A Pre-History of Quantum Gravity: The Seventeenth Century Legacy and the Deep Metaphysics of Space beyond Substantivalism and Relationism

Edward Slowik

Abstract: This essay demonstrates the inadequacy of contemporary substantivalist and relationist interpretations of quantum gravity hypotheses via an historical investigation of the debate on the underlying ontology of space in the seventeenth century. Viewed in the proper context, there are crucial similarities between seventeenth century theories of space and contemporary work on the ontological foundations of spacetime theories, and these similarities challenge the utility of the substantival/relational dichotomy by revealing a host of underlying conceptual issues that do not naturally align with that distinction.

1. Introduction.

Even given the most basic and clear-cut conception of substantivalism and relationism—where the substantivalist holds, and the relationist rejects, that space/spacetime is an independently existing entity—it has become quite evident that the attempts to ascribe either a substantivalist or relationist interpretation to classical gravitation theories is an exercise fraught with perils, since that the sophisticated forms of both ontologies are seemingly identical as regards their content in the modern setting of general relativity.[1] What is less well-known, however, is that this metaphysical quagmire has likewise ensnarled philosophers concerned with the ontology of quantum gravity (QG), which will, it is hoped, link the physics at the spatiotemporal micro-realm of quantum mechanics (QM) with the large-scale structure of space and time in general relativity (GR). In short, the general consensus would seem to be that sophisticated versions of both substantivalism and relationism are equally consistent, or equally problematic, interpretations of QG (e.g., Rickles 2005, Earman 2006), a conclusion that is apparently reflected in the rival appropriations of an important QG hypothesis, Loop Quantum Gravity (LQG), for either Leibnizian relationism or Newtonian susbtantivalism. For example, a Leibnizian lineage for LQG has been put forward by Smolin (2000, 119-120; 2006, 200-203), among many others. Yet, in Dainton (2010), which defends the relevance of the substantival/relational dichotomy in GR (380-381), it is argued that the ontology of LQG "seems as substantival as any conception", prompting Dainton to ask, "What could be less Leibnizian?", despite the fact that LQG is "very different from Newton's absolute space" (405-406). In short, why does the substantival/relational dichotomy lead to such conflicting assessments? Since this is one the most basic and important ontological divisions in the philosophy of space and time, it is imperative to investigate what has gone wrong, and to examine if there are better alternatives.

This essay will explore this philosophical quandary, and offer an alternative range of conceptual distinctions that lie below the rather imprecise and obscure dichotomy imposed by contemporary substantivalism and relationism. In particular, an examination of a range of seventeenth century metaphysical speculation on the deep ontology of space, e.g., by Gassendi, More, Newton, Leibniz, and others, will reveal a host of uncanny similarities with the modern QG program. As will be demonstrated, these similarities concern (i) the nature, and possible dissimilarity, of the spatial geometry at the fundamental level of ontology and at the macroscopic level of matter or fields, and (ii) unique forms of both platonism and nominalism as regards the status of spatial geometry. It is with respect to these two issues that both the seventeenth century and the contemporary QG debates are concerned; and, importantly, these two issues lie athwart the equivocality of the substantivalist/relationist division. Indeed, since these new sets of issues and distinctions are not congruent with the substantival/relational dichotomy, the conclusions of this essay can be interpreted as undermining the relevance of that dichotomy for space (spacetime) theories, although a fairly trivial version of the dichotomy, parasitic on the platonism/nominalism distinction, can still be invoked, as will be explained. The results of our investigation will also challenge those who consider the contemporary division between a background independent/dependent formulation of a theory's spacetime geometry, which is a central theme in the search for QG, as the modern equivalent of the substantival/relational divide. The conclusions reached in this essay might strike the reader as controversial; but, on both historical and philosophical grounds, it will be argued that the inadequacies of the substantival/relational distinction, especially as regards the deep ontology of space, merit its overthrow.

In sections 2, 3, and 4, various similarities and differences between Newton, Leibniz, and other seventeenth century thinkers, will be surveyed, with the lessons gathered from our analysis applied, in section 5, to the strategies proposed among competing QG hypotheses and to various QG issues, such as background independence and nominalism.

2. The Ontological Foundation of Space in The Seventeenth Century.

If anything is disclosed in the competing ontological interpretations of Smolin and Dainton, recounted above, it has little to do with the adequacy of the substantival/relational dichotomy. Rather, it exposes the enduring aspiration among latter-day thinkers to appropriate Newton (a presumed substantivalist) and Leibniz (a presumed relationist) as the proper historical ancestor of a particular modern theory of spacetime, such that a clear line of descent can be established. Yet, the actual details of the spatial hypotheses of seventeenth century natural philosophers undermine such attempts, as we will now begin to explore. In this section, the emphasis will be placed on Newton and Leibniz, as the alleged historical representatives of, respectively, substantivalism and relationism.

One of the concessions that can be made to the traditional substantival/relational dichotomy should be admitted at this point, however. Newton does, and Leibniz does not, allow the possibility of the existence of spatial geometry in a completely void space. We will dub these respective hypotheses: "trivial substantivalism", that space can exist absent of matter; and "trivial relationism", that space cannot exist absent of matter. As the adjective 'trivial' suggests, this distinction is not very informative, since, as will be argued in later sections, it fails to address the deeper issue that forms the basis of this distinction, namely, Newton's platonism and Leibniz' nominalism as regards spatial geometry.

2.1. Newton. Put briefly, if substantivalism is "the postulation of the independent reality of space as a kind of substance" (Sklar 1974, 161), then there were likely very few substantivalists prior to the modern substantival/relational debate. Newton's *De gravitatione,* following Gassendi, Charleton and numerous other thinkers back to at least Patrizi, insists that space "has its own manner of existing which is proper to it and which fits neither substance nor accident": space is not a substance because it cannot "act upon things, yet everyone tacitly understands this of substance" (Newton 2004, 21), nor is it an accident (property), "since we can clearly conceive extension existing without any subject, as when we imagine spaces outside the world or places empty of any body whatsoever, . . ." (21-22). While this last passage clearly denies that space is an accident of body, it leaves open the possibility that space could be related to God's existence in a property-like fashion. In fact, space does seem to require a "subject" given his famous "emanation" claims, which imply that space (somehow) follows from God's existence: "[space] is as it were an emanative effect of God and an affection of every kind of being" (21); and, "space is eternal in duration and immutable in nature because it is the emanative effect of an eternal and immutable being" (26). The resolution of this puzzle resides in the fact that Newton rejects the "inherence" conception commonly associated with accidents: after admitting that space is a form of "substantial reality", he adds that it does "not need to be inherent in a subject" (32). Unlike More, who did posit space as a property inherent in God in his later *Enchiridium* (More 1995, 56-57), Newton consistently conceives space as a sort of quasi-property that depends upon God, sans inherence, of course: for instance, he claims that God contains "all other substances in Him as their underlying principle and place", and he rejects the possibility "that a dwarf-god should fill only a tiny part of infinite space with this visible world created by him" (Newton 1978, 123).

2.2. Leibniz. If substantivalism is not a particularly accurate depiction of Newton's deep ontology of space, relationism is an equally unfortunate characterization of Leibniz' underlying spatial ontology. The modern relationist conception posits material bodies/events as the basis for the relations that constitute space, such that the metric (distance) and overall geometry of space is dependent on, and can be reduced to, material bodies/events (and where unextended point masses/events could serve as this reductivist basis; see, e.g., Sklar 1974, 167; Friedman 1983, 217). Overall, there are many relationist-like aspects to Leibniz' conception, in particular, his acceptance of trivial relationism: “that there is no space where there is no matter and that space in itself is not an absolute reality” (2000, L.V.62). Following Newton, Leibniz reckons that space cannot act upon things (NE:II.xiii.17), but, also like Newton, space does not inhere in individual beings in the traditional Scholastic accident sense (L.V.47). In accordance with the substance/accident metaphysics, he insists that there can be no *ontologically unsupported* spatial properties: “Now extension must be the affection of something extended. But if that space is empty, it will be an attribute without a subject, an extension without anything extended” (L.IV.9). Yet, even granting that extension is an individual bodily property that cannot transfer from one substance to another, Leibniz does not rule out the possibility that the world’s extension, which corresponds to his idealized notion “space”, could still function as something like a unique holistic property of the entire material world.

This last suggestion is, in fact, supported in a work on the principle of the identity of the indiscernibles, where Leibniz claims that “there are no purely extrinsic denominations [i.e., purely spatial differences], *because* of the interconnection of things”, and, “if place does not itself make a change [i.e., no extrinsic denominations], it follows that there can be no change which is merely local” (MP 133, emphasis added; see, also, NE:II.xxv.5). This global, or holistic, basis for space is linked to the dynamical interconnections among all bodies, an hypothesis that, therefore, can be seen as upholding a unique form of spatial or geometric nominalism (see sections 3 and 4 for more on Leibniz’ nominalism):

> In general, place, position and quantity, such as number and proportion, are merely relations, and *result from* other things which by themselves either constitute or terminate a change. To be in a place seems, abstractly at any rate, to imply nothing but position. But in actuality, that which has a place must express place in itself; so that distance and the degree of distance involves also a degree of expressing in the

> thing itself a remote thing, *either of affecting it or receiving an affection from it.* So, in fact, situation really involves a degree of expressions (MP 133; emphasis added).

The specific details of Leibniz' account are beyond the scope of this essay (see, Slowik 2009, 2011), but one should first resist the temptation to interpret "expression" as denoting a purely phenomenal relationship, in the perceptual, mind-based sense.[2] Leibniz offers many non-perceptual examples of expression (e.g., linear projections/solids, models/machines), which suggest something like the modern notion of a partial isomorphism: "What is common to all these expressions is that we can pass from a consideration of the relations in the expression to a knowledge of the corresponding properties of the thing expressed" (L 207). Accordingly, "expression" indicates a structural relationship between any two things (i.e., it is not just between perceptions and the material world), and so Leibniz' idea would seem to be that each body/substance, taken "in itself", expresses distance relations to "remote things" via dynamic change, "affecting it or receiving an affection from it". At a deeper level, however, the world's dynamical interconnections implicate the monadic realm, "things which by themselves either constitute or terminate a change". In particular, Leibniz' account of extension, and its idealization, space, is grounded in an internal quality of constitutive simple substances, monads, such that bodily extension "results from" monadic intrinsic properties. Leibniz goes on to argue that extended quantity and position "are mere results, which do not constitute any intrinsic denominations *per se,* and so they are merely relations which demand a foundation derived from the category of quality [i.e., the action or primitive force of monads], that is, from an intrinsic accidental denomination" (MP 133-134). To sum up, Leibnizian space may be a property-like feature of the entire material world, a point raised in his criticisms of Clarke: "Thus, by making space a property, the author falls in with my opinion, which makes it an order of things and not anything absolute" (L.IV.9).[3]

Yet, like all of the other seventeenth century thinkers, God plays a foundational role in Leibniz' deep ontology of space. In the *New Essays,* he states that space's "truth and reality are grounded in God, like all eternal truths", and that "space is an order [of situations] but that God is the source" (NE:II.xiii.17). At greater length, he follows Descartes by positing that only God's operations can be assigned a spatial location, a view also known in as the "extension of power" doctrine:

> Where space is in question, we must attribute immensity to God, and this also gives parts and order to his immediate operations. He is the source of possibilities and of existents alike, the one by his essence and the other by his will. So that space like time derives its reality only from him, and he can fill up the void whenever he pleases. It is in this way that he is omnipresent. (NE:II.xv.2)

To summarize, space (and time) obtain their "reality only from [God]", and God's "essence" is responsible for the *possibility* of any existing thing in space (more on this in section 3), such that his will can fill up any void. Relations receive a similar treatment: "relations and orderings are to some extent 'beings of reason', although they have their foundations in things; for one can say that their reality, like that of eternal truths and of possibilities, comes from the Supreme Reason" (NE:II.xxv.1). Finally, as regards the basic constituents of Leibniz' world, monads, God plays a similar foundational role: "a monad, like a soul, is, as it were, a certain world of its own, having no connections of dependency except with God" (AG 199). Nevertheless, as mentioned above, the interconnections of the world also implicate monadic order: "since each body acts on every other body, more or less, in proportion to its distance, . . . it follows that each monad is a living mirror . . . endowed with internal action, which represents the world from its own point of view and is ordered as the universe itself" (AG 207).

At this juncture, Newton's absolute conception of space is likely to be contrasted with the alleged relational character of Leibniz' hypotheses, and by this means the substantivalist and relationist will insist on the utility of their dichotomy. Nevertheless, the analysis of place in the *New Essays* casts serious doubt on any difference between Newton and Leibniz that centers upon space's function:

> 'Place' is either *particular,* as considered in relation to this or that body, or *universal;* the latter is related to everything, and in terms of it all changes of every body whatsoever are taken into account. If there were nothing fixed in the universe, the place of each thing would still be determined by reasoning, if there were a means of keeping a record of all the changes or if the memory of a created being were adequate to retain them . . . . However, what we cannot grasp is nevertheless determinate in the truth of things. (NE:II.xiii.8)

In the preceding discussion, Philalethes, Locke's spokesman, contends that "same place" is relative to different material frameworks: "The chess-board, we also say, is in the *same place* . . . if it remains in the same part of the cabin, though, perhaps, the ship which it is in [has set sail] . . ." (NE:II.xiii.8). However, Leibniz rejects this body-based relational conception, which he refers to as "particular" place ("in relation to this or that body"), and offers his "universal" notion of place instead, such that it "is related to everything, and in terms of *it* all changes of every body whatsoever are taken into account". Leibniz' claim that "if there were nothing fixed in the universe, the place of each thing would still be determined by reasoning" thus mimics Newton's absolutism in the *Principia* (Newton 2004, 66). A modern relationist, on the other hand, must describe "same place" with respect to a material reference frame: they cannot, as does Leibniz, countenance the possibility that there may be no fixed material frames at all, yet insist that the same place is still “determinate in the truth of things”—determinate with respect to what? Leibniz’ claim, consequently, suggests that there is something else besides material existents, his universal place, that measures all changes of bodily place. Of course, Leibniz would deny that universal place is an independent entity that can exist apart from matter; rather, it is simply an internal feature of some sort in bodies/monads that, most likely, allows a reconstruction of the prior places that all bodies had occupied. Nonetheless, this conclusion still runs counter to relationist dogma, for any record of a universal place within matter is analogous to, or functions like, absolute place—although it is absolute space reinterpreted as an internal feature of each body/monad. Finally, there are relationist objection that can be raised that concern the so-called static and kinematic “shift” arguments in the Leibniz-Clarke correspondence, although we will postpone this discussion to section 4. Relational motion is a different topic, furthermore, which is beyond the bounds of this essay, but it does not effect the deep ontology of space (but, see endnote 12).

2.3. Preliminary Conclusions. As revealed above, both Newton and Leibniz regard extension/space as requiring some form of foundation in a substance or entity, broadly construed, and this strongly suggests that space functions, in an ontological sense, as some sort of property. It may not be a property that is internal to, or inheres in, God for Newton and Leibniz, but they both claim that space is dependent on God;[4] and Leibniz, additionally, views space much like a holistic property of the entire world’s dynamical interconnections, ultimately grounded at the monadic level. In short, both reject the notion that space is either an independent entity in its own right or that it can act upon things, thus it is not a substance. And, since both adhere to the Aristotelian substance/property doctrine, any relationist construal of space as the extension *between* bodies would be reckoned "an attribute without a subject, an extension without anything extended" (L.IV.9), and thus outright rejected. It is in this sense that the modern attempts to appropriate Newton and Leibniz as would-be substantivalists or relationists (e.g., Sklar 1974, Friedman 1983, etc.) go seriously awry. The modern substantival/relational debate, in contrast, is the likely outgrowth of the rise of the late nineteenth century's inertial frame concept and an accompanying (positivist-influenced) disinterest in archaic non-empirical, metaphysical, and theological approaches to physics—in brief, the contemporary stalemate that afflicts the modern spacetime ontology debate is largely the result of this vain effort to fit the seventeenth century's square metaphysics peg into the contemporary scene's round physics hole; that is, the modern dichotomy strives to remain consistent to Newton and Leibniz but without utilizing their stock of metaphysical presuppositions.

Given the recent emphasis on the dual role of *g* as both the metric and gravitational field in GR, the prospects for the modern spacetime ontology debate have faded even further, since the competing claims of *g* as either the unique spacetime substance or just another physical field are, it would appear, in principle irresolvable or conventional; i.e., there is no longer any relationist *unsupported* extension between matter if *g* is a physical field—it is "internal" on both relationist and substantivalist construals of GR. The common refrain that the postulated entities in QG, whether strings, quantum loops, etc., can support either substantivalism or relationism is, therefore, merely the subatomic analogue of this fruitless quarrel over the ontological status of such macroscopic "things" as the metric/gravitational field.[5]

3. Classifying Spatial Ontology in the Seventeenth Century.

3.1. Geometric Levels and Platonism/Nominalism. In order to more accurately pinpoint the differences between Newton, Leibniz and others in the seventeenth century concerning the deep ontological foundations of space, it is necessary to focus on two of the main issues in contention: the geometric properties at the various levels of spatial ontology, and the whether those geometric properties support platonism or nominalism.

The first question concerns the similarity or difference in the types of geometry posited at the foundational level of the entity/entities that ground space's existence, and/or from which space emerges: we will dub this distinction, 'FLG', for foundational level geometry. In the seventeenth century, the geometry of space, i.e., the geometry at the macrolevel of material bodies, is Euclidean,[6] but the nature of the geometric features at the foundational level, i.e., God and Leibniz' monads, could take different forms. Leibniz' *New Essays* puts forth three ways that a being can be related to the macrolevel of place/space, a three-part division that will be of much service in our subsequent analysis:

> The Scholastics have three sorts of *ubeity,* or ways of being somewhere. The first is called *circumscriptive.* It is attributed to bodies in space which are in it point for point, so that measuring them depends on being able to specify points in the located thing corresponding to points in space. The second is the *definitive.* In this case, one can "define"—i.e. determine—that the located thing lies within a given space without being able to specify exact points or places which it occupies exclusively. That is how some people have thought that the soul is in the body, because they have not thought it possible to specify an exact point such that the soul or something pertaining to it is there and at no other point. . . . The third kind of ubeity is *repletive.* God is said to have it, because he fills the entire universe in a more perfect way than minds fill bodies, for he operates immediately on all created things, continually producing them, whereas finite minds cannot immediately influence or operate upon them. (NE:II.xxiii.21)

In what follows, we will explore how these three types of ubeity relate to the spatial geometry at the macrolevel.

As for circumscriptive ubeity, Leibniz mentions only bodies (whereas Newton and More would include all beings), but the idea is that the entity is mapped to three-dimensional Euclidean space in a point by point manner, much like the modern notion of an isomorphism. Leibniz' analysis also assumes that the entity (whether a body, God, etc.) fully shares in the geometric properties intrinsic to macrolevel space, the most important of these properties being the metric (distance), as Leibniz specifically mentions: "measuring them depends on being able to specify points in the located thing corresponding to points in space". The second way that a being can be related to space is "definitive", wherein "the located thing lies within a given space without being able to specify exact points or places which it occupies exclusively". Unlike the metrical structure implicit in circumscriptive ubeity, which also incorporates the topology of space, definitive ubeity is a topological conception alone, for the length or extension of the entity is indeterminate, i.e., it is not "possible to specify an exact point such that the soul or something pertaining to it is there and at no other point". More carefully, if an entity obtains a Euclidean metrical determination, then an exact set of continuously structured spatial points needs to be specified for that entity, but, since Leibniz states that the exact points cannot be determined, the continuously extended regions needed for Euclidean metrical space cannot be applied to that entity. Hence, because the being's spatial properties are limited to individual points alone within a certain region of space, all that definitive ubeity can furnish is something akin to the topological notion of a neighborhood (which is non-metrical).[7] As will be discussed in later sections, a notion that is closely aligned with definitive ubeity, especially as regards its topological emphasis, is “holenmerism”, the thesis that a being is whole in every part of space, namely, the points of space. Finally, there is “repletive” ubeity, which Leibniz assigns to God, and who “operates immediately on all created things, continually producing them, whereas finite minds cannot immediately influence or operate upon them”. Although it is not mentioned in this passage, Leibniz rejects the notion that God’s being is situated in space (see section 2.2 and 3.4), rather, only God’s actions can be situated. So, leaving aside the effects of God actions, repletive ubeity equates with the absence of all macrolevel geometric properties as regards the being itself. Repletive ubeity will also be true for Leibniz’ monads, as will be discussed below.

Returning to geometry of the foundational entity, FGL, the three types of ubeity presented in Leibniz’ discussion—circumscriptive, definitive, and repletive—therefore correlate with, respectively, three types of geometrical properties; metrical, topological, and pregeometric. “Pregeometric”, in its most general sense, will signify either the absence of geometrical properties or the possession of geometrical properties that differ significantly from the geometric properties at the macrolevel of space. The macrolevel of space, furthermore, is either the Euclidean space of the seventeenth century theorists, or, for modern QG theories, the geometry at the higher spatial levels assumed in QM or GR. In what follows, we will dub these three positions, in their order of presentation; FGL(met), FGL(top), FGL(prg). Accordingly, in the seventeenth century: circumscriptive ubeity, FGL(met), holds that the spatial properties of the foundational entity are identical with Euclidean space; definitive ubeity, FGL(top), contends that the foundational entity only possesses the topological properties of Euclidean space; and repletive ubeity, FGL(prg), is the thesis that the foundational entity is either non-spatial or manifests unique spatial properties not found at the macrolevel of Euclidean space.

The second general issue addresses whether spatial geometry *at the macrolevel of matter or physical fields,* is platonist or nominalist, a distinction that we will dub 'ML(plt)', for macrolevel geometric platonism, and 'ML(nom)', for macrolevel geometric nominalism. While the interpretation of platonism and nominalism is quite variable and complex, our use of the distinction will center on whether geometry at the macrolevel exists either independently of all material or physical instantiations, ML(plt), or the geometry at the macrolevel only exists as long as matter or a physical field instantiates those geometric structures, ML(nom). How platonism and nominalism apply to the geometry, if any, at the foundational level of ontology, i.e., FL(plt) and FL(nom), will be postponed until section 5.3.

Employing these definitions, we can now present the real issues that separate Newton, Leibniz, and other seventeenth century natural philosophers on the ontological foundations of space. In contrast to the substantivalist/relationist dichotomy, these new conceptual distinctions will also allow a more accurate assessment of the true lineage of these seventeenth century theories among the competing contemporary QG theories, as will be presented in section 5.

3.2. Newton on Spatial Ontology. Newton's hypotheses of space favor a similarity of geometric structure at both the bodily scale and for God, who directly provides the foundation of space; and he sides with a platonic realism about spatial geometry: FGL(met), and ML(plt). In the *De grav,* he states: "For the delineation of any material figure is not a new production of that figure with respect to space, but only a corporeal representation of it, so that what was formerly insensible in space now appears before the senses. . ." (Newton 2004, 22). Such sentiments attest to a platonism concerning geometry, needless to say, but not independently of God, as noted in section 2.1. As regards geometry at the different levels, both foundational (God) and body, Newton holds that there is only one geometry for all beings, even God, and so it is the same at both levels. We have already examined some of the statements that confirm this position; e.g., God contains "all other substances in Him as their underlying principle and place" (Newton 1978, 132). Yet, the best evidence is presented in the *De grav,* where the "determined quantities of extension" thesis is put forward. In brief, Newton presents an hypothesis of body that denies the existence of corporeal substance, and is such that God directly grounds bodily properties, including extension, rather than corporeal substance: "extension takes the place of the substantial subject in which the form of the body [i.e., the determined quantities] is conserved by the divine will" (Newton 2004, 29). The rationale for this Spinoza-like view is theological, at least to some degree, "[f]or we cannot posit bodies of this kind without at the same time positing that God exists, and has created bodies in empty space out of nothing . . ." (31). He rejects earlier views of substance, especially Descartes' dualism, by reasoning that "if the distinction of substances between thinking and extended is legitimate and complete, God does not eminently contain extension within himself", and, "hence it is not surprising that atheists arise ascribing to corporeal substance that [i.e., extension] which solely belongs to the divine" (31-32). Accordingly, if there is no difference between corporeal and incorporeal substance, since God is the only true substance, then there is only one attribute of extension, i.e., God's extension—hence God's extension is the same as bodily extension, or FGL(met). Finally, it should be noted that Henry More is the main advocate of FGL(met) and ML(plt) in seventeenth century England, and has close similarities with Newton's approach (see, More 1995, 56-57; Slowik 2008).

3.3. Gassendi on Spatial Ontology. Unlike many of his contemporaries and predecessors, Newton and More deny "holenmerism", a doctrine that does admit a difference in geometric properties with regard to various incorporeal and corporeal substances. On holenmerism, incorporeal beings are "whole in every part", which thereby allays any concerns about their actual or metaphysical divisibility.[8] Gassendi accepts this holenmerist view of God, which is equivalent to FGL(top), by declaring:

> [W]e conceive an infinity as if of extension, which we call [God's] immensity, by which we hold that he is everywhere. But, I say *as if* of extension, lest we imagine that the divine substance were extended through space like bodies are. Indeed, although the divine substance is supremely indivisible and whole at any time and any place, yet doubtless as corporeal substance is said to be extended—that is not at one point only but is spread out through many parts of space—so there is a kind of divine extension, which does not exist in one place only, but in many, indeed, in all places. (1976, 94)

On Gassendi's estimation, bodies occupy space by being extended ("spread out") across many points, but his qualification, "as if of extension", with respect to God would seem to imply that God only shares with bodies the property of occupying the points of space, i.e., that "divine extension", as he also calls it, lacks the dimensional extension of body across the points of space, even though "[God] is not at one point only". Since space is continuous ("space cannot be broken into two by any force, but remains continuous, the same, and motionless", Gassendi 1972, 395), and since God only occupies the points of this continuous space (e.g., he elsewhere refers to God's "immensity according to which he is *present* in every place", 1972, 396; emphasis added), it thus follows that only the topological properties of space are applicable to God, but not the metrical properties of space.[9] Put differently, while God and matter share topological structure, the holenmerist doctrine that God is "whole in every part" undermines the ascription of Euclidean metrical structure to this being—hence, FGL(top). Furthermore, since Gassendi accepts that space is three-dimensional and Euclidean in structure at the ontological level of bodies (see, e.g., Grant 1981, 210), and is independent of matter, he sides with Newton in accepting our form of geometric platonism, ML(plt). Specifically, while God is not really extended, God grounds a form of incorporeal extension that is congruent to the corporeal dimensions of body at that ontological level, and this fact accounts for the dimensionality of any vacuum: space is "an incorporeal and immobile extension in which it is possible to designate length, width, and depth so that every object might have its place . . . ." (Gassendi 1972, 391). Hence, the congruence of incorporeal and corporeal dimensionality justifies our "Platonic" designation as regards his spatial geometry at the macro-level, since the dimensionality of space and the place of every body are independent of material existents. In conclusion: FGL(top), ML(plt).

In addition, God's ontological role is unique in Gassendi's natural philosophy, given his further contention that space and time, which are infinite, are neither substances nor accidents but a more general category of being (1972, 384). He reasons that "since it follows from the perfection of the divine essence that it be eternal and immense, all time and space are therefore connoted", and insists that God "both exists supremely in Himself . . . [and] also necessarily exists in all time and in every place" (1976, 94). In short, there is a form of co-dependence between God and space: "That God be in space is thought to be a characteristic external to His essence, but not with respect to His immensity, the conception of which necessarily involves the conception of space" (1976, 94; cf. Newton above).[10] Therefore, although God is not the cause of space and time for Gassendi (or for Newton), the fact that God's immensity entails infinite space, and God exists necessarily, hence justifies our FGL(top) classification.

3.4. Leibniz on Spatial Ontology. While Leibniz' accepts that God's immensity grounds space, as noted in section 2.2, his many criticisms of a spatially extended God in the Clarke correspondence (e.g., L.V.50), clearly rule out a similarity of geometric structure at both the foundational and material levels of reality—and the same holds for his basic ontological unit of ontology (other than God), namely, monads: as simple substances, they have no parts, "[b]ut where there are no parts, neither extension, nor shape, nor divisibility is possible" (AG 213). The non-spatiality of the monads is, in fact, a common theme in Leibniz' late work: e.g., "there is no spatial or absolute nearness or distance among monads" (L.607); and, "monads, in and of themselves, have no position with respect to one another, that is, no real position which extends beyond the order of phenomena" (AG 201). Accordingly: FGL(prg). Yet, Leibniz's version of FGL(prg) is quite different from Gassendi's non-metrical conception of God, a difference that is most clearly exposed in his rejection of holenmerism in the correspondence with Clarke: "[t]o say [a soul] is, the whole of it, in every part of the body is to make it divisible of itself. To fix it to a point, to diffuse it all over many points, are only abusive expressions, *idola tribus"* (Leibniz and Clarke 2000, 16-17; L.III.12). In contrast to both Newton's "determined quantities of extension" hypothesis of an extended God and Gassendi's holenmerist idea of an unextended God, Leibniz rebuffs the notion that "God discerns what passes in the world by being present to the things", rather, God discerns things "by the dependence on him of the continuation of their existence, which may be said to involve a continual production of them . . .” (2000, 56; L.V.85). In short, “God is not present to things by situation but by essence; his presence is manifested by his immediate operation” (2000, 16-17; L.III.12), where “immediate operation” is correlated with the continual conservation or reproduction of the world.

Turning to the geometric platonism/nominalism issue, since “there is no space where there is no matter” (L.V.62), Leibniz opts for a geometric nominalism at the material level, ML(nom).[11] Yet, although space is not “an absolute being” (L.III.5), it still represents “real truths” (L.V.47), even in the absence of matter: “[t]ime and space are of the nature of eternal truths, which equally concern the possible and the actual” (NE:II.xiv.26), and “truth and reality are grounded in God, like all eternal truths” (NE:II.xiii.17). The God-grounded “truths” concerning space, accordingly, also determine the range of possibilities for the arrangement of bodies in space. On the numerous ways that the world could be filled with matter, Leibniz states that “there would be as much as there possibly can be, given the capacity of time and space (that is, the capacity of the order of possible existence); in a word, it is just like tiles laid down so as to contain as many as possible in a given area.” (AG 151). Since these truths are *independent* of existing bodies, this form of explanation, in effect, betrays a strong penchant for absolutism—but, it is an absolutism about the truths of geometry conceived in a nominalist fashion, secured via God’s immensity. On this rather slender, but hugely important, issue—geometric platonism versus nominalism—one can trace most of the significant differences between Newton and Leibniz (and others) on space.[12]

At this point, a few words are in order regarding Leibniz’ remarks on the possibility of a vacuum, and how this relates to his spatial ontology and the eternal truths of space.

In brief, while Leibniz holds that a vacuum is "not in agreement with divine wisdom" (AG 170), he often admits that space is not by necessity a plenum, whether outside the confines of a finite material world, or within the material world: concerning the former, he states that "[a]bsolutely speaking, it appears that God can make the material universe finite in extension . . . ." (L.V.30); and, as regards the latter, he judges that "we can refute someone who says that if there is a vacuum between two bodies then they touch, since two opposite poles within an empty sphere cannot touch—geometry forbids it" (NE:II.xv.11). There are even hints that a complete vacuum state is possible, for Leibniz explains that God could prevent a monad's primitive force from bringing about extended matter, and thus potentially all of the monads could be effected in this way. In a letter from 1692, he states that primitive force is "a higher principle of action and resistance, from which extension and impenetrability emanate when God does not prevent it by a superior order" (A.I.vii.249; Adams 1994, 351).[13] Furthermore, since "there is no space where there is no matter" (L.V.62), and "extension must be the affection of something extended" (L.IV.9), the Leibnizian void lacks extension. As E. Sylla (2002) explains, there were similar theories put forward in the late Medieval period, in particular, by the fourteenth century natural philosopher, Nicole Oresme, who accepted a nominalist account of space that is strikingly similar to Leibniz' view on many points. Like Leibniz, Oresme contemplates a spherical vacuum that lacks extension, but which nonetheless can be attributed a sort of indirect extension by means of the possible bodies that God could bring about to fill that void (Sylla 2002, 269-271). In the *New Essays,* Leibniz adds that "[i]f there were a vacuum in space (for instance, if a sphere were empty inside), one could establish its size" (NE:II.xv.11). As for a temporal vacuum, on the other hand, "it would be impossible to establish its length"; likewise, "if space were only a line, and if bodies were immobile, it would also be impossible to establish the length of the vacuum between two bodies" (NE:II.xv.11). Consequently, three-dimensional space allows the surrounding bodies to completely determine the size of a vacuum, unlike the contrasting one-dimensional cases he constructs. This would appear to explain the intended meaning behind Leibniz' claim, quoted above, about the predetermined capacity of space to be filled with bodies (e.g., AG 151), since, although unextended, these void spaces are set within a fixed geometric structure secured via God's immensity (i.e., God's essence grounds the possibilities of space; see section 2.2).

3.5. Barrow and Descartes on Spatial Ontology. Finally, a brief glance at Barrow and Descartes will help to round out our analysis of seventeenth century spatial ontologies. In accordance with the prevailing theologically-based ontology of the period, Barrow also reckons that space is dependent on God: "there was Space before the World was created, and . . . there is now an Extramundane, infinite Space, (where God is present) . . . ." (Barrow 1976, 203). By declaring that there was "Space before the World", this passage has platonist overtones, and likely prompted those assessments that group Barrow with the absolutists (substantivalists): e.g., Barrow's "space exactly anticipates Newton's conception of absolute space . . ." (Hall 1990, 210). Nevertheless, Barrow actually follows Leibniz' (and Oresme's) nominalism, for he explicates space's "existence" via the God-based capacity to receive bodies (in keeping with the Scholastic "imaginary" space tradition; see, Grant 1981, chapter 6). For instance, he explains that time "does not imply an actual existence, but only the Capacity or Possibility of the Continuance of Existence; just as space expresses the Capacity of a Magnitude contain'd in it" (1976, 204). Hence, Barrow's "Space before the World" is the mere capacity to receive bodily magnitude, just like Leibniz: ML(nom), and either FGL(prg) or FGL(top), since evidence for this last categorization is lacking.

Descartes' conception of space shares many features in common with Leibniz' views, especially the espousal of God's "extension by power": where "[s]uch a power, being only a mode in the [corporeal] thing to which it is applied, could not be understood to be extended once the extended thing corresponding to it is taken away" (Descartes 1991, 373). As he later notes, "[i]t is certain that God's essence must be present everywhere for his power to be able to manifest itself everywhere; . . ." (1991, 381); and, despite his substance dualism, he adds that "[i]n the case of all other substances [besides God], we perceive that they can exist only with the help of God's concurrence" (Descartes 1985, 210). Therefore, as with Leibniz, God is the foundation of space by way of matter, and "since it is a complete contradiction that a particular extension should belong to nothing" (1985, 230), a vacuum is impossible: ML(nom), FGL(prg).

3.6. Reflections on Modern Relationism and Leibniz' Spatial Ontology. As we have seen, Leibniz' conception of the geometric truths of space are both grounded by God and independent of matter: e.g., "[t]ime and space are of the nature of eternal truths, which equally concern the possible and the actual" (NE:II.xiv.26); "truth and reality are grounded in God, like all eternal truths" (NE:II.xiii.17); and, concerning how the world can be filled with matter, "there would be as much as there possibly can be, given the capacity of time and space (that is, the capacity of the order of possible existence); in a word, it is just like tiles laid down so as to contain as many as possible in a given area" (AG 151). Some commentators, such as Belot (2011, 2), have inferred from this evidence that Leibniz is a realist about geometry at the phenomenal level of matter. However, this quite justifiable observation overlooks the fact that Leibniz' realism about space at this level stems from God's immensity, and so his realism differs in only one significant way from Newton's similar God-grounded spatial realism; namely, platonism versus nominalism at the material level, a distinction that evades trivial substantivalism and trivial relationism since that dichotomy conflates the ontological and geometrical/mathematical aspects of spatial theories. From a modern perspective, one might strive to equate Newton's platonism with a straightforward realism about geometric structure at the material level, as well as Leibniz' nominalism with a modal realism at this level, but this approach fails to account for the rationale behind these different realist ascriptions, non-modal versus modal: (a) an underlying ontology (God) that is actually present in space, thus explaining Newton's realism, and (b), an underlying ontology (God, monads) that is not present in space, thereby explaining Leibniz' modal realism. Put differently, both Leibniz and Newton would deny the assumption that bodies/fields alone can ground geometric truths, but this is the exact motivation behind the modern approach to spacetime ontology. While any deeper facets of spatial ontology were of little interest in the context of classical mechanical and gravitation theories, since their focus was naturally fixed on the higher realm of matter or fields, this is no longer the case now that the attention of theoretical physicists has shifted to the search for QG. Once the microlevel, and a difference between the micro and macro, are thrown into the mix, the long forgotten ontological concerns that formed the very basis of the spatial theories of seventeenth century natural philosophy suddenly reclaim their once dominate status. It is for these reasons that a more nuanced scheme for assessing spatial ontology is required, such as the difference in spatial geometric levels and the platonist/nominalist divide utilized in this essay. In short, the standard substantivalist/relationist distinction is simply incapable of recording these more fine-grained differences, as is manifest in its impoverished and conflicting appraisals of QG (and even GR).

As just discussed, one might attempt to put forward a modal relationist hypothesis as the contemporary equivalent of Leibniz' nominalism, a strategy expertly developed in Belot (2011, 173-185). While Belot's efforts are quite informative, it nonetheless seems to strain the coherence of relationist doctrine. A true modal relationist must, presumably, posit spatial (spatiotemporal) modality on actually existing matter/fields, or on the possibility of matter/fields coming into existence. Leibniz' hypotheses, on the contrary, fix the truths of spatial structure, not on bodies or on the possibilities of bodies, but on God: "He is the source of possibilities and of existents alike, the one by his essence and the other by his will. So that space like time derives its reality only from him" (NE:II.xv.2). Likewise, a complete and permanent vacuum state does seem plausible given Leibniz' additional claim that God could block the emergence of extended matter (see section 3.4). If one is forced to choose between substantivalism and relationism, consequently, then Leibniz' spatial hypotheses would seem to fall more comfortably on the absolutist/substantivalist side of the debate, and not modal relationism. Indeed, a theory whose fixed (nominalist) spatial truths and structures do not depend on matter/fields—but instead posits that matter, and hence the instantiated truths of space, emerge from a deeper and quite different layer of ontology (in this case, monads)—not only eludes modal relationist doctrine, but would seem to demand a separate classification beyond traditional substantivalism and relationism. That dichotomy, once again, grew out of the classical theories of nineteenth and twentieth century macrolevel physics, but struggles to find applicability and relevance within the context of QG, an observation first disclosed in section 1.

4. Platonism/Nominalism, Geometric Background, and the Shift Arguments.

4.1. Background Dependence/Independence. While philosophers of space and time have largely ignored the significance of the platonism/nominalism distinction for interpreting the substantival/relational dispute, a close cousin of the ML(plt)/ML(nom) divide can be detected in one of the central themes connected to the search for QG, namely, background independence. Among the competing interpretations of this doctrine (see, Rickles 2008, 352-355, for excellent survey), background independence can be minimally construed as the "freedom from 'background structures', where a background structure is some element of the theory that is fixed across the models of the theory" (French and Rickles 2006, 1-2, n.1). The metric is normally the structural element at issue, hence the variable metric in GR marks that theory as background independent. Likewise, as French and Rickles go on to note, "background independence, when used in the context of quantum gravity, is usually meant in a restricted sense, covering the freedom from a background metric alone" (2006, 2, n.1). Conversely, if a theory's metric is background dependent, then all formulations of the theory must conform to a predetermined, fixed geometry regardless of the matter configuration or other factors. This last stance is consistent with ML(plt), of course; but, since Euclidean geometry is standard throughout the seventeenth century, it would appear that all of these earlier theories are background dependent, including the ML(nom) cases. For instance, Leibniz defines "distance" in the *New Essays* as "the size of the shortest possible line that can be drawn from one [point or extended object] to another", and comments that "[t]his distance can be taken either absolutely or relative to some figure which contains the two distant things", and where "a straight line is absolutely the distance between two points" (NE:II.xiii.3). Leibniz' choice of the term "absolute" to signify the Euclidean concept of a straight line (as the shortest distance) thereby calls into question those attempts, such as Smolin (2006, 201), to enlist Leibniz as an early advocate of the background independence cause.[14]

4.2. The Shift Arguments. The difference between geometric platonism and nominalism is also useful for understanding the static and kinematic shift scenarios, as well as the structuralism intrinsic to both Newton and Leibniz' respective approaches (see, French and Rickles (2006) for an investigation of structuralism with respect to the substantivalist/relationist debate). Since structuralism is concerned with the structural relationship among things, as opposed to the things themselves, it is often regarded as more akin to relationism than substantivalism. Nevertheless, Newton takes a very structuralist line on the identity of the parts of space, a strategy that he employs to demonstrate "the immobility of space" (Newton 2004, 25). The parts of space cannot move because "[t]he parts of duration and space are understood to be the same as they really are only because of their mutual order and position; nor do they have any principle of individuation apart from that order and position, which consequently cannot be altered" (2004, 25). Given Newton's geometric platonism, and the fact that an immobile God grounds the parts of space, it follows that an identical configuration of bodies can occupy many different positions in space, static shifts, as well as motions in space, kinematic shifts.

Leibniz' structuralism, on the other hand, is best understood via his nominalism. Because God's essence serves as the foundation of the Euclidean capacity of space (as above), and space depends on bodies, nominalism entails that there can be only one instantiation of the same relative configuration of bodies, unlike on Newton's scheme. For example, if space "is nothing at all without bodies but the possibility of placing them, then those two states, the one such as it is now, the other supposed to be the quite contrary way [static shift], would not at all differ from one another" L.III.5). Specifically, if space is only God's idea prior to the material world's instantiation of space—i.e., "the possibility of placing them", secured via God's essence—then to claim that the material world could have had a different spatial location while retaining its relative configuration (e.g., the material world has been uniformly repositioned three feet to the left) is to demand that space must exist both prior to, and independently of, the material world's instantiation of matter (since this prior and independent existence of space is the only way that the same relative configuration of bodies can obtain a different position in space). But, of course, this is just what Leibniz nominalism denies, and thus a uniform and unobservable static shift would amount to nothing more, on Leibniz' scheme, than a relabeling of the places already instantiated by the material world, which is a mere difference in scale or gauge.

The same holds true for any kinematic shift, since any uniform addition or subtraction of speed or difference in direction as regards all bodies does not effect the dynamical interconnections among those bodies—and it is the dynamical interactions among bodies that is associated with space at the macrolevel (see section 2.2). At a deeper level, the motions of bodies ultimately results from the internal forces that comprise the monads, and which are manifest in the derivative force of bodies: “as for motion, what is real in it is force or power; that is to say, what there is in the present state which carries with it a change in the future” (FW 207); “I, however, do not consider motion to be a derivative force but think rather that motion, being change, follows from such force” (L 533). Consequently, given his unique conception of force, any equal change in the velocity (speed or direction) of the world’s occupants would only result in a different total numerical value of the whole world’s conserved quantity, which Leibniz measures as mv^2; but, this would represent merely another undetectable difference in scale factor. Put differently, motion derives from internal forces for Leibniz, and so a uniform change in the velocity of all of the world’s inhabitants is just a uniform addition or subtraction of the world’s force, which thereby renders the change equivalent to those thought experiments that, say, double the size of all of the world’s objects (and which are often regarded as indiscernible).

To sum up, the platonist/nominalist divide helps to elucidate the different forms of structuralism intrinsic to both Newton and Leibniz’ theories, as well as assists in understanding the rationale behind Leibniz’ rejection of the shift arguments (although his rejection of kinematic shifts requires a nominalism that is conjoined with his belief in the dynamical interconnections of all bodies, which in turn stems from the primitive force of monads). Yet, it is important to note that other nominalist approaches to space, similar to Leibniz’ version, did admit uniform shifts of the entire material world, and this difference might be traceable to the difference between FGL(top) and FGL(prg) surveyed above, which in the seventeenth century stands for the difference between, respectively, holenmerism and the extension of power. As first introduced in section 3.4, Oresme treats an intra-world vacuum along the same lines as Leibniz, employing possible bodies, yet, unlike Leibniz, he reckons that God could move the entire world in a rectilinear kinematic shift (1968, 369). For Oresme, whose deep ontology of space is much closer to Gassendi's than Leibniz' ontology, God's immensity is both classified as "whole in every part" holenmerism,[15] and identified with all spaces/places, including the vacuum outside the world (see, also, Grant 1981, 350, n.127; 349, n.123).[16] Hence, while Oresme's nominalism correlates with ML(nom), his ontology accepts FGL(top) by way of holenmerism. Given that holenmerism posits God's unextended but point-like presence in space (as is also the case with Gassendi's God), there is, accordingly, a consistent basis upon which to posit a kinematic shift of the world—i.e., God's actual presence in space, even though it is a non-dimensional, point-like presence. While not possessing any dimensional quantity, Oresme's deep ontology of space, i.e., God, can surely register the change of the material world's position from one point to another, presumably as a sort of topological change, and so a kinematic shift makes sense on this scheme (although the distance traversed would be indeterminate given the lack of geometric quantity). Leibniz, on the other hand, rejects holenmerism, and favors the extension of power doctrine instead, such that God is not actually present in space per se. As discussed in section 3.4, since only God's operation of conserving the world can be situated under the extension of power hypothesis, a Leibnizian kinematic shift is thus not applicable on the grounds that it is inconsistent with Leibniz' conception of a non-situated God. Whether or not this additional line of argument played a role in Leibniz' decision to reject the shift scenarios remains unclear, needless to say, but it does pose an intriguing possibility since Oresme and Leibniz' respective spatial theories are nearly identical but diverge quite drastically on these two issues, i.e., holenmerism versus extension of power, and kinematic shift versus no kinematic shift.

5. The Deep Metaphysics of Space from the Seventeenth Century to Quantum Gravity.

The preceding analysis sets the stage for a closer examination of various QG hypotheses, background independence, pregeometry,[17] spacetime emergence,[18] and, ultimately, of the deficiencies in the substantivalist/relationist dichotomy as it applies to the seventeenth century and QG.

5.1. Geometric Levels and Quantum Gravity. Returning to our division of spatial geometric levels, FGL, there is a fascinating, and apparently natural, analogue of this distinction within the diverse array of QG hypotheses (albeit some QG hypotheses will pose various classificational difficulties due to their complex and hybrid construction). One might question the relevance of this exercise, of course, given that the seventeenth century's preoccupation with the theological underpinnings of space would seem to have little in common with the modern search for QG. Yet, as mentioned previously, the situation confronting both the seventeenth century and the QG theorist is exactly the same: both are concerned with constructing an adequate theory of space, time, and the physical world based on a pre-given theory, specifically, the western God, on the one hand, and GR and QM, on the other. Both "research programs", as it were, strive to retain the essential features of that underlying theory, but both recognize the need to adapt, revise, and sometimes overturn, various elements of the established system in the process of securing their respective goals (namely, a spatiotemporal theory grounded upon God, for the seventeenth century, and a spatiotemporal theory that successfully integrates GR and QM, for contemporary physics).

Turning to these analogies, Newton and More's FGL(met) would seem to correspond to the pattern of the earliest geometrodynamic hypotheses, as well the older canonical quantization techniques, since these approaches rely upon the general geometric structure employed by the foundational theory, which is, respectively, GR and QFT (quantum field theory, which is the conjunction of QM and the flat Minkowskian spacetime of special relativity). In the (naïve) covariant quantization strategy that flourished up through roughly the early 1970s, the metric of the foundational theory, QFT, is split into two parts, the fixed background metric (usually Minkowskian), which "defines spacetime, namely it defines location and causal relations" (Rovelli 2004, 12), and a dynamical component that relies on perturbation techniques to secure the postulated graviton (and hence extend QFT to gravity). In the old geometrodynamics (which is not technically a QG hypothesis, but similar[19]), GR is the foundational theory, with the metric and the curvature of spacetime taken as the basic groundwork from which all other physical phenomena are presumed to be derived or constructed. The geometric outlook that motivates geometrodynamics also prompts Sklar's well-known concept of supersubstantivalism: "not only does spacetime have reality and real structural features, but in addition, the material objects of the world, its totality of ordinary and extraordinary material things, are seen as particular structured *pieces* of spacetime itself" (1974, 221). Newton's "determined quantities of extension" hypothesis, surveyed in section 3.2, fits the supersubstantivalist definition quite nicely, that is, if one substitutes the term "spacetime" with the term "God's spatial extension". If viewed within the context of the deep metaphysics of space, however, the various attempts to tie Descartes to geometrodynamics fail (e.g., Graves 1971, 87), since Descartes grounds space (= matter) on a non-spatial, non-geometric conception of God, as we have seen.

In addition, the first period or phase of String theory, roughly up through the mid-1990s, would likely fit the FGL(met) category as well. Despite invoking a number of compactified extra dimensions at the microlevel,[20] the perturbative method employed by these theories presupposes a classical spacetime backdrop and its metric:

> [T]he propagation of the [one-dimensional] string is viewed as a map $X : \rightarrow M$ from a two-dimensional worldsheet *W* to spacetime *M* (the 'target spacetime'). The quantization procedure quantizes *X*, but not the metric γ on *M*, which remains classical. . . . [T]he classical spacetime metric γ on *M* satisfies a set of field equations that are equivalent to (the supergravity version of) Einstein's field equations for general relativity plus small correction of Planck size: this is the sense in which general relativity emerges from string theory as a low-energy limit. (Butterfield and Isham 2001, 71)

While the metric at the microlevel and macrolevel are, approximately, the same in these string theories, hence FGL(met), the already significant topological differences at these two levels have evolved into a potentially more radical set of dissimilarities in the second phase of non-perturbative string theories. As Butterfield and Isham note, concerning the possibility that there might exist a minimum spacetime length in these later approaches (via the duality symmetries), "these developments suggest rather strongly that the manifold conception of spacetime is not applicable at the Planck length; but is only an emergent notion, approximately valid at much larger length-scales" (Butterfield and Isham 2001, 73; and, Witten 1989, 350-351). Consequently, the trajectory of the development of non-perturbative string theories seems headed towards FGL(prg), where the foundational level of ontology exhibits entirely different geometric structures than at the macrolevel: i.e., contra FGL(met), a discrete geometry at the microlevel, but the standard differential geometry of the macrolevel emergent theory (GR); and, contra FGL(top), a topology at the microlevel that likewise diverges from the macrolevel topological structure.

The well-known rival of string theory is, of course, LQG (loop quantum gravity), which does not rely upon a classical metric, unlike string theory. As a later variant of the canonical quantization program, a theory like LQG "uses a background dimensional manifold (but it uses no metric)", where this (spatial) manifold "becomes part of the fixed background in the quantum theory—so that . . . there is no immediate possibility in discussing quantum changes in the spatial topology" (Butterfield and Isham 2001, 76). Therefore, LQG upholds FGL(top). So, regarding the question that first prompted our investigation, i.e., "Which seventeenth century philosophy of space best resembles the structure of LGQ?", we are finally in a position to provide an answer: it is neither Smolin's choice of Leibniz, who accepts FGL(prg), nor Dainton's preference for Newton, who endorses FGL(met)—rather, it is Gassendi, since he endorses FGL(top)! As discussed in section 3.4, by declaring that "there is no spatial or absolute nearness or distance among monads" (L.607), it follows that any ascription of metrical properties to Leibniz' monadic ontology is ruled out, but so would most topological properties. A topological space involves a neighborhoods of points and their various non-metrical interrelationships, such as continuity and connectedness. Yet, since monads have "no position with respect to one another", and each monad is "a certain world of its own, having no connections of dependency except with God" (AG 199), even these weaker topological notions are apparently excluded. In short, the structure of a continuous manifold at the foundational level, FGL(top), is incompatible with Leibniz' spatial ontology at that level, but not with respect to Gassendi's, for the latter situates God in the points of a Euclidean space and its corresponding continuous topology (but not the former), as explained in section 3.3.

5.2. Pregeometry: Leibniz and QG. There is, however, a group of modern QG strategies that would seem analogous to the pregeometry of monads, namely, start with a mere set of points, *M*, without topological or differential structure, and build the continuous topological and metrical macrolevel structures from this foundation. On Butterfield and Isham's estimation, "this set is formless, its only general geometrical property being its cardinal number", and is such that "there are no relations between the elements of *M*, and no special way of labeling any such elements [i.e., no topology]" (2001, 81). Butterfield and Isham's analysis is part of a larger discussion of alternative QG strategies, different from string theory and LQG, where the quantization is imposed "below the metric". Quantum effects and structures can then be introduced at this lower level and associated, depending on the particular QG scheme, with any of a host of sub-metric structures, e.g., *M*, causal, algebraic, topological, differential, etc., in an ascending hierarchy (with different hierarchies erected based on the particular QG strategy). These sub-metric QM structures thus lie underneath, and can be said to generate or bring about, GR and QM's common geometrical presuppositions as employed in their standard mathematical formalisms, i.e., a Lorentzian metric on a four-dimensional topological, differentiable manifold. Among these different strategies, the most Leibnizian might reside in the utilization of a commutative ring of differentiable functions (e.g., C^* algebras) in lieu of a differentiable manifold, since the main goal of Leibniz' *analysis situs* is to provide an algebraic model of spatial situation (L 248-249), and is thus in keeping with his overall worldview that takes algebra/arithmetic as primary, and geometry as derived.[21]

There are many QG theories that fit this general category: e.g., causal sets, spin foam models, computational universe, etc. For example:

> Causal set theory arises by combining discreteness and causality to create a substance that can be the basis of a theory of quantum gravity. Spacetime is thereby replaced by a vast assembly of discrete "elements" organized by means of "relations" between them into a "partially ordered set" or "poset" for short. None of the continuum attributes of spacetime, neither metric, topology nor differentiable structure, are retained, but emerge it is hoped as approximate concepts at macroscales. (Dowker 2005, 446)

In what follows, however, we will concentrate on the quantum causal histories program (QCH). R. Hedrich provides the colorful description, "geometrogenesis", for the process by which "spacetime emerges from a pregeometric quantum substrate" in QCH (Hedrich 2009a, 22), with this substrate correlating with the set *M* and a causal structure in Butterfield and Isham's account.

> [QCH's] basic assumptions are: There is no continuous spacetime on the substrate level. The fundamental level does not even contain any spacetime degrees of freedom at all. — Causal order is more fundamental than properties of spacetime, like metric or topology. — Causal relations are to be found on the substrate level in form of elementary causal network structures. . . . [M]acroscopic spacetime is necessarily dynamical, because it results from a background-independent pregeometric dynamics. But, the dynamics of the effective degrees of freedom on the macro-level are necessarily decoupled from the dynamics of the substrate degrees of freedom. If they would not be decoupled, there would not be any spacetime or gravity on the macro-level, because there is none on the substrate level. In the same way, causality on the macro-level, finding its expression in the macro-level interactions, is decoupled from causality on the substrate-level. And spacetime-locality on the macro-level, if it emerges from the dynamics of coherent excitation states, has nothing to do with locality on the substrate graph structure level. (Hedrich 2009a, 22-23)

The analogue of these QG hypotheses will be readily evident to the Leibnizian devotee. First, monads and their intrinsic primitive forces correspond to the discrete elementary quantum events, which in the QCH program are excitation states in a finite-dimensional

Hilbert space (as the discrete nodes in a graph structure).[22] For Leibniz, matter and space emerge from a micro-realm that, like QM and QG theories, is more aptly described in terms of force: a monad is “endowed with primitive power” such that the “derivative forces [of bodies] are only modifications and resultants of the primitive forces” (AG 176). Second, the derivative nature of the spatial and dynamical properties of bodies, as opposed to the intrinsic primitive forces of the non-spatial, non-material monads which brings about bodies, thus correlates with Hedrich’s technical term “decoupling”: that is, the emergence of a macrolevel of spatial and dynamical properties that is quite different from, and seemingly independent of, the pre-spatial and dynamical properties at the microlevel that generate the macrolevel properties (“spacetime-locality on the macro-level, if it emerges from the dynamics of coherent excitation states, has nothing to do with locality on the substrate graph structure level”). For Leibniz, monads (like God) are not in space per se, but they are the means by which God “brings about” matter and, hence, instantiates his nominalist account of space: “[c]ertainly monads cannot be properly in absolute place, since they are not really ingredients but merely requisites of matter” (L.607); and, “properly speaking, matter is not composed of constitutive unities [monads], but results from them” (AG 179; see, e.g., Rutherford 1995a, for an extended analysis). Much has been written on whether or not monads are really in space (see, e.g., Cover and Hartz 1994), a debate inflamed by these kinds of fairly opaque quotations;[23] yet, QG theories provide a concrete example of the type of world view that Leibniz was likely striving to establish (see, Garber 2009, 383-384, who briefly mentions a similar interpretation).

A third similarity between QCH and Leibniz relates to one of the major themes of our investigation, namely, nominalism:

> But what are these coherent, propagating excitation states, resulting from the substrate dynamics and leading to spacetime and gravity? And how do they give rise to spacetime and gravity?—The answer given by the *Quantum Causal Histories* approach consists in a coupling of geometrogenesis to the genesis of matter. The idea is that the coherent excitation states resulting from and at the same time dynamically decoupled from the substrate dynamics are matter degrees of freedom. And they give rise to spacetime, because they behave as if they were living in a spacetime. (Hedrich 2009a, 23).

By its “coupling of geometrogenesis to the genesis of matter”, i.e., that the emergence of space is coupled to the emergence of matter, QCH can truly claim a lineage with Leibniz’ brand of nominalism, as opposed to the matter-less platonism of LQG. A vacuum state occurs in LQG when the **s**-knots (equivalence classes of spin networks formed by spatial diffeomorphisms), which secure the QM basis of space, lack the requisite quantum excitations needed for the existence of matter (“the quantum state of the gravitational field is such that it has no excitations”, Rickles 2005, 426). The quantization strategy employed in LQG, which admits vacuum solutions but retains its **s**-knot quantum geometry, is thus closer to the matter-based platonism of Newton and Gassendi, unlike Leibniz and QCH, which both link the emergence/actualization of space (spacetime) to the emergence of matter. Of the two theories, LQG and QCH, there are other reasons for preferring QCH as more comparable to Leibniz’ monadic system. The result of LQG’s quantization of the metric of GR is an array of spin networks with finite area and volume, which essentially constitutes “quantum chunks” of space (Rovelli 2001, 110). The QM-rooted spin networks are therefore inconsistent with the non-spatial, non-geometric character of monads, and the same is true of the spatial diffeomorphisms required to form the **s**-knots from the spin networks (since diffeomorphisms are geometric transformations on a differential, hence continuous, manifold, contra Leibniz’ FGL(prg)). Moreover, given the direct quantization of GR's metric, gravity is rendered a fundamental interaction for LQG; but gravity is emergent for both Leibniz and QCH, since it is tied to the existence of matter at the macro-scale. Rather, the spin networks in LQG, which are contiguous discrete chunks of a quantum field, are much closer to Leibniz' conception of contiguous discrete chucks of matter, as opposed to the non-contiguous discrete objects that comprise his pregeometric monadic metaphysics. This last point is nicely explained by Rovelli as it pertains to LQG:

> This discreteness of the geometry, implied by the conjunction of GR and QM, is very different from the naive idea that the world is made by discrete bits of something. It is like the discreteness of the quanta of the excitations of a harmonic oscillator. A generic state of spacetime will be a continuous quantum superposition of states whose geometry has discrete features, not a collection of elementary discrete objects. (Rovelli 2001, 110)

Once again, this description more accurately tracks Leibniz' material plenum, as opposed to the deep metaphysical entities, monads, that underlie his material realm.

Nevertheless, there is one significant issue on which Leibniz' monadic system diverges from QG theories, namely, causal or dynamical structure at the microlevel, like QCH's quantum channels (the lines of the graphs that connect the vertices). Because "monads have no windows through which something can enter or leave" (AG 214) there is as an absence of any inter-monadic causal mechanism at that scale. What is needed is a mechanism that could connect or interrelate the monads so as to generate matter and space, a process that would roughly correlate with the dynamics of the pregeometric substrate in QCH. One might be tempted to interpret Leibniz' enigmatic concept of a "substantial chain", which appears in the late correspondence with Des Bosses, as a remedy for the lack of an inter-monadic connection, where a substantial chains is defined as "something substantial which is the subject of [the monads'] common predicates and modifications, that is, the subject of the predicates and modifications joining them together" (AG 203). Leibniz' preferred monadic view, in brief, is to characterize the continuous mathematical structure of space and time as "ideal", whereas real existents are discrete: "For space is something continuous, but ideal, whereas mass is discrete, indeed an actual multiplicity, or a being by aggregation, but one from infinite unities [monads]. In actual things, simples are prior to aggregates; in ideals things, the whole is prior to the part" (LDB 141). In the letters to Des Bosses, however, Leibniz suggests that the substantial chain introduces real continuity into the world of existents: "[r]eal continuity can arise only from a substantial chain" (AG 203). Nevertheless, like matter, "monads aren't really ingredients of this thing [substantial chain] which is added [to the monads], but requisites for it . . ." (AG 198). That is, the substantial chain is a property that "results from" the monads, as is also the case with matter. In fact, in a passage cited previously, Leibniz provides the very same explanation for the emergence of matter as he does for the substantial chain: "[c]ertainly monads cannot be properly in absolute place, since they are not really ingredients but merely requisites of matter" (L.607). Therefore, the substantial chain arises at the macrolevel, and so it does not constitute the sought-after *microlevel* connection.[24]

5.3. Background Independence/Dependence and Geometric Nominalism. From the modern QG perspective, Smolin has argued that the substantival/relational dichotomy converts to a dispute over background dependent/independent methods (Smolin 2006, 199), thus it follows that the fixed background metric and point manifold employed by the early varieties of string theory renders those theories more substantivalist (absolutist) than the alternative QG options that only rely on a point manifold, such as LQG. As noted earlier, however, the utilization of the manifold's topological, dimensional, and differential structure can still be deemed to violate a fully background independent scheme, and it is for these reasons Smolin declares that LQG is only partially relational (2006, 215). Nevertheless, whether it is metric or manifold structure that counts as a more substantivalist orientation is itself a contentious issue; see, Earman (1989, chaps. 8 and 9), for a defense of manifold structure as the better candidate. If one accepts Earman's argument, then LQG and Covariant Quantization theories are *both* equally substantivalist, contra Smolin, since both employ a point manifold. A further obstacle for Smolin's attempt to link the substantivalism/relationism dichotomy to background dependence/independence is that one of the most substantivalist leaning theories, geometrodynamics, which Sklar associates with supersubstantivalism, is background independent, and thereby should count as relationist given Smolin's conjecture (see section 5.1).

A somewhat different way of explaining the inadequacy of using the background dependence/independence divide as a substitute for the substantival/relational dichotomy connects with our earlier analysis of platonism and nominalism. In short, whether the background geometry is fixed or variable is not relevant to the platonist/nominalist distinction; rather, it is the presence of geometric structure in the absence of all physical entities or processes that is crucial, since that possibility would violate nominalism. For similar reasons, the argument that LQG is in conflict with relationism, because it allows vacuum solutions (see, Rickles 2005, 425; Earman 2006, 21) is misleading due to the fact that the underlying quantum processes, spin networks and the **s**-knots constructed from them, remain even in vacuum solutions. Hence, while the traditional matter-based conceptions of spatial relationism and nominalism are indeed undermined by these vacuum solutions, the finite value of the vacuum energy and its effects (virtual particles, Casimir effect, etc.) in QM and QFT upholds a non-matter, field-based form of nominalism, since there are no voids totally absent of energy (likewise for sophisticated metric-field relationist interpretations of GR, for gravity waves in an otherwise empty unverse carry energy). Moreover, Leibniz would seem to support the possibility of an analogous vacuum state (see section 3.4, and the A.I.vii.249 quote). Unlike LQG, however, Leibniz' nominalist spatial geometry is only instantiated by matter, and so a matter-less world is absent any spatial geometry, whereas LQG's vacuum state retains its **s**-knot spatial structure—it is for these reasons that Gassendi's theory more closely resembles LQG than Leibniz' theory, as first mentioned in section 5.1.

Furthermore, any attempt to foist a non-reductive spacetime "fundamentalism" on all ontological appraisals of QG theories can be defeated employing the same nominalist line of argument. Earman, in particular, has offered the following defense of a non-reductive spacetime construal of LQG:

> [A]lthough *classical* general relativistic spacetime has been demoted from a fundamental to an emergent entity, spacetime *per se* has not been banished as a fundamental entity. After all, what LQG offers is a quantization of classical general relativistic spacetime, and it seems not unfair to say that what it describes is *quantum* spacetime. This entity retains a fundamental status in LQG since there is no attempt to reduce it to something more fundamental. (Earman 2006, 21)

Yet, to portray the physical Hilbert space of LQG as a fundamental entity (where "fundamentalism" is, presumably, a species of substantivalism) is to beg the question against a non-fundamentalist interpretation, for it seems much more plausible to invoke the nominalist conclusion that the Hilbert structure is linked to the existence of physical quantum states; i.e., quantum states are the fundamental entities, not the Hilbert space.

Put differently, it appears totally unwarranted to saddle the physical quantum states with a sort of platonic Hilbert space, i.e., as a fundamental entity, since that would entail that the Hilbert space could remain in existence even in the absence of the physical quantum states, contra nominalism. Furthermore, as Dieks correctly points out with regard to non-relativistic QM, "the Hilbert space formalism does not start from a space-time manifold in which particles are located. The quantum state is given by a vector in Hilbert space, and has in general no special relation to specific space-time points. Rather, 'position' is treated in the same way as 'spin' or other quantities that are direct particle properties: all the quantities are 'observables', represented by Hermetian operators in Hilbert space" (Dieks 2001, 16). Consequently, Earman's own defense of the point manifold as the basis of substantivalism is not applicable in the case of traditional non-relativistic QM, and, with respect to relativistic QM theories, it is the physical QM field that serves as the nominalist-friendly fundamental entity.

More carefully, recalling the distinction first introduced in section 3.1, if the platonism/nominalism question is pushed to the fundamental or foundational level of ontology, FL(plt) and FL(nom), then all of our examined theories, whether from the seventeenth or twentieth/twenty-first centuries, align with nominalism, FL(nom). As revealed in this essay, God is the entity required for the existence of space in the seventeenth century, thereby securing a nominalist foundation for space via this unique (immaterial) entity. In the same way, modern QG theories are not committed to a platonic background structure given the complete nonexistence of the relevant QG entities and processes. For the seventeenth century and QG theories, geometric background structures are predicated on the physical (or metaphysical) processes associated with its foundational entity, which favors the nominalist position.

Nominalism at the foundational level operates somewhat differently than at the material level, however. At this foundational level, seventeenth century philosophers only required a sort of congruence of the domain of the God's substance or operation and the extent of space, since they all reject the inherence conception that treats space as an internal accident of God (with the exception of More and possibly other Cambridge neo-platonists, such as Raphson; see, More 1995, 56-57). For all of the seventeenth century thinkers surveyed above, space is not "external" to God. To be exact, space cannot exceed either the bounds of God's own extension (Newton and More) or God's non-extended immensity, where that non-extended immensity can take the form of either holenmerism (Gassendi and Charelton) or the extension of power (Descartes and Leibniz). As previously disclosed, Newton denies "that a dwarf-god should fill only a tiny part of infinite space" (Newton 1978, 123), and Gassendi claims that "since it follows from the perfection of the divine essence that it be eternal and immense, all time and space are therefore connoted" (Gassendi 1976, 94). For Leibniz, "[t]he immensity and eternity of God are things more transcendent than the duration and extension of creatures, ...", yet, "[t]hose divine attributes do not imply the supposition of things extrinsic to God, such as are actual places and times" (L.V.106). This dependence of space on God is further revealed in his rejection of the idea that space is God's place, since that would imply that "there would be a thing [space] coeternal with God and independent of him" (L.V.79). Hence, while God is not situated in space for Leibniz, God's extension of power, which is situated, is at least congruent with the world's actual or possible spatial extension; if not, space would be independent of God. Finally, since monads generate the matter that instantiates space (and are a sort of interface between Leibniz' God and the material world), it naturally follows that space is not independent of the monads.

In a similar fashion, there is a sort of congruence of the physical quantum states and their Hilbert spaces, or the field in QFT and its Minkowski spacetime, in that the QM-based QG theories do not sanction void spaces entirely devoid of energy, where an absolute void would imply that the geometry at this foundational level exceeds the bounds of, or is external to, its physical entities/fields and their associated states and observables. One could even go so far as to claim a certain analogy between God's grounding the possibilities of bodies at the macro-level in Leibniz' spatial ontology (as above, NE:II.xv.2), and, for a physical system in QM, the state vectors grounding the probability of the physical observables in a Hilbert space. In many of the pregeometric QG hypotheses, in fact, it is often claimed that macrolevel space emerges from "internal" QM processes, a description that upholds the nominalist ban on entirely void, i.e., platonic, spaces: e.g., in the model of Kaplunovsky and Weinstein (1985), "the distinction between 'geometric' and 'internal' degrees of freedom can be seen as a low-energy artifact that has only phenomenological relevance. Space is finally nothing more than a fanning out of a quantum mechanical state spectrum" (Hedrich 2009a, 16).

Turning to string theory, the development of background independent, non-perturbative techniques (string field theory) would seem to have alleviated many of the of the above worries, yet, even leaving aside these background independent advances, as long as any string theory does not sanction void spaces absent the strings and their vibrations and interactions, even the fixed background structure of the older forms of string theory can be seen as siding with nominalism over platonism. Given the rise of the braneworld scenarios in M-theory (a further development of string theory), another potential nominalist strategy is to link the existence of three-dimensional space to three-dimensional branes (where strings are one-branes). For example: "If a three-brane is enormous, perhaps infinitely big, . . . [a] three-brane of this sort would fill the space we occupy. . . . Such ubiquity suggests that rather than think of the three-brane as an object that happens to be situated within our three spatial dimensions, we should envision it as the very substrate of space itself" (Greene 2011, 113-114).

Thus far, we have defined background-independence as the denial of a fixed geometric structure for all models of a particular physical theory, but, drawing on the work of, e.g., Brown (2005, 140) and Brown and Pooley (2006, 71), Alexander Bird has argued that background independence might also incorporate the "action-reaction principle". In the case of space, this principle stipulates that space must be able to act and be acted upon, a state of affairs that is manifest in the reciprocal influence between GR's metric and stress-energy. This leads to the following definition of background independence (which Bird dubs "background-free"): "In a true theory, any structure appearing in the laws of that theory is subject to being affected by changes elsewhere" (Bird 2007, 165).

A few observations are in order concerning this strategy. First, as disclosed in section 2, space cannot act upon things for either Newton or Leibniz (a point also noted by Brown and Pooley 2006, 71), thus modern spatial ontologies based on the action-reaction principle cannot appeal to the traditional substantival/relational dichotomy for support. Nor does the action-reaction principle apply to the foundational entity in that period, whether God (e.g., "space is eternal in duration and immutable in nature because it is the emanative effect of an eternal and immutable being", Newton 2004, 26) or monads (since a monad is "a certain world of its own, having no connections of dependency except with God", AG 199). Rather, it is only corporeal substance (matter) and finite immaterial substances (souls/angels) that fit the criterion of the action-reaction principle in the seventeenth century. Second, if the action-reaction principle is, in fact, used as the basis of a new conception of spatial ontology, then it also marks a departure from the platonism/nominalism distinction, since platonism and nominalism only pertain to the existence/non-existence of mathematical structures in the absence of matter; i.e., causal powers are excluded. As put forward in this essay, the trivial substantivalism/relationism dichotomy is simply the modern equivalent of the platonism/nominalism divide as regards physical geometry, hence the action-reaction principle can be seen as an attempt to put space within the category of physical entities, and not physical geometry. Yet, this strategy raises troubling questions as regards the extent of the background structures that are, so to speak, "physicalized". All of the existing QG hypotheses would seem to accept some form of background structure, whether geometrical, topological, causal, etc., that is not subject to action-reaction, so there is little justification within the search for QG for this interpretation of background independence for all such fixed structures. Moreover, since Bird declares that "any structure appearing in the laws of that theory" must be subject to being affected, does this imply that the laws of arithmetic or logic must be subject to the action-reaction principle as well? Since arithmetic is definitely a structure that appears in all QG theories, it must therefore partake in action-reaction affects. And, if not, then why is the mathematical field of geometry subject to that principle and not the mathematical field of arithmetic? Essentially, the advocates of the action-reaction principle, in their quest to overcome the strictures of the substantival/relational dichotomy, have only succeeded in revealing the deep metaphysical mysteries associated with the platonist/nominalist question for all physical theories, in particular, the bias that exempts all mathematical structures from the action-reaction principle save the geometric structures (see, Slowik 2005, for a more general discussion of this topic).

Lastly, it should be noted that Smolin's quest for a completely background independent QG theory provides a unique Leibnizian twist to the action-reaction principle explored above. In response to the query, "Can there be a fully background-independent approach to quantum theory?", he states, "I believe that the answer is only if we are willing to go beyond quantum theory, to a hidden variables theory" (Smolin 2006, 232). In more detail, he argues:

> We know from the experimental disproof of the Bell inequalities that any viable hidden variables theory must be non-local. This suggests the possibility that the hidden variables are relational. That is, rather than giving a more detailed description of the state of an electron, relative to a background, the hidden variables may give a description of relations between that electron and the others in the universe (Smolin 2006, 232)

While the details need not concern us, Smolin's hidden variables version of a fully background independent QG theory evokes the holistic, pre-established harmony of Leibniz' monadic metaphysics. Although "the monad's natural changes come from an *internal principle,* since no external cause can influence it internally" (AG 214), their pre-established harmony mimics the holistic interconnections that Smolin seeks: "This interconnection or accommodation of all created things to each other, and each to all the others, brings it about that each simple substance [monad] has relations that express all the others, and consequently, that each simple substance is a perpetual, living mirror of the universe" (AG 220). Smolin describes his hidden variables strategy as "relational"; but the relational aspect of these entities, whether a monad or a QG hidden variables electron, is not *spatial* relationism, but the non-spatial interrelatedness of *intrinsic* metaphysical (monad) or physical (electron) *properties*—and this demonstrates, once again, the inability of the traditional substantival/relational distinction to probe the conceptual depths of the QG, and monadic, realms.

6. Conclusion.

One of the goals of this essay has been to demonstrate that the substantivalist/relationist debate has long since outlived its usefulness in assessing the ontology of spacetime theories. The evidence for this allegation resides in the ambiguity and uncertainty that characterizes any application of the distinction, whether in the seventeenth century or in the modern context of QG, as well as GR. In its place, a different set of distinctions has been offered that concern (i) the different levels of spatial geometry at the macro and foundational levels, and (ii) the platonist/nominalist divide in spatial geometry—and these new dichotomies, which more accurately track the content of both seventeenth century and modern QG theories, do not naturally align with the substantival/relational distinction, as we have seen. Consider substantivalism: with respect to (i), some alleged substantivalists embrace a similarity of geometric structure at the bodily and foundational level (More, Newton), but some do not (Gassendi); as regards (ii), some alleged substantivalists favor platonism (More, Newton, Gassendi), but some do not (Barrow). And, while both of the alleged relationists in our investigation (Descartes, Leibniz) side with the same camp concerning (i) and (ii), i.e., both posit a difference in geometry at foundational and bodily level, as well as accept geometric nominalism, they do so for reasons that the standard substantival/relational distinction is seemingly powerless to explain. Furthermore, if the possibility of a vacuum were invoked as a means of separating substantivalists from relationists, and thereby, Newton from Descartes, then Leibniz would now count a substantivalist since he admits that a vacuum is possible. Hence, despite the obvious similarities between Descartes and Leibniz (and leaving aside relational motion), the substantivalist/relationist dichotomy simply cannot pair them together in a natural way, and this demonstrates, once again, that it is far too crude and erratic an instrument to assess spatial ontologies.

In this essay, a more accurate set of dichotomies on the deep ontology of space has been offered that does accomplish a number of important goals. First, it successfully groups together seventeenth century spatial ontologies that are indeed similar on specific issues, but it also accounts for their differences concerning other issues: specifically, Newton and More, but not Gassendi, with FGL(met); Newton, More and Gassendi with ML(plt), Leibniz and Descartes with FGL(prg); Leibniz, Descartes, and Barrow with ML(nom). Second, our two-part dichotomy not only successfully partitions the various QG approaches into natural categories, but, more importantly, it also provides a basis for drawing successful analogies with seventeenth century theories, e.g., Leibniz with the pregeometry of QCH, and Gassendi with the continuous topological structure required for LQG. Moreover, it offers a consistent explanation for why Leibniz' nominalism does not support the shift scenarios, whereas Oresme's nominalism does, since the former holds FGL(prg), while the latter accepts FGL(top). Ironically, our system also successfully accomplishes some of the goals that have eluded previous assessments that rely upon the substantival/relational dichotomy to draw historical analogies: it links Newton, but not Descartes, with geometrodynamics, and Leibniz and Descartes with a pregeometric subvenient entity which lacks any continuous degrees of freedom.

To summarize, with the attention of philosophers of physics now focused on the deep ontology of space, the inadequacies of the substantival/relational dichotomy have become all too apparent. While that distinction is somewhat serviceable in the context of Newtonian mechanics, it has become practically dysfunctional in the debates on the status of the metric-field in GR and, especially, in the assessment of QG hypotheses. The deep ontology of space, which is a paramount concern for seventeenth century thinkers and QG theorists alike (but not necessarily Newtonian mechanists), may now hopefully prompt a much needed recalibration of the tools used for ontological appraisal by philosophers of space and time.

REFERENCES

Adams, R. (1983). "Phenomenalism and Corporeal Substance in Leibniz", in *Midwest Studies in Philosophy,* Vol. 8, ed. by P. A. French et. al. Minneapolis: University of Minnesota Press, 217-257.

Adams, R. (1994). *Leibniz: Determinist, Theist, Idealist.* Oxford: Oxford University Press.

Barrow, I. (1976). *Lectiones Geometricae,* trans. by M. Capek, in *The Concepts of Space and Time: Their Structure and Development,* ed. by M. Capek. Dordrecht: Reidel, 203-208.

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

Belot, G. (2011). *Geometric Possibility.* Oxford: Oxford University Press.

Bird, A. (2007). *Nature's Metaphysics.* Oxford: Oxford University Press.

Brown, H. (2005). *Physical Relativity.* Oxford: Oxford University Press.

Brown, H. and Pooley, O. (2006). "Minkowski Space-Time: A Glorious Non-Entity", in *The Ontology of Spacetime,* vol. 1, ed. by D. Dieks. Amsterdam: Elsevier, 67-92.

Butterfield, J. and Isham, C. (2001). "Spacetime and the Philosophical Challenge of Quantum Gravity", in *Physics meets Philosophy at the Planck Scale,* ed. by C. Callender and N. Huggett. Cambridge: Cambridge University Press, 33-89.

Cao, T. Y. (1997). *Conceptual Development of 20th Century Field Theories.* Cambridge: Cambridge University Press.

Cover, J. A., and Hartz, G. A. (1994). "Are Leibnizian Monads Spatial?", *History of Philosophy Quarterly,* 11, 295-316.

Dainton, B. (2010). *Time and Space.* 2nd ed. Montreal: McGill-Queen's University Press.

Descartes, R. (1985). *The Philosophical Writings of Descartes, Vol.1,* eds. and trans. by J. Cottingham, R. Stoothoff, D. Murdoch. Cambridge: Cambridge University Press.

Descartes, R. (1991). *The Philosophical Writings of Descartes, Vol.3, The Correspondence,* eds. and trans. by J. Cottingham, et al. Cambridge: Cambridge University Press.

Dieks, D. (2001). "Space-time Relationism in Newtonian and Relativistic Physics", *International Studies in the Philosophy of Science,* 15, 5-17.

Dorato, M. (2000). "Substantivalism, Relationism, and Structural Spacetime Realism", *Foundations of Physics,* 30, 1605-1628.

Dowker, F (2005). "Causal Sets and the Deep Structure of Spacetime", in *100 Years of Relativity: Space-Time Structure: Einstein and Beyond,* ed. by A. Ashtekar. New Jersey: World Scientific, 445-464.

Earman, J. (1989). *World Enough and Space-Time*. Cambridge: MIT Press.

Earman, J. (2006). "The Implications of General Covariance for the Ontology and Ideology of Spacetime", in *The Ontology of Spacetime,* vol. 1, ed. by D. Dieks. Amsterdam: Elsevier, 3-23.

Friedman, M. (1983) *Foundations of Space-Time Theories.* Princeton: Princeton University Press.

Furth, M. (1967). “Monadology”, *Philosophical Review,* 76, 169–200.

Garber, D. (2009). *Leibniz: Body, Substance, Monad.* Oxford: Oxford University Press.

Gassendi, P. (1972). *The Selected Works of Pierre Gassendi,* edited and translated by C. G. Brush. New York: Johnson.

Gassendi, P. (1976). “The Reality of Infinite Void”, translated by M. Capek and W. Emge, in *The Concepts of Space and Time,* Dordrecht: D. Reidel, 1976, 91-96.

Grant, E. (1981). *Much Ado About Nothing: Theories of Space and Vacuum from the Middle Ages to the Scientific Revolution.* Cambridge: Cambridge University Press.

Graves, J. C. (1971). *The Conceptual Foundations of Contemporary Relativity Theory.* Cambridge: MIT Press.

Greene, B. (2011). *The Hidden Reality.* New York: Knopf.

Hall, A. R. (1990). *Henry More and the Scientific Revolution.* Cambridge: Cambridge University Press.

Hartz, G. A. (2007). *Leibniz’s Final System.* London: Routledge.

Hedrich, R. (2009a). “Quantum Gravity: Has Spacetime Quantum Properties?”, philsci-archive.pitt.edu/archive/00004445

Hedrich, R. (2009b). “Quantum Gravity: Motivations and Alternatives”, philsci-archive.pitt.edu/archive/00004820

Hoefer, C. (1996). “The Metaphysics of Space-Time Substantivalism”, *Journal of Philosophy,* XCIII, 5-27.

Holden, T. (2004). *The Architecture of Matter*. Oxford: Oxford University Press.

Jesseph, D. M. (1993). *Berkeley’s Philosophy of Mathematics*. Chicago: University of Chicago Press.

Kaplunovsky, V. and Weinstein, M. (1985). “Space-Time: Arena or Illusion?”, *Physical Review,* D 31, 1879-1898.

Koyré, A. and Cohen, I. B. (1962). “Newton and the Leibniz-Clarke Correspondence”, *Archives internationales d’histoire des sciences,* 15, 63-126.

Leibniz, G. W. (1923). *Sämtliche Schriften und Briefe,* ed. by Akademie der Wissenschaften der DDR. Darmstadt and Berlin: Akademie-Verlag. Cited as [A], with series, volume, and page.

Leibniz, G. W. (1969). *Leibniz: Philosophical Letters and papers,* 2nd ed., ed. and trans. by L. E. Loemker. Dordrecht: Kluwer. Cited as [L].

Leibniz, G. W. (1989). *Leibniz: Philosophical Essays,* ed. and trans. by R. Ariew and D. Garber. Indianapolis: Hackett. Cited as [AG].

Leibniz, G. W. (1995). *Leibniz: Philosophical Writings,* ed. and trans. by M. Morris and G. H. R. Parkinson. Rutland, Vermont: C. Tuttle. Cited as [MP].

Leibniz, G. W. (1996). *New Essay on Human Understanding,* ed. and trans. by P. Remnant and J. Bennett. Cambridge: Cambridge University Press. Cited as [NE], with book, chapter, section.

Leibniz, G. W. (1998). *Philosophical Texts,* trans. by R. Francks and R. S. Woolhouse. Oxford: Oxford University Press. Cited as [FW].

Leibniz. G. W. (2000). *Leibniz and Clarke Correspondence,* ed. and trans. by R. Ariew. Indianapolis: Hackett. Cited as [L], with letter, section.

Leibniz, G. W. and B. Des Bosses. (2007). *The Leibniz-Des Bosses Correspondence,* ed. and trans. by B. Look and D. Rutherford. New Haven: Yale University Press. Cited as [LDB].

LoLordo, A. (2007). *Pierre Gassendi and the Birth of Early Modern Philosophy.* Cambridge: Cambridge University Press.

Magirus, J. (1642). *Physiologiae peipateticae contractio,* Lib.1, Cap. VIII, Cambridge.

McGuire, J. E. (1978). "Newton on Place, Time, and God: An Unpublished Source", *British Journal for the History of Science,* 11, 114-129.

McGuire, J. E., and Slowik, E. (2011). "Newton's Ontology of Omnipresence and Infinite Space", forthcoming in *Oxford Studies in Early Modern Philosophy,* vol. 6.

More, H. (1995). *Henry More's Manual of Metaphysics: A Translation of the* Enchiridium Metaphysicum *(1679),* Parts I and II, trans. by A. Jacob, Hildesheim: Olms.

Newton, I. (1978). "Tempus et Locus", in "Newton on Place, Time, and God: An Unpublished Source", trans. and ed. by J. E. McGuire, *British Journal for the History of Science,* 11, 114-129.

Newton, I. (2004). *Philosophical Writings,* translated and edited by A. Janiak and C. Johnson, Cambridge: Cambridge University Press.

Oresme, N. (1968). *Le Livre Du Ciel et Du Monde,* ed. and trans. by A. D. Menut and A.J. Denomy, Madison: University of Wisconsin Press, 1968.

Pasnau, R. (2011). *Metaphysical Themes: 1274-1671.* Oxford: Oxford University Press.

Rickles, D. (2005). "A New Spin on the Hole Argument", *Studies in History and Philosophy of Modern Physics,* 36, 415-434.

Rickles, D. (2008). "Quantum Gravity: A Primer for Philosophers", in *The Ashgate Companion to Contemporary Philosophy of Physics,* ed. by D. Rickles. Aldershot: Ashgate Publishing Limited, 262-365.

Rickles, D., and French, S. (2006). "Quantum Gravity meets Structuralism: Interweaving Relations in the Foundations of Physics", in *The Structural Foundations of Quantum Gravity,* eds., D. Rickles, S. French, and J. Saatsi. Oxford: Oxford University Press, 1-39.

Rovelli, C. (1997). "Halfway through the Woods: Contemporary Research on Space and Time", in *The Cosmos of Science.* ed., J. Earman and J. Norton. Pittsburgh: University of Pittsburgh Press, 180-224.

Rovelli, C. (2001). "Quantum Spacetime: What do we know?", in *Physics meets Philosophy at the Planck Scale,* ed. by C. Callender and N. Huggett. Cambridge: Cambridge University Press, 101-122.

Rovelli, C. (2004). *Quantum Gravity.* Cambridge: Cambridge University Press.

Rutherford, D. (1995a). *Leibniz and the Rational Order of Nature*. Cambridge: Cambridge University Press.

Rutherford, D. (1995b). "Metaphysics: The Late Period", in *The Cambridge Companion to Leibniz.* Cambridge: Cambridge University Press, 124-175.

Rynasiewicz, R. (1996). "Absolute Versus Relational Space-Time: An Outmoded Debate?", *Journal of Philosophy,* XCIII, 279-306.

Sklar, L. (1974). *Space, Time, and Spacetime,* Berkeley: University of California Press.

Slowik, E. (2005). "Spacetime, Ontology, and Structural Realism", *International Studies in the Philosophy of Science,* vol. 19, 2005, 147-166.

Slowik, E. (2008). "Newton's Neo-Platonic Ontology of Space", forthcoming in *Foundations of Science*.

Slowik, E. (2009). "The 'Properties' of Leibnizian Space: Whither Relationism?", forthcoming in *Intellectual History Review.*

Slowik, E. (2010). "Newton, the Parts of Space, and the Holism of Spatial Ontology", forthcoming in *HOPOS: The Journal of the International Society for the History of Philosophy of Science*.

Slowik, E. (2011). "Space and the Extension of Power in Leibniz' Monadic Metaphysics", unpublished manuscript.

Smolin, L. (2000). *Three Roads to Quantum Gravity.* New York: Basic Books.

Smolin, L. (2006). "The Case for Background Independence", in *The Structural Foundations of Quantum Gravity,* eds., D. Rickles, S. French, and J. Saatsi. Oxford: Oxford University Press, 196-239.

Stachel, J. (2002). "'The Relations between Things' versus 'The Things between Relations': The Deeper Meaning of the Hole Argument", in *Reading Natural Philosophy,* ed. by D. Malament. Chicago: Open Court, 231-266.

Sylla, E. (2002). "Space and Spirit in the Transition from Aristotelian to Newtonian Space", in *The Dynamics of Aristotelian Natural Philosophy from Antiquity to the Seventeenth Century,* eds., C. Leijenhorst, C. Lüthy, J. Thijssen. Leiden: Brill, 249-287.

Witten, E. (1989). "The Search for Higher Symmetry in String Theory", *Transactions of the Royal Society of London,* A329, 349-357.

---

[1] A nice overview is Belot (2000). As for examples, see, e.g., Hoefer (1996) for metric-field substantivalism; Rovelli (1997) for metric-field relationism; and Dorato for a structural realist (2000) reading that is similar, in an ontological sense, to metric-field relationism. The "out-moded" nature of the dichotomy, as regards classical gravitational theories, is defended in Rynasiewicz (1996).

[2] That is, one should not construe Leibniz' use of "expression" as indicating a purely phenomenalist interpretation of the corporeal world, and hence space; e.g., Furth (1967). As used in this context, a purely phenomenalist interpretation is equivalent to idealism, and idealism is the immaterialist hypothesis that limits ontology to just idea/perceptions, minds/souls, and a non-material God.

[3] A more famous endorsement of a property-like (or subject-accident) interpretation of spatial relationships is provided in the Leibniz-Clarke correspondence: "I shall adduce another example to show how the mind uses, on occasion of accidents which are in subjects, to fancy to itself something answerable to those accidents out of the subjects. The ratio or proportion between two lines L and M may be conceived three several ways: as a ratio of the greater L to the lesser M; as a ratio of the lesser M to the greater L; and lastly as something abstracted from both, that is, as the ratio between L and M without considering which is the antecedent or which is the consequent, which is the subject and

which is the object. . . . In the first way of considering them, L the greater, in the second, M the lesser, is the subject of that accident which philosophers call relation. But which of them will be subject in the third way of considering them? It cannot be said that both of them, L and M together, are the subject of such an accident; for if so, we should have an accident in two subjects, with one leg in one and the other in the other, which is contrary to the notion of accidents. Therefore we must say that this relation, in this third way of considering it, is indeed out of the subjects; but being neither a substance nor an accident, it must be a mere ideal thing, the consideration of which is nevertheless useful" (L.V.47). In short, according to his first two interpretations, Leibniz views relations as internal accidents of either subject L or M, such that the relation is somehow between the two subjects. The third way of examining the relationship, on the other hand, is simply an idealization of the first two, and, importantly, it is not advanced as contradicting, or a more accurate interpretation of, the other two "internalist" ways of considering the relation.

[4] One of the often overlooked lessons of Grant (1981) is God's ubiquitous role as the ontological foundation of space for nearly all natural philosophers from roughly the early middle ages up to at least the beginning of the eighteenth century. With the demise of this theological basis, extension then found its "support" in such doctrines as Wolffian monads, Boscovichian forces, the electromagnetic aether, and ultimately, the gravitational field in GR.

[5] An additional impediment for any meaningful comparison between seventeenth century and modern spatiotemporal theories is their drastically different conceptions of geometry. Modern differential geometry, with its many component geometric structures (manifold, affine, metric, etc.), is utterly foreign to the classical, Euclidean conception shared by both Newton and Leibniz, where each component geometrical structure is regarded as a limit or boundary of the next higher dimensional component: e.g., "space can be distinguished into parts whose common boundaries we usually call surfaces; and these surfaces can be distinguished in all directions into parts whose common boundaries we usually call lines; and again these lines can be distinguished in all directions into parts which we call points" (Newton 2004, 22). Likewise, Leibniz often asserts that points "strictly speaking, are extremities of extension, and not in any way, the constitutive parts of things; geometry shows this sufficiently" (AG 228). On this form of geometric "holism" (or monism), so to speak, the kind of isomorphic mappings that generate the modern "hole" arguments are simply inapplicable, since points cannot be separated from the larger geometric structures if they are mere boundaries: i.e., there is no point manifold, *M*, and thus no diffeomorphisms, (h)$g = g^*$, that can generate the (observationally indistinguishable) models $\langle M, g^*, T^* \rangle$ from $\langle M, g, T \rangle$ that plague the modern manifold substantivalist (see, Earman 1989, chap. 9). Put simply, the independence of the various geometric structures in modern differential geometry generates the familiar underdetermination worries, such as the hole argument. See, Slowik 2010, for more on this topic.

[6] For example, in the context of assessing Euclid's axiomatic geometry, and the fact that our senses seem to conflict with its geometric conclusions, Leibniz comments that "what I value most in geometry, considered as a contemplative study, [is] its letting us glimpse the true source of eternal truths and of the way in which we can come to grasp their necessity, which is something that the confused ideas of sensory images can never distinctly reveal" (NE:IV.xii.6).

[7] As Grant recounts, the use of circumscriptive and definitive ubeity to signify the manner by which, on the one hand, bodies, and on the other, souls and angels, relate to space was common in the Scholastic period (1981, 130). Likewise, in exploring Peter Lombard's use of these distinctions, Grant describes circumscriptive ubeity as the view that the entity "fully occupies and fills its place" and is "fully delimited and circumscribed by the termini of that place", whereas definitive ubeity is the view that the entity "is delimited and defined locally only by the terminus of a place . . . but does not occupy its place as a dimensional [i.e., extended] entity" (1981, 342 n.66). Although slightly different in emphasis, Grant's analysis upholds the fact that circumscriptive and definitive ubeity correlate, respectively, with the metrical and topological components of space, since an entity's non-dimensional "occupation" of place/space entails that it is only the (non-dimensional) points of place/space that can be ascribed to that entity (and not a dimensional length).

[8] Some commentators (e.g., Pasnau 2011, 338, n.21) have tried to defend holenmerism as Newton's preferred ontology of space, but this is quite dubious given the paltry evidence for holenmerism and the quite powerful evidence in favor of God's actual extension (for anti-holenmerist interpretations of Newton, see Grant 1981, 253; Slowik 2008; McGuire and Slowik 2011). More's anti-holenmerist strategy is to claim that both God and space are "simple", i.e., not actually divisible, but merely conceptually divisible (More 1995, 58), a position that Newton defends in *De grav*: "lest anyone should for this reason imagine God to be like a body, extended and made of divisible parts, it should be known that spaces themselves are not actually divisible . . ." (Newton 2004, 26). Elsewhere, in a work from the 1690s, Newton makes similar claims about both God and space: "[t]he most perfect idea of God is that he be one substance, simple, indivisible . . ." (Newton 1978, 123), and, "space itself has no parts which can be separated from one another, ... For it is a single being, most simple, and most perfect in its kind" (Newton 1978, 117). Hence, God and space are both extended in the same way, FGL(met), which is contradicted by holenmerism.

[9] On the continuity of Gassendian space, see LoLordo (2007, 119-124). As Holden observes (2004, 105), Walter Charleton, the great champion of Gassendi's natural philosophy in England, departs from Gassendi on this issue, for Charleton argues for a discrete minimal structure for both bodies and space, whereas Gassendi held only an atomic minima, or least part, for matter.

[10] Edward Grant claims that, for Gassendi, space is "coeternal with and independent of God" (1981, 212), which seems to imply that space could exist in the absence of God.

But, any such suggestion is utterly refuted in the passage quoted above, which employs the seventeenth century's internal/external attribute dichotomy: "That God be in space is thought to be a characteristic external to His essence, but not with respect to His immensity, the conception of which necessarily involves the conception of space" (1976, 94). So, given this internal/external dichotomy, by denying that space is external to God's immensity, it follows that space is "internal" to God's immensity (where a philosophical tract that employs this distinction can be found in, e.g., Magirus 1642). Accordingly, it is quite implausible to infer that space retains any real independence from God, especially given the further claim that God "necessarily exists in all time and in every place" (1976, 94). Additionally, Gassendi holds that both space and God are infinite and immobile (1976, 91-95), which is also indicative of the close interdependence between God and space (once again, cf. Newton's *De grav*).

[11] One of the most straightforward declarations of nominalism can be found in the *New Essays,* where numbers and extension are compared: "[I]n conceiving several things at once one conceives something in addition to the number, namely the things numbered; and yet there are not two pluralities, one of them abstract (for the number) and the other concrete (for the things numbered). In the same way, there is no need to postulate two extensions, one abstract (for space) and the other concrete (for body)" (NE:II.iv.5). "Geometric nominalism", as used in this essay, is the thesis that spatial geometry is not an abstract entity (or universal) over and above matter, but simply the "concrete" extended material body or field. "Geometric platonism", on the other hand, does judge spatial geometry to be an abstract entity that can exist apart from matter. Accordingly, one could view our platonist/nominalist distinction as equivalent to trivial substantivalism and trivial relationism, although this obviously reverses the chronology of the development of spatial theories: in effect, trivial substantivalism and trivial relationism represent a somewhat garbled modern surrogate of the older platonism/nominalism dichotomy for space.

[12] As noted previously, relational motion is a separate subject that is beyond the scope of this investigation. Starting with Newton and Clarke, the inadequacies involved in basing Newtonian mechanics on relational motion became a chief factor in assessing the *spatial* ontologies of such alleged relationists as Descartes, Leibniz and their followers, in the eighteenth and subsequent centuries. Yet, this line of attack, besides being irrelevant to the ontology of space, entirely overlooks the theological component that underwrites the ontology of space in the seventeenth century—and, it is this neglected theological component that most closely matches the issues surrounding the contemporary search for QG. The deep metaphysical "entity" that underlies all spatial geometries in the seventeenth century is, accordingly, crucial for understanding the overall spatial ontology debate, including the relationship that QG bears with these earlier hypotheses (hence there is no subliminal theological message motivating this project, nor would the author welcome any such misguided attempts).

[13] In more detail, although a monad's extended secondary matter would not arise if God prevented it, with secondary matter equating with bodily extension at the macrolevel, the

unextended primary matter would remain at the microlevel. See, Slowik 2011, on the primary/secondary, and primitive/derivative force, distinctions.

[14] In spite of these observations, Jean Buridan offered a different God-grounded, nominalist-inspired approach to the vacuum in the late Medieval period that hints at a peculiar form of background independence. If the terrestrial realm below the lunar sphere was transformed into a vacuum, Buridan concludes that, due to the absence of the dimensional quantity instantiated in matter, that vacuum would be without any measurable size. As Sylla notes, "[i]f so, then God could create many worlds there, even worlds much larger than what was destroyed. A body in motion inside the evacuated lunar sphere could move with high velocity for a long time and never get any closer to one side or further from the other" (2002, 262). While this scenario might more plausibly resemble an anti-realism as regards geometry in that void sphere (or even a multiply connected spaces?), another way to envision it is as a limited case of background independence, since many different geometric "truths" are admissible within that sphere given the same God-grounded ontology (i.e., different geometries compatible with the same theory).

[15] Oresme argues: "Thus, outside the heavens, then, is an empty incorporeal space quite different from any other plenum or corporeal space . . . . Now this space of which we are talking is infinite and indivisible, and is the immensity of God and God Himself" (1968, 176; quoted in Grant 1981, 349, n.123). Also, "Now this space of which we are talking is infinite and indivisible, and is the immensity of God Himself" (1968, 177).

[16] Oresme claims: "Notwithstanding that He is everywhere, still is He absolutely indivisible and at the same time infinite… for the temporal duration of creatures is divisible in succession; their position, especially material bodies, is divisible in extension; and their power is divisible in any degree or intensity. But God's [duration] is eternity, indivisible and without succession. . . . His position is immensity, indivisible and without extension" (1968, 721).

[17] "Pregeometry", in the context of QG, does not necessarily mean non-geometrical, but simply non-GR; i.e., it is not the continuous, differential structure assumed in the standard constructions of GR that employ differential geometry; see, Hedrich (2009a, 14, n.31). See, also, Hedrich 2009b.

[18] Emergence is a notoriously difficult concept, but our analysis will use this term to include both of the strategies explored in Butterfield and Isham (2001) for going beyond the standard ingredients of QM and GR, i.e., a four-dimensional manifold and a classical, Lorentzian metric: (i) quantization, which is the quantizing of a classical structure "and then to recover it as some sort of classical limit of the ensuing quantum theory"; and (ii) emergence, where the classical structure is seen as "an approximation, valid only in regimes where quantum gravity effects can be neglected, to some other [more fundamental] theory" (2001, 35).

[19] In Cao's history, the origins of "pregeometry" is correlated with Wheeler's later development of quantum geometrodynamics, in particular, the difficulties associated with reconciling quantum fluctuations in geometrodynamics with a multiply connected space: "According to quantum geometrodynamics, there are quantum fluctuations at small distances in geometry, which lead to the concept of multiple connected space. . . . However, 'quantum fluctuations' as the underlying element of his geometrical picture of the universe paradoxically also undermined this picture. Quantum fluctuations entail change in connectivity. This is incompatible with the ideas of differential geometry, which presupposes the concept of a point neighborhood. With the failure of differential geometry, the geometrical picture of the universe also fails: it cannot provide anything more than a crude approximation to what goes on at the smallest distances. If geometry is not the ultimate foundation of physics, then there must exist an entity—Wheeler calls it 'pregeometry'—that is more primordial than either [differential] geometry or particles, and on the foundation of which both are built" (Cao 1997, 111).

[20] In more detail, Butterfield and Isham explain that "[i]n perturbative superstring theories, the target spacetime *M* is modeled using standard differential geometry, and there seems to be no room for any deviation from the classical view of spacetime. However, in so far as the dimension of *M* is greater than four, some type of 'Kaluza-Klein' scenario is required in which the extra dimensions are sufficiently curled up to produce no perceivable effect in normal physics [e.g., GR], whose arena is four-dimensional spacetime" (Butterfield and Isham 2001, 72). See, also, Rickles (2008, 311-323).

[21] "[P]hysics makes use of principles from two mathematical sciences to which it is subordinated, geometry and dynamics. . . . Moreover, geometry itself, or the science of extension, is, in turn, subordinated to arithmetic, since, as I said above, there is repetition or multitude in extension; and dynamics is subordinated to metaphysics, which treats cause and effect" (G IV 400; AG 251-252).

[22] "The basic structure [at the micro-level] is a discrete, directed, locally finite, acyclic graph. To every vertex (i.e. elementary event) of the graph, a finite-dimensional Hilbert space (and a matrix algebra of operators working on this Hilbert space) is assigned. So, every vertex is a quantum system. Every (directed) line of the graph stands for a causal relation: a connection between two elementary events; formally it corresponds to a quantum channel, describing the quantum evolution from one Hilbert space to another. So, the graph structure becomes a network of flows of quantum information between elementary quantum events. Quantum Causal Histories are informational processing quantum systems; they are quantum computers" (Hedrich 2009a, 22).

[23] Leibniz apparently assigns a sort of derivative position to monads in space, but it is via the body which results from the monads: "[A]lthough monads are not extended, they nevertheless have a certain kind of situation in extension, that is, they have a certain ordered relation of coexistence with others, namely, through the machine which they control" (L 531).

[24] It should also be added that many commentators are quite skeptical that Leibniz overthrows his preferred monadic view of bodies and extension for this alternative conception based on the substantial chain; see, e.g., Rutherford 1995b, 162-163, and Hartz 2007, 107.