to have a causal explanation can itself be causally explained. That amounts to a denial of the consequent of (47), not a denial of (46). Second, notice that I agree. Lines (48)-(58) show that it's a theorem that facts, which report on how reporters lack causal explanations, cannot themselves be causally explained. It is because that theorem can be established, that from (46), it follows that every reporter has a causal explanation.

Premise (44) seems plainly true. Given that a causal explanation of an arbitrary reporter [x] is backed by an obtaining causal relation—one that involves there being a cause of the purely contingent fact that [x] reports on—then clearly all reporters that are causally explained have causes. But I have just argued that all reporters have causal explanations. So it follows that all purely contingent events have causes (*i.e.*, (45) holds).

[149] And here I use some content from my "Yet Another New Cosmological Argument" paper.

4.2.6.1 Objections to the Universality of Causation

John D. Norton (2007) argued that one should not be satisfied with a causal depiction of the world's structure if that picture is recommended to one prior to systematic physical investigation of the world. He said "causal fundamentalism" is "a kind of *a priori* science that tries to legislate in advance how the world must be."[150] For Norton, causal fundamentalists are committed to a principle of causality, which, in one of its forms, asserts that "*every effect has a cause*."[151] If such a principle were true, it would place an *a priori* "restriction on the factual content of…science…"[152] The problem, as Norton sees it, is that if the principle of causality holds, then determinism follows. But classical and quantum mechanics contradict determinism (as does the general theory of relativity).[153] The principle of causality is therefore false.

But the principle of causality does not imply determinism.[154] Determinism is a stronger thesis. It says that "[t]he natural laws and the way things are at time t determine the way things will be at later times."[155] Notice the lack of explicit appeal to causal notions.[156] What is required are stronger determining relations established by antecedent conditions coupled with natural laws. I'm not suggesting that one cannot understand

---

[150] Norton (2007a, p. 15) emphasis mine.

[151] Norton (2007a, p. 36) emphasis in the original. For an interesting discussion of various principles of causality see Nagel (1961, pp. 316-324).

[152] Norton (2007a, p. 15).

[153] See Norton (2007a, pp. 17-18, pp. 22-28).

[154] A point made even in introductory metaphysics textbooks. Carroll and Markosian (2010, pp. 50-51).

[155] Loewer (2008, p. 327). Or,

> "*Determinism* is the thesis that a complete statement of a universe's natural laws together with a complete description of the condition of the entire universe at any point in time logically entails a complete description of the condition of the entire universe at any other point in time." Mele (2009, p. 561) emphasis in the original

Cf. Lewis (1983).

[156] Scriven (1975, p. 6) seems to make this point.

determinism by appeal to causation. Consider, for example, this definition from the pen of Thomas Pink:

> Causal determinism is the claim that everything which happens, including our own actions, has already been causally determined to occur. Everything that happens results from earlier causes—*causes which not only influence, but determine their effects by ensuring that these effects* ***must*** *occur*, leaving no chance for things to happen otherwise. So, if causal determinism is true, then what will happen at any time in the future is already entirely fixed and determined by the past.[157]

But notice that Pink uses ***modal*** causal determination language. The idea is that one has a type of causal determinism only if every effect has a cause and causes entail or necessitate their effects. Causation is therefore "a species of strict necessitation" on such characterizations of determinism.[158] The problem is that causation is not a type of entailment. If that were true, then indeterministic causation would be impossible (Koons (2000, p. 47)), and although my project seeks to establish a theory of deterministic causation, I do believe it is possible that the world is indeterministic and that at such worlds there are obtaining causal relations, its just that theories of indeterministic causation are significantly more difficult to get right, and I'm attempting to exercise good philosophical methodology by seeking to get clear on the easier case, leaving a theory of indeterministic causation as difficult homework. I should also add that one's theory of deterministic causation should not affirm that deterministic causes necessitate their effects. It seems perfectly possible that if *c* actually causes *e*, there's a world at which *c* occurs, and yet the presence of other events swamp (by causal influence) *c*'s causal

[157] Pink (2013, p. 303) emphasis mine.
[158] The point is in Koons (2000, p. 47).

efficacy such that *c* does not causally give rise to *e* due to the presence of the mitigating or swamping causal circumstances.[159]

Norton (2007) was wrong. The universality of causation does not imply determinism. Are there other reasons then for resisting the principle of causality? Enter Norton's (now famous) dome case in classical mechanics (see Norton (2007, pp. 22-28)). That thought experiment involved a sphere on the very top of a dome, which due to no external causal influences, spontaneously moves off of the top of the dome, sliding down its side in some indeterminate direction. Norton argued forcefully, and convincingly that such a case is consistent with Newtonian mechanics and that such an underlying physical theory fails to provide any discernable probabilities for the occurrence of the event of the sliding. This is supposed to show that there lies within Newtonian mechanics room for indeterminism and uncaused events.

Newtonian mechanics is false. Norton's dome case is a counterfactual one. It's a possible scenario. I am completely open to the possibility that some events lack causes. The universality of causation with respect to purely contingent events does not hold at every possible world, for the principle that all reporters could be causally explained in a way backed by obtaining causal relations is at best a contingent truth. Thus, the universality of causation is completely consistent with Norton's dome case.

4.2.7 Causation is Well-Founded[160]

In his very important work, *Realism Regained: An Exact Theory of Causation, Teleology, and the Mind* (2000), Robert Koons proffered a very interesting argument for

[159] See on this Mumford and Anjum (2011, p. 53).
[160] This sub-section is taken from my unpublished paper "On the Carroll-Chen Model".

the well-foundedness of the causal relation (see p. 113) which depended upon the universality of causation. A close cousin of that argument proceeds as follows.

(65) All purely contingent events have causes and there is a purely contingent event *m* that is the sum of all purely contingent events. [Premise]

(66) If all purely contingent events have causes and there is a purely contingent event *m* that is the sum of all purely contingent events, then *m* has a cause, call it *c*. [Premise]

(67) If for any obtaining causal relation that composes *m*, the cause in such a relation is preempted by *c*, then it is not the case that there is a complex purely contingent event *m* that is the sum of all purely contingent events. [Premise]

(68) If *c* causes *m*, then either, for any obtaining causal relation which composes *m*, the cause in such a relation will be preempted by *c*, or else *c* causes *m* by indirectly (through the transitivity of causation) causing all of its constituent purely contingent events by being the initial cause of *m*'s earliest obtaining purely contingent event or events. [Premise]

(69) If *m* is an infinitely long causal chain whose links involved only purely contingent events, then it is not the case that *c* causes *m* by indirectly (through the transitivity of causation) causing all of its *initial* constituent purely contingent events. [Premise]

(70) Therefore, it is not the case that *m* is an infinitely long causal chain whose links involve only purely contingent events. [Conclusion]

The first conjunct of (65) follows from the universality of causation. The second conjunct follows from mereological universalism (a popular assumption). (66) is an obvious truth. With respect to justification for (67), one should first pick out any obtaining causal relation that helps compose *m*. The cause in such a relation, if preempted by *c*, will bar *c* from causally producing its effect. Since this would hold for any obtaining causal relation, there simply could not be an *m* given that a cause *c* brings about *m*, since every would-be cause featured in causal relations building up *m* would fail to actually bring about the relevant effects. (69) is certainly true. An infinitely long causal

chain has no initial constituent purely contingent fact. That leaves (68). Why would one affirm it? Why could we not uphold the claim that *c* causes *m* by causing—*via* overdetermination—all of *m*'s constituent purely contingent facts? Koons (2000, p. 113) failed to (at least) *explicitly* defend the supposition that we are dealing here with a case of preemption instead of a case of *symmetric overdetermination*, or even *joint causation*.

There are several ways to supplement Koons' argumentation. We might follow Martin Bunzl who argued that symmetric overdetermination is impossible (see Bunzl (1979)), though he still admitted that there is *explanatory* overdetermination see p. 145), but Bunzl's reasoning required a specific analysis of events, particularly the analysis of Donald Davidson (1967). [161] Davidson's analysis includes identity or individuation conditions for events (Davidson (1969), (2001, p. 179)), where some event e_1 is identical to some other event e_2, just in case, for any event x, x directly causes e_1 just in case, x directly causes e_2, and for any event x, e_1 directly causes x just in case, e_2 directly causes x (see (ibid.); and the discussion in Simons (2003, p. 374)). This view of the identity conditions of events is flawed, for as Myles Brand (1977, p. 332) pointed out, it equates all events which do not have direct causes, and which do not directly cause other events. It is an undesirable consequence that all ineffectual events are identical. So we should abandon Davidson's analysis of events because of its view of the identity conditions *of* causal *relata*.

There is a different path for defending a related but weaker thesis: With respect to the actual world, there are no cases of overdetermination. One might have good reasons

[161] See Bunzl (1979, p. 145, and p. 150).

for believing in explanatory exclusion, and causal closure.[162] Some believe that if those two dogmas hold, then there are no actual cases of overdetermination. Wim De Muijnck goes further, "[m]etaphysically speaking, no such thing as overdetermination seems possible; this is a consequence…of causal closure and explanatory exclusion" (De Muijnck [2003], p. 65). I, however, find causal closure to be objectionable, and so it is best to look for proper substantiation of premise (68) elsewhere.

Some philosophers have suggested that symmetric overdetermination is improbable. One response to this charge which draws from Schaffer (2003, pp. 27-29); and Paul (2007) is that "quantitative"[163], and/or "constitutive overdetermination"[164] is prevalent. If one is a non-reductionist about the structure of material objects, then a great many cases of macroscopic causation will involve Paul's constitutive overdetermination, in that the parts which compose such wholes (any macro-level material entity) will contribute to causally producing that which the macro-level entity (the whole) brings about (*cf.* Paul[165] (2007, pp. 276-7)). Schaffer recommends that one fend off the objection that parts of the causally efficacious object are not metaphysically distinct enough to

[162] Kim defined causal closure as the thesis that "…*any physical event that has a cause at time t has a physical cause at t*." Kim (1989b, p. 43 emphasis in the original). He says that explanatory exclusion is the principle that "[n]o event can be given more than one *complete* and *independent* explanation." Kim (1989a, p. 79 emphasis in the original).

[163] Mackie's term, from Mackie (1974, p. 43); *cf.* De Muijnck (2003, pp. 65-6); Schaffer (2003, p. 28). Schaffer tells us that, "…quantitative overdetermination occurs whenever the cause is decomposable into distinct and independently sufficient parts". Schaffer (2003, p. 28).

[164] Paul's term from Paul (2007).

[165] I should point out that Paul believes that the consequence of there being such prevalent constitutive overdetermination is "mysterious and problematic". Paul (2007, p. 277). She attempts to rid the world of such prevalence by arguing that fundamental causal *relata* are property instances shared by overlapping entities involved in obtaining causal relations. See Paul (2007, p. 282).

breed overdetermination, by noting that the parts are "*nomologically* correlated" while still "*metaphysically* distinct".[166] I agree with Schaffer's response.

Let me recommend a different strategy. Give attention to a standard explication of symmetric overdetermination as articulated by L.A. Paul (2007, pp. 269-70 emphasis mine):

> In contemporary discussions of causation, standard cases of symmetric causal overdetermination are defined (roughly) as cases involving multiple distinct causes of an effect where the causation is neither joint, additive, nor preemptive (*and it is assumed the overdetermining causes do not cause each other*)…Each cause makes exactly the same causal contribution as the other causes to the effect (so the causal overdetermination is *symmetric*); each cause without the others is sufficient for the effect; and for each cause the causal process from cause to effect is not interrupted.

Now pick out an arbitrary obtaining causal relation which composes *m*. Label the cause *D*, and the effect *E*. If we understand symmetric overdetermination in the way Paul recommends, we cannot say that *c* is a direct overdetermining cause with *D* of *E*, precisely because *c* is a cause of *D* in that it is the cause of *m*. Perhaps a charitable reading of Koons (2000, p. 113) would suggest that by his admission that (in the case as I have adjusted it) *c* is "causally prior" to *D* in that *c* is also the cause of *D*, *c* and *D* cannot be overdetermining causes of *E*. On the charitable reading, my attempted improvement on Koons (2000, p. 113) *per* this paragraph only involves further elaboration upon just how causal priority precludes a symmetric overdetermination reading of the relevant case.

One might think that the charitable reading does not help preclude a joint causation understanding of the case of concern. But this is not right. We were supposing

[166] Schaffer (2003, p. 42. n. 9 emphasis in the original). The objection is tied to Kim (1989a). Some interpret Kim as suggesting that overdetermination just doesn't involve the causation of an event by an object and the parts, which compose it. See Sider (2003a, p. 719. n. 2).

in the Koons-style reasoning above that *D* is a sufficient cause of *E*. So *D* is enough to bring about *E*, and since we are not dealing here with symmetric overdetermination, the relationship between *c*, *D*, and *E* must be understood in terms of asymmetric overdetermination, *i.e.*, preemption.

The above Koons-style argument will generalize to any infinitely long causal chain composed of obtaining causal relations that involve only purely contingent events.

4.3 A New Realist Theory of Causation

Causation is an irreflexive, transitive, asymmetric, and well-founded two-place relation that holds between occurring events. We can say more:

> (**The Account**): Necessarily, for any actually occurring event *x*, and for any actually occurring event *y*, *x* causes *y*, just in case, *y* actually causally depends for its occurrence and contingent content upon *x*'s occurrence.

where the causal dependence relation is a two-place relation that is formally asymmetric, transitive, irreflexive, and both universal and well-founded when the relation connects purely contingent events. The contingent content of an event is the universal or relational property contingently exemplified by the substance or substances featured in that actually occurring event. That the substance has the property it does is properly attributable to the occurrence of the cause of that event. Causal structure "is, at bottom, dependency structure."[167]

One might think that (**The Account**) needs to be revised. You might argue that for any given effect *e* brought about by causes, (**The Account**) implies that any event that made a difference to how *e* occurred is a cause of *e*. Of course, such a result is illicit (call

[167] Hall (2011, p. 101) emphasis removed. For Hall, the quoted statement holds for one of two different types of causation.

this the *too-many-causes* objection). If one tried to avoid the *too-many-causes* objection by demanding that in non-intuitive cases, difference making events which are merely that, do not also serve as causal dependency bases for the imagined effect, (**The Account**) would be susceptible to a triviality charge, it "would give" the notion of causal dependency in the (**The Account**) "a 'whatever it takes' cast that would smack of triviality."[168] But (**The Account**) is not susceptible to this objection. This is because *e* would need to depend for its occurrence (its concreteness) on its causes. Mere difference makers (in the above sense) do not serve as such existence dependency bases. They help fix the contingent content of events but not much else. Still, I am worried by the charge of triviality. Can we say more about the nature of causal dependency and causal structure? Can we, in particular, link such dependency to natural laws? Almost everyone believes there exists some type of connection between laws and causation. Strange that (**The Account**) does not explicitly posit a connection.

We can add some meat to the bones of (**The Account**) thereby ensuring that causation is connected to natural nomicity (at least when causation is natural) by adding an *intrinsicness thesis*.[169] The idea (leaning heavily upon Hall (2004)) is that when causation is a natural relation, causal structures are intrinsic in a way that entails the following thesis:

> (**Intrinsicness Thesis** (**IT**)): "Let *S* be a structure of events consisting of event *e*, together with all of its causes back to some earlier time *t*. Let *S** be a structure of events that intrinsically matches *S* in relevant respects, and that exists in a world with the same laws. Let *e** be the event in *S** that corresponds to *e* in *S*. Let *c* be some

[168] Borrowing Hall's (2004, p. 287) language for a different point.
[169] As in Hall (2004, p. 264).

> event in *S* distinct from *e*, and let *c** be the event in *S** that corresponds to *c*. Then *c** is a cause of *e**."[170]

Let me now make a few comments on precisely how I'm appropriating Hall's (**IT**) thesis. First, by attaching (**IT**) to (**The Account**) for natural causation, I'm intending to affirm the conjunction that is <(**IT**) and (**The Account**)> when the cause or causes in an obtaining causal relation feature substances that are physical entities and the events in the causal relation are *purely contingent* (*q.v.*, propositions (4), (5), and (7) above).

Second, by 'S* intrinsically matches S in relevant respects' I mean "S* is an intrinsic duplicate of S", and by 'S* is an intrinsic duplicate of S', I mean, "S and S* can be represented by an ordered pair {{S}, {S*}} such that each of the constituent events of the members of that pair bear the self-same intrinsic primitive relations".[171] An intrinsic primitive relation R is what Rae Langton and David Lewis (1998, p. 343) called a "basic intrinsic relation". Constituent events of the members of the ordered pair {{S}, {S*}} bear the same basic intrinsic relations if, and only if, those constituents (a) stand in the same qualitative relations which fail to be disjunctive and fail to be the negation of disjunctive relations, and (b) they (the constituents) stand in the same qualitative relations that "are independent of accompaniment or loneliness".[172] The members of any ordered pair {a, b} are independent of loneliness if, and only if, those members could exist with some contingent entity g and stand in R (an intrinsic primitive relation), a and b could exist with g and yet fail to bear R, a and b could exist without any contingent entity such

---

[170] Quoting Hall (2004, p. 264) emphasis mine. I've replaced his apostrophes with asterisks. Hall assumes (i) causal reductionism, (ii) Maudlin's theory of natural laws, and (iii) that the fundamental natural laws are deterministic (ibid., 261). Fortunately, Hall admits that neither assumptions (i) nor (ii) are necessary for an affirmation of (**IT**) (see Hall (2004, pp. 257-258; p. 261. n. 9). Assumption (iii) is unproblematic in this context since I'm providing an account of *deterministic* fundamental causation.

[171] This departs significantly from Hall's own understanding of (**IT**) (for which see Hall (2004b, p. 265, pp. 286-290)).

[172] Langton and Lewis (1998, p. 343).

as g and yet bear R. And finally, a and b could fail to exist without any contingent entity such as g and yet fail to bear R.

Third, Hall (2004) included all of the causes of *e* stretching back to an antecedent time since a great many causes bring about their effects with other causes and through causal processes featuring intermediates (ibid., 264-265, 270-274).

Fourth, one might find my characterization of intrinsic causal structures objectionable. Surely in cases involving preemption (*q.v.*, *e.g.*, **Fig. 1** and its accompanying explanation), the presence of the preempted cause may affect or influence the obtaining causal process. This is perhaps why Hall included the "in relevant respects" clause. I, however, do not see a problem here. The influences involved are often gravitational, and these have a straightforward causal interpretation (see chapt. 3). Thus, while an event *A* may preempt event *B* in causing *C*, *B*'s presence *causally* influences *A*, and influences *C*. In fact, event *B* may even influence the concrete state of affairs that is the obtaining causal relation connecting *A* and *C*. Because these influence relations are causal, they amount to additional obtaining causal relations that are themselves intrinsic. The presence of *B* does make a difference to the causal process connecting events *A* and *C*, but that is only because such difference making amounts to causation. Because structures S and S* include "all…causes back to some earlier time *t*" these structures will include event *B*. Thus, the difference making presence of preempted backup causes does nothing to subvert my characterization of intrinsic causal structures.

Fifth, although Hall motivates (**IT**) by appeal to causal reductionism, that motivation can be easily jettisoned. In fact, (**IT**) is more at home in a realist approach to

causation than a reductionist one, as Hall (2004b, pp. 257-258[173]) himself seems to admit and as Armstrong (2004) and Menzies (1999, pp. 314-317, *cf*. pp. 319-320) argued.[174]

Sixth, I have added (**IT**) to (**The Account**) when natural causal relations are in view so as to save the account from triviality. As I see things, (**IT**) helps in this way by yielding several important implications. For example, if (**IT**) holds for natural causation, then natural "causal relations are *stable* under perturbations of the environment of the process exhibiting them."[175] This implication enables (**The Account**) to handle numerous difficult cases discussed in the causation literature, including symmetric overdetermination cases, and early, late, and trumping preemption cases.

Consider **Fig. 1** below:

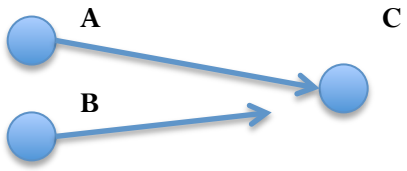

Fig. 1: Late Preemption

Fig. 1 is a neuron diagram. The blue circles represent firing neurons (events), the arrows are causal stimulatory connections, and the times at which these events and connections are established is read off of the illustration from left to right. Italic letters will represent the event of the firing of the labeled neuron, while bold letters will represent individual neurons. Thus, neurons **A** and **B** fired at a time t_0, while **C** fired at a time t_1.[176] What **Fig. 1** says, therefore, is that **A**'s firing caused **C**'s firing, and while **B** fired at the same time **A** fired, its stimulatory signal failed to reach **C** at t_1, though had **A** failed to fire, **C** would

[173] "This position [an intrinsic view of causation] is most naturally developed as part of a certain kind of non-reductionist position about causation, according to which facts about what causes what are metaphysically primitive…" Hall (2004, p. 258).

[174] See Armstrong (1997) and Tooley (1990) *inter alios*.

[175] Hall (2004b, p. 264).

[176] See Collins, Hall, and Paul (2004, p. 17).

have still fired since the stimulatory signal sent out from the event that is **B**'s firing would have brought about **C**'s firing. Various counterfactual theories of causation have a hard time with the above.[177] But (**The Account**) coupled with (**IT**) handles **Fig. 1** well. Again, "causal relations are *stable* under perturbations of the environment of the process exhibiting them."[178] Adding *B* and its stimulatory signal to the relevant environment of the causal relation's obtaining does nothing to subvert the fact that *A* caused *C*.[179]

Now consider Figure 2:

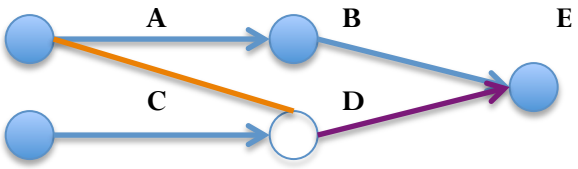

Fig. 2: Early Preemption[180]

In this case, *A* causes *B*, which in turn contributes to **E**'s firing. But a separate causal process is initiated by *C*'s sending a stimulatory signal to **D**, although because **A**'s firing also sends an inhibitory signal to **D**, **D** fails to fire (the inhibitory signal keeps **C**'s stimulatory signal from causing **D** to fire). Were **D** to have fired, it would have sent a stimulatory signal to **E**, thereby causing **E**'s firing. **A** is therefore an early preemptor of **C**, since its firing inhibits *D* cutting off the causal process that was to extend from *C* to *E*. Early preemption cases such as this give both regularity and simpler counterfactual accounts of causation a very hard time,[181] but for my specific view, early preemption cases are unproblematic. *E* actually causally depends on *A*. Additions to that structure

[177] The case is problematic for theories resembling Lewis's (1973a) account.
[178] Hall (2004, p. 264).
[179] My account of events may entail that in the counterfactual situation in which **A** fails to fire and yet **B** fires, *C* is not what results. Rather, an event that occurs later than t_1 occurs, and since times are essential to events, the effect of *B* cannot be *C*.
[180] See Collins, Hall, and Paul (2004, p. 18); Paul (2009, p. 168). The orange line is an inhibiting signal sent from **A** to **D**.
[181] As has been pointed out by Collins, Hall, and Paul (2004, p. 18); and Paul (2009, p. 168).

involving **C**, **D**, and the inhibitory signal sent from **A** to **D** does nothing to undercut this fact. The truth of (**IT**) guarantees this for causal relations such as those that connect *A* and *E*.

What of symmetric overdetermination cases such as **Fig. 3** below?

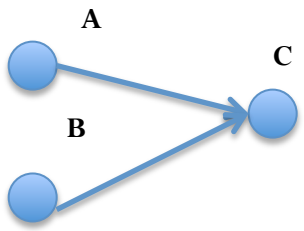

Fig. 3: Symmetric Overdetermination

In **Fig. 3**, both *A* and *B* causally produce *C* by sending their own causally sufficient stimulatory signals to **C**. Each signal reaches **C** at the same time, and both **A** and **B** fire at the same time. This example is also trouble for a number of different theories of causation, but it should not trouble the proponent of (**The Account**) plus (**IT**) for natural causation. *A* and *B* are both causes of *C*. Period. There's simply nothing more to say.

Finally, consider the infamous trumping preemption case illustrated by **Fig. 4** below:

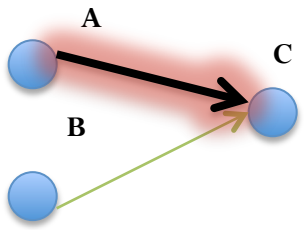

Fig. 4: Trumping Preemption

In **Fig. 4**, both *A* and *B* send stimulatory signals to *C*, except that **A**'s firing is significantly more intense than **B**'s firing, and so as a result, *A*'s stimulatory signal is

significantly more intense than *B*'s. Because *A* and its stimulatory signal are so overpowering, **A**'s firing is the cause of *C*. Moreover, one should not understand **B**'s firing as an additional cause of *C* since the intensity of **A**'s firing trumps *B* (hence the skinny yellow arrow). If you do not have that intuition, perhaps the quoted pericope below will help one have the relevant seeming:

> The sergeant and the major are shouting orders at the soldiers. The soldiers know that in case of conflict, they must obey the superior officer. But as it happens, there is no conflict. Sergeant and major simultaneously shout 'Advance!'; the soldiers hear them both; the soldiers advance…since the soldiers obey the superior officer, they advance because the major orders them to, not because the sergeant does. The major preempts the sergeant in causing them to advance. The major's order trumps the sergeant's.[182]

The case as described by the above illustrative story is very helpful since it highlights precisely why the trumping preemption phenomenon is unproblematic for (**The Account**). What fixes the contingent content of the event that is the soldier's advancing is the major's order, not the sergeant's. (**The Account**), therefore, provides the right result since it counts as the cause only that which fixes such content.

Suppose one duplicated the trumping preemption case as described by the excerpt above, but this time one added in a commanding general. The general's command will trump the major's, but by (**IT**) the Major's order will count as the cause of the advance, *reductio ad absurdum*. Recall that my theory of events is very much in the property exemplification camp. Events are therefore fragile entities. Once we continue to add in overly powerful causal processes (at third, fourth, and fifth levels) trumping all other potential causes and causal processes, one wonders whether or not the effect remains the same. One wonders, for example, whether or not the token event that is the advancing of

[182] Lewis (2000, p. 183) who credits the example to Bas van Fraassen in ibid., 183 n. 3. *Cf.* Schaffer (2000).

(say) five specific army rangers is one and the same as the token event involving army rangers moving forward on account of orders issued by a commanding general. Surely the effect occurs in a way that is in some sense different than it would have otherwise been had the major ordered the advance. For example, perhaps the advance becomes a charge. The intensity with which a cause acts on other objects has a bearing on what events are produced given that events are sufficiently fragile entities.

4.4 General Objections to Causal Anti-Reductionism

As is common with realist and/or non-reductive approaches to causation (see Anscombe (1971); Brand (1975); Broad (1968); Carroll (1994), (2009); Peterson (1898, p. 61); Scriven (1971), (1975, p. 15); Taylor (1966); Woodward (2003)[183]), (**The Account**) does not reduce causation to anything non-causal. One way to quickly see this is that the *analysans* of (**The Account**) includes the clause '*causal* dependence'. But it is important to point out that (**The Account**) is not primitivist about causation. Primitivism implies that causation has no analysis whatsoever, and while anti-reductionism is implied by primitivism, anti-reductionism does not imply primitivism.

Because (**The Account**) is non-reductive it is susceptible to a number of general complaints commonly lodged against causal anti-reductionism. For example, some would maintain that causal realism or anti-reductionism is just plain uninformative.[184] But such a charge cannot be appropriately lodged against (**The Account**) especially when it is coupled with (**IT**) for physical causation. This is because (**The Account**) links causation to causal dependence and other notions. It also specifies what causal dependence for

[183] See also Fales (1990, pp. 11-25); and Tooley (1987), (1997, pp. 84-122), (2003, p. 392).

[184] See Ehring (1997, p. 62). Carroll (2009, pp. 290-291) provides a plausible line of response to this worry, as does Woodward (2003, pp. 20-22). I will, to some extent, follow them in the main text above.

contingent content amounts to, while also precisely detailing the formal nature of that dependence. Furthermore, (**IT**) links physical causation to laws and entails that physical causation is intrinsic. These are substantive and informative facets of (**The Account**) for physical causation.

Woodward (2003, p. 21) has pointed out that one can ensure the non-triviality and therefore informativeness of a non-reductive account of causation by revealing precisely how it conflicts with other reductive and non-reductive accounts. I should therefore clearly disclose that (**The Account**) is incompatible with Woodward's (2009, p. 250) own non-reductive manipulationist theory of causation and causal explanation since it assumes that events (understood in terms of (37) above), and not the values of variables, are *sole* causal *relata*, and that not all obtaining causal relations are backed by laws. (**The Account**) makes no room for interventions, and does not incorporate talk of probabilities. Moreover, Woodward's commitment to the underlying thesis—the idea that laws always back obtaining causal relations—entails a type of philosophical naturalism.[185] My account avoids this implication.

The most serious charge against causal realism is one from ontological parsimony. Some philosophers (*e.g.*, Sider (2011)) would maintain that since the notion of causation is not indispensable to the ideology of our best theories, that notion does not carve reality at the joints, and so that notion should not be regarded as fundamental. Causation is dispensable to our best theories because adding that notion "to physical theory…doesn't seem to enhance its explanatory power."[186] *Pace* Sider, causal talk is

[185] See the comments in Woodward (2003, p. 173).

[186] Sider (2011, p. 15). In the context of the quote in the main text, Sider is directly discussing natural laws, but on page 16 he goes on to point out that what he says about laws applies also to causation. See also Schaffer (2008, p. 91).

indispensable to the ideology of our best theories. I tried to show this in sect. 1, but one can, for all intents and purposes, set those considerations aside. Given (**The Account**), and (**IT**), I believe that instances of dimensioned realization or microphysical determination involve instances of causation and not a few of our best theories require successful functional analyses of scientific phenomena and therefore make use of obtaining dimensioned realization relations.[187] The realist can therefore respond to parsimony worries of this variety by explicating precisely how it is that realization essentially involves causation.

4.5 Causal Realization and Causal Grounding

4.5.1 Dimensioned Realization

Dimensioned realization is a many-one asymmetric[188], irreflexive[189], and transitive[190] determination and dependence relation thought to actually hold between property instances or states of affairs.[191] Given (**The Account**), causation can also be a many-one asymmetric and irreflexive relation that holds between property instances so long as those instances involve substances contingently exemplifying universals or relational properties at times. But is there something to the determination aspect of dimensioned realization that precludes one from interpreting or understanding obtaining dimensioned realization relations as obtaining causal relations in the sense of (**The Account**)? I do not believe so. Consider the account of Carl Gillett:

---

[187] See Aizawa and Gillett (2009).

[188] "It should be noted that realization is an essentially asymmetric relation and therefore it has at least one of the marks of a genuine dependency relation." Poland (1994, p. 193)

[189] Bennett (2011, p. 84. n. 12).

[190] Physical realization is thought by many to be a transitive relation. See Horgan and Tienson (1996, p. 23); and Marr (1982).

[191] See Aizawa (2013); Gillett (2002), (2003), (2011). *Cf*. Gillett (2007) and the discussions in Bennett (2011, pp. 82-85); Polger (2004, pp. 116-125); Shoemaker (2007, pp. 32-33).

> (71) Events involving the instantiation of properties f_1-f_n realize an event involving an individual i exemplifying a property d in circumstance *C*, just in case, in *C*, properties f_1-f_n collectively impart or provide powers to either the individual i or its parts "in virtue of which" individual i "has powers that are individuative of an instance of" property d, "but not vice versa."[192]

The emphasized portion of the above definition of realization is what's important for my purposes. Gillett and company provide no real analysis of the collective "imparting" or "contributing" that extends from the realizing base to the realized entity or entities. (**The Account**) coupled with (**IT**) suggests a causal interpretation of such imparting. Individual i or its parts come into the possession of the relevant powers on account of causal contribution. The individuals exemplifying the realizer base properties (in this case f_1-f_n) constitute events which together cause individual i or its parts to inherit the relevant powers. Individual i's having the relevant causal power in *C* (at the relevant temporal index) causally depends upon constituent individuals having properties f_1-f_n at a time.

What place is there in my theory of causation for the powers explicitly referred to in the definition of realization above? Does not (**The Account**) commit me to the tradition that has typically understood causal structure in terms of dependence structure and not in terms of capacities, and causal powers?[193] Yes. I am committed to the causal dependency tradition, but I am also open to a deeper metaphysical story about why it is that causal dependency relations obtain, and these relations may obtain by virtue of powers and capacities possessed by individuals governed by causal laws.[194] Unfortunately, the powers and capacities approach to causation and the metaphysics of

[192] Gillett (2002, p. 322); Gillett (2003, p. 594). Polger and Shapiro (2008) object to the view, but Gillett (2011) has responded convincingly.

[193] See the discussion in Hall (2011, p. 101).

[194] If such a deeper story were successful it would still be anti-reductionist, and thoroughly incompatible with, for example, general reductive theories such as Humeanism.

science in general "is still programmatic with nothing that is widely regarded as demonstrated."[195] That said; I do believe one can accommodate the real existence of the powers needed for Gillett's metaphysic of realization while remaining well within the confines of the framework already adopted. Recall that even primitivists about powers regard them as universals instantiated by or in substances.[196] Individual's such as i have or exemplify powers that are "individuative of an instance of" the further property d. That individual's having that power is itself an event. That event causally depends upon the occurrence of several events involving certain micro-constituents having various properties such as f_1-f_n. And I should add that insofar as instances of multiple realization require obtaining realization relations, multiple realization can also be interpreted causally.[197]

4.5.2 Grounding

According to Jonathan Schaffer (2009), (2010, pp. 345-348), grounding or priority relations are well-founded, transitive, and asymmetric relations of dependence that obtain between actual concrete entities. Schaffer contrasts this kind of dependence and priority with causal dependence, musing that when *x* is prior to *y*, *x* is not *causally* dependent upon *y* (Schaffer (2010, p. 345)). This latter point is too hasty.

Assume that (**The Account**) holds. Now through the following imaginary episode, peer with the mind's eye into a possible situation that is no doubt familiar to those who have read the causation literature (Schaffer (2000, pp. 165-166 *adjusted here*)):

---

[195] Mumford (2009, pp. 268-269).

[196] Ibid., p. 269.

[197] Gillett's account lays down four conditions that must be satisfied for obtaining multiple realization relations. One of these conditions includes the necessary and sufficient conditions for obtaining realization relations. See Aizawa (2013, p. 71) who cites Gillett (unpublished).

(72) Merlin casts a spell that turns a "prince into a frog" at 7:00pm.

Arguably, the object that is a frog is a new entity, one that did not exist before.[198] The frog owes its nature and positive ontological status to the magical causal activity of Merlin. So in *Possible Situation*, Merlin's magical activity is causally prior to the frog's beginning to exist at 7:00pm. Or, at least, Merlin's magical activity is causally prior to the event that is the frog's instantiating its essence at 7:00pm, or the event that is the frog's instantiating all of the properties it has or had at 7:00pm. Its plausible then to think that Merlin's magical activity is prior to either the actual entity that is the frog, or the relevant state of affairs that involves the frog's coming to be at 7:00pm, in such a way that the frog or the relevant event depends for its nature and positive ontological status upon the magical activity of Merlin. Now given my arguments that causation is well-founded, asymmetric, and transitive, and given (**The Account**) it seems that causal priority can be legitimately understood as a kind of deep grounding priority when one event grounds another (*contra* Schaffer).

[198] If you don't think this, then put a twist on *Possible Situation* such that Merlin casts a spell that brings the frog into existence at 7:00pm (a veritable instance of *creatio ex nihilo*). This seems perfectly conceptually possible in that I can conceive of such a states of affairs, and there does not seem to be a metaphysical law (on the assumption that causal realism is true) to which this situation is contrary, and so the situation is also metaphysically possible.

Chapter 5 An Account of Token Physical Explanation

> "We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances".
> - Newton (1966, p. 398)

It is time to defend my view of physical explanation. The view I discuss and defend is not an account of general scientific explanation. I'm not interested in articulating in what sense GTR subsumes STR for example. Nor does my account detail the sense in which there can be explanations of natural laws (as in Friedman (1974)). Rather, I'm interested in token physical explanation of obtaining states or occurring events.

The provision of both explanations *of particular phenomena* and descriptions of empirical phenomena constitute the heart and soul of physical science. William Alston (1971) disagreed. For Alston, well-ordered science should not give pride of place to token physical explanations of states. Even the "pure" or theoretical sciences are chiefly concerned (by Alston's lights) with the discovery of natural laws. Alston proposed that with respect to explaining particular states we are, more often than not, at a disadvantage epistemically in two different ways.

First, an explanation of a particular state, even with somewhat idealized laws in hand, has need of that which *is responsible for the specific state* in question.[1] The problem is that often we cannot identify in many specific instances what precisely those responsible entities are. The relevant factors may be epistemically removed from us since such factors may be unobservable, or hidden away in some inaccessible part of the past.[2] I respond that this appears to be a pseudo-problem. It is indeed sometimes the case that

[1] Alston (1971, p. 29).
[2] Ibid.

parts of the etiologies of events are hidden from us. That may in fact mean that no explanation that depends upon an appeal to such parts will be complete. But why is that problematic? Alston does not show that in the context of physical theories (what he calls "pure" science) all would-be token physical explanations suffer from this problem. In point of fact, Alston depends most heavily upon special science cases. His supporting evidence can be accepted and his more general conclusion affirmed in the context of the special sciences. I'm providing an account of token *physical* explanation, that is, explanation in physics. There may not be physical explanations of the kind I have in mind in the special sciences, and that is because laws (quoting Maudlin) "ought to be capable of playing some role in explaining the phenomena that are governed by or are manifestations of" them.[3] There may not be any such things as special science laws. They are not exceptionless as the laws of physics appear to be.

Second, the laws that back token physical explanations may be of a form that makes it too difficult to discern that which is responsible for the state reported on in the *explanandum* or *explananda*. Alston's case for this latter point is extremely weak. He conceives of laws as providing either necessary (NC laws) or sufficient conditions (SC laws) for some event-types. I think it is obvious that a law that merely reports on the necessary conditions for event-types will not provide us with enough information to ascertain the responsible variables. We are in no better situation with laws that give the sufficient conditions for the *explanandum* or *explananda*. But these matters should not worry us. As I indicated above, no contemporary account of natural laws explicates them

[3] Maudlin (2007, p. 8).

in terms of NC laws. In fact, I'm aware of no account that understands them in terms of SC laws either.[4]

Physical science is very much in the business of describing, but it also concerns itself with explaining particular physical facts. For example, many physicists have attempted to explain the universe's low-entropy state. In truth, many of the Nobel prizes in physics are given for discoveries that yield powerful physical explanations of distinct states. And even for those that are given for important discoveries, often those discoveries provide impetus for the search for token physical explanations of physical states. For example, in the report giving the scientific background on the Nobel Prize in physics in 2011 (compiled by the class for physics of the Royal Swedish academy of sciences) we have:

> …observations of type Ia supernovae (SNe) at distances of about 6 billion light years by two independent research groups, led by Saul Perlmutter and by Brian Schmidt and Adam Riess respectively, reveal that presently the expansion rate instead is accelerating. Within the framework of the standard cosmological model, *the acceleration is generally believed to be caused by the vacuum energy* (sometimes called 'dark energy')…The observations present us with a challenge…What is the source of the dark energy that drives the accelerating expansion of the Universe? Or is our understanding of gravity as described by general relativity insufficient? Or was Einstein's 'mistake' of introducing the cosmological constant one more stroke of his genius? Many new experimental efforts are underway to help shed light on these questions.[5]

Why are there concrete states of the cosmos involving its accelerated expansion? What is responsible for its acceleration? The discoveries of Perlmutter, Schmidt, and Riess motivated token physical explanation seeking,[6] and the contemporary token physical

[4] I believe that Tim Maudlin's (2007) account of laws allows one to escape the problem.
[5] Class of Physics of the Royal Swedish Academy of Sciences (2011, p. 1, pp. 14-15).
[6] See for example Riess et. al. (1998).

explanation is that the acceleration of the universe is due to or is "by energy in the vacuum".[7]

5.1 Explanations as Arguments

The physical sciences do concern themselves with token physical explanations. But what are such explanations like? I believe they are, in terms of their form, arguments. This is the third dogma of empiricism.[8] The dogma has an illustrious philosophical history. It can be traced back to Aristotle's *Posterior Analytics* (Bk. 1, Chapt. 2), and has been defended in more modern times by Richard Braithwaite (1968, p. 22), Carl G. Hempel and Paul Oppenheim (1948, pp. 137-138), Ernest Nagel (1961, pp. 29-46), Karl Popper (1959), and Michael Strevens (2008, p. 77), (2012, pp. 448-449). Every physical explanation must involve only *essential* premises reporting on either initial conditions, or occurring purely contingent events (or both), as well as true natural laws that are altogether causally sufficient for the occurrence of the event or events reported on by the conclusion. The premises are essential in that each contributes to the aforesaid causal sufficiency, and each is necessary for guaranteeing that sufficiency.

Every argument that is a scientific explanation must, in a factive manner, remove puzzlement about why the event reported on in the conclusion occurs with the particular contingent content it features.[9] When a set of propositions *q* scientifically explains *p* (E^sqp, for short), both *q* is true, and *p* is true. In addition, properly functioning cognizers who know that E^sqp, also know why the target event reported on in *q* occurs. This is the

[7] Ibid., 1027.
[8] Salmon (1998, p. 95-107).
[9] The idea that explanations involve removal of puzzlement appears in Barnes (1982, p. 54); Ohreen (2004, p. 118); and Pruss (2006).

sense in which scientific explanation contributes to our understanding of the world. Or so I will argue.

The aforementioned is an adumbration of my view. More needs to be said. Before I can provide a thorough statement and defense of my account, however, I will need to deal with the host of objections to the third dogma, for if any of these succeed, my account will never get off the ground.

Consider first the complaint that scientific explanations are temporally asymmetric, while arguments and inferences are not always temporally asymmetric. As Wesley Salmon stated, "[w]e have many records, natural and humanly-made, of events that have happened in the past; from these records we can make reliable inferences into the past."[10] However, we do not explain past events by means of future ones. But this worry does not apply to my account of scientific explanation. Causal constraints are placed on the types of arguments and inferences that are legitimate explanations. If scientific explanations must be temporally asymmetric, that asymmetry is inherited from the underlying temporal asymmetry of causation.[11] I do, however, believe that not all scientific explanations are temporally asymmetric since obtaining causal relations that do not relate a temporally prior cause to a temporally subsequent effect back some such explanations. For example, in the general theory of relativity the gravitational field's action on a particle "whose history is" a curve in spacetime is *independent* of time.[12] And I have already argued that such action is causal (see chapt. 3). The explanation of, for example, the inertial motion of the particle that involves the action of the gravitational

[10] Salmon (1998, p. 102).
[11] Strevens (2008, pp. 24-27).
[12] Hawking and Ellis (1973, pp. 71-72).

field is not temporally asymmetric, though it is formally asymmetric, since the underlying and backing causal relation is formally asymmetric.

Wesley Salmon (1998, pp. 95-97) has argued that scientific *explanans* cannot countenance irrelevancies though arguments can. This fact shows that there is some disparity between the two notions. Scientific explanations are not arguments. But I respond as follows: One *cannot* simply add in whatever premises one wants to deductive arguments that are scientific explanations so long as validity is not disturbed, for as I stated above, arguments that are physical explanations must involve *only essential* premises reporting on either initial conditions, or occurring purely contingent events (or both), as well as true natural laws that are altogether causally sufficient for the occurrence of the event or events reported on by the conclusion. Call the event or events reported on in the conclusion of such arguments the *explananda* of those arguments. One might now counter that every cause in the etiology of the *explananda* or *explanandum* counts as an event that must figure in the premises that constitute the scientific *explanans*, and since causation is transitive (see chapt. 4), a great many *explananda* will have *explanans* that involve events reaching far back into the history of the cosmos. These events that are far removed, temporally speaking, from the *explananda* seem irrelevant, though my account seems to suggest that they must nonetheless figure in the proper scientific *explanans* of those *explananda*. This seems absurd.

The above represents a problem for virtually every causal account of scientific explanation.[13] I answer that what causes ought to be included in the *explanans* of some *explananda* or *explanandum* are those, which would remove an ideal agent's (an agent in

[13] See the discussions in Railton (1981, pp. 240-247); Salmon (1984, p. 207, p. 275); and Strevens (2008, pp. 41-65).

the context in which the explanation is being proffered) puzzlement about why the event(s) reported on in the conclusion, occurred with the particular contingent content it/they featured. An ideal agent in such cases is simply one whose cognitive faculties are not subject to cognitive malfunction and who can justifiably believe (in a knowledge conducive way) on the basis of the content of the premises, that the event(s) reported on in the conclusion, occurred with the content it possessed.[14] Whether or not puzzlement is removed in such scenarios depends upon the practical interests of the ideal agent in question. And here I coopt and adjust some relevant pieces of the epistemic practical interests literature.[15] "There are cases in which two people are similarly situated, but one has" their puzzlement removed by a report on the content of a particular *explanans* "whereas the other does not, because one has greater practical investment in the" phenomenon that is being explained.[16] Thus, whether or not one has successfully explained *q* by appeal to *p* depends upon the practical facts about the interested inquirer(s). Explanation is an "interest-relative" phenomena (following Stanley (2007, pp. 168-169) on knowledge).

What is the precise relationship between the practical interests of an ideal agent and the etiology of the *explanandum* or *explananda* one is attempting to remove puzzlement about? I will not commit to any specific account. It may be that the degree to which one is practically invested in the physical details of a particle taking a certain trajectory around a binary pulsar system requires a far more detailed and more exhaustive report on the causes and influence relations resulting in the particles exact trajectory. Thus, the standards are high in physics literature. More information about the etiology is

[14] I'm assuming the proper functionalist analysis of knowledge in Plantinga (1993b).
[15] Fantl and McGrath (2002); Stanley (2005); (2007).
[16] Stanley (2005, p. 2).

therefore required in the reports of the relevant premises of the *explanans*. When, however, an ordinary ten-year-old is told that the particle traveled down trajectory *t*, and that ten-year-old asks "why did it take trajectory *t*?", one's explanation need not be nearly as informative or exhaustive in its report on the involved influence relations, though it is important to note that the premises of the argument will still need to be causally sufficient for the occurrence of the phenomenon in question.

How many causes ought to be reported on in an *explanans* is connected to the practical interests of an ideal version of the agent(s) for whom the explanation is being provided. The practical interests themselves depend upon the serious practical questions the agent ought to be considering.[17] These questions are themselves linked to the goals the agent would have were they rational.[18] They are also dependent upon the decisions the agent would make were they completely rational. The details of rational decision-making and the like I leave to those philosophers working on practical rationality, and decision theory. There is therefore both a practical and normative element to explanation.

But can there be token physical explanations of events that are highly unlikely? Does not the fact that physical explanations are arguments suggest that the *explanandum* or *explananda* are probable or likely conditional on the premises of such arguments? As Salmon put it: "A high probability is demanded by the requirement that the explanation be an argument to the effect that the event in question *was to be expected*, if not with certainty, then with high probability, in virtue of the explanatory facts."[19] This suggests that scientific explanations, understood as arguments, can never remove puzzlement

[17] Ibid., p. 92.
[18] Ibid.
[19] Salmon (1998, p. 97) emphasis mine.

about why some highly unlikely event (*e.g.*, the decay of the nucleus of a piece of uranium) occurred.

The difficulty can be overcome by an invocation of indeterministic causal sufficiency. Some causes may bring about an effect even though the cause's bringing about that effect only have a small chance of resulting in such production. Think, for example about Schaffer's (2000, p. 40) cases involving spell casting. Morgana can cast a spell, which only has a .4 chance of resulting in the occurrence of some event. If the event in question occurs, it seems right to say that Morgana's spell was the cause of the event. An ideal gas in a box with perfectly elastic walls that is in a thermodynamic equilibrium state, may undergo a highly unlikely fluctuation that results in the low-entropic state of the entire physical system. It seems right to think of the prior state of the system together with backing laws as the cause of the fluctuation despite the fact that the objective probability of the fluctuation's occurrence is low. Furthermore, a proper theory of indeterministic causation may suggest that it is more probable or likely given that the cause occurred, that the effect in question occurs, though the overall objective probability of the effect is still low.[20]

5.1.1 Causal Sufficiency and Deductive Inference

Some scientific explanations are deductively sound arguments. The premises of such arguments entail respective conclusions. But there is, of course, more to say. Because causation is indispensable to scientific explanations, such explanations involve premises that report on obtaining antecedent conditions or events, and natural laws that

[20] David Lewis's (1973a) account of indeterministic causation is like this, and while I am a realist about deterministic causation, I don't see any inconsistency in affirming a reductive theory of indeterministic causation.

causally entail the event or events reported on in the conclusion of the argument (similar to Strevens (2008)). The arguments in question must have restricted logical forms. They must be instances of *modus ponens* or modal *modus ponens*, where at least one of the indispensable premises is at least a material conditional (though it can be a strict conditional) having as one of its sub-sentential parts an antecedent that contains all of the other indispensable premises as conjuncts. The consequent of the conditional will contain the conclusion as its only sub-sentential part.

What ensures the truth of the conditional premise is the fact that the events, laws, and antecedent conditions discussed in the antecedent of the conditional are all causally sufficient for the occurrence of the event(s) in the consequent. If the laws in question are true, and the antecedent conditions or events that constitute the cause of the target event occurred, then the target event will itself occur.

Causal sufficiency may be probabilistic, or deterministic. The difference amounts to the type of causal relation that obtains between the *relata* reported on in the premises, and the target event(s) in the conclusion. If the causal relation is deterministic, the backing laws will be deterministic, and the account of causation defended in chapter 4 will be applicable. If, however, the involved causal sufficiency is probabilistic, then the backing natural laws will be probabilistic, and the causation in play will be indeterministic. My take on either type of causal sufficiency requires no particular commitment to any one view of deterministic or indeterministic laws. Nor does what I say about causal sufficiency require a commitment to any one view of indeterministic causation.[21]

[21] There are many accounts of indeterministic causation. I do not pretend to know what such causation amounts to.

Physical explanations understood as arguments provide one with warrant for one's beliefs about why the events in question occurred (I call this knowledge-why). They do this so long as one justifiably believes that the true premises of the argument entail the true conclusion though one need not actually grasp the entailment relationship itself.

5.1.2 Explanatory Abductive Inference and Physical Explanation

While physical science is in the business of physically explaining phenomena, it would be inappropriate to characterize a lot of the business of actual science as progressing solely by means of providing such explanations. In point of fact, I believe that often times physicists infer to the besti explanation. And so, I naturally agree with Gilbert Harman (1965), *there actually are inferences to the best explanation* (IBEs).[22] These inferences constitute a class of inference making that is not reducible to inductive or deductive inference making. IBEs constitute a unique class of ampliative inferences that are not even fully captured by the deliverances of probability and confirmation theory. In this subsection, I will seek to say precisely what such inference making amounts to in the context of physical inquiry, and I will assume explanationism, where explanationism is the view that IBEs, in the context of physical inquiry, provide warrant or epistemic justification for beliefs in hypotheses understood as scientific explanations of phenomena in the sense articulated and defended above.[23]

---

[22] The most convincing argument, I think, for IBE appeared in the work of Weintraub (2013). Cartwright (1983), Hacking (1983), and van Fraassen (1980) disagree. Others respect some form of abductive reasoning though they reject the thesis that there is any such thing as abductive *inference*. See, for example, Ben-Menahem (1990) and Kapitan (1992).

[23] The position that is explanationism was first discussed in Cornman (1980). *Cf.* Liption (2004); Lycan (1988), and Lycan (2002, pp. 417-430).

IBEs, in the context of physical science, are explanatory arguments. They have logical forms expressed schematically as:

(1) Fact 1, Fact 2,…, Fact N cry out for an explanation.
(2) There are an appropriate class of potential physical explanations E_1,…,E_n of Fact 1, Fact 2,…, Fact N.
(3) E_2 is the best potential physical explanation of Fact 1, Fact 2,…, Fact N.
(4) Therefore, it is credible that E_2 physically explains Fact 1, Fact 2,…, Fact N.

Facts 1,…, Fact N report on the occurrence of physical phenomena (call these events or phenomena *results*). These facts are the *explananda*.

What work does the locution 'it is credible that' do in (4)? That operator simply highlights the fact that the inference is not deductive. Premises (1)-(3) do not entail the truth of (4). Rather, the inference from (1)-(3) to (4) is ampliative. Some, such as Lycan (2002, p. 413) prefer to use the qualifier "probable" or "it is probable that" in the conclusion of abductive arguments, but I do not want to suggest the idea that ampliative inferences of this kind reduce to truths about probabilities.

What about the clause 'appropriate class of potential physical explanations'? What is a potential explanation, and what would constitute an appropriate class of such entities? A potential physical explanation is an argument that (i) satisfies all of the desiderata of a valid and sound token physical explanation articulated above, that (ii) has a conditional premise whose antecedent is nomologically possible, and that (iii) involves a conclusion that is Fact 1, Fact 2,…, Fact N. If the explanatory argument is cogent (*i.e.*, all of its premises are true, and there is sufficient justification from a heuristic of epistemic values that buttresses premise (3)), then the appropriate class of potential physical explanations is a set that must at least include a potential explanation that does in fact attenuate cognitive dis-ease about, remove puzzlement about, or reduce one's

surprise concerning the *explananda*.[24] That is to say, E_2 provides one with knowledge-why.

The set of potential explanations is an appropriate class in that it also includes arguments or physical explanations whose conditional premises have antecedents that report on nomologically possible deterministic or indeterministic causes of the *results*. The class is also "appropriate" in so far as the arguments that are the potential explanations possess a particular epistemic nature. These potential explanations are such that were you to consider them in isolation they would, were you rational, provide one with at least defeasible *prima facie* epistemic justification for belief in the proposition that the facts reported on in the premises actually do scientifically explain the *explananda*, and therefore the results.

Having an appropriate class of potential explanations is important. One does not want to allow for easy abductive inference making in the sense that one's range of competing explanations is significantly poor and therefore qualitatively worse than E_2 from the start. The field of competition must be *real* competition. What is more, E_2 itself cannot be intrinsically implausible. It must pass over a threshold.[25] The threshold, I believe, is one intimately related to knowledge-why. Cogent IBEs provide one with *warrant* for one's belief that the best explanation successfully and legitimately removes puzzlement about the results.[26]

---

[24] At least, one's ideal self will have such dis-ease removed. That explanation involves the reduction of surprise or the reduction of cognitive dis-ease was the incite of Bruce Glymour (2007, p. 133).

[25] Lycan (2002).

[26] As in Bergman (2006) and Plantinga (1993b). I'm assuming that warrant is that which separates knowledge from mere true belief.

5.1.3 Epistemic Virtues

As I alluded to in the above, what supports premise (3) is an appropriation of a set of epistemic values that privilege E_2 over the other potential explanations in the appropriate set. Here is a list of the values I believe constitute a substantial heuristic for testing competing hypotheses or potential explanations:

(1) Explanatory power
(2) Explanatory scope
(3) Explanatory plausibility
(4) Coherence
(5) Testability
(6) Less ad hocness
(7) Comparative superiority[27]

In this subsection, I will focus most intently on (1). I will argue that while epistemic probability plays an indispensable role in accounting for that virtue, it *does not* account for all the virtues in the sense that the best explanation just is the most epistemically probable one (whether in the subjective or objective sense).

5.1.3.1 Explanatory Power and Epistemic Probability

The explanatory power epistemic virtue is one, which says that the best explanation will be the potential explanation that renders the *explananda* more epistemically probable than any of the competing potential explanations do. The idea is that the probability of E_2 given Fact 1,…, Fact N and one's background knowledge will be greater than the probability of any other competing potential explanation (in the appropriate class of competitors) given the same facts and our background knowledge.

E_2 is epistemically probable given Fact 1,…, Fact N. Many understand such epistemic conditional probabilities in subjective Bayesian terms,[28] and from my reading

[27] I've drawn on the lists in Moreland and Craig (2003, p. 62); and Lycan (2002, pp. 415-416).

I've discerned two ways subjective Bayesians define conditional probabilities. First, one might say that Q is epistemically conditionally probable on R given that Pr(Q) < Pr(Q/R). A second way of understanding Q's being highly probable on R amounts to it being the case that the Pr(Q/R) is sufficiently high (above some threshold) say. But suppose that the second understanding of epistemic conditional probability is correct. Plantinga's (1993b, p. 143) objection will now run as follows: (Claim): I can know two propositions Q and R, though Q is epistemically conditionally improbable on R (at the same moment in which I know Q and R). I can know, for example, that <Nine out of ten superpartners have spin along their x-axises and that a certain particle (George) is a superpartner.> (call this proposition R), and I can also know that <George does not have spin along its x-axis.> (call this proposition Q). I think it is intuitively obvious that Pr(Q/R) is low. But if that's right, then the Bayesian relativization of epistemic conditional probabilities will not explain the epistemic conditional probability of Q on R, since if I know Q and R, my credence in each will be so high that Pr(Q/R) will be high if not one. The Bayesian approach therefore seems wrong to me. It says one cannot know two propositions Q and R, though Q is epistemically conditionally improbable on R.

Suppose the first way of understanding epistemic conditional probability is right. Now Plantinga's other (1993b, pp. 143-144) objection runs.[29] Let R be the proposition that <George has spin along its x-axis.> We can easily set up artificial scenarios in which my credence function in R is greater than my credence function in R given Q. But intuitively, the epistemic conditional probability of Q on R is very high. It seems at least

[28] See many of the essays in the collection of Eagle (2011a).
[29] See also Plantinga (1993a, pp. 129-131).

to be intuitively obvious that Q is evidence for R irrespective of what my background knowledge is like. The subjective Bayesian therefore seems trapped.

But how ought we to best understand conditional epistemic probabilities? I don't know. There are many other accounts.[30] It seems clear that explanatory inferences of the abductive sort should be connected to probability. I therefore leave a gap in my more general theory to be filled in by some theory of epistemic conditional probability that differs from the standard subjective Bayesian stories previously discussed.

If the above argumentation is correct, then we ought not rest our account of epistemic conditional probability on subjective Bayesianism. Likewise, we ought not rest our account of explanatory power upon subjective Bayesianism since explanatory power involves conditional epistemic probability. But now we can infer that IBE inference making does not reduce to some type of probabilistic inference making. The epistemic values thought to be central to abductive inference making cannot be completely captured by the subjective Bayesian framework since it fails to capture the value that is explanatory power.[31]

What of Bayesian confirmation theory and measures of such confirmation?[32] Does not that equipment enable one to discern the sense in which a hypothesis H_1 is more confirmed than another hypothesis H_2?[33] Why doesn't the equipment of Bayesian confirmation theory subsume IBE inference making? Recall that it was an assumption of this chapter that there is such a thing as IBE inference making that such explanatory

[30] See Collins (2012, pp. 228-233); Otte (1987); Plantinga (1993b, pp. 159-175); Titelbaum (2014).

[31] Lycan calls the view that explanatory inferences do their justifying independent of confirmation or probability theory, "ferocious explanationism" Lycan (2002, pp. 425-430). He provides some interesting arguments for the view as well.

[32] Howson and Urbach (1993, pp. 117-164).

[33] Eells and Fitelson (2000).

reasoning provides epistemic justification for one's belief in the conclusions of cogent IBEs. While work on Bayesian confirmation theory has come a long way, especially in trying to account for many of the epistemic virtues referenced in sect. 5.1.3.2 below, there is a widespread consensus in contemporary formal and traditional epistemology that the Bayesian framework does not provide anything like a substitute for traditional epistemological notions such as epistemic justification and/or warrant (that which separates knowledge from true belief).[34] Thus, if explanatory inferences of the IBE sort do provide epistemic justification for belief in their conclusions, then those inferences cannot be reduced to Bayesian confirmation plus some measure of that confirmation.

5.1.3.2 Other Values

The other epistemic values in the heuristic can be adumbrated as follows[35]:

> **Explanatory scope**: The best potential physical explanation in the appropriate set is one that physically explains more than the competing potential explanations in the appropriate set.
>
> **Explanatory plausibility**: The best potential physical explanation in the appropriate set is one that is a material implication of more truths that are accepted by the physics community.
>
> **Coherence**: The best potential physical explanation in the appropriate set is one that is consistent with known logical laws, and the known metaphysical laws.
>
> **Testability**: The best potential physical explanation in the appropriate set is one that has the most implications that are currently testable by the physics community.
>
> **Less ad hocness**: The best potential physical explanation in the appropriate set is one that involves "fewer new suppositions not already implied by existing knowledge than rival hypotheses."[36]

[34] Some may think that internal rationality (of some variety) is a necessary condition for epistemic justification. Some evidentialists may go in for the necessary condition claim. See Moss (2013) who may be the one exception to the claim made in the main text above.

[35] I lean once again on Moreland and Craig (2003, p. 62); and Lycan (2002, pp. 415-416).

[36] Moreland and Craig (2003, p. 62).

> **Comparative superiority**: The best potential physical explanation in the appropriate set is one that strikes the best balance of the above values in comparison to any balance that is struck by competing potential physical explanations in the appropriate set.

Of course, more needs to be said about all of the above values. Unfortunately neither time nor space permits me to defend any full-fledged theories of these values. I therefore leave that task for another project.

5.2 Conclusion

I've provided a theory of physical explanation. If that theory is correct, we now know what scientific attempts to explain the low-entropic state are *real* attempts to explain that state. It is time now to examine two of the best representative attempts.

Chapter 6 Explaining the Past Hypothesis

6.1 The Past hypothesis is Not Brute

There is currently some controversy over whether or not the past hypothesis cries out for an explanation (see *e.g.*, Price (2004); and Callendar (2004a), (2004b)). If the relevant state does not cry out for an explanation, then one would be well within one's epistemic rights in characterizing that hypothesis as brute in that it has no explanation. Still, a veritable gaggle of philosophers and physicists find the initial low-entropy state to be highly unnatural or improbable[1] and on that basis maintain that the past hypothesis cries out for an explanation.[2] In fact, most cosmologists working on the low-entropy initial condition vie for a dynamical explanation of that condition. As Andreas Albrecht noted,

> …most cosmologists would instinctively take a different perspective. They would try and look further into the past and ask how such strange 'initial' conditions could possibly have been set up by whatever dynamical process went before. Albrecht (2004, p. 374-5)

I agree with Albrecht, the past hypothesis is not brute. The reason for my agreement with Albrecht is that the relevant hypothesis could be causally explained. An omnicompotent being could bring it about. And since the prolegomena (chapt. 2) of this work argued that both propositions (23) and (24) are coherent, and metaphysically possible, it follows that every purely contingent event could be caused. Causal relations usually back both causal and scientific explanations, and so if there is a cause of the universe's low-entropy state, then there is probably a causal or scientific explanation of the past hypothesis. Thus, there

---

[1] See *e.g.*, Carroll (2008a p. 48, p. 50); (2006, p. 1132); Carroll and Chen (2004, p. 3); *Cf.* Carroll (2010, p. 288). For the claim that the state is improbable see Penrose (2005, pp. 729-731); and Price (2004). The fact that a state is unnatural does not necessarily imply that that state is improbable.

[2] Even some of those who would insist that such a state is brute believe that it could be explained. See Callendar, (2004a, p. 199), though *cf.* his comments in (2004b, p. 241).

could be a causal explanation of the past hypothesis. Chapt. 4 provided a proof for the claim that if a purely contingent fact, such as the past hypothesis, could be causally explained, then it does in fact have a causal explanation. Thus, the past hypothesis has a causal explanation, and given my theory of scientific explanation, we can say that that explanation is either causal and non-scientific, or scientific.

Contemporary cosmology is overflowing with attempts to scientifically explain the relevant state by appeal to inflation (*e.g*., Davies (1983) and Guth (2004, p. 37), pre-big bang models (*e.g*., Steinhardt and Turok (2002a), (2002b), (2005), and other developments in cosmology and cosmogeny (*e.g*., holographic cosmology for which see Banks (2007)). In this chapter I will evaluate two of the most worked out attempts, *viz*., the multiverse explanation proffered by Sean Carroll and Jennifer Chen (2004) (the Carroll-Chen model or CC-M), and the explanation that falls out of the holographic cosmogenic model in the work of Tom Banks and Willy Fischler (the Banks-Fischler model or BF-M). If both the explanations proposed by the CC-M and BF-M fail, then those who would maintain that the past hypothesis cannot be scientifically explained will have one important building block in a more cumulative case against interlocutors who argue that the past hypothesis is primed for scientific explanation.

6.2 The Scientific Attempts

6.2.1 The Carroll-Chen Multiverse Model

My examination of the CC-M will proceed as follows: Sect. 6.2.1.1 provides an informal explication of the CC-M. Sect. 6.2.1.4 subjects the CC-M to some philosophical criticism. I argue that the model's purported explanation of the arrow of time fails on account of the model's inconsistency and incompleteness. Sect. 6.2.1.5 suggests that Carroll and Chen (henceforth C&C) cannot plausibly maintain that entropy is unbounded

from above, and that the model's recommended mechanisms for universe nucleation are implausible.

6.2.1.1 Details

As I noted in chapter 1, our universe began in an extremely smooth, non-empty homogeneous state. That initial non-empty smoothness or homogeneity just is the initial low-entropy state of the cosmos.[3] Our best science suggests that our arrow of time points in the direction of entropic increase, since our best science suggests that time's arrow *reduces* to the arrow of entropic increase.[4,5] C&C find these facts to be "unnatural" (Carroll (2008a, p. 48, p. 50); (2006, p. 1132); C&C (2004, p. 3); *Cf*. Carroll (2010, p. 288)). Their model attempts to advance a promising strategy for understanding the arrow of time and initial smoothness naturally. The strategy itself recommends a scientific explanation of the initial smoothness and so also the arrow of time. This explanation has need of the conjecture that the initial low-entropy state was produced by way of "dynamical evolution from a generic state" (C&C (2004, p. 6, p. 29); *cf*. C&C (2005, p. 1671)). The following theses are indispensable to the proposed scientific explanation:

---

[3] As Roger Penrose stated, the "early spatial uniformity represents the universe's extraordinarily low initial entropy" Penrose (2010, p. 76); Penrose (2005, pp. 706-707)). Most writing on the subject agree with Penrose here. See the broader discussions in Albrecht (2004, pp. 371-374); Greene (2004, pp. 171-175); North (2011, p. 327); Penrose (1979, pp. 611-617), (1989b, pp. 251-257), (2010, pp. 73-79); Price (1996, pp. 79-83), (2004, pp. 227-228); and Wald (1984, pp. 416-418), (2006, p. 395)). Callendar ([2010], pp. 47-51) articulates some problems for the standard way of understanding entropy and gravity. Earman ([2006], pp. 417-8, cf. the comments on p. 427) is very skeptical of the contemporary orthodoxy on these matters.

[4] Let me say here what I'm concerned with when I discuss or mention *the* arrow of time. First, I am not interested in the asymmetry of time itself. I am, however, concerned with the asymmetry of the contents of the cosmos (on this distinction see Price (1996, pp. 16-17); North (2011, p. 312)). There are, therefore, many arrows of time, though some maintain that these arrows can be reduced to the thermodynamic arrow. It is this supposed principal arrow with which I'm worried when I comment on *the* arrow of time below.

[5] "The low-entropy starting point is the ultimate reason that the universe has an arrow of time, without which the second law would not make sense." Dyson, Kleban, and Susskind (2002, p. 1). *Cf*. Bousso (2012, pp. 2-3, and p. 9) for a different view. The discussion of these sorts of issues in North (2011) is first-rate.

(**Thesis 1**): Our metagalaxy was produced by a background Universe that is an empty/pure (dS) or asymptotic (AsDS) de Sitter space-time.[6]
(**Thesis 2**): The Universe produced our metagalaxy by means of a fluctuation. Such a fluctuation gave birth to a proto-inflationary region. It was this region which sparked the process of eternal inflation that is responsible for the large-scale structure of our metagalaxy.
(**Thesis 3**): Entropy is unbounded from above.

I will now informally discuss each claim, and in the process shed more light on less central aspects of the CC-M.

6.2.1.2 The Background de Sitter Space and Unbounded Entropy

The strategy itself recommends a scientific explanation of the initial smoothness and so also the arrow of time. This explanation has need of the conjecture that the initial low-entropy state was produced by way of "dynamical evolution from a generic state". C&C seek a scientific explanation of our metagalaxy's initial low-entropy state that does not include finely tuned boundary conditions or temporally asymmetric micro-dynamics (C&C (2004, p. 6, p. 27)). In order to acquire such an explanation, C&C need a background Universe. This background space-time, has a supposedly generic initial Cauchy hypersurface that is wholly natural. There is also a sense in which the entire background space is admitted to be natural. For C&C, however, "natural means high-entropy" (ibid., 7), thus the background space-time can be understood as a "middle moment" (to borrow Carroll's wording) with the highest amount of entropy that an individual interrelated cosmos with a positive vacuum energy can have. Carroll (2010, p. 362) wrote:

[6] Below, I follow the convention of Russian cosmologists in regarding the universes that help compose the multiverse as metagalaxies that are spawned somehow by a background space-time that I will (not necessarily following the convention of others) call the 'Universe' (capital-U). See Glushkov (2005, p. 16) who seems to follow the former convention), and Leslie's (1989, p. 1) point regarding the convention tied to the term 'metagalaxy'.

> That middle moment was not finely tuned to some special very-low-entropy initial condition, as in typical bouncing models. It was as high as we could get, for a single connected universe in the presence of a positive vacuum energy. That's the trick: allowing entropy to continue to rise in both directions of time, even though it started out large to begin with.

In their (2004) depiction of the CC-M, the background space-time evolves in two directions away from some arbitrary generic initial surface. There is then further evolution on both sides of the surface into de Sitter phases with a positive cosmological constant. Details about the nature of the initial surface are left to the imagination, though C&C suggest that such specifics are irrelevant. One can define an initial condition over that initial surface since it is not a surface that is "an equilibrium state with maximal entropy."[7] In fact, such a condition over the initial Cauchy surface will be the surface "of minimum entropy" (C&C (2004, p. 5)). Thus, entropy increases away from the initial surface in two directions. Such dual entropic increase constitutes the dependency base for two arrows of time. As the two sides of space-time approach their respective de Sitter phases, each arrow of time will become in some sense ambiguous. This is because empty de Sitter phases are in thermal equilibrium states. There is, therefore, no entropic increase once either side of the ultra-large scale structure reaches respective de Sitter phases, and this further implies that there are no arrows of time during the corresponding phases of the cosmic evolution of the Universe.

In subsequent work (*e.g.*, Carroll (2006, p. 1134)), Carroll seems to modify the CC-M (this modified version of the account will be individuated *via* the locution '^{M}CC-M'). ^{M}CC-M's background space shares some affinities with the space-time described by

[7] Carroll and Chen (2004, p. 27). I'm borrowing their wording here. The quotation in context is about something different, *viz*., the fact that the background space is never in an equilibrium state because baby universes can always be generated resulting in the further increase of entropy.

Willem de Sitter's solution to Einstein's field equations. That solution's line element is as follows (using de Sitter's coordinates):

$$ds^2 = -\mathrm{d}r^2 - R^2 \sin^2(r/\mathrm{R})\,(d\varphi^2 + \sin^2\varphi\, d\theta^2) + \cos^2(r/\mathrm{R})\, c^2\, dt^2 \qquad \text{(Eq. 1)}^8$$

(Eq.1) predicts that matter (what de Sitter called "world-matter") is completely missing from the space, and so de Sitter's space is empty (de Sitter (1918, p. 229)). The background space of the ^{M}CC-M is likewise empty.

(Eq. 1) implies that the cosmological constant is positive in value. And in contemporary cosmology and astrophysics, a positive cosmological constant is thought to correspond to the real presence of (dark) vacuum energy. Thus, de Sitter's space-time includes a positive vacuum energy, and the same turns out to be true of the ^{M}CC-M's background space. The space-time geometry recommended by (Eq. 1) is such that the space described is hyperbolical. More generally, de Sitter space-time is represented as a Lorentzian 4-sphere within a Minkowskian 5-space with the following metric $ds^2 = dt^2 - dw^2 - dx^2 - dy^2 - dz^2$.[9] And lastly, because the Universe on the ^{M}CC-M is a pure de Sitter space-time, it is past-geodesically complete (see (Carroll (2010, p. 350, pp. 361-2)).

6.2.1.3 Nucleated Metagalaxies and Unbounded Entropy

dS space is very cold, less than 10^{-28} ^{o} Kelvin, though its temperature is still above zero (Carroll (2010, p. 313; Gibbons and Hawking (1977, p. 2739)). The temperature of de Sitter space-time is positive because it possesses "thermal radiation with a

[8] Given that $r_0 = 0$ and that $l = 3/R^2$; where R corresponds to a positive constant, and *r* is the Schwarzschild radius. The equation is from de Sitter (1918, p. 230); but see also the discussion in de Sitter (1917, p. 7); and Earman (1995, p. 7).

[9] Penrose (2005, p. 747-748); Misner, Thorne, and Wheeler (1973, p. 745); and for an extensive treatment of de Sitter and anti-de Sitter space-times see Hawking and Ellis (1973, pp. 124-134); but see also the discussions in Bousso (1998), (2000b); and Ginsparg and Perry (1983, pp. 245-251). I should add here that de Sitter space is also thought to have infinite volume. See Carroll and Chen (2004, p. 27), and see the nice illustration of the space in Carroll (2006, p. 1135).

characteristic wavelength of the order of the Hubble radius." (quoting Gibbons and Hawking (1977, p. 2739) The fact that de Sitter space-time has a positive temperature implies that that space-time countenances fluctuations which result in the existence of "…new inflating patches, which can eventually evolve into universes like ours" (C&C (2005, p. 1673)). With a positive vacuum energy, and the positive temperature of the background space, fluctuations can cause an inflaton field to ascend its potential so as to produce the beginning stages of eternal inflation, *that is to say*, the production of a sufficiently ample vacuum energy (C&C (2004, p. 27); Carroll (2006, p. 1133), (2008b, p. 8)). With respect to how this might all precisely work, Carroll seems to rely heavily upon the tunneling story written down by Edward Farhi, Alan Guth, and Jemal Guven (1990), he remarked:

> …de Sitter space, the solution of Einstein's equation in the presence of a positive cosmological constant, is unstable; there must be some way for it to undergo a transition into a state with even more entropy. *Chen and I imagined that the mechanism was the quantum creation of baby universes, as suggested by Farhi, Guth, and Guven* [14]… Carroll (2008b, p. 8 emphasis mine)

And while it is true that our metagalaxy began in a very low-entropy state, that state exhibited more entropy than the relevant "tiny comoving volume of de Sitter" space "from which it arose…" (C&C (2004, p. 26)). This is because the entropy density *per* that tiny volume of de Sitter space is considerably low (C&C (2005, p. 1673); Carroll (2006, p. 1133); *cf*. Aguirre, Carroll and Johnson (2011, p. 1)). The fluctuations in de Sitter space are not random, but are the consequence of the obtaining of a certain condition that is itself produced by the space. C&C remarked, "[b]ecause the entropy *density* of the background is so low, it is easier to fluctuate into a small proto-inflationary patch than into a universe that looks like ours today" (C&C (2005, p. 1673 emphasis in the

original)). Thus, thermal fluctuations, in an empty de Sitter space in which there is low-entropy density in the background, yield a proto-inflationary patch out of which our metagalaxy can form *via* the mechanism of eternal inflation.

Because advanced stages of the Universe's evolution are empty de Sitter on both the CC-M and ^{M}CC-M, metagalaxy nucleation conditions arise. The birth of metagalaxy's with respective eternally inflating phases produces an avenue for unbounded entropic increase (Carroll (2010, p. 360-1, p. 365)). That entropy in the Universe is unbounded from above has very clear implications. First, if (**Thesis 3**) is true, then the amount of energy in the background space is infinite. Second, given (**Thesis 3**), there are infinitely many degrees of freedom. And third, (**Thesis 3**) implies that with respect to the Universe, there is no such thing as an entropic or thermodynamic equilibrium state. If any of these implications are proven false, it will follow by *modus tollens* that (**Thesis 3**) is false as well.

6.2.1.4 Philosophical Objections to the CC-M

Science is not the sole arbiter of truth. In fact, scientists themselves appropriate various philosophical tools for the purposes of evaluating and assessing scientific theories and models. It is in the spirit of philosophical evaluation that I argue—in this section—that certain philosophical considerations weigh heavily against the CC-M in that they show the model cannot provide an explanation of our metagalaxy's initial low-entropy state, and that the model's background Universe cannot be as described.

6.2.1.4.1 Inconsistency, Ambiguity, and Admitted Incompleteness

Formulations of the CC-M are inconsistent.[10] The CC-M is ambiguously described. And the scientific explanation of our initial non-empty and smooth state provided by the CC-M is *admittedly* incomplete. Given such inconsistency and incompleteness, the C&C's explanation fails.[11]

On the CC-M, our metagalaxy is a closed and "essentially *autonomous*" system, "free from outside influences" (Carroll [2010], p. 335 emphasis in the original). One might wonder how our metagalaxy achieved such independence on the CC-M. According to some of Carroll's work, such independence was achieved by means of the mechanism of metagalaxy nucleation developed by Edward Farhi, Alan Guth, and Jemal Guven ([1990], I will refer to their tunneling story with the locution 'FGG'). On the FGG, when there is successful nucleation, metagalaxies completely separate from their mother Universe. Here is Carroll's description of the process:

> What we see is simultaneous fluctuation of the inflaton field, creating a bubble of false vacuum, and of space itself, *creating a region that pinches off from the rest of the universe*. The tiny throat that connects the two is a wormhole…But this wormhole is unstable and will quickly collapse to nothing, leaving us with *two disconnected spacetimes*: the original parent universe and the tiny baby. Carroll (2010, pp. 357-8 emphasis mine); *cf*. Carroll (2008b, p. 56).

---

[10] Unless otherwise indicated, in this section just about everything I say about the CC-M holds for the ^{M}CC-M. Therefore, (again, unless I indicate otherwise) wherever one sees 'CC-M', read '^{M}CC-M' as well.

[11] Before I proceed, I should provide a bit of an apologetic for what I'm up to in this section. First, both C&C are completely honest and humble about the CC-M's incompleteness. I do not mean to mercilessly pile on their worries about how to complete the model. My contention below will be that given scientific realism and the fact that substantive portions of the CC-M are inconsistent and admittedly not well-understood, one cannot plausibly maintain that the CC-M provides a legitimate explanation of the low-entropy state. That is an important academic and philosophical point. Second, subsequent sections of this paper criticize the model on the assumption that there *are* ways of providing the details. So even if one does not agree with the aforementioned contention, one will still have to respond to some damaging criticism.

Importantly though, the background de Sitter space (or the regions of that space that are empty de Sitter) have no respective arrows of time. This is because empty de Sitter space is in a state of thermal equilibrium. Prior to universe nucleation, there is no entropic increase. Such a fact (noted by Carroll himself (2010, p. 355)) makes interpreting Carroll's comments regarding the relationships between the arrows of time *per* metagalaxies, and the direction of time in the background space difficult to interpret, for he stated that "…local direction of time [*i.e.*, the direction of time in our metagalaxy] may not be related to that of the background space-time" Carroll (2006, p. 1134). But again, with respect to the background space-time, or at least the appropriate regions thereof, there just is no direction of time. Something is awry.

Is the FGG nucleation process governed by a time parameter? If it is, which time parameter is it? When we give attention to Carroll's writings, we see in them a clear commitment to the thesis that the nucleation process is in fact governed by a time parameter. For example, Carroll's illustration of the nucleation process in Carroll (2010, p. 357, Fig. 85) includes a time axis. That figure indicates that the process of FGG tunneling and metagalaxy nucleation occurs in time. In fact, Carroll believes that the background Universe increases its entropy through the nucleation of universes which themselves increase in thermal entropy, and this process of entropic increase is thought to be something which transpires *in time*. But which time? It cannot be a local time peculiar to the nucleated metagalaxy, for that entire space-time does not come into being until it pinches off near the end of the process. Likewise, the time parameter governing the Universe cannot be the time parameter governing the *entire* process of entropic increase *via* nucleation, since Carroll insists that on the heels of the pinching off stage of the

process, one is left with two completely independent and autonomous space-times. Such independence is a consequence of the assumed mechanism of universe nucleation. FGG entails that no worldline can be drawn from mother to baby universe. In fact, for FGG-style mechanisms "no causal curve from the original phase can enter the new phase after the tunneling event…"[12] Thus, in order for the process to be one which occurs in time, a hyper or external time parameter is required.[13] However, the idea of an external time parameter is implausible. Carroll (2010, pp. 341-2) disapproves of the idea.

A criticism akin to the one I have articulated here was voiced by Eric Winsberg (2012, pp. 401-2). Winsberg would no doubt agree, that if (as Carroll insists) the model entails a never ceasing increase in entropy (*in time*) through the nucleation of universes, then there is "an external time parameter, something Carroll explicitly, and correctly, rejects…" (ibid., p. 402)

There is a second inconsistency in the model (and here I lean on Nikolić (2008, p. 2)), though this second charge applies only to the CC-M (and so not the ^{M}CC-M). The initial Cauchy hypersurface in the background space-time is thought to be generic. But this is not so. At every Cauchy hypersurface of the background space, save the *initial* Cauchy hypersurface, entropy increases away from that hypersurface out along a single direction in time. Only at the initial Cauchy hypersurface does entropy increase in two directions. And so I agree with Nikolić, "…the initial hypersurface having two directions of time is not typical at all" (Nikolić (2008, p. 2)).

---

[12] Aguirre, Gratton, and Johnson (2007, p. 123501-9). Their comments pertain to a generalization of the geometry of the FGG mechanism, what they call '"L" tunneling geometry'. Importantly, these authors go on to point out that "[h]olographic considerations would seem to conflict with the L geometries (at least for transitions to higher vacuum energy)…" (ibid.) Carroll takes the holographic principle seriously. He (2010, p. 281) stated, "[t]he holographic principle is a very general idea; it should be a feature of whatever theory of quantum gravity eventually turns out to be right."

[13] The criticism is essentially Eric Winsberg's.

Although I will discuss scientific issues relevant to claim (2) below, I want to immediately point out a perceived ambiguity and incompleteness in Carroll's discussion of universe nucleation. First, I have already noted above, that Carroll (*q.v.* p. 5) interprets his work with Chen in such a way that it is committed to the quantum tunneling mechanism of Farhi, Guth, and Guven (1990). But something is amiss. In their original (2004) paper, C&C explicitly deny that their mechanism of nucleation involves any such quantum tunneling process. They stated:

> In our discussion is that we [*sic*] examine the case of an *harmonic oscillator potential without any false vacua*; in such a potential we can simply fluctuate up *without any tunneling*. The resulting period of inflation can then end via conventional slow-roll, *which is more phenomenologically acceptable than tunneling from a false vacuum* (as in "old inflation" [7]). Thus, the emptying-out of the universe under typical evolution of a generic state can actually provide appropriate initial conditions for the onset of inflation, which then leads to regions that look like our universe. Carroll and Chen (2004, p. 21 emphasis mine)

But C&C (2004, pp. 22-23; pp. 25-26; *cf*. n. 4 on p. 26) concede that the fluctuation route to metagalaxy nucleation and large-scale structure formation is incredibly improbable.

I described the incompleteness of the model as "admitted incompleteness" because Carroll himself (with collaborators Aguirre and Johnson (2011, pp. 23-24)) criticized the FGG mechanism for universe nucleation confessing (independently) in a different place that that mechanism is "extremely speculative" Carroll (2006, p. 1133).

In other work (particularly, Carroll (2012); *cf*. (2006, p. 1133); (2010, pp. 284-6)), Carroll indicated that the multiverse is a prediction of string theory and inflation. His optimism concerning string theory is somewhat surprising since "...there is presently no fully satisfactory embedding of de Sitter space into string theory" (Bousso, DeWolfe, and Myers (2003, pp. 297-8)). And "[a]ll *explicit* and fully trustworthy solutions that have ever been constructed in string theory have a non-positive cosmological constant" (Van

Riet (2011, p. 2); *cf*. Stominger (2001, p. 2)). Captivatingly, Carroll (with Johnson, and Randall) seems to agree, "…string theory…seems to favor Minkowski or anti-de Sitter vacua" (Carroll, Johnson, and Randall (2009, p. 2)).

There are further problems with injecting string theory into the model, for that theory requires a great many dimensions which must somehow be compactified into any pure or asymptotically de Sitter space if one or the other is your space of choice. The problem is that there are no-go theorems proving that compactified theories which abide by the null energy condition (along with several other plausible conditions for string theoretic models) cannot be wed to inflationary theory.[14] It has also been shown that compactified theories which *violate* the null energy condition, but which otherwise satisfy other very plausible conditions (for string theoretic models) cannot be united with inflationary theory or theories. (Steinhardt and Wesley (2009, pp. 104026-6 to 104026-8)). So I'm not sure what to make of Carroll's claim that a multiverse is a prediction of inflation coupled with string theory. The two are not necessarily agreeable partners.

The foregoing reasoning indicates that FGG nucleation out of a de Sitter space-time is merely speculative and that Carroll's discussion of it should be thought of as exploratory. I believe it is therefore safe to conclude that a central piece of the model is missing, and so the CC-M is incomplete in that it does not have a clear recommended dynamical path from the background Universe to the birth of metagalaxies like ours.

The incompleteness of the CC-M has a bearing on the question of whether or not the model provides a legitimate scientific explanation of our initial low-entropy state. Assuming some robust version of scientific realism, explanations, when they successfully

[14] I have in mind the results of Steinhardt and Wesley (2009, pp. 104026-4 to 104026-6). Though *cf*. Koster and Postma (2011).

explain, are at least approximately true. It is not clear how an *explanans* can be verisimilar, if it is unclear which proposition, if any, is expressed by that *explanans* on account of the kind of incompleteness the CC-M displays. Thus, I find this gap in the model to be severely delimiting. We cannot, in my opinion, justifiably claim that the CC-M proffers an actual scientific explanation of the initial non-empty smoothness of our metagalaxy, since it is altogether unclear what the explanation *is* on the CC-M.

6.2.1.5 Scientific Objections to the CC-M

The CC-M does not pass philosophical muster. I will now argue that even given the failure of preceding philosophical argumentation, the CC-M suffers from insurmountable scientific problems and so cannot actually explain our metagalaxy's initial low-entropy state.

6.2.1.5.1 Unbounded Entropy?

I will now take up (**Thesis 3**). I maintain that the *N*-bound confirms the Tom Banks/Willy Fischler Λ-N correspondence thesis, at least when the background space of the ^{M}CC-M is in view, and that such confirmation means that (**Thesis 3**) is false. I also argue that while it is unclear if the *N*-bound holds for the background space of the CC-M, there are arguments to which one can turn for the purposes of establishing Λ-N correspondence for that space, and so (**Thesis 3**) is false given the CC-M as well.

6.2.1.5.1.1 Λ-N Correspondence

Tom Banks (2000, p. 5) has argued that the value of Λ, the cosmological constant, is the inverse of the value of *N*. *N* is the logarithm of the dimension of Hilbert space in quantum theory. By consequence, if one's quantum theory conceives of *N* as finite, then

that quantum theory will contain finitely many dimensions (Bousso (2000b, p. 2. n. 2)). The correspondence of Λ to N entails that there is a large (though finite) number of degrees of freedom. If, however, N really is finite, then quantum theories of gravity featuring infinitely many degrees of freedom will be implausible.

Raphael Bousso has noted that proofs of what he calls the "*N*-bound" constitute evidence for Λ-N correspondence.[15] The N-bound states that every space-time with $\Lambda > 0$ is a space-time whose total *observable* entropy is bounded by:

(5): $N = 3\pi/\Lambda$ (Eq. 2)[16]

Or, any space-time with a positive cosmological constant is one which cannot feature an observable entropy whose value is greater than $N = 3\pi/\Lambda$.[17] The N-bound trivially holds for empty de Sitter space-times like the background space of the ^{M}CC-M. In addition, Bousso at one time believed that one could show that the N-bound is valid for asymptotically de Sitter space-times—such as our metagalaxy—on the basis of the generalized second law. He remarked:

> It is not difficult to see that the *N*-bound is true for vacuum solutions like de Sitter space (a trivial case). Moreover, one can argue that it is satisfied for all space-times which are asymptotically de Sitter at late times, by the generalized second law of thermodynamics. Bousso (2000b, p. 3)

But my use of Bousso's work will not require such a generalization. That I can ignore the stronger argumentation for the more general point is advantageous, for Bousso himself (with collaborators) provided counter-examples to the *N*-bound (see Bousso, DeWolfe,

---

[15] His argument is explanatory: "It is hard to see what, other than the Λ-N correspondence, would offer a compelling explanation [of] why such disparate elements appear to join seamlessly to imply a simple and general result" Bousso (2000b, p. 18).

[16] Bousso (2000b, p. 3). The type of entropy in play appears to be information-theoretic or Von Neumann entropy. This fact is irrelevant. The main argument of this section still runs.

[17] Bousso (2000b, p. 2). In subsequent discussion, I will sometimes speak of *N*-bound validity for a space-time. What I mean by such a judgment is that Eq.2 (proposition 5) holds for those space-times.

and Myers (2003). These counter-examples involved space-times with dimensionality greater than four. Moreover, Clarkson, Ghezelbash, and Mann (2003) attempted to show that the *N*-bound is invalid for a four-dimensional Taub-Bold space-time that is locally asymptotically de Sitter, and which features NUT charge (magnetic mass) and (unfortunately) closed timelike curves (ibid., pp. 360-1). With respect to *N*-bound validity, the only point that my argumentation requires is that the *N*-bound is valid for dS or empty de Sitter space-time, and both Bousso (2000b), (2012, p. 29) and Lee Smolin (2002, pp. 45-6) have acknowledged its validity in that context.

How does all of this relate to the ^{M}CC-M? Recall proposition (3) above, and remember that if (3) holds, then there are infinitely many degrees of freedom (Carroll and Chen (2004, p. 7; *cf*. pp. 14-5, and p. 30)). The *N*-bound, which is trivially valid for empty de Sitter space (the very background space of ^{M}CC-M) is strong confirming evidence for the Banks/Fischler Λ-*N* correspondence thesis (as Bousso suggested). But *N* comports to the logarithm of the dimension of the Hilbert space in quantum theory. If the correspondence thesis is right, then *N* is probably finite. Therefore, there should be finitely many dimensions of Hilbert space in the correct quantum theory, and so there are also only finitely many degrees of freedom. This conclusion ensures that (3) is false. Entropy is not unbounded from above. The argument in play can be summarized as follows:

(Premise 1): If the Λ/N correspondence thesis holds for dS space-time, then the correct quantum theory describing that space-time will feature a finitely dimensional Hilbert space.

(Premise 2): If the *N*-bound is valid for dS space-time, and the best explanation of *N*-bound validity for dS space-time is the Λ/N correspondence thesis, then the Λ/N correspondence thesis holds for dS space-time.

(Premise 3): The *N*-bound is valid for dS space-time, and the best explanation of *N*-bound validity for dS space-time is the Λ/N correspondence thesis.
(Premise 4): If the correct quantum theory for an empty dS space-time features a finitely dimensional Hilbert space, then dS space-time features only finitely many degrees of freedom.
(Premise 5): If dS space-time features only finitely many degrees of freedom, then the global entropy of dS space-time cannot be unbounded from above.
(Conclusion): Therefore, the global entropy of dS space-time cannot be unbounded from above.

The first premise is true by virtue of the meaning of the correspondence thesis. The second premise holds on account of the cogency of inference to the best explanation reasoning. In the absence of defeaters and underdetermination, such reasoning provides cognizers with epistemic justification for their belief that the purported best explanation holds. The first conjunct of premise three follows from points already made above. The second conjunct follows from the fact that there is simply no competing explanation of the relating of the two seemingly incommensurable parameters, *viz*. Λ and *N* (Bousso (2000b, p. 18). It seems that the correspondence thesis wins by default. Premises four and five seem straightforward enough, and our conclusion follows from elementary moves in propositional logic.

In an attempt to defend the ^{M}CC-M, one might respond by emphasizing that the means by which the Universe increases its entropy is by giving birth to metagalaxies (Carroll (2010, pp. 359-360)). Appeals to the *N*-bound do nothing to subvert that possibility. This response is flawed. According to C&C, if it is not the case that there are infinitely many degrees of freedom, then their story regarding universe nucleation and unbounded entropy cannot run. Entropy is unbounded from above *only if* there are

infinitely many degrees of freedom. The above argumentation cuts down this necessary condition, and so results in a bound on entropy.

Again the argument from the *N*-bound shows that with respect to the background de Sitter space-time of the ^{M}CC-M, there are finitely many degrees of freedom. Carroll (2008b, pp. 6-7) himself believes that the ^{M}CC-M would in that case have a fundamental problem with Poincaré recurrence. Recall that on the basis of Newtonian mechanical laws of motion, and with respect to an energetically isolated system whose volume is finite, Poincaré proved an important theorem. The result is this: given the aforementioned assumptions, a relevant system which starts off in state *s* at *t*, will, given enough time, evolve back into a state arbitrarily close to *s*, and it will do this infinitely many times (paraphrasing Sklar (1993, p. 36). There are quantum analogs of this theorem, and Carroll (2008b, pp. 6-7) believes he can escape these analogs by appeal to an infinitely dimensional Hilbert space. But you will remember that the argument from the *N*-bound cuts down the dimensions of Hilbert space to only a finite amount due to the Banks/Fischler Λ-*N* correspondence thesis. Thus, by Carroll's own lights, the problem of Poincaré recurrence remains.

6.2.1.5.1.2 The N-Bound and the CC-M

Does the argument from the *N*-bound apply equally well to the background space-time of the CC-M? I am not sure. C&C's description of that space is fragmented. We do not know the dimensionality of the space, nor what precise generic conditions the space evolves away from. In addition, we do not know what precise kinds of matter occupy the space in its non-de Sitter regions. Ignorance of these matters makes it difficult to determine *N*-bound validity, for although Bousso (2000b) originally argued that the *N*-

bound is valid for all space-times with a positive cosmological constant. As I have already pointed out, he would later (with collaborators) reverse his opinion on the matter by proffering counter-examples to his original proof (Bousso, DeWolfe, and Myers (2003, p. 299). But let us suppose that the *N*-bound is not valid for the background space of the CC-M. Tom Banks (2000, pp. 5-6) provided three convincing arguments all demonstrating that the Λ-*N* correspondence thesis holds for AsDS space-times. From the little we can discern about the nature of the background space of the CC-M, we can somewhat safely infer that that space is AsDS. Hence, the Hilbert space of the appropriate quantum theory describing that space-time is finitely dimensional. (**Thesis 3**) is therefore false when either the CC-M or ^{M}CC-M is in view.

I will now continue to assume that the CC-M/^{M}CC-M[18] is complete, and move on and reflect, in the next sub-section, on (**Thesis 2**), evaluating the proposed mechanisms for universe nucleation in the work of C&C.[19]

6.2.1.5.2 Nucleation and Metagalaxy Creation

As I have already pointed out, Carroll seems to commit himself to the quantum tunneling process of universe nucleation as articulated by Farhi, Guth, and Guven (1990). That process will not serve as a proper mechanism for the nucleation of our metagalaxy, if our metagalaxy has an *initial* singularity. On this point Farhi, Guth, and Guven ([1990],

[18] Throughout the remainder of the paper, one may read '^{M}CC-M' wherever one sees 'CC-M'. All subsequent argumentation will be applicable to both.

[19] For some the following nagging objection will remain: Fields in QFT admit infinitely many degrees of freedom, therefore something is wrong with the above argumentation. The reasoning is out of touch with the contemporary state of the art in quantum cosmology. Numerous considerations suggest that QFT breaks down and most cosmologists (it seems) no longer believe that QFT will reside prominently in the endgame quantum theory of gravity. In fact, Nobel Prize winner David J. Gross has said that "[t]he longstanding problem of quantizing gravity is probably impossible within the framework of quantum field theory…We need to go beyond QFT, to a theory of strings or to something else, to describe quantum gravity." Gross (1997, p. 10).

p. 419) stated, "…any plausible scheme to create a universe in the laboratory must avoid an initial singularity." As a result, Farhi, Guth, and Guven try to articulate a theory of quantum tunneling which avoids the Penrose singularity theorem of (1965). I will argue that while the FGG mechanism may escape the Penrose theorem, it does not escape other theorems which entail that our metagalaxy has an initial singularity, and that our metagalaxy is past-geodesically incomplete.

6.2.1.5.2.1 The EGS Theorem and Related Results

According to the EGS theorem (proven in Ehlers, Geren, and Sachs (1968)), given the Copernican principle[20], and that observers situated in some expanding model discern (*via* observations) that free and unrestrained "propagating background radiation is" isotropic, the space-time in which such observers are situated must be FLRW.[21] Clifton, Clarkson, and Bull (2012) (CCB) showed that space-time geometry is, for an observer, FLRW "using the CMB alone" without the Copernican principle (ibid., p. 051303-4). Their proof also indicates that "our *entire* causal past must…be FLRW" (ibid., p. 051303-3 emphasis mine). One acquires their results by assuming that an observer beholds isotropic cosmic microwave background radiation (CMBR) while the Sunyaev-Zel'dovich effect ((SZ) which involves baryonic matter scattering the photons

[20] The Copernican principle says, roughly, that our causal past and position in space-time is not unique or distinctive. Stoeger, Maartens, and Ellis (1995, p. 1).

[21] Borrowing some wording from Smeenk (2013, pp. 630-1). See also (Stoeger, Maartens, and Ellis 1995, p. 1). There is a nice discussion of these matters in Clarkson and Maartens 2010; Maartens (2011); and Weinberg (1972, pp. 395-403), *cf*. [2008], p. 3). It is important to add that the result from Ehlers, Geren, and Sachs does not extend to times prior to the decoupling era. (1968, p. 1349 "the result presented cannot be taken to mean that the universe *in its earliest stages* was necessarily a Friedmann model…" emphasis mine)

of the CMBR (Clarkson (2012, p. 19)) is present in that beholding.[22] The idea is that if a single onlooker observes blackbody CMBR that is isotropic, and that CMBR is accompanied by particular SZ-related scattering events, then that observer can infer that her universe is FLRW, given that the necessary assumptions of the EGS theorem (save the Copernican principle) hold, and that either (a) the observer's observations are over a prolonged period of time, or (b) the SZ-related effects involve double scattering (paraphrasing Clarkson (2012, p. 19)). I should add that the CCB results hold even given the presence of dark energy, it is just that such dark energy must be susceptible to a scalar field description.[23]

Both the EGS and CCB results are significant since our observations regarding the cosmic microwave background radiation suggest that that blackbody radiation is *nearly* isotropic.[24] The qualifier 'nearly' is important since it seems that both EGS and CCB reasoning require highly idealized propagating radiation in so far as that radiation

[22] Clifton, Clarkson, and Bull (2012, pp. 051303-1 to 051303-2). For more on the Sunyaev-Zel'dovich effect see Weinberg (2008, pp. 132-5).

[23] It may be that in order to alleviate worries about fine-tuning and the cosmological constant, one should appropriate a scalar field model of dark energy. In addition, it seems that the best way of understanding dark energy *via* quintessence is to posit a scalar field model of dark energy. As Weinberg remarked, "[t]he natural way to introduce a varying vacuum energy is to assume the existence of one or more scalar fields, on which the vacuum energy depends, and whose cosmic expectation values change with time." Weinberg (2008, p. 89) For more on dark energy and scalar field models of such energy, see Sahni (2002, pp. 3439-41).

[24] Clarkson and Maartens ([2010], p. 2) stated,

> "Isotropy is directly observable in principle, and indeed we have excellent data to show that the CMB is isotropic about us to within one part in $\sim 10^5$ (once the dipole is interpreted as due to our motion relative to the cosmic frame, and removed by a boost)."

Weinberg (2008, p. 129) confesses that treating the CMBR as perfectly isotropic and homogeneous is "a good approximation". He says that "the one thing that enabled Penzias and Wilson to distinguish the background radiation from radiation emitted by earth's atmosphere was that the microwave background did not seem to vary with direction in the sky." (ibid.)

must be exactly isotropic.[25] Our metagalaxy's CMBR exhibits certain anisotropies[26], and so it is unclear what work these theorems can do for me.[27]

There are related results which do not rely on a condition of perfectly isotropic CMBR. For example, Stoeger, Maartens, and Ellis (1995, p. 1) argued that our cosmos is approximately or nearly FLRW given the Copernican principle, the fact that background blackbody radiation is freely propagating everywhere and that such radiation is perceived, by observers, to be approximately or nearly isotropic (plus a few additional technical assumptions). Maartens and Matravers (1994) have articulated a matter analog of the EGS theorem. Their result establishes that our universe is FLRW given the Copernican principle, and that a class of galactic observations along a postulated observer's world line is isotropic.[28]

The most formidable EGS-like result was recently discussed by Roy Maartens (2011, pp. 5121-5) in his excellent review of much of the associated literature.[29] The theorem has it that with respect to a region of a space-time featuring dark energy (whether understood in terms of a perfect fluid, quintessence, or cosmological constant) and dust matter, *if* (a) the Copernican principle holds, (b) the observed CMBR "rest frame is geodesic"[30] with an expanding four-velocity, and (c) the self-same radiation is

[25] Clifton, Clarkson, and Bull admit to their idealized assumptions in Clifton, Clarkson, and Bull (2012, p. 051303-4).

[26] See Hawking and Ellis (1973, pp. 353-4). For a discussion of the CMBR anisotropies, see Lyth and Liddle (2009, pp. 152-69); and Weinberg (2008, pp. 129-48).

[27] Ehlers, Geren, and Sachs (1968) also ignored the cosmological constant.

[28] These galactic observations correspond to propositions (O1)-(O4) in Maartens and Matravers (1994, p. 2694). They are *not* observations of isotropic background blackbody radiation. See also Maartens (2011); and *cf*. Hasse and Perlick (1999).

[29] His discussion of the specific result I am interested in is an expansion on his earlier work with Chris Clarkson in Clarkson and Maartens (2010).

[30] Maartens (2011, p. 5131).

collisionless with a vanishing octupole, quadrupole and dipole[31], *then* the *metric* of the relevant spacetime is FLRW.[32] The assumptions of this theorem are quite weak. I therefore agree with Maartens "[t]his is the most powerful observational basis that we have for background homogeneity and thus an FLRW background model" (Maartens (2011, p. 5125)).

What is the relevance of all of this to the CC-M? It turns out that every FLRW model (with matter like ours) features an *initial* singularity.[33] And since the assumptions of several of the EGS-like results are quite weak, we are justified in maintaining that our metagalaxy is best described by an FLRW model. Thus, the FGG mechanism for metagalaxy nucleation cannot be the mechanism responsible for our universe's nucleation out of a background de Sitter space. Some other theory of nucleation that is not impeded by the singular nature of our metagalaxy is required.

6.2.1.5.2.2 The BGV-Theorem

On the standard hot big bang model, implications of proper solutions to Einstein's field equations imply that our metagalaxy is geodesically incomplete in that our metagalaxy features an initial singularity. Attempts to avoid this implication were blocked by work on singularity theorems in the 1960s and 1970s. For example, Robert Geroch (1966), Stephen Hawking (1965), (1966a), (1966b), (1967) and Roger Penrose (1965) showed that any time-oriented space-time which satisfies modest conditions will

[31] Such that $F_{\mu} = F_{\mu\nu} = F_{\mu\nu\alpha} = 0$ holds (from equation 3.24 of Maartens (2011, p. 5125).

[32] See Maartens (2011, p. 5125, p. 5131).

[33] "FLRW models with ordinary matter have a singularity at a finite time in the past." Smeenk (2013, p. 612). Hawking and Ellis stated, "…there are singularities in any Roberston-Walker space-time in which $\mu > 0$, $p \geq 0$ and Λ is not too large." Hawking and Ellis (1973, p. 142). See also Wald (1984, pp. 213-214); and the discussion of FLRW models in Penrose (2005, pp. 717-723).

be time-like or null geodesically incomplete.[34] In (1970) Hawking and Penrose attempted to generalize on this work by advancing "[a] new theorem on space-time singularities".[35] Hawking would later describe this newer theorem as one which predicts that there are singularities in the future, and that there is a singularity in the past "at the beginning of the present expansion of the universe."[36] The theorem had need of four seemingly modest conditions, one of which demanded that space-time be described by Einstein's field equations along with a cosmological constant that is negative or equal to zero in value. It turned out that this modest condition was not modest enough. When inflationary stages of cosmic evolution are added to the standard model, a positive cosmological constant is required, thus, the Hawking-Penrose theorem "cannot be directly applied" to such models.[37]

Later theorems were proven. One of these was a result of the work of Arvind Borde and Alexander Vilenkin (1996, pp. 819-22). They showed that a space-time is past-null geodesically incomplete if that space-time satisfies what were perceived to be even more modest conditions than those used to deliver erstwhile singularity theorems.[38] One such condition (*viz*., the null convergence condition which is implied by the weak

[34] See the review of many of these theorems in Hawking and Ellis (1973, pp. 261-75).

[35] Hawking and Penrose (1970, p. 529). This paper also provides an excellent review of both Hawking and Penrose's previous work on singularity theorems (see especially (ibid., pp. 529-33).

[36] Hawking (1996, p. 19).

[37] The quoted bit is from Hawking and Penrose (1970, p. 531). Of course, they were not concerned with inflationary cosmology in 1970. Here is the broader context of the quote, "…we shall require the slightly stronger energy condition given in (3.4), than that used in I. This means that our theorem cannot be directly applied when a *positive cosmological constant* l is present." Hawking and Penrose (1970, p. 531 emphasis in the original). Many authors have noted that inflationary cosmological models violate the strong energy condition (the condition having to do with the value of l) of the Hawking-Penrose theorem. See, for example, Wall (2013, pp. 25-6. n. 13); and Borde and Vilenkin (1996, p. 824. n. 17), *inter alios*.

[38] The three conditions are stated in Borde and Vilenkin (1996, p. 819).

energy condition) was shown to be problematic in light of diffusion regions, and so that condition was not mild enough.[39]

Borde and Vilenkin would later return, this time with Alan Guth, to prove a newer theorem.[40] The Borde-Guth-Vilenkin (BGV) theorem entails that all space-times whose Hubble parameters are on average greater than zero, are past-geodesically incomplete.[41] Notice that the theorem does not necessarily suggest that the relevant space-times feature an initial singularity. This is because the theorem is not actually a *singularity* theorem. The theorem only implies that every past-null or past-timelike geodesic is such that it cannot extend further than a past-boundary $\mathcal{B}$.[42]

The BGV has broad application potential since it only relies on a single, model independent assumption. For example, Borde, Guth, and Vilenkin apply the theorem to the early cyclic cosmogenic model of Steinhardt and Turok (2002a).[43] They also apply the theorem to a particular *part* of the ultra-large-scale structure in the higher-dimensional model of Martin Bucher (2002). This latter application is *apropos* because it is very loosely analogous to an application of the BGV to our independent nucleated metagalaxy on the CC-M.[44] One need not apply the BGV to ultra-large scale structure *in toto*.

---

[39] See Borde and Vilenkin (1997).

[40] Borde, Guth, and Vilenkin (2003).

[41] "The result depends on just one assumption: The Hubble parameter H has a positive value when averaged over the affine parameter of a past-directed null or noncomoving timelike geodesic." (Borde, Guth, and Vilenkin [2003], p. 151301-4). See also Mithani and Vilenkin (2012, p. 1) "…it [the BGV] states simply that past geodesics are incomplete provided that the expansion rate averaged along the geodesic is positive: $H_{av} > 0$."); and Vilenkin (2013a), (2013b, p. 2).

[42] Vilenkin (2013a, p. 2).

[43] Borde, Guth, and Vilenkin (2003, p. 151301-4); cf. Guth (2004, p. 49) See also (Mithani and Vilenkin (2012, pp. 1-2).

[44] Keep in mind that on the CC-M, our metagalaxy is an autonomous, independent space-time. Inquiring about whether or not the BGV applies to our metagalaxy and not the entire Universe makes sense.

Our space-time or metagalaxy is such that it can be accurately described with a Hubble constant whose value is on average greater than zero. Hence, the BGV theorem can be easily applied to our metagalaxy. This point is underscored by the fact that the BGV was originally developed for the purposes of demonstrating that inflationary models are past-incomplete. Carroll and Chen are fans of inflation (*a fortiori* eternal inflation). They believe that in the past our metagalaxy exhibited an extraordinary inflationary stage of cosmic evolution. And so the theorem should be easily applicable to our metagalaxy as understood by the CC-M.

Is the presence of a past-boundary indicative of an initial singularity? For my present intents and purposes, it is. Farhi, Guth, and Guven define an initial singularity as "…a point on the boundary of space-time at which at least one backward-going (maximally extended) null geodesic terminates."[45] The BGV entails such geodesic incompleteness given that our metagalaxy satisfies the Hubble parameter condition (which on the CC-M it does).

C&C discuss the BGV theorem, citing (Borde, Guth, and Vilenkin (2003)) and interpreting the result in such a way that it suggests that eternal inflationary models have singularit*ies*.[46] This reading of the theorem is multiply flawed.[47] C&C seem to imagine that because singularities "occur all the time at the center of black holes, and eventually disappear as the black hole evaporates" the BGV is unproblematic for their model (Carroll and Chen (2004, p. 27. n. 6)). They go on to remark that the fact that the theorem entails the presence of singularities does not itself entail that there is a "spacelike"

[45] Farhi, Guth, and Guven (1990, p. 419).
[46] Carroll and Chen (2004, p. 27. n. 6).
[47] Vilenkin stated, (2013b, p. 2) "[e]ven though the BGV theorem is sometimes called a 'singularity theorem', it does not imply the existence of spacetime singularities."

boundary "for the entire spacetime."[48] This is a misstatement of the result. The theorem implies the existence of just such a boundary (as Vilenkin himself noted). An interesting, *separate* question is whether or not the BGV applies to the Universe, or to our metagalaxy given the CC-M. I have argued that it at least applies to our metagalaxy.

6.2.1.5.2.3 Evasion by the Quantum?

What about escaping the singularity and geodesic incompleteness *via* the quantum? Surely there is some hope that a more complete cosmogenic model outfitted with a full-blooded quantum understanding of gravity will consign our metagalaxy's initial singularity and past boundary to the trash bin of physical cosmology. McInnes reports that "[i]t has been argued…that quantum-mechanical effects allow the singularity in the Farhi-Guth 'wormhole' to be evaded..." (McInnes (2007, p. 20), who cites Fischler, Morgan, and Polchinski (1990); though *cf*. Vachaspati (2007)). Carroll has expressed similar optimism.[49] Sadly however, quantum cosmogony does not justify such optimism. There is no piece of classical cosmology on which the BGV theorem essentially relies, and for which we have *sufficient* evidence that that piece will be completely done away with in the quantum regime. In other words, the BGV theorem does not assume a classical theory of gravity. Vilenkin made this point clear:

> A remarkable thing about this theorem is its sweeping generality. We made no assumptions about the material content of the universe. We did not even assume that gravity is described by Einstein's equations. So, if Einstein's gravity requires some modification, our conclusion will still hold. The only assumption that we made was that the expansion rate of the universe never gets below some nonzero value, no matter how small. *This assumption should certainly be satisfied in the*

[48] Ibid.

[49] See Carroll (2008a, p. 4), (2010, p. 50, pp. 349-50, particularly p. 408. n. 277 "Also, the concept of a 'singularity' from classical general relativity is unlikely to survive intact in a theory of quantum gravity."), but *cf*. Penrose (1996, p. 36) for a different view.

> *inflating false vacuum*. The conclusion is that past-eternal inflation without a beginning is impossible.[50]

But what about my use of results which capitalize on the EGS theorem and related reasoning? Are not those results classical? Yes, the results are classical. They depend upon the assumption that Einstein's field equations describe the cosmos. However, we have no conclusive evidence that these results will be overturned by a complete quantum cosmology.

Perhaps you are still dissatisfied with my argumentation. The question, "how can we be sure that there is an initial space-time singularity at $\mathcal{B}$ in a full quantum physical context?" may still strike you as a deep worry. I believe I can mollify the force of such a worry, since Aron C. Wall (2013) has recently proven a *quantum* singularity theorem that relies only upon the generalized second law (GSL),[51] which states that *generalized* entropy never decreases as time marches forward.[52] Or, with respect to any causal horizon, the sum of the horizon entropy, plus the field entropy external to any such horizon will necessarily increase as time marches forward (Wall, (2012, p. 104049-1)). Interestingly, the GSL implies that the thermodynamic behavior of certain open systems (*e.g.*, a causal horizon's exterior) is akin to that of certain closed systems (ibid.).

I should add here that Wall is chiefly concerned with the *fine-grained* GSL defined in (Wall ([2013], p. 6, *cf.* p. 10)). The fine-grained version of the GSL requires a

---

[50] Vilenkin (2006, p. 175 emphasis mine). Abhay Ashtekar (2009, p. 9), a loop quantum cosmology proponent, acknowledged that the BGV does not rely on Einstein's field equations.

[51] It seems that C&C go in for a generalized second law. In their discussion of black hole entropy and Hawking radiation, they stated that "one can prove [69], [70], [71], [72] certain versions of the Generalized Second Law, which guarantees that the radiation itself, free to escape to infinity, does have a larger entropy than the original black hole." Carroll and Chen (2004, p. 18)

[52] Or, with respect to any causal horizon, the sum of the horizon entropy, plus the field entropy external to any such horizon will necessarily increase as time marches forward (Wall, (2012, p. 104049-1). Interestingly, the GSL implies that the thermodynamic behavior of certain open systems (*e.g.*, a causal horizon's exterior) is akin to that of certain closed systems (ibid.).

"fine-grained…definition of the state…used to compute…entropy." (ibid., p. 10) This means that the state one uses for computational purposes represents "the complete information about a state", and not just "information available to an observer" ([ibid.], p. 6). What I will go on to say below is true for the fine-grained GSL. So understand all subsequent reference to the GSL as reference to the fine-grained GSL.

While the GSL does not hold for any and all horizons, it does hold for de Sitter horizons[53], "any future-infinite timelike worldline"[54], and "every state of the universe".[55] Moreover, given that the GSL holds for every state, its time-reverse will hold for every state (Wall (2013, p. 10, and see also Wall 2009)). The time-reverse GSL says "that for any past-infinite worldline W_{past}, the past horizon $H_{past} = \partial I^{+}(W_{past})$ cannot *increase* as time passes…" (Wall (2013, p. 10 emphasis in the original)).

Now, what Wall shows is the following equivalence:

> (7): The GSL is true, just in case, given that there is some null surface *F* according to which the generalized entropy is diminishing on *F* at an arbitrary point, *F* is not a horizon. (Paraphrased from (Wall (2013, p. 18))

But (7) implies:

> (8): It is not the case that there is an infinite (toward the future) worldline W_{fut}, which relates to *F* in such a way that *F* is—for the relevant observer—a future horizon. Wall (2013)

Therefore, by Wall's theorem three, some null surfaces cannot be indefinitely extended.[56] This conclusion can be tied to two assumptions (*viz*., that the GSL holds, and that global hyperbolicity holds) and then used to show that the relevant space-time (for which the

[53] Wall (2012, p. 104049-1). Davies (1984), and Davies *et. al*. (1986) argued that a GSL applies to de Sitter space, though *cf*. Davis, Davies, and Lineweaver (2003).
[54] Wall (2013, p. 9).
[55] Ibid., p. 10.
[56] Theorem 3 is stated and proven in Wall (2013, p. 19).

assumptions hold, and for which null surfaces cannot be indefinitely extended) is future-null-geodesically incomplete "because there is a singularity somewhere on [*F*]" ((Wall (2013, p. 19). And see the proof for this in (ibid., pp. 19-20)).

A similar result can be proven given the time-reversed GSL. One can therefore show that the relevant space-time is *past* null-geodesically incomplete (Wall (2013, p. 20)). Wall explicitly notes how his results can be understood within a quantum context (ibid. and pp. 32-37) and correctly observes that he has secured something like a quantum analog of Penrose's (1965) singularity theorem.

With respect to an application of Wall's theorem to our FLRW metagalaxy, he stated:

> Putting all these considerations together, if the GSL is a valid law of nature, it strongly suggests that either the universe had a finite beginning in time, or else it is spatially finite and the arrow of time was reversed previous to the Big Bang. In the latter case, it could still be said that the universe had a beginning in a thermodynamic sense, because both branches of the cosmology would be to the thermodynamic future of the Big Bang. Wall (2013, pp. 27-8)

Of course, the CC-M posits an eternally inflating FLRW sub-model of our metagalaxy. Thus, the reversed arrow of time idea cannot be added to that sub-model.

You might maintain that C&C need not appropriate the FGG proposal. There are, after all, suggested improvements of the tunneling story told there. Why then cannot C&C simply side-step the objections in this section by appropriating one of these ameliorations. The problem is that other mechanisms like the one in Fischler, Morgan and Polchinski (1990) fail if our metagalaxy features an initial singularity. That is why Fischler, Morgan, and Polchinski diligently seek to rub initial singularities out (see (ibid. pp. 4046-7)).

We can conclude then, that Wall provides us with yet another reason for why we ought to believe that our metagalaxy is past-null geodesically incomplete. This, I believe, serves as a significant defeater for the claim that our metagalaxy nucleated by means of the FGG mechanism from a background de Sitter space.

6.2.1.5.2.4 Fluctuation

The means by which our metagalaxy came forth out of a background space need not have involved a quantum tunneling process like the one recommended by Farhi, Guth, and Guven. In fact, C&C's original paper (2004) did not use the FGG mechanism. Rather, it urged that a suitable proto-inflationary patch could have—*via* the harmonic oscillation of a potential—fluctuated into existence from the background de Sitter space. But C&C believe that the probability that the relevant patch should fluctuate into existence by means of the recommended process is incredibly small. And that this patch should spark the process of eternal inflation is also regarded as incredibly improbable.[57] In fact, the probability is so small that C&C describe it as possibly "the smallest positive number in the history of physics…" (Carroll and Chen (2004, p. 26. n. 4)). C&C can acknowledge wholeheartedly such a small probability without fear or trepidation because their model is very much a "wait and see" model (*cf.* McInnes (2007 p. 8)). Because the background space-time is eternal, and geodesically complete, fluctuations of just the right sort will inevitably occur, *a fortiori*, they will occur an infinite amount of times. On this "wait and see" feature of the model, C&C (2004, p. 27 emphasis mine)) stated:

[57] Carroll and Chen (2004, p. 25). There is also the separate question of how likely it is that our metagalaxy's large scale structure is due to some prior inflationary era. Carroll and Tam address this question to some degree in their (2010).

> The total spacetime volume of the de Sitter phase will continue to increase, just as in eternal inflation. The total spacetime volume of the de Sitter phase is therefore infinite, and the transition into our proto-inflationary universe is guaranteed eventually to occur. *Indeed, it will eventually occur an infinite number of times*.

The more general idea seems to be that because the de Sitter vacuum is both unstable and eternal, anything that can physically occur, will occur, and it will occur an infinite amount of times.

One can see how the infinities are in some sense compounded on the CC-M once one realizes that the mechanism for producing the large-scale structure of our metagalaxy is eternal inflation. According to Alan Guth, on such a sub-model, "anything that can happen will happen: in fact, it will happen an infinite number of times" (Guth (2004, p. 49)). The latter implication of eternal inflation is relevant since—you will remember—the means by which entropy increases without bound is through the birth of metagalaxies. Because our metagalaxy will evolve into a de Sitter space, it will eventually start to behave like the background Universe, and spawn proto-inflationary patches that eternally inflate into even more metagalaxies. But you see, Guth's point is that eternal inflation also implies the inevitable birth of other metagalaxies without the extra thesis that our metagalaxy is an asymptotically de Sitter space-time. For on eternal inflation, certain regions of space never stop inflating. Some of these inflating regions will give birth to other universes in which physical constants and parameters may vary (see Linde (2004, pp. 431-2); and Steinhardt (2011, p. 42)).

So the background universe yields an infinite amount of metagalaxies, and an infinite amount of these will, through eternal inflation, yield an infinite amount of metagalaxies as well. What's the problem? The problem is that this wreaks havoc on probability judgments. If your sample space is infinite, it does not appear possible to have

a well-defined probability measure to underwrite your probability and likelihood judgments. This problem of infinities and probabilities in eternal inflation-based cosmologies is well-known (see Page (2008, p. 063536-1 and the literature cited therein)). However, it is also well-known that there is no current satisfactory solution to the problem. In fact, Paul Steinhardt noted that "[m]any remain hopeful even though they have been wrestling with this issue for the past 25 years *and have yet to come up with a plausible solution*" (Steinhardt (2011, p. 42 emphasis mine)).

Notice that my criticism here would run even if C&C dispensed with eternal inflating sub-models. The problem of infinities appears when theorizing about ultra-large-scale structure (*i.e.*, the Universe). The problem is compounded when eternal inflating sub-models of metagalaxies such as our own are added in. I conclude then, that while C&C's original paper does not invoke the FGG mechanism (despite judgments from Carroll to the contrary), a heretofore-unresolved theoretical problem remains, the problem of infinity and likelihood.

Kimberly K. Boddy, Sean Carroll, and Jason Pollack (2014) have recently attempted to avoid the infinities pregnant within inflationary theory by arguing that quantum fluctuations needed during the inflationary era to induce eternally inflating regions never occur due to the phenomenon of quantum decoherence as understood by the many-worlds or Everettian interpretation of QM (see ibid., pp. 3-4, p. 28). The proposal will not help Carroll escape the clutches of the measure problem as articulated here since the existence of infinitely many universes is guaranteed by the existence of the Universe or multiverse itself. The background space-time that is empty dS produces an infinite amount of metagalaxies without the mechanism of eternal inflation. Second,

many-worlds interpretations of QM face a deeply perplexing problem. How does one justify the Born rule of QM given such an interpretation? (See on this Albert (2012)). I find the attempts to derive the Born rule from considerations having to do with decision theory to be dependent upon questionable assumptions (*e.g*., Wallace's (2012, p. 178-179) diachronic consistency and state supervenience principles). I also find the reasoning to be a bit circular (Baker (2007)). Thus, this newer work provides no escape from the measure problem.

6.2.2 The Banks-Fischler Holographic Model

The CC-M is admittedly though still woefully incomplete. This incompleteness transfers to its proposed scientific explanation of our initial low-entropy state. Even if we grant that the model and its accompanying explanation are in some sense complete, all of its essential theses are false. We should therefore refrain from looking to the CC-M for a dynamical explanation of the arrow of time. Let us now turn to the BF-M.

In a series of very sophisticated and thought provoking papers, Tom Banks and Willy Fischler (with some additional collaboration) forged an exceedingly plausible holographic cosmogenic and cosmological model of the universe.[58] The Banks-Fischler model (BF-M) rests atop a holographic theory of spacetime (henceforth HST) that is itself a framework for quantum theories of gravity that incorporates some ideas from quantum field theory (QFT), and that generalizes string theory.[59] Banks and Fischler (B&F) believe that their generalization of string theory provides a correct quantum theory of gravity, which fits cleanly within the framework of their dense black hole fluid

[58] Banks (2007), (2009), (2010), (2011a), (2012a), (2012c); (2015); Banks and Fischler (2001), (2004), (2005), (2015); Banks, Fischler, and Mannelli (2005); Banks, Fischler, Torres, and Wainwright (2013).

[59] Banks (2009, p. 1); (2010, p. 4875); (2012a, p. 1241004-1).

cosmological model of our flat FLRW cosmos. B&F also maintain that their distinctive model solves well-known problems in cosmology including the isotropy, flatness, and homogeneity problems.[60] Importantly, B&F also claim that the model provides a successful scientific explanation of our universe's initial low-entropy state.[61]

6.2.2.1 Quantum Physics and the BF-M

The BF-M is supposed to have broad enough generality that it subsumes various string theories as special cases. It is also a generalization of string theory in the sense that it is supposed to provide the theorist with both the string theoretic kinematics and dynamics of spacetimes with varying asymptotics (*e.g.*, AdS, AsDs, dS, and asymptotically flat FLRW spacetimes). Below I present the assumed theory of non-relativistic quantum mechanics that is at work behind the scenes of the BF-M. I will then summarize the details of B&F's specific quantum theory of fundamental structure, the theory which paints a picture of that structure from which classical geometry emerges, *i.e.*, the picture from which one can derive the classical geometric structure of our FLRW universe.

6.2.2.1.1 Banks on Non-Relativistic Quantum Mechanics[62]

Using the state of an ammonia molecule as an example, Banks (2011b) argued that (a) quantum mechanics delivers to us an essentially fundamental probabilistic view of reality, and (following Koopman (1931)) that (b) classical mechanics is really just an instance or special case of quantum theory. Banks (2011b) then argued that quantum

[60] Banks, Fischler, and Mannelli (2005, p. 123514-8).

[61] Banks remarked, "…holographic cosmology can explain the low-entropy of the initial conditions for the normal part of the universe." Banks (2009, p. 7)

[62] And here I lean heavily upon Banks (2011b) which draws on some ideas in Koopman (1931), and (1932).

reality is fundamentally probabilistic in the sense that even given that one is certain that some measurement outcome occurs, the probability that some other (perhaps incompatible) outcomes obtained is still (very possibly) any value between 0 and 1. For Banks, this fact further implies that with respect to incompatible observables, the exclusive disjunction is not well defined in the sense that the law of excluded middle appears to be broken.[63] I should add here that because of (a) above, crucial to Banks' outlook on non-relativistic QM is his assumed interpretation of probability. In his published work, he seems to assume a finite frequentist interpretation of experimental physics, though he admits that while such an interpretation is "mathematically rigorous" it is "only a fantasy in the real world, where we have no idea whether we have an infinite amount of time to do the experiments".[64] In the context of quantum cosmology (the context of the BF-M) the choice interpretation of probability is Bayesian. Banks therefore appears to be a pluralist about the interpretation of probability much like Donald Gillies (2000). While I will reserve my more serious complaints about the choice interpretation of QM and the assumed interpretation of probability for later, I do want to admit to being a bit befuddled by Banks' pluralism. One's quantum cosmology will depend upon one's quantum theory of gravity, but quantum gravity is a unification (of some variety) of quantum mechanics and the general theory of relativity. It therefore rests in some way upon some interpretation of non-relativistic QM. But in light of an affirmation of (a), probability is playing a crucial role in Banks' assumed interpretation. But how can one's interpretation of probability at the level of non-relativistic quantum mechanics be

[63] Banks (2011b).

[64] Banks (2011b, p. 0). Notice the above worry is one usually lodged against finite frequentism (see Hájek (2012, sect. 3.4)). If Banks were a *hypothetical* or *infinite* frequentist he would not find the above objection very troubling, though there are others to fear (see Hájek (2009), (2011)). Finite frequentism is the view that "[t]he probability of an attribute A in a finite reference class B is the relative frequency of actual occurrences of A within B." Hájek (2011, p. 397).

frequentist, while one's interpretation of probability in the context of quantum cosmology be Bayesian, when one's quantum cosmology inherits one's outlook on non-relativistic quantum mechanics? The two interpretations entail mutually exclusive tenets about probability. It seems that Banks owes us a story about how his pluralism works in the context of quantum cosmology and non-relativistic QM.

Let me now say more about Banks' motivation for rejecting excluded middle. For Banks, QM requires the collapse of the wave function, and that amounts to just an application of the Bayesian rule of conditional probability. However, the probabilities of QM do not abide by the law of conditional probabilities because by Banks' lights, that law depends on the law of excluded middle. But Banks maintains that excluded middle is undercut by the following fact:

> Even when we've specified the state of a system completely, by answering yes or no to every possible question in a compatible set, there are an infinite number of other questions one can ask of the same system, whose answer is only known probabilistically. The formalism predicts a very definite probability distribution for all of these other questions.[65]

The thought is that in QM one has a probability measure defined over a space of projections that lives on a Hilbert space. With a density matrix in hand, with respect to every single projection "P", one receives a definition of TrP\ ρ that in turn yields a value between 1 and 0. If one has in hand a pure density matrix it's false that with respect to two projectors P1 and P2 there are only four possibilities (*viz*., both are true, both are false, P1 is true and P2 is false, P2 is true and P1 is false). The fact that there are more than the four possibilities suggests that something is wrong with LEM.[66]

---

[65] Banks (2011b, p. 7).

[66] Banks (personal correspondence 3/14/2015). If there's an error in the above, the fault is mine.

One can complete the above summary of Banks' interpretation of QM by simply adding in details of a slightly modified version of the Copenhagen interpretation of QM.[67] That interpretation has been clearly expressed in a number of publications, and I refer the reader to the explications in Bohr (1958), Wallace (2008, pp. 21-39), and Weinberg (2013, pp. 81-96) for all the details.

6.2.2.1.2 The Holographic Theory of Quantum Gravity[68]

Unlike quantum geometridynamical approaches to quantum gravity, the HST does not quantize Einstein's field equations (EFEs), for they are hydrodynamical equations valid for causal diamonds that feature sufficiently high entropy.[69] The motivation for such an outlook lies within the arguments of Ted Jacobson (1995). Jacobson derived the EFEs from thermodynamics or more precisely, he derived the EFEs from the relation entropy stands to area (*i.e.*, the area of causal diamonds). For B&F, there is room for the quantization of hydrodynamical equations only in the context of low energy fluctuations *per* ground states of physical systems.[70]

The theory of quantum gravity the HST provides is very general. More specific and detailed theories of quantum gravity can vary between spacetimes with different asymptotics. Recall that in cosmology, one of the parameters responsible for such asymptotics is the value of the cosmological constant sometimes featured in the EFEs.

---

[67] Banks is not fully satisfied with the Copenhagen take on decohering histories. Banks (personal correspondence 3/14/2015).

[68] For what follows, I lean heavily upon Banks (2009), (2010), (2011a), (2011b), and Banks, Fischler, and Mannelli (2005). I should add here that I will assume that spacetime is a pair (M, g_{ab}), where M is connected, smooth, and 4-dimensional (I have in mind the non-compactified dimensions). We will also need to define over M a Lorentzian metric (Lorentzian because it is of Lorentz signature (1, 3)) that is itself smooth, non-degenerate, and pseudo-Riemannian, and stipulate that there lives on spacetime a continuous timelike vector field (*i.e.*, spacetime is time-oriented), and that there are no closed time-like curves or closed causal curves in (M, g_{ab}). Moreover, add the further fact that (M, g_{ab}) is globally hyperbolic, and so spacetime is or can be partitioned by Cauchy hypersurfaces.

[69] The notion of a causal diamond is defined below.

[70] Banks (2015, p. 2).

However, Jacobson derived the EFEs without the cosmological constant term. Thus, B&F conjecture that its value (when positive) is the inverse of the value of *N*, where *N* is the logarithm of the dimension of the Hilbert space in the correct quantum theory describing spacetime.[71] If such a conjecture is right, then the correct quantum theory will feature a Hilbert space that only has a finite number of dimensions.[72]

The geometric structure of spacetime is given by the Lorentzian metric g_{ab}. There are two metric determining factors: the conformal factor and the causal structure of spacetime. This is an implication of the further fact that two metrics featuring the same causal structure are equivalent up to a weyl transformation.[73]

According to the HST, the causal structure of spacetime is fixed by causal diamond structure. In fact, causal diamonds are the fundamental *geometrical* building blocks. They are constructed out of the intersections of the interior of the future light-cone of a spacetime point *y*, and the interior of the past light-cone of a spacetime point *x* (where *x* and *y* are members of *M*).[74] The HST represents the timelike trajectory of a particle *via* a nested sequence of diamonds. Nested diamonds are also used to characterize the ever-increasing timelike separation of pairs of points on the edges of the diamonds. Certain of the causal diamonds may even overlap, and these overlap spaces are represented with the notation $\mathcal{O}(n; x, y)$. The HST associates with causal diamonds Hilbert spaces. Hilbert spaces $\mathcal{H}(n, x)$ associated with causal diamonds and $\mathcal{O}(n; x, y)$

[71] Banks (2000); *cf*. Banks (2015, pp. 15-18).

[72] I argued for the truth of this conjecture in my discussion of the Carroll-Chen cosmological model above.

[73] Banks (2011a).

[74] It's clear that early on, Banks collapsed causal structure into light-cone structure. He believes that the global causal structure is given by causal diamond structure, but because such causal diamond structure is itself constituted by light-cone structure, causal structure must be reducible to light-cone structure. See his remarks in Banks (2009, p. 2). However, later on Banks seemed to prefer a definition of causal diamond that appealed to future and past domains of influence.

specify the conformal factor (which is given by the areas of the holographic screens of the diamonds (more on this below)) and the causal structure of spacetime.[75] And so, in the overlap spaces involving pairs of causal diamonds that intersect, causal diamonds are assigned to the overlap spaces. This overlap space has a maximal area that in the intersection itself. The causal diamond of the intersection can be connected with "a common tensor factor in the Hilbert spaces of the individual diamonds" *viz*., $\mathcal{H}_1 = \mathcal{O}_{12} \otimes \mathcal{N}_1$, and $\mathcal{H}_2 = \mathcal{O}_{12} \otimes \mathcal{N}_2$.[76]

Causal diamonds are themselves characterized by sequences of operator algebras A(n).[77] Embedded operators of causal diamonds commute in such a way that they commute with every other operator that one needs to describe larger diamonds in which they are embedded.[78] Algebras A(n) are nested in a way expressed by A(n+1) = A(n) $\otimes$ P.[79]

But what about the conformal factor? The net of operator algebras associated with a sufficiently large set of sequences of causal diamonds (those diamonds that encode causal structure) together with the holographic screens associated with those diamonds provides the determining base of the conformal factor.

According to B&F, linking both causal structure and conformal factor to the geometric structure of spacetime can only be achieved by appeal to the strong form of the holographic principle (see Bousso (1999)). Thus, B&F think of the geometric structure yielded by classical causal diamonds as emerging from quantum mechanical structure.

---

[75] Banks (2012a, p. 121004-2). For a discussion of the formalism see lines 1) through 4) below.

[76] Banks (2010, pp. 4875-4876). The subscripts represent differing causal diamonds. So subscript 1 is causal diamond 1, and subscript two is causal diamond 2. The two diamonds overlap.

[77] For details regarding operator algebras, see Kadison and Ringrose (1997).

[78] Banks, Fischler, and Mannelli (2005, p. 123514-3); see also Banks (2011a).

[79] Banks (2012a, p. 121004-2).

But what is the CEB? Well note first (and here I lean on Banks (2011a)) that the d – 1 "dimensional boundary of a causal diamond is a null surface".[80] One secures a cut over a null surface on to d – 2 dimensions by introducing a foliation of spacelike surfaces over the manifold M. The CEB says that the entropy S of the causal diamond is less than or equal to the area of the diamond's holographic screen divided by 4 by lp^2. According to Banks (2011a), given the CEB, it will follow that all causal diamonds are such that the entropy of the boundaries of the relevant diamonds is bounded "by the area of the maximal area d-2 surface on the boundary."[81] These considerations suggest B&F's conjecture, that the entropy of a causal diamond is just the logarithm of the dimension of the Hilbert space of that diamond.[82]

Add to the above the further fact that covariant entropy bound is really just a bound over density matrices since the systems in causal diamonds are quantum systems. More specifically, B&F argue that the density matrices of causal diamonds are maximally uncertain.[83]

All of the above considerations indicate that the quantum aspects of the HST require that the fundamental variables of quantum mechanics are pixels on holographic screens of diamonds with orientations.[84] These variables, or pixels are themselves

---

[80] Banks and Kehayias (2011, p. 1. n. 1).

[81] Banks, Fischler, and Mannelli (2005, p. 123514-2).

[82] The holographic entropy bound implies "a finite entropy for any causal diamond whose future boundary is a finite timelike separation from the Big Bang." Banks, Fischler, Mannelli (2005, p. 123514-1). See also Banks (2011a).

[83] Banks (2011a).

[84] One pixelates the holographic screen of causal diamonds via fuzzy geometry (Banks (2010, p. 4878)). The functional algebras become matrix algebras. The details are discussed in Banks (2010, pp. 4879-4890).

Pixels have orientations, at least in the classical limit. Two things fix these orientations, a holographic screen element that is transverse to the other determining factor *viz*., an associated null ray. Solutions to the Cartan-Penrose equation $0 = \bar{\varphi}\gamma^{\mu}\varphi(\gamma_{\mu})^{\beta}_{\alpha}\varphi_{\beta}$ (given that φ_{β} is the Dirac spinor) encode the aforementioned information about orientations and null rays (Banks, Fischler, and Mannelli (2005, p. 123514-5); Banks (2010, p. 1241004-3)).

nothing above and beyond the degrees of freedom enjoyed by supersymmetric particles that should be understood as penetrators of the holographic screen of the relevant causal diamonds.[85] That HST involves supersymmetric particles is no surprise, since (again) HST is a generalization of string theory. It therefore predicts the existence of superpartners. Pixels of holographic screens have associated Hilbert spaces with a finite amount of dimensions, and this implies that holographic screens with finite area have associated algebras with a non-commutative basis that is finite (Banks (2009, p. 2)). The tensor product of the Hilbert spaces of individual pixels on the screen of a causal diamond just is the Hilbert space of the diamond.

Generally speaking, the HST suggests that spacetime is emergent. Its classical structure is derived from quantum mechanical structure that determines causal diamond structure and a conformal factor (the elements sufficient for determining the spacetime metric). That quantum mechanical structure amounts to density matrices, pixelated holographic screens with associate Hilbert spaces, and operator algebras assigned to the density matrices inside classical causal diamond structure. A full picture of the HST will emerge once we add in details about its kinematics and dynamics. I will try to summarize some of the relevant details in my articulation of the cosmological model that is the BF-M.

6.2.2.2 Cosmology and the BF-M

6.2.2.2.1 Kinematics, Dynamics, and Time in our Universe

Let S be the initial big bang surface. The topology (and not the geometry) of that slice of space (*per* non-compact dimensions) in a holographic spacetime is given by a (d

[85] Banks (2009, p. 2).

– 1)-dimensional spatial lattice.[86] An integer variable t represents proper time in that it "is a monotonic measure of the proper time τ" that is "traversed between the past and future tips of the diamond represented by $\mathcal{H}(t,x)$".[87] When causal diamonds grow larger and larger (when one adds more and more pixels to the screens of the diamonds[88]), the proper time becomes discretized and turns into smaller units. Banks added, "the smallest proper time interval measurable in a large causal diamond is inversely proportional to the energy of a black hole whose horizon area is equal to the area of the holographic screen."[89]

According to the BF-M, coordinate systems are ways of "covering space-time by trajectories of [detectors]."[90, 91] Trajector**ies** of detectors near the big bang surface or touching that surface form a lattice. These trajectories are themselves given by sequences of Hilbert spaces, and trajectories nearest to one another yield the overlap sequences of diamonds discussed above.[92]

The variable x in $\mathcal{H}(t,x)$ will represent a spatial location on the aforementioned lattice. All of the points that live on the lattice have Hilbert spaces described by the equation: $\mathcal{H}(n,x) = \otimes \mathcal{P}^n$, where $\mathcal{P}$ is a pixel Hilbert space that gives the geometry of dimensions that are compactified, it therefore represents the Hilbert space of the pixel

---

[86] Banks (2010, p. 4876); Banks (2009, p. 4).
[87] Banks (2009, p. 5).
[88] Banks, Fischler, and Mannelli (2005, p. 123514-5).
[89] Banks (2009, p. 5).
[90] Banks, Fischler, and Mannelli (2005, p. 123514-7).
[91] The notion of a detector is akin to that of an observer. An observer is:

> "a large localized quantum system, which is capable of carrying out 'almost classical' measurements on its environment. Any such observer will follow a timelike trajectory through space-time. We can describe this trajectory in terms of causal diamonds in the following manner." Banks, Fischler, and Mannelli (2005, p. 123514-3)

[92] Ibid.

super-algebra.[93] The Hilbert spaces associated with points on the lattice represent sequences of causal diamonds. Recall that such diamonds are geometric diamonds of trajectories. They model the timelike separation of points on the trajectory. That is to say, the diamonds model "the proper time separation of its future tip from the point where it crosses the spacelike slice"[94]. The upper limit or "maximal value that *n* attains as" *t* approaches infinite values is given by N(x) (Banks (2010, p. 4876)). Notice that the approach appeals to time slices. In fact, according to Banks (2010, p. 4876) all "causal diamonds at" a certain "fixed time have" holographic screens that feature the same areas. This is directly due to the chosen slices of space. Banks adds that "equal area slicings exist in all commonly discussed classical space-times."[95]

As we noted above, some causal diamonds overlap, and the kinematic rules of such overlap spaces are given by (1)-(3) below (taken and corrected from Banks (2009, p. 5)):

(1) $\mathcal{H}(t,x) = \mathcal{O}(t;x,y) \otimes \mathcal{N}_1(t,x,y)$
(2) $\mathcal{H}(t,y) = \mathcal{O}(t;x,y) \otimes \mathcal{N}_2(t,y,x)$

where $\mathcal{N}$ is the Hilbert space of one of the overlapping causal diamonds. Banks (2009, p. 5) notes that "the overlap Hilbert space $\mathcal{O}$ is the same for *x* and *y*, but the Hilbert spaces $\mathcal{N}$ may be different." With respect to points *x* and *y*, nearest to one another on the lattice referenced above, the following rule holds:

(3) $\mathcal{N}_1(t,x,y) = \mathcal{N}_2(t,y,x) = \mathcal{P}$ for any time t.

These rules imply that closest neighboring detectors (the observer like entities that travel down trajectories) share the same information save that which is stored on one single

[93] Banks (2009, p. 4).
[94] Banks (2010, p. 4876).
[95] Ibid.

pixel.[96] The dimensionality of $\mathcal{O}$ or the overlap Hilbert space is a function "of the minimal number of lattice steps between x and y."[97]

As I pointed out above, the dynamics of HST and so of the BF-M is thought to be relative to space-time asymptotics, though the BF-M and HST suggest that the local dynamical goings-on within a causal diamond are restricted to that diamond and so dynamical evolution only affects those physical systems or degrees of freedom within the relevant diamonds themselves (no cross-over dynamical influence from one diamond to another). The Hamiltonian governing the dynamics of physical systems in the BF-M *is time-dependent* (where time is discrete) in our universe, and "the Arrow of Time" is a "fundamental input to the definition of cosmology."[98] Banks, Fischler, and Mannelli believe they have an argument for such an outlook at least given that our universe ends in a Big Crunch. They remarked:

> …we could define both Big Bang and Big Crunch cosmologies (with, for simplicity, a past or future with the asymptotic causal structure of Minkowski space), in terms of semi-infinite sequences of Hilbert spaces. However, in the Big Bang case, the initial conditions would be subject to our purity constraint for causal diamonds whose tip lies on the singularity. By contrast, in the Big Crunch, the initial conditions would be described in terms of scattering data in the remote past. Even if we discussed finite causal diamonds whose future tip lay on the Big Crunch, it would not make sense to assume the final state in those causal diamonds was pure. It has been correlated with the states in each other causal diamond, by evolution of the scattering data down to the singularity.[99]

According to the BF-M, causal diamonds close to the big bang are realized by quantum states that are pure states (the purity constraint). However, the dynamics of the BF-M prohibit evolution from non-pure states involving scattering data to the pure earliest state. This is because according to the BF-M, dynamical cosmic evolution is described by the

---

[96] Banks (2009, p. 5).
[97] Ibid.
[98] Banks, Fischler, and Mannelli (2005, p. 123514-4).
[99] Ibid., emphasis in the original.

causal diamond and conformal factor framework. There is only one diamond in the large but finite sequence of causal diamonds describing cosmic evolution in a quasi-Gold universe that reaches the Big Crunch.[100] This prohibits cosmic evolution from Crunch to Big Bang, and so Banks et. al. conclude: "…we contend that the intrinsic formulation of a theory of quantum cosmology forces us to introduce a time asymmetry, when there is a cosmological singularity." [101] A similar conclusion would follow from the purity constraint, the dynamics of the BF-M, and a spacetime that is asymptotically de Sitter. But its time to more fully specify the dynamics of the BF-M:

1) Let $\mathcal{H}_{in}(t)$ be, in pixel variables that are fermionic, a perturbation of a Hamiltonian that is bilinear.[102] The time-dependent Hamiltonian operator $\mathcal{H}(t)$ is really just the sum of another operator $\mathcal{H}_{in}(t)$ which depends on $\mathcal{H}_{out}(t)$ and those pixel operators in $\mathcal{P}^t$. The operator $\mathcal{H}_{out}(t)$ commutes with both $\mathcal{P}^t$, and $\mathcal{H}_{in}(t)$. $\mathcal{H}_{in}$ designates Hilbert spaces associated with diamonds, while $\mathcal{H}_{out}$ is that Hilbert space associated with the quantum theory that describes spacetime in entirety. [103]
2) All detectors traveling down trajectories and situated on the spatial lattice referenced above are described by "the same sequence of time-dependent Hamiltonians $\mathcal{H}(t)$".[104]
3) $\mathcal{O}(t,x,y) = \otimes\, \mathcal{P}^{t-d(x,y)}$ where d(x, y) is "the minimum number of lattice steps between the points" x and y. [105] $\mathcal{H}(t-d(x,y))$ specifies the Hamiltonians of overlap spaces.[106]

It has been shown that a flat FLRW spacetime geometry follows from the above quantum mechanical descriptions of reality.[107] The model of the cosmos that emerges fits very nicely with a cosmos that is understood as a dense black hole fluid (hence DBHF).[108]

---

[100] See ibid., p. 123514-4. n. 6.
[101] ibid., p. 123514-4. Italics removed.
[102] The bilinear form is discussed in Banks (2009, p. 6).
[103] Banks (2009, p. 6), (2010), (2012).
[104] Banks (2009, p. 6).
[105] Banks (2010, p. 4876).
[106] Banks (2009, p. 6), (2010), (2012).
[107] See Banks, Fischler, and Mannelli (2005).
[108] The details are discussed in Banks (2009, p. 6).

6.2.2.2.2 The Dense Black Hole Fluid

The model under discussion says that our universe is a big bang universe, though there is no initial singularity.[109] The past-tips of causal diamonds lie on the big bang hypersurface (a surface with the same topology as a flat 3D space[110]). Quantum dynamics near that surface is chaotic in the sense that the Hamiltonian describing goings-on close to that surface is random in that a special collection of $\text{Hamiltonians}_{\text{in}}$ peculiar to sufficiently small causal diamonds (diamonds classically modeling extremely early physical systems) are privileged by the HST framework.[111]

The time-dependent $\text{Hamiltonian}_{\text{out}}$ near the big bang hypersurface is, for every moment of time near that surface, a randomly selected distribution of $\text{Hamiltonians}_{\text{in}}$ related to the various trajectories constituting the lattice.[112] Large causal diamonds are described by a time dependent Hamiltonian with a time independent spectral density. The spectral density in play is the same one featured in a conformal field theory with 1+1 dimensions.[113] The universe considered as a physical system therefore receives "a random kick at each time."[114] That system is described by an entropy-energy density relation $\sigma \sim \sqrt{\rho}$.[115] In fact, a cosmos with equation of state $p = \rho$ and for which the approximatation $\sigma \sim \sqrt{\rho}$ holds will be one not unlike a type of system of black holes.[116]

---

[109] This is because classical geometric descriptions are only relevant to large diamonds. Singularities are classical extrapolations to times when the causal diamonds are Planck size (see Banks (2015, p. 4)).

[110] Banks and Fischler (2015, p. 9).

[111] Banks, Fischler, and Mannelli (2005, p. 123514-6).

[112] Ibid., 123514-1.

[113] Ibid.

[114] Ibid.

[115] Where s is approximately $R_S^{-(d-1)} R_S^{d-2}$ (in Planck units given that R_S is the Schwarzschild radius), and where r is approximately $R_S^{(d-3)} R_S^{-(d-1)} \sim \sigma^2$ (in Planck units). See Banks (2012c, p. 89).

[116] Ibid.

Banks (2012c, p. 91) shows that for large diamonds the system in question will look and behave "like a flat FRW" cosmos.

The BF-M yields an isotropic cosmos since its overlap rules suggest as much, and it incorporates the invariance SO(3).[117] Likewise, the BF-M's overlap rules yield a homogeneous cosmos.[118] That leaves flatness among the standard cosmological puzzles. Again, the equation of state describing our universe (call it U) in the BF-M is $p = \rho$.[119] U cannot therefore involve negative spatial curvature if it saturates the covariant entropy bound in diamonds that are further along in the sequence of diamonds.[120] The cosmological constant is an initial condition, and input. Its value is, again, inversely related to the value of N.

So as to solve the cosmological or causal horizon problem the BF-M includes a theory of inflation (the holographic theory of inflation based on the less realistic Everlasting Holographic Inflationary model, or EHI).[121] I will not explore the details of that model here. I wish only to disclose that it avoids the implication that is eternal inflation thought to fall out of generic slow role inflationary models (see Guth (2004); Steinhardt (2011)) because it treats the inflaton field like a classical field and so avoids those quantum woes that breed eternally inflating regions due to quantum fluctuations of that field.[122]

---

[117] Demonstrations are in Banks, Fischler, and Mannelli (2005, p. 123514-8).

[118] Banks (2012c, p. 91).

[119] An equation of state is normally a specification of the relationship between state variables usually derivable from the fundamental equation (Peliti (2003, p. 40)).

[120] ibid. A relevant demonstration of this appears in Fischler and Susskind (1998). Banks (2015, p. 4) remarked "[f]latness follows from an assumption of asymptotic scale invariance for causal diamonds much larger than the Planck scale but much smaller than the Hubble scale of the [cosmological constant]."

[121] See Banks (2015, pp. 5-12); Banks and Fischler (2015, pp. 11-15); Banks, Fischler, Torres, and Wainwright (2013).

[122] Chief among these woes is the measure problem.

6.2.2.3 Objections to the BF-M

I am interested in the BF-M because it's a model that attempts to provide a scientific explanation of the past hypothesis. So far I have focused on describing the BF-M's quantum theory of gravity, and cosmology. Such exposition was important because of the form of the proposed explanation. B&F maintain that they have the correct theory of quantum gravity. In the context of that theory, they argue that the only way to account for classical geometric structure is on the supposition that the cosmos began in an exceedingly low-entropy state. Banks (2015, p. 5) remarked, "the reason the universe began in a low-entropy state, is that this is the only way in which the model produces a complex approximately classical world."[123] Again, the claim is essentially that the correct theory of quantum gravity coupled with the correct quantum cosmology requires that the universe began in a low-entropy state. But, of course, if there are problems with B&F's quantum cosmology and quantum theory of gravity, then the purported explanation will fail. Sections 6.2.2.3.1, 6.2.2.3.2, and 6.2.2.3.3 attempt the feat of explicating various problems with the HST framework. Here, however, I'd like to address the attempted explanation head on, granting for the sake of argument that the BF-M is entirely correct.

The quotation of Banks (2015, p. 5) above suggests that the explanation of the low-entropy state of the cosmos is anthropic in nature. Recall what the anthropic principle states: "what we expect to observe must be restricted by the conditions necessary for our presence as observers".[124] Notice the place of observers in the principle. Banks' anthropic explanation does not require an appeal to observers.[125] He maintains

[123] Banks (2015, p. 5). *Cf*. Banks (2012c, p. 98).
[124] Carter (1974, p. 291).
[125] Notice that the absence or presence of observers in the anthropic-like explanation fails to enable Banks to escape the two objections voiced in the main text.

that according to the BF-M, the initial low-entropy state is necessary for the production of classical geometric structure. Even granting that not so obvious necessity claim, Banks' resolution of the low-entropy problem is still problematic. Consider the fact that the low-entropy state, coupled with the laws and rules of the BF-M *scientifically explains* classical geometric structure. But Banks' anthropic explanation asserts that the existence of such classical structure, together with the laws of the model *scientifically explain* the low-entropy state. We have, quite clearly, an explanatory circle. Circles are bad.

Consider now a second objection to Banks' anthropic resolution. The BF-M's proposed explanation does not seem to be an explanation in any sense of the term. Given attention to the following analogy: The only way there could be (given the biological laws) a chicken is if there were a chicken egg in the state of being fertilized in its past. But it is most definitely wrong for one to insist that the existence of the chicken together with the biological laws explains the state of the past egg. A report on the true and relevant biological laws and on the fact that there could not, according to those laws, be a chicken of the kind we are considering without there being a fertilized egg in its past does absolutely nothing to remove puzzlement about why there's a fertilized egg in the chicken's past. Why was there such a low-entropy state at all? What accounts for that state? That, given the BF-M, such a state is necessary for the existence of classical structure we observe does nothing to answer these questions, just as in (*mutatis mutandis*) the chicken and egg case.

My last objection rests on the account of scientific explanation in chapt. 5. Anthropic-style explanations are not scientific explanations of events or states according to that account. Thus, given my theory of scientific explanation, the proposal of B&F

cannot be properly understood as being in the business of *scientifically* explaining the low-entropy past.

6.2.2.3.1 Problems with String Theory

I now turn to some criticisms of the BF-M. Consider first the fact that the BF-M rests upon a holographic theory of quantum gravity. As I've noted several times now, that understanding of quantum gravity is a *generalization* of string theory.[126] A plausible principle regarding evidence and generalizations says that: If all of the instances of a conjectured generalization are unrealistic, or are such that they encounter problems, then one has some reason to at least defer on the generalization itself. As we shall see, there are good reasons for doubting just about every specific string theory currently on offer.[127]

First, it is well known that *there is absolutely no experimental or empirical evidence for the existence of strings*.[128] Second, string theories have been unable to account for the standard model of particle physics at large or long length scales.[129] Third, string theories are completely unrealistic in that "...there is presently no fully satisfactory embedding of de Sitter space into string theory"[130], and "[a]ll explicit and fully trustworthy solutions that have ever been constructed in string theory have a non-positive

[126] The central tenets of string theory especially as they pertain to cosmology were articulated in chapt. 3.

[127] For a fine summary of the various string theories see Becker, Becker and Schwarz (2007, pp. 6-16).

[128] Laughlin (2005, p. 212) stated, "[t]here is no experimental evidence for the existence of strings in nature, nor does the special mathematics of string theory enable known experimental behavior to be calculated or predicted more easily."

[129] Laughlin (2005, pp. 124-125).

[130] Bousso, DeWolfe, and Myers (2003, p. 297-298). There are no-go theorems that seek to establish that certain compactified theories (string theories) are incompatible with de Sitter space-time (see Maldacena and Nuñez (2000, pp. 26-27)).

cosmological constant."[131] There is an abundance of evidence that our cosmos is one that is accurately described by EFEs with a positive cosmological constant.

6.2.2.3.2 Classical Logic Again

BF-M's assumed non-relativistic quantum theory involves a rejection of classical logic in so far as it involves a rejection of the law of excluded middle. The prolegomena of the present work (particularly in chapt. 2) went through great lengths to show that one ought to appropriate as one's choice logic, a truly classical logic. My reasons were pragmatic in that I argued that one cannot do mathematical physics of the kind that underlies QM and GTR without a classically driven mathematics (see for more on this Hellman (1998)). For example, there is no non-classical proof of the Extreme Value Theorem.[132] This is because the only way to prove the theorem is by *reductio*. Proofs by *reductio* require the excluded middle introduction rule. But the Extreme Value Theorem is essential to proofs of several singularity theorems in general relativity (see Wald (1984, pp. 236-237)). Thus, one cannot have the mathematical physics that is necessary for establishing important physical results without classical logic, and the law of excluded middle. I therefore find Banks' rejection of the law of excluded middle problematic, and if his take on quantum theory entails such a rejection, my reasoning here would constitute a *modus tollens* argument against his interpretation of quantum theory.

6.2.2.3.3 Non-Relativistic Quantum Mechanics

The non-relativistic interpretation of QM is a modified Copenhagen interpretation. I do not believe this interpretation provides a plausible response to the

[131] Van Riet (2011, p. 2).

[132] The theorem states that "a continuous function on a compact domain assumes its maximum (minimum) value at some point." Hellman (1998, p. 431).

measurement problem, but I will not revisit that well-traveled territory here. I do, however, want to point out that the assumed interpretation of probability in the choice interpretation is suspect. This is an important criticism since Banks maintains that reality is intrinsically probabilistic.

The frequentist interpretation of probability is operationalist. It confuses states featuring measurements and the like with probabilities, just as the behaviorist confuses actions understood as behaviors with mental states.[133] But there are well-known problems with operationalism. There is a well-established philosophical consensus concerning its falsehood. I will not rehearse the often repeated objections here.[134]

Second, Hájek has noted that frequentism over generates existents. The truth of probability judgments about oneself rather easily guarantees the existence of other minds and the falsity of solipsism. The fact that it is highly unlikely or the fact that the probability that Winston will suffer from a brain tumor is .1 just means that one tenth of human persons out in the world have brain tumors. The truth of the probability judgment entails the existence of other human persons. This is obviously too quick.[135]

6.3 The Past hypothesis: Where are We Now?

We have seen that two of the best attempts at scientifically explaining the past hypothesis fail. We could extend the project to cover other models, such as eternally inflating models as well as cyclic universe models. But all of these will suffer from similar problems (*e.g.*, inflation does not explain the low-entropy state it presupposes it, and the cyclic universe model requires unbounded entropy which the Banks-Fischler Λ-N

[133] The analogy is Hájek's (2011, p. 402).
[134] See Chang (2009).
[135] ibid., 402.

correspondence thesis refutes). It looks as if there can't be a physical explanation of the low-entropy state.

If one is in the mood, one might conditionally accept the above claim and ask, "where does that leave us?" Well, the past hypothesis is not a brute fact though representative quantum cosmological models fail to scientifically explain the universe's initial entropic state. My argumentation therefore provides some reason for maintaining that the explanation of the past hypothesis will not be scientific. It will not be a token physical explanation in the sense explicated in chapt. 5. This leaves my current project in a state of *aporia*. A very important and exquisite feature of our universe cries out for an explanation and yet we have some inductive evidence that it cannot be scientifically explained.

Chapter 7 Conclusion

What has this series of essays accomplished? In chapt. 1, I presented the standard story on the arrow of time puzzle, musing that the best (and certainly most popular) solution to that puzzle requires as its backbone, the past hypothesis (the idea that our universe began in a special low-entropy state). Chapt. 2 presented some plausibility arguments in favor of several philosophical positions including an Aristotelian substance theory of concrete particulars, logical monism plus classical logic as the one true logic, necessitism, and that two possibility claims are such that belief in them can receive *prima facie* epistemic justification. Chapt. 3 then used most of the philosophical prolegomena of chapt. 2 to knock down David Lewis's Humean supervenience thesis, Theodore Sider's new fangled Humeanism, and two direct arguments for causal reductionism (the idea that obtaining causal relations are nothing above and beyond lawfully related physical events). Chapt 4 built on top of the demolition work of chapt. 3, a new realist theory of causation coupled with a novel theory of causal *relata*. Chapt. 5 used the content of the two preceding chapters to explicate a novel theory of token physical explanation of states. Chapters 3 through 5 therefore provided an answer to the question, "what would it take to scientifically explain the universe's initial low-entropy state?". Chapter six examined two of the most fully worked out quantum cosmological models that try to remove puzzlement about that state. I criticized each model and ended the project in *aporia*. In this final chapter, I'd like to say something about that *aporia*, something that may make it more potent.

The low-entropy past is one of very many other fine-tuned parameters. And here by 'fine-tuned' I mean, that the relevant parameter or constant may be measured by a mathematical value that actually happens to fall within a range or interval of values, the

physical consequences of which, is that the universe is life-permitting rather than life-prohibiting. The type of life I have in mind is any carbon, water, or silicon-based life. Here is a representative list of such parameters, and constants that are commonly believed to be fine-tuned by most physicists who have written on the topic:

(1) The Cosmological Constant[1]
(2) The Weak Force[2]
(3) The Strong Force[3]
(4) The Electromagnetic Force[4]
(5) The Proton and Neutron Mass Difference[5]
(6) Gravity[6]

On top of (1)-(6) we can add the further fact that most physicists who have written on the topic of fine-tuning maintain that a number of laws of nature are such that were they false or non-existent, no life of any kind would be natural nomologically possible:

(7) The Pauli-Exclusion Principle[7]
(8) Bohr's Quantization Rule[8]

Add to the first two types of examples, the additional type of examples having to do with initial conditions:

(9) The Low-Entropy State[9]
(10) The Ratio of Radiation Density to Matter Density[10]
(11) The Density Perturbations (those responsible for star formation)[11]
(12) The Mass Density of the Early Universe[12]

---

[1] Barnes (2012); Collins (2012).
[2] Collins (2003, p. 188).
[3] Barrow and Tipler (1986).
[4] Barrow and Tipler (1986).
[5] Collins (2012).
[6] Collins (2003, pp. 189-190); Rees (2000, p. 30).
[7] Dyson (1979, p. 251); Collins (2012, pp. 211-213).
[8] Collins (2012, pp. 211-213).
[9] See Barnes (2012); Carroll (2010).
[10] See Collins (2012); Davies (1982); Rees (2000).
[11] See Barnes (2012); Collins (2012); Davies (1982); Rees (2000).
[12] See Collins (2012); Davies (1982); Rees (2000).

We can also pile on the further fact that the underlying mathematical physical descriptions of the cosmos are both comprehensible, applicable to the cosmos, and such that they can be used to provide a formulation of the very laws of physics. A number of world renowned physicists have found this "problem of the applicability of mathematics"[13] to be the most fascinating and suggestive problem about our cosmos:

Roger Penrose:

> "…profound interplay between the workings of the natural world and the laws of sensitivity of thought—an interplay which, as knowledge and understanding increase, must surely ultimately reveal a yet deeper interdependence of the one upon the other." Penrose (1978, p. 84)

Heinrich Hertz:

> "One cannot escape the feeling that these mathematical formulae have an independent existence and intelligence of their own, that they are wiser than we are, wider even than their discoverers, that we get more out of them than was originally put into them." As quoted by Steiner (1998, p. 13)

Eugene Wigner:

> "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve." Wigner (1967, p. 237)

Steven Weinberg:

> "It is positively spooky how the physicist finds the mathematician has been there before him or her." As quoted by Steiner (1998, p. 13)

Richard Feynman:

> "I find it quite amazing that it is possible to predict what will happen by mathematics, which is simply following rules which really have nothing to do with the original thing." Feynman (1967, p. 171)

Johannes Kepler:

> "Thus God himself was too kind to remain idle, and began to apply the game of signatures, signing his likeness into the world; therefore I chance to think that all nature and the graceful sky are symbolized in the art of geometry." As quoted by Steiner (1998, p. 14)

---

[13] On this problem see especially Steiner (1998).

The means by which we discovered the fine-tuned constants, parameters, initial conditions, and the laws of nature was by means of mathematical physics (among other things). But, it appears that it's a recognized fact that these tools of mathematics are themselves miracles. They, oddly enough, apply in elegant ways to our cosmos, and they are such that we can grasp them and work with them, and appreciate the (Penrose) interplay between their contents and the cosmos. These facts of elegant applicability, and comprehension seem inexplicable, and they constitute (in Wigner's terms) a veritable gift we neither deserve nor fully understand.

What does all of the above mean? I'd like to conjecture that the *aporia* I left the reader with at the end of chapt. 6 is less surprising given these facts. The cosmos seems to want us to both understand it and appreciate its kindness. These considerations, I believe, push us to seek a non-physical explanation of the past hypothesis, one that perhaps also accounts for the aforementioned cases of fine-tuning.

References

Adams, R.M. (1979). 'Primitive Thisness and Primitive Identity', *The Journal of Philosophy*. **76**, 5-26.

Ade, P.A.R. Aikin, R.W. Barkats, D. Benton, S.J. Bischoff, C.A. Bock, J.J. Brevik, J.A. Buder, I. Bullock, E. Dowell, C.D. Duband, L. Filippini, J.P. Fliescher, S. Golwala, S.R. Halpern, M. Hasselfield, M. Hildebrandt, S.R. Hilton, G.C. Hristov, V.V. Irwin, K.D. Karkare, K.S. Kaufman, J.P. Keating, B.G. Kernasovskiy, S.A. Kovac, J.M. Kuo, C.L. Leitch, E.M. Lueker, M. Mason, P. Netterfield, C.B. H.T. Nguyen, O'brient, R. Ogburn IV, R.W. Orlando, A. Pryke, C. Reintsema, C.D. Richter, S. Schwarz, R. Sheehy, C.D. Staniszewski, Z.K. Sudiwala, R.V. Teply, G.P. Tolan, J.E. Turner, A.D. Vieregg, A.G. Wong, C.L. Yoon, K.W., (2014). 'Detection of B-Mode Polarization at Degree Angular Scales by BICEP2', *Physical Review Letters*. **112**, 241101.

Aguirre, A. Carroll, S.M. and Johnson, M.C. [2011]: 'Out of Equilibrium: Understanding Cosmological Evolution to Lower-Entropy States', arXiv:1108.0417v1 [**hep-th**].

Aguirre, A. Gratton, S. and Johnson, M.C. [2007]: 'Hurdles for Recent Measures in Eternal Inflation', *Physical Review D*. **75**, 123501.

Aharonov, Y.A. (1984). 'Aharonov-Bohm Effect and Non Local Phenomena', in *Proceedings of the International Symposium on the Foundations of Quantum Mechanics in the Light of New Technology*. Singapore: World Scientific.

Aharonov, Y.and Bohm, D. (1959). 'Significance of Electromagnetic Potentials in the Quantum Theory', *The Physical Review*. **115**, 485-491.

Aizawa, K. (2013). 'Multiple Realization by Compensatory Differences', *The European Journal for Philosophy of Science* **3**, 69-86.

Aizawa, K. and Gillett, C. (2009). 'The (Multiple) Realization of Psychological and other Properties in the Sciences', *Mind and Language*. **24**, 181-208.

Albert, D.Z. (1994). 'The Foundations of Quantum Mechancis and the Approach to Thermodynamic Equilibrium', *The British Journal for the Philosophy of Science*. **45**, 669-677.

Albert, D.Z. (1996). 'Elementary Quantum Metaphysics', In J. Cushing, A. Fine, and S. Goldstein (eds.), *Bohmian Mechanics and Quantum Theory: An Appraisal*. Dordrecht: Kluwer, 277-284.

Albert, D.Z. (2000). *Time and Chance*. Cambridge, MA: Harvard University Press.

Albert, D.Z. (2010). 'Probability in the Everett Picture', in Simon Saunders, Jonathan Barrett, Adrian Kent, and David Wallace (eds.), *Many Worlds? Everett, Quantum Theory, and Reality*. Oxford: Oxford University Press, 355-368.

Albert, D.Z. (2015). *After Physics*. Cambridge, MA: Harvard University Press.

Albrecht, A. (2004). 'Cosmic Inflation and the Arrow of Time', in John D. Barrow, Paul C.W. Davies, and Charles L. Harper, Jr. (eds.), 2004, *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*. New York, NY: Cambridge University Press, 363-401.

Alston, W.P. (1971). 'The Place of the Explanation of Particular Facts in Science', *Philosophy of Science*. **38**, 13-34.

Alston, W.P. (1976). 'Has Foundationalism Been Refuted?', *Philosophical Studies*. **29**, 287-305.

Alston, W.P. (1991). *Perceiving God: The Epistemology of Religious Experience*. Ithaca, NY: Cornel University Press.

Anscombe, G.E.M. (1971). *Causality and Determination: An Inaugural Lecture*. Cambridge: Cambridge University Press.

Aristotle. (1984). *The Complete Works of Aristotle: The Revised Oxford Translation*, ed. J. Barnes Princeton, NJ: Princeton University Press.

Armstrong, D.M. (1968). *A Materialist Theory of the Mind*. London and Henley: Routledge & Kegan Paul.

Armstrong, D.M. (1973). *Belief, Truth and Knowledge* New York, NY: Cambridge University Press.

Armstrong, D.M. (1978a). *Nominalism and Realism: Universals and Scientific Realism* Volume 1 New York, NY: Cambridge University Press.

Armstrong, D.M. (1978b). *A Theory of Universals: Universals and Scientific Realism* Volume 2 New York, NY: Cambridge University Press.

Armstrong, D.M. (1983). *What is a Law of Nature?* Cambridge: Cambridge University Press.

Armstrong, D.M. (1988). 'Reply to van Fraassen', *Australasian Journal of Philosophy*. **66**, 224-229.

Armstrong (1996). 'Dispositions as Categorical States', in Time Crane (ed.), *Dispositions: A Debate*. New York, NY: Routledge, 15-18.

Armstrong, D.M. (1997). *A World of States of Affairs* (Camridge Studies in Philosophy). New York, NY: Cambridge University Press.

Armstrong, D.M. (2004). 'Going through the Open Door Again: Counterfactual versus Singularist Theories of Causation', John Collins, Ned Hall, and L.A. Paul (eds.), *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 445-457.

Arntzenius, F. (2012). *Space, Time, & Stuff*. New York, NY: Oxford University Press.

Aronson, J.L. (1982). 'Untangling Ontology from Epistemology in Causation', *Erkenntnis*. **18**, 293-305.

Ashtekar, A. and Hansen, R.O. (1978). 'A Unified Treatment of Null and Spatial Infinity in General Relativity.I. Universal Structure, Asymptotic Symmeteries, and Conserved Quantities at Spatial Infinity', *Journal of Mathematical Physics*. 19, 1542-1566.

Ashtekar, A. (1986). 'New Variables for Classical and Quantum Gravity', *Physical Review Letters*. **57**, 2244-2247.

Ashtekar, A. (2009). 'Singularity Resolution in Loop Quantum Cosmology: A Brief Overview', *Journal of Physics: Conference Series*. **189**, 012003.

Audi, R. (2011). *Epistemology: A Contemporary Introduction to the Theory of Knowledge*. (Routledge Contemporary Introductions to Philosophy) Third Edition. New York, NY: Taylor and Francis.

Bailey, A.M. (2012). 'No Bare Particulars', *Philosophical Studies*. **158**, 31-41.

Baker, D. (2007). 'Measurement Outcomes and Probability in Everettian Quantum Mechanics', *Studies in History and Philosophy of Modern Physics*. **38**, 153-169.

Balashov, Y. and Janssen, M. (2003). 'Presentism and Relativity', *The British Journal for the Philosophy of Science*. **54**, 327-346.

Banks, T. (2000). 'Cosmological Breaking of Supersymmetry or Little Lambda Goes Back to the Future II', arXiv:hep-th/0007146v1.

Banks, T. (2007). 'Entropy and Initial Conditions in Cosmology', arXiv:hep-th/0701146v1 16 Jan 2007.

Banks, T. (2009). 'Holographic Space-Time from the Big Bang to the de Sitter Era', *Journal of Physics A: Mathematical and Theoretical*. **42**, 304002. (19pp.)

Banks, T. (2010). 'Holographic Space-Time and Its Phenomenological Implications', *International Journal of Modern Physics A*. **25**, 4875-4887.

Banks, T. (2011a). Tom Banks: Lectures on Holographic Space-Time. Rutgers University Department of Physics and Astronomy.

Banks, T. (2011b). 'The Interpretation of Quantum Mechanics' Blog post on *Cosmic Variance*. Nov. 2011. URL = http://blogs.discovermagazine.com/cosmicvariance/files/2011/11/banks-qmblog.pdf

Banks, T. (2012a). 'Holographic Spacetime', *International Journal of Modern Physics D*. **21**, 1241004.

Banks, T. (2012b). 'The Top 10^{500} Reasons not to Believe in the Landscape', arXiv:1208.5715 [hep-th] 28 Aug 2012.

Banks, T. (2012c) 'Holographic Cosmology and the Arrow of Time', in L. Mersini-Houghton and R. Vaas (eds.), *The Arrows of Time*. (Fundamental Theories of Physics) Springer-Verlag, Berlin Heidelberg, 69-108.

Banks, T. (2015). 'Holographic Inflation and the Low Entropy of the Early Universe', arXiv:1501.02681v1 [hep-th] 12 Jan 2015.

Banks, T. and Fischler, W. (2001). 'An Holographic Cosmology', arXiv:hep-th/0111142v1 15 Nov 2001.

Banks, T. and Fischler, W. (2004). 'Holographic Cosmology', arXiv:hep-th/0405200v1 23 May 2004.

Banks, T. and Fischler, W. (2005). 'Holographic Cosmology 3.0', *Physica Scripta*. **T117**, 56-63.

Banks, T. and Fischler, W. (2011). 'Holographic Theories of Inflation and Fluctuations', arXiv:1111.4948v2 [hep-th] 6 Dec 2011.

Banks, T. and Fischler, W. (2015). 'Holographic Inflation Revised', arXiv:1501.01686v2 9 Jan 2015.

Banks, T. Fischler, W. and Mannelli, L. (2005). 'Microscopic Quantum Mechanics of the *p=r* Universe', *Physical Review D*. **71**, 123514.

Banks, T. Fischler, W. Torres, T.J. Wainwright, C.L. (2013). 'Holographic Fluctuations from Unitary de Sitter Invariant Field Theory', arXiv:1306.3999v1 [hep-th] 17 Jun 2013.

Banks, T. and Kehayias, J. (2011). 'Fuzzy Geometry via the Spinor Bundle, with Applications to Holographic Space-time and Matrix Theory', arXiv:1106.1179v2 [hep-th] 2 Nov 2011.

Barnes, L. (2012). 'The Fine-Tuning of the Universe for Intellegent Life', *Publications of the Astronomical Society of Australia* **29**, 529-564.

Barwise, J. and Perry, J. (1983). *Situations and Attitudes*. Cambridge, MA: MIT Press.

Barrow, J.D. and Tipler, F.J. (1986). *The Anthropic Cosmological Principle*. New York, NY: Oxford University Press.

Bealer, G. (2002). 'Modal Epistemology and the Rationalist Renaissance', In Tamar Szabó Gendler and John Hawthorne (eds.), *Conceivability and Possibility*. Oxford: Clarendon Press, 71-125.

Beall, J.C. and Restall, G. (1999). 'Defending Logical Pluralism', consequently.org/papers/defplur.pdf

Beall, J.C. and Restall, G. (2000). 'Logical Pluralism', *Australasian Journal of Philosophy*. **78**, 475-493.

Beall, J.C. and Restall, G. (2006). *Logical Pluralism*. Oxford: Oxford University Press.

Becker, K. Becker, M. and Schwarz, J.H. (2007). *String Theory and M-Theory: A Modern Introduction*. New York, NY: Cambridge University Press.

Beebee, H. (1998). 'Causation & Persistence: A Theory of Causation by Douglas Ehring', Review by Helen Beebee. *The British Journal for the Philosophy of Science*. **49**, 181-184.

Beebee, H. (2003). 'Seeing Causing', *Proceedings of the Aristotelian Society*. **103**, 257-280.

Beebee, H. (2009). 'Causation and Observation', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation* New York, NY: Oxford University Press, 471-497.

Beeson, M.J. (1985). *Foundations of Constructive Mathematics: Metamathematical Studies*. Berlin; New York: Springer-Verlag.

Bekenstein, J.D. (1981). 'Universal Upper Bound on the Entropy-to-Energy Ratio for Bounded Systems', *Physical Review D*. 23:2, 287-298.

Belot, G. (2011). *Geometric Possibility*. New York, NY: Oxford University Press.

Bencivenga, E. (2002). 'Putting Language First: The 'Liberation of Logic from Ontology', in Dale Jacquette (ed.), *A Companion to Philosophical Logic* (Blackwell Companions to Philosophy). Malden, MA: Blackwell Publishers, 293-304.

Ben-Menahem, Y. (1990). 'The Inference to the Best Explanation', *Erkenntnis*. **33**, 319-344.

Bennett, J. (1988). *Events and Their Names*. Indianapolis, IN: Hackett Publishing Company.

Bennett, K. (2011). 'Construction Area (No Hard Hat Required)', *Philosophical Studies*. **154**, 79-104.

Bergmann, M. (2006). *Justification without Awareness: A Defense of Epistemic Externalism*. New York, NY: Oxford University Press.

Bianchi, M. (2012). 'Recent Trends in Superstring Phenomenology', in Jeff Murugan, Amanda Weltman, and George F.R. Ellis (eds.), *Foundations of Space and Time: Reflections on Quantum Gravity*. New York, NY: Cambridge University Press, 140-163.

Bigelow, J. and Pargetter, R. (1990). 'Metaphysics of Causation', *Erkenntnis* **33**, 89-119.

Biggs, S. (2011). 'Abduction and Modality', *Philosophy and Phenomenological Research*. **83**, 283-326.

Bird, A. (2007). *Nature's Metaphysics: Laws and Properties*. Oxford: Clarendon.

Bishop, E. (1967). *Foundations of Constructive Analysis*. New York, NY: McGraw-Hill.

Boddy, K. Carroll, S. and Pollack, J. (2014). 'De Sitter Space without Quantum Fluctuations', arxiv.org/abs/1405.0298v1 **[hep-th]**.

Bohr, N. (1958). 'Quantum Mechanics and Philosophy—Causality and Complementarity', R. Klibansky (ed.), *Philsoophy in the Mid-Century*. La Nuova Italia Editrice, Florence.

Boltzmann, L. (1872). 'Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen', Reprinted in Brush (2003, pp. 262-349).

Borde, A. (1994). 'Open and Closed Universes, Initial Singularities, and Inflation', *Physical Review D*. **50**, pp. 3692-3702.

Borde, A. Guth, A.H. and Vilenkin, A. (2003). 'Inflationary Spacetimes Are Incomplete in Past Directions', *Physical Review Letters*. **90**, 151301.

Borde, A. and Vilenkin, A. (1996). 'Singularities in Inflationary Cosmology: A Review', *International Journal of Modern Physics D*. **5**, 813-824.

Borde, A. and Vilenkin, A. (1997). 'Violation of the Weak Energy Condition in Inflating Spacetimes', *Physical Review D*. **56**, 717-723.

Bousso, R. (1998). 'Proliferation of de Sitter Space', *Physical Review D*. **58**, 083511.

Bousso, R. (1999a). 'A Covariant Entropy Conjecture', *Journal of High Energy Physics*. 07 (1999) 004.

Bousso, R. (1999b). 'Holography in General Space-Times', *Journal of High Energy Physics*. 06 (1999) 028.

Bousso, R. (2000a). 'The Holographic Principle for General Backgrounds', *Classical and Quantum Gravity*. **17**, 997-1005.

Bousso, R. (2000b). 'Positive Vacuum Energy and the *N*-Bound', *Journal of High Energy Physics*. 11(2000)038.

Bousso, R. (2002). 'The Holographic Principle', *Reviews of Modern Physics*. **74**, 825-874.

Bousso, R. (2012). 'Vacuum Structure and the Arrow of Time', arXiv:1112.3341v2 **[hep-th]**.

Bousso, R. DeWolfe, O., and Myers, R.C. (2003). 'Unbounded Entropy in Spacetimes with Positive Cosmological Constant', *Foundations of Physics*. **33**, pp. 297-321.

Bousso, R. and Freivogel, B. (2007). 'A Paradox in the Global Description of the Multiverse', *Journal of the High Energy Physics*. 06 (2007): 018.

Bowen, K.A. (1979). *Model Theory of Modal Logic: Kripke Models for Modal Predicate Calculi* (Synthese Library- Volume 127). Dodrecht: Reidel.

Bradley, F.H. (1930). *Appearance and Reality*. Oxford: Oxford University Press.

Braithwaite, R.B. (1968). *Scientific Explanation: A Study of the Function of Theory, Probability and Law in Science*. Based Upon the Tarner Letures 1946. London: Cambridge University Press.

Brand, M. (1975). 'On Philosophical Definitions', *Philosophy and Phenomenological Research*. **36**, 151-172.

Brand, M. (1977). 'Identity Conditions for Events', *American Philosophical Quarterly*. **14**, 329-337.

Brand, M. (1980). 'Simultaneous Causation', in Peter van Inwagen (ed.), *Time and Cause: Essays Presented to Richard Taylor*. Dordrecht: Holland/Boston: USA/London: England, 137-153.

Bricker, P. (2001). 'Island Universes and the Analysis of Modality', in G. Preyer and F. Seibelt (eds.), *Reality and Humean Supervenience: Essays on the Philosophy of David Lewis*.

Bridges, D.S. (1979). *Constructive Functional Analysis*. London; San Francisco: Pitman.
Bridges, D.S. (1981). 'Towards a Constructive Foundation for Quantum Mechanics', in F. Richman (ed.), *Constructive Mathematics* (Springer Lecture Notes in Mathematics, No. 873), 260-273.
Bridges, D.S. (1995). 'Constructive Mathematics and Unbounded Operators—A Reply to Hellman', in *Journal of Philosophical Logic*. **24**, 549-561.
Broad, C.D. (1968). *The Mind and its Place in Nature*. London: Routledge & Kegan Paul Ltd.
Brown, H.R. (2005). *Physical Relativity: Space-time Structure from a Dynamical Perspective*. New York, NY: Oxford University Press.
Brown, H.R. and Lehmkuhl, D. (2013). 'Einstein, the Reality of Space, and the Action-Reaction Principle', arXiv:1306.4902v1 [physics.hist-ph] 20 Jun 2013.
Brown, H. Myrvold, W. and Uffink, J. (2009). 'Boltzmann's H-Theorem, its Discontents, and the Birth of Statistical Mechanics', *Studies in History and Philosophy of Modern Physics*. **40**, 174-191.
Brush, S.G. (ed.) (2003). *The Kinetic Theory of Gases*. London: Imperial College Press.
Bucher, M. (2002). 'A Braneworld Universe from Colliding Bubbles', *Physics Letters B*. **530**, 1-9.
Bueno, O and Shalkowski, S.A. (2009). 'Modalism and Logical Pluralism', *Mind*. **118**, 295-321.
Bunzl, M. (1979). 'Causal Overdetermination', *The Journal of Philosophy*. **76**, 134-150.
Burge, T. (2010). *Origins of Objectivity*. New York, NY: Oxford University Press.
Butterfield, J. (2006). 'Against Pointillisme about Mechanics', *The British Journal for the Philosophy of Science*. **57**, 709-753.
Byerly, H. (1979). 'Substantial Causes and Nomic Determination', *Philosophy of Science*. **46**, 57-81.
Callender, C. (2004a). 'Measures, Explanations and the Past: Should 'Special' Initial Conditions be Explained?', *The British Journal for the Philosophy of Science*. **55**, 195-217.
Callender, C. (2004b). 'There is No Puzzle about the Low-entropy Past', Christopher Hitchcock (ed.), *Contemporary Debates in Philosophy of Science* (Contemporary Debates in Philosophy). Malden, MA: Blackwell Publishing, 240-255.
Callender, C. (2010). 'The Past Hypothesis Meets Gravity', in Gerhard Ernst and Andreas
Hüttemann (eds.), *Time, Chance and Reduction: Philosophical Aspects of Statistical Mechanics*. Cambridge: Cambridge University Press, 34-58.
Campbell, C.A. (1957). *On Selfhood and Godhood*. (The Gifford Lectures) London: George Allen and Unwin.
Campbell, K. (1990). *Abstract Particulars*. Oxford: Blackwell.
Carnap, R. ([1937] 1949). *The Logical Syntax of Langauge*. Translated by Amethe Smeaton London: Routledge & Kegan Paul Ltd.
Carroll, J.W. (1994). *Laws of Nature*. New York, NY: Cambridge University Press.
Carroll, J.W. (2009). 'Anti-Reductionism', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 279-298.

Carroll, J.W. and Markosian, N. (2010). *An Introduction to Metaphysics* (Cambridge Introductions to Philosophy). New York, NY: Cambridge University Press.

Carroll, S.M. (2004). *Spacetime and Geometry*: *An Introduction to General Relativity*. San Francisco, CA: Pearson Education.

Carroll, S.M. (2006). 'Is Our Universe Natural?', *Nature*. **440**, 1132-1134.

Carroll, S.M. (2008a). 'The Cosmic Origins of Time's Arrow', *Scientific American*. **298**, 48-57.

Carroll, S.M. (2008b). 'What if Time Really Exists?', arXiv:0811.3772v1 [**gr-qc**].

Carroll, S.M. (2010). *From Eternity to Here: The Quest for the Ultimate Theory of Time*. New York, NY: Dutton.

Carroll, S.M. (2012). 'Does the Universe Need God?', in J.B. Stump and Alan G. Padgett (eds.), 2012, *The Blackwell Companion to Science and Christianity*. Malden, MA: Blackwell Publishers, 185-197.

Carroll, S.M. and Chen, J. (2004). 'Spontaneous Inflation and the Origin of the Arrow of Time', arXiv:hep-th/0410270v1.

Carroll, S.M. and Chen, J. (2005). 'Does Inflation Provide Natural Initial Conditions for the Universe', *General Relativity and Gravitation*. **37**, 1671-1674.

Carroll, S.M. Johnson, M.C. and Randall, L. (2009). 'Dynamical Compactification from de Sitter Space', *Journal of High Energy Physics*. 11(2009)094.

Carroll, S.M. and Tam, H. (2010). 'Unitary Evolution and Cosmological Fine-Tuning', arXiv:1007.1417v1 [**hep-th**].

Carter, B. (1974). 'Large Number Coincidences and the Anthropic Principle in Cosmology', in M.S. Longair (ed.), *Confrontation of Cosmological Theories with Observational Data*. Dordrecht: Reidel, pp. 291-298.

Cartwright, N. (1983). *How the Laws of Physics Lie*. Oxford: Clarendon Press.

Cartwright, N. (1993). 'In Defence of 'This Worldly' Causality: Comments on van Fraassen's Laws and Symmetry', *Philosophy and Phenomenological Research*. **53**, 423-429.

Cartwright, N. (2007) 'Counterfactuals in Economics: A Commentary,' In J. K. Campbell, M. O'Rourke, and H. Silverstein (eds.), *Causation and Explanation*. Cambridge, MA: MIT Press, 191-216.

Cartwright, N. and Alexandrova, A. with Efstathiou, S. Hamilton, A. and Muntean, I. (2005). 'Laws', in Frank Jackson and Michael Smith (eds.), *The Oxford Handbook of Contemporary Philosophy*. New York, NY: Oxford University Press, 792-818.

Chalmers, D.J. (Online). 'The Two-Dimensional Argument Against Materialism', URL = < http://consc.net/papers/2dargument.html>

Chalmers, D.J. (2002). 'Does Conceivability Entail Possibility?', in Tamar Szabó Gendler and John Hawthorne (eds.), *Conceivability and Possibility*. New York, NY: Oxford University Press, 145-200.

Chalmers, D. (2009). 'The Two-Dimensional Argument against Materialism', in Brian P. McLaughlin, Ansgar Beckermann, and Sven Walter (eds.), *The Oxford Handbook of Philosophy of Mind*. New York, NY: Oxford University Press, 313-338.

Chalmers, D.J. (2012). *Constructing the World*. Oxford: Oxford University Press.

Chang, H. (2009). 'Operationalism', The Stanford Encyclopedia of Philosophy (Fall 2009 Edition). Edward N. Zalta (ed.), URL = http://plato.stanford.edu/archives/fall2009/entries/operationalism/

Chisholm, R. (1964). 'Human Freedom and the Self' The Lindley Lecture, 1964 pp. 3-15 reprinted in Laura Waddell Ekstrom (ed.), *Agency and Responsibility: Essays on the Metaphysics of Freedom*. Boulder, CO: Westview Press, 126-137.

Chisholm, R.M. (1966). 'Freedom and Action', in Keith Lehrer (ed.) *Freedom and Determinism*. New York, NY: Random House, 11-44.

Chisholm, R. (1970). 'Events and Propositions', *Noûs*. **4**, 15-24.

Chisholm, R. (1971). 'States of Affairs Again', *Noûs*. **5**, 179-189.

Chisholm, R. (1989). *On Metaphysics*. Minneapolis, MN: University of Minnesota Press.

Chisholm, R. (1990). 'Events without Times: An Essay on Ontology', *Noûs*. **24**, 413-427.

Chisholm, R. (1994). 'Ontologically Dependent Entities', *Philosophy and Phenomenological Research*. **54**, 499-507.

Chisholm, R. (1996). *A Realistic Theory of Categories: An Essay on Ontology*. New York, NY: Cambridge University Press.

Choi, S. and Fara, M. (2014). 'Dispositions', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2014 Edition). http://plato1.stanford.edu/archives/spr2014/entries/dispositions/

Church, A. (2009). 'Referee reports on Fitch's 'A Definition of Value'', In J. Salerno (ed.), *New Essays on the Knowability Paradox* New York, NY: Oxford University Press, 13-20.

Ciufolini, I. and Wheeler, J.A. (1995). *Gravitation and Inertia*. Princeton, NJ: Princeton University Press.

Clarke, R. (1993). 'Toward a Credible Agent-Causal Account of Free Will', *Noûs* **27**, 191-203.

Clarke, R. (2003). *Libertarian Accounts of Free Will*. New York, NY: Oxford University Press.

Clarkson, C. (2012). 'Establishing Homogeneity of the Universe in the Shadow of Dark Energy', arXiv:1204.5505v1 **[astro-ph.CO]**.

Clarkson, C.A. Coley, A.A. and O'Neill, E.S.D. (2001). 'Cosmic Microwave Background and Scalar-Tensor Theories of Gravity', *Physical Review D*. **64**, 063510.

Clarkson, R. Ghezelbash, A.M., and Mann, R.B. (2003). Entropic *N*-Bound and Maximal Mass Conjecture Violations in Four-Dimensional Taub-Bolt (NUT)-dS spacetimes', *Nuclear Physics B*. **674**, 329-364.

Clarkson, C. and Maartens, R. (2010). 'Inhomogeneity and the Foundations of Concordance Cosmology', *Classical and Quantum Gravity*. **27**, 124008.

Cleland, C. (1987). 'Change, Process and Events', *CSLI Report*, No. CSLI-87-95 (1987), 1-36.

Cleland, C. (1991). 'On the Individuation of Events', *Synthese*. **86**, 229-254.

Clifton, T. Clarkson, C. and Bull, P. (2012). 'Isotropic Blackbody Cosmic Microwave Background Radiation as Evidence for a Homogenous Universe', *Physical Review Letters*. **109**, 051303.

Collins, J. Hall, N. Paul, L.A. (2004). 'Counterfactuals and Causation: History, Problems, and Prospects', in John Collins, Ned Hall, and L.A. Paul, *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 1-57.

Collins, T. (2003). 'Evidence for Fine-Tuning', Neil A. Manson (ed.), God and Design: The Teleological Argument and Modern Science. New York, NY: Routledge Press, 178-199.

Collins, R. (2012). 'The Teleological Argument: An Exploration of the Fine-Tuning of the Universe', *The Blackwell Companion to Natural Theology*. Malden, MA: Blackwell Publishers, 202-281.

Cornman, J. (1980). *Skepticism, Justification, and Explanation*. Dordrecht: Reidel.

Cross, T. (2012). 'Goodbeye, Humean Supervenience', in Karen Bennett and Dean W. Zimmerman (eds.), *Oxford Studies in Metaphysics*. Vol. 7. Oxford: Oxford University Press, 129-153.

Danks, D. (2009). 'The Psychology of Causal Perception and Reasoning', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 447-470.

Davidson, D. (1967). 'Causal Relations', *The Journal of Philosophy*. **64**, 691-703.

Davidson, D. (1969). 'The Individuation of Events', in Nicholas Rescher (ed.), *Essays in Honor of Carl G. Hempel*. Dordrecht: Reidel, 216-237.

Davidson, D. (1985). 'Reply to Quine on Events', in Ernest LePore and Brian P. McLaughlin (eds.), *Actions and Events: Perspectives on the Philosophy of Donald Davidson*. New York, NY: Oxford University Press, 172-176.

Davidson, D. ([1980] 2001). 'The Individuation of Events' in Donald Davidson, *Essays on Actions and Events*. 2nd Edition. New York, NY: Oxford University Press, 163-180.

Davies, P.C.W. (1982). *The Accidental Universe*. Cambridge: Cambridge University Press.

Davies, P.C.W. (1983). 'Inflation and Time Asymmetry: Or What Wound Up the Universe', *Nature*. **301**, 398-400.

Davies, P.C.W. (1984). 'Mining the Universe', *Physical Review D*. **30**, 737-742.

Davies, P.C.W. Ford, L.H. and Page, D.N. (1986). 'Gravitational Entropy: Beyond the Black Hole', *Physical Review D*. **34**, 1700-1707.

Davis, T. M. Davies, P.C.W. and Lineweaver, C.H. (2003). 'Black Hole versus Cosmological Horizon Entropy', *Classical and Quantum Gravity*. **20**, 2753-2764.

De Muijnck, W. (2003). *Dependences, Connections, and Other Relations: A Theory of Mental Causation*. (Philosophical Studies Series 93) Dordrecht: Kluwer Academic Publishers.

de Sitter, W. (1917). 'On Einstein's Theory of Gravitation, and its Astronomical Consequences', *Monthly Notices of the Royal Astronomical Society*. **78**, 3-28.

de Sitter, W. (1918). 'On the Curvature of Space', *KNAW*, Proceedings, Amsterdam. **20**, 229-243.

Dowe, P. (2000). *Physical Causation* (Cambridge Studies in Probability, Induction, and Decision Theory). New York, NY: Cambridge University Press.

Ducasse, C.J. (1968). *Truth, Knowledge and Causation*. London: Routledge & Kegan Paul.

Dürr, D. Goldstein, S. and Zanghi, N. (1992). 'Quantum Equilibrium and the Origin of Absolute Uncertainty', *Journal of Statistical Physics*. **67**, 843-907.

Dürr, D. Goldstein, S., and Zanghì, N. (1996). 'Bohmian Mechanics as the Foundation of Quantum Mechanics', James T. Cushing, Arthur Fine, and Sheldon Goldstein (eds.),

Dyson, F. (1979). *Disturbing the Universe*. New York, NY: Harper and Row.

Dyson, L. Kleban, M. and Susskind, L. (2002). 'Disturbing Implications of a Cosmological Constant', *Journal of High Energy Physics*. 10 (2002) 011.

Eagle, A. (2007). 'Pragmatic Causation', in Huw Price and Richard Corry (eds.), *Causation, Physics, and the Constitution of Reality: Russell's Republic Revisited*. New York, NY: Oxford University Press, 156-190.

Eagle, A. (ed.) (2011a). *Philosophy of Probability: Contemporary Readings* (Routledge Contemporary Readings in Philosophy). New York, NY: Routledge Press.

Eagle, A. (2011b). 'Introduction', In Antony Eagle (ed.), *Philosophy of Probability: Contemporary Readings* (Routledge Contemporary Readings in Philosophy). New York, NY: Routledge press, 27-47.

Earman, J. (1984). 'Laws of Nature: The Empiricist Challenge', in Radu J. Bogdan (ed.), *D.M. Armstrong*. Profiles Volume 4. Dordrecht: Reidel, 191-223.

Earman, J. (1989). *World Enough and Space-Time: Absolute versus Relational Theories of Space and Time*. Cambridge, MA: MIT Press.

Earman, J. (1995). *Bangs, Crunches, Whimpers, and Shrieks: Singularities and Acausalities in Relativistic Spacetimes*. New York, NY: Oxford University Press.

Earman, J. (2006). 'The "Past Hypothesis": Not even False', *Studies in History and Philosophy of Modern Physics*. **37**, 399-430.

Eddington, A.S. (1923). *The Mathematical Theory of Relativity*. Cambridge: Cambridge University Press Reprinted by Bibliolife.

Edgington, D. (1997). 'Mellor on Chance and Causation', *The British Journal for the Philosophy of Science*. **48**, 413-433.

Eells, E. and Fitelson, B. (2000). 'Measuring Confirmation and Evidence', *The Journal of Philosophy*. **97**, 663-672.

Ehlers, J. (1987). 'Folklore in Relativity and What is Really Known', in M.A.H. MacCallum (ed.), *General Relativity and Gravitation: Proceedings of the 11th International Conference on General Relativity and Gravitation*. New York, NY: Cambridge University Press, 61-71.

Ehlers, J. Geren, P. and Sachs, R.K. (1968). 'Isotropic Solutions of the Einstein-Liouville Equations', *Journal of Mathematical Physics*. **9**, 1344-1349.

Ehring, D. (1987). 'Causal Relata', *Synthese* **73**, 319-328.

Ehring, D. (1997). *Causation and Persistence: A Theory of Causation*. New York, NY: Oxford University Press.

Ehring, D. (2009). 'Causal Relata', in Helen Beebee, Christopher Hitchcock and Peter Menzies (eds.), *The Oxford Handbook of Causation* New York, NY: Oxford University Press, 387-413.

Einstein, A. (1922). *The Meaning of Relativity: Four Lectures Delivered at Princeton University, May, 1921*. Edited by John Gahan, translated by Edwin P. Adams. Princeton: Princeton University Press Reprinted by Desmondous Publications, 2013.

Einstein, A. (1948). 'Quantenmechanik und wirlichkeit', *Dialectica*. **2**, 320-324.

Einstein, A. ([1923] 1952). 'The Foundation of the General Theory of Relativity', in H.A. Lorentz, A. Einstein, H. Minkowski, and H. Weyl with notes by A. Sommerfeld and trans. By W. Perrett and G.B. Jeffery, *The Principle of Relativity: A Collection of Original Memoirs on the Special and General Theory of Relativity*. New York, NY: Dover Publications, Inc., 111-164.

Einstein, A. (2002). 'On the Foundations of the General Theory of Relativity.' Reprinted in *The Collected Papers of Albert Einstein*, Volume 7, English Translation. Princeton, NJ: Princeton University Press.

Einstein, A. and Grommer, J. (1927). *Allgemeine relativitatstheorie und bewegungsgesetz*. Berlin: Preussiche Akademie der Wissenchaften. 2-13.

Einstein, A. and Infeld, L. (1949). 'On the Motion of Particles in General Relativity Theory', *Canadian Journal of Mathematics*. **1**, 209-241.

Ekstrom, L.W. (2001). 'Indeterminist Free Action', in Laura Waddell Ekstrom (ed.), *Agency and Responsibility: Essays on the Metaphysics of Freedom*. Boulder, CO: Westview Press, 138-157.

Elga, A. (2000). 'Statistical Mechanics and the Asymmetry of Counterfactual Dependence', *Philosophy of Science*. (Supplement: Proceedings of the 2000 Biennial Meeting of the Philosophy of Science Association. Part I: Contributed Papers (Sep., 2001) **68**, S313-S324.

Ellis, B. (2002). *The Philosophy of Nature: A Guide to the New Essentialism*. Montreal & Kingston: McGill-Queen's University Press.

Fair, D. (1979). 'Causation and the Flow of Energy', *Erkenntnis*. **14**, 219-250.

Fales, E. (1990). *Causation and Universals*. New York, NY: Routledge.

Fantl, J. and McGrath, M. (2002). 'Evidence, Pragmatics, and Justification', *The Philosophical Review*. **111**, 67-94.

Fara, M and Williamson, T. (2005). 'Counterparts and Actuality', *Mind*. **114**, 1-30.

Farhi, E. Guth, A. and Guven, J. (1990). 'Is it Possible to Create a Universe in the Laboratory by Quantum Tunneling?', *Nuclear Physics B*. **339**, pp. 417-490.

Feynman, R.P. Leighton, R.B. and Sands, M.L. (1965). *The Feynman Lectures on Physics*. Reading, MA: Addison-Wesley.

Feynman, R. P. (1967). *The Character of Physical Law*. Cambridge, MA: MIT Press.

Field, H. (2003). 'Causation in a Physical World', in Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics*. New York, NY: Oxford University Press, 435-460.

Field, H. (2009). 'Pluralism in Logic', *The Review of Symbolic Logic* **2**, 342-359.

Fischler, W. Morgan, D. and Polchinski, J. (1990). 'Quantization of False-Vacuum Bubbles: A Hamiltonian Treatment of Gravitational Tunneling', *Physical Review D*. **42**, 4042-4055.

Fischler, W. and Susskind, L. (1998). 'Holography and Cosmology', arXiv:hep-th/9806039.

Fitch, F.B. (1963). 'A Logical Analysis of Some Value Concepts', *The Journal of Symbolic Logic*. **28**, 135-142.

Flint, T. and Freddoso, A. (1983). 'Maximal Power', in Alfred Freddoso (ed.), *The Existence and Nature of God*. Notre Dame: University of Notre Dame Press, 81-113.

Fodor, J.A. (1974). 'Special Sciences (Or: The Disunity of Science as a Working Hypothesis)', *Synthese* **28**, 97-115.

Foster, J. (1982-1983). 'Induction, Explanation and Natural Necessity', *Proceedings of the Aristotelian Society*. **83**, 87-101.

Foster, J. (2001). 'Regularities, Laws of Nature, and the Existence of God', *Proceedings of the Aristotelian Society*. **101**, 145-161.

Foster, J. (2004). *The Divine Lawmaker: Lectures on Induction, Laws of Nature, and the Existence of God*. New York, NY: Oxford University Press.

Frankel, L. (1986). 'Mutual Causation, Simultaneity and Event Description', *Philosophical Studies* **49**, 361-372.

French, S. (2008). 'The Structure of Theories', Stathis Psillos and Martin Curd (eds.), *The Routledge Companion to Philosophy of Science*. New York, NY: Routledge Press, 269-280.

French, S. (2014). *The Structure of the World: Metaphysics and Representation*. New York, NY: Oxford University Press.

Friedman, M. (1974). 'Explanation and Scientific Understanding', *The Journal of Philosophy*. **71**, 5-19.

Frisch, M. (2005). *Inconsistency, Asymmetry, and Non-Locality: A Philosophical Investigation of Classical Electrodynamics*. Oxford: Oxford University Press.

Frisch, M. (2009). '"The Most Sacred Tenet"? Causal Reasoning in Physics', *The British Journal for the Philosophy of Science*. **60**, 459-474.

Frisch, M. (2014). *Causal Reasoning in Physics*. Cambridge: Cambridge University Press.

Gabbay, D.M. (1976). *Investigations in Modal and Tense Logics with Applications to Problems in Philosophy and Linguistics* (Synthese Library). Springer.

Gale, R. and Pruss, A.R. (2002). 'A Response to Oppy and to Davey and Clifton', *Religious Studies*. **38**, 89-99.

Garson, J.W. (1984). 'Quantification in Modal Logic', in D.M. Gabbay and F. Guenthner (eds.), *Handbook of Philosophical Logic*, 2nd Edition. Volume 3. AA Dordrecht, The Netherlands: Kluwer Academic Publishers, 249-307.

Garson, J.W. (1991). 'Applications of Free Logic to Quantified Intensional Logic', Karel Lambert (ed.), *Philosophical Application of Free Logic*. New York, NY: Oxford University Press, 111-142.

Geirsson, H. (2005). 'Conceivability and Defeasible Modal Justification', *Philosophical Studies*. **122**, 279-304.

Geroch, R. (1966). 'Singularities in Closed Universes', *Physical Review Letters*. **17**, 445-447.

Geroch, R. (1970). 'Domain of Dependence', *Journal of Mathematical Physics*. 11, 437-449.

Geroch, R. (1972). 'Structure of the Gravitatioanl Field at Spatial Infinity', *Journal of Mathematical Physics* **13**, 956-968.

Geroch, R. (1977). 'Asymptotic Structure of Space-Time', in F.P. Esposito and L. Witten (eds.), *Asymptotic Structure of Space-Time*. New York, Springer, 1-105.

Geroch, T. (1978). *General Relativity: From A to B*. Chicago, IL: University of Chicago Press.

Geroch, R. (2013). *General Relativity: 1972 Lecture Notes*. Montreal and Quebec, Canada.

Geroch, R. and Jang, P.S. (1975). 'Motion of a Body in General Relativity', *Journal of Mathematical Physics*. **16**, 65-67.

Gibbons, G.W. and Hawking, S.W. (1977). 'Cosmological Event Horizons, Thermodynamics, and Particle Creation', *Physical Review D*. **15**, 2738-2751.

Gillett, C. (2002). 'The Dimensions of Realization: A Critique of the Standard View', *Analysis* **62**, 316-323.

Gillett, C. (2003). 'The Metaphysics of Realization, Multiple Realizability, and the Special Sciences,' *The Journal of Philosophy* **100**, 591-603.

Gillett, C. (2007). 'Understanding the New Reductionism: The Metaphysics of Science and Compositional Reduction', *The Journal of Philosophy* **104**, 193-216.

Gillett, C. (2010). 'Moving Beyond the Subset Model of Realization: The Problem of Qualitative Distinctness in the Metaphysics of Science', *Synthese*. **177**, 165-192.

Gillett, C. (2011). 'Multiply Realizing Scientific Properties and their Instances', *Philosophical Psychology* **24**, 727-738.

Gillett, C. (unpublished). "Making sense of levels in the Sciences".

Gillies, D. (2000). *Philosophical Theories of Probability* (Philosophical Issues in Science). New York, NY: Routledge.

Glymour, B. (2007). 'In Defense of Explanatory Deductivism', in Joseph Keim Campbell, Michael O'Rourke, and Harry Silverstein (eds.), *Causaiton and Explanation*. Malden, MA: MIT Press, 133-153.

Goldman, A.I. (1970). *A Theory of Human Action*. Princeton, NJ: Princeton University Press.

Goldstein, S. and Zanghì, N. (2013). 'Reality and the Role of the Wave Function in Quantum Theory', in Alyssa Ney and David Z. Albert (eds.), *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*. New York, NY: Oxford University Press, 91-109.

Ginsparg, P. and Perry, M.J. [1983]: 'Semiclassical Perdurance of De Sitter Space', *Nuclear Physics*. **B222**, 245-268.

Gralla, S.E. and Wald, R.M. (2008). 'A Rigorous Derivation of Gravitational Self-Force', *Classical and Quantum Gravity*. **25**, 205009.

Grandy, R. (2002). 'Many-Valued, Free, and Intuitionistic Logics', in Dale Jacquette (ed.), *A Companion to Philosophical Logic* (Blackwell Companions to Philosophy). Malden, MA: Blackwell Publishers, 531-544.

Greene, B. (1999). *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory*. London, UK: Random House.

Greene, B. (2004). *The Fabric of the Cosmos: Space, Time, and the Texture of Reality*. New York, NY: Random House, Inc.

Gregory, D. (2004). 'Imagining Possibilities', *Philosophy and Phenomenological Research*. **69**, 327-348.

Grishchuk, L.P. and Polnarev, A.G. (1980). 'Gravitational Waves and Their Interaction with Matter and Fields', in A. Held (ed.), *General Relativity and Gravitation: One Hundred Years after the Birth of Albert Einstein*. New York and London: Plenum Press, 393-434.

Gross, D.J. (1997). 'The Triumph and Limitations of Quantum Field Theory', arXiv:hep-th/9704139v1.

Gustason, W. and Ulrich, D.E. (1989). *Elementary Symbolic Logic*. 2nd Edition. Prospect Heights, IL: Waveland Press Inc.

Guth, A. (2004). 'Inflation', in Wendy L. Freedman (ed.), *Measuring and Modeling the Universe* (Carnegie Observatories Astrophysics Series Volume 2) Cambridge: Cambridge University Press, 31-51.

Hacking, I. (1983). *Representing and Intervening*. Cambridge: Cambridge University Press.

Hájek, A. (2009). 'Fifteen Arguments against Hypothetical Frequentism', *Erkenntnis*. **70**, 211-235.

Hájek, A. (2011). ''Mises Redux' – Redux: Fifteen Arguments against Finite Frequentism', in Antony Eagle (ed.), *Philosophy of Probability: Conemporary Readings*. (Routledge Conempoary Readings in Philosophy) New York, NY: Routledge Press, 395-409.

Hájek, A. (2012). 'Interpretations of Probability', The Stanford Encyclopedia of Philosophy (Winter 2012 Edition). Edward N. Zalta (ed.), URL = http://plato.stanford.edu/archives/win2012/entries/probability-interpret/

Hale, B. (2013). *Necessary Beings: An Essay on Ontology, Modality, and the Relations Between Them*. New York, NY: Oxford University Press.

Hall, N. (Manuscript). 'Humean Reductionism about Laws of Nature', at URL = <https://www.umass.edu/philosophy/events/papers/Humean%20red'ism%20re%20laws.pdf>

Hall, N. (2000). 'Causation and the Price of Transitivity', *The Journal of Philosophy*. **97**, 198-222.

Hall, N. (2004a). 'Causation and the Price of Transitivity', in John Collins, Ned Hall, and L.A. Paul (eds.), *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 181-203. Reprinted from Hall (2000).

Hall, N. (2004b). 'The Intrinsic Character of Causation', in Dean W. Zimmerman (ed.), *Oxford Studies in Metaphysics*. Volume 1. New York, NY: Oxford University Press, 255-300.

Hall, N. (2011). 'Causation and the Sciences', in Steven French and Juha Saatsi (eds.), *The Continuum Companion to the Philosophy of Science*. London: Continuum International Publishing Group, 96-119.

Hardy, L. (2007). 'Towards Quantum Gravity: A Framework for Probabilistic Theories with Non-fixed Causal Structure', *Journal of Physics A* **40**, 3081-3099.

Harman, G.H. (1965). 'The Inference to the Best Explanation', *The Philosophical Review*. **74**, 88-95.

Harman, G. (1986). *Change in View: Principles of Reasoning*. Cambridge, MA: MIT Press/Bradford Books.

Hasse, W. and Perlick, V. (1999). 'On Spacetime Models with an Isotropic Hubble Law', *Classical and Quantum Gravity*. **16**, 2559-2576.

Hausman, D.M. (1998). *Causal Asymmetries*. New York, NY: Cambridge University Press.

Hawking, S.W. (1965). 'Occurrence of Singularities in Open Universes', *Physical Review Letters*. **15**, 689-690.

Hawking, S.W. (1966a). 'The Occurrence of Singularities in Cosmology', *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*. **294**, 511-521.

Hawking, S.W. (1966b). 'The Occurrence of Singularities in Cosmology. II.', *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*. **295**, 490-493.

Hawking, S.W. (1967). 'The Occurrence of Singularities in Cosmology. III. Causality and Singularities', *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*. **300**, 187-201.

Hawking, S.W. (1996). 'Classical Theory', in Stephen Hawking and Roger Penrose, *The Nature of Space and Time*. Princeton, NJ: Princeton University Press, 3-26.

Hawking, S.W. and Ellis, G.F.R. (1973). *The Large Scale Structure of Space-Time*. New York, NY: Cambridge University Press.

Hawking, S.W. and Penrose, R. (1970). 'The Singularities of Gravitational Collapse and Cosmology', *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences*. **314**, 529-548.

Hawkins, E. Markopoulou, F. and Sahlmann, H. (2003). 'Evolution in Quantum Causal Histories', *Classical and Quantum Gravity*. **20**, 3839-3854.

Hawthorne, J. (2004). *Knowledge and Lotteries*. New York, NY: Oxford University Press.

Hawthorne, J. (2006). 'Why Humeans are Out of Their Minds', in John Hawthorne, *Metaphysical Essays*. New York, NY: Oxford University Press.

Hayaki, R. (2006). 'Contingent Objects and the Barcan Formula', *Erkenntnis*. **64**, 75-83.

Healey, R. (1997). 'Nonlocality and the Aharonov-Bohm Effect', *Philosophy of Science*. **64**, 18-41.

Healey, R. (2007). *Gauging What's Real: The Conceptual Foundations of Contemporary Gauge Theories*. New York, NY: Oxford University Press.

Hedman, C.G. (1972). 'On When There Must Be a Time-Difference between Cause and Effect', *Philosophy of Science*. **39**, 507-511.

Hellman, G. (1993). 'Constructive Mathematics and Quantum Mechanics: Unbounded Operators and the Spectral Theorem', *Journal of Philosophical Logic*. **22**, 221-248.

Hellman, G. (1997). 'Quantum Mechanical Unbounded Operators and Constructive Mathematics: A Rejoinder', *Journal of Philosophical Logic*. **26**, 121-127.

Hellman, G. (1998). 'Mathematical Constructivism in Space-time', *The British Journal for the Philosophy of Science*. **49**, 425-450.

Hempel, C.G. and Oppenheim, P. (1948). 'Studies in the Logic of Explanation', *Philosophy of Science*. **15**, 135-175.

Hitchcock, C. (1995). 'The Mishap at Reichenbach Fall: Singular vs. General Causation', *Philosophical Studies*. **78**, 257-291.

Hitchcock, C.R. (1996). 'The Role of Contrast in Causal and Explanatory Claims', *Synthese*. **107**, 395-419.

Hitchcock, C. (2001). 'The Intransitivity of Causation Revealed in Equations and Graphs', *The Journal of Philosophy*. **98**, 273-299.

Hitchcock (2007). 'What Russell Got Right', in H. Price and Corry (eds.), *Causation, Physics, and the Constitution of Reality: Russell's Republic Revisited*. Oxford: Clarendon Press, 45-65.

Hodges, W. (2001). 'Classical Logic I: First-Order Logic', in Lou Goble (ed.), *The Blackwell Companion to Philosophical Logic*. Malden, MA: Blackwell Publishers, pp. 9-32.

Hoefer, C. (2009). 'Causation in Spacetime Theories', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 687-706.

Holland, P.R. (1993). *The Quantum Theory of Motion*. Cambridge: Cambridge University Press.

Horgan, T. and Tienson, J. (1996). *Connectionism and the Philosophy of Psychology* Cambridge, MA: MIT Press.

Horwich, P. (1987). *Asymmetries in Time: Problems in the Philosophy of Science*. Cambridge, MA: MIT Press.

Howson, C. and Urbach, P. (1993). *Scientific Reasoning: The Bayesian Approach*. 2nd Edition. Chicago, IL: Open Court.

Huggett, N. (2006). 'The Regularity Account of Relational Spacetime', *Mind* **115**, 41-73.

Hughes, G.E. and Cresswell, M.J. (1996). *A New Introduction to Modal Logic*. New York, NY: Routledge.

Infeld, L. (1954). 'On the Motion of Bodies in General Relativity Theory', *Acta Physica Polonica*. **13**, 187-204.

Infeld, L. and Schild, A. (1949). 'On the Motion of Test Particles in General Relativity', *Reviews of Modern Physics*. **21**, 408-413.

Irzik, G. (1996). 'Can Causes Be Reduced to Correlations?', *The British Journal for the Philosophy of Science* **47**, 249-270.

Jacobson, T. (1995). 'Thermodynamics of Spacetime: The Einstein Equation of State', *Physical Review Letters*. **75**, 1260-1263.

Jacobson, T. and Smolin, L. (1988). 'Nonperturbative Quantum Geometries', *Nuclear Physics* **B299**, 295-345.

Jackson, F. (1977). *Perception: A Representative Theory*. New York, NY: Cambridge University Press.

Jauch, J.M. (1968). *Foundations of Quantum Mechanics*. Reading, MA: Addison-Wesley Publishing Co.

Jenkins, C.S. (2008). 'Modal Knowledge, Counterfactual Knowledge and the Role of Experience', *The Philosophical Quarterly*. **58**, 693-701.

Jenkins, C.S. (2010). 'Concepts, Experience and Modal Knowledge,' In John Hawthorne and Jason Turner (eds.), *Philosophical Perspectives 24, 2010 Epistemology* Malden, MA: Wiley Periodicals, Inc, 255-279.

Johnson, W.E. (1921). *Logic*. Cambridge: Cambridge University Press.

Jordan, T.F. (1969). *Linear Operators for Quantum Mechanics*. New York, NY: John Wiley & Sons, Inc.

Kadison, R.V. and Ringrose, J.R. (1997). *Fundamentals of the Theory of Operator Algebras: Volume 1: Elementary* (Graduate Studies in Mathematics Volume 15). Providence, Rhode Island: American Mathematical Society.

Kant, I. ([1788] 1998). *Critique of Pure Reason*. Translated and edited by Paul Guyer and Allen W. Wood. New York, NY: Cambridge University Press.

Kapitan, T. (1992). 'Peirce and the Autonomy of Abductive Reasoning', *Erkenntnis*. **37**, 1-26.

Kim, J. (1966). 'On the Psycho-Physical Identity Theory', *American Philosophical Quarterly*. **3**, 227-235.

Kim, J. (1973a). 'Causation, Nomic Subsumption, and the Concept of Event', *The Journal of Philosophy*. **70**, 217-236.

Kim, J. (1973b). 'Causes and Counterfactuals', *The Journal of Philosophy*. **70**, 570-572.

Kim, J. (1973c). 'Events as Property Exemplifications', in Jaegwon Kim, *Supervenience and Mind: Selected Philosophical Essays*. New York, NY: Cambridge University Press, 33-52.

Kim, J. (1976). 'Events as Property Exemplifications', in Myles Brand and D. Walton (eds.), *Action Theory*. Dordrecht: D. Reidel, 159-177.

Kim, J. (1989a). 'Mechanism, Purpose, and Explanatory Exclusion', *Philosophical Perspectives*. Vol. 3 (Philosophy of Mind and Action Theory) Ridgeview Publishing Company, 77-108.

Kim, J. (1989b). 'The Myth of Nonreductive Materialism', *Proceedings and Addresses of the American Philosophical Association*. **63**, 31-47.

Kim, J. (1993a). '"Strong" and "Global" Supervenience Revisited', in Jaegwon Kim, *Supervenience and Mind: Selected Philosophical Essays*. New York, NY: Cambridge University Press, 79-91.

Kim, J. (1993b). 'Events as Property Exemplifications', in Jaegwon Kim, *Supervenience and Mind: Selected Philosophical Essays*. New York, NY: Cambridge University Press, 33-52.

Kim, J. (1993c). 'Postscripts on Supervenience', in Jaegwon Kim, *Supervenience and Mind: Selected Philosophical Essays*. New York, NY: Cambridge University Press, 161-171.

Kim, J. (1998). *Mind in a Physical World*. Cambridge, MA: MIT Press.

Kim, J. (2003). 'Supervenience, Emergence, Realization, Reduction', Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics* New York, NY: Oxford University Press, 556-584.

King, P. (1992). 'Duns Scotus on the Common Nature and the Individual Differentia', *Philosophical Topics* **20**, 51-76.

King, P. (2000). 'The Problem of Individuation in the Middle Ages', *Theoria* **66**, 159-184.

Koons, R. (2000). *Realism Regained: An Exact Theory of Causation, Teleology, and the Mind*. New York, NY: Oxford University Press.

Koopman, B.O. (1931). 'Hamiltonian Systems and Transformations in Hilbert Space', *Proceedings of the National Academy of Sciences of the United States of America*. **17**, 315-318.

Koopman, B.O. and Neumann, J.V. (1932). 'Dynamical Systems of Continuous Spectra', *Proceedings of the National Academy of Sciences of the United States of America*. **18**, 255-263.

Koster, R. and Postma, M. (2011). 'A No-Go for No-Go Theorems Prohibiting Cosmic Acceleration in Extra Dimensional Models', arXiv:1110.1492v2 [**hep-th**].

Kripke, S. (1959). 'A Completeness Theorem in Modal Logic', *The Journal of Symbolic Logic*. **24**, 1-14.

Kripke, S. (1963). 'Semantical Considerations on Modal Logic', *Acta Philosophica Fennica*. **16**, 83-94.

Kutach, D. (2001). *Entropy and Counterfactual Asymmetry*, PhD. Dissertation, Rutgers University.

Kutach, D. (2002). 'The Entropy Theory of Counterfactuals', *Philosophy of Science* **69**, 82-104.

Kutach, D. (2007). 'The Physical Foundations of Causation', Huw Price and Richard Corry (eds.), *Causation, Physics, and the Constitution of Reality: Russell's Republic Revisited*. New York, NY: Oxford University Press, 327-350.

Kutach, D. (2013). *Causation and its basis in Fundamental Physics* New York, NY: Oxford University Press.

Kvanvig, J. L. (2006). *The Knowability Paradox*. New York, NY: Oxford University Press.

Kvart, I. (1991). 'Transitivity and Preemption of Causal Relevance', *Philosophical Studies*. **64**, 125-160.

Ladyman, J. Presnell, S. and Short, A.J. (2008). 'The Use of the Information-Theoretic Entropy in Thermodynamics', *Studies in History and Philosophy of Modern Physics*. **39**, 315-324.

Lamprecht, S.P. (1930). 'Of a Curious Reluctance to Recognize Causal Efficacy', *The Philosophical Review*. **39**, 403-414.

Langton, R. and Lewis, D. (1998). 'Defining 'Intrinsic'', *Philosophy and Phenomenological Research*. **58**, 333-345.

Laplace, P. ([1825] 1995). *Philosophical Essay on Probabilities*. Translated by A.I. Dale. New York, NY: Springer.

Laughlin, R.B. (2005). *A Different Universe: Reinventing Physics from the Bottom Down*. New York, NY: Basic Books.

Lavis, D.A. (2005). 'Boltzmann and Gibbs: An Attempted Reconciliation', *Studies in History and Philosophy of Modern Physics*. **36**, 245-273.

Lemmon, J. (1967). ''Comments' on D. Davidson's 'The Logical Form of Action Sentences'', in Nicholas Rescher (ed.), *The Logic of Decision and Action*. Pittsburgh, PN: University of Pittsburgh Press, 96-103.

Lenzen, V.F. (1932). 'Physical Causality', in George P. Adams, J. Loewenberg, and Stephen C. Pepper (eds.), *Causality*. Berkeley, CA: University of California Press, 69-96.

Lenzen, V.F. (1954). *Causality in Natural Science*. Springfield, IL: Charles C. Thomas Publisher.
Leslie, J. (1989). *Universes*. New York, NY: Routledge.
Lewis, D. (1973a). 'Causation', *The Journal of Philosophy*. **70**, 556-567.
Lewis, D. (1973b). *Counterfactuals*. Malden, MA: Blackwell Publishing.
Lewis, D. (1979). 'Counterfactual Dependence and Time's Arrow', *Noûs*. **13**, 455-476.
Lewis, D. (1983). 'New Work for a Theory of Universals', *Australasian Journal of Philosophy*. **61**, 343-377.
Lewis, D. (1986a). *Philosophical Papers, Volume II*. New York, NY: Oxford University Press.
Lewis, D. (1986b). *On the Plurality of Worlds*. Malden, MA: Blackwell Publishers.
Lewis, D. (1986c). 'Postscripts to "Causation"', In David Lewis, *Philosophical Papers, Volume II*. New York, NY: Oxford University Press, 170-211.
Lewis, D. (1986d). 'Causal Explanation', in David Lewis, *Philosophical Papers*, *Volume II*. New York, NY: Oxford University Press, 214-240.
Lewis, D. (1994). 'Humean Supervenience Debugged', *Mind* **103**, 473-489.
Lewis, D. (1999). *Papers in Metaphysics and Epistemology*. New York, NY: Cambridge University Press.
Lewis, D. (2000). 'Causation as Influence', *The Journal of Philosophy*. (Special Issue) **97**, 182-197.
Lewis, D. (2004a). 'Causation as Influence', in John Collins, Ned Hall, and L.A. Paul (eds.), *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 75-106.
Lewis, D. (2004b). 'Void and Object', in John Collins, Ned Hall, and L.A. Paul (eds.), *Causation*
and Counterfactuals. Cambridge, MA: MIT Press, 277-290.
Linde, A. (2004). 'Inflation, Quantum Cosmology, and the Anthropic Principle', in John D. Barrow, Paul C.W. Davies, and Charles L. Harper (eds.), 2004, *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*. New York, NY: Cambridge University Press, 426-458
Linsky, B. and Zalta, E. (1994). 'In Defense of the Simplest Quantified Modal Logic', *Philosophical Perspectives*, **8**, *Logic and Language*. 431-458.
Linsky, B. and Zalta, E. (1996). 'In Defense of the Contingently Nonconcrete', *Philosophical Studies* **84**, 283-294.
Lipton, P. (2004). *Inference to the Best Explanation* (International Library of Philosophy). 2nd Edition New York, NY: Routledge Press.
Lipton, P. (2009). 'Causation and Explanation', Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 619-631.
Locke, J. ([1690] 1975). *An Essay Concerning Human Understanding* Oxford: Clarendon Press.
Loewer, B. (1996). 'Humean Supervenience', *Philosophical Topics*. **24**, 101-127.
Loewer, B. (2001). 'Determinism and Chance', *Studies in History and Philosophy of Modern Physics*. **32**, 609-620.
Loewer, B. (2004). 'David Lewis's Humean Theory of Objective Chance', *Philosophy of Science*. 71, 1115-1125.

Loewer, B. (2007). 'Counterfactuals and the Second Law', in Huw Price and Richard Corry (eds.), *Causation, Physics, and the Constitution of Reality: Russell's Republic Revisited*. New York, NY: Oxford University Press, 293-326.

Loewer, B. (2008). 'Determinism', in Stathis Psillos and Martin Curd (eds.), *The Routledge Companion to Philosophy of Science*. New York, NY: Routledge Press, 327-336.

Loewer, B. (2012). 'Two Accounts of Laws and Time', *Philosophical Studies*. **160**, 115-137.

Lombard, L. (1986). *Events: A Metaphysical Study* (International Library of Philosophy). London: Routledge & Kegan Paul.

Loux, M.J. (1976). 'The Concept of a Kind', *Philosophical Studies*. **29**, 53-61.

Loux, M.J. (1978). *Substance and Attribute*. Dordrecht: D. Reidel.

Loux, M.J. (2006). *Metaphysics: A Contemporary Introduction*. Third Edition. New York, NY: Routledge Press.

Lowe, E.J. (2000).

Lowe, E.J. (2013). 'What is the Source of Our Knowledge of Modal Truths?', *Mind*. **121**, 919-950.

Lüders, G. (1954). 'On the Equivalence of Invariance under Time Reversal and under Particle-Antiparticle Conjugation for Relativistic Field Theories', *Kong.Dan.Vid.Sel.Mat.Fys.Med*. **28N5**, 1-17.

Lycan, W.G. (1988). *Judgement and Justification*. Cambridge: Cambridge University Press.

Lycan, W.G. (2002). 'Explanation and Epistemology', in Paul K. Moser (ed.), *The Oxford Handbook of Epistemology*. New York, NY: Oxford University Press, 408-433.

Lyth, D.H. and Liddle, A.R. (2009). *The Primordial Density Perturbation: Cosmology, Inflation and the Origin of Structure*. Cambridge: Cambridge University Press.

Maartens, R. (2011). 'Is the Universe Homogeneous?', *Philosophical Transactions of The Royal Society A: Mathematical, Physical & Engineering Sciences*. **369**, 5115-5137.

Maartens, R. and Matravers, D.R. (1994). 'Isotropic and Semi-Isotropic Observations in Cosmology', *Classical and Quantum Gravity*. **11**, 2693-2704.

Mackie, J.L. (1974). *The Cement of the Universe: A Study of Causation*. Oxford: Oxford University Press.

Mackie, J.L. (1980). *The Cement of the Universe: A Study of Causation* (Clarendon Library of Logic and Philosophy). New York, NY: Oxford University Press.

Mahan, G.D. (2009). *Quantum Mechanics in a Nutshell*. Princeton, NJ: Princeton University Press.

Majors, B. (2005). 'Moral Discourse and Descriptive Properties', *The Philosophical Quarterly*. **55**, 475-494.

Malament, D. (2004). 'On the Time Reversal Invariance of Classical Electromagnetic Theory', *Studies in History and Philosophy of Modern Physics*. **35**, 295-315.

Malament, D.B. (2009). 'A Remark about the "Geodesic Principle" in General Relativity', http://philsci-archive.pitt.edu/5072/1/GeodesicLaw.pdf

Malament, D.B. (2012). *Topics in the Foundations of General Relativity and Newtonian Gravitation Theory*. Chicago, IL: University of Chicago Press.

Maldacena, J. and Nuñez, C. (2000). 'Supergravity Description of Field Theories on Curved Manifolds a No Go Theorem', arXiv:hep-th/0007018v2 8 Jul 2000.

Manchak, J.B. (2013). 'Global Space-time Structure', in Robert Batterman (ed.), *The Oxford Handbook of Philosophy of Physics*. New York, NY: Oxford University Press, 587-606.

Markopoulou, F. (2004). 'Planck-Scale Models of the Universe', in John D. Barrow, Paul C. W. Davies, and Charles L. Harper Jr., Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity. New York, NY: Cambridge University Press, 550-563.

Markopoulou, F. and Smolin, L. (1997). 'Causal Evolution of Spin Networks', *Nuclear Physics B*
508, 409-430.

Marr, D. (1982). *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information*. San Francisco, CA: W.H. Freeman.

Martin, R.M. (1969). 'On Events and Event-Descriptions', in Joseph Margolis (ed.), *Fact and Existence: Proceedings of the University of Western Ontario Philosophy Colloquium 1966*. Toronto: University of Toronto Press, 63-74.

Maslen, C. (2004). 'Causes, Constrasts, and the Nontransitivity of Causation', in John Collins, Ned Hall, and L.A. Paul (eds.), *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 341-357.

Mattingly, J. (2006). 'Which Gauge Matters', *Studies in History and Philosophy of Modern Physics*. **37**, 243-262.

Maudlin, T. (2002). 'Remarks on the Passing of Time', *Proceedings of the Aristotelian Society*, *New Series*, **102**, 259-274.

Maudlin, T. (2003). 'Distilling Metaphysics from Quantum Physics', In Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics*. New York, NY: Oxford University Press, 461-487.

Maudlin, T. (2007). *The Metaphysics within Physics*. New York, NY: Oxford University Press.

Maurin, A. (2014). 'Tropes', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy*. (Spring 2014 Edition). URL = <http://plato.stanford.edu/archives/spr2014/entiries/tropes/>.

McDermott, M. (1995). 'Redundant Causation', *The British Journal for the Philosophy of Science*. **46**, 523-544.

McInnes, B. (2007). 'The Arrow of Time in the Landscape', arXiv:0711.1656v2 [**hep-th**].

McLaughlin, B.P. (1997). 'Supervenience, Vagueness, and Determination', *Noûs*. Vol. **31** Supplement: *Philosophical Perspectives*, 11. *Mind, Causation, and World*, 209-230.

McLaughlin, B. and Bennett, K. (2014). 'Supervenience', *The Stanford Encyclopedia of Philosophy* (Spring 2014 Edition), Edward N. Zalta (ed.), forthcoming URL = <http://plato.stanford.edu/archives/spr2014/entries/supervenience/>.

McTaggart, J.M.E. ([1921] 1968). *The Nature of Existence*. Volume 1. Cambridge: Cambridge University Press.

Meinertsen, B.R. (2000). 'Events, Facts and Causation', *Poznan Studies in the Philosophy of the Sciences and the Humanities*. **76**, 145-181.

Mele, A.R. (2009). 'Causation, Action, and Free Will', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 554-574.

Mellor, D.H. (1995). *The Facts of Causation*. London: Routledge Press.

Mellor, D.H. (2004). 'For Facts as Causes and Effects', in J. Collins, N. Hall, and L.A. Paul (eds.) *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 309-323.

Menzies, P. (1989). 'A Unified Account of Causal Relata', *Australasian Journal of Philosophy*. **67**, 59-83.

Menzies, P. (1996). 'Probabilistic Causation and the Pre-emption Problem', *Mind*. **105**, 85-117.

Menzies, P. (1999). 'Intrinsic Versus Extrinsic Conceptions of Causation', in Howard Sankey (ed.), *Causation and Laws of Nature*. Kluwer Academic Publishers, 313-329.

Merricks, T. (1994). 'Endurance and Indiscernibility', *The Journal of Philosophy*. **91**, 165-184.

Merricks, T. (1995). 'On the Incompatibility of Enduring and Perduring Entities', *Mind* **104**, 523-531.

Merricks, T. (1998). 'Against the Doctrine of Microphysical Supervenience', *Mind* **107**, 59-71.

Misner, C.W. Thorne, K.S. and Wheeler, J.A. (1973). *Gravitation*. San Francisco, CA: W.H. Freeman and Company.

Mithani, A. and Vilenkin, A. (2012). 'Did the Universe Have a Beginning?', arXiv:1204.4658v1 [**hep-th**].

Mook, D.E. and Vargish, T. (1987). *Inside Relativity*. Princeton, NJ: Princeton University Press.

Moore, M. (2009). *Causation and Responsibility: An Essay in Law, Morals, and Metaphysics*. Oxford: Oxford University Press.

Moreland, J.P. (2001). *Universals* (Central Problems of Philosophy). Montreal & Kingston: McGill-Queen's University Press.

Moreland, J.P. and Craig, W.L. (2003). *Philosophical Foundations for a Christian Worldview*. Downers Grove, IL: InterVarsity Press.

Moss, S. (2013). 'Epistemology Formalized', *The Philosophical Review*. **122**, 1-43.

Mumford, S. (2009). 'Causal Powers and Capacities', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 265-278.

Mumford, S. and Anjum, R.L. (2011). *Getting Causes from Powers*. New York, NY: Oxford University Press.

Nagel, E. (1961). *The Structure of Science: Problems in the Logic of Scientific Explanation*. New York: Harcourt, Brace & World, Inc.

Nerlich, G. (2003). 'Space-Time Substantivalism', in Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics*. New York, NY: Oxford University Press, 281-314.

Newton, I. (1966). *Principia*. Berkeley and Los Angeles, CA: University of California Press.

Nikolić, H. (2008). 'Comment on "Spontaneous Inflation and the Origin of the Arrow of Time"', arXiv:hep-th/0411115v1.

Nolt, J. (2011). 'Free Logic', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2011 Edition). URL = <http://plato.stanford.edu/archives/spr2011/entries/logic-free/>.

Noordhof, P. (1998). 'Causation, Probability, and Chance', *Mind* **107**, 855-975.

North, J. (2008). 'Two Views on Time Reversal', *Philosophy of Science*. **75**, 201-223.

North, J. (2011). 'Time in Thermodynamics', in Craig Callender (ed.), *The Oxford Handbook of Philosophy of Time*. New York, NY: Oxford University Press, 312-350.

Northcott, R. (2008). 'Causation and Contrast Classes', *Philosophical Studies*. **139**, 111-123.

Norton, J. (2005). 'Eaters of the Lotus: Landauer's Principle and the Return of Maxwell's Demon', *Studies in History and Philosophy of Modern Physics*. **36**, 375-411.

Norton, J. (2007a). 'Causation as Folk Science', in H. Price and Corry (eds.), *Causation, Physics, and the Constitution of Reality: Russell's Republic Revisited*. Oxford: Clarendon Press, 11-44.

Norton, J. (2007b). 'Do the Causal Principles of Modern Physics Contradict Causal Anti-Fundamentalism?' in P.K. Machamer and G. Wolters (eds.), *Thinking about Causes: From Greek Philosophy to Modern Physics*. Pittsburg, PN: University of Pittsburgh Press, 222-234.

Norton, J. (2015). 'What Can We Learn about the Ontology of Space and Time from the Theory of Relativity', in Lawrence Sklar (ed.), *Physical Theory: Method and Interpretation*. New York, NY: Oxford University Press, 185-228.

O'Connor, T. (2000). *Persons and Causes: The Metaphysics of Free Will*. New York, NY: Oxford University Press.

O'Connor, T. (2002). 'Libertarian Views: Dualist and Agent-Causal Theories', in Robert Kane (ed.), *The Oxford Handbook of Free Will*. New York, NY: Oxford University Press, 337-355.

Ohreen, D.E. (2004). *The Scope and Limits of Folk Psychology*. Bern: Peter Lang.

Oppy, G. (2000). 'On 'A New Cosmological Argument'', *Religious Studies* **36**, 345-353.

Otte, R. (1987). 'A Theistic Conception of Probability', *Faith and Philosophy*. **4**, 427-447.

Page, D. (2005). 'Hawking Radiation and Black Hole Thermodynamics', *New Journal of Physics*. **7**, 1-32.

Page, D. (2008). 'Is our Universe Likely to Decay within 20 Billion Years?', *Physics Review D*. **78**, 063535.

Palais, R.S. (2008). 'Linear Operators and their Properties', in Timothy Gowers (ed.) with June Barrow-Green & Imre Leader (associate editors), *The Princeton Companion to Mathematics*. Princeton, NJ: Princeton University Press, 239-241.

Papineau, D. (2008). 'Must a Physicalist be a Microphysicalist?', in Jakob Hohwy and Jesper Kallestrup (eds.), *Being Reduced: New Essays on Reduction, Explanation, and Causation*. Oxford: Oxford University Press, 126-148.

Parsons, T. (1994). 'Ruth Barcan Marcus and the Barcan Formula', In Walter Sinnott-Armstrong (ed.), *Modality, Morality, and Belief*. New York: Cambridge University Press, 3–11.

Paśniczek, J. (2001). 'Can Meinongian Logic be Free?' in Edgar Morscher and Alexander Hieke (eds.), *New Essays in Free Logic: In Honour of Karel Lambert* (Applied Logic Series, vol., 23), Dordrecht: Kluwer, 227-238.

Pasnau, R. (2011). *Metaphysical Themes 1274-1671*. Oxford: Clarendon Press.

Paul, L.A. (2004). 'Aspect Causation', in John Collins, Ned Hall, and L.A. Paul (eds.), *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 205-224.

Paul, L.A. (2007). 'Constitutive Overdetermination', in Joseph Keim Campbell, Michael O'Rourke, and Harry Silverstein (eds.), *Causation and Explanation*. Cambridge, MA: MIT Press, 265-290.

Paul, L.A. (2009). 'Counterfactual Theories', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 158-184.

Paul, L.A. and Hall, N. (2013). *Causation: A User's Guide*. Oxford: Oxford University Press.

Peacocke, C. (1997). 'Metaphysical Necessity: Understanding, Truth and Epistemology', *Mind*. **106**, 521-574.

Peliti, L. (2003). *Statistical Mechanics in a Nutshell*. Princeton, NJ: Princeton University Press.

Penrose, R. (1965). 'Gravitational Collapse and Space-Time Singularities', *Physical Review Letters*. **14**, 57-59.

Penrose, R. (1971). 'Angular Momentum: An Approach to Combinatorial Spacetime', in T. Bastin (ed.), *Quantum Theory and Beyond*. Cambridge: Cambridge University Press, 151-180.

Penrose, R. (1978). 'The Geometry of the Universe', In Lynn Arthur Steen (ed.), *Mathematics Today: Twelve Informal Essays*. New York, NY: Springer-Verlag, 83-125.

Penrose, R. (1981). 'Time-Asymmetry and Quantum Gravity', in C.J. Isham, R. Penrose, and D.W. Sciama (eds.), 1981, *Quantum Gravity 2: A Second Oxford Symposium*. New York, NY: Oxford University Press, pp. 244-272.

Penrose, R. (1989a). *The Emperor's New Mind*. New York, NY: Oxford University Press.

Penrose, R. (1989b). 'Difficulties with Inflationary Cosmology', *Annals of the New York Academy of Sciences*. **571**, 249-264.

Penrose, R. (1996). 'Structure of Spacetime Singularities', in Stephen Hawking and Roger Penrose, *The Nature of Space and Time*. (Princeton Science Library). Princeton, NJ: Princeton University Press, 27-36.

Penrose, R. (2005). *The Road to Reality: A Complete Guide to the Laws of the Universe*. New York: Vintage Books.

Penrose, R. (2010). *Cycles of Time: An Extraordinary New View of the Universe*. New York, NY: Vintage Books.

Persson, J. (2002). 'Cause, Effect, and Fake Causation', *Synthese*. **131**, 129-143.

Peterson, J.B. (1898). 'The Empirical Theory of Causation', *The Philosophical Review*. **7**, 43-61.

Pettit, P. (1993). 'A Definition of Physicalism', *Analysis*. **53**, 213-223.

Pink, T. (2013). 'Free Will and Determinism', in Timothy O'Connor and Constantine Sandis (eds.), *A Companion to the Philosophy of Action* (Blackwell Companions to Philosophy). Malden, MA: Wiley-Blackwell, 301-308.

Plantinga, A. (1974). *The Nature of Necessity* (Clarendon Library of Logic and Philosophy). New York, NY: Oxford University Press.

Plantinga, A. (1988). 'Positive Epistemic Status and Proper Function', in James Tomberlin (ed.), *Philosophical Perspectives, 2, Epistemology, 1988*. Atascadero, CA: Ridgeview, 1-50.

Plantinga, A. (1993a). *Warrant: The Current Debate* New York, NY: Oxford University Press.

Plantinga, A. (1993b). *Warrant and Proper Function* New York, NY: Oxford University Press.

Plantinga, A. (2003). *Essays in the Metaphysics of Modality*. Edited by Matthew Davidson. New York, NY: Oxford University Press.

Poland, J. (1994). *Physicalism: The Philosophical Foundations*. Oxford: Clarendon Press.

Polger, T.W. (2004). *Natural Minds*. Cambridge, MA: MIT Press.

Polger, T.W. (2007). 'Realization and the Metaphysics of Mind', *Australasian Journal of Philosophy* **85**, 233-259.

Polger, T.W. and Shapiro, L.A. (2008). 'Understanding the Dimensions of Realization', *The Journal of Philosophy*. **105**, 213-222.

Pollock, J. (1976). *Subjunctive Reasoning*. Dordrecht: Reidel.

Pooley, O. (2013). 'Substantivalist and Relationalist approaches to Space-time', Robert Batterman (ed.), *The Oxford Handbook of Philosophy of Physics*. New York, NY: Oxford University Press, 522-586.

Popper, K.R. (1959). *The Logic of Scientific Discovery*. New York: Basic Books.

Preyer, G. and Siebelt, F. (2001). *Reality and Humean Supervenience: Essays on the Philosophy of David Lewis*. New York, NY: Rowman and Littlefield Publishers Inc.

Price, H. (1996). *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time* New York, NY: Oxford University Press.

Price, H. (2002). 'Burbury's Last Case: The Mystery of the Entropic Arrow', in Craig Callender (ed.), *Time, Reality and Experience*. Cambridge: Cambridge University Press, 19-56.

Price, H. (2004). 'On the Origins of the Arrow of Time: Why There is Still a Puzzle about the Low-Entropy Past', in Christopher Hitchcock (ed.), *Contemporary Debates in Philosophy of Science* (Contemporary Debates in Philosophy). Malden, MA: Blackwell Publishing, 219-239.

Price, H. (2011). 'The Flow of Time', in Craig Callender (ed.), *The Oxford Handbook of Philosophy of Time*. New York, NY: Oxford University Press, 276-311.

Price, H. and Weslake, B. (2009). 'The Time-Asymmetry of Causation', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 414-443.

Priest, G. (2001). 'Logic: One or Many?', in B. Brown and J. Woods (eds.), *Logical Consequences, Rival Approaches*. Hermes Science Publications, 23-28.

Priest, G. (2008). *An Introduction to Non-Classical Logic: From If to Is* Second Edition. New York, NY: Cambridge University Press.
Prior, A.N. (1968). *Papers on Time and Tense*. Oxford: The Clarendon Press.
Prugovečki, E. (1971). *Quantum Mechanics in Hilbert Space*. Volume 41 New York, NY: Academic Press.
Pruss, A.R. (2006). *The Principle of Sufficient Reason: A Reassessement* (Cambridge Studies in Philosophy). New York, NY: Cambridge University Press.
Pruss, A. and Rasmussen, J. (manuscript). *Necessary Existence*.

Psillos, S. (2009). 'Regularity Theories', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 131-157.
Quine, W.V. (1960). *Word & Object* (Studies in Communication). Cambridge, MA: MIT Press.
Quine, W.V. (1985). 'Events and Reification', in Ernest LePore and Brian P. McLaughlin (eds.), *Actions and Events: Perspectives on the Philosophy of Donald Davidson*. New York, NY: Oxford University Press, 162-176.
Railton, P. (1981). 'Probability, Explanation, and Information', *Synthese*. **48**, 233-256.
Ramsey, F.P. (1931). *The Foundations of Mathematics*. New York, NY: Harcourt, Brace and Co.
Ramsey, F.P. (1990). *Philosophical Papers*. Cambridge: Cambridge University Press.
Rea, M. (1998). 'In Defense of Mereological Universalism', *Philosophy and Phenomenological Research*. **58**, 347-360.
Redhead, M. (1987). *Incompleteness Nonlocality and Realism: A Prolegomenon to the Philosophy of Quantum Mechanics*. New York, NY: Oxford University Press.
Rees, M. (2000). *Just Six Numbers: The Deep Forces that Shape the Universe*. New York, NY: Basic Books.
Reid, T. (1969). *Essays on the Active Powers of the Human Mind*. Cambridge, MA: MIT Press.
Reid, T. ([1788] 1983). 'Essays on the Active powers of Man', in R.E. Beanblossom and K. Lehrer (eds.), *Inquiry and Essays Indianapolis*, IN: Hackett, 297-368.
Rickles, D. (2005). 'Interpreting Quantum Gravity', *Studies in History and Philosophy of Modern Physics*. **36**, 691-715.
Rickles, D. (2008). 'Quantum Gravity: A Primer for Philosophers', in Dean Rickles (ed.), *The Ashgate Companion to Contemporary Philosophy of Physics*. Aldershot and
Riess, A.G. Filippenko, A.V. Challis, P. Clocchiatti, A. Diercks, A. Garnavich, P.M. Gilliland, R.L. Hogan, C.J. Jha, S. Kirshner, R.P. Leibundgut, B. Phillips, M.M. Reiss, D. Schmidt, B.P. Schommer, R.A. Smith, R.C. Spyromilio, J. Stubbs, C. Suntzeff, N.B. and Tonry, J. (1998). 'Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant', *The Astronomical Journal* **116**, 1009-1038.
Roca-Royes, S. (2011). 'Conceivability and De Re Modal Knowledge'. *Noûs*. **45**, 22–49.
Rodriguez-Pereyra, G. (2014). 'Nominalism in Metaphysics', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Summer 2014 Edition). http://plato.stanford.edu/archives/sum2014/entries/nominalism-metaphysics/

Rosen, G. (2012). 'Abstract Objects', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy*. (Spring 2012 Edition). http://plato.stanford.edu/archives/spr2012/entries/abstract-objects/>.

Rosenberg, A. (1974). 'On Kim's Account of Events and Event-Identity', *The Journal of Philosophy*. **71**, 327-336.

Rosenberg, A. (1992). 'Causation, Probability, and the Monarchy', *American Philosophical Quarterly*. **29**, 305-318.

Rosenkrantz, G. and Hoffman, J. (1980). 'What an Omnipotent Agent Can Do', *International Journal for Philosophy of Religion*. **11**, 1-19.

Rosenkrantz, G. and Hoffman, J. (2012). 'Omnipotence', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2012 Edition). URL = http://plato.stanford.edu/archives/spr2012/entries/omnipotence/
Burlington: Ashgate Publishing Limited and Ashgate Publishing Company, 262-383.

Rovelli, C. (1997). 'Halfway through the Woods: Contemporary Research on Space and Time', in John Earman and John D. Norton (eds.), The Cosmos of Science; Essays on Exploration. Pittsburg, PN: University of Pittsburg Press, 180-223.

Rovelli, C. (2004). *Quantum Gravity* (Cambridge Monographs on Mathematical Physics). New York, NY: Cambridge University Press.

Rovelli, C. (2008). 'Loop Quantum Gravity', *Living Reviews in Relativity*. **11**, 5.

Rovelli, C. (2011a). 'Simple Model for Quantum General Relativity from Loop Quantum Gravity', *Journal of Physics: Conference Series*. **314**, 012006.

Rovelli, C. (2011b). 'A New Look at Loop Quantum Gravity', *Classical and Quantum Gravity*. **28**, 114005.

Class of Physics of the Royal Swedish Academy of Sciences (2011). 'The Accelerating Universe', URL = <http://www.nobelprize.org/nobel_prizes/physics/laureates/2011/advanced-physicsprize2011.pdf>

Rueger, A. (1998). 'Local Theories of Causation and the a posteriori Identification of the Causal Relation', *Erkenntnis*. **48**, 25-38.

Ruetsche, L. (2011). *Interpreting Quantum Theories*. New York, NY: Oxford University Press.

Russell, B. (1912-1913). 'On the Notion of Cause', *Proceedings of the Aristotelian Society*. **13**, 1-26.

Sahni, V. (2002). 'The Cosmological Constant Problem and Quintessence', *Classical and Quantum Gravity*. **19**, 3435-3448.

Sahlmann, H. (2012). 'Loop Quantum Gravity', in Jeff Murugan, Amanda Weltman, and George F.R. Ellis (eds.), *Foundations of Space and Time: Reflections on Quantum Gravity*. New York, NY: Cambridge University Press, 185-210.

Salmon, W.C. (1984). *Scientific Explanation and the Causal Structure of the World*. Princeton, NJ: Princeton University Press.

Salmon, W.C. (1998). *Causality and Explanation*. New York, NY: Oxford University Press.

Schaffer, J. (2000). 'Trumping Preemption', *The Journal of Philosophy*. (Special Issue) **97**, 165-181.

Schaffer, J. (2003). 'Overdetermining Causes', *Philosophical Studies*. **114**, 23-45.

Schaffer, J. (2005). 'Contrastive Causation', *The Philosophical Review*. **114**, 327-358.
Schaffer, J. (2008). 'Causation and Laws of Nature: Reductionism', in John Hawthorne, Theodore Sider, and Dean W. Zimmerman (eds.), *Contemporary Debates in Metaphysics* (Contemporary Debates in Philosophy) Malden, MA: Blackwell Publishers, 82-107.
Schaffer, J. (2009). 'On What Grounds What', in D. Chalmers, D. Manley, and R. Wasserman (eds.), *Metametaphysics: New Essays on the Foundations of Ontology*. Oxford: Clarendon Press, 347-383.
Schaffer, J. (2010). 'The Internal Relatedness of All Things', *Mind* **119**, 341-376.
Schrödinger, E. (1935). 'Discussion of Probability Relations between Separated Systems', *Proceedings of the Cambridge Philosophical Society*. **31**, 555-563.
Schurz, G. (2002). 'Alethic Modal Logics and Semantics', in Dale jacquette (ed.), *A Companion to Phiosophical Logic* (Blackwell Companions to Philosophy). Malden, MA: Blackwell Publishing, 442-477.
Schwarz, W. (2011). 'Generalising Kripke Semantics for Quantified Modal Logics', (Manuscript).
Scriven, M. (1971). 'The Logic of Cause', *Theory and Decision*. **2**, 49-66.
Scriven, M. (1975). 'Causation as Explanation', *Noûs*. **9**, 3-16.
Sen, A. (1981). 'On the Existence of Neutrino "Zero-Modes" in Vacuum Spacetimes', *Journal of Mathematical Physics*. **22**, 1781-1786.
Shoemaker, S. (2003). 'Realization, Micro-Realization, and Coincidence', *Philosophy and Phenomenological Research* **67**, 1-23.
Shoemaker, S. (2007). *Physical Realization*. New York, NY: Oxford University Press.
Shramko, Y. and Wansing, H. (2012). 'Truth Values', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2012 Edition). URL = <http://plato.stanford.edu/archives/win2012/entries/truth-values/>.
Sider, T. (2001). *Four Dimensionalism: An Ontology of Persistence and Time*. New York, NY: Oxford University Press.
Sider, T. (2003a). 'Review: What's So Bad about Overdetermination?', *Philosophy and Phenomenological Research*. **67**, 719-726.
Sider, T. (2003b). 'Reductive Theories of Modality', in Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics*. New York, NY: Oxford University Press, 180-208.
Sider. T. (2003c). 'Maximality and Microphysical Supervenience', *Philosophy and Phenomenological Research* **66**, 139-149.
Sider, T. (2009). 'Williamson's Many Necessary Existents', *Analysis*. **69**, 250-258.
Sider, T. (2011). *Writing the Book of the World*. New York, NY: Oxford University Press.
Siegel, S. (2009). 'The Visual Experience of Causation', *The Philosophical Quarterly*. **59**, 519-540.
Simons, P. (2001). 'Calculi of Names: Free and Modal', in Edgar Morscher and Alexander Hieke (eds.), *New Essays in Free Logic: In Honour of Karel Lambert* (Applied Logic Series 23) Dordrecht: Kluwer Academic Publishers, 49-65.
Simons, P. (2003). 'Events', in Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics*. New York, NY: Oxford University press, 357-385.

Sklar, L. (1993). *Physics and Chance: Philosophical Issues in the Foundations of Statistical Mechanics*. New York, NY: Cambridge University Press.

Skow, B. (2013). 'Are There Non-Causal Explanations (of Particular Events)?', *The British Journal for the Philosophy of Science*. **0**, 1-23.

Smeenk, C. (2013). 'Philosophy of Cosmology', in Robert Batterman (ed.), 2013, *The Oxford Handbook of Philosophy of Physics*. New York, NY: Oxford University Press, 607-652.

Smith, Q. (2007). 'Kalam Cosmological Arguments for Atheism', in Michael Martin (ed.), 2007, *The Cambridge Companion to Atheism*. New York, NY: Cambridge University Press, 182-198.

Smith, S.R. (2013). 'Causation in Classical Mechanics', in Robert Batterman (ed.), *The Oxford Handbook of Philosophy of Physics*. New York, NY: Oxford University Press, 107-140.

Smolin, L. (2001). *Three Roads to Quantum Gravity*. New York, NY: Basic Books.

Smolin, L. (2002). 'Quantum Gravity with a Positive Cosmological Constant', arXiv:hep-th/0209079v1.

Smolin, L. (2004a). 'An Invitation to Loop Quantum Gravity', arXiv:hep-th/0408048v3.

Smolin, L. (2004b). 'Quantum Theories of Gravity: Results and Prospects', John D. Barrow, Paul C.W. Davies, and Charles L. Harper Jr. (eds.), *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*. Cambridge: Cambridge University Press, 492-527.

Smolin, L. (2005). 'An Invitation to Loop Quantum Gravity', arXiv:hep-th/0408048v3.

Sosa, E. (2000). Modal and Other A-Priori Epistemolgy: How Can We Know What is Possible and What Impossible?. *Southern Journal of Philosophy*. Suppl. **38**, 1-16.

Sosa, E. (2007). *A Virtue Epistemology: Apt Belief and Reflective Knowledge, Volume I*. New York, NY: Oxford University Press.

Sosa, E. (2009). *Reflective Knowledge: Apt Belief and Reflective Knowledge, Volume II*. New York, NY: Oxford University Press.

Sosa, E. (2011). *Knowing Full Well* (Soochow University Lectures in Philosophy). Princeton, NJ: Princeton University Press.

Sosa, E. and Tooley, M. (1993). 'Introduction', in Ernest Sosa and Michael Tooley (eds.), *Causation* (Oxford Readings in Philosophy). New York, NY: Oxford University Press, 1-32.

Spirtes, P. Glymour, C. and Scheines, R. (2000). *Causation, Prediction, and Search*. Cambridge, MA: MIT Press.

Stanley, J. (2005). *Knowledge and Practical Interests*. New York, NY: Oxford University Press.

Stanley, J. (2007). 'Précis of Knowledge and Practical Interests', *Philosophy and Phenomenological Research*. **75**, 168-172.

Steglich-Petersen, A. (2012). 'Against the Contrastive Account of Singular Causation', *The British Journal for the Philosophy of Science*. **63**, 115-143.

Steiner, M. (1986). 'Events and Causality', *Journal of Philosophy*. **83**, 249-264.

Steiner, M. (1998). *The Applicability of Mathematics as a Philosophical Problem*. Cambridge, MA: Harvard University Press.

Steinhardt, P.J. (2011). 'The Inflation Debate: Is the Theory at the Heart of Modern Cosmology Deeply Flawed?', *Scientific American*. April 2011, pp. 37-43.

Steinhardt, P.J. and Turok, N. (2002a). 'Cosmic Evolution in a Cyclic Universe', *Physical Review D*. **65**, 126003.
Steinhardt, P.J. and Turok, N. (2002b). 'A Cyclic Model of the Universe', *Science*. **296**, 1436-1439.
Steinhardt, P.J. and Turok, N. (2005). 'The Cyclic Model Simplified', *New Astronomy Reviews*. **49**, 43-57.
Steinhardt, P.J. and Wesley, D. (2009). 'Dark Energy, Inflation, and Extra Dimensions', *Physical Review D*. **79**, 104026.
Stoeger, W.R. Maartens, R. and Ellis, G.F.R. (1995). 'Proving Almost-Homogeneity of the Universe: An Almost Ehlers-Geren-Sachs Theorem', *The Astrophysical Journal*. **443**, 1-5.
Stoljar, D. (2010). *Physicalism*. New York, NY: Routledge.
Strevens, M. (2007). 'Review of Woodward Making Things Happen*', *Philosophy and Phenomenological Research*. **74**, 233-249.
Strevens, M. (2008). *Depth: An Account of Scientific Explanation*. Cambridge, MA: Harvard University Press.
Strevens, M. (2012). 'Précis of *Depth*', *Philosophy and Phenomenological Research*. **84**, 447-460.
Strevens, M. (2013). *Tychomancy: Inferring Probability from Causal Structure* Cambridge, MA: Harvard University Press.
Strominger, A. (2001). 'The ds/CFT Correspondence', *Journal of High Energy Physics*. 10(2001)029.
Sklar, L. (1974). *Space, Time, and Space-time*. Berkely and Los Angeles, CA: University of California Press.
Strawson, P.F. (1959). *Individuals: An Essay in Descriptive Metaphysics*. New York, NY: Routledge Press.
Swinburne, R. (1997). 'The Irreducibility of Causation', *Dialectica*. **51**, 79-92.
Tamir, M. (2012). 'Proving the Principle: Taking Geodesic Dynamics Too Seriously in Einstein's Theory', *Studies in History and Philosophy of Modern Physics*. **43**, 137-154.
Tavakol, R. and Zalaletdinov, R. (1998). 'On the Domain of Applicability of General Relativity', *Foundations of Physics*. **28**, 307-331.
Taylor, R. (1966). *Action and Purpose*. Englewood Cliffs: Prentice Hall.
Taylor, R. (1992). *Metaphysics*. 4th Edition. Englewood Cliffs, NJ: Prentice-Hall.
Thomson, J.J. (1971). 'Individuating Actions', *The Journal of Philosophy*. **68**, 774-781.
Tidman, P. (1994). 'Conceivability as a Test for Possibility', *American Philosophical Quarterly* **31**, 297-309.
Tooley, M. (1987). *Causation: A Realist Approach*. New York, NY: Oxford University Press.
Tooley, M. (1990). 'Causation: Reductionism versus Realism', *Philosophy and Phenomenological Research*. **50**, Suppl. (Autumn, 1990), 215-236.
Tooley, M. (1997). *Time, Tense, and Causation*. Oxford: Clarendon Press.
Tooley, M. (2003). 'Causation and Supervenience', in Michael J. Loux and Dean W. Zimmerman (eds.), *The Oxford Handbook of Metaphysics*. New York, NY: Oxford University Press, 386-434.

Tooley, M. (2009). 'Causes, Laws, and Ontology', in Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 368-386.

Uffink, J. (2008). 'Boltzmann's Work in Statistical Physics', in Edward N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2008 Edition). URL = http://plato.stanford.edu/archives/win2008/entries/statphys-Boltzmann/

Vachaspati, T. (2007). 'On Constructing Baby Universes and Black Holes', arXiv:0705.2048v1 [**gr-qc**]

Vaidya, A. J. (2010). 'Understanding and Essence', *Philosophia*. **38**, 811–833.

Van Cleve, J. (1985). 'Three Versions of the Bundle Theory', *Philosophical Studies* **47**, 95-107.

Van Cleve, J. (2008). 'The Moon and Sixpence: A Defense of Mereological Universalism', in Theodore sider, John Hawthorne, and Dean W. Zimmerman (eds.), *Contemporary Debates in Metaphysics* (Contemporary Debates in Philosophy). Malden, MA: Blackwell Publishers, 321-340.

van Fraassen, B.C. (1980). *The Scientific Image*. Oxford: Clarendon Press.

van Fraassen, B.C. (1989). *Laws and Symmetry*. New York, NY: Oxford University Press.

Van Riet, T. (2011). 'On Classical de Sitter Solutions in Higher Dimensions', arXiv:1111.3154v2 [hep-th].

Vendler, Z. (1967). 'Causal Relations', *The Journal of Philosophy*. **64**, 704-713.

Vilenkin, A. (2006). *Many Worlds in One: The Search for Other Universes*. New York: Hill and Wang.

Vilenkin, A. (2013a). 'Arrows of Time and the Beginning of the Universe', arXiv:1305.3836v1 [**hep-th**].

Vilenkin, A. (2013b). 'Arrows of Time and the Beginning of the Universe', arXiv.1305.3836v2 [**hep-th**].

Wald, R.M. (1984). *General Relativity*. Chicago, IL: University of Chicago Press.

Wald, R.M. (2006). 'The Arrow of Time and the Initial Conditions of the Universe', *Studies in History and Philosophy of Modern Physics*. **37**, 394-398.

Wall, A.C. (2009). 'Ten Proofs of the Generalized Second Law', *Journal of High Energy Physics*. 06(2009)021.

Wall, A.C. (2012). 'Proof of the Generalized Second Law for Rapidly Changing Fields and Arbitrary Horizon Slices', *Physical Review D*. **85**, 104049.

Wall, A.C. (2013a). 'The Generalized Second Law implies a Quantum Singularity Theorem', arXiv:1010.5513v3 [**gr-qc**].

Wall, A.C. (2013b). 'A Discrete, Unitary Causal Theory of Quantum Gravity', *Classical and Quantum Gravity*. **30**, 115002.

Wallace, D. (2008). 'Philosophy of Quantum Mechanics', in Dean Rickles (ed.), *The Ashgate Companion to Contemporary Philosophy of Physics*. Aldershot, England, 16-98.

Wallace, D. (2011). 'The Logic of the Past-Hypothesis', http://philsci-archive.pitt.edu/8894/.

Wallace, D. (2012). *The Emergent Multiverse: Quantum Theory according to the Everett Interpretation* Oxford: Oxford University.

Weatherall, J.O. (2011). 'A Brief Remark on Energy Conditions and the Geroch-Jang Theorem', arXiv:1106.2336v1 [physics.hist-ph] 12 Jun 2011.

Weaver, C.G. (2012). 'What Could be Caused Must Actually be Caused', *Synthese* **184**, 299-317.

'Erratum to: What could be caused must actually be caused', *Synthese*. **183**, 279.

Weaver, C.G. (2013). 'A Church-Fitch Proof for the Universality of Causation', *Synthese*. **190**, 2749-2772.

Weaver, C.G. (draft). 'On the Carroll-Chen Model', arXiv:1309.4976v2 [physics.hist-ph].

Weinberg, S. (1972). *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity*. New York: John Wiley & Sons, Inc.

Weinberg, S. (2008). *Cosmology*. New York, NY: Oxford University Press.

Weinberg, S. (2013). *Lectures on Quantum Mechanics*. New York, NY: Cambridge University Press.

Weinstein, S. (2001). 'Absolute Quantum Mechanics', *The British Journal for Philosophy of Science* **52**, 67-73.

Weintraub, R. (2013). 'Induction and Inference to the Best Explanation', *Philosophical Studies*. **166**, 203-216.

Weltman, A. Murugan, J. and Ellis, G.F.R. (2012). 'Conversations in String Theory', Jeff Murugan, Amanda Weltman, and George F.R. Ellis (eds.), *Foundations of Space and Time: Reflections on Quantum Gravity*. New York, NY: Cambridge University Press, 419-434.

Weslake, B. (draft). 'Proportionality, Contrast and Explanation', Version 6836ef4 November 21st, 2011 Retrieved 5/15/2012 from thttp://bweslake.s3.amazonaws.com/research/papers/weslake_prince.pdf

Weyl, H. (1949). *Philosophy of Mathematics and Natural Science*. Revised and Augmented English Edition. Based on a translation by Olaf Helmer. Atheneum: Originally published by Princeton, NJ: Princeton University Press.

Wheeler, J.A. and Ford, K. (1998). *Geons, Black holes, and Quantum Foam*. New York, NY: W.W. Norton and Company, Inc.

Whewell, W. (1840). *Philosophy of the Inductive Sciences Founded Upon Their History*. London: J.W. Parker and Son.

Wigner, E. (1967). *Symmetries and Reflections: Scientific Essays*. Bloomington, IN: Indiana University Press.

Williams, D.C. (1951). 'The Myth of Passage', *The Journal of Philosophy*. **48**, 457-472.

Williams, D.C. (1953). 'On the Elements of Being I', *The Review of Metaphysics* **7**, 3-18.

Williamson, T. (1990). 'Necessary Identity and Necessary Existence', in Rudolf Haller and Johannes Brandl (eds.), *Wittgenstein—Eine Neubewertung Towards a Re-evaluation*. Springer-Verlag Berlin Heidelberg, 168-175.

Williamson, T. (1998). 'Bare Possibilia', *Erkenntnis*. **48**, 257-273.

Williamson, T. (2000). 'Logic and Existence', *Proceedings of the Aristotelian Society*. **100**, 321-343.

Williamson, T. (2002). 'Necessary Existents', in A. O'Hear (ed.), *Logic, Thought and Language*. Cambridge: Cambridge University Press, 233-251.

Williamson, T. (2007). *The Philosophy of Philosophy* Malden, MA: Blackwell Publishers.

Williamson, T. (2010). 'Modal Logic within Counterfactual Logic', in Bob Hale and Aviv Hoffmann (eds.), *Modality: Metaphysics, Logic, and Epistemology*. New York, NY: Oxford University Press, 81-96.

Williamson, T. (2013). *Modal Logic as Metaphysics*. Oxford: Oxford University Press.

Wilson, N.L. (1974). 'Facts, Events and Their Identity Conditions', *Philosophical Studies*. **25**, 303-321.

Winsberg, E. (2012). 'Bumps on the Road to Here (from Eternity)', *Entropy*. **14**, 390-406.

Woodward, J. (2003). *Making Things Happen: A Theory of Causal Explanation*. New York, NY: Oxford University Press.

Woodward, J. (2009). "Agency and Interventionist Theories", Helen Beebee, Christopher Hitchcock, and Peter Menzies (eds.), *The Oxford Handbook of Causation*. New York, NY: Oxford University Press, 234-262.

Wright, L. (1976). *Teleological Explanations: An Etiological Analysis of Goals and Functions*. Berkeley and Los Angeles, CA: University of California Press.

Yablo, S. (1992a). 'Cause and Essence', *Synthese*. **93**, 403-449.

Yablo, S. (1992b). 'Mental Causation', *The Philosophical Review*. **101**, 254-280.

Yablo, S. (1993). 'Is Conceivability a Guide to Possibility?', *Philosophy and Phenomenological Research.* **53**, 1-42.

Yablo, S. (2004). 'Advertisement for a Sketch of an outline of a Prototheory of Causation', in John Collins, Ned Hall, and L.A. Paul (eds.), *Causation and Counterfactuals*. Cambridge, MA: MIT Press, 119-137.

Zee, A. (2010). *Quantum Field Theory in a Nutshell*. Princeton, NJ: Princeton University Press.

Zee, A. (2013). *Einstein Gravity in a Nutshell*. Princeton, NJ: Princeton University Press.

Zimmerman, D.W. (1997). 'Distinct Indiscernibles and the Bundle Theory', *Mind*. **106**, 305-309.