SUPERSUBSTANTIVALISM AND THE UNIFICATION OF PHYSICS

by

J. R. VAUGHT, B.A., M.A.

A Dissertation Presented to the Graduate Faculty of
Saint Louis University in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy

2016

COMMITTEE IN CHARGE OF CANDIDACY:

Associate Professor Kent Staley,
Chairperson and Advisor

Associate Professor Scott Berman

Associate Professor Jonathan Jacobs

Dedication

A lot of people have contributed to my growth as a scholar over the years, and my thanks goes out to all of them, from Transylvania University to Saint Louis University. My family and friends, likewise, have also supplied me with years of support and encouragement. But, I'd like to dedicate this particular work to one very special person who sacrificed so much in the hope of giving me a better life than he had: my father David Ray Vaught.

Acknowledgements

I’d like to acknowledge, and thank, Kent Staley who has given me a *great* deal of help with this work. He read countless drafts, always taking considerable time and care to provide me with sound advice. I'd also like to acknowledge the significant constructive criticisms that both Scott Berman and Jon Jacobs provided to me. This work certainly would never have been completed without their help.

Table of Contents

Chapter I: Introduction to Supersubstantivalism

The spacetime debate boils down to a single question: are we reifying spacetime when we attribute to it properties and utilize it in scientific theories? To reify an entity is to take something which is not a physical thing in and of itself, something which is merely an absence of some other physical thing, and to treat it as if it were itself a physical thing. One can reify a shadow for instance, it seems to be so dynamic and singular we take this absence of light to be an actual thing, we think of a room which suddenly is filled with shadows as a room which has had physical things added to it, namely shadows, instead of just a room in which material stuff was removed, namely light. The essential question of the spacetime debate, the debate over the nature of spacetime, is whether this process is what is being done with spacetime when we treat it like a physical thing in scientific theories.[1] Is spacetime an actual physical thing, and thus a substance, in which other things are located, or is spacetime merely a set of relations that are possessed by other physical objects like people?[2] This debate is commonly looked at as having two main families of responses: either spacetime is a substance which, in some sense, "holds" other physical objects and/or properties, what is often referred to as a Substantivalism; or spacetime is not a substance, it is merely a set of physical relations between other physical substances like distance and simultaneity, what is often referred to as a Relationalism. Substantivalist theories often have the benefit of treating spacetime as an independent entity, and commonly are very useful in both physical theories and mathematical treatments of those

[1] I'm using "physical" and "material" here as interchangeable.

[2] I realize I'm being a bit sloppy with terms like "physical thing" and "substance" without strictly defining them, but I am only trying to sketch the basic ideas and motivations here.

theories. However, Relationalist theories typically maintain a superior degree of parsimony above Substantivalist theories.

In the family of Substantivalisms though there is a variety that, until quite recently, has been largely overlooked by those interested in the spacetime debate: Supersubstantivalism. Supersubstantivalism is the position that spacetime exists as a substance, but moreover is the *only* substance in existence. All of that is to say, there is an only a single substance in existence: spacetime. All physical objects we commonly take to be real "solid" objects are in fact not separate substances, but rather merely collections of properties manifested by the one substance spacetime. For example, a cat would not be an actual solid substance on this view, rather it would be an amalgamation of various properties, like color and impenetrability. Normally when we think of a physical object, like a cat or a rock, we think of this solid *stuff* which is somehow this impenetrable region of space full of some kind of material substance. But Supersubstantivalism would reduce these impenetrable regions to geometric shapes that reject penetration from other geometric shapes; there is no stuff there, there is simply force in a given region, and we know from things like magnetic force that regions can exhibit force even if they are devoid of material objects. In fact, Supersubstantivalism in some ways can be seen as an idea which is the result of a logical progression that originates with the experiments of Ernest Marsden and Hans Geiger (1908-1913) under the direction of Ernest Rutherford when their results in studies with gold foil and alpha particles demonstrate that atoms themselves are predominately empty space with subatomic pieces like electrons and protons. Still later experiments would indicate that these subatomic parts too are mostly empty space and are reductively composed of yet smaller parts like quarks. Material objects have progressively been shown to be composed of smaller and smaller physical parts which are kept positioned precisely in larger and larger regions of empty space not by the material parts touching each other but by forces reaching across these growing regions of empty space to press against the other material parts.

This progression of material objects becoming more and more composed by forces pushing against each other over regions of empty space, and less and less by solid matter rigidly occupying certain regions of space has advanced to greater and greater degrees all the way from ancient Greece to today's modern physics. Supersubstantivalism can be seen as the ultimate, and final, step in this progression. All solid material parts have been removed and the material objects are now exhaustively composed of forces (and properties) interacting across empty space. I suggest that Supersubstantivalism is supported by this fact; as this historical progression has tended toward the better and more correct understandings of the nature of the world. Furthermore, it seems that the furthering of this progression toward Supersubstantivalism would also be a furthering toward a more correct understanding of the world--just as all the previous steps of this progression have tended toward! And as Bertrand Russell (1954) suggests, when you have gotten to the point where all you can find are discrete properties like charge and impenetrability regulated to just certain regions of a substance, what need is there to posit a second superfluous type of substance that the properties adhere in given that they can just as readily adhere directly in the first substance? He states, "...the difference between 'matter' and 'empty space' is, I believe, merely a difference as to the causal laws governing successions of events, not a difference expressible as that between the presence or absence of substance, or as that between one kind of substance and another" (Russell 121-122).

The thesis of Supersubstantivalism, while perhaps counter-intuitive, is a powerful one as it not only combines the beneficial qualities of both standard Substantivalisms and

Relationalisms, but also opens numerous other doors. And admittedly Supersubstantivalism has been gaining in popularity in philosophy of physics communities in academia, but overall it still remains beneath the radar of average philosophers and metaphysicists. [3] The purpose of this dissertation is to demonstrate the large amount of promise the position of Supersubstantivalism holds for not only the spacetime debate but also for philosophy in general. In particular, I will argue in this dissertation that there is a strong abductive argument focusing on parsimony of substance and causal unification that I believe suggests that Supersubstantivalism is the best explanation of spacetime and its nature.

So, with the purpose of this treatise now established allow me to end this perfunctory introduction with a brief outline of the subsequent chapters and their respective purposes. In order to give and fully examine this abductive argument I have referred to I will start by devoting a chapter to looking at the surprisingly far reaching history of the spacetime debate and the thesis of Supersubstantivalism, which will be the subsequent chapter. Following this chapter I think it will be useful, prior to actually looking at the abductive argument, to first look at the concepts of explanation, abduction, and parsimony themselves and how these items could provide good reasons to accept Supersubstantivalism as the best explanation of the nature of spacetime. This subject will be the basis for chapter three, a meta-level examination and discussion about the nature of explanation, abduction, and parsimony, and how these three relate to one another. Once these two sections, chapters two and three, have established a clear intellectual terrain around abductive arguments and the spacetime debate the actual examination of this abductive argument will be featured in chapter four. Chapter four will begin by providing a detailed look at the abductive argument that Supersubstantivalism is the best explanation of the nature of

[3] Hartry Field (1985), Bradford Skow (2005), as well as Michael Esfeld and Vincent Lam (2006), are a few examples of those writing on the subject.

spacetime. I will examine both its strengths and weaknesses in the effort to further the spacetime debate, ultimately arguing that at the very least Supersubstantivalism is a strong enough, and promising enough candidate, that it deserves much greater attention by both the scientific and philosophical communities.   Chapter five will be dedicated to looking at the major objections a serious Supersubstantivalism view would run into, which I will argue is a solitary threat: the Hole Argument. In this penultimate chapter I will provide a detailed explanation, and discussion, of the infamous Hole Argument, in due course arguing that it alone is not sufficient to cause one to disregard the findings of the previous chapter. Lastly, the final chapter, chapter six, will of course be a conclusion that attempts to sum up the findings of the dissertation and to give educated speculation about the benefits and potential this position holds.

Chapter II: The History of the Spacetime Debate

i. Introduction

My purpose in this dissertation is to argue that there is a strong abductive argument to be made for Supersubstantivalism as the best explanation of the nature of spacetime, and that as such Supersubstantivalism deserves much greater academic attention. Prior, however, to engaging in this task I believe it is helpful to lay out the relevant historical and conceptual terrain, and then to examine any pertinent meta-level issues which germane to this discussion, like the nature of explanation for instance. The purpose of this second chapter is to do the first of those two preliminary jobs. This chapter will provide a historical and conceptual overview of both the spacetime debate in general, and also, what is perhaps of even more importance, of Supersubstantivalism itself.

ii. History of the Spacetime Debate

To begin let's direct our attention to the spacetime debate as it has occurred throughout the history of philosophy and physics. Although ancient philosophers such as the Pre-Socratics, Plato, and Aristotle did actively try to define and conceptually grasp the true nature of space and time, the spacetime debate as it is understood today in the 21st Century really begins in the works of Sir Isaac Newton.[4] With the birth of the Enlightenment and the Scientific Revolution the desire to empirically and rationally come to a thorough understanding of reality--space and

[4] If one is interested in looking at the works of Ancient Philosophy which deal with this subject I recommend Nick Huggett (1999).

time included--was, in a sense, the "holy grail" of philosophers of the time. Writers of the time like Rene Descartes (1984) offered theories which attempted to explain things like the dynamics of nature, and each of these works were, to varying degrees, influential on the relevant academic discussions of the day.[5] However, it is really with Newton's publication of the *Philosophiae Naturalis Principia Mathematica* (or *PNPM* for short) in 1687 that marks the beginning of the modern spacetime debate.

With the publication of the *PNPM* the modern spacetime debate begins, and the philosophical community finds an implicit theory in this work which will eventually become known as the Substantivalist theory of space (or spacetime for the post-Einsteinian).[6] Substantivalism will be on one side of this philosophical debate, the side that claims spacetime is an actual substance separate from concrete physical objects. Newton actually first writes on the nature of space and time prior to his *magnum opus* (i.e. the *PNPM*) in a work called *De Gravitatione* (the exact date of this work is unknown, but scholars suspect it was written before 1685). *De Grav* (short for *De Gravitatione*) is not published during Newton's lifetime, but it is discovered after Newton's death and the piece is published posthumously. *De Grav* and the *PNPM* together are the main textual sources for Newton's thought on the nature of space and time.[7]

Newton's view, although correctly labeled I argue as Substantivalism, is actually quite subtle and nuanced. In fact, in the *PNPM* and *De Grav* Newton actually purposefully chooses *not* to define space. At the beginning of *De Grav* Newton writes, "The terms 'quantity',

---

[5] One example of this which will be discussed later is Newton's infamous Bucket Experiment.

[6] However, it should be noted that there is some contention about exactly what the nature of his project is, and whether or not one is retroactively attributing contemporary understandings of absolute spacetime onto Newton's original position. For more on this debate one should seen Howard Stein (1967), Andrew Janiak (2008), and Mary Domski (2010). For the sake of this work I'm going to go with the assumption that Newton did in fact hold something similar to modern Substantivalism.

[7] For copies of both the *PNPM* and *De Grav* see Newton (2004).

'duration', and 'space' are too well known to be susceptible of definition by other words" (Newton 12). In the *PNPM* Newton writes further:

> ...[I]f the meanings of words are to be defined by usage, then it is these sensible measures which should properly be understood by the terms 'time', 'space', 'place', and 'motion', and the manner of expression will be out of the ordinary and purely mathematical if the quantities being measured are understood here. Accordingly those who there interpret these words as referring to the quantities being measured do violence to the Scriptures. And they no less corrupt mathematics and philosophy who confuse true quantities with their relations and common measures. (69)

However, though Newton refuses to explicitly define these terms like "space," there is certainly sufficient textual evidence to suggest the way in which Newton understood these terms implicitly. For example, in Newton's earlier work, *De Grav*, he makes several comments which seem to suggest the way he thinks of space. He writes, "...I suppose in these definitions that space is distinct from body, and...I determine that [absolute] motion is with respect to the parts of that space, and not with respect to the position of neighboring bodies" (14). Moreover, in the *PNPM* Newton writes, "Absolute, true, and mathematical time, in and of itself and its own nature, without reference to anything external, flows uniformly and by another name is called duration.... Absolute space, of its own nature without reference to anything external, always remains homogeneous and immovable" (64). These comments are prime examples of the way Newton understands the concept of space. These comments demonstrate that for Newton, space and time are independent *things* which exist in addition to concrete objects and, as later writers like Lawrence Sklar (1976) will go on to assert, one can correctly understand space in the Newtonian picture as a kind of container for concrete objects. In fact Sklar will go on to call this kind of Substantivalism, Traditional or Container Substantivalism. Newton, throughout his career, consistently treats space as an entity in its own right; space for Newton is an entity which does not depend on concrete objects for its existence.

Nevertheless, one would be remiss to ignore the subtle nuances that exist in Newton's system, and the complex motivations which were present in Newton's mind. As scholars like Barry Dainton (2001) have noted, Newton's overall system is motivated by many esoteric concerns. John Maynard Keynes (1956) famously dubbed Newton "the last of the magicians" (Keynes 311) due to the extent to which Newton's belief in mystical and esoteric things, particularly in relation to God, affected his works.[8] In fact, as Julian Barbour notes, "Newton is explicitly seeking to demonstrate, through phenomena [in the *PNPM*], the transcendent basis of all motion. But he aims even higher; the boy from Grantham has set his eye on the *anatomy of God*" (Barbour 628). The physical universe for Newton is God's sensorium, and thus all of his work on spacetime is for him intimately connected to his thinking on God and existence in general.

For example, in Newton's nuanced, and ultimately mystical system, it should be noted that Newton seems to *explicitly* state in *De Grav* that he does *not* consider space to be a substance, properly so-called. This nuance of the Newtonian system seems to fly directly in the face of the modern labeling of Newton as a Substantivalist. In *De Grav* he writes:

> Perhaps now it may be expected that I should define extension as substance, or accident, or else nothing at all. But by no means, for it has its own manner of existing which is proper to it and which fits neither substances nor accidents. It is not substance: on the one hand, because it is not absolute in itself, but is as it were an emanative effect of God and an affection of every kind of being; on the other hand, because it is not among the proper affections that denote substance, namely actions, such as thoughts in the mind and motions in the body. For although philosophers do not define substance as an entity that can act upon things, yet everyone,

[8] The so-called Philosopher's Stone is one good example of Newton's subversive and esoteric interests.

> tacitly understands this of substances, as follows from the fact that they would readily allow extension to be substance in the manner of body if only it were capable of motion and of sharing in the actions of body. (Newton 21)

This passage is quite obviously problematic for those who wish to understand Newton as a Substantivalist, and goes a long way in showing just how nuanced Newton's view is. It is certainly not immediately clear how one should reconcile this explicit statement of Newton's with his other statements in *De Grav* and the *PNPM* which seem to indicate Newton's belief in Traditional Substantivalism. The definition of a substance Newton seems to be utilizing in the above quotation is that a substance, properly so-called, must be capable of both independent existence and the exhibiting of causal powers. Presumably space does neither on Newton's view as it, first, depends on God for its existence and, second, seems to have no causal interactions with other objects. For the former fact, if God never existed, Newton is claiming, neither would space. For the latter fact, space seems never to *do* anything, it is action-less and consequently devoid of causal powers--at least in Newton's day.[9] As a result, Newton concludes, it does not deserve the exacting title of substance.[10]

Even so, this strict understanding of a substance seems somewhat stringent when compared with contemporary understandings of substance. Under the strict understanding of substance that Newton is employing it seems like hardly *anything* would qualify as such, but God himself ! However, one of course need not understand the definition of a substance in such a strict manner. Instead one could choose to understand a substance in a much more conventional sense, like a thing which grounds properties *á la* Locke, or as a thing which doesn't

[9] As I will argue in later chapters the Post-Einsteinian view has it that space actually does have causal powers.
[10] The same goes for time on Newton's position.

depend on other particular *material* objects besides itself.[11] Indeed, one can choose to understand space simply as a substance insofar as its existence does not depend on concrete, material objects, and in fact most contemporary philosophers in the spacetime debate tend to understand substance as such. As such, it seems we can understand Substantivalism as a position which merely maintains that spacetime does not depend on material objects for its existence. Thus, even though it seems like Newton explicitly states that space isn't a substance, it still seems as if he can appropriately be placed in the group of Substantivalists as contemporary philosophers which understand the thesis as follows: that space exists independently of material objects and their relations. Newton most certainly seems to agree with that statement, even if he doesn't hold that space is a *true* substance as he regards it. [12]

Moreover, even if causal powers were to be important for a substance as Newton suggests, in principle this criterion can be met by appealing to Albert Einstein's Theory of General Relativity (1916).[13] Under at least some interpretations of Einstein's Theory of General Relativity spacetime acts in causal manner. For example, if one defines causation in terms of counterfactual dependence then spacetime does exhibit causation, as specific properties of geodesics traveled by free particles counterfactually depend on spatial properties. Accordingly, even though Newton does explicitly deny space (or spacetime) as a true substance this issue is

[11] In this latter option the existence of non-material things like God do not come into play, something exists as a substance as long as it doesn't depend on other material things for its existence.

[12] It is of worth to note that R. Torretti (1999) argues that Newton actually introduces a novel ontological category with his concept of spacetime, a relational order that exists independent of concrete material objects but which the identity conditions of its parts (i. e. places) are constituted exclusively by relations the parts bear to each other.

[13] I say in principle here because although one *can* interpret Einstein's General Relativity as ascribing causal powers to spacetime, one doesn't *have* to interpret Einstein's work this way. There are perfectly consistent interpretations of General Relativity which do not ascribe causal powers to spacetime. One could understand the relationship between matter and spacetime in General Relativity as merely a dynamic relationship, and not a causal one. It would be interesting to know what Newton would have made of General Relativity's potential attribution of causal powers to spacetime, as he explicitly denies that spacetime has causal powers, but perhaps if he had been appraised of General Relativity it may have affected the way he looks at spacetime and its potential substancehood.

quite readily resolved by folding causal powers into the nature of spacetime (*via* Einstein's Theory of General Relativity), and by using a weaker interpretation of the term "substance."

When a modern Substantivalist employs the term "substance" with regard to spacetime he or she typically means spacetime is a substance insofar as it is something above and beyond the material concrete objects found within spacetime, and that spacetime itself is not merely a relation of those concrete material objects. It is this weaker notion of spacetime which may or may not exhibit causal powers and enjoys independent existence from the material concrete objects which most modern Substantivalists use to count Newton as one of their ranks.[14] Thus, one can--correctly--understand Newton as belonging in this camp of Substantivalists. As Sklar writes, "Nonetheless, the 'substantivality' of the position is clear enough in that the claim is made that the temporal instants and their structure would exist whether events occurred at any of these instants or not." (Sklar 162). The members of this ideological camp hold that spacetime exists completely independent of the material concrete objects that exist within it. It is not *merely* in virtue of the relations between existent concrete material objects that spacetime exists; a direct denial of the traditional thesis held by Relationalists, which is the opposing side of the spacetime debate.

Historically, Gottfried Wilhelm Leibniz is perhaps one of the best examples of the contrary position of Relationalism in the spacetime debate. Leibniz generated a plethora of philosophical and mathematical writings during his lifetime, and while the entirety of his writings is extensive perhaps the best examples of his adherence to the Relationalist thesis is evidenced in what has become known as the *Leibniz-Clarke Correspondence.* In this now

[14] Again, when I say Newton would count as this kind of Substantivalist, I mean he would accept spacetime as a substance if he were using the more modern, and weaker, understanding of a substance as something which merely exists independently of concrete material objects and which may or may not exhibit causal powers.

infamous correspondence Leibniz debated one of Newton's ardent followers, Samuel Clarke, through a series of letters about the subject of spacetime's ontological status, among other things. It is in this correspondence one can find some key examples of Leibniz's position of Relationalism. He writes that:

> ...I hold space to be something merely relative, as time is.... I have many demonstrations, to confute the fancy of those who take space to be a substance, or at least an absolute being. But I shall only use, at the present, one demonstration, which the author here gives me occasion to insist upon. I say then, that if space was an absolute being, there would something happen for which it would be impossible there should be a sufficient reason. Which is against my axiom. And I prove it thus. Space is something absolutely uniform; and, without the things placed in it, one point of space does not absolutely differ in any respect whatsoever from another point of space. Now from hence it follows, (supposing space to be something in itself, besides the order of bodies among themselves,) that 'tis impossible there should be a reason, why God, preserving the same situations of bodies among themselves, should have placed them in space after one certain particular manner, and not otherwise; why every thing was not placed the quite contrary way, for instance, by changing East into West. But if space is nothing else, but that order or relation; and is nothing at all without bodies, but the possibility of placing them; then those two states, the one such as it now is, the other supposed to be the quite contrary way, would not at all differ from one another. Their difference therefore is only to be found in our chimerical supposition of the reality of space in itself. (Leibniz 146-147)

First, it's worthwhile to point out that Leibniz's position here, while certainly indicative of the Relationalist position as a whole would, nevertheless, encounter at least two problems if offered today as a novel argument for the position of Relationalism. Leibniz's appeal to the Principle of Sufficient Reason would alone be enough to complicate things, as modern quantum mechanics is generally understood to offer direct challenge to this principal--or at least the Copenhagen Interpretation of it.

In the early 20th Century the emergence of quantum mechanics began to directly challenge this principle. Instead of supporting the Principle of Sufficient Reason (or PSR), a principle which has an extensive list of philosophical support, the new science of quantum mechanics placed a great deal of stress on PSR. Indeed modern quantum mechanics (with the exception of Bohmian interpretations of quantum mechanics) seem to suggest that there really are genuine instances of causation in our world where certain events occur *not* as the result of a sufficient cause, but instead as a result of a probabilistic cause.[15] This divergence from the traditional Principle of Sufficient Reason would be the first point of contestation Leibniz's argument would encounter in today's philosophical environment. Secondly, Leibniz's above proof would also encounter opposition with the claim that space requires uniformity. Although space could be absolutely uniform, in today's philosophical environment, it is generally acknowledged that with the emergence of Non-Euclidean Geometries such as Riemannian Geometry and Bolyai-Lobachevsky Geometry that it is no longer necessary that space *must* be uniform. That is to say, given certain developments in mathematics and geometry in the past century it at least seems possible that space may not be uniform (*i.e.* that its metric could be different at different places).[16]

---

[15] Even the infamous Copenhagen Interpretation, which allows sufficient causation to apply to the wave function as long as the Schrödinger Equation applies, has it that when wave collapse occurs causation becomes probabilistic.

[16] For example, Henri Poincare (1952) provides examples in which space has different metrics at different places without an appeal to physical objects. That is to say, the nature of spacetime is such that it just naturally has one kind of metric in one section, and an entirely different metric in a different section. The result is that it at least seems conceivable that spacetime not be uniform. Indeed Poincare makes arguments to the effect that for all we know space is *not* uniform; for all we know the rigid rods we use to measure space may shrink as we move into new parts of space to measure. If such were the case, in principle, there is no empirical way in which an observer could determine that his or her geometrical space was uniform or not. Indeed, this kind of argument is used by Poincare to argue for a kind of geometrical conventionalism. For more on this subject one should see Hans Reichenbach (1958), Richard Swinburne (1968), and Sklar (1976).

Nevertheless, despite these particular problems with Leibniz's above "proof" of Relationalism, it is hopefully evident that the position of Relationalism, which holds the thesis that space is not a substance but rather is *merely* the set of relational properties of other existing substances (*i.e.* concrete material objects), is certainly possible. That is to say, although Leibniz's above proof may not be the best argument for this particular thesis, the thesis of Relationalism is nonetheless consistent with the modern treatment of spacetime by physicists. The thesis of Relationalism entails that there exists no *independent* substance called space or spacetime, but rather that what we know of as space is merely the collection of certain relational properties that existing entities have with respect to one another.

Another example, a better example, of a Relationalist argument Leibniz employs against Substantivalism is the Static Shift Argument. In the famous correspondence Leibniz has with the Newtonian disciple Alexander Clarke, Leibniz elucidates this kind of thought experiment. Leibniz writes:

> To suppose two things indiscernible, is to suppose the same thing under two names. And therefore to suppose that the universe could have had at first another position of time and place, than that which it actually had; and yet that all the parts of the universe should have had the same situation among themselves, as that which they actually had; such a supposition, I say, is an impossible fiction. (Leibniz 37)

In this passage Leibniz draws attention to his famous Principle of the Identity of Indiscernibles (or PII). PII is the philosophical principle that if two entities share every discernible property in common, then the two things must in fact actually be the *same* thing.[17] This principle of Leibniz's allows for the formulation of a rather strong argument for Relationalism. In this

[17] I realize I'm being a tab bit sloppy here, PII could also stand for the Principle of the Indiscernability of Identicals, the converse of the above: $x=y \rightarrow \forall P\,(Px \leftrightarrow Py)$. Unless otherwise noted, please understand me to be referring to the former and not the latter when I say "PII."

argument Leibniz asks the Substantivalist to imagine a static shift of the universe, a hypothetical universe where every single object is moved exactly, let's say, one meter to the right. This hypothetical universe is empirically *indistinguishable* from the current universe, but on the view of the Substantivalist this hypothetical universe must be a distinct universe from our own. Using PII it follows that the two must in fact be the same universe, and thus Substantivalism, which would need to maintain that these two hypothetical universes are actually distinct, is false. Under Leibniz's view of Relationalism, there is no discernible difference between these two hypothetical universes and as such there is no problem in maintaining that they are in fact the *same* universe.[18]

Accordingly, the position of Relationalism maintains that things like space, or spacetime, are merely relational properties which are exhibited by concrete material objects. [19] Following Leibniz, the next major historical proponent of Relationalism which advances the overall spacetime debate is Ernst Mach (1960), a philosopher who went on to have a considerable influence on none other than Albert Einstein and his ground-breaking theories of relativity (1905 and 1916, special and general respectively). [20] Mach's overall persuasion is one of an extreme

[18] Leibniz also has a similar argument which utilizes PII and what's known as a dynamic shift. The Dynamic Shift Argument is virtually identical to the Static Shift Argument except instead of the second universe being moved a static amount the second universe is imagined to be moving at some kind of uniform velocity which the initial one isn't. The end result is that, again, there is no discernible difference between these two universes, but nonetheless the Substantivalist must maintain they are in fact distinct universes.

[19] It is worth noting that even though my discussion of the original Relationalist position is best represented by Leibniz, there are in fact several other historically notable individuals which also maintained this thesis of Relationalism. For example, George Berkeley (1992) espouses a severe critique of Newton's position in his text *De Motu*, and he is a prime example of the Relationalist position in addition to Leibniz.

[20] Although it should be noted however, as I will go on to assert, that as time went on, Mach's philosophy seems to have less and less of an impact on Einstein's thinking. Indeed, by the publication of his Theory of General Relativity in 1916 Einstein seems to have developed many notions quite contrary to Mach's earlier positivistic philosophy.

positivist, much like that of the later Rudolf Carnap.[21] He criticizes Newton, and indeed the entire Substantivalist position, for positing an entity that is not only unsupported by empirical evidence, but is *in principle* unobservable.

For Mach, an early positivist, any theory which purports to describe entities which have no empirical evidence supporting them is simply ungrounded, and should be rejected as a consequence. He writes:

> It is scarcely necessary to remark that ... Newton has again acted contrary to his expressed intention only to investigate *actual facts*. No one is competent to predicate things about absolute space and absolute motion; they are pure things of thought, pure mental constructs, that cannot be produced in experience. All our principles of mechanics are, as we have shown in detail, experimental knowledge concerning the relative positions and motions of bodies.... No one is warranted in extending these principles beyond the boundaries of experience. In fact, such an extension is meaningless, as no one possesses the requisite knowledge to make use of it. (Mach 279)

Now, it is consistent with what Mach says here that he is only remaining agnostic about the epistemological status of entities like absolute motion and absolute space. That is to say, one does not have to read Mach here as denying the ontological status of these things. Indeed, Mach's own words, "No one is competent to predicate things about absolute space and absolute motion ..." (279), seem to imply that no one is competent to predicate anything about such entities whether for or against their existence. However, historically Mach is typically understood as a "card-carrying" Relationalist, which is not just to say that Mach thinks no one is justified in making claims about the existence of absolute motion and space based on empirical evidence, but that he is saying something much, much stronger about the nature of motion and

[21] Indeed, as Thomas Uebel (2014) asserts, Mach can be considered one of the "fathers" of the Vienna Circle and the overall philosophical movement of Logical Positivism, and of course Logical Positivism is one of the defining philosophical movements of the early 20th Century.

space. That is to say, traditionally most scholars interpret Mach to be making the stronger claim that absolute motion and absolute space are not only unjustifiable from an empirical standpoint, but that moreover they do not exist. Hence, it is reasonable to conclude that it is much more likely that, by those words above, Mach means such things are fictions, and both motion and space are only intelligible as relative notions.

Throughout Mach's writings on the spacetime debate there is one particular point which I feel demands a closer examination. Historically, the so-called Bucket Experiment found in Newton's *PNPM* has been taken as an argument for the existence of absolute motion and absolute space based upon the observation of what are called *inertial* effects.[22] An inertial frame of reference is one in which Newton's first law of motion is valid.[23] Inertial effects are those effects that are observed when an object undergoes certain "forces" when the object is in or on a frame of reference which is accelerating.[24] In Newton's *magnum opus The PNPM* he includes a rather interesting thought experiment involving a stationary bucket of water, which is suspended by a rope and the rope is twisted such that, when released, the bucket will start spinning around in the opposite direction the rope was twisted. As anyone who wishes to carry out this simple experiment will soon discover, the bucket isn't moving anywhere, it is simply rotating, *but* the water inside the bucket will start to climb the walls of the bucket. A centrifugal "force" pushes the water up the sides of the bucket, and traditionally many later physicists, like

---

[22] For present purposes I'm assuming the historical reading of Newton's infamous bucket experiment which says that the bucket experiment in *PNPM* is a thought experiment designed by Newton to demonstrate observable inertial effects which in turn suggest the existence of absolute motion and absolute space. However, it should be noted that many scholars, like Robert Rynasiewicz (2014) for example, now contend with this traditional understanding of Newton's work. In fact, if Rynasiewicz is to be believed, the infamous bucket experiment is not aimed at proving the existence of absolute motion and absolute space via inertial effects, but is rather a thought experiment directly aimed at Descartes's system of physics.

[23] Newton's First Law of Motion is simply that an object at rest tends to stay at rest, and likewise an object in motion tends to stay in motion at the same velocity and direction, unless it is acted upon by an unbalanced force.

[24] I put "forces" in quotation marks because most physicists do not consider inertial forces true "forces."

Mach, took this experiment to be Newton's attempt at arguing for the existence of absolute motion and absolute space based on these kinds of inertial effects.[25] Mach takes Newton to be arguing for absolute space because we see the water rising up the walls of the bucket. When the rotational motion of the bucket begins the water is observed to be completely flat, as it was when the bucket was still. However, after some time has elapsed the water begins to take on a concave shape, which seems to be an indication that the water has acquired rotational motion. The water has *not* moved relative to the bucket, and so--the assumption goes-- only motion with respect to absolute space can explain why the water has acquired this rotational motion and the concave surface. At least, this interpretation seems to be the one Mach lends to Newton's famous bucket experiment.

In response to this bucket experiment and his reading of it Mach argues that it provides absolutely no empirical grounds for believing in either absolute space or absolute motion.[26] For Mach there is *only* relative motion, and thus inertial effects must be explainable in terms of change in motion relative to *something*. Mach suggests that the inertial effects observed in the bucket experiment could be understood in terms of its motion relative to the distant stars.[27] However, even though Mach does provide a possibility for what it is that is causing these inertial effects, movement with respect to the center of mass in the universe, he fails at providing any consistent account of the various laws of nature and mechanics which are involved in creating these inertial effects. Mach is simply asserting that inertial effects are not good grounds for

[25] As I noted previously, there is serious scholarly doubt as to whether this is what Newton hoped to accomplish by including this infamous bucket experiment. Regardless however, even if Newton did not intend to include this argument from inertial effects as an argument for the existence of absolute motion and absolute space, it can be taken as such, and most definitely this way is how Mach read Newton's thought experiment.

[26] It is worth noting that Mach's critique of Newton here is somewhat reminiscent of Berkeley (1992) and his earlier critique of Newton's project in *De Motu*.

[27] Or, as Mach later argues, perhaps the motion could be thought of as relative to the mean center of matter in the universe (wherever that may be).

positing absolute space because we can in fact find something with respect to which the entities in question are moving. Yet, as John Earman (1989) notes this idea is somewhat bizarre sounding on the face of it, "Think about it for a moment. Would you seriously entertain the possibility that the reason you get seasick is due to your motion relative to the stars? Is this notion any more plausible than astrology?" (Earman 211). Nevertheless, despite this somewhat counter-intuitive aspect of Mach's view his view does go on to have a considerable impact on the spacetime debate.[28] First, his challenge to the inertial effects arguments of Substantivalists goes on to have a considerable impact on later thinkers like Sklar (1976) and Huggett (1999). Second, and perhaps more importantly, his work goes on to have a considerable influence on Einstein and his development of Special and General Relativity.

The development of relativistic physics by Einstein changed not only the scientific world as we know it, but it also changed the course of the spacetime debate--and the effect that Mach's empirical and relativistic philosophy had on Einstein is considerable.[29] As Sklar notes:

> [Einstein's] basic chain of reasoning [goes] like this: As far as *local* observation can tell, the mechanical effects of gravitation are indiscriminable from the inertial effects resulting from using an accelerated system in which to perform one's measurements in the absence of a gravitational field. Let us conjecture that this local equivalence of gravity with accelerated coordinate systems holds for all phenomena, not just mechanical phenomena. This will give us, as a result, a theory of the action of gravitation on light, and further, since special relativity convinces us that putting a coordinate system into motion changes the spatiotemporal features of the world as determined by an observer fixed in that system, this will also convince us that gravitation affects the spacetime structure of the world as well. (Sklar 211)

[28] Also, Julian Barbour and Bruno Bertotti (1977, 1982) have tried to go back and strengthen Mach's position by eliminating some of the vagueness the initial position has. Nevertheless, even despite the work that has been done here it is still debatable as to whether the position is, at the end of the day, viable or not. For a nice review of this subject see Gordon Belot (2000).

[29] It should be noted however that Mach is certainly not the only person to have a noticeable effect on Einstein. The writings of Poincare (1952) and Immanuel Kant (1998) were also important to Einstein and his development of both Special and General Relativity.

Following Einstein's Theory of General Relativity in 1916 the spacetime debate undergoes several noteworthy changes. For example, it is Einstein's use of Minkowski spacetime in his coordinate systems which eventually works to combine the two previously separate ideas of space and time into one single entity: spacetime. Another example is found in his use of non-Euclidean Geometries. His use of non-Euclidean Geometries opens the door for the use of these in Substantivalist theses; no longer must a Substantivalist consider spacetime as necessarily Euclidean in structure.

However, one of the most important aspects of Einstein's work is his abandonment of the Maxwellian aether and the replacement of this idea with a "relativistic aether." The "relativistic aether" being spacetime coordinate systems which not only affect the geodesic paths of matter, but also enjoy an inter-connected causal structure between the spacetime coordinate structures and the matter/energy density of a volume.[30] Indeed, Einstein historian Ludwik Kostro (2000) writes that:

> It is worth considering whether his concept of a relativistic ether has survived down to the present time. Our answer to this question must be positive, although the term 'new ether' itself was--for a long time--almost forgotten in the community of scientists. However, the idea of a space-time continuum with a metric (or even richer) structure, with physical properties, actively participating in physical processes and having a certain density or distribution of energy (that is, materiality of a special kind) treated as a field, has survived.... The belief that the so called 'vacuum' has a structure of its own, that it actively participates in physical processes, and that it is not empty, has become a part of physics for good. (Kostro 153)

[30] I recognize the use of "causal" here is somewhat problematic, and as such one can understand this use of causal as simply meaning a dynamical structure.

Now granted, it is far from obvious that General Relativity *requires* Substantivalism; certainly that is not the case, but it is fair to say that Einstein at least, towards the end of his career, seems to have moved from an initially Machian perspective to one that is much more Substantivalist. Hence the term "new ether" that Kostro shows Einstein used on a number of occasions in his later years.[31] Yet, hopefully one sees from my discussion here the kind of Substantivalism that seems to be favored by the late Einstein is *drastically* different from that envisioned by Newton. Newton saw absolute space and time as static and Euclidean, and Einstein's variety of spacetime, if it is to be understood as Substantivalist, is much more dynamic and non-Euclidean. In the kind of Substantivalism Kostro suggests the later Einstein held there is a dynamical core, which is completely absent in the "classic," or Newtonian, variety of Substantivalism.

Since the days of Einstein the spacetime debate has undergone still more significant changes. In an attempt to summarize the major changes in the spacetime debate which occurred in the first half of the 20th Century, Hans Reichenbach (1958) writes a very thorough review of the spacetime debate, geometrical epistemology, and the post-relativistic world of physics. As Reichenbach describes it, one can conceive of "geometry [simply] as a theory of relations," (Reichenbach 103) and as such it is perfectly possible for one to conceive of a geometrization of spacetime, even the one which Einstein's physics suggests, merely as a very unique description of dynamics between certain relations. If such was the case Einstein's Relativity Theory is not as a literal description of reality, just a consistent mathematical formalism which can correctly predict phenomena. The replacement of Newton's physics by Einstein's does not solve the spacetime debate.

[31] Although again I would like to state that there certainly is a consistent Relationalist interpretation of General Relativity to be had; all I am suggesting here is that the later Einstein most likely favored a Substantivalist approach, and that he forever changed this thesis by showing novel ways it could be understood.

Building on the work of Reichenbach (1958) and Richard Swinburne (1968), Sklar's work (1976) skillfully defines and structures the modern understanding of the spacetime debate in philosophy and physics, and advances a new tactic to combat inertial effect arguments from Substantivalists. Sklar argues that with inertial arguments like the Bucket Experiment which insist that understanding effects, like why the water in the bucket gains a concave shape even though it is not accelerating with respect to the bucket, make a mistaken assumption. The Bucket Argument has it that to explain the inertial effects on the water, the water has to be accelerating with respect to *something*. Newton would claim the inertial effects occur when the water is accelerating with respect to absolute space, while Mach would insist that the inertial effects occur when the water is accelerating with respect to the stars. However, Sklar questions that very assumption. Sklar argues that the Relationalist can simply abandon this assumption that the water has to be accelerating with respect to something in order to explain the inertial effects it undergoes. As Dainton (2001) explains it, Sklar is suggesting that one can posit "a primitive monadic property that bodies on some trajectories possess, which comes in different quantities, and inertial effects are associated with the possession of this property" (Dainton 179-180).[32] In addition to furthering the Relationalist position, it is this work by Sklar which also best lays out the chief concerns raised by the classical debate between Newton and Leibniz, the changes raised by Einstein's relativistic physics, the concerns about the epistemology of geometry raised by Poincare (1952) and Reichenbach (1958), and the current major players in the spacetime debate. Almost unanimously contemporary scholars start with this influential work of Sklar's when they try to familiarize themselves with the modern spacetime debate.

[32] Nick Huggett (1999) also suggests an alternative to this traditional understanding of inertial effects. Once one starts plotting time and space world lines are created, straight ones if the object has a constant velocity and curved if they do not. He suggests that inertial effects can be understood as the forces experienced by an object with a curved world line (see pg. 193).

iii. History of the Hole Argument

Following Sklar's important modern primer on the subject however, there has been a major development on the Relationalist side of the debate: the Hole Argument.[33] Ironically, the Hole Argument was advanced originally by Einstein during his initial work on the Theory of General Relativity, but was later discarded by Einstein and subsequently wasn't noticed for its importance to the spacetime debate until many years later.[34] The Hole Argument, revived by John Earman and John Norton (1987), is an argument which is quite reminiscent of Leibniz's Static and Dynamic Shift Arguments against Substantivalism, as well as Poincare's arguments for geometrical conventionalism.[35] The argument is succinctly described by John Norton (2015) as follows:

> 1. If one has two distributions of metric and matter fields related by a hole transformation, manifold [S]ubstantivalists must maintain that the two systems represent two distinct physical systems.
> 2. This physical distinctness transcends both observation and the determining power of the theory since:
>   - The two distributions are observationally identical.
>   - The laws of the theory cannot pick between the two developments of the fields into the hole.
> 3. Therefore the manifold substantivalist advocates an unwarranted bloating of our physical ontology and the doctrine should be discarded. (Norton 12-13)

[33] An in-depth analysis of this problem and its possible responses will be covered in more detail in a later chapter, what follows is merely a cursory explanation of the issue and how it fits into the overall debate.

[34] The Hole Argument emerged in the works of Einstein and M. Grossmann (1913), and then was later revived by Earman and Norton (1987). Although, it should be noted that it was really John Stachel in 1980 who first noticed the significance of this argument with respect to the spacetime debate at a talk in Jena (for a copy of this talk see Stachel (1989)). I say this development is quite ironic insofar as the Hole Argument is utilized in the contemporary literature as an advancement of the Relationalist theory, but the originator of this argument, Einstein, is more correctly classified as a Substantivalist according to historians like Kostro (2000).

[35] Leibniz's two arguments have already been discussed sufficiently in this paper, and unfortunately Poincare's arguments are too subtle and complicated to go into detail here, but if one is interested in this subject he or she should see Poincare (1952). However, I will come back to this point of the similarity between Leibnizian Shifts and the Hole Argument later in Chapter V.

As the Hole Argument states, modern spacetime theories have the possibility for quite a bit of what is called gauge freedom. In Einstein's General Relativity a physical system has, among other things, a metric which acts as a function determining the distances between elements in the system, and it turns out it is rather arbitrary which metric one decides to use as long as one stays consistent. What this amounts to is that it is possible to take a subregion of a region and alter some of its covariant properties, like say the metric of that subregion, such that empirically the change is not discernible to an observer. A property is covariant just in case it is a function of the coefficients and variables of another function that is invariant under linear transformations, except for a factor equal to a power of the determinant of the transformation. Covariance is the measurement of how two, or more, variables change together, and utilizing this kind of property it's possible to translate a physical system from one frame of reference to another without altering the relative relationships within the system. When one physical system, at a given coordinate set, is translated to a completely different coordinate set this translation is called a Galilean Transformation. Likewise, when a physical system is translated from one person's frame of reference to another person's frame of reference this is usually called a Lorentz Transformation.[36]

Since the metric of a physical system is a somewhat arbitrary covariant property it is possible to have one spacetime region with a given metric, and a subregion which has some covariant property like the metric altered. From the perspective of an observer, the observer will not be able to empirically differentiate between the spacetime region as it originally was and the one that contains a subregion with a different metric. The result is that empirically the two corresponding regions of spacetime are indistinguishable, but the serious Substantivalist has to

[36] A Lorentz Transformation can be thought of as a Galilean Transformation that takes into account Einstein's Special Relativity and how different frames of reference can affect things like time and length as well as electromagnetic properties.

maintain the two spacetime regions are in fact distinct; after all, one possesses a completely different metric than the corresponding region. Now, there are various ways in which Substantivalists can respond to this argument, but regardless the Hole Argument has considerably strengthened the Relationalist position in the wake of Sklar's primer on the debate and it is certainly something any serious modern Substantivalist will need address.[37] Nevertheless, the camp of Substantivalism hasn't been entirely inert in the past few decades either.[38]

iv. History of Supersubstantivalism

On a final point about the general debate itself however, it should be noted that even though both Sklar (1976) and Dainton (2001) describe the modern spacetime debate as having three main positions, heretofore the historical discussion has been restricted to just the two positions of Substantivalism and Relationalism. As both philosophers note, there is a third position in the spacetime debate called Supersubstantivalism.[39] Where Relationalism is the view that only concrete material objects exist and spacetime is merely the collection of the spatial and temporal relations enjoyed by those objects, and Substantivalism is the thesis that both material objects and spacetime exist as real ontological entities, Supersubstantivalism is the position that only spacetime exists and concrete material objects are merely collections of various properties

[37] For examples of Substantivalist responses to the Hole Argument see Carl Hoeffer (1996), Carolyn Brighouse (1994), and Tim Maudlin (1990). Another way of fixing this problem is to argue for gauge invariance, Luca Lusanna and Massimo Pauri (2006) is an example of this kind of argument.

[38] I will not be going into detail about these various examples of modern Substantivalists as I don't think doing so will contribute significantly to my position. However, I would like to point out that there are examples of this position out there, and as such the debate is still very much alive in today's philosophical community. For examples of Substantivalists in contemporary philosophical literature one can see such works as Robert DiSalle (1995), which offers novel arguments for the position of spacetime Substantivalism.

[39] Sklar does tend to refer to this thesis of Supersubstantivalism, but others like Michael Esfeld and Vincent Lam (2006) refer to it as Cartesian-Spinozan Substantivalism. I will consistently refer to this thesis just as Supersubstantivalism.

of impenetrability and the like possessed by particular regions of spacetime. Some, like Dennis Lehmkuhl (2009), argue that the position of Supersubstantivalism may go as far back as Plato (1997), but regardless it certainly can be seen in philosophers like Descartes (1984), and Baruch Spinoza (2002) in the Modern Period.[40]

Supersubstantivalism, I assert, is a greatly neglected position in the spacetime debate (only recently has the subject received any significant attention at all), and as I argue that it is ultimately the best answer in this debate I will now turn my attention to fully explicating this underappreciated position. Supersubstantivalism is a species of Substantivalism in that it, like Traditional or Container Substantivalism, holds that spacetime exists independent of any and all material objects and their properties. However, Supersubstantivalism insists that material objects do not exist independent of spacetime. The thesis of Supersubstantivalism states that spacetime alone exists as an independent substance, and all material objects are exhaustively reducible to regions of spacetime and certain properties which inhere in the substance of spacetime. One can view this position as being on the opposite end of the spectrum from Relationalism. Relationalism, one end of the spectrum of what exists, holds that only material objects exist as independent substances, and spacetime is not any kind of substance capable of remaining in the absence of material objects. Traditional Substantivalism, which is in the middle of this spectrum, claims that both material objects and spacetime exist as independent entities, neither of which is ontologically dependent on the other. Supersubstantivalism, being located on the other extreme of this spectrum, has it that only spacetime exists as an independently existing substance.

[40] Some scholars, such as Bradford Skow (2005) even argue that Newton fits in this camp, though I for one have reservations about making such a claim, and I think many others would likewise dispute this point. I also have strong doubts about whether Plato belongs in this list either.

Yet, Supersubstantivalism is not a monolithic position, it is itself composed of several different varieties. For example, Jonathan Schaffer (2009) distinguishes between three main varieties of the position which disagree about the status of material objects: the identity view which has it that material objects are identical to regions of spacetime, "spacetime regions can play the main role of material objects, in serving as the pincushions for properties" (Schaffer 133); the eliminative view which outright denies the existence of material objects; and the constitution view which holds that material objects are constituted by, but not identical to, regions of spacetime.

Moreover, Supersubstantivalist species are also sometimes demarcated based on the nature of the physical properties which subsist in, or are "pinned" to, the substance of spacetime. One species, Radical Supersubstantivalism, is first explicitly suggested by Samuel Alexander (1920) who argues that not only can all material objects be exhaustively reduced to regions of spacetime and their respective properties, but that all those respective properties which adhere in spacetime can be exhaustively reduced to geometric properties about its metric, structure, and the motion of observed phenomena. This species of Supersubstantivalism is further developed by the work of Einstein (1952) as he reduces gravity from a force that pushes and pulls to a geometrical warping of spacetime geodesics, but it sees far greater formalization with the work of John Wheeler (1962).[41] Although Wheeler's particular formulation of Radical Supersubstantivalism was ground breaking, it eventually ran into difficulties about how all

[41] I should be clear on this point however, while Wheeler, who is certainly a proponent of Supersubstantivalism, sees Einstein as beginning this process of the geometrization of physics it is not obvious that Einstein would have placed himself in this camp of Supersubstantivalism, though that is certainly possible. I am not however claiming that Einstein was, in fact, a Supersubstantivalist, although that certainly seems possible.

physical properties could be understood entirely in terms of geometry.[42] However, though their particular formulation of Radical Supersubstantivalism, which Wheeler called Geometrodynamics, was ultimately abandoned, other formulations of Radical Supersubstantivalism are still advanced and discussed in the field today.[43]

On the other hand, what is called Modest Supersubstantivalism puts forward that the various properties, which are not all reducible to geometrical properties, simply reside directly in the various respective spacetime regions. So, for example, under this view of Supersubstantivalism a material object may be reduced to a spacetime region which contains properties like impenetrability, quantum spin, and electrical charge that are pinned directly to this region in that the properties are held in this region in that the properties are located here and have no further reducible explanations. Descartes's (1984) view of spacetime is this kind of Supersubstantivalism, these regions of extension possess these irreducible properties and these regions and their properties are identical to the material objects which are found there. Spinoza (2002) also fits into this category of Modest Supersubstantivalism. Indeed, most proponents of Supersubstantivalism historically have fallen into this version of Supersubstantivalism, as the Radical version did not emerge until the work of Alexander (1920).

Supersubstantivalism thus appears in numerous forms and varieties in scholarship, and while I will not argue for any one particular version of this thesis, I will argue that the overall position is so promising that it deserves much more focus and attention as I believe it holds the potential for significant advances in physics and metaphysics. I will leave the question of which understanding of Supersubstantivalism is the best one, which is the *correct* one, open. I will be

---

[42] Quantum spin and spinors are examples of things which were problematic for Wheeler's theory to fully encapsulate. Quantum spin, in particular, is a paradigm example of a physical property that seems to defy exhaustive reduction to geometry.

[43] Contemporary examples of this kind of work can be found in various complete field theories in physics for instance, a good survey of such positions can be found in Lehmkuhl (2009).

arguing that Supersubstantivalism in general is likely the best explanation of the nature of spacetime, but not that any *particular* form of Supersubstantivalism is better necessarily than any of the others. Presumably there is a fact of the matter about this point, I just will not be addressing such a topic in this dissertation as it rightfully deserves much more depth than is possible herein. So, while I argue there is a good chance Supersubstantivalism is the true nature of spacetime--or at least that it's so promising it at least deserves more research focused on it--I do not endorse any particular version of this thesis over another. I do believe some versions of Supersubstantivalism are more plausible than others however, but, again, it is not the place of this document to provide an argument for one above another—merely to argue for the strength of this thesis in general. The thesis that whatever the best explanation of the nature of spacetime is it will likely be a species of Supersubstantivalism. Now, with a basic background history of the general debate over the nature of spacetime in place, it is time to turn attention to the various meta-level concerns which are crucial to abductively arguing that some form of Supersubstantivalism is the best explanation of the nature of spacetime. Such a look at the meta-level aspects of this argument will be the purpose of the following chapter.

Chapter III: What Makes an Explanation the Best?

i. Introduction to Explanation and Abduction

There's a theory in the philosophy of science called the "No Miracle Theory" which is about the nature of the logical schemas science uses to acquire knowledge. This abductive argument asserts that if science didn't succeed, at least partially, at getting the nature of the world right it would be a flat out miracle that all of the devices, operations, and predictions we build out of that knowledge work. The best explanation of this predictive success, and the work accomplished by that success, is that the theory is actually true. Up to this point I have only discussed the long detailed history of the spacetime debate and argued for the importance that this debate has, I have not actually given an argument for Supersubstantivalism. However, before I give this abductive argument I need to first analyze both abduction in general, and the nature of explanation which is relevant to this argument. In particular, I will examine the importance of parsimony of substances and causal unification to the loveliness (*i.e*. success) of a given explanation.[44] I will begin this endeavor by first looking at the nature of abduction and its reliability.

[44] The term "parsimony of substance" should be taken from here on out, unless noted otherwise, as shorthand for "the parsimony of types of substances and/or the parsimony of the number of substances." Now obviously since the term can refer to more than one version of parsimony it should be stated that one kind would be superior to the other (i. e. parsimony of types of substances is more theoretically important than the number of token substances), though both kinds of parsimony are theoretically important. The term "causal unification" I use to signify the property of an explanation where the explanation takes multiple causal stories of distinct phenomena which are implied by rival explanations and unifies them under a single kind of causal story. A causal story that is implied by that explanation, and which details and/or explicates all the relevant distinct phenomena under one rubric. Moreover, the term loveliness is one I'm borrowing from Peter Lipton (2004) which he uses to describe the elegance and strength of explanations used in abduction.

Abduction is much newer to the philosophical scene than its logical cousins, deduction and induction.[45] C. S. Peirce (1931) was one of the first philosophers to argue for abduction being considered its own distinct form of logical inference.[46] Deduction, though somewhat tricky to define, is usually understood as a system of logical inference whereby the premises of a given argument guarantee a certain conclusion; that is to say the premises provide enough support so as to necessitate the conclusion. Induction is typically understood as a system of logical inference where the premises do not guarantee a given conclusion but rather offer a degree, a probability, of that conclusion being true.[47] Abduction is the system of logical inference where the conclusion is the best explanation of the premises out of all the known possible candidates for a particular set of premises based on that explanation possessing some superior qualities relevant to the criteria that its alternative counterparts lack. So, with abduction the premises do not guarantee the truth of the conclusion (one can think of such a guarantee as a probability of 100%). Nor do they offer information which provides a probability of the truth of the conclusion. Rather the premises in the abductive argument are explained by the conclusion and this particular conclusion happens to be the best one available to explain all the premises, and so in lieu of a better explanation (i.e. an explanation which meets the chosen criteria better) abduction tells us to infer the original explanation as the correct explanation of the given phenomenon. Peirce understands an abductive argument as one where a fact is observed, and a particular explanation, if assumed, would make the fact a matter of course. Given that this

[45] Although I distinguish between deduction, induction, and abduction not all philosophers do so. For example, Lipton (2004) uses the word induction to refer to *any* argument pattern which isn't guaranteed (*i.e.* isn't deductive).

[46] Aristotle did reference this kind of logic but he does not develop it as Peirce did.

[47] As I say this understanding is only typical. Frequentism for instance will say that the probability of the conclusion is the frequency of a certain state of affairs occurring in trails, and not the probability of the conclusion coming true. However, for conclusions that do not involve stochastic processes at all this approach does not attribute probabilities to the conclusion period at all but rather does not judge said conclusions.

particular explanation seems to be the best explanation, or to use Peirce's (1931) words most economical explanation, the sufficient explanation is assumed and so the observed fact then follows as a matter of course. Accordingly this system of inference is sometimes called Inferences to the Best Explanation (IBE's).

ii. Abduction, Theories of Explanation, and Parsimony

Abduction (or an IBE) might seem, at first glance, somewhat inferior to its argumentative siblings, after all IBE's do not guarantee the explanations we derive from them and so it is certainly possible that a perfectly good IBE argument results in us accepting a false conclusion. However, IBE's are not only widely used in both academic and colloquial settings, but they seem to be very successful in the sense of providing robust explanations. I argue it is for this pragmatic reason, that abduction is very useful, that it should be used in scientific endeavors. For example, Tim Lewens (2006) argues that one prime example of abduction's use in science is found in one of the most famous scientific theories of the modern age: Darwin's Theory of Evolution.[48] Darwin (1959) writes in support of his use of abduction:

> It can hardly be supposed that a false theory would explain, in so satisfactory a manner as does the theory of natural selection, the several large classes of facts above specified. It has recently been objected that this [abductive method] is an unsafe method of arguing; but it is a method used in judging of the common events of life, and has often been used by the greatest natural philosophers. (Darwin 748)

[48] For more on this subject see Lipton (2004), Harmon Halcomb III (2014), or Paul Thagard (1978). All of these scholars likewise argue Darwin is using abduction in his famous theory of evolution. However, it's fair to say there are scholars out there who disagree. E. Lloyd (1994), and Eliot Sober (1984) are prime examples of such disagreement.

Moreover, Darwin's support of abduction, and its success in science, is not an isolated event. Antoine Lavoisier (1862) is another prime example of a scientist successfully utilizing abduction to further the progress of our understanding of the universe. Lavoisier (1862) writes:

> I have deduced all explanations from a single principle, that is that pure air, vital air, is composed of a particular principle of its own, that forms the base, and that I have named the *oxygen principle*, combined with the material of the fire and heat. This principle once accepted, the difficult principles of chemistry seem to vanish and dissipate, and all phenomenon are explained with an astonishing simplicity. (Lavoisier 623)[49]

This quotation too is evidence of the use of abduction to further scientific progress, abduction is successful precisely because it's a reliable form of inference. Lavoisier (1862) argues for abduction in this manner when he was writing about the elimination of phlogiston from scientific theory. The history of science is filled with a copious amount of examples of abduction being used to further science, and there is a substantial majority of philosophers that endorse abduction and its usefulness.[50] This impressive track record abduction holds in the sciences, I argue, is sufficient to demonstrate that its use in a debate like the spacetime debate is certainly warranted. However, accepting the use of abduction is one thing, and it is quite another to accept a certain criterion as what makes an explanation the "best." Now I will proceed to elaborate on the criteria I will be using to argue that Supersubstantivalism is the best explanation of the nature of spacetime.[51]

---

[49] This quotation is found in the original French edition of *Oeuvres Complêtes.* Vol. II. I would like to thank Cathy Badon for translating the original French into English for me.

[50] Examples of such are found in Nancy Cartwright (1983), J. Vogel (1990), T. Day and H. Kincaid (1994), E. Barnes (1995), S. Rappaport (1996), Alexander Bird (1998), and S. Psillos (2002). All are prime examples of philosophers and scholars who endorse abduction for use in both science and philosophy.

[51] Although Peirce (1931) is a famous proponent of abduction I will not be utilizing his understanding of it for the purposes of this text, instead I will be relying on Lipton's (2004) more modern understanding of abduction.

However, before I can properly begin explicating what makes one explanation better than its rivals it must first be discussed what exactly is meant by the term "explanation." An explanation is a set of statements, the *explanans* (or the speech acts which relate such statements), which are adduced to account for another statement which describes the matter in question, the *explanandum*. In the history of science there have been several theories offered as a more detailed account of exactly how the *explanans* explains the *explanandum*. For example, Carl Hempel and Paul Oppenheim (1948) provide one of the first detailed accounts of explanation called The Deductive-Nomological Model (DN Model). The DN Model holds that an explanation is composed of a deductive argument which possesses an essential premise, a nomological law, and empirical observations. The result is an understanding of explanation that claims that to explain a particular phenomenon one deduces a description of that phenomenon from a law and observations that form a sound argument which predicts the particular phenomenon that's being explained. So, in a good explanation, on this model, the *explanans* deductively implies the *explanandum*.[52]

The Hempelian DN Model of explanation is, outside of Aristotle, by far one of the oldest and most influential models of explanation. To a great extent it shaped the subsequent academic discussion of explanation in the philosophy of science. However, it certainly isn't the only model to do so. Wesley Salmon (1984), after abandoning more statistical approaches like his Statistical Relevance (SR) Model, has championed a Causal Mechanical (CM) Model of

[52] There is another explanation model which I'm largely going to gloss over here and it is Hempel's (1965) Statistical Inductive Model (SI Model). The SI model varies from the regular DN model only in that it works with statistical laws instead of deductive ones. Although I'm leaving out explicit discussion of this model given its extreme likeness to the DN model--it varies only in the kind of laws it deals with--I think it is apparent anything I say about the DN Model will also follow about the SI Model, and so I'm leaving it out of the explicit discussion here.

explanation.[53] As James Woodward (2003) notes, the CM approach to explanation maintains that:

> We may think of the *CM* model as an attempt to capture the "something more" involved in causal and explanatory relationships over and above facts about statistical relevance, again while attempting to remain within a broadly Humean framework. The *CM* model employs several central ideas. A *causal process* is a physical process, like the movement of a baseball through space, that is characterized by the ability to transmit a *mark* in a continuous way. ("Continuous" generally, although perhaps not always, means "spatio-temporally continuous".) Intuitively, a mark is some local modification to the structure of a process—for example, a scruff on the surface of a baseball or a dent an automobile fender. A process is capable of transmitting a mark if, once the mark is introduced at one spatio-temporal location, it will persist to other spatio-temporal locations even in the absence of any further interaction. In this sense the baseball will transmit the scuff mark from one location to another. (Woodward 2009)

This model appeals to purely causal mechanical processes as explaining why a certain event occurs when it does.[54] The CM Model is a realist theory, one that rejects the strict classic Humean understanding of causation (although it keeps parts of the classic Humean model like the relevant entities needing to be spatio-temporally adjacent). The CM model, like many

[53] Salmon's SR Model was intended to capture a sense of causal relevance with regard to statistically relevant properties that he felt was significantly lacking from models like the DN Model. The model focused on the intuition that certain significant properties were essential to understanding causation. However, this model was found to be flawed (just because a property is statistically relevant to a generic causal process that does not mean that those properties are operative on any given occasion), and thus Salmon abandoned this view.

[54] Obviously it's possible that an event doesn't have a purely mechanical process which necessitates it. If one chooses to accept the Copenhagen Interpretation of quantum mechanics, and indeed it is originally for this reason that both Hempel (1965) and Salmon (1971) attempt to provide a statistical based model to account for the causation the standard Copenhagen Interpretation has occurring on the quantum level, some causal processes only have probabilistic causal influence. However, since I have addressed concerns of the SI and SR Models earlier I will let this kind of statement stand as it refers to the remaining kind of explanation which still needs to be discussed. However, it is worth noting that while the standard Copenhagen Interpretation I am referring to here is usually thought of as involving causation Niels Bohr, one of the founding fathers of Quantum Mechanics, believed that causation was not strictly applicable to any phenomena that wasn't fully deterministic in the classic sense.

models of explanation, understands explaining as the answering of a why question.[55] When the English word why, which is an expositive, is spoken that speech act is usually taken to be an illocutionary act where one requests information, usually in the form of words, which is intended to provide an understanding of the subject, an explanation.[56] Peter Achinstein (1983) writes that a sentence *S* explains *q* by uttering *u* when the following criteria are met (where *S* denotes a speaker, *q* expresses an indirect question, and *u* represents a sentence):

> 1) *S* utters *u* with the intention that that his or her utterance of *u* will render *q* understandable.
> 2) *S* believes *u* expresses a proposition that is a correct answer to *Q* (*Q* is the direct form of the question whose indirect form is *q*).
> 3) *S* utters *u* with the intention that his or her utterance renders *q* understandable by producing the knowledge of the proposition expressed by *u* that is a correct answer to *Q*.[57]

Accordingly, on Achinstein's view an explanation provides a body of knowledge that both answers some specific question and allows one to understand that particular answer.

Salmon (1984) defends his causal realism by rejecting the Humean conception of causation as being merely linked chains of events, and by articulating a theory of continuous causal processes which enter into causal interactions and transfer causal marks. The CM Model consequently employs quite a bit of technical language. A *causal process*, on this view, is a physical process, like a billiard ball striking another billiard ball, that is characterized by the ability to transmit a causal *mark* in a continuous way. A causal mark, or more simply just a

---

[55] Not all models of explanation understand an explanation as a speech act, the DN model for example understands an explanation as a certain structure of a linguistic entity, i. e. an argument.
[56] For more on illocutionary speech acts one should see J. L. Austin's (1962) monumental work *How to Do Things with Words*.
[57] These criteria are paraphrased from Achinstein (1983) pages 16-18; they are individually necessary and jointly sufficient conditions. A direct question is of the form, "Why does *X* have property *P*?" and an indirect question is one which asks for the same information but in a way where the verb of the question comes after its subject, "Could you tell me why *X has* property *P*?"

mark, is a local modification to the structure of a process—like the billiard balls striking each other and causing a dent from the impact. A causal process can transmit a mark if the mark will persist to other locations even in the absence of any further interaction. These causal processes are to be contrasted, on Salmon's (1984) account, with *pseudo processes* which cannot truly transmit a mark. An example of a pseudo process would be something like the interaction of the shadows of finger puppets. The shadow of a finger puppet can change as it comes into contact with another finger puppet shadow, but only as long as someone's hand is there providing the respective shapes in close proximity. If you were to remove one, or the other, the shadows and their respective shapes would dissipate. The modifications to the shadows will not be transmitted by the structure of the shadows themselves, as they would in the case of a genuine causal process. Salmon (1984) provides a general method of assembling these instructions by first compiling a list of statistically relevant factors and analyzing that list for regularities and dynamic patterns. Eventually one ends up with a causal model of these statistical relationships derived from empirical testing based on the evidence. The CM Model is deeply reductionistic insofar as it insists that an adequate explanation is only achieved when the most fundamental causal mechanisms of a phenomenon have been articulated; it is key for the instructions to conserve entities in the explanations that result (i. e. the largest number of phenomena should be subsumed under the most general types). Salmon’s (1984) CM Model is thus quite similar to Hempel’s DN Model in that both champion ideal forms of explanation, rather than anything laypeople are likely to utilize in their daily routines.

Philip Kitcher's (1989) Unificationism holds that a scientific explanation aims to provide a unified account of the widest possible range of phenomena derived from the fewest possible initial substances and/or conditions, or at least the fewest argument patterns needed to derive descriptions that range of phenomena. Successful unifications tend to exhibit relationships among phenomena that had previously been considered unrelated, and this tendency is something we expect a good explanation to do, Kitcher (1989) argues. What is important of course from the philosophical perspective however is whether this highly intuitive idea of unification being the essence of what a good explanation aims at can be formulated in more precise and explicit terms. Michael Friedman (1974) had attempted to provide such an account for the Unificationist approach to explanation, but his work had suffered from several technical problems.[58] So the challenge quickly becomes being able to capture this highly intuitive idea in precise and accurate terms. Fortunately, the Unificationist model finally gains a plausible and explicit framework with the work of Kitcher (1989)--although it too is far from complete as many like James Woodward (2003) will testify.

Like Salmon's (1984) CM Model, Kitcher's framework for Unificationism comes equipped with some fairly technical vocabulary. In his system a schematic sentence is a sentence in which some of the vocabulary--the vocabulary which doesn't involve logical operators, functions, and/or quantifiers--is replaced by variables. Kitcher's example is of the sentence "Organisms homozygous for the sick cell allele develop sickle cell anemia," where that sentence is associated with schematic sentences like "Organisms homozygous for *A* develop *P*," and "For all *X* if *X* is *O* and *A* then *X* is *P*." What Kitcher calls filling instructions specify exactly what kinds of terms, in this respective domain of interest, may be substituted for which elements in the schema. Filling instructions might, for instance, tell us to switch out "allele" with *A*, and "sickle cell anemia" (or the respectively appropriate trait) with *P*. Now, Kitcher states that one can make arguments, or schematic arguments, from sequences of these schematic sentences, and

[58] See Kitcher (1976) for more about the technical problems suffered by Friedman's (1974) model of Unificationism.

what he calls classifications are used to identify which schematic sentences are premises and which are conclusions. These classifications also tell one what rules of inference are being used within the schematic arguments. What Kitcher (1989) calls an argument pattern is thus an ordered triple consisting of a schematic argument, a set of sets of filling instructions (one for each variable used in the argument), and a classification of the argument. The more restrictions which an argument pattern obligates of the arguments inside it the more stringent it is said to be.

The idea of an explanation in the Unificationist Model is one where as many different descriptions of phenomena as possible are derivable from as few and as stringent argument patterns as possible. The larger the range of derived conclusions is, and the smaller and more stringent the argument patterns are, the more unified the explanation is. Kitcher (1989) writes:

> Science advances our understanding of nature by showing us how to derive descriptions of many phenomena, using the same pattern of derivation again and again, and in demonstrating this, it teaches us how to reduce the number of facts we have to accept as ultimate. (Kitcher, 1989 423)

Unfortunately Kitcher (1989) does not provide a formal way of weighing the worth of each aspect of his approach. So, one does not have an explicit way of deciding which aspects should be sacrificed when the need is present. What should go first, should we allow a smaller number of conclusions in order to maintain a fewer number of patterns? Or should we allow an argument pattern to be less stringent so that fewer of those patterns can be used? It is not clear what Kitcher thinks one should do when faced with a situation where he or she must tweak explanations to match data. Although he does suggest that it will often be reasonably clear how these considerations should be weighed in the evaluation of particular candidate explanations. Woodward (2014) suggests that:

> The derivations we regard as good or acceptable explanations [should be viewed as] instances of patterns that taken together score better according to the criteria just described than the patterns instantiated by the derivations we regard as defective explanations.... [L]et us define the *explanatory store* $E(K)$ as the set of argument patterns that maximally unifies K, the set of beliefs accepted at a particular time in science. Showing that a particular derivation is a good or acceptable explanation is then a matter of showing that it belongs to the explanatory store. (Woodward 47)

Explanatory stores thus are sets of argument patterns which explain and unify all the beliefs in K.

iii. Explanation and Supersubstantivalism

However, regardless of the theory of explanation you support I argue that parsimony of substances and causal unification are key to evaluating competing explanations of spacetime. That is to say, the properties of the parsimony of respectively key items, like the types of substances, and the unification of causal stories are vital to the idea of explanation under any of its various guises. Consider the classic DN Model for starters. In the DN Model one typically begins by positing a premise that encapsulates a nomological dynamic observed in nature, which connects some kind of antecedent event (or groups of events) and some kind of consequent event (or groups of events). Parsimony in general, and the parsimony of substances in particular, are crucially important to nomological statements of this kind, and though this fact isn't peculiar to the DN Model it is certainly true of it. Thus, the nomological statements in the DN Model typically have to affirm things like "All X are Y..." (or, alternatively, "If X then Y..."). Parsimony has always proven to be beneficial to this kind of enterprise; Newton united celestial mechanics and terrestrial mechanics into one system of mechanics, Maxwell united electrical behavior and magnetic behavior under one single type of behavior, Einstein united Newtonian mechanics with electromagnetic behavior. Thus, there certainly seems to be a very accepted precedent in nomological formulations for holding parsimony as a priority, but furthermore, I argue, one of the more important applications of this principle of parsimony is the number of types, or kinds, of substances and the actual number of substances. To pick the parsimony of types of substances, or the amount of substances, as being important to an explanation is to make a specific application of the more general maxim that parsimony in explanations is desirable. And choosing the parsimony of the kinds of substances, or the number of substances, is something most scholars who write about the spacetime debate agree on. Nor am I the only person which believes that these considerations constitute such a prioritization, especially with regard to spacetime.[59]

One could interject at this point however, why should we prioritize the parsimony of the types of substances, or the number of substances, with regards to explanations about spacetime? Why shouldn't we, instead, prioritize other kinds of parsimony (e. g. the number of terms in the equations that describe its relevant dynamics or the number of interactions the substances can engage in) with regards to spacetime? I answer that by arguing for the prioritization of the parsimony of types of substances and the number of substances I am only arguing that this particular type of parsimony is important for explanations of spacetime, I'm not making any claims to the effect that other applications of parsimony may, or may not, be important to the explanation of spacetime. I'm arguing that with the parsimony of types of substances and the number of substances we have found something that is very important to spacetime explanations, and so the presence of this kind of parsimony reflects well on a given explanation and the absence of this kind of parsimony reflects poorly on a given explanation. Now, it's entirely possible that there are other kinds of parsimony which may be relevant to spacetime

[59] For more on this see Jonathan Schaffer (2009), Dennis Lehmkuhl (2009), and Braford Skow (2005).

explanations, but that is irrelevant to the matter at hand unless someone can find a list of kinds of parsimony of which the presence significantly outweighs the kind of parsimony I am drawing attention to. I will admit that it is feasible that someone could find a set of kinds of parsimony that the presence of which outweighs the fact that the explanation for spacetime I am providing possesses an optimal amount of the kind of parsimony I am drawing attention to and the rival position being considered lacks. However, I find such an event implausible. As noted previously, the parsimony of the kinds of substances and the number of substances have time and again been singled out as important to the explanation of spacetime while the parsimony of most other elements have been consistently ignored. I can think of no work in the field currently which could offer a rival set of parsimonious elements that would outweigh the set I have selected. Thus, I argue that a DN explanation of spacetime would favor and prioritize the presence of the parsimony of kinds of substances and the number of substances (the key here of course is the connection between laws and parsimony--the more fundamental and parsimonious laws are the more phenomena they cover).[60]

Furthermore, I also argue that the DN Model of explanation would also prioritize causal unification. They tend to seek to link the greatest number of outcomes with the fewest number of antecedent events in order to be as general as possible. The unification of causal stories thus is certainly an attractive element of the kind of laws that would be utilized in DN explanations. The more previously separate causal stories that a new law can combine into one cohesive picture the more attractive that law seems, particularly in the case of explanations where we

[60] One might further object here saying that the DN Model's favoritism of parsimony would depend on its relevance to the identification of laws, which under a Lewisian position is perhaps straight-forward, but what about an Armstrongian understanding of laws? This point is a fair one, the DN Model doesn't really rate explanations, it only classifies what is necessary for an explanation. Regardless, as long as a theory of explanation focuses on concepts that are clearer when they are parsimonious then that understanding will inadvertently favor parsimonious explanations over nonparsimonious ones.

desire the law to predict a maximal amount of outcomes. As with parsimony, there are a plethora of examples from the history of science where a new law is created specifically to unite previously separate causal stories into one unified causal story. All of the previously mentioned examples with Newton, Maxwell, and Einstein indicate this fact. Indeed, one might even choose to understand the very purpose of science as that of continually unifying more and more causal stories under more and more general laws. Consequently, I argue, the DN Model of explanation would prioritize the parsimony of types of substances and the number of substances, as well as causal unification, in its explanations. Both of these two elements are very desirable for an explanation under the DN Model, and it follows that it would be very plausible that an explanation of spacetime under the DN Model which possessed a high degree of these elements, or even better a maximal amount of these elements, would be considered the better explanation if the rivals lacked these elements. However, to be clear I am arguing that the DN Model is consistent with this view of parsimony and causal unification being important, I am not arguing that there is something unique to the DN Model that makes parsimony important on this view of explanation. At this point I only want to stress that these elements are of extreme importance to explanations and that it is possible that a maximal level of these elements could cause a particular explanation to be considered the best even if one understood explanations under the DN Model. Although what I have said up to now in this chapter only demonstrates that's the case if we understand explanation under the classic DN Model; I will now proceed to argue that the same follows for both the CM and Unificationist Models of explanation.

The CM Model of explanation focuses on causal processes which transfer causal marks in a continuous fashion, the causal mark being some kind of change in the structure of a process. I argue that the CM Model would prioritize the parsimony of substances in its explanations just as much as the DN Model does. The CM Model utilizes statements of causal processes where the DN Model utilizes nomological statements. Both seek to delineate the most broad and detailed explanations from non-explanatory discourse, and as such both cherish situations where a minimal amount of antecedent states of affairs predict a maximal amount of consequent states of affairs. Indeed, one of Salmon's (1984) original motivations for arguing for the CM Model over the DN Model was that the CM Model offered a "something more" which the DN Model did not. The CM Model is intended to provide an actually real process by which the causation involved is communicated, and not just constantly conjoined events. It seeks to provide the actual causal mechanisms and interactions that the DN Model hinted at with its nomological statements.[61] Thus, the CM Model is also consistent with the prizing of the parsimony of substances and causal unification because those elements have consistently shown to be useful in providing science with the most general causal processes which can lead to the largest class of causal interactions.

The Unificationist Model of explanation is perhaps the easiest case to argue for in terms of it valuing the parsimony of substances and causal unification and being consistent with the view that these features improve explanations. As Kitcher (1989), and Friedman (1974) before him, argue there is a very strong intuitive and pragmatic case to be made that the very act of explanation in science aims at simplifying and uniting the greatest amount of explanatory stories as possible. Kitcher (1981) writes:

[61] One important class of objections to the DN model concerned explanations based on nomological relationships (e.g. examples utilizing Boyle's law that are not causal), or ones where the nomological relationships run in the opposite temporal direction of the causal ones (e. g. examples utilizing nomological relationships in cases like that of the length of a flagpole's shadow). One advantage that can certainly be claimed for CM over DN is that it avoids these kinds of problems by making the causal requirements explicit.

> To grasp the concept of explanation is to see that if one accepts an argument as explanatory, one is thereby committed to accepting as explanatory other arguments which instantiate the same pattern. To say that members of a set of arguments instantiate a common pattern is to recognize that the arguments in the set are similar in some interesting way. (Kitcher, 1981 516)

Now granted Kitcher's account focuses on the parsimony of argument schemes and not substances, but parsimonious argument schemes can be made such by having a parsimonious amount of substances which result in a more parsimonious amount of filling instructions. After all, the fewer substances which exist, the fewer meaningful filling instructions which can be created. The fewer filling instructions which can be created, the fewer dynamic interactions which exist.[62] Thus, I believe the Unificationist Model of explanation most certainly would value the parsimony of substances and causal unification in its explanations. Indeed, the paradigm examples of causal unification and parsimony I've previously drawn attention to serve to support this understanding just as well as it does the previous two.

Consequently, I assert that parsimony of substance and causal unification are elements prioritized in explanations regardless of which model you chose to understand explanation under. As I have just demonstrated, these two elements get at the heart of what explanations aim for, describing fundamental constituents of reality and how they interact, and this fact is evident from the historical precedent of scientific advance. Prioritizing these two elements in the past has consistently tended science toward progress, toward the ability to predict nature more and more accurately. I suggest that this success is indicative of these two elements elevating the chances of the respective explanation as being true.

[62] This statement is assuming of course one doesn't needlessly insert filling instructions with irrelevant disjunctions, like "A ... or X ... or ...."

Regardless of how one chooses to understand the term explanation one will arrive at a place where explanations with parsimony of substance and causal unification are better for it. Now that we've established at least some elements which consistently make explanations better than others we've opened up a way to go about accomplishing the goal set forth in the first chapter. The goal, ultimately, is to provide a plausible and convincing argument for accepting Supersubstantivalism as the best explanation for spacetime. However, let us first finish discussing the nature of abduction, as it is being used in this thesis, and how these abductive arguments work. As I stated earlier I will be drawing on Lipton's (2004) account for my understanding of abduction. That is to say, the abductive argument I will be giving in the following chapter will be an abductive argument as Lipton (2004) understands it (as opposed to, say, Peirce). Lipton's account states that with an abductive argument, or an Inference to Best Explanation (IBE), is an inferential practice governed by explanatory considerations. As he states: "...there is always more than one possible explanation for any given [thing] ... so we cannot infer something simply because it is a possible explanation. [The explanation chosen] must somehow be the best of competing explanations" (Lipton 56). So, the standard formulation of abduction is that given evidence E, which has candidate explanations X_1, ..., X_n, one should infer the truth of X_i which best explains E. The details of how one goes about determining which X_i qualifies as the best explanation of E varies slightly depending on how one chooses to understand the word explanation, but as I've argued regardless of how one chooses to understand explanation it follows that nonetheless certain elements of explanations are to be prioritized, namely the parsimony of substances and causal unification. Likewise, Lipton (2004) argues that regardless of both how one interprets explanation and what particular thing is being explained some elements are indicative of a contrastively better explanation. He states that with IBE's the loveliness of an explanation is guide to the likelihood of it, "After all, if Inference to the Best Explanation is a reasonable account, loveliness and likeliness will tend to go together, and indeed loveliness will be a guide to likeliness" (Lipton 61). Loveliness is somewhat a technical term for Lipton and the formulation of abduction he, and I, have in mind. Loveliness, as a technical term of abduction, refers to a degree of parsimony and causal unification that a theory possesses. Loveliness refers to an explanation's "theoretical elegance, simplicity, and unification [as] a guide to inference" (66). Lipton provides support for this belief by positing, among other things, examples of just such a thing occurring in the history of philosophy. One such example Lipton points to is the so-called "brain in a vat" argument, where the skeptic argues that, for all you and I know, we could just all be brains in vats somewhere in a laboratory and the world we think we feel and see is simply an artificial world being fed to our brainstem by a computer of some kind. He writes:

> Another well-known philosophical application of Inference to the Best Explanation is to argue for various forms of realism. For example, as part of an answer to the Cartesian skeptic who asks how we can know that the world is not just a dream or that we are not just brains in vats, the realist may argue that we are entitled to believe in the external world since hypotheses that presuppose it provide the best explanation of our experiences. It is possible that it is all a dream, or that we are really brains in vats, but these are less good explanations of the course of our experiences that the ones we all believes, so we are rationally entitled to our belief in the external world. (69)

Explanations which embrace parsimony and unification tend to be better explanations than those that do not. In fact, overall, Lipton claims that "Explanatory loveliness is used as a symptom of likelihood (the probability of *E* given *H*), and likelihoods help to determine likeliness or posterior probability" (115). And whether or not an explanation possesses explanatory loveliness is dependent on whether it possesses certain inferential virtues like parsimony and unification, "Thus among the inferential virtues commonly cited are [among others] ... simplicity..." (Lipton 122). And this view is supported by far more than just Lipton (2004), this view is supported by numerous other thinkers such as Hempel (1966), Thomas Kuhn (1977), W. V. O. Quine and J. S. Ullian (1978), and William Newton-Smith (1981). Thus, I argue it is rather reasonable to conclude that not only is abduction a useful and successful type of reasoning, but that moreover abduction tends to favor the same kind of inferential virtues that explanation does, and as such parsimony of substance and causal unification gain a level of priority among crucial elements to be looked at when judging the which explanation is the best. As a result it follows that if there were an abductive argument which showed that Supersubstantivalism was maximally parsimonious with regards to substances and maximally causally unified it is plausible to conclude that, barring significant evidence to the contrary, these grounds could qualify Supersubstantivalism as the best explanation, and thus by abduction the correct explanation, of spacetime.

We have established that the presence of parsimony of substances and causal unification serve to make an explanation better than others that either do not possess these traits or the ones that possess them but to a lesser degree, let us assess what has been said so far and what remains to be shown. First, it has been established that abductive arguments have frequently been utilized in philosophy and science to explain the world around us. Ostensibly there is at least a good reason to think that it is plausible that there could be an argument which claims Supersubstantivalism is the best explanation of spacetime. It is plausible to think so regardless of how one chooses to understand the term explanation. Among other things, the presence of parsimony of substance and causal unification can, and do, make certain explanations better than others. An explanation possessing parsimony of substance in this case is taken to mean that *explanans* of the explanation makes essential reference to a minimal number of both types of substances and substances themselves. And the phrase causal unification in this case is taken to mean that a minimal set of statements in the *explanans* has sufficiently accounted for a maximal set of statements in the *explanandum*. Thus, it is certainly plausible that there could be an abductive argument that prioritizes parsimony of substance and causal unification in which Supersubstantivalism comes out as the best explanation of spacetime. The following chapter aims at providing just such an abductive argument.

Chapter IV: The Abductive Argument for Supersubstantivalism

i. Outline of the Argument

The debate over the nature of spacetime is traditionally seen as having two main competitors: Substantivalism and Relationalism. Traditionally however most scholars overlook a third position which has long-reaching roots--Supersubstantivalism. Supersubstantivalism is the position that not only does spacetime exist, but moreover it is the *only* substance which exists. On this view spacetime is the sole substance in existence--all other entities either do not exist or are reducible to this single fundamental ontological substance. This chapter plans to offer an abductive argument in support of Supersubstantivalism as the best explanation of the nature of spacetime.

This chapter will take, on assumption, certain understandings about the nature of explanations and abductive arguments (*i.e*. what are some of the most important elements we look for in IBE's). I will consider explanations improved when they incorporate the unification of facts and regularities under an increasingly fewer number of concepts, entities, and assumptions (though by making this statement I do not mean parsimony is the *only* thing which improves a theory). Likewise, abductive arguments are, to use Lipton's (2004) terminology, more "lovely" (*i.e.* superior) when they possess a higher level of parsimony as compared to rival explanations, especially where the number of concrete entities and dynamical laws are concerned. And perhaps most importantly I will work from the standpoint that while causal unification and ontological parsimony are individually important aspects to contrastive explanations, the combination of these two elements together--the account possesses both a parsimony of entities (where this example of parsimony is not by itself an example of causal unification) while at the same time providing a maximally unified causal explanation of the explanandum in question--is a crucial attribute in an explanation. Hence, in this chapter I will be taking on assumption the things established in the preceding chapters.

In this chapter I will examine the benefits that could be garnered by adopting a theory of Supersubstantivalism as an explanation of the properties of spacetime. In making this examination I will be drawing particular attention to the various benefits which such an adoption can provide, paying particular attention to the benefits of the extreme increase of both ontological parsimony and causal unification to an explanation of the properties of spacetime. After a careful examination of the various benefits, and some of the disadvantages, gained by accepting Supersubstantivalism I will ultimately argue that the overall promise of this view calls for a far greater amount of attention and work concentrated on Supersubstantivalism as it could provide the most unified and parsimonious understanding of the universe possible. That is to say, I will examine the strength of the abductive argument for Supersubstantivalism.

Thus, this chapter will focus on the examination of the abductive argument I have been suggesting. I will begin by laying out in detail this position, and this description will include specific points about what is meant by metaphysical terms like "substance" and how spacetime fabric grounds the rest of the universe on this view. This description will be followed by two chief parts of an abductive argument that best supports Supersubstantivalism. Both parts contribute to the promising superiority of Supersubstantivalism as an explanation of the nature of spacetime as compared to its two main families of rivals: Relationalisms and Traditional Substantivalisms.[63] The first part concerns the parsimonious and causal unificatory benefits that Supersubstantivalism holds over its challengers. The second part details how

[63] Here when I say "Traditional" Substantivalisms, I have in mind all the kinds of Substantivalisms *sans* Supersubstantivalism. For example, this list would include what Lawrence Sklar (1976) calls "Container" Substantivalism.

Supersubstantivalism can lend important developments to key mysteries in the annals of physics, such as, for example, the equivalence of energy and mass that Einstein predicts in 1905. I will argue that while each of these parts separately makes a plausible case for the truth of Supersubstantivalism, the conjunction of both of these makes for a very persuasive case for Supersubstantivalism. I will additionally draw attention to various other pragmatic reasons that lend significant support for the acceptance of Supersubstantivalism.[64] The ultimate result, I argue, is two-fold: 1) Traditional Substantivalisms are no longer viable options in the spacetime debate (as I argue Supersubstantivalism will always be superior), and 2) even though Relationalisms offer viable answers to the spacetime debate Supersubstantivalism possesses a lot of promise which its competitor lacks, and thus it is, I argue, the more promising explanation of the properties of spacetime, and as such it should be explored and studied more--for if I am correct, the benefits will be considerable.

ii. Explication of the Position of Supersubstantivalism

Let us begin then with what was advertised first, a detailed description of the story told by Supersubstantivalism. Supersubstantivalism is the thesis that not only does spacetime exist as a substance, but, it is the *only* substance that exists! That is to say, no other concrete substances exist beyond spacetime, and any entities which appear to be concrete substances are in fact merely regions of spacetime with certain properties exhibited. On this view then there is one, and only one, substance in existence. By substance I mean what the Ancient Greeks meant by the word *ousia* (or the Latin *substantia*): something which stands underneath or grounds

[64] Here I have in mind pragmatic reasons provided by the works of others like Terry Horgan and Matjaz Potrc (2000) and Jonathan Schaffer (2012), among others. Indeed, I even think a case can be made that one can understand Ontic Structural Realists like James Ladyman and Don Ross (2009) as a variety of Supersubstantivalists; and possibly Moderate Structural Realists like Michael Esfeld and Vincent Lam (2006).

properties. So, I am employing the word substance in the manner Howard Robinson (2014) characterizes it in his Stanford Encyclopedia entry on the substance, "substances in a given philosophical system are those things which, according to that system, are the foundational or fundamental entities of reality" (Robinson 1). I use substance to be the term for the basic constituents of reality which are able to possess properties. In this view then there turns out to be exactly one of these substances: spacetime.

This definition of substance however demands more clarification about what exactly a property is on this view. On the view I am suggesting here a property is something which can be predicated or attributed to a substance, or a higher level non-fundamental thing which is grounded in a substance (i.e. a region or a cat). Properties are defined by the fact that for one to be instantiated it must be predicated of a particular substance, or predicated of a non-fundamental thing which is in turn grounded itself in a substance; where on the other hand substances do not owe their existence, or instantiation, to any particular property.

According to Supersubstantivalism there is only one substance in existence, and it is a substance which has regions and these regions can possess various properties. Since spacetime is the only true substance in existence on this view, if we are going to have other physical objects of any kind they must be ontologically dependent on spacetime regions with various properties. That is to say, *all* physical objects are ontologically dependent on spacetime. For example, if we assume a cat is reducible then we could say the cat is composed of atoms, the cat is grounded in atoms.[65] The grounding relation connects the two relata here, the cat and a certain set of atoms,

[65] The term "grounds" here is meant to signify the idea of metaphysical grounding and explanation typified by Kit Fine (2012). However, it should be noted here I am not making any claims about grounding/composition being sufficient for reduction. Reduction is a question left open at this point.

such that one is grounded irreflexively in the other.[66] In this example the cat is grounded in the atoms, and in turn the atoms are grounded in regions of spacetime that exhibit certain properties like impenetrability and/or stress-energy-momentum tensors.[67] There are such things as cats but they are not fundamental entities in the universe's ontology; rather the universe's ontology has only one true substance: the spacetime fabric. And that spacetime fabric grounds all the other non-fundamental entities in the universe, which is to say all other non-fundamental physical things in creation are composed of regions of the spacetime fabric (*i. e*. the one substance) which exhibit certain properties. All non-fundamental objects are ontologically dependent on the spacetime substance and the properties which manifest themselves on it. Furthermore, all of the causal interactions that are between non-fundamental entities, the causal interactions of the cat's muscles moving, are ontologically dependent on causal interactions of the fundamental substance spacetime and its properties. So, my position is one of the ontological dependence of commonplace objects and physical things, as well as their causal interactions, on spacetime, its properties, and their causal interactions.[68]

However, as I indicated previously, Supersubstantivalism itself has at least two different varieties. Following the example of philosophers like Dennis Lehmkuhl (2009) I will call these two different varieties Modest Supersubstantivalism and Radical Supersubstantivalism. The former is the kind of position employed by the likes of Baruch Spinoza (2002) where regions of

---

[66] Thus, the grounding relation G is a two-place relation where fundamental and non-fundamental entities are the relata.

[67] The grounding relation is transitive.

[68] To be clear, the interaction here is between the properties which manifest in the single substance spacetime. There is only one substance, and as such it cannot be substances interacting which account for the causation. Rather it is the dynamics of the various properties in the various regions of the substance which accounts for the causation. Now then, to be clear, presumably the substance spacetime acts on itself in order to manipulate the various properties. It is worth being clear that while the view I'm suggesting here is Eliminativist, one could also choose this position and understand it as a kind of Reductionism. However, I worry that the latter kind of view would only end up weakening the coming abductive argument by lessening the parsimony of the ontological framework at work here.

spacetime, the only true substance, can have various properties like impenetrability and color pinned directly to the spacetime fabric.[69] That is to say, the properties would inhere directly to the spacetime region as opposed to some kind of material object on top of the spacetime fabric. The properties are not reducible to anything else. On this view spacetime is the only concrete, fundamental entity, but it is one that possesses modes, or ways it can be, beyond simple geometric properties which one would expect of spacetime regions. However, on the other view, Radical Supersubstantivalism, these non-geometric properties are denied. This view has it that *all* physical properties are ultimately reducible to strictly geometric properties of the respective spacetime regions. I do not plan on arguing for one variety of Supersubstantivalism over the other, I am arguing simply for the truth that one of the two is the correct way to understand the nature of spacetime. For the most part the argument I will be giving works equally well for both brands of Supersubstantivalism.[70]

So, the story so far is that there exists spacetime fabric which is a substance, in fact it's the only substance in existence. Now, there's no need to check and make sure your cat Socrates is still in the next room--yes he is--there are still entities in our world like cats and dogs, rocks and airplanes. However, any entity which is not spacetime is a non-fundamental entity, and is grounded by spacetime according to the grounding relation *G* as previously described. These entities exist, they just are not *fundamental*. What this situation means is that there is such an entity as a cat (although it's non-fundamental), the cat is grounded by organ systems and tissues,

[69] This metaphor I employ here, and elsewhere, of a property being "pinned" to spacetime fabric can be understood as a property being grounded in the substance of spacetime such that an observer would observe the given property manifesting itself in a given region of the substance. Furthermore, a given region of spacetime (the one substance) can be defined by a mathematical/geometric formalism (*e. g*. like General Relativity's formalism). It is *not* my intention to suggest the one fundamental substance of spacetime has parts, it does not.

[70] I say for the most part because it does seem likely that the ontological parsimony and causal unification considerations I am pointing toward in the first part of the abductive argument would favor Radical Supersubstantivalism over Modest Supersubstantivalism as the former reduces all properties to one type of property and unifies the explanation of all properties in geometric properties or emergent properties which appear at some higher organizational level.

organ systems and tissues are grounded by cells, and so on until (since grounding is transitive but irreflexive) we can finally say the cat is grounded by sub-atomic quarks, leptons, and bosons given those entities turn out to be the most fundamental components of matter (*i.e*. assuming some smaller fundamental parts aren't discovered at some point in the near or distant future). These sub-atomic particles (e. g. quarks, leptons, and bosons) would then in turn be grounded by the spacetime fabric that underlies them (along with their various properties). Thus, we can say the cat is grounded by the spacetime fabric that underlies him. The cat is not a fundamental concrete entity, but he is grounded by a fundamental concrete entity and because of perspective and linguistic brevity we have come up with terms for non-fundamental entities which are collections of that fundamental entity in certain regions which appear, because of our macroscopic perspective, as whole entities like cats and dogs.

As mentioned earlier when it comes to contrastive explanations I'm assuming that explanations which unify the highest amount of causal stories, while positing the fewest entities and laws, tend to be the better explanations. If Explanation A can explain the matter at hand using four entities and four sets of laws, each of which explains only the way one of those four entities behaves, and Explanation B can explain the same matter using one entity and one set of laws which explains the way that one entity behaves, then Explanation B is that much better than Explanation A.[71] If we are asked to pick between Explanations A and B as to which is more likely to be true of our world we should, all else being equal, we pick Explanation B. The virtues of parsimony and unification in judging contrastive explanations are of extreme importance, if

[71] One might ask here, how much is "that much?" Suffice it to say that by "that much" I intend a substantial and significant amount, which is to say that this addition of parsimony adds a significant improvement to the explanation. The addition of parsimony significantly adds to how good an explanation is, and that is the only point I wish to push here. Hence, while I don't specifically designate if it's twice as good, four times as good, or what have you, I think all that's needed here is the belief this parsimony addition improves the explanation (given the addition of parsimony doesn't prevent the explanation from accurately describing the respective explanandum).

not paramount. However, even if one were to accept this statement as true I still haven't yet made an argument that Supersubstantivalism necessarily qualifies as being more parsimonious and more unificatory than its rivals.

iii. Parsimony & Abduction: Supersubstantivalism vs. Rivals

I will now proceed to examine if such might be the case. I will first examine how Supersubstantivalism qualifies as parsimonious (and thus the "loveliest" explanation to use Lipton's language) because it is far more conservative with respect to the number of entities in its ontology. Next, I will examine whether Supersubstantivalism is more unificatory in that it unites all other causal stories available in the account (e. g. causal stories which explain the various specific details about the specific state of affairs in questions, like how fast the particles in question move, *et cetera*). And then finally, I will examine whether these two facts taken together result in Supersubstantivalism being a better contrastive explanation as compared to its rivals which lack these qualities.

To start then I will examine first whether Supersubstantivalism possesses a level of parsimony about the amount of fundamental entities in the explanatory story that is first, desirable in an explanatory theory, and second, something that its competitors cannot match. Ontological parsimony has an excellent track record in the sciences, from Newton’s combination of terrestrial and celestial physics to Einstein’s use of relativity and frame transformations to eliminate the need for an *aether*, or frame of absolute rest, in electromagnetism. Moreover, the absence of parsimony tends to have an equally good track record of suggesting a theory as false; phlogiston theory is dismissed for its unnecessary entities. Supersubstantivalism, regardless of whether it's the Modest variety or the Radical, posits only one fundamental entity, and that one entity is spacetime (i.e. the one big piece of spacetime fabric which presumably covers all of creation).

It will suffice to show Supersubstantivalism possesses a superior level of parsimony by showing it necessarily possesses a lesser number of required entities to explain the whole of creation, if such is the case. To do so one need only sketch the total number of required entities that Supersubstantivalism and its competitors possess. Let us begin then by sketching Supersubstantivalism, it obviously comes out, at the end of the day, with only one necessary entity: the spacetime fabric itself. So, the tally for Supersubstantivalism is the loneliest number, one. In order to look, contrastively, at the other kinds of competitors Supersubstantivalism faces in the spacetime debate let us look first at all the other varieties of Substantivalism. All other varieties of Substantivalism will come out with a minimum of two necessary entities, because after all even if there is only one physical entity in all of existence it plus the spacetime fabric, on this view, would be a minimum of two. It would seem the only way the other varieties of Substantivalism could match Supersubstantivalism on this account is by denying the existence of any material objects, after all if a Substantivalist didn't agree to the existence of the spacetime fabric they wouldn't be a Substantivalist. Hence, it seems to readily follow that the other varieties of Substantivalism, whatever they may be, will necessarily lose to Supersubstantivalism on this account, as all of them will necessarily have to agree to more than one necessary substance in existence.[72] That then is one opponent down and one to go.

The next adversary to examine is Relationalism and all its varieties. Relationalism and its various types are a bit more difficult to look at however. Granted, as long as there are two or more objects in the Relationalist world we are talking about it will lose to Supersubstantivalism

[72] I suppose, in principle, there could be a Substantivalist world where nothing but the fabric exists, but since you and I are in this particular world we are talking about I hope it's obvious that that possible world isn't ours.

as one is less than two. In any Relationalist world with more than a single entity the number of substances must total more than one. Hence, it is apparent that, with the exception of the Relationalist world which possesses only one substance, Relationalism loses this match.

However, one might question why couldn't we imagine a Relationalist world where there is but one substance, and thus one entity, let's say some kind of pantheistic world for example. This kind of Relationalism is the only one which even has any chance of being equal with Supersubstantivalism on the matter of required entities; it should be clear that none of the others do since their number of required entities will obviously equal more than one. Yet there is this one particular type of Relationalism which must be examined before any kind of blanket statements can be made about all types of Relationalism. Now, for this type of Relationalism to even tie with Supersubstantivalism it must posit only one substance in all of creation. Certainly such a world is possible, but is it likely given the kind of stuff we need to explain in *our* world?

This monistic type of Relationalism is quite unusual in several respects. First, unless we are prepared to accept that the same exact substance can exist in two completely isolated spatial regions at the same temporal instant, we must rule out this world as being our own actual world. Presumably in our actual world there are multiple entities, say you and me, and we do not exist in the same spatial coordinates. So, if, as this monistic Relationalist view would have it, you and I are really composed of the exact same substance it would have to be the case that this same substance can exist simultaneously in two separate spatial locations.[73] In Supersubstantivalism this situation of course isn't a problem since the intervening space is itself the same substance that composes both you and I. However, since monistic Relationalism would insist spacetime is merely the relational properties you and I exhibit it cannot appeal to this kind of holistic solution,

[73] In Sider's (2001) Four-Dimensionalism a single substance is composed of a worm of spacetime regions, but a substance never has separate, non-local parts in the same timeslice.

the monistic substance would have to simultaneously be at two separate places. I think most people would conclude that two spatially separate substances are actually *two* distinct substances. Granted, they may be the same type of substance, but I argue they would not be the exact *same* substance as this view would require for there to be just the one substance in existence. For the two spatially separated substances to actually be, in fact, the same substance would require a violation of locality.[74] Thus, while I will concede that there could be a possible Relationalist world where only one single substance existed I think it is readily observed that this possible world is not our own. Looking at our own actual world I will take it to be uncontroversial to assert that if our world is a Relationalist world there is at least two separate substances in it (although on this view there could be just one *type* of substance). For example, I would imagine it is rather uncontroversial to argue that if our world is a Relationalist world (i.e. spacetime is not a ubiquitous single substance which underlies all of existence) then there is at least two substances in our world: you and me.[75] At the very least, the fact that you and I exist, with some kind of spatially separate distinctness between us, should qualify as proof that if Relationalism is true of our world it is such a kind as that it has at least two substances in its

[74] Here the word "locality" is meant in the strict sense of the principle that things have particular and singular locations in space and time--not to be confused with the term "locality" as it is used in physics and relativity where the term instead denotes the position that objects can only be causally influenced by things in their proximate surroundings or light cones (i.e. the difference between events being space-like or time-like).

[75] Granted you could advocate an unusual form of Relationalist which claims there are no substances at all, though in this case it's not clear what would be the things which had relations between each other (i. e. it seems there would be *nothing* at all on this view). Ladyman and Ross (2009) presumably have a belief something like this one (at least they claim not to believe in any particular substance, although they seem non-committal about whether spacetime itself is a substance). If the structure is itself considered a substance, then it would seem Ladyman and Ross's view is the same as Supersubstantivalism. If, however, the structure isn't considered a substance this view does seem to be a more ontologically parsimonious view than Supersubstantivalism. Yet, this view seems to be a rather bizarre one, this thing holds properties, and is the structure behind all we experience, but it's not a substance? What is a substance but a placeholder for properties? It would seem Ladyman and Ross would not be any more ontologically parsimonious on this view. Thus, it seems Ladyman and Ross's view could indeed be seen as on par with Supersubstantivalism, if the two are not identical in the first place. Additionally, it's also important to point out that it would also be possible for a Relationalist to believe in only a single substance, however I will address this concern later on.

ontology. Thus, I argue that if one insists on seeing our world as a Relationalist world he or she must see it as one that has two or more substances in its ontology, and as such it follows that there is no Relationalist picture which can explain our actual world which is more parsimonious as regards to necessary token entities than Supersubstantivalism. Out of all the various explanations which can explain our actual world, none of them has fewer necessary entities than Supersubstantivalism. Nor am I alone in concluding Supersubstantivalism possesses this degree of parsimony over and above its rivals. For example, W. V. O Quine (1963) and David Lewis (1986) both argue for views like Supersubstantivalism claiming the view is more economical than the rival alternatives.

Consequently, I argue that when it comes to views that possess the most parsimonious level of necessary entities to explain our actual world Supersubstantivalism wins. Now, however, one might argue, so what? Just because Supersubstantivalism possesses the most parsimonious level of one desired trait doesn't mean it follows, even abductively, that Supersubstantivalism is the best explanation of our actual world. To this response I say: absolutely! This superior level of parsimony is just one example of the superior abductive traits Supersubstantivalism possesses over its competitors. Let us now turn our attention to the second important trait to which I wish to draw attention.[76]

The second important abductive trait I wish to draw attention to is causal unification. Unification is a very desirable trait in abductive arguments between contrastive explanations. In the words of Kitcher, "Science advances our understanding of nature by showing us how to

---

[76] I am here looking at the number of token substances, not the number of type substances, and I do it this way because I believe examining token substances will better display the parsimony differences here. If one would rather examine type substances between Supersubstantivalism and Relationalism it seems as if the two will bottom out at a minimum of one type of substance and thus be equal on this account. So, if I am correct here I argue that we can disregard the numbers shown by the examination of type substances since if we are comparing X + 2 and Y + 2 it seems rather obvious we can disregard the equivalent extra factors here and examine the one they disagree on.

derive descriptions of many phenomena, using the same pattern of derivation again and again, and in demonstrating this, it teaches us how to reduce the number of facts we have to accept as ultimate" (Kitcher 423). Lipton concurs with this point writing, "Explanations or patterns of explanation that explain more and more diverse phenomena, explanations that do more to reveal the unity beneath superficially messy phenomena, are explanations that provide greater understanding" (Lipton 139). Not only is it, by itself, an important component of the attractiveness of an abductive argument, but for Unificationists it also provides a very beneficial element to causal stories. Granted, the parsimony I'm referring to here is ontic while Kitcher's Unificationism uses parsimony much more in the sense of argument schemes, however I argue the former result in the latter. For example, the fewer fundamental substances an argument scheme employs the fewer facts one could accept as ultimate, after all if you add substances you would also be adding facts that pertain to those substances. Thus, ontic parsimony while not strictly the same thing as argumentative scheme parsimony tends to promote it. Moreover, it is the combination of this element to the previous element of parsimony which results in what I argue is one of the best reasons to accept Supersubstantivalism: it can unify all of our causal stories together and it can do so with a minimum number of actual entities.

Supersubstantivalism can offer more causal unification than any of its competitors it seems in the following way. Supersubstantivalism posits only one concrete entity in existence, the spacetime fabric itself, and because on this view every non-fundamental entity in existence is grounded in the one fundamental entity, whatever causal story you tell about how any given entity acts will, ultimately, have to reduce down to a causal story about the spacetime fabric and its properties. As such this account gives the perfect metaphysical backing for a true Grand Unified Theory (GUT), which has long been the "holy grail" of theoretical physics. In a GUT there would be a base set of equations which dictate the way the respective dynamics operate in regions of this one single entity (i. e. spacetime), and thus all higher level causal stories would be grounded in such a story where our one single entity possesses regions with certain properties which act according to certain set laws and equations. Indeed, this achievement (i.e. finding exactly what the equations are in this GUT) was the goal Einstein spent most of his later career working on.[77] Granted, some potential GUT's, such as a more fully developed Quantum Field Theory, are only expectations of what current theories could become, not the current state of these theories. As such, these potential GUT's would of course depend on certain developments and advancements in these fields and not just the addition of Supersubstantivalism to these theories. However, the point I wish to stress here is that the position of Supersubstantivalism has unique potential to contribute to great developments in both science and philosophy, and as such it deserves a much greater degree of exploration and investigation.

It is important to see here that Supersubstantivalism promises a degree of causal unification that its competitors are hard pressed to match. By definition any other variety of Substantivalism must possess at least two substances, spacetime and at least one material object.[78] And here I keep the talk to *kinds* of substances because presumably even though there

[77] Admittedly Kitcher's Unificationism only requires that the argument schemas accurately describe the relevant phenomena, and so it's entirely possible that one could ignore substances altogether and create a scientific explanation which makes no references to substances at all. However, if one is indeed of this persuasion it is unlikely he or she would care about the spacetime debate to begin with since it focuses on whether or not spacetime is a substance. Accordingly, while I admit this position is a possibility I'm shelving it for now since the topic at the moment is precisely whether or not Supersubstantivalism is a viable explanation of the nature of spacetime.

[78] It is of course possible for there to be a Substantivalist world which has only spacetime and no material objects in it at all (here I'm excluding the possibility of such a world having material objects which don't exist as separate objects but are actually reducible to the spacetime fabric since that would of course just be Supersubstantivalism the account we are contrasting this one with). However, I think it is fair to say that such a possible world cannot be our actual world since it at least seems like we have material objects of some kind in our world. Again, if these objects are not separate objects from spacetime but reduce down to spacetime then the position is Supersubstantivalism, and so if these objects exist at all in a different variety of Substantivalism they must exist as separate substances.

could be more than one physical object as long as they are the same kind of substance it seems that they could be subsumed under a single causal story, namely the causal story which depicts how that kind of substance behaves. Given that any other variety of Substantivalism must involve two or more entities, or substances, then it would seem we must tell at least two kinds of distinct causal stories: one for the way the substance of spacetime operates, and a completely different story for the way the other kind of substance operates. So, the result here is that any other variety of Substantivalism must give a less unified causal story about how the world and its inhabitants function. Hence, other varieties of Substantivalism will have a lesser degree of causal unification than Supersubstantivalism.

One should consider however, what if a single fundamental substance can account for all the needed phenomena, but for it to do so it must tell an increasingly complex, yet single, causal story (i. e. a single causal story where the single fundamental substance behaves in way φ which explains phenomenon X, behaves in way ψ which explains phenomenon Y, etc.)? Is such a single causal story really superior to multiple fundamental substances which can account for their respective causal story in a simple (i. e. not complex) fashion? The answer to this question depends of course on what is meant by "superior." If one means does it have a higher degree of causal unification, then yes it does. One causal story, however complex, is fewer in number than multiple causal stories even if they are each far simpler[79]. However, one might press the point, yes but is such an account really more parsimonious than the account which provides multiple, yet simpler, causal stories? This position raises a fair point, but I argue it is reasonable to believe

[79] Likewise, if the causal stories involve fewer ontological substances they are also improved. However, I'm not suggesting that you can get causal unification "on the cheap," so to speak. After all, this kind of explanatory improvement cannot be done willy-nilly, but rather only when there is a good reason to unify the previously separate causal stories (like in the case of electricity and magnetism). But when it can be done, the explanation becomes certainly improved.

that because Supersubstantivalism is more causally unifying it is preferable to other varieties of Substantivalism. Causal unification is a very appealing attribute of an explanatory story.

What about Relationalism though, wouldn't it be equal to Supersubstantivalism with regard to kinds of substances in existence, and as such be equal to Supersubstantivalism in terms of how unified of a causal story it gives? Well, it is true that there is a species of Relationalism which can compete with Supersubstantivalism on the kinds of substances in existence--namely the kind of Relationalism which holds that all matter is one particular kind of substance and nothing else exists whether spacetime or other kinds of material substances. In this monistic kind of Relationalism (it's monistic in the sense it admits to only one kind of substance although there might be multiple separate instantiations of that particular kind of substance), one could make an argument that it is just as causally unified as Supersubstantivalism: there is one kind of substance which obeys one set of unified causal laws (at least such a world is possible), and this world is just as causally unified a world as in a Supersubstantivalist world where there is only one kind of substance and it obeys one set of unified causal laws.[80] I admit there seem to be no argument a Supersubstantivalist could give for why this Monistic Relationalism should be considered abductively inferior to Supersubstantivalism when it comes to examining the causal unification of the given explanation.

The Supersubstantivalist could perhaps draw attention to the fact that a Monistic Relationalist would have to account for the standard types of physical objects on the Standard Model which are distinct from spacetime (this view cannot be grounded in a single substance like spacetime after all): fermions and bosons (on the Supersubstantivalist picture both can be looked at as spacetime regions with certain properties and thus the same substance, but not on

[80] Although here the two are equal in terms of the number of type substances, and not necessarily the number of token substances.

the Monistic Relationalist picture).[81] That is to say, on the materialist Relationalist account, including the Monistic Relationalist account, that there are material objects substantially distinct from spacetime, and most physicists agree there are at least these two kinds of fundamental material objects: matter and fields. Thus, the Supersubstantivalist could point to this fact and argue that a materialist Relationalist account would have to posit at least two kinds of substances to explain our particular world, and hence the Monistic Relationalist account isn't really a possible candidate to explain our world and consequently Supersubstantivalist loses its chief rival in contrastive explanations. The name of the game, at the moment at least, is which account possesses the highest amount of causal unification (e. g. how many types of substances are in the account), and while the Supersubstantivalist account and the Monistic Relationalist account seem tied on this front Supersubstantivalism may insist that while that may be true in general it is not true of our specific world. We are not looking at what would be the most causally unified explanation bar none, but what would be the most causally unified explanation that could explain our world (that is, after all, what we care about). So, the Supersubstantivalist may point to what seems to be empirical evidence that without spacetime as an underlying substance to unify the traditionally separate physical substances the Monistic Relationalist seems to not be able to explain our world (it would need to posit at least two kinds of substances, fermions and bosons, and that would make it dualistic, we would obviously have a contradiction in terms).

However, this would be a flawed position on the part of the Supersubstantivalist, as the opponent could rightly insist that there is no reason why we have to consider these two different kinds of material objects as being grounded in two different types of substances (say two different types of fields where fields are considered the single fundamental substance, matter

[81] Just to be clear, when I say fermions and bosons I intend the smallest most fundamental kind of these particles and not the larger composites made up of these particles (i. e. protons, neutrons, etc.).

fields and other kinds of fields). Hence, this monistic version of Relationalism is still on equal footing with its rival contrastive explanation Supersubstantivalism. The Relationalist has a fair point here, but could the Supersubstantivalist still claim parsimonious superiority at least in regards to the actual token number of substances required to explain the various phenomena of existence (even if perhaps not causal unificatory superiority)? Here again it seems as if Supersubstantivalism would have no luck, the Monistic Relationalist could argue that there is just a single substance, say a field, and thus the two are still on equal footing.[82]

So, Supersubstantivalism seems to be tied with Monistic Relationalism (at least in terms of the parsimony of kinds of substances and hence causal unification and the parsimony of token substances). There seems to be only one substantial point the Supersubstantivalist can make in order to argue that it is superior to Monistic Relationalism. There is good reason to think that any kind of Relationalist account, the monistic one included, is impossible because they cannot adequately describe the dynamic properties Einsteinian Relativity gives to the behavior or spacetime.[83] Hence, to sum up, Supersubstantivalism seems superior to other kinds of Substantivalisms and all species of Relationalisms with the exception of Monistic Relationalism which only possesses a slight advantage. Consequently, after a comparison of the various advantages that Supersubstantivalism holds over its rivals it is reasonable for one to conclude that Supersubstantivalism is, if not the best explanation for the nature of spacetime, then at least

[82] I find this kind of Relationalism extremely interesting since I'm not entirely convinced that Supersubstantivalism and this view may not be entirely mutually exclusive (i. e. the spacetime substance and the single unified field are actually the same substance). However, to properly examine this possibility one would need to take a long look at the metaphysical status of fields and their nature and ontological status. Such an endeavor would entail more than this work intends to perform, this work is intended simply to examine the status of Supersubstantivalism as to whether it is a promising candidate for the best explanation of the nature of spacetime.

[83] See Baker (2004) and Lehmkuhl (2009) for examples of this kind of work. Baker's work focuses on properties of spacetime like the Cosmological Constant which a Relationalist would have a difficult time explaining.

an extremely promising option. Let us continue this examination by now turning attention to some of the other promising contributions of Supersubstantivalism.

What perhaps may be more important than realizing separately that Supersubstantivalism is more parsimonious with regards to the number of entities required in the explanatory story than at least most its competitors, and that Supersubstantivalism is more causally unifying than most of its competitors (monistic Relationalism being the one main exception in both cases), is that Supersubstantivalism is *both* more parsimonious with regards to entities in its causal story *and* that story is more causally unificatory than its competitors. I argue that while each of these facts, by themselves, lend strength to the abductive argument for Supersubstantivalism, it is the combination of these two being simultaneously true of Supersubstantivalism that lends some of the best credence to the truth of this position: it can accomplish both parsimony and causal unification at the same time. It obviously follows that if Supersubstantivalism outpaces its competitors with respect to the parsimony of entities in the ontology and the unification of the causal stories used to explain the world, then Supersubstantivalism outperforms its competitors with respect to the conjunction of those two features. However, it is because these two aspects reinforce each other that their conjunction provides more support to the position than either of them being considered in isolation would. Parsimony is certainly an explanatory virtue on its own, as is causal unification (i.e. having one causal story to explain three things in lieu of three causal stories to explain three things), yet I argue that an explanation that can increase its causal unification to a maximum degree by utilizing a maximum degree of parsimony is the better explanation (as long as the parsimony is of a relevant kind, which I argue the parsimony of number of substances, and types of substances, needed to be posited is). And I argue it is more than just a simple addition of the two explanatory virtues, there is something about the nature of causal unification which makes it increasingly valuable if it can be done with an increasing degree of parsimony. Thus, an explanation which can do both at the same time, is superior to an explanation which can do only one. Granted, causal unification is a kind of parsimony, but not all kinds of parsimony count as causal unification. For example, the rejection of the additional element of phlogiston is an example of parsimony being employed, but there's no causal unification (i.e. different causal stories have not been united into a single causal story). However, the inclusion of both the causal stories of electricity and of magnetism are both united into a single causal story of electromagnetism, and that is a kind of parsimony which results in causal unification (i.e. the rendering of two separate causal stories into a single causal story which explains both explanandi). So, an explanation which possesses both causal unification and ontological parsimony, is better than one which just possesses either causal unification or just plain parsimony (i.e. parsimony which isn't a kind of causal unification). Perhaps another example would be helpful here. If an explanation possesses just plain parsimony it is better than a rival explanation which lacks this parsimony, Einstein's explanation of electromagnetism was superior to Maxwell's original explanation because it lacked an unnecessary entity, the aether. If an explanation possesses causal unification it is better than a rival explanation which lacks this unification, the explanation of the electroweak force (which combines electromagnetism with the nuclear weak force) is better than the explanation of the electromagnetic force. An explanation which both has separate causal unification (i. e. it unifies separate causal stories) and ontological parsimony (e. g. the parsimony of positing fewer substances in a given explanation to explain the same explanandum) is better than an explanation which possesses only one of these improvements.[84]

[84] One may argue that the causal parsimony is entailed by the ontological parsimony, and indeed sometimes it is. However, here I mean to make it clear that the two are technically separate.

So far we've seen that Supersubstantivalism excels in parsimony and causal unification in comparison to most of its competitors (though admittedly it is rather close in some regards), but there is more abductive evidence that could lend credence to the acceptance of Supersubstantivalism and this evidence needs attention as well. In the field of physics there are several persisting conundrums that physicists have long struggled with, and I plan to examine whether the acceptance of Supersubstantivalism could provide significant progress in these various issues. Take Relativity Theory and Quantum Mechanics for example. Relativity Theory provides a story of how the universe functions at large masses and high speeds, while Quantum Mechanics provides a story of how the universe functions at the levels of the very small and minute, and even though Relativity Theory and Quantum Mechanics are both highly verified empirically they are conceptually incompatible. In their current formulations both cannot be jointly applied to systems where both seem applicable (a quantum-scale system with gravitational forces). Relativity Theory presumes things like determinism and continuity while Quantum Mechanics looks at the world as if indeterminism, probability, and measurement all have fundamental roles in the world of physics. Supersubstantivalism, via unified field theory, provides one possible way of reconciling this seeming incompatibility. Physicists Mendel Sachs (2004) and Frank Wilczek (2008) both argue that such a paradigm shift, the adoption of a kind of Supersubstantivalism, seems to lend itself to addressing this seeming incongruity in modern theoretical physics. In fact, there are currently numerous competing theories in contemporary physics which are attempting to fashion the mathematical guts of something like this paradigm shift. In fact, Dennis Lehmkhul (2009) and Hartry Field (1985) also argue that not only is unified field theory the best option for a unified physics as it would resolve the aforementioned incompatibilities, but that such a theory even *presumes* Supersubstantivalism![85] Even though

[85] John Earman (1989) agrees with Field (1985) on this point.

this benefit is only potential (obviously we do not currently have empirical evidence validating something like unified field theory), it is an extremely pragmatic one, and so it's fair to say this point certainly doesn't detract from the appeal of Supersubstantivalism, if anything it improves it.

iv. What Supersubstantivalism Can Do for Physics

However, there are still more reasons why we should consider Supersubstantivalism as the best current understanding of the nature of spacetime, and many of these can be found in the conundrums of physics. Each of these add strength to the abductive argument, but for brevity's sake let me demonstrate this potential by examining a prime example of what I am talking about. By way of demonstration let us examine what I think is perhaps the most important mystery that Supersubstantivalism could help answer (though it certainly isn't the only one). Einstein's Special Theory of Relativity predicts, among other things, that energy and rest mass are equivalent (per a factor of the speed of light). It has never been entirely clear in physics how this prediction is supposed to be understood, and while various ways of handling this issue have been developed these ways seem to raise just as many questions as answers. There seem to be four possible interpretations here: 1) mass and energy are not the same property, nor do they convert the one to the other; 2) mass and energy are not the same property, but they do convert one to another; 3) mass and energy are the same property, and they do not convert one to the other; and 4) mass and energy are the same property, and they convert one to the other.

Some, like H. Bondi and C. B. Spurgin (1987), have argued that the equivalence involves nothing more than two completely different properties which have equivalent magnitudes (option 1). Others, like W. Rindler (1977), argue that the two are different properties which enjoy some kind of transformation from one to the other (option 2). And still others, like A. Eddington

(1929) and R. Torretti (1996), argue that the two are in fact the same property and that this sameness explains the equivalence (option 3).[86] If Eddington (1929) and his camp have the right of it, and I shall examine if this fact is likely or not, Supersubstantivalism could be used to fill in this mysterious element left in their explanation, and if so then this fact would be an extreme benefit to Supersubstantivalism. So, I shall examine whether Supersubstantivalism can help explain this equivalence and solve a long held puzzle in physics. If it can, this fact would lend yet more strength to the abductive argument for Supersubstantivalism.

First, we should see if there is good reason to accept option 3, and thus need Supersubstantivalism to help understand how the two seemingly different properties can really be the same property of one thing. Let us start with option 1 and the argument Bondi and Spurgin (1987) give for why one should believe that Einstein's equation does not mean mass is equivalent to energy, nor that the two are the same property. Bondi and Spurgin (1987) argue that Einstein's equation no more establishes that energy and mass are equivalent than $m = \rho V$ establishes that mass and volume are equivalent. They argue that while it is the case that their scalar values are equal they are measured in different dimensions. However, consider the following argument which is commonly used to demonstrate that mass really does get converted to energy (or that they are the same property to begin with). This argument utilizes G. N. Lewis and R. C. Tolman's law for the conservation of momentum (1909), which itself only depends on assuming a principle of relativity--a principle which neither Bondi nor Spurgin will argue with. Lewis and Tolman's (1909) law of momentum conservation says that the sum of the momenta of a system multiplied by the Lorentz factor is always equal to a constant. This law of

[86] Obviously, no one would seriously consider logical option 4.

conservation, taken with the relativity principle, allows one to conclude a conservation of energy as well[87]:

$$\sum_i E_i = m_i c^2 / \sqrt{1 - v_i^2/c^2}$$

Lewis and Tolman (1909) ask one to imagine two particles with equal rest mass moving at $\underset{v}{\rightarrow}$ and $\underset{-v}{\rightarrow}$ which collide in a perfectly inelastic collision. What these two scientists show is that the energy before the collision would be:

$$2m_0 c^2 / \sqrt{1 - v^2/c^2}$$

where m_0 is the rest mass. After the collision occurs the velocity has no choice but to go to 0, inelastic collisions are ones contrasted against elastic collisions (i. e. one in which the particles bounce off each other). Technically speaking an inelastic collision is one in which kinetic energy is not conserved (though momentum and overall energy is conserved). Thus, the energy after collision is just $2M_0c^2$, where M_0 is the rest mass after collision (you leave unknown whether or not $m_0 = M_0$). By the conservation of energy:

$$2M_0 c^2 = 2m_0 c^2 / \sqrt{1 - v^2/c^2}$$

[87] In addition to Lewis and Tolman's (1909) work on this subject, E. Zahar (1989) also demonstrates that the one law can be used to derive the other given the principle of relativity.

Obviously we can simply divide the 2 from each side as well as c^2, and we are left with the result that the rest mass after collision is the same thing as the rest mass before collision divided by the square root of 1 minus v^2/c^2. So, the rest mass after collision *must* be greater than the rest mass prior to the collision. This *Gedankenexperiment* seems to demonstrate that energy and mass can be converted one to another.[88] After all what else could have happened when the removal of a velocity (it went from being in motion to being at rest) and nothing else leads to an increase in rest mass in order for the equality to be maintained? The velocity, and nothing else, was removed and the rest mass, and nothing else, increased. The removal of the one leads to an increase of the other and while this information isn't enough to make it clear exactly how this "conversion" happened but it is enough to suggest a "conversion" did occur. That is to say, at least this experiment demonstrates that there is a regularly re-occurring dynamic where disappearance in velocity is followed by an increase in rest mass, and this case is enough to at least suggest that the energy has been converted to mass.[89]

Let us turn to talk about causation, does this correlation imply causation? Does the disappearance in velocity *cause* the increase in rest mass? I answer that there is a very high degree of certainty here that yes one did cause the other (no other explanation seems to lend itself). I'm not going to pick a particular view on the guts of causation here, rather I'm going to let the reader pick his or her favorite as I don't think which theory it is ultimately will affect this point. So, feel free to use anything from David Lewis's (1986) counter-factual view of cause to Wesley Salmon's (1984) mark transmission theory of cause. What is to the point is that I think the following criteria are needed for a reasonable causal claim to be made:

[88] Another great example is when an electron/positron pair collide and annihilate each other: $e^- + e^+ \rightarrow \gamma + \gamma$.

[89] I want to be clear though, at this early stage I'm not suggesting some kind of physical or metaphysical conversion is happening (although that could be the case) only that a dynamic conversion describable by this law is happening.

1) Event B must immediately follow Event A in time (this criteria eliminates B causing A unless you allow for backwards causation).
2) There is no third Event C which caused both B and A.
3) Event B and A occurring are not the result of chance or coincidence.
4) There is not any other Event D which it is more plausible to think caused Event B.[90]

If those four criteria are met, I argue one can make a warranted causal claim that event A caused event B. I think these criteria have been met by the loss of velocity and the increase of rest mass, and so I argue it's safe to conclude that the loss of velocity caused the increase in rest mass. If that weren't the case the increase of mass, one which has no other obvious source save the energy loss, would result in violation of long-held conservation laws. Hence, given that Einstein's derivation isn't flawed, and this fact is supported by scholars like Roberto Torretti and John Stachel (1982), a close look at the conservation laws and the relativity principle here demands that we consider abandoning Bondi and Spurgin's (1987) interpretation. It seems that either the two are distinct properties which somehow "convert" one to another like Rindler (1977) argues, or the two must really be one and the same property viewed from different perspectives like Eddington (1929) and Torretti (1996) argue (I'm not yet claiming that one or the other is the right way to look at the situation, just that it seems wrong to think neither occurred).

Now let us turn to the idea that the two are somehow metaphysically transformed one into the other. Marc Lange (2002) provides several arguments which purport to demonstrate that this transformation does not occur. He argues that only mass, particularly rest mass, is real. Energy, on the other hand, is not Lorentz-invariant, the measure of it can change depending on

[90] All four conditions here are intended as necessary, but the conjunction of all four are sufficient. However, one may object to this set of conditions that simply because you lack no more plausible cause of B than A could be that you are simply ignorant of what kinds of things cause B. Yet, isn't that exactly what a reasonable abductive argument claims? They claim that, unless more information comes to light, event A is the most reasonable cause of event B. If more information were to come to light however, then this conclusion may have to be overturned, but unless this information has emerged I argue that it is reasonable, at least at this juncture, to conclude that A causes B.

which frame of reference it is measured from. Rest-mass on the other hand *is* Lorentz-invariant, measured from any reference frame a given mass is always measured as the same value. Only Lorentz-invariant properties are objectively real, so he argues. Since one property is "real" (i. e. it describes an objective fact of reality) and the other property isn't, the two cannot be somehow physically or metaphysically transformed from one to the other. Thus, Lange argues, mass and energy cannot be converted one to the other, and this argument seems to be a rather effective way of showing that Rindler's position is not viable either.

So, since no one would seriously be interested in the view that energy and mass are the same property *and* they convert, then by the process of elimination we can move on to the position that I assert is both the correct one, and the position I will argue Supersubstantivalism can seriously benefit. The position I'm advocating here (position 3) is insisting that these two properties are actually one and the same property of an underlying substance, and both are "real," even by Lange's standard. As Lange himself admits, it seems that if mass and energy in Einstein's equation are both real properties then "plainly just two ways of expressing the same property" (Lange 224).[91] There is obviously a kind of energy mass is equivalent to which is Lorentz-invariant: rest-energy E_0. Since the so-called rest-energy is also Lorentz-invariant it is thus also "real" by Lange's standard. If the two are both "real" then by Lange's admission the two properties are really one and the same. Thus, it is the case that some energy is equivalent, and exchangeable, to mass.[92] Now, this result obviously does not mean that all energies are the same thing as masses, but that it is the case that mass and energy *can* be the same thing.

Now, again, the position I'm advocating for the Supersubstantivalist is that the two, mass and energy, are really two sides of the same coin (*i. e*. the two are ultimately the same property

[91] For the record, by "Einstein's equation" I mean $E_0 = \gamma mc^2$.

[92] Here the term "exchangeable" is meant to signify that either the mass and energy are the same thing or that they are transformable one to the other.

of a single underlying substance). Lange himself even notes one of the best reasons to accept that these two things, rest-mass and rest-energy, are the same property. In the case of a system of gas where we examine it as a set of molecules we can add kinetic energy to it by heating it up, but when we switch to the perspective of the body of gas as a whole that additional kinetic energy now appears as a part of that thing's mass. He writes:

> What was kinetic energy contributed by the heat in the original perspective becomes part of the gas's mass in the new perspective. This 'conversion' of energy into mass is not the transformation of one kind of stuff into another...we have just seen that this 'conversion' of energy into mass is not a real physical process at all. *We* 'converted' energy into mass simply by *changing our perspective* on the gas: shifting from initially treating it as many bodies to treating it as a single body. (Lange 236)

What seemed like one property in one vantage point, seems like another in a different vantage point. This fact certainly seems to be good evidence that the two properties are one and the same property, just as the Supersubstantivalist here contends.

However, one may object as Lange (2002) has asserting that while "[a] body's energy (γmc^2) and 'relativistic mass' (γm) are plainly just two ways of expressing the same property, differing merely in units. But this property is *not* objectively real, since it is not Lorentz-invariant” (224). Fortunately for the Supersubstantivalist however, this argument overlooks one very crucial point. There *is* a type of energy that's Lorentz-invariant. As Lange clearly holds, Einstein's infamous equation shows that mass can be converted into energy (although again he insists that this conversion is not a metaphysical transformation of one substance into another; it's only a dynamic). Keep in mind that this equation holds for all kinds of mass, including rest-mass, which is Lorentz-invariant. Thus, for any given rest-mass there is--on pain of Special

Relativity being false--an equivalent amount of, if you will, rest-energy that accompanies rest-mass.[93] So for any given rest-mass, there is a corresponding thing, let's call it rest-energy.[94]

Now, an opponent could argue, how can this be the case if mass is not additive but energy is?[95] Two main ways of addressing this concern comes to mind. First, one could argue that being additive is a matter of perspective (consider examples of bodies of gas molecules that have are given more kinetic energy, their kinetic energy creates a large mass only when you switch perspectives from individual molecules to the gas as a whole). So, additivity is not something essential to property itself of its identity, it seems to be based on perspective (not a frame of reference!). Hence, one aspect of a property being additive, based on perspective, is not evidence that that aspect cannot be of the same property as another aspect that isn't additive based on perspective. Second, if one accepts that mass and energy are two aspects of the same property, as linked by Einstein's infamous equation, in the first place then there is no "mass defect." The mass which is lost in "mass defect" examples are easily accounted for by Einstein's equation, in the sense that the mass lost can easily be accounted for in energy gained, and thus as long as one accepts a Law of Mass-Energy-Momentum Conservation instead of separate conservation laws the loss is readily accounted for.

So, with option 3 (*i. e*. that mass and energy are the same property, but do not convert one to the other) how do we metaphysically understand this equivalence between mass and energy?

---

[93] Francisco Fernflores (2012) argues the same.

[94] In fact, L. B. Okun (1989) argues that the very concept of relativistic mass is an antiquated one, which is not used by physicists but merely remains in the popular imagination because of an inaccurate understanding of Einstein's work. Okun argues that modern physicists have a single mass concept which is invariant: $m = \sqrt{(E^2 - p^2)}$. So, if we follow Okun then the argument is thereby strengthened since we have only one "real" invariant mass, and by Einstein's original equation $E_0 = m c^2$. The E_0 is rest energy specifically. So, Einstein's equation is actually indicative of two Lorentz-invariant things.

[95] Take from example the case of the tritium nucleus (one proton, two neutrons) that decays into a helium-3 nucleus (two protons, one neutron, an electron, and an anti-neutrino), in this example the mass of the former is not equal to the mass of the latter. So, there is a mass defect here, where a portion of mass seems to vanish. Thus, mass is not additive.

What does such a view look like? Elie Zahar (1989) is one such example. He argues that adopting this same property view of mass and energy leads to the following conclusion: the previous distinction between the two physical entities of our world, matter (defined by mass and energy) and fields (defined by energy), no longer holds water.[96] Zahar argues the failing of this previous distinction is evidence that there really is only one substance (spacetime), and a single property (mass/energy), which gives rise to both matter and fields. The Supersubstantivalist would presumably argue that their position could provide a much richer version of Zahar's view (1989); namely, that spacetime fabric *is* that single substance which exhibits a single property of mass/energy which describes a vital element of this single entity! This addition to Zahar's view (1989) provides a consistent, detailed account to explain the mass/energy conversion of Special Relativity. If correct, I argue that this fact would significantly add to the attractiveness of Supersubstantivalism as an explanation of the nature of spacetime. Adding Supersubstantivalism to Zahar's interpretation (1989) provides a much richer, and more complete, answer to this long-held puzzle of theoretical physics.

I will not reproduce Einstein's own derivation of the equivalence of mass and energy, but rather I will take it to have already been proven and as such can be referred to like any sound derivation.[97] I will take as a true premise Einstein's equation that the energy of a system is equal to the rest mass of that system multiplied by the speed of light squared, and that Zahar's position

[96] Einstein and Infeld (1938) argue for this position as well. Although some modern philosophers, such as Fernflores (2012), argue this distinction between matter and fields is a bit archaic. In the contemporary Standard Model rather than having a clear distinction between matter and fields there are rather fermions (particles which tend to associate with "hard" matter like quarks and electrons) and bosons (what are sometimes called force carriers, some of which have a non-zero rest mass and some which have a zero rest mass). In any event, for the purposes of the current discussion I believe it is safe enough to overlook this recent distinction and for the sake of simplicity continue to focus on the most fundamental furniture of the universe having mass and/or energy as core attributes.

[97] It should be noted however some, like M. Lange (2001), have questioned the validity of Einstein's derivation, but Roberto Torretti and John Stachel (1982) have demonstrated that the derivation is sound. Moreover, I think there has been sufficient empirical verification of the equivalence as well.

is one of the most promising interpretations of this famous equation. I will now turn to examining Zahar's position (i. e. that mass and energy measure the same property) that the equivalence has ramifications for the nature of matter and fields, and look more closely at how Supersubstantivalism can benefit this position. My ultimate goal here is to show that there is a strong abductive argument to be made for both theses, and that taken together they can inform one another such that the end result is a hybrid of the two which provides a very parsimonious and causally unificatory explanation of the universe, and as such there are convincing abductive grounds on which to accept not only the same property interpretation of mass/energy equivalence but more importantly there are convincing abductive grounds on which to accept Supersubstantivalism.

If mass and energy are the same property viewed under two different perspectives then the distinction between the types of physical stuff in the world which used to be thought fundamental breaks down. If one understands the physical world as having two kinds of physical substances which are defined by mass and/or energy, this same property interpretation favors the elimination of distinguishing these different types of fundamental substances as distinct. This one type of substance is what is basic in the universe, and everything else beyond that one substance and its direct properties are matters of perspective and appearance. If there is no longer any way to distinguish the types of fundamental substances as distinct it follows that there are either distinct fundamental entities but no way of determining that there are two, or there is only one type of fundamental substance, as well as one token substance, out of which we get the physical things of our universe. I argue the former view is one that seems to have no epistemic motivation. Thus, I argue it is reasonable to conclude the latter.

With there being only one kind of fundamental substance we are left with a quandary: what is its nature? Zahar (1989) argues that this mysterious substance is some *je ne sais quoi*. I argue a spacetime fabric capable of possessing properties (e. g. mass energy, or the stress-energy-momentum tensor) is the answer to this question, and its nature is detailed by dynamical laws of a unified field theory. As I mentioned previously, unified field theory seems to be the best chance physics has of providing one set of laws which can describe all four known forces as well as the behavior of the various subatomic zoo of particles. I argue that it seems this view is the best contrastive view to adopt about the nature of spacetime and the nature of the universe. The result of adopting this view is that we have one substance in existence, the spacetime fabric, and that spacetime fabric possesses properties on certain regions of it like mass-energy-momentum tensors. The result is that all matter and all fields are grounded in this same individual substance. This one fundamental substance, spacetime, has various properties at various coordinates and these are what ground all non-fundamental entities.[98] And while we can give more macroscopic causal accounts of how the non-fundamental entities behave this ability is so precisely because those causal accounts are themselves grounded by, ultimately, a causal account which appeals to a single substance and the dynamical laws it obeys. Thus, all causal accounts are unified in this one universe-wide causal account of the entire universe and how the various fields (I say fields here because one can understand this view to have reduced everything down to fields of properties on spacetime) are behaving on it. In fact, as I alluded to earlier, Bertrand Russell (1954) can even be seen as arguing for this kind of Supersubstantivalist view. Russell writes, "...the difference between 'matter' and 'empty space' is, I believe, merely a

[98] One possibility here could be that the non-fundamental entities are being made using unrestricted mereology. Ted Sider (2001) even ostensibly seems to be arguing for such a position, although I'm not convinced he has actually claimed to be a Supersubstantivalist since he does not seem to completely rule out Relationalism in his book.

difference as to the causal laws governing successions of events, not a difference expressible as that between the presence or absence of substance, or as that between one kind of substance and another" (Russell 121-122). Russell makes it clear that matter and empty space shouldn't be regarded as different substances, but rather as only being distinguished by the kinds of causal laws which are applicable to a given region. Thus, I argue that the work Supersubstantivalism can do by adding itself to the same-property view of mass/energy equivalence, which seems to be work no competing candidate can quite accomplish as parsimonious or as causally unified, adds still more to the loveliness of Supersubstantivalism.

In fact, I argue that the current state of physics suggests that Traditional Substantivalism is no longer a viable option in the spacetime debate at all. Traditional Substantivalism holds that there are, at least, two fundamental kinds of substances in our world: spacetime and physical objects. However, as has been demonstrated, if one conceives of spacetime as property bearing spacetime, believing that physical objects are some kind of distinct substance from spacetime becomes a superfluous belief, what possible purpose could this belief serve? A close look at Einsteinian Relativity establishes that physical objects are designated by mass and/or energy, and in modern physics this property is typically depicted as a mass/energy/momentum-stress density tensor (usually depicted as $T_{\mu\nu}$), all particles and fields alike have mass/energy/momentum-stress density tensors that describe them. If something is a physical object it must have this second-order tensor which describes it at least in part, if something is not described by this tensor it is not a physical object.

However if one accepts that spacetime is a substance, and thus can be the bearer of properties, one can understand the "mark of the physical," this tensor, as being possessed by a particular region of spacetime. If one allows for the preceding, what need would there be to posit a second type of substance which exists on top of the first type of substance and which bears the property of the tensor even though the substance of spacetime could just as easily serve this same explanatory role? It seems that there is no need, nor role for this second type of substance to play if one has already accepted Substantivalism and Einsteinian Relativity. As such, it would seem that Traditional Substantivalism is a metaphysically bloated theory which posits superfluous substances, which I argue is always avoided in judging competing explanations in abductive arguments. Thus, in the same tradition as Russell (1954), I argue Traditional Substantivalism is no longer a truly viable option in the contemporary spacetime debate. The real debate is, I assert, between Relationalism and Supersubstantivalism, and Supersubstantivalism is the better explanation of the two. As the better of the two it is thus the better option to select when answering the question: what is the nature of spacetime?

v. What Supersubstantivalism Can do for Metaphysics

With that being said, I also believe there are several other pragmatic reasons for accepting Supersubstantivalism outside of ontologies, causal stories, and physics. For example, there are some notable metaphysical and epistemic motivations for accepting Supersubstantivalism as the nature of spacetime. Each of these add their own individual weight to the benefits of accepting Supersubstantivalism as the correct explanation of spacetime, but since I am not personally advancing any of my own novel arguments with regards to them I will simply list some prime examples of the various works I have in mind.

The work of Terry Horgan and Matjaz Potrc (2000) is an example of some of the other metaphysical and epistemic motivations for Supersubstantivalism. Horgan and Potrc argue that the upshot of Supersubstantivalism is that "...the position, because of the combination of its dramatic ontological parsimony and its capacity to accommodate ordinary and scientific claims as genuinely true, is a viable metaphysical-cum-semantical position that deserves to be taken very seriously and to be further articulated and explored" (Horgan and Potrc 1). Horgan and Potrc argue that, among other things, Supersubstantivalism, or what they call Blobjectivism, can provide a theory which has "metaphysically lightweight" posits and a way of explaining how vagueness comes about, and I have already discussed the position's connection to philosophical vagueness. My point here is that even though I believe the considerations I've already put forth concerning austere parsimony, the tremendous causal unification, and the key advancements in the understanding of some of the cornerstones of our modern understanding of the physical world that Supersubstantivalism provides is enough to make Supersubstantivalism the better contrastive explanation, my points seem to be just the tip of the iceberg when it comes to the explanatory virtues this thesis provides. As Horgan and Potrc state, this position most certainly warrants serious attention and further work. I cannot underscore just how much potential this view has in not only addressing the spacetime debate but also numerous other philosophical issues such as metaphysical issues like the nature of vagueness, philosophy of physics issues in quantum mechanics, and philosophy of religion issues.

I believe the preceding examination has demonstrated that the mounting abductive virtues of Supersubstantivalism are sufficient to demonstrate that there is a considerably good reason to accept, or at least strongly consider, this thesis as the best explanation of the nature of spacetime. As such, I argue this view demands considerably more attention than has previously been given it, as it seems poised to potentially reap a considerable amount of philosophical benefits in several areas.

Chapter V: The Hole Argument and Supersubstantivalism

i. Introduction to the Hole Argument

The debate over the ontological status of spacetime, as we have seen in the previous chapters, is the debate over what the best explanation of the properties of spacetime is (i.e. does spacetime constitute a substance above and beyond the relative properties of physical objects). This debate's three main types of positions: Relationalisms, monist positions which claim that material objects are the only fundamental substances in existence and that spacetime does not exist independently of these material objects and the relational properties they possess between themselves; Traditional Substantivalisms, dualist positions which claim that since spacetime does exist independently of material objects and their relational properties there are two fundamental kinds of substances in the universe; and finally Supersubstantivalisms, monist positions which claim that not only does spacetime exist independently of material objects but that the converse happens *not* to be true, material objects do *not* exist independently of spacetime and as such spacetime is the only fundamental substance in the universe.[99] In the past, the first two options, Relationalisms and Traditional Substantivalisms, were often looked at as the main contenders in this debate over whether spacetime exists as a fundamental type of substance. However, as I've argued I think it is reasonable to assert that parsimony concerns can readily refocus the debate as being primarily between the two monist types of options Relationalism and

[99] My description of these positions as monist and dualist are respective to the minimum amount of substances that the respective view commits to, it is certainly possible that each of these views could hold that more fundamental types of substances exist if one adds to them other kinds of substances like immaterial souls. Obviously, it is entirely possible for any of these views to be added to a view which posits immaterial souls and thus the minimum number of basic types of substances would increase. Thus, when I call these positions monist or dualist I am referring to the minimum number of types of substances the view would adhere to, and not necessarily the actual one or the maximum one.

Supersubstantivalism. I've tried to make a powerful argument that there is good reason to suspect that parsimony and causal unification can elevate Supersubstantivalism to the superior type of explanation of the nature and properties of spacetime.

However, even if I have succeeded since the work of John Earman and John Norton (1987) Relationalisms have been seen to hold a very important trump card over any specie of Substantivalism, Supersubstantivalisms included—the Hole Argument.[100] Hence, it seems that if any kind of argument based on parsimony and causal unification can be utilized successfully to argue for Supersubstantivalism it must also be coupled with a way to disarm the Hole Argument, or at least demonstrates that it is not the new significant worry for Substantivalism and Supersubstantivalism that it has been depicted as in the previously referred to scholarship. The Hole argument is, after all, the chief objection Relationalists tend to raise against Supersubstantivalism. It is the purpose of this chapter to provide an argument that dulls the teeth of this Hole Argument, I will demonstrate that the Hole Argument is not a new and formidable opponent of Supersubstantivalism. Instead, I will argue that the Hole Argument is nothing more than a modern version of the same objections Leibniz delivered hundreds of years ago. It is a new, perhaps more sophisticated, way of looking at Leibniz's original problem, but it is not a new and more significant problem than what was noticed by Leibniz long ago. The Hole Argument is nothing but a glorified, albeit complex, version of Leibniz's original argument, and thus it's not a new significant threat, which it is often seen as, for Supersubstantivalism. That is to say, it's at least not any more of a threat than Leibniz's original arguments are.

Now, granted, some might say, so what? Aren't Leibniz's original arguments enough to show that Supersubstantivalism is false? What does all of this matter have to do with the

[100] For more on this consensus of the importance of the Hole Argument see Butterfield (1989), Earman (1989), Maudlin (1990), Norton (1987, 1992, 1993), and Bartels (1994, 1996).

viability of Supersubstantivalism? If the Hole Argument is simply a more complex spin on the Shift Arguments Leibniz introduced then to inoculate Supersubstantivalism against its threat one needs to examine those original arguments and see if they warrant sufficient grounds upon which one should disregard the huge preponderance of benefit which I have argued is gained by accepting Supersubstantivalism as the best explanation of the nature of spacetime. I will argue no, the original arguments of Leibniz do not provide sufficient reasons why Supersubstantivalism should be judged not viable as the best explanation of spacetime. I will argue that at the very *best* Leibniz's arguments show that Supersubstantivalism could have indeterministic elements, but that alone isn't sufficient to dismiss Supersubstantivalism given all the superior elements it does possess over Relationalism. In particular, I will suggest that arguments, like Baker (2004), are the best indication that the Hole Argument and Leibniz's arguments do not provide sufficient grounds on which to dismiss any specie of Substantivalism, because they are equipped to explain accepted features of spacetime that Relationalism cannot.

This chapter begins by briefly tracing the general train of thought of how the middle dualist option of Traditional Substantivalism can be eliminated by considerations of parsimony and how the Hole Argument is often seen as the chief card the Relationalist has against the Supersubstantivalist. Following this section the chapter will then proceed to provide a detailed explanation of the both the Hole Argument itself and its history, as well as its recognition of being a *new* formidable opponent for any Substantivalist. Once this point has been established the chapter will then turn to demonstrating the Hole Argument is nothing but complex version of Leibniz's original arguments, and as such it does not qualify as the new formidable threat it is often seen as. Furthermore, it will be shown that the real question is do the original arguments of Leibniz constitute sufficient evidence to overlook what I argue is evidence that

Supersubstantivalism is, at best, the best explanation of the nature of spacetime, or, at worst, a promising candidate for such an explanation which deserves much more philosophical attention and focus than it has previously in the past--the terrain of the spacetime debate has forever been changed. Moreover, I will try to draw attention to what I think is the best chance Supersubstantivalism has to overcome the challenge put forth by arguments from indeterminism like Leibniz's, and expand on this argument in a way which could potentially provide empirical evidence about whether Supersubstantivalism is a better explanation of the nature of spacetime than Relationalism.

Let me begin then by saying that when I argue that the Hole Argument does not pose the new serious threat to Supersubstantivalism that is often construed as posing, the argument I am making is of course equally applicable to Traditional Substantivalisms, but I will focus my concern with only Supersubstantivalisms because I think that Traditional Substantivalisms can be eliminated based on parsimony reasons. Bertrand Russell (1954) advocates just such a position. He argues that it is redundant to argue that spacetime exists, and on top of that substance there are other substances that act as holders for the properties of objects even though the substance of spacetime, which is already there, could readily serve this purpose. The fact is if we posit the existence of some kind of substance to be the holder of the properties we find in the objects of our physical world, and we have good reason to think that spacetime constitutes just such a substance (which both Traditional Substantivalisms and Supersubstantivalisms assume), then there seems to be no good reason why we should posit a secondary type of substance, namely physical objects, on top of the spacetime substance to be the holder of these properties. Spacetime can just as readily be the immediate holder of these properties, and if we posit both substances we wind up with a proverbial "fifth wheel." If we already believe spacetime is a substance, properly so-called, and that we need a substance to be the holder of the properties we observe in our world in things like cats and dogs, why would we posit *another* substance to be the holder of those properties when we already have one?

Consider the following example where you are making a pizza for a friend and yourself. You love the taste of deep dish pizza crust, and so the first thing you do is put the dough for this deep dish crust on the oven sleeve which will eventually be placed in the brick oven. After you do this part, your friend sticks her head in the kitchen and tells you, "Don't forget that we have toppings to put on the pizza, so you need to put down some crust to act as a placeholder for the sauce and toppings we have to put on the pizza."[101] Now, in such a situation, who in his or her right mind would think, "Oh right, I have to have something for the sauce and toppings (i. e. the properties) to be on, I better add a new layer of crust for that purpose." Obviously you wouldn't, you would instantly realize that the deep dish crust you have already put down readily serves that purpose, and as such no additional crust is needed in order to contain the sauce and toppings. The conclusion, I argue, that is to be drawn from this line of reasoning is that Traditional Substantivalism, as classically understood (Lawrence Sklar 1976), is an out-dated and obsolete theory, one which we have no good reason to hold on to anymore—if we ever did. If one is so disposed as to want a type of Substantivalism, why not choose Supersubstantivalism since it is the more parsimonious option (i.e. it avoids positing a pointless extra substance(s))? Therefore, I argue once we jettison Traditional Substantivalisms as a kind of option in the spacetime debate we are really left with just two possible types of explanation of the properties and nature of spacetime: Relationalisms and Supersubstantivalisms.

Now, Relationalism, as a thesis, is itself originally also motivated by concerns of parsimony from thinkers like Gottfried Wilhelm Leibniz (1999) and Ernst Mach (1960). These

[101] The crust can be understood as a kind of container which holds the "properties" that make up the pizza.

thinkers believed it was more intuitive to believe that physical objects actually exist, and that it was superfluous to posit another substance on top of physical substances to explain spacetime which they argue could be readily explained by appealing simply to the relational properties that the physical substances possessed.[102] However, following the work of these thinkers our understanding of the dynamics of spacetime has blossomed to the point where it seems less and less likely that all the properties and dynamics physics attributes to spacetime can be accounted for by only appealing to properties of physical objects.[103] Consequently, the initial motivation for Relationalism has been compromised by the emergence of properties, like the Cosmological Constant, which are seemingly possessed by spacetime itself and not physical objects. The initial intuitive parsimonious motivation for Relationalism now betrays it as it insists that just as Relationalism is more parsimonious than Traditional Substantivalism, and thus should be preferred over it, Supersubstantivalism should be insisted on even more so because it is that much more parsimonious than Relationalism (i.e. spacetime has properties that seem hard to be accounted for with physical object substances, but physical objects do not have any properties that it seems hard for the spacetime substance to account for).

At least I argue that such is the case, as does Oliver Pooley (2012). He maintains, "... [S]ubstantivalism is recommended by a rather straightforward realist interpretation of our best physics. This physics presupposes geometrical structure that it is natural to interpret as primitive and physically instantiated in an entity ontologically independent of matter.... One might

[102] One may notice this reasoning is virtually the inverse of the reasoning I alluded to with Supersubstantivalism. This similarity is not a coincidence, as I will ultimately argue, I think that when it comes down to it one can think of spacetime as the fundamental substance and can coherently conceive of material objects as being reducible to this substance, but that it is not nearly so easy to conceive of material objects as the fundamental substance and spacetime as reducible to them.
[103] This development is a healthy dose of irony considering Mach's work is one of the main things which inspire a young Albert Einstein to develop his infamous theories of relativity which in turn lead to speaking of spacetime as itself possessing things like metrics and the so-called Cosmological Constant. For some examples of work that argues such see the likes of David Baker (2004), Oliver Pooley (2012), and Hartry Field (1985).

therefore wonder: why even try to be a [R]elationalist?" (Pooley 20). Pooley argues that in the contemporary spacetime debate there only remains one chief reason to prefer Relationalism as the best explanation of the properties of spacetime: the Hole Argument. Accordingly, it seems incumbent to address this last significant obstacle to the acceptance of Supersubstantivalism as the best explanation of the properties of spacetime.[104] Thus, I will turn to explaining the Hole Argument and why it is purported to be a threat for Supersubstantivalisms, before I examine the primary response to this argument, as well as my own response to the Hole Argument.

Let us now examine the origins of the Hole Argument, what exactly it maintains, and why it is supposedly so detrimental to Supersubstantivalism. The Hole Argument originally stems from the work of Albert Einstein where a despondent Einstein considers that perhaps his dream of a generally covariant theory of gravity was an impossibility given that he was having such trouble coming up with the appropriate equations. So he attempted to do the opposite, prove that such a thing is in fact impossible. That is to say, he attempted to show that it was, in principle, impossible to have a generally covariant theory of gravity. Einstein's attempt at showing generally covariant theories of gravity were impossible of course ultimately failed, and he recognized this fact and went on to actually create the generally covariant theory of gravity for which he has become so famous. Subsequently this attempt at showing generally covariant theories of gravity were an impossibility was relegated to a rather obscure shelf of scientific history, and it was readily forgotten about in the scientific and philosophical world. It was not until the work of John Stachel (1980 and 1986) that Einstein's work on this so-called Hole Argument came back into notice of philosophers. Stachel's work led to the combined effort of John Earman and John Norton (1987) where the two recasted Einstein's original Hole Argument

[104] Although obviously this assumes the abductive argument for Supersubstantivalism I am referring to succeeds. In this paper I am merely working on diffusing the Hole Argument given that such an argument for Supersubstantivalism is cogent.

using active general covariance to introduce indeterminism into Substantivalist theories. This argument, Earman and Norton argue, is a powerful arrow in the quiver of Relationalism, as it shows that any kind Substantivalism, Supersubstantivalism included, entails indeterminism.

Prior to understanding Earman and Norton's (1987) formulation of Einstein's Hole Argument it is first important to be clear about some of the technical vocabulary which is involved with the Hole Argument. Let us begin by considering the property of general covariance that Einstein originally considered unviable--and indeed initially one would think a theory where all the laws of nature operated uniformly regardless of the frame of reference they occupy would be a fool's errand. For one property, or solution to a function, to be covariant with another property, or solution to a function, the two must vary, under given conditions, at a constant ratio, and so translating these values into any given coordinate system will still yield the same relative numbers (of course if two values do not vary at all from coordinate system to coordinate system they will be trivially covariant as the ratio between them never changes since the values themselves never change). Specifically, the covariant quantity must not deviate from its original relative proportions with respect to the other quantity it is being said to be covariant with; if two properties are translated to a different coordinate set they must both either remain unchanged or at least remain in the same relationship one to the other. However, the term "general covariance" is used to mean something very specific in relativistic physics. Usually general covariance is used in physics to signify laws, or equations, which are coordinate independent. That is to say, something, like a theory, is generally covariant just in case the equations and laws of the theory change homogenously under arbitrary differentiable coordinate transformations.[105] In such a theory the source of the reference frame of the properties found in

[105] Typically covariance refers to equations and constants which do not change form when they undergo things like coordinate transformations. For example, the E and B fields from Maxwell's Equations are covariant, they undergo

the equations does not determine or affect the solution for those equations. What Einstein was searching for with his General Theory of Relativity were covariant equations which could be used to describe the way gravity worked in the universe such that no frame of reference is considered privileged; the equations and their solutions should appear the same in all possible frames of reference[106].

Now on to some vital terminology: a coordinate system, a manifold, and a metric field. All these ideas build on each other. Starting with the most primitive of these mathematical entities we have coordinate sets, fields which utilize numbers, or coordinates, that uniquely determine points in a system. These coordinate systems combine to form manifolds, which are also very minimal mathematical objects, a topological space of locally homeomorphic coordinate systems (homeomorphic to a topological vector space over the reals) of distinct points with disjoint neighborhoods. These manifolds are typically differentiable but they do not include more complex information like distance or angles; you simply have sets of points with locally flat space in their approximate neighborhoods, but you have no idea what the global characteristics of the manifold will be (i.e. the global characteristics could turn out to be that of a sphere or a torus even though locally it is flat and Euclidean).[107] It is a metric field, or metric, which fills in this missing information; a metric captures the geometric and causal (i.e. notions of past and present) properties of a given manifold. Metrics, technically speaking, are covariant

---

coordinate transformations when inertial frames are changed. The fields are translated to other coordinate frames homogenously. This concept is not to be confused with the related concept of invariance, like the speed of light *c* (300,000 km/sec) which remains completely unchanged regardless of what frame of reference it is being considered from.

[106] This point is precisely where Einstein realizes tensor calculus is the key to his covariant theory of gravity. The use of tensors allows one to describe changes to scalars, vectors, and even other tensors without reference to any particular coordinate system.

[107] In more technical terms a manifold is a second-countable Hausdorff space where every point has a local neighborhood homeomorphic to R^3.

second-rank symmetric tensors on a manifold.[108] Fundamentally being a field of tensors a metric defines notions like volume, curvature, and distance in the manifold.

As stated previously, at one point, Einstein produced an argument he thought would demonstrate that such an enterprise of a covariant theory of gravity was a fool's errand (though he later dismissed this idea). Alan MacDonald (2001) describes the process as follows:

> Einstein was aware of the possibility of generally covariant field equations, but he believed -- wrongly, it turned out -- that they could not possess the correct Newtonian limit. He then proposed a field equation covariant only under linear coordinate transformations. To buttress his case against generally covariant field equations, Einstein devised his hole argument, which purported to show that no generally covariant field equation can be satisfactory. When Einstein discovered his fully satisfactory generally covariant field equation for general relativity in 1915, it became apparent that there is a hole in the argument. (MacDonald 1)

Einstein realized that one can take a symmetric spherical region and base one gravitation field off of it, while then making a coordinate change and basing a second gravitational field off of that one. The two are empirically equivalent, but the two are also distinguishable in a mathematical sense and thus there are at least two solutions (actually an infinite number) to any given set of field equations. Thus, the set of equations is unsatisfactory in the sense that it fails to lead to a single mathematical answer for a given situation, a foremost goal of most scientific theories.

Actually however, this argument does, in part, do what Einstein originally set out to do, it does show that as Einstein originally understood the situation there could not be any generally covariant field equations that described gravity. The solution to this problem, Einstein ultimately

[108] Tensors are a further development of vectors. Consider it this way, if a number is simply a magnitude, and a vector is a magnitude with a direction, a tensor is a magnitude with multiple directions (e. g. tension on an I-beam).

realizes, is to make the spacetime metric and the gravitational field for the most part identical—the field can be considered as virtually the same thing! When this change is made the problem created by Einstein's Hole argument disappears, and using this understanding he goes on to create his generally covariant field equations for gravity. Thus, this Hole Argument eventually allows Einstein to gain a valuable insight into the nature of gravity and goes on to help him to understand the full ramifications of General Relativity. However, once Einstein used this Hole Argument to work his way toward his complete theory it then sat unused on the shelf for a very long time. It is not until the late 20th Century that it is revived first by Stachel (1980 and 1986) and then secondly, and more elegantly, by Earman and Norton (1987). What these later philosophers discover about Einstein's Hole Argument is that the points Einstein gleaned from it can be utilized through a reworking of the argument such that it can be used to argue for the thesis of Relationalism.

Earman and Norton’s formulation of the Hole Argument takes what Einstein did with a spherical symmetrical region (a hole) and gauge variance and proceeds as follows to argue that Substantivalisms of any sort result in indeterminacy. Passive general covariance occurs just when a metrical field is translated into a different coordinate system, and eventually Einstein’s entire set of equations end up qualifying as this kind of covariance. However, active general covariance is where the hole of the Hole Argument truly becomes important. Active general covariance is where one takes a distance *d* between two given objects, let's call them P and Q, and relates the distance in one metric to the distance in a completely different metric. These two distances are said to be related by an active diffeomorphism. Active covariance can relate distances in different metrics smoothly, such that no empirical difference is noticed. It is *via* this different take on general covariance, and diffeomorphisms, that Earman and Norton adjusts

Einstein's work to develop the Hole Argument. The active covariance of a symmetrically spherical region or object like the sun or a planet can generate an infinite number of empirically equivalent metrics (and hence gravitational fields since we know the two are basically equivalent under General Relativity). The problem here of course is that such could be produced by any such given region resulting in a situation where there is no way to determine which diffeomorphism, which metric and gravitational field, is actually the case given a position like Supersubstantivalism! The result here is that any observer would not be able to fully predict exactly which metrics and gravitational fields are the case, which is ideally the goal of science and thus these theories Supersubtantivalism would be indeterminate.

So to summarize, this new version of the Hole Argument says the following. A symmetrically spherical spacetime region in a manifold can be given one metric and then, with an active diffeomorphism, a person can find an empirically equivalent metric which is related to the first one by a smooth transformation. The problem is that this argument implies that for practically any region of spacetime there is an infinite number of empirically equivalent, but numerically distinct metrics, which means that the theory does not make a single prediction about the way the world is, like what kind of gravitational field is located there for instance, but instead makes an infinite number of them![109] As touched on earlier, metrics are covariant tensor fields which provide information about the geometrical structure of a given manifold which defines things like distance, curvature, angle, and volume. These metrics allow for any

[109] As indicated previously, a gravitational field according to General Relativity is intended to provide much of the same information a metric does, and so if a particular theory predicts an infinite number of empirically equivalent metrics for a region it also predicts an infinite number of empirically equivalent gravitational fields for that same region. So, for every possible metric which exists that describes a region there is a corresponding gravitational field which exists that also describes that same region because as Einstein's insight in General Relativity goes gravity (and gravitational fields) just are spacetime curvature. This insight comes from what Einstein calls his "*glücklichste Gedanke meines Lebens*" (happiest thought of his life), the realization that gravity and acceleration are in fact one and the same thing, it is this realization that leads to Einstein's idea that a gravitational field is simply the way spacetime behaves in a given region (which of course is why a metric and a gravitational field are virtually the same for General Relativity).

coordinate systems to be translated such that they accurately depict what is occurring empirically, like what gravitational fields are present. For the Relationalist this result isn't a problem, since the metrics are all empirically equivalent there is just the one set of spacetime relations between physical objects and the result can be explained by simple gauge variance.[110] However, unfortunately for positions like Supersubstantivalism each metric seems numerically distinct even if it is empirically indistinguishable from any of its cohorts. Each numerically distinct metric placed on the spacetime manifold means a numerically distinct gravitational field on this view. Thus, it seems a Supersubstantivalist must accept there are an infinite number of possible ways the spacetime manifold, the substance, can be, and there is no empirical way to determine which one a person is in. So, at best, it seems Supersubstantivalisms of all varieties imply indeterminism about spacetime and its properties.

If Supersubstantivalism implies there are infinitely many gravitational fields located at a given region of spacetime which are all empirically indistinguishable, how can one know which is actually the fact of the matter? Is it always the same one? Does it change with time? If it doesn't change, how can we determine which one is really the case? Hence, Supersubstantivalism seems indeterministic with respect to which possible gravitational fields are actually the case according to the Hole Argument, but Relationalism, with respect to this issue, can maintain it is a fully deterministic theory since it predicts exactly one and only one gravitational field for a given spacetime region. And such, the Relationalist argues, is why Relationalisms are the best type of explanation of spacetime and its properties since it doesn't have this fatal flaw.

Let's now provide a more formal version of the Hole Argument. Say there is a massive object, a supermassive blackhole. Consider the Hubble Volume of spacetime surrounding this

[110] Earman and Norton (1987) call this equivalence Leibniz Equivalence.

supermassive blackhole. Let us say for the sake of argument there is nothing else in existence. Since the object, the blackhole, has a great deal of mass it would generate a gravitational field which can be described by a metric, let us call it g(r). If we assume that active general covariance holds in this world then there is a smooth coordinate transformation $r \rightarrow r'$ where r' is the same as r for points which are inside the blackhole's event horizon, but is different for all points outside the event horizon within the Hubble Volume surrounding our supermassive blackhole. The coordinate system inside the blackhole is obviously not affected by the transformation, but the form of the metric outside the blackhole has been transformed. It follows that there are now two metrics, g(r) and g(r'), which both describe the gravitational field created by the blackhole although there is no *empirical* difference between the original world where g(r) describes the gravitational field and the world post-active general covariance where g(r') describes the gravitational field. According to Relationalism g(r) and g(r') are the same gravitational field because they are empirically equivalent, but under Supersubstantivalism g(r) and g(r') describe two different distinct gravitational fields. The question then for a Supersubstantivalist becomes which gravitational field correctly describes the world in question, in this case our world with the supermassive blackhole? Presumably only one possible gravitational field is correct--we would be in one world or the other--but Supersubstantivalism doesn't seem to be able to correctly predict which we are actually in. Thus, the Relationalist argues that the Hole Argument demonstrates that Supersubstantivalism is indeterministic about, at the very least, gravitational fields and metrics, and insofar as this feature is in general a flaw undesirable in our theories about the universe Supersubstantivalism is a worse explanation of the properties of spacetime than Relationalism. Relationalism does not need to accept this same indeterminism since under Relationalism all the various empirically equivalent metrics, and thus the corresponding gravitational fields, are in fact the *same*. As a result of this Leibniz Equivalence the theory of General Relativity under Relationalism only predicts a single gravitational field. So, Relationalism is the better thesis to accept to explain the nature of spacetime and its properties, and it should be accepted on pain of indeterminism.

ii. The Hole Argument Evaluated

The Hole Argument is often seen as the single most formidable argument against Supersubstantivalism in the contemporary discussion on spacetime theory, it is the one obstacle that a serious opponent of Relationalism must confront if he or she intends to successfully argue for the truth of alternate theories like Supersubstantivalism. I will demonstrate first that the Hole Argument is not the novel and profound objection to Supersubstantivalism (and indeed any Substantivalism) that it is often construed to be. Once I have demonstrated that the Hole Argument is nothing more than a complex Leibnizian Shift Argument, I will turn to examine the two major alternatives in the literature for dealing with this so-called threat. I will argue that the Leibnizian Arguments, in light of certain reasons (*i.e*. the fact that spacetime seems to exhibit independent properties beyond those which are derived from the relational properties between physical entities), are not sufficient to overshadow the considerable benefits of Supersubstantivalism and render it no longer the best explanation of the properties of spacetime. In the past the Supersubstantivalist has had two main strategies which have been adopted in order to address this worry of indeterminism raised by the Hole Argument. I will briefly examine both of these strategies, and then argue that in light of these the considerable benefits provided by the acceptance of Supersubstantivalism render the Hole Argument a weak objection.

The Hole Argument is nothing more than an inventive, albeit complex, rendition of a very classical problem for any specie of Substantivalism: the Leibnizian Shift Arguments. Leibniz famously argued that Relationalism is superior to any variety of Substantivalism, Supersubstantivalism included, because it avoids the indeterminism which results from uniformly altering the framework of physical systems in the theory. In Leibniz's famous correspondence with Samuel Clarke (a proponent of Newton's theory on spacetime) he famously argues that any species of Substantivalism will inevitably result in indeterminism because any world with spacetime as a separate substance in it can be altered such that all physical objects inside the spacetime can be changed in a uniform way, say statically shifted to the left by a foot and the result would be imperceptible. From the perspective of any kind of Substantivalist the world with everything moved to the left must be an entirely different world, it can't be the original world because spacetime is an objective entity with objective properties and hence each world would have distinct properties. The Relationalist can simply maintain that the two are in fact the same world, since the relations between the objects haven't changed (i. e. no properties of objective entities have changed).[111] Thus, since the species of Substantivalisms cannot distinguish between the two possible worlds (the original and the statically shifted worlds), but the Relationalisms can it looks like the former is indeterministic while the latter is not. There are multiple physical models that the former cannot distinguish between when trying to predict which physical model will best approximate our actual world.

The entire point of Leibniz's arguments is to demonstrate that the beliefs of the various species of Substantivalism inevitably lead to indeterminism, and thus these positions are untenable. I argue that this point is the exact same as that which is perpetuated by the Hole

[111] Leibniz also has another example of the same point where everything is moving at a constant velocity in a given direction instead of remaining at rest.

Argument: the acceptance of spacetime as a separate substance allows one to create unobservable changes in world such that the respective theory whose ontology includes this separate substance will be unable to distinguish between worlds with the unobservable change and those without it. The Leibnizian Shift Arguments argue that you can cause unobservable changes to the universe because of spacetime's existence as a separate substance, and thus the positions which accept this ontology lead to indeterminism. The Hole Argument argues that you can cause unobservable changes to the universe because of spacetime's existence as a separate substance, and thus the positions which accept this ontology lead to indeterminism. The majority of scholars who write on the Hole Argument freely admit the close connection between the two arguments, what is sometimes called Leibniz Equivalence (Earman and Norton 1987, Maudlin 1988, Butterfield 1989, and Bartels 1994 and 1996).[112] I further argue that the two are really the same basic argument, as they each lend to the same conclusion--one is simply much more sophisticated than the other.

These two pro-Relationalism arguments were used by Leibniz during his lifetime to argue against the concept of absolute spacetime in positions like Newton and Clarke's. The point of these two arguments is that theses which embrace spacetime as a substance, like Supersubstantivalism, inevitably cause themselves to be indeterministic because given the tenets of the respective theory one can readily create a case with two possible worlds that are indistinguishable empirically (i.e. from within the possible world itself), but which are matter of

[112] Although it should be noted that Marco Giovanelli 2011 argues that there is a significant difference between the two arguments. He argues Leibniz's arguments involve global transformations while the Hole Argument involves transformations which occur only on a small local scale. Or as he writes, "Thus in Leibniz-style thought experiments worlds that at first sight *physically different* turn out to be *mathematically identical*; in the hole argument apparently *mathematically different* worlds reveal themselves as *physically identical*" (Giovanelli 25). However, this point seems rather marginal. The Hole Argument is indeed somewhat different, and certainly more complex, than the Leibnizian Shift Arguments, but essentially the conclusion is identical.

fact numerically distinct from one another. The tactic of the Shift Arguments is to use the fact spacetime is a substance on this view to generate a possible world which is empirically indiscernible from ours but is numerically distinct. The Hole Argument shares the same basic strategy, though admittedly the Hole Argument does require and utilize a substantially more complex theoretical and mathematical framework to generate the same result the Shift Arguments do. The Hole Argument utilizes a certain feature of Supersubstantivalism (its claim that spacetime is a substance) to generate two numerically distinct, but empirically indistinguishable, possible worlds. Since Supersubstantivalism cannot distinguish between them (i.e. tell you which you are actually in) but Relationalism can (i.e. claim a false dichotomy is at work and the two worlds are in fact the same world), Relationalism is a superior explanation of the properties of spacetime. The strategy should sound familiar; the Shift Arguments do the same kind of move. Thus, even though the Hole Argument emerges much, much later in the dialogue on spacetime, and even though it utilizes much more sophisticated mathematical machinery than its counterparts, it is really just an elaborate rendition Leibniz's Shift Arguments, and as such, I argue, the Hole Argument offers no more support to Relationalism than Leibniz's original arguments did. They all are saying virtually the same thing, because theses like Supersubstantivalism allow for possible worlds which are formally distinct but empirically identical it leads to indeterminism, but theses like Relationalism do not because it is impossible to create two possible worlds on such a view where two possible worlds are empirically identical but formally distinct. This ability of a theory to generate formally distinct possible worlds which are empirically identical is what is at the root of both the Leibnizian Shift Arguments and the Hole Argument.

However, I argue it is ridiculous to view the Leibnizian Shift Arguments as not being strong enough to cast sufficient doubt on a thesis like Supersubstantivalism, but the Hole Argument is—they should rise and fall together. One essentially says no more than the other. It would be a mistake to interpret the Hole Argument as being any more problematic for a position like Supersubstantivalism than Leibniz's original Shift Arguments are. Leibniz's arguments are certainly worth academic attention, but they demonstrate nothing contradictory, absurd, or false as resulting from Supersubstantivalism only that it is indeterministic with respect to certain non-empirical elements. Given that these two arguments are really just varying degrees of complexity all lending toward the same conclusion the real question becomes what can someone who accepts a kind of Substantivalism say to argue that the acceptance of spacetime as a separate substance is still reasonable and responsible given this charge of indeterminism. Next I will examine the major attempts in the literature to try and accomplish just this feat. Ultimately, I will argue that one tactic in particular seems to be the best way to do so, and I will attempt to build on this strategy.

The first strategy most commonly employed by Supersubstanitvalists against the Hole Argument is to argue that a manifold and its objects cannot be separated from the respective metric which describes it in the first place. That is to say, the manifold by itself does not constitute a substance, only the manifold plus the metric qualifies as a substance. If one maintains that the substance of spacetime is simply the manifold, and any number of empirically equivalent metrics, and thus the corresponding gravitational fields, can be placed upon it such as is described in the Hole Argument, then you get a case of indeterminism because each different metric placed upon the manifold would have to be a different possible world and Supersubstantivalism has no way of deciding which possible world is the actual. However, one could, instead, insist that the manifold by itself is *not* the spacetime substance, but rather that the spacetime substance is the entirety of the manifold plus the metric. I imagine a Supersubstantivalist may wish to even argue that the spacetime substance is at minimum identical to the manifold, the metric, and the stress-energy tensor field that lies over the manifold.[113] The idea of this approach is to stop the Hole Argument before it even gets started by denying one of the initial premises, namely the premise that the spacetime substance is identical to just the manifold itself, and thus any smooth transformations occurring would necessitate not just new metric, and thus an additional gravitational field supervening on the original substance, but an actual transformation of the first substance into a second one. I believe this strategy is a promising one for remedying the difficulties raised by the Hole Argument, but I argue that this approach, while it's potentially a viable approach it actually goes farther than is needed to fix the problem inherent in the Hole Argument.[114]

Another strategy is that employed by James Weatherall (2015). Weatherall argues that the Hole Argument is a product of misleading claims made in the mathematical formalism of the setup, and close attention to the mathematical formalism will block the Hole Argument as we know it. He argues:

> This discussion may be summed up as follows. There is a sense in which [Lorentzian Manifolds] (M, g_{ab}) and $(M, \widetilde{g_{ab}})$ are the same, and there is a sense in which they are different. The sense in which they are the same—that they are isometric, or isomorphic, or agree on all invariant structure—is wholly and only captured by $\tilde{\psi}$. The (salient) sense in which they are different—that they assign different values of the metric to the "same" point—is given by an entirely different map, namely 1_M. But—and this is

[113] Tim Maudlin (1988) and Carl Hoefer (1996) are two examples of this approach.

[114] Another related strategy that has emerged in the past decade is that favored by Luca Lusanna and Massimo Pauri (2008) , which utilizes a mathematical treatment which leads to gauge fixing that prevents the Hole Argument from generating the numerically distinct, yet empirically equivalent, gravitational fields. They argue their position leads to a kind of Structuralism (specifically they call it Point Structuralism) which is a *tertium quid* option that combines the best parts of both Traditional Substantivalisms and Relationalisms.

> the central point—one cannot have it both ways. Insofar as one wants to claim that these Lorentzian manifolds are physically equivalent, or agree on all observable/physical structure, one has to use $\tilde{\psi}$ to establish a standard of comparison between points. And relative to this standard, the two Lorentzian manifolds agree on the metric at every point—there is no ambiguity, and no indeterminism. (This is just what it means to say that they are isometric.) Meanwhile, insofar as one wants to claim that these Lorentzian manifolds assign different values of the metric to each point, one must use a different standard of comparison. And relative to this standard—that given by 1_M—the two Lorentzian manifolds are not equivalent. One way or the other, the Hole Argument seems to be blocked. (Weatherall 13-14)

Weatherall does not make an explicit judgment on whether Relationalisms or Substantivalisms are the better way to understand the nature of spacetime. He only argues that the Hole Argument exploits common misconceptions about mathematical formalisms; at best Weatherall believes the Hole Argument only succeeds in showing that a manifold under two different metrics can be isometric, but of course that is trivially true from the definitions involved. In order to make the two Lorentzian Manifolds empirically equivalent we must create an isometric map, $\tilde{\psi}$, and they are only isometric considered against that mapping. Now, in order to make the claim that the two Lorentzian Manifolds are mathematically inequivalent (i. e. their respective metrics do not agree at all points) we must make this claim relative to a different mapping, 1_M, which no longer shows the two Lorentzian Manifolds as isometric. Weatherall argues one cannot have it both ways, in order to make the claim that the two Lorentzian Manifolds are different, so as to facilitate the claim that there is an indeterminism, one has to destroy the basis by which the two are isometric. Thus, he claims one cannot simultaneously hold that the two are both isometric and not isometric, and hence the Hole Argument does not imply that Substantivalisms are inherently indeterministic.

iii. My Position on the Hole Argument

The strategy I recommend, involves drawing attention to properties of spacetime and accepted scientific theories like General Relativity that indicate spacetime has properties which cannot be readily explained with Relationalism. One of the best examples of this strategy is David Baker (2004). Baker argues that Relationalists cannot explain Λ, or what's called the Cosmological Constant, in Einstein's equations for General Relativity. He maintains, "Therefore, a universe described by a cosmological constant of the sort conceived by Einstein is not a universe friendly to relationism. If the universe's expansion is found to be accelerating, and a cosmological constant introduced into the field equations is the best explanation, then relationism about space and time will become a far less defensible position" (Baker 14). The Cosmological Constant is a term Einstein originally introduced into his equations in order to, at the time, "hold back" gravity and render the universe static.[115] Lambda, the Cosmological Constant, acts to provide a repulsive counterbalance to the attractive force of gravity, something which becomes all the important after it was discovered in 1929 that our universe is actually expanding.[116] It is a term which acts to cause spacetime, irrespective of the matter in it, to expand at a constant accelerating rate, in fact it seems to expand even without matter in it. As such the Cosmological Constant is a bare property of spacetime itself, not the relation(s) of any material objects (it after all occurs to empty space devoid of material objects), a negative energy density that exists as a property of empty spacetime.

This Cosmological Constant, which is widely accepted by modern science, thus seems to be a product of empty space. Baker writes:

---

[115] Einstein believed, initially in 1917, in a static universe which did not expand nor contract, but given his theory of gravity an energy density of a vacuum was needed to keep the universe from imploding in on itself.
[116] In fact now it's known that galaxies in our universe are *accelerating* away from each other.

> In an attempt to vindicate the relationist ideas of Mach and make possible a static distribution of matter in the universe, Einstein introduced the cosmological constant Λ into the field equations of GR. Here I argue that because Λ manifests itself as a constant, repulsive gravitational force between all objects, a built-in tendency of the universe to expand, it is an instance of nontrivial causal powers that we ought to ascribe to spacetime itself. Ironically, then, it seems that observations of a nonzero Λ provide empirical evidence for the substantivalist position. (Baker 2)

The Cosmological Constant is a property of empty spacetime that seems hard to attribute to material objects or the relations between them since Λ seems to exist even in space devoid of any local material objects, and the presence of material objects does not seem to affect the constant. This point of course becomes very troublesome for the Relationalist to explain. Relationalists, as a point of principle, assert that all of nature is composed of material objects, and any properties exhibited should be explainable as belonging to either a material object or as a relation between multiple material objects. However, it seems readily apparent the Relationalist cannot do so here.

Now, one may have the instinct to say, why can't a Relationalist simply argue that in fact there is no such thing as spacetime which has this force acting on it like the Cosmological Constant, just like there are no such things as gravitational waves--there are only material objects which obey law-like relations such that it gives the *appearance* of a substance like spacetime propagating force between the respective objects. As Baker argues however Λ itself doesn't lend itself to this kind of interpretation. For the Relationalist to be right, General Relativity would have to be in some sense flawed. Consider a universe with a nonzero Λ (like our own). Einstein's famous theory of General Relativity gives us the following field equation for describing gravity: $R_{ij} - 1/2\ Rg_{ij} + \Lambda g_{ij} = \kappa T_{ij}$, where R_{ij} is the Ricci Curvature Tensor, g_{ij} is the metric tensor, R is the scalar curvature, and T_{ij} is the stress-energy tensor.[117] In a region of empty space, one where $T_{ij} = 0$, the equation will reduce down to $R_{ij} = \Lambda g_{ij}$. So, since we supposed Λ doesn't equal zero, neither can R_{ij} the Ricci Curvature Tensor. Baker writes:

> Taking the trace of this Ricci tensor, we find that the scalar curvature is $R = 4\Lambda$. Thus we can immediately see that the new field equations entail constant average curvature of spacetime in the absence of matter. The basic, sourceless solution to the field equations is no longer flat Minkowski spacetime; instead, it is dictated by the value of Λ. (Baker 9)

How could a Relationalist explain an empty area of space with such a feature? Well, one suggestion is that perhaps Λ is some kind of physical field which has been projected over the empty spacetime and that's what explains the curvature in the absence of material objects. Baker contends that since General Relativity is a non-linear theory, contributions to the field do not simply add together, and so "Λ's contribution to the metric field cannot in general be isolated from the contribution of matter sources" (10). As such, unless the Relationalist wants to argue that General Relativity is wrong, and that spacetime does not in fact curve as such in the absence of material objects, it seems he or she must admit he or she cannot explain why spacetime, a nonexistent entity, is curved.

Now, it is possible the Relationalist could argue that all this reasoning is just the result of meaningless formalism. After all, it's not like we can empirically test whether this empty region of space is curved like predicted by General Relativity--we'd have to introduce matter to do so. However, Baker argues this matter is easily resolved. Imagine two points O_1 and O_2 where one is accelerating away from the other as a result of Λ. Now, imagine the two are so far apart they are space-like separated, no causal interaction between the two points can occur. Let us use O_1 as a reference point to measure O_2. Given the, by stipulation, nonzero curvature of Λ O_2 will

[117] κ is a shorthand for $8\pi G/c^4$ where G is Newton's Gravitational Constant.

accelerate away from O_1 at a rate proportional to r. So what could explain this acceleration? It cannot be any law-like interaction or law between O_1 and O_2 because no causal interaction can occur between them. Thus, it seems only the curvature of spacetime, according to Λ, can account for this acceleration, Relationalism seems at a loss to explain this acceleration.

Given Baker's arguments against Relationalisms I argue one can go a step further. It is possible that Λ so warps our universe's global spacetime that it is measurable, and if detected I argue this curvature Relationalism cannot explain would be empirical evidence of the falsity of Relationalism. However, according to the most recent data from WMAP, unfortunately for Supersubstantivalism, the current evidence suggests that the global curvature of spacetime is flat within a .4% margin of error. This finding is truly unfortunate, as I argue it could permanently lay the nature of spacetime debate to rest, as a significant amount of curvature globally due to Λ would, given the success of arguments like Baker's, indicate Relationalism is most likely false. However, if the global curvature of spacetime is flat then it shows nothing, both Relationalisms and Substantivalisms could be consistent with that.

In conclusion, the Hole Argument, what is arguably the most significant threat to modern Substantivalist theories, is really nothing but a modern, albeit complex, rendition of the same basic argument advanced by Leibniz in the past. Now, this could still be considered a threat to a thesis like Supersubstantivalism, just as Leibniz's arguments are, but I argue it is not a threat sufficient to make Relationalism the superior explanation of the properties of spacetime given the evidence at hand. Given the theory of General Relativity things like the Cosmological Constant and the curvature of spacetime seem to suggest that a species of Substantivalism is far preferable to Relationalism. Hence, given the abductive arguments made previously for Supersubstantivalism I argue that, all things considered, Supersubstantivalism is one of the best theories currently available which can explain the nature of spacetime, and the Hole Argument is not capable of changing this fact. As a result, I argue, Supersubstantivalism is, at the very least, a thesis worth considerable attention in the near future philosophically, as it is perhaps the best explaination of the nature of spacetime we have.

Chapter VI: Conclusion

I have argued that there is good reason to think that Supersubstantivalism is the best explanation of the nature of spacetime. Supersubstantivalism combines the theoretical advantages of Substantivalisms with the parsimony of Relationalisms. It unites and simplifies the causal stories we tell as well as our ontologies. It helps answer a myriad of conundrums in physics like energy-mass equivalence, and it has the potential to answer many more.[118] Supersubstantivalism even seems to provide a fair amount of benefits for issues in metaphysics.[119] The only significant obstacles to Supersubstantivalism obtaining, like the Hole Argument for instance, seem to not be of sufficient weight to override the abductive benefits central to accepting Supersubstantivalism as the best explanation of the nature of spacetime.

Thus, I argue Supersubstantivalism makes sense as the best explanation of the nature of spacetime, and at the very least deserves a considerable more amount of attention from academia. The benefits of more attention focused on Supersubstantivalism could be considerable indeed. As I have argued previously in this dissertation there are numerous fields in philosophy and physics which could benefit from adopting this view and recognizing the insightful connections that this view can bring about, and promising connections exist beyond what I've explicitly talked about in this treatise. For example, the ontological singularity of Supersubstantivalism has numerous applications to the philosophy of religion and pantheism. Consider the philosophy of religion problem of *creatio ex nihilo* for instance. The problem of *creatio ex nihilo* asks how anything, even God, could create anything from nothing, a problem

[118] An example of another physics conundrum Supersubstantivalism could potentially benefit is the mysterious nature of light and how it propagates in a wave-like manner through empty space.
[119] For an example of this see Horgan and Potrc (2000).

which many philosophers, both ancient and contemporary, have argued is logically impossible.[120] Not only are laws of conservation violated, but more importantly there is a serious metaphysical problem here: how can something come from nothing? This issue has been a great source of debate since Parmenides. Supersubstantivalism and pantheism can provide a ready solution to this problem. If God is identical to spacetime fabric then he simply has to emit his energy which distorts spacetime fabric in various ways (i. e. such that it takes on certain properties like geometrical distortion) all issuing forth from a singularity like the Big Bang Theory would suggest.[121] In such a view there are not any new substances, rather the one substance in existence, spacetime, simply distorts geometrically and/or takes on new properties such that the Big Bang and all ensuing occurrences take place on that one substance. On such a view no new substance or creation needs to be made, rather our universes plays out like waves on the ocean.

Another example of how Supersubstantivalism could benefit a different area of academia is the long-standing enigma involving wave-particle duality. Ever since the early days of the 20th Century philosophers and physicists have both noted the disconcerting realization that both light, and matter more generally, seems to exhibit both wave-like properties, like interference patterns and frequency, and particle-like properties, like localized location when measured. In fact Niels Bohr had argued as early as 1927 that both natures should be accepted as fundamental properties of matter/energy. However, even so the glaring incommensurability between these two seemingly mutually exclusive natures have been a significant problem for philosophers and physicists. And this seemingly intractable problem has resisted attempts to resolve it for over

[120] Although admittedly some thinkers directly attribute this power to God, the power to make something from nothing.
[121] If one is interested in the radical Supersubstantivalism where all physical properties are reducible to geometric distortion of spacetime he or she should see works like John Wheeler (1962) and Samuel Alexander (1920).

eighty years. However, while the immediate situation isn't sufficient to provide a complete treatment for a problem as technical and complicated as this one, I do want to point out there is at least considerable *initial* hope that Supersubstantivalism could offer an answer to this seeming inconsistency between the wave-like and particle-like properties of matter/energy. Under Supersubstantivalism one could argue that particles as we know them *are* waves (or more specifically distortions of a medium) in the spacetime fabric. It certainly isn't immediately obvious that such a treatment could resolve all the problems involved in wave-particle duality, but it does suggest a ready base upon which to build a good explanation of why matter/energy seems to exhibit both particle and wave-like behavior.

What I have tried to demonstrate throughout this dissertation is that Supersubstantivalism is a grossly overlooked and underappreciated position in the spacetime debate. If abductive arguments are worth anything then I hope I have shown significant reasons why Supersubstantivalism should be treated as far more reasonable of a contender in the spacetime debate than its parent plain Substantivalism, and why overall Supersubstantivalism seems to be the best candidate in the spacetime debate. Not only does Supersubstantivalism arguably seem to be the best candidate to describe the nature of spacetime, but I argue it also has the possibility of bringing a good deal of advancement to a great many philosophical problems. As such let me conclude this dissertation by again suggesting that at the very least Supersubstantivalism deserves a much greater degree of attention than it has traditionally received.

Bibliography

Achinstein, Peter. *The Nature of Explanation.* New York: Oxford University Press, 1983.

Alexander, Samuel. *Space, Time, and Diety*. 2 vols. London: Macmillan and Co., 1920.

Austin, J. L. *How to Do Things with Words*. Oxford: Clarendon Press, 1962.

Baker, David. "Spacetime Substantivalism and Einstein's Cosmological Constant." *Philosophy of Science Assoc. 19th Biennial Meeting - PSA2004: Contributed Papers.* Austin: PSA 2004 Contributed Papers. 1-15, (2004).

Barbour, Julian. *Absolute or Relative Motion?* 2 vols. Cambridge: Cambridge University Press, 1989.

Barbour, Julian and Bruno Bertotti. "Gravity and Inertia in a Machian Framework." *Nuovo Cimento.* 38: 1-27, (1977).

----. "Mach's Principle and the Structure of Dynamical Theories." *Proceedings of the Royal Society A, London*. 382 (1783): 295-306, (1982).

Barnes, E. "Inference to the Loveliest Explanation." *Synthese*. 103: 251-277, (1995).

Bartels, A. "Modern Essentialism and the Problem of Individuation of Spacetime Points." *Erkenntnis*. 45 (1): 25-43, (1996).

----. "What Is Spacetime If Not a Substance? Conclusions from the New Leibnizian Argument." Eds. U. Mayer and H. J. Schmidt. *Semantical Aspects of Spacetime Theories*, pp. 41-51. Mannheim: B.I. Wissenshaftverlag, 1994.

Belot, Gordan. "Geometry and Motion." *British Journal for the Philosophy of Science.* 51: 561–595, (2000).

Berkeley, George. *De Motu and The Analyst: A Modern Edition with Introductions and Commentary*. Ed. and Trans. D. Jesseph. Dordrecht: Kluwer Academic Publishers, 1992.

Bird, Alexander. *Philosophy of Science*. London: Oxford University Press, 1998.

Bondi, H. and C. B. Spurgin. "Energy Has Mass." *Phys. Bull.* 38: 62–63, (1987).

Brighouse, Carolyn. "Spacetime and Holes." *In Proceedings of the 1994 Biennial Meeting of the Philosophy of Science Association*. Eds. D. Hull, M. Forbes, and R. Burian. Volume 1, pp. 117-125. East Lansing: Philosophy of Science Association, 1994.

Butterfield, Jeremy N. "The Hole Truth." *British Journal for the Philosophy of Science*. 40: 1-28, (1989).

Cartwright, Nancy. "Causation and Physics: Causal Processes and Mathematical Derivations." *Proceedings of the Biennial Meeting of the Philosophy of Science Association*. 2: 391-404, (1984).

Dainton, Barry. *Time and Space.* Ithaca: McGill-Queen's University Press, 2001.

Darwin, Charles. *The Origin of Species by Charles Darwin: A Variorum Text.* Ed. M. Peckham. Philadelphia: University of Pennsylvania Press, 1959.

Day, T. and H. Kincaid. "Putting Inference to Best Explanation in Its Place." *Synthese*. 98: 271-295, (1994).

Descartes, Rene. *The Philosophical Writings of Descartes*. 3 vols. Trans. John Cottingham, Robert Stoothoff, Dugald Murdoch. Cambridge: Cambridge University Press, 1984.

DiSalle, Robert. "Spacetime Theory as Physical Geometry." *Erkenntnis*. 42: 317-337, (1995).

Domski, Mary "Newton's Empiricism and Metaphysics." *Philosophy Compass.* 5 (7): 525-534, (2010).

Earman, John. *World Enough and Spacetime.* Cambridge: MIT Press, 1989.

Earman, John and John Norton. "What Price Spacetime Substantivalism? The Hole Story." *British Journal for the Philosophy of Science*. 38: 515-525, (1987).

Eddington, A. *Space, Time, and Gravitation.* London: Cambridge University Press, 1929.

Einstein, Albert. "The Foundation of the General Theory of Relativity." *The Principle of Relativity*. Eds. H.A. Lorentz *et al*., pp. 109-164. New York: Dover, 1952.

Einstein, A. and M. Grossmann. *Entwurf einer verallgemeinerten Relativitatstheorie und einer Theorie der Gravitation.* Leipzig: Teubner, 1913.

Einstein, A. and L. Infeld. *The Evolution of Physics*. New York: Simon and Schuster, 1938.

Esfeld, Michael and Vincent Lam. "Moderate Structural Realism about Space-time." *Synthese.* 160 (1): 27-46, (2006).

Fernflores, Francisco. "The Equivalence of Mass and Energy." *The Stanford Encyclopedia of Philosophy* (Spring 2012 Edition), Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/spr2012/entries/equivME/>.

Flores, F. "Einstein's 1935 Derivation of $E = mc^2$." *Stud. Hist. Phil. Mod. Phys.* 29 (2): 223–243, (1998).

Field, Hartry. "Can We Dispense with Space-time?" *PSA 1984: Proceedings of the 1984 Biennial Meetings of the Philosophy of Science Association.* Eds. P. Asquith and P. Kitcher. 2: 33-90, (1985).

Fine, Kit. "A Guide to Ground." *Metaphysical Grounding: Understanding the Structure of Reality*. Eds. Fabrice Correia and Benjamin Schnieder, pp. 37-80. New York: Cambridge University Press, 2012.

Friedman, Michael. "Explanation and Scientific Explanation." *The Journal of Philosophy*. 71 (1): 5-19, (1974).

Giovanelli, Marco. **"**Leibniz, Kant und der moderne Symmetriebegriff.**"** *Kant-Studien.* 102 (4): 422-454, (2011).

Halcomb, Harmon, III. "Evolutionary Psychology." *The Stanford Encyclopedia of Philosophy* (Spring 2014 Edition). Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/spr2014/entries/evolutionary-psychology/>, (2014).

Hempel, Carl. *Aspects of Scientific Explanation*. New York: Free Press, 1965.

----. *Philosophy of Natural Science*. London: Pearson Publishing, 1966.

Hempel, Carl and Paul Oppenheim. "Studies in the Logic of Explanation." *Philosophy of Science.* 15 (2): 135-175, (1948).

Hoeffer, Carl. "The Metaphysics of Space-Time Substantivalism." *Journal of Philosophy*. 93 (1): 5-27, (1996).

Horgan, Terry and Matjaž Potrč. "Blobjectivism and Indirect Correspondence**.**" *Facta Philosophica.* 2: 249-270, (2000).

Hugget, Nick. "Why Manifold Substantivalism Is Probably Not a Consequence of Classical Mechanics". *International Studies in the Philosophy of Science.* 13 (1): 17-34, (1999).

Janiak, Andrew. *Newton as Philosopher*. Cambridge: Cambridge University Press, (2008).

Kant, Immanuel. *The Cambridge Edition of the Works of Immanuel Kant*. 14 vols. Eds. and Trans. Paul Guyer and Allen Wood. Cambridge: Cambridge University Press, 1998.

Keynes, John Maynard. *Essays and Sketches in Biography*. New York: Meridian Books, 1956.

Kitcher, Philip. "Explanation, Conjunction and Unification." *Journal of Philosophy*. 73: 207-212, (1976).

----. "Explanatory Unification." *Philosophy of Science*. 48 (4): 507-531, (1981).

----. "Explanatory Unification and the Causal Structure of the World." *Scientific Explanation*. Vol. 13. *Minnesota Studies in the Philosophy of Science*. Eds. P. Kitcher and W. Salmon, pp. 410-505. Minneapolis: University of Minnesota Press, 1989.

Kostro, Ludwik. *Einstein and the Ether.* Montreal: Apeiron, 2000.

Kuhn, Thomas. *The Essential Tension*. Chicago, University of Chicago Press, 1977.

Ladyman, James and Don Ross. *Everything Must Go: Metaphysics Naturalized*. New York: Oxford University Press, 2009.

Lange, Marc. *An Introduction to the Philosophy of Physics*. Oxford: Blackwell, 2002.

----. "The Most Famous Equation." *Journal of Philosophy*. 98 (5): 219-238, (2001).

Lavoisier, Antoine. *Oeuvres Complêtes*. Vol. 2. Paris: Imprimerie Impériale, 1862.

Leibniz, Gottfried. "Reading: Leibniz-Clarke Correspondence." *Space from Zeno to Einstein.* Ed. Nick Huggett, pp. 143-158. Cambridge: MIT Press, 1999.

Lehmkuhl, Dennis. *Spacetime Matters: On Super-Substantivalism, General Relativity, and Unified Field Theories.* Doctoral Dissertation: Oxford University, 2009.

Lewens, Tim. *Darwin.* London: Routledge, 2006.

Lewis, David. *On the Plurality of Worlds.* Oxford: Blackwell Publishing, 1986.

Lewis, G. N. and R. C. Tolman. "The Principle of Relativity and Non-Newtonian Mechanics." *Philosophical Magazine.* 5 (18): 709-726, (1909).

Lipton, Peter. *Inference to the Best* Explanation. 2 nd ed. *International Library of Philosophy*. Eds. José Luis Bermúdez, Tim Crane, and Peter Sullivan. New York: Routledge, 2004.

Lloyd, E. *The Structure and Confirmation of Evolutionary Theory*. 2nd ed. Princeton: Princeton University Press, 1994.

Lusanna, Luca and Massimo Pauri. "Explaining Leibniz Equivalence as Difference of Non-Inertial Appearances: Dis-solution of the Hole Argument and Physical Individuation of Point-events." *Studies in History and Philosophy of Modern Physics*. 37: 692-725, (2006).

MacDonald, Alan. "Einstein's Hole Argument." *Am. J. Phys*. 69: 223-225, (2001).

Mach, Ernst. *The Science of Mechanics: A Critical and Historical Account of Its Development*. 6th ed. Trans. Thomas J. McCormack. LaSalle: The Open Court Publishing Company, 1960.

Maudlin, Tim. "The Essence of Space–time." *PSA 1988*. 2: 82-91, (1988).

----. "Substances and Spacetimes: What Aristotle Would Have Said to Einstein." *Studies in the History and Philosophy of Science*. 21: 531-561, (1990).

Newton, Isaac. *Newton: Philosophical Writings*. Ed. Andrew Janiak. Cambridge: Cambridge University Press, 2004.

Newton-Smith, William. *The Rationality of Science.* London: Routledge, 1981.

Norton, John. “Einstein, the Hole Argument and the Reality of Space.” *Measurement, Realism and Objectivity*. Ed. John Forge, pp. 153-188. Dordrecht: Reidel, 1987.

----. “General Covariance and the Foundations of General Relativity: Eight Decades of Dispute.” *Reports on Progress in Physics*. 56: 791-858, 1993.

----. "The Hole Argument." *The Stanford Encyclopedia of Philosophy*. (Fall 2015 Edition). Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/fall2015/entries/spacetime-holearg/>, (2015).

----. “The Physical Content of General Covariance.” *Studies in the History of General Relativity: Einstein Studies*. Vol. 3. Eds. J. Eisenstaedt and A. Kox, pp. 281-315. Boston: Birkhauser, 1992.

Okun, L. B. "The Concept of Mass." *Physics Today*. 42 (6): 31-36, (1989).

Peirce, C. S. *Collected Papers.* Eds. C. Hartshorn and P. Weiss. Cambridge: Harvard University Press, 1931.

Plato. *Plato: Complete Works.* Ed. John Cooper. Indianapolis: Hackett Publishing Company, 1997.

Poincare, Henri. *Science and Hypothesis.* New York: Dover, 1952.

Pooley, Oliver. *Substantivalist and Relationalist Approaches to Spacetime*. Oxford: Oxford University Press, 2012.

Psillos, S. *Causation and Explanation*. Montreal: McGill-Queen's University Press, 2002.

Quine, W. V. O. "Simple Theories of a Complex World." *Synthese.* 15 (1): 103-106, (1963).

Quine, W. V. O. and J. S. Ullian. *The Web of Belief.* 2nd ed. New York: Random House, 1978.

Rappaport, S. "Inference to the Best Explanation: Is It Really Different from Mill's Methods?" *Philosophy of Science.* 63: 65-80, (1996).

Reichenbach, Hans. *The Philosophy of Space and Time.* New York: Dover Publications, Inc., 1958.

Rindler, W. *Essential Relativity*. New York: Springer-Verlag, 1977.

Robinson, Howard. "Substance." *The Stanford Encyclopedia of Philosophy* (Spring 2014 Edition). Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/spr2014/entries/substance/>, 2014.

Russell, Bertrand. *The Analysis of Matter*. New York: Dover Publications Inc., 1954.

Rynasiewicz, Robert. "Newton's Views on Space, Time, and Motion." *The Stanford Encyclopedia of Philosophy* (Summer 2014 Edition). Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/sum2014/entries/newton-stm/>, 2014.

Sachs, Mendel. *Quantum Mechanics and Gravity*. New York: Springer, 2004.

Salmon, Wesley. *Scientific Explanation and the Causal Structure of the World*. Princeton: Princeton University Press, 1984.

----. "Statistical Explanation." *Statistical Explanation and Statistical Relevance.* Ed. W. Salmon, pp. 29-87. Pittsburgh: University of Pittsburgh Press, 1971.

Schaffer, Jonathan. "Grounding, Transitivity, and Contrastivity." *Metaphysical Grounding*. Eds. Fabrice Correia and Benjamin Schnieder, pp. 122-138. New York: Cambridge University Press, 2012.

----. "Monism: The Priority of the Whole." *Philosophical Review*. 119 (1): 31-76, (2010).

----. "Spacetime the One Substance." *Philosophical Studies.* 145: 131-148, (2009).

Sider, Theodore. *Four-Dimensionalism*. Oxford: Clarendon Place, 2001.

Sklar, Lawrence. *Space, Time, and Spacetime*. Berkeley: University of California Press, 1976.

Skow, Bradford. *Once Upon a Spacetime*. New York: New York University Press, 2005.

Sober, Eliot. *The Nature of Selection: Evolutionary Theory in Philosophical Focus*. Cambridge: MIT Press, 1984.

Spinoza, Baruch. *Spinoza: Complete Works.* Indianapolis: Hackett Publishing, 2002.

Stachel, John. “Einstein's Search for General Covariance.” *Einstein and the History of General Relativity. Einstein Studies.* Vol. 1. Eds. Don Howard and John Stachel, pp. 63-100. Boston: Birkhäuser, 1989.

----. “What Can a Physicist Learn from the Discovery of General Relativity?” *Proceedings of the Fourth Marcel Grossmann Meeting on Recent Developments in General Relativity.* Ed. R. Ruffini, pp. 1857-1862. Amsterdam: North-Holland, 1986.

Stachel, John. and Robert Torretti. “Einstein's First Derivation of Mass-Energy Equivalence.” *Am. J. Phys.* 50 (8): 760–761, (1982).

Stein, Howard. “Newtonian Space-Time.” *The* Annus Mirabilis *of Sir Isaac Newton 1666-1966*. Ed. Robert Palter, pp. 174-200. Cambridge: MIT Press, 1967.

Swinburne, Richard. *Space and Time.* New York: St. Martin's Press, 1968.

Thagard, Paul. “The Best Explanation: Criteria for Theory Choice.” *Journal of Philosophy*. 75: 76–92, (1978).

Torretti, Robert. *The Philosophy of Physics.* Cambridge University Press, 1999.

----. *Relativity and Geometry*. New York: Dover, 1996.

Uebel, Thomas. "Vienna Circle." *The Stanford Encyclopedia of Philosophy*. (Spring 2014 Edition). Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/spr2014/entries/vienna-circle/>, 2014.

Vogel, J., “Cartesian Skepticism and Inference to the Best Explanation.” *Journal of Philosophy*. 87: 658–666, (1990).

Weatherall, James. "Regarding the 'Hole Argument.'" <http://philsci-arcive.pitt.edu/11578/>. [Preprint], 2015.

Wheeler, John. *Geometrodynamics*. New York: Academic Press, 1962.

Wilcezk, Frank. *The Lightness of Being: Mass, Ether, and the Unification of Forces.* New York: Basic Books, 2008.

Woodward, James. *Making Things Happen: A Theory of Causal Explanation*. New York: Oxford University Press, 2003.

----. "Scientific Explanation." *The Stanford Encyclopedia of Philosophy* (Winter 2014 Edition). Ed. Edward N. Zalta. <http://plato.stanford.edu/archives/win2014/entries/scientific-explanation/>, 2014.

Zahar, Elie. *Einstein's Revolution: A Study in Heuristic*. La Salle: Open Court, 1989.

Vita Auctoris

Jimmy Ray Vaught (or J. R. Vaught) was born in Somerset, Kentucky on May the 18th, 1982. He was raised in south central, rural, Kentucky in what is known as Casey County. His post-secondary education began at Transylvania University, resulting in a B. A. with Honors in Philosophy in 2004. Jimmy took a brief two year hiatus after undergraduate college before enrolling at Georgia State University and being awarded a M. A. in Philosophy specializing in both Philosophy of Mind and Philosophy of Religion (Jimmy, at the time of his matriculation, was the only student in the history of the Georgia State University Philosophy Department to have accomplished such). In 2016 he will earn his Ph. D. in Philosophy at Saint Louis University with the defense of his dissertation *Supersubstantivalism and the Unification of Physics*. His professional specialization is in Philosophy of Science and Philosophy of Physics, with a secondary concentration in Philosophy of Religion.

Jimmy has taught courses like *Critical Thinking*, *Formal Logic*, *Introduction to Philosophy*, *Ethics*, *Applied Ethics*, and *Philosophy of the Human Person* at institutions like Georgia State University and Saint Louis University. He has published works in scholarly resources such as the Catholic Encyclopedia, and has given several talks on Philosophy of Science at institutions like the University of Illinois at Edwardsville and Saint Louis University. He has also received several honors from the institutions he attended (e. g. graduating *Summa Cum Laude* and being inducted to the honorary *Phi Sigma Tau*), as well as having also received honors from organizations like the American Cancer Society (he being a teenage cancer survivor himself).