VOLUME 44 Issue 4 November 2013 ISSN 1355-2198

Studies in History and Philosophy of Science Part B

Studies in History and Philosophy of Modern Physics

Available online at www.sciencedirect.com
ScienceDirect

Studies in History and Philosophy of Modern Physics 44 (2013) 490–499

Contents lists available at ScienceDirect

Studies in History and Philosophy of Modern Physics

journal homepage: www.elsevier.com/locate/shpsb

The deep metaphysics of quantum gravity: The seventeenth century legacy and an alternative ontology beyond substantivalism and relationism

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ARTICLE INFO

Article history:
Received 8 May 2013
Accepted 29 August 2013
Available online 25 October 2013

Keywords:
Quantum gravity
Substantivalism
Relationism
Newton
Leibniz

ABSTRACT

This essay presents an alternative to contemporary substantivalist and relationist interpretations of quantum gravity hypotheses by means of an historical comparison with the ontology of space in the seventeenth century. Utilizing differences in the spatial geometry between the foundational theory and the theory derived from the foundational, in conjunction with nominalism and platonism, it will be argued that there are crucial similarities between seventeenth century and contemporary theories of space, and that these similarities reveal a host of underlying conceptual issues that the substantival/relational dichotomy fails to distinguish.

When citing this paper, please use the full journal title *Studies in History and Philosophy of Modern Physics*

1. Introduction

Even granting the most basic and clear-cut conception of substantivalism and relationism – where substantivalists hold, and relationists reject, 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 the sophisticated forms of both ontologies are seemingly identical as regards their content in the modern setting of general relativity (GR).[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 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 substantivalism. For example, a Leibnizian lineage for LQG has been put forward by Smolin (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). Since the substantival/relational dichotomy is the most basic and important ontological division in the philosophy of space and time, it is imperative to investigate why it leads to such conflicting assessments, and to examine if there are better alternatives.

This essay will begin to meet this challenge by offering an alternative range of conceptual distinctions that lie below the imprecise 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, by Gassendi, More, Newton, Leibniz, and others, will reveal a host of uncanny similarities with modern QG strategies: these similarities concern (i) the spatial geometry at both the foundational level of ontology and at the derived or resulting levels of ontology, and (ii) platonism and nominalism as regards the spatial geometry at these two levels. As will be demonstrated,

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[1] As for examples, see, e.g., Hoefer (1996) for metric-field substantivalism; Rovelli (1997) for metric-field relationism; and, Dorato (2000). For the "out-moded" nature of the dichotomy, see Rynasiewicz (1996).

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http://dx.doi.org/10.1016/j.shpsb.2013.08.004

(i) and (ii) more directly concern both the seventeenth century and the contemporary QG approaches to spatial ontology than the manifest equivocalities of the substantivalist/relationist division—and, quite importantly, (i) and (ii) obviates the dubious ontological distinctions between the sophisticated substantivalist and sophisticated relationist interpretations of LQG, as well as for the metric-field in GR. Our investigation will also question whether the geometric background independent/dependent distinction is the modern equivalent of the substantival/relational divide.

In Section 2, 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 3, to the strategies proposed among competing QG hypotheses and to various issues, such as background independence and nominalism.

2. Classifying spatial ontology in the seventeenth century

If anything is disclosed in the competing interpretations of Smolin and Dainton, 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 substantivalism or relationism. Yet, the actual details of seventeenth century spatial hypotheses undermine such attempts.

2.1. 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 ontology of space, it will be necessary to focus on two main issues. The first concerns those geometric structures posited at (a) the "foundational level" of ontology (entity/entities associated with that theory) that are identical to (b) the geometric structures posited at the "secondary level" of ontology, where the secondary level entity/entities are grounded on, emerge, or result from, the foundational level of ontology: we will dub this distinction, FGL, for foundational geometric level, with the foundational level usually, but not always, linked to the microphysical realm ("microlevel"), and the resultant, secondary level entities often, but not always, associated with the observable macroscopic level ("macrolevel"). In the seventeenth century, the geometry of space at the secondary macrolevel of material bodies is Euclidean, but the nature of the geometric features at the foundational level, i.e., God and/or Leibniz' monads, could take different forms. Leibniz' *New Essays* puts forth three ways that a being can be related to place/space at the secondary macrolevel:

> 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. (1996, II.xxiii.21)

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

As for circumscriptive ubeity, Leibniz mentions only bodies (whereas Newton 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 a modern isomorphism. Leibniz' analysis also assumes that the entity (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 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, all that definitive ubeity can furnish is something akin to topological notions (see also Grant, 1981, 342, n. 66). As will be discussed later, a concept that is closely aligned with definitive ubeity is "holenmerism", the thesis that a being is whole in every part, or point, of space. Finally, there is "repletive" ubeity, which Leibniz assigns to God who "operates immediately on all created things". Although not mentioned in this passage, Leibniz rejects the notion that God is situated in space (see Section 2.4), rather, only God's actions can be situated. So, leaving aside God's actions, repletive ubeity equates with the absence of all macrolevel geometric properties as regards God's being itself, and it also holds true for Leibniz' monads, as will be discussed below.

Returning to the spatial 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 that are shared between the foundational entity and the entity/entities at the secondary level, metrical, topological, and pregeometric, where "pregeometric" signifies that the foundational entity's metrical and topological properties differ significantly from the metrical and topological properties manifest at the secondary level, or that the foundational entity lacks geometric properties altogether. The resultant secondary level of spatial geometry, furthermore, is the Euclidean space of the seventeenth century theorists, and, for modern QG theories, it is often the geometry assumed in GR or quantum field theory (QFT, the field version of QM). 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 the metric of Euclidean space (and which includes the topology of 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 metrical and topological spatial properties not found at the secondary macrolevel Euclidean space. When we turn to modern QG theories in Section 3, the emphasis will be the same, with FGL denoting the geometric structures of the foundational level theory that are identical to the geometric structures utilized by the secondary level theory, with the latter grounded upon, and resulting from, the foundational theory (although there may be no such identical structures shared among these levels).

The second general issue addresses whether spatial geometry at the secondary level is either independent of, or dependent on, the entities that arise at that level, a distinction that we will dub, SL(v-plt), for secondary level geometric virtual-platonism, and SL(nom), for secondary level geometric nominalism. The rationale behind the "virtual-platonism" designation stems from its limited range: virtual-platonism does not imply the existence of abstract objects, which are the metaphysical items often associated with traditional platonism, but simply claims that the spatial geometry at the secondary level can exist in the absence of the entities, usually matter or fields at the macrolevel, that arise or emerge at the secondary level (from the foundational level), i.e., secondary level entities do not instantiate (bring into existence) space at the secondary level. SL(nom), in contrast, holds that space at the secondary level only exists when instantiated by secondary level entities. In what follows, virtual-platonism and nominalism will be used in place of substantivalism and relationism, for the former pair better conveys the difference between a theory that regards spatial geometry as, respectively, independent of, or dependent on, entities (usually macrolevel material bodies/fields); and, more importantly, the virtual-platonism/nominalism distinction is better suited for application to the foundational and secondary level distinction. The virtual-platonism/nominalism distinction is likewise more historically accurate than the substantivalism/relationism dichotomy since Newton and Leibniz were influenced by the platonist and nominalist traditions prevalent in their day, e.g., Cambridge Neoplatonism. How platonism and nominalism relate to the geometry, if any, at the foundational ontological level, i.e., FL (v-plt) and FL(nom), will be postponed until Section 3.3.

2.2. *Newton on spatial ontology*

Following a long tradition, *Newton's De gravitatione* states that space is not a substance because it cannot "act upon things, yet everyone tacitly understands this of substance" (Newton, 2004, 21). Using the terminology above, Newton's spatial hypotheses favor circumscriptive ubeity, for he assigns the same geometric structure at both the bodily (secondary) level and for God (foundational level), with the latter directly providing the foundation of space, and he also sides with virtual-platonism about spatial geometry: FGL(met), and SL(v-plt). In *De grav*, he argues: "[f]or 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" (22). Such sentiments support geometric virtual-platonism since these structures would exist even in the absence of all bodies (secondary level entities). There are many passages that confirm FGL(met), e.g., God contains "all other substances in Him as their underlying principle and place" (Newton, 1978, 132), but the best evidence is the "determined quantities of extension" thesis put forward in *De grav*. In brief, Newton presents a conception of material bodies that denies the existence of corporeal substance, and where 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" (2004, 29). The rationale for this Spinoza-like view is theological 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 Descartes' view of substance 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 [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 that all beings share, God's extension; therefore, FGL (met). Finally, it should be noted that Henry More is the main advocate of FGL(met) and SL(v-plt) in Newton's time (see, More, 1995, 56–57).

2.3. *Gassendi on spatial ontology*

Unlike many of his contemporaries and predecessors, Newton and More deny "holenmerism" (definitive ubeity), 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" of space, and thus not (metaphysically) divisible. 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. (Gassendi, 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 implies 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 ("lest we imagine that the divine substance were extended through space like bodies are"). Since space is continuous ("space… remains continuous, the same, and motionless", Gassendi, 1972, 395), and since God only occupies the points of this continuous space (e.g., God "is present in every place", 396), it thus follows that only topological properties are applicable to God. Put differently, while God and matter share topological structure, the holenmerist doctrine (definitive ubeity) 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 Euclidean at the secondary level of bodies (see also Grant, 1981, 210), and is independent of matter (secondary level entities), he sides with Newton in accepting our form of geometric virtual-platonism, SL(v-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" (1972, 391). Hence, the congruence of incorporeal and corporeal dimensionality and the possibility of a vacuum justifies our virtual-platonism designation as regards spatial geometry at the secondary macrolevel. Finally, there is a form of co-dependence between Gassendi's God and space that justifies the FGL(top) classification: "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). In sum: FGL(top), SL(v-plt).

2.4. *Leibniz on spatial ontology*

Like all of the other seventeenth century thinkers, God plays a foundational role in Leibniz' deep ontology of space. In the *New Essays*, he contends 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" (Leibniz, 1996, II.xiii.17). Yet, in contrast to both Newton's "determined quantities of extension" hypothesis of a God extended through space (circumscriptive ubeity) and Gassendi's holenmerist idea of an unextended but spatially situated God (definitive ubeity), 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" (Leibniz, 2000, 56; L.V.85). All of these themes are nicely encapsulated in the following passage:

> If God were extended he would have parts. But duration confers parts only on his operations. 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. (1996, II.xv.2)

Therefore, while Leibniz' accepts that God's immensity grounds space, his acceptance of a non-spatial God (repletive ubeity) clearly rules out a similarity of geometric structure at the foundational and secondary (material) levels of reality—and the same holds for his basic ontological unit of ontology (other than God), namely, monads. As a simple substance, a monad, like God, has no spatial parts, "[b]ut where there are no parts, neither extension, nor shape, nor divisibility is possible" (Leibniz, 1989, 213). The non-spatiality of the monads is, in fact, a common theme in Leibniz' late work, and this includes both the metrical and topological aspects of space: e.g., "there is no spatial or absolute nearness or distance among monads. And to say that they are crowded together in a point or disseminated in space is to use certain fictions of our mind" (Leibniz, 1969, 604); and, "monads, in and of themselves, have no position with respect to one another" (1989, 201). Leibniz, moreover, rejects the FGL(top) conception of incorporeal beings, i.e., where God and souls are situated in the points of space, for he explicitly rejects 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" (2000, 16–17; L.III.12). Accordingly, for both God and monads, FGL(prg). In short, "God is not present to things by situation but by essence; his presence is manifested by his immediate operation" (16–17; L.III.12), where "immediate operation" is correlated with the continual conservation or reproduction of the world (as is also evident in the earlier quotation on repletive ubeity in Section 2.1). A somewhat analogous conception will be seen at work regarding how monads relate to the secondary macrolevel of bodies (see Section 3.2).

Turning to platonism/nominalism, since "there is no space where there is no matter" (52, L.V.62), Leibniz opts for a geometric nominalism at the secondary level, SL(nom).[2] Yet, although space is not "an absolute being" (15, L.III.5), it still represents "real truths" (47, 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" (1996, II.xiv.26). 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.[3]

2.5. *Barrow and Descartes on spatial ontology*

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, such as Hall (1990, 210). Nevertheless, Barrow actually follows Leibniz' nominalism, for he explicates space's "existence" via the God-based, non-dimensional capacity of space to receive dimensional 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, SL (nom), and, since evidence is lacking, either FGL(prg) or FGL(top).

Descartes' conception of space shares many features in common with Leibniz' views, especially the espousal of God's repletive ubeity (using Leibniz' term), or FGL(prg): 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 that substances "can exist only with the help of God's concurrence" (Descartes, 1985, 210). And, since matter is identical with space (227), and a vacuum is impossible (230), SL(nom).

2.6. *Reflections on seventeenth century and contemporary spatial ontologies*

One of the major themes of our investigation is that seventeenth century natural philosophers regard extension/space as requiring some form of foundation in a substance or entity, broadly construed. 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 nonetheless dependent on God. 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. Likewise, since both adhere to the Aristotelian substance/property doctrine, any relationist construal of space as the extension between bodies would be rejected as "an attribute without a subject, an extension without anything extended" (23; L.IV.9). It is in this sense that modern attempts to appropriate Newton and Leibniz as would-be

[2] A straightforward declaration of nominalism from the *New Essays* compares numbers and extension: "[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)" (1996, II.iv.5).

[3] See (1996, II.xiii.8) on Leibniz' "universal place", which mimics Newton's absolutism. Relational motion is a separate subject beyond the scope of this investigation—but, generally, the seventeenth century theories of motion that allegedly support relationism (Descartes, Leibniz) are irrelevant to the deep metaphysics that underwrites their respective spatial hypotheses, namely, God. Furthermore, it is the analysis of this neglected metaphysical component in correlation with the structures at the secondary level that will allow comparisons between seventeenth century and QG theories (although the deep metaphysics underlying QG theories is natural, and not supernatural).

substantivalists or relationists go seriously awry (e.g., Sklar, 1974; Friedman, 1983). In brief, the contemporary stalemate that afflicts the modern spacetime ontology debate is largely the result of a vain effort to remain consistent to Newton and Leibniz but without utilizing their stock of metaphysical presuppositions.

In order to better grasp how the platonism/nominalism distinction can assist the evaluation of spatial ontologies, it is worth examining the important contribution of Belot (2011). As we have seen, the truths of Leibnizian space are both grounded by God and independent of matter: e.g., 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" (1989, 151). Belot (2011, 2) infers from this evidence that Leibniz is a realist about geometry at the phenomenal level of matter. However, this justifiable observation overlooks the fact that Leibniz' realism about space at that level stems from God's immensity, and so his realism differs in only one significant way from Newton's God-grounded spatial realism; namely, at the secondary material macrolevel, Newton's virtual-platonism versus Leibniz' nominalism, a distinction that evades the contemporary substantivalism/relationism debate since that dichotomy conflates the ontological and geometrical/mathematical aspects of spatial theories, and thus it cannot track these more fine-grained distinctions. From a modern perspective, one might strive to equate Newton's virtual-platonism with a straightforward realism about geometric structure at the secondary material level, and Leibniz' nominalism with a modal realism at that 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 (via circumscriptive ubeity), FGL(met), in conjunction with his virtual-platonism, SL(v-plt), thus explaining Newton's geometric realism at the secondary level; and (b), an underlying ontology (God, monads) that is not present in space (via repletive ubeity), FGL(prg), in conjunction with his nominalism, SL(nom), thereby explaining Leibniz' geometric modal realism at the secondary level. Put differently, both Leibniz and Newton would deny the assumption that bodies/fields alone can ground spatial geometry, since only God can—but, a macrolevel body/field foundation is the motivation behind the modern approach to spacetime ontology (e.g., the sophisticated metric-field versions of both substantivalism and relationism in GR).

As just discussed, one might advance a modal relationist hypothesis as the contemporary equivalent of Leibniz' nominalism, a strategy developed in Belot (2011, 173–185). While Belot's efforts are informative, it nonetheless strains the coherence of relationist doctrine. A true modal relationist must posit spatial (spatiotemporal) modality on actually existing matter/fields, or on the possibility of matter/fields coming into existence given at least one existing body. 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" (1996, II.xv.2). Likewise, a complete vacuum state does seem plausible given his additional claim that God could block the emergence of extended matter, and hence space: Leibniz states that a monad's 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" (quoted in Adams, 1994, 351). 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 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 quite different, non-spatial layer of ontology – not only eludes modal relationism, but would seem to demand a separate classification beyond substantivalism and relationism.

3. 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, spacetime emergence,[4] and, ultimately, of the deficiencies in the substantivalist/relationist dichotomy as it applies to the seventeenth century and QG.

3.1. 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 foundational entity or theory, specifically, the western God, on the one hand, and GR and QM (QFT), 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 correspond to the earliest geometrodynamic hypotheses (as a canonical quantization approach), as well the older covariant quantization techniques, since these approaches rely upon the general metrical structure employed by the foundational theory, which is, respectively, GR and QFT. 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), with the graviton being the secondary level entity constructed from the foundational theory, QFT. In the old geometrodynamics, 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 (i.e., as the secondary level

[4] Emergence is a difficult concept, but our analysis will use this term to include both of the strategies explored in Butterfield & Isham (2001) for going beyond the standard ingredients of QM (via QFT) 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). The difficulties associated with developing a theory of emergent spacetime are mentioned in Lam & Esfeld (2013).

entities). 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 2.2, 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 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 foundational microlevel, 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 foundational microlevel of strings and the secondary macrolevel of GR is, 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 subsequent development of non-perturbative string theories (see also Cao, 1997, 111). 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" (2001, 73). 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, both topological and metrical, than at the secondary macrolevel of GR.

The well-known rival of string theory is LQG (loop quantum gravity), which, unlike string theory, does not rely upon a classical metric but does rely upon a classical topological manifold. Rather, LQG quantizes the metric of GR, incorporating a discrete quantum substructure at the foundational level but regaining the classical metric as an emergent phenomena at the secondary level. 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" (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 LQG?", 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 2.4, by declaring that "there is no spatial or absolute nearness or distance among monads" (1969, 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" (1989, 199), even these weaker topological notions are apparently excluded. That is, if monads were situated in the points of Euclidean secondary macrolevel space, then classical topological structure would be applicable to Leibniz' ontology of monads, via FGL(top), but Leibniz consistently rejects this possibility: "I do not think it appropriate to regard souls [i.e., monads] as though in points" (Leibniz, 2007, 123–127). 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.

3.2. 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 secondary macrolevel structures upon 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 a host of possible 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 QG structures thus lie underneath, and can be said to generate or bring about, GR and QFT'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 would lie in the utilization of a discrete quantum substructure, similar to LQG's quantization strategy, but absent LQG's need for a differentiable manifold. Since the main goal of Leibniz' *analysis situs* is to provide an algebraic model of spatial situation (1969, 248–249), forsaking the spatial metric and manifold components is thus in keeping with his overall world-view, an approach that takes algebra/arithmetic as primary, and geometry as derived (1989, 251–252).

There are many QG theories that fit this general category, such as causal sets, 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). Hedrich (2009, 22) provides the colorful description, "geometrogenesis", for the process by which "spacetime emerges from a pregeometric quantum substrate" in QCH, with the "quantum substrate" correlated to 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. (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).[5] For Leibniz, matter and space emerge from a hidden realm of constitutive entities that, like QM and QG theories, is more aptly described in terms of force: a monad is "endowed with primitive power" so that the "derivative forces [of bodies] are only modifications and resultants of the primitive forces" (1989, 176). Second, the derivative nature of the spatial and dynamical properties of bodies, as opposed to the intrinsic primitive forces of the non-spatial monads which bring about bodies, thus correlates with the term "decoupling"; i.e., the emergence of secondary macrolevel spatial and dynamical properties that are quite different from, and seemingly independent of, the foundational micro-level pre-spatial dynamical properties that generate those macrolevel properties. 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" (1963, 607); and, "properly speaking, matter is not composed of constitutive unities [monads], but results from them" (1989, 179; see Rutherford, 1995; Garber, 2009, 383–384, briefly suggest a particle-physics interpretation as well).

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?… 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, 2009, 23)

By its "coupling of geometrogenesis to the genesis of matter", i.e., the emergence of space at the secondary level is coupled to the emergence of matter at that level, QCH can truly claim a lineage with Leibniz' brand of nominalism, as opposed to LQG, the latter permitting possible states that are absent matter at the secondary level but which retain topological structure at that level. That is, a vacuum state occurs in LQG when the foundational level **s**-knots, which constitute the discrete structure of space (by means of equivalence classes of spin networks formed by spatial diffeomorphisms), lack the requisite quantum excitations needed for the existence of matter (see Rickles, 2005, 426–427). In short, using the new taxonomy, LQG's version of space at the secondary level upholds FGL(top) even in the complete absence of matter. For this reason, LQG is closer to Gassendi's theory, where a matter-less topological space is possible at the secondary level as well, and unlike the strategy employed by Leibniz and QCH, where the emergence/actualization of space (spacetime) at the secondary level is linked to the emergence of matter at that level. (However, as will be explained in Section 3.3, LQG actually supports nominalism at the secondary level since the metric-field counts as a secondary level entity in addition to matter. Gassendi, on the other hand, supports virtual-platonism since his secondary level entity is matter, and space at the secondary level is instantiated by the foundational level entity, God, rather than by the secondary level 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 secondary macrolevel. 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.

Nevertheless, there is one significant issue on which Leibniz' monadic system diverges from QG theories, namely, causal or dynamical structure at the foundational level, such as QCH's quantum channels (the lines of the graphs that connect the vertices; see footnote 5). Because "monads have no windows through which something can enter or leave" (1989, 214) there is as an absence of any inter-monadic causal mechanism at that level. On the other hand, even granting the legitimacy of this criticism (as regards the analogy between QCH and Leibniz' monadic system), a counter-reply might reside in the fact that the type of connection that binds the elementary quantum events in QCH is quantum information. The nature of quantum information within QM is difficult to assess, but it would seem to be a type of physical property that, for lack of a better description, is nonetheless situated near the material/immaterial divide (see, e.g., Bub, 2010 on QM information). Consequently, since the lines that connect the nodes of the graph structure in QCH represent a flow of quantum information, and, since quantum information evokes "immaterialist" connotations, it could be interpreted by the Leibnizian as an acceptable surrogate for an intermonadic

[5] "The basic structure [at the microlevel] 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… 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, 2009, 22).

connection at the foundational monadic level. Whether or not this strategy is plausible is open to question, of course, but there are precedents for utilizing a graph structure to model Leibniz monads (e.g., Barbour & Smolin, 1992).

3.3. Background independence versus nominalism

From the modern QG perspective, Smolin has argued that the substantival/relational dichotomy converts to a dispute over background dependent (fixed geometry for all models) or background independent methods (more than one geometry possible for these models), thus it follows that the early String theories that employed a fixed background metric and manifold are more substantivalist (absolutist) than the alternative QG options that only rely on a point manifold, such as LQG (Smolin, 2006, 199). 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 that Smolin declares LQG to be only partially relational (2 1 5). Leaving aside the problem of which geometric component structure should be identified with substantivalism, manifold or metric (see Earman, 1989, 201), 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 virtual-platonism and nominalism. In short, whether the background geometry is, or is not, fixed is not a crucial factor in the platonist/nominalist distinction; rather, it is the presence of geometric structure at a given ontological level in the absence of all physical entities or processes at that level that is crucial, since that possibility would refute nominalism at that level.

For these reasons, the argument that LQG is in conflict with relationism, because it allows vacuum solutions (see, Rickles, 2005, 425; Earman, 2006, 21), gains no traction against our new system of classifying spatiotemporal ontology. LQG does not violate nominalism because the secondary level theoretical entity/entities, i.e., the entities postulated by GR, in particular, GR's metric-field (which are all emergent phenomena or properties of the foundational theory's **s**-knots), instantiate the spatial structures required at the secondary level. Additionally, not only is there no vacuum state of the metric-field (i.e., a region of the manifold lacking a metrical value), but since the metric is also the gravitational-field, which carries energy, the metric/gravitational-field can thus legitimately claim to be a nominalist-friendly physical thing (see Earman & Norton, 1987, 519, who detail some of the physical consequences of gravity waves). Accordingly, given our new taxonomy, there is no conceptual room to invoke a further distinction between sophisticated substantivalist and sophisticated relationist interpretations of GR's metric-field—at the secondary level, both of these rival interpretations fall under nominalism (as opposed to virtual-platonism), and hence are identical as judged by our new ontological scheme.

Leaving aside GR's emergence at the secondary level, the allegation that LQG permits a vacuum state is somewhat misleading due to the fact that the underlying quantum processes at the foundational microlevel would still remain. Although traditional matter-based conceptions of spatial relationism are indeed undermined by these vacuum solutions, the finite value of the vacuum energy and its effects in QFT (virtual particles, Casimir effect, Higgs field) upholds a non-matter, field-based form of nominalism at the foundational microlevel, since there are no voids totally absent of energy at that level. Likewise for the energy of the metric-field in GR (as noted above), whether conceived as an emergent secondary level feature of QG or as the foundational entity in standard GR. More carefully, recalling the distinction first introduced in Section 2.1, if the platonism/nominalism question is pushed to the foundational level of ontology, FL(v-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 foundational entity required for the existence of space in the seventeenth century, thereby securing nominalism at the foundation level via that unique (immaterial) entity. In the same way, modern QG theories are not committed to a virtual-platonist background structure at the foundational level given the complete nonexistence of the relevant QG entities and processes at that level. So, just as nominalism does not discriminate between sophisticated substantivalist and sophisticated relationist interpretations at the secondary level of GR's emergent metric, the same holds true at the foundational level in QG (or if the metric is taken as the foundational entity in standard GR). For these reasons, our new system also provides an insight as to why Earman and Rickles' arguments are only effective against a relationist (or nominalist) interpretation of LQG if confined to matter at the secondary level.

Nominalism at the foundational level, furthermore, is well-documented, both for seventeenth century philosophers of space and modern QG theories. At this foundational level, seventeenth century philosophers required a sort of congruence of the domain of God's substance or operation and the extent of space, so that space is not "external" to God, a possibility that would undermine nominalism. To be exact, space cannot exceed either the bounds of God's own extension (Newton) or God's non-extended immensity, whether that non-extended immensity takes the form of definitive ubeity (Gassendi) or repletive ubeity (Descartes and Leibniz). Newton, for instance, denies "that a dwarf-god should fill only a tiny part of infinite space" (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" (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" (2000, 61; L.V.106); and, since monads generate the matter that instantiates space, 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 at that level. (The same holds true for standard GR, since there are, once again, no metrical voids that would undermine a nominalist interpretation of that theory.) One could even go so far as to claim a certain analogy between God's grounding the possibilities of bodies at the macrolevel in Leibniz' spatial ontology (as above, 1996, 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 space emerges from "internal" QM processes, a description that upholds the nominalist ban on entirely void spaces (virtual-platonism) at the foundational level: 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, 2009, 16).

3.4. Pre-established Harmony and QG

Lastly, it should be noted that Smolin's quest for a completely background independent QG theory provides a unique Leibnizian twist to that principle, for he employs a hidden variables conception of QM as a key component. 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 (2 3 2).

While not directly mentioning Leibniz' monadic system, Smolin's hidden variables approach to a fully background independent QG theory not only evokes the holistic, pre-established harmony of Leibniz' monadic metaphysics, but, in fact, was inspired by it (Barbour & Smolin, 1992; Barbour, 2003). Although "the monad's natural changes come from an internal principle, since no external cause can influence it internally" (Leibniz, 1989, 214), their pre-established harmony mimics the holistic interconnections of a hidden variables theory: "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" (2 2 0). Smolin describes his hidden variables strategy as "relational"; but the relational aspect of these entities, whether a monad or a 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 substantival/relational distinction to probe the conceptual depths of the foundational realm of ontology, whether in the seventeenth century or in modern QG theories.

4. Conclusion

The main goal of this essay has been to expose the limited capacity of substantivalism and relationism to assess spatial ontologies by offering an alternative, and more successful, classificational system. The evidence for the weakness of the substantivalist/relationist dichotomy resides in the uncertainty that characterizes any application of the distinction, whether in the seventeenth century or in the context of QG and GR. In its place, a different set of distinctions has been advanced that concern (i) the different levels of spatial geometry at the foundational and secondary levels, and (ii) the platonist/nominalist divide in spatial geometry at these levels—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 metrical structure at the bodily (secondary) and foundational level (More, Newton), but some do not (Gassendi); as regards (ii), some alleged substantivalists favor virtual-platonism at the secondary level (More, Newton, Gassendi), but some do not (Barrow). And, while both of the alleged relationists in our investigation (Descartes, Leibniz) are in the same camp concerning (i) and (ii), i.e., both posit a difference in metrical and topological structure at the foundational and secondary levels, as well as accept geometric nominalism at the secondary level, modern substantivalism and relationism cannot adequately explain these similarities since they do not take into account issues (i) and (ii). For instance, while issue (i) is clearly not a factor in the modern dichotomy, if the possibility of a vacuum were invoked as a surrogate for nominalism, our issue (ii), and hence as a means of separating substantivalists from relationists, then Leibniz would now count as substantivalist since he admits the possibility of a vacuum. Therefore, despite the obvious similarities between Descartes and Leibniz' theories of space, the substantivalist/relationist dichotomy simply cannot pair them together in a natural way.

In contrast, our new set of dichotomies concerning the deep ontology of space 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); Gassendi with FGL(top); Newton, More and Gassendi with SL(v-plt), Leibniz and Descartes with FGL(prg); Leibniz, Descartes, and Barrow with SL(nom). In addition, FL(nom) is upheld by all of the theories surveyed in our examination, whether in the Early Modern period or as regards contemporary QG hypotheses (as well as QM and GR). Second, our two-part dichotomy not only successfully partitions the various QG approaches into natural categories, but, more importantly (on historical and philosophical grounds), it also provides a basis for drawing successful analogies with seventeenth century theories, e.g., Leibniz with the pregeometry of QCH, Gassendi with the continuous topological structure required for LQG, and Newton with the fixed background metric in early String theory. 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.

Finally, the new taxonomy advanced in this essay has an important advantage in that it does not utilize nor sanction the apparently arbitrary and unconstructive ontological distinction between the sophisticated substantivalist and sophisticated relationist interpretations of LQG and the metric-field in GR (whether as an emergent feature of a QG theory or in standard GR). While the substantivalist/relationist distinction is somewhat serviceable in the context of macrolevel Newtonian mechanics, it has become practically dysfunctional in the debates on the status of the metric-field in GR and in the assessment of QG hypotheses. The deep ontology of space, which is a paramount concern for seventeenth century thinkers and QG theorists alike, may now hopefully prompt a much needed recalibration of the tools used for ontological appraisal by philosophers of space and time.

Acknowledgments

An earlier version of this paper was presented at the 2010 meeting of the Philosophy of Science Association in Montreal, Canada. I would like to thank members of the audience for their comments and, in particular, Dean Rickles for several helpful conversations on quantum gravity theories.

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