1 The Origins of the Absolute-Relational Controversy

Because it conveys so vividly a sense of the once fashionable attitudes toward the absolute-relational controversy, Reichenbach's "Theory of Motion According to Newton, Leibniz, and Huygens" (1924) ought to be required reading for all students of the controversy. Here are a half dozen of Reichenbach's themes.

1. Newton was a great physicist, but both he and Samuel Clarke, his spokesman in the famous Leibniz–Clarke correspondence, were philosophical dunces.[1] ("It is ironic that Newton, who enriched science so immensely by his physical discoveries, at the same time largely hindered the development of its conceptual foundations"; Newton "turns into a mystic and a dogmatist as soon as he leaves the boundaries of his special field"; Clarke operates with "the complacency of a person not inhibited by any capacity for further enlightenment.")

2. Leibniz and Huygens were the men of real philosophical insight. (It was their "unfortunate fate to have possessed insights that were too sophisticated for the intellectual climate of their times.")

3. Newton's key mistake was to stray from his own empiricist principles. ("Newton begins with very precisely formulated empirical statements, but adds a mystical philosophical superstructure [namely, absolute space and time]."[2])

4. Newton's conception of space and time as "autonomous entities existing independently of things" shows that he was unable to emancipate himself from "the primitive notions of everyday life."

5. Leibniz's and Huygens's views on space and time are vindicated by relativity theory. ("In their opposition to Newton, physicists of our day rediscovered the answers which Newton's two contemporaries had offered in vain"; the Leibniz–Clarke correspondence "reads like a modern discussion of the theory of relativity.")

6. Newton's interpretation of the infamous rotating-bucket experiment was refuted by Mach. ("The decisive answer to Newton's argument concerning centrifugal force was given by Mach.") Mach's own interpretation of rotation is embodied in Einstein's general theory of relativity (hereafter, GTR). ("As is well known, Mach's answer is based on the fact that centrifugal force can be interpreted relativistically as a dynamic effect of gravitation produced by the rotation of the fixed stars.")

Depending upon their inclinations, students can either take heart from or stand appalled at the fact that one of the heavyweights of twentieth-century philosophy of science was so consistently wrong on so many fundamental points.[3]

1 Newton on Absolute Space and Time

Newton's Scholium on Absolute Space and Time, reproduced as an appendix to this chapter, should be read with an eye to disentangling various senses in which space, time, and space-time can be or fail to be absolute. At this stage the reader is urged to avoid making judgments about Newton's views and to concentrate instead on trying to get a firm grip on what his views are. As an initial guide, keep in mind that Newton is making at least four interrelated but distinct kinds of claims: (1) *Absolute Motion:* space and time are endowed with various structures rich enough to support an absolute, or nonrelational, conception of motion. (2) *Substantivalism:* these structures inhere in a substratum of space or space-time points. (3) *Nonconventionalism:* these structures are intrinsic to space and time. (4) *Immutability:* these structures are fixed and immutable. I pause to give the reader the opportunity to renew his acquaintance with the Scholium. (Take all the time you need; I can be patient.)

A number of comments about the opening paragraphs of the Scholium are called for here. Later chapters will examine Newton's argument from rotation, which appears in the latter part of the Scholium.

Introductory paragraph

Recall Reichenbach's claim that Leibniz had emancipated himself from the primitive notions of everyday life. Newton is here declaring his own emancipation. He is warning the reader that the terms 'time,' 'space,' 'place,' and 'motion' are not being used in their ordinary-language senses but are being given special technical meanings.

Paragraph I

Three elements of this paragraph call for emphasis and explication. First, when Newton says that absolute time "flows equably," he is not to be parsed as saying that time flows and that it flows equably. A literal notion of flow would presuppose a substratum with respect to which the flow takes place. But just as Newton rejected the idea that the points of absolute space are to be located with respect to something deeper, so he would have rejected locating the instants of time with respect to anything deeper. The phrase 'flows equably' refers not to the ontology of time but to its structure. In part, Newton is asserting that it is meaningful to ask of any two events e_1 and e_2, How much time elapses between the occurrence of e_1 and e_2? Included, of course, is the special case of simultaneous or cotemporaneous events, for which the lapse is zero. Thus, according to Newton, we have absolute simultaneity and absolute duration in that there is a unique way to partition all events into simultaneity classes, and there is an observer-independent measure of the temporal interval between nonsimultaneous events. Leibniz agreed about the absolute character of simultaneity ("*whatever exists is either simultaneous with other existences or prior or posterior*" [Loemker 1970, p. 666]), though he disagreed about the grounding of the relation of simultaneity (see section 6 below).

Second, in saying that time flows equably "without relation to anything external," Newton is asserting that the temporal interval between two events is what it is independent of what bodies are in space and how they behave.

Third, in distinguishing true mathematical time from some sensible and external measure of it, Newton is asserting that the metric of time is intrinsic to temporal intervals and that talk about the lapse of time between e_1 and e_2 is not elliptical for talk about the relation of e_1 and e_2 to the behavior of a pendulum, a quartz watch, or any other physical system. Of course, we have to use such devices in attempts to come to know what the interval is, but as Newton notes later in the Scholium, any such device may give the "wrong" answer: "It may be, that there is no such thing as equable motion, whereby time may be accurately measured. All motions may be accelerated and retarded, but the flowing of absolute time is liable to no change." Those who wish to deny Newton's intrinsicality thesis often accompany the denial with an assertion of a conventionality thesis to the effect that there is no fact of the matter about what the "correct" extrinsic metric standard is.

Paragraph II

"Absolute space, in its own nature, without relation to anything external, remains always similar and immovable." Newton is here asserting that the structure of space is absolute in that it remains the same from time to time in any physically possible world and from physically possible world to physically possible world. This immovable structure was assumed to be that of Euclidean three-space $\mathbb{E}^3$. In his early essay "De gravitatione" (c. 1668) Newton gave a theological motivation for this doctrine of the immutability of spatial structure: space is "immutable in nature, and this is because it is an emanent effect of an eternal and immutable being" (Hall and Hall 1962, p. 137). Even those of Newton's contemporaries who would have rejected the doctrine that space is an emanent effect of God would hardly have questioned the assumption of the fixity of spatial structure,[4] and over two centuries were to pass before the appearance of a successful scientific theory, Einstein's GTR, in which this assumption was dropped.

"Relative space is some movable dimension or measure of the absolute spaces." In part, this is a reiteration of Newton's intrinsicality and non-conventionalist stances: talk about the spatiotemporal separation of events e_1 and e_2 is not to be analyzed as talk about the relation between the events and extrinsic metric standards such as "rigid rods" and pendulum clocks. But the full meaning of Paragraph II cannot be appreciated without coming to grips with an ambiguity in Newton's use of 'space.' In one sense, 'space' means instantaneous space; that is, in space-time terminology, an instantaneous slice of space-time, which slice is supposed to have the character of $\mathbb{E}^3$ (see figure 1.1a). There are two other meanings of "space" that are implicit in paragraph II but emerge more explicitly in the following two paragraphs.

Paragraphs III and IV

"Place is a part of space which a body takes up, and is according to the space, either absolute or relative." "Absolute motion is the translation of a body from one absolute place into another; and relative motion, the translation from one relative place into another." A second meaning of 'space' that emerges from these passages is that of a reference frame, or a means of identifying spatial locations through time. To claim that space is absolute in this sense is to claim that there is a unique, correct way to make the identification so that for any two events e_1 and e_2, even ones lying in different instantaneous spaces (see figure 1.1b), it is meaningful to ask, Do e_1 and e_2 occur at the same spatial location? The identification procedure can be given by specifying a system of paths oblique to the planes of absolute simultaneity; with the specification indicated in figure 1.1b, the answer to the question is no.

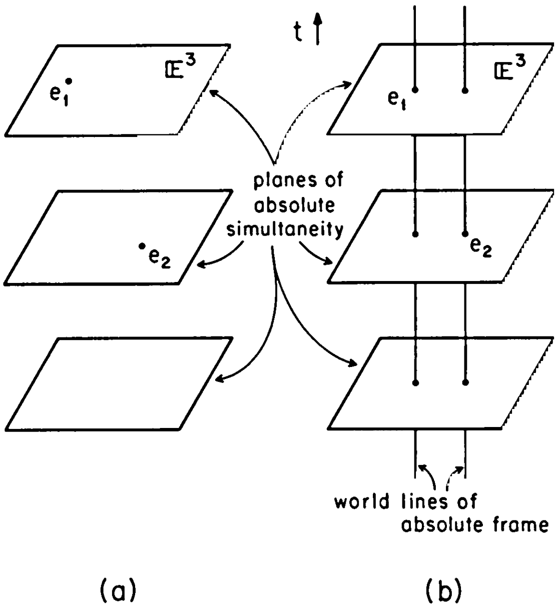

Figure 1.1
Absolute simultaneity and absolute position in Newtonian space-time

In yet a third sense, 'space' denotes a substance or substratum of points underlying physical events. The absolute frame of reference may then be thought of as being generated by the world lines of the points of absolute (or substantival) space. Spatial relations among bodies are parasitic on the spatial relations of the points of space that the bodies occupy.

Newton freely admits that "the parts of space cannot be seen, or distinguished from one another by our senses" and that as a result "in their stead we use sensible measures of them."

And so, instead of absolute places and motions, we use relative ones; and that without any inconvenience in common affairs: but in philosophical disquisitions, we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them. For it may be that there is no body really at rest, to which the places and motions of others may be referred.

A sympathetic modern gloss might run thus. Absolute space is a theoretical entity; that is, it is an entity not directly open to observation. It nevertheless makes good scientific sense to postulate this entity, because the explanation of various phenomena that are observable, particularly those involving rotation, calls for an absolute concept of motion, which in turn must be grounded on absolute space. Newton's argument here will be examined in detail in later chapters, but for now note that the argument does not involve a repudiation of the most basic form of the doctrine of the relativity of motion. Indeed, part of Newton's mistake, paradoxically, was that he joined the relational theorists in subscribing to a radical form of the relativity doctrine, according to which any assertion of the form "x moves" is always to be analyzed as "x moves relative to y." Where Newton parts company with the relationist is, in the first instance, in his belief that a well-founded theory of motion cannot rely only on material bodies as values for y.

2 Senses of Absoluteness

The following summarizes some of the leading senses of absoluteness that occur in Newton's Scholium. To mesh with the discussion in later chapters, the somewhat anachronistic but more revealing terminology of space-time is used.

1. Space-time is endowed with various structures that are intrinsic to it.

2. Among these structures are absolute simultaneity (i.e., a unique partition of events into simultaneity classes) and an absolute duration (i.e., a measure of temporal lapse that is independent of the path connecting the events).

3. There is an absolute reference frame that provides a unique way of identifying spatial locations through time. As a result, there is an absolute or well-defined measure of the velocity of individual particles and a well-defined measure of spatial separation for any pair of events.

4. The structure of space-time is immutable; i.e., it is the same from time to time in the actual world and from this world to other physically possible worlds.

5. Space-time is a substance in that it forms a substratum that underlies physical events and processes, and spatiotemporal relations among such events and processes are parasitic on the spatiotemporal relations inherent in the substratum of space-time points and regions.

Whether any or all of this is merely metaphysical gibberish, as Reichenbach would have it, remains to be seen.

3 Relationism

There are two reasons why relationism is a more elusive doctrine than absolutism. First, there is no relationist counterpart to Newton's Scholium, the *locus classicus* of absolutism. Leibniz's correspondence with Clarke is often thought to fill this role, but it falls short of articulating a coherent relational doctrine and it even fails to provide a clear account of key points in Leibniz's own version of relationism (there is, for example, no mention of Leibniz's reaction to Newton's bucket experiment). Second, there are almost as many versions of relationism as there are relationists.

At the risk of some distortion it is nevertheless useful to state three themes that form the core of classical relationism. The first theme is about both the nature of motion and the structure of space-time.

R1 All motion is the relative motion of bodies, and consequently, space-time does not have, and cannot have, structures that support absolute quantities of motion.

Huygens, as we will see in chapters 3 and 4, was a forthright exponent of this theme. Leibniz's position is more difficult to interpret, for his doctrine of "force" seems at times to threaten to undermine the relational conception of motion (see section 6.10). I shall use 'relational conception of motion' to refer to theme (R1). Please resist Reichenbach's invitation to confuse 'relational' with 'relativistic' in the sense of the special and general theories of relativity (see chapter 5).

The second theme is a denial of space-time substantivalism.

R2 Spatiotemporal relations among bodies and events are direct; that is, they are not parasitic on relations among a substratum of space points that underlie bodies or space-time points that underlie events.

This antisubstantivalist theme is sounded in Huygens's writing, especially in a number of manuscripts composed during the last years of his life and written in direct reaction to Newton's Scholium (see chapters 3 and 4). It is also sounded in Leibniz's correspondence with Clarke, as when he announces in his third letter that "As for my opinion, I have said more than once, that I hold space to be something merely relative.... For space denotes, in terms of possibility, an order of things which exist at the same time" (Alexander 1984, pp. 25–26). There follows immediately a demonstration designed to "confute the fancy of those who take space to be a substance." This famous argument will be examined in detail in chapter 6.

One of the most glaring deficiencies of the classical discussions and of the current philosophical literature is the lack of a persuasive account of the relation between (R1) and (R2). In chapter 3 I shall show that (R1) entails (R2), at least under the assumption that a minimal form of determinism is possible. Classical entries in the absolute-relational debate give the impression that both Newton and his contemporaries assumed that (R2) entails (R1), with Newton and his supporters arguing that $\neg$(R1) and, therefore by *modus tollens*, that $\neg$(R2), while relationists argued that (R2) and concluded by *modus ponens* that (R1). Unfortunately, the classical discussions are burdened by a mistake by Newton and a double countermistake by his critics. Newton seems to have thought that since "*x* moves" is short for "*x* moves relative to *y*" and since absolute motion is motion relative to absolute space, "*x* accelerates (absolutely)" means that "*x* accelerates relative to absolute space." His critics tended to swallow this move but countered correctly that Newton's sense of absolute motion entails the otiose notions of absolute velocity and absolute change of position and then concluded incorrectly that they had shown that no sense of absolute, or nonrelational, motion is required. (If the reader is confused at this juncture, I can only say, have courage and read on.) I shall argue that the failure of (R1) and other considerations do militate against (R2), although the kind of substantivalism that emerges need not be anything like that envisioned by Newton. Indeed, I shall argue that abandoning the immutability of space-time structure (as is done in GTR) while maintaining the possibility of determinism forces one to abandon a standard account of space-time substantivalism (see chapter 9). The modern upshot of the absolute-relational debate is thus a conception of space and time that is radically different from what either Newton or his critics advocated.

The third theme asserts that all spatial predication is relational in nature.

R3 No irreducible, monadic spatiotemporal properties, like 'is located at space-time point *p*,' appear in a correct analysis of the spatiotemporal idiom.[5]

While Huygens and Leibniz did not address this issue in these terms, there can be little doubt that they would have endorsed (R3), since they would have been unhappy to see smuggled in through the back door of ideology what they thought they had ruled out of the ontology with theme (R2). It is interesting to note in this regard that Leibniz's famous argument against substantivalism works equally well (or ill) against the monadic conception of spatiotemporal predication (see chapter 6).

The absolute-relational contrast is far from being a dichotomy. A possible, third alternative, which I shall call the property view of space-time, would take something from both camps: it would agree with the relationist in rejecting a substantival substratum for events while joining with the absolutist in recognizing monadic properties of spatiotemporal location. At first glance, this mongrel view does not seem to have much to recommend it, for it abandons the simplicity and parsimony that makes relationism attractive, and at the same time it gives up the ability of absolutism to explain monadic spatiotemporal properties. But like many cross breeds, this one displays a hardiness, and it will make various appearances in the chapters to come.[6]

At the risk of prejudging the outcome of future discussion, I would nevertheless like to indicate three reasons why I find Teller's (1987) version of the property view unacceptable. The first relates to his motivation. Teller claims that the substantivalist is committed to two theses: (1) that space-time points necessarily exist and (2) that necessarily, each physical event occurs at some space-time point. He concludes that "both these theses suggest ... that space-time points are abstract objects rather than concrete particulars.... So the inclination to think of space-time points as necessary suggests thinking of them as more like properties than particulars" (1987, p. 426). In response, I note that the modern substantivalist rejects thesis (1); indeed, the operation of deleting points from the space-time manifold is one of the standard devices used by general relativists in constructing cosmological models (see chapter 8). Substantivalists do accept thesis (2), but I fail to see how doing so makes space-time points analogous to quantities or determinables like mass; indeed, the substantivalist's analysis of events makes it pellucid that space-time points are being treated as substances in the sense of objects of predication. This leads me to my second reason for being unhappy with Teller's property view. I agree with Teller's sentiment that there are instances where there is no real difference between calling something a property versus calling it a concrete thing. But modern field theory does provide a powerful reason for assigning space-time points to the latter rather than the former category (see chapter 8). Finally, I will argue in chapter 9 that Einstein's "hole construction" gives a powerful reason to reject one leading form of space-time substantivalism, and exactly the same argument works against Teller's property view.

The three relational themes sounded above are largely negative: there is no absolute motion; space or space-time is not a substance; and there are no irreducible, monadic spatiotemporal properties. What, then, is the relationist's positive account of space, time, and space-time? The classical relationist can reply in two steps. First, there are at base only physical bodies, their intrinsic nonspatiotemporal properties (such as mass), and their spatiotemporal relations. Second, the relation between the absolutist and the relationist models of reality is, to use one of Leibniz's favorite concepts, one of representation, with the representation being one-many. This representational ploy will receive detailed scrutiny in the later chapters, especially chapters 6 to 9.

4 Leibniz and the Ideality of Space

In the correspondence with Clarke, Leibniz's attack on absolute space includes the charge that space and time are not fully real, that they are "ideal." In his introduction to the correspondence, H. G. Alexander states, "The ideality of space and time follows, for Leibniz, from the fact that they are neither individual substances nor aggregates of individual substances; for only these are fully real" (Alexander 1984, p. xxv). This is not a wholly satisfactory explanation. It is true that in the Leibnizian metaphysic what are ultimately real are the individual substances or monads and their nonrelational properties, and what we call the physical world is but an appearance or phenomenon.[7] But the monadology is not at issue in the polemic with Clarke, where the dispute on the nature of space and time is focused on the phenomena of physics. These phenomena are not mere appearances but are, in Leibniz's terminology, true appearances or well-founded phenomena. Indeed, there are passages from the 1680s in which Leibniz specifically refers to space and time as well-founded phenomena. ("Space, time, extension, and motion are not things but well-founded modes of our consideration." "Matter, taken for mass itself, is only a phenomenon or well founded appearance, as are space and time also."[8]) Such passages only seem to compound the puzzle of the ideality thesis.

The puzzle is resolved by noting that such passages disappear in the 1690s, when Leibniz begins to make use of a trichotomy consisting of the monads, well-founded phenomena, and a third realm consisting of entities variously labeled 'ideal', 'mental', and 'imaginary'. It is to this third category that space and time are confined in Leibniz's later writings.[9] As Cover and Hartz (1986) have emphasized, this third layer was added largely as a product of Leibniz's struggle with the labyrinth of the continuum. ("I acknowledge that time, extension, motion, and the continuum in general, as we understand them in mathematics, are only ideal things."[10]) Very roughly, Leibniz's doctrine is that in real things the part is prior to the whole, that a real thing is actually divided into definite parts; whereas in a continuum, such as space or time, the whole is prior to the parts and, indeed, there are no actual parts to a continuum but merely infinitely many potential and arbitrary divisions. ("A continuous quantity is something ideal which pertains to possibles and to actualities only in so far as they are possible. A continuum, that is, involves indeterminate parts, while on the other hand, there is nothing indefinite in actual things, in which every division is made that can be made. Actual things are compounded as is a number out of unities, ideal things as is a number out of fractions; the parts are actually in a real whole but not in the ideal whole."[11])

Leibniz forced himself to enter the labyrinth of the continuum by combining various paradoxes of infinity, learned from Galileo's writings, with a dubious reading of the axiom that the whole is greater than the part. Thus, consider the naive (and defensible) view that a continuum is actually and definitely divided, its parts being extensionless points. Leibniz rejected this conception of the composition of the continuum on the grounds that the points in, say, the interval $[0, 1]$ can be put into one-to-one correspondence with the points in a proper subinterval, say $[0, \frac{1}{2}]$, contradicting the axiom. Tracing the origins and ramifications of these quaint and unfruitful ideas is an interesting exercise in Leibniz scholarship, but it is not one that I shall attempt here.[12]

5 Other Relationisms

Modern relationists, or at least those who want to see themselves as heirs to Leibniz's philosophy of space and time, may sound one or more of the themes of section 3, but some are apt to identify relationism with the denial of Newton's claims that the metrical structures of space and time are intrinsic. Reichenbach and his followers are also intent on maintaining an ideological purity. Space and time, they hold, are constructed out of physical objects, their states, and relations between them. And further, only certain kinds of relations, taken in intension, are "objective" or "real," namely, those grounded in causal relations, such as the relation of causal connectibility. These two latter themes combine to produce various conventionality theses about space-time structure. Thus, on Reichenbach's view, the standard simultaneity relation ($\varepsilon = \frac{1}{2}$) used in the special theory of relativity (hereafter STR) is conventional unless it is definable, and perhaps uniquely definable, in terms of acceptable causal relations.[13]

The Leibniz corpus, like the Bible, can be cited in support of almost any idea, and so it is not at all surprising to find sources in Leibniz's writings for both the nonintrinsicality thesis and the causal thesis. In the "Metaphysical Foundations of Mathematics," written during the same period as the correspondence with Clarke, Leibniz clearly enunciates the nonintrinsicality thesis: "*Quantity or magnitude is that in things which can be known only through their simultaneous compresence—or by their simultaneous perception.* Thus it is impossible for us to know what a *foot* or a *yard* is unless we actually have something to serve as a measure which can be applied to successive objects after each other" (Loemker 1970, p. 667). And the same essay also contains a nascent causal theory of time: "*Time is the order of existence of things which are not simultaneous....* If one of two states which are not simultaneous involves a reason for the other, the former is held to be *prior*, the latter *posterior*" (Loemker 1970, p. 666). I will have occasion to refer to those ideas at various points, but the main focus of the present study will be on the themes (R1) to (R3) of section 3.

Yet other relationist themes are to be found in the useful "Appendix on Relationism" in J. R. Lucas's *Space, Time, and Causality* (1984). However, many of the issues raised by Lucas are engaged by probing one or more of the senses of relationism already noted. Thus, for example, Lucas says that the relationist must hold as a matter of empirical fact, methodological principle, or conceptual necessity that all laws of nature are covariant (invariant?) under various sorts of transformations. In chapters 2 and 3 we shall see how invariance principles are crucial to an assessment of (R1) of section 3. As another example, Lucas's relationist holds that space and time are homogeneous and that space is isotropic. Why? One reason can be discerned by pursuing Leibniz's argument against substantivalism (theme [R2] of section 3), for the argument appears at first blush not to work if homogeneity and isotropy are abandoned (but see chapters 7 and 9). A less *ad hominem* reason is that the relationist will want to maintain that space and time are causally inefficacious. But notice that in the setting of classical space-time theories (chapter 2), space and time can be homogeneous, and space isotropic, while *space-time* is causally efficacious, because, for example, it possesses inertial or other structures that undermine the relational character of motion (contrary to theme [R1]). Another variant on the theme of the causally inefficacious status of space and time is that the very notion of causation demands it: "Causes must be repeatable: A mere difference in space and time cannot make any difference *per se*."[14] The possibility of determinism will figure in chapter 9 as part of an argument against one modern form of space-time substantivalism.

6 The Vacuum

A recurring topic in Leibniz's side of the correspondence with Clarke is criticism of the notion of a vacuum or an empty region of space.[15] The participants in this debate had the luxury of knowing what they were talking about; an empty region of space is a region unoccupied by matter. (This is the absolutist's characterization of the vacuum, but the relationist will have no trouble in providing a relational gloss, at least as long as space is not wholly empty.) We do not enjoy any such luxury for a combination of reasons: because classical particle ontology has been replaced by a dualistic particle-field ontology, because STR entails the equivalence of mass and energy, because GTR implies that the structure of space-time is not fixed and immutable, and because of the peculiarities of quantum field theory. We can maintain the spirit of the classical definition of empty space while accommodating the first two points by taking the vanishing of the relativistic energy-momentum tensor T^{ij} to be the relativistic explication of the notion of an empty space-time region. While this explication seems satisfactory in the context of STR, it has the awkward consequence of counting regions of general relativistic space-times as empty, even though these regions contain gravitational waves of sufficient strength to knock down the Rock of Gibraltar.[16] When we turn to relativistic quantum field theory, the classical notions become even more diffuse. For example, the so-called vacuum state characterizes a completely empty space (at least from the point of view of an inertial observer), but this state nonetheless contains a high degree of dynamical activity in the form of vacuum fluctuations that can have important physical consequences.[17]

But before becoming exercised at the difficulties of extending the classical notion of empty space into the relativistic and quantum realms, we should pause to consider what significance, if any, this notion has for the core of the absolute-relational controversy. A passage from Leibniz's fifth letter to Clarke seems to commit him to denying the possibility of a vacuum: "Since space in itself is an ideal thing, like time, space out of the world must be imaginary.... The case is the same with empty space within the world; which I take also to be imaginary" (Alexander 1984, p. 64). However, C. D. Broad (1946) seems to me to be on target in interpreting this passage, not as a denial of the possibility of the vacuum *per se*, but rather as a denial of the existence of substantival space, either outside of a finite material universe or inside of Guerike's vacuum pump. Earlier in the same letter Leibniz writes, "Absolutely speaking, it appears that God can make the material universe finite in extension; but the contrary appears more agreeable to his wisdom" (Alexander 1984, p. 64). I take it that Leibniz would likewise have acknowledged that God can make a universe with a vacuum inside the system of matter. The qualifier "appears" in this passage is also significant, since it is Leibniz's acknowledgment that it is not certain that the principle of sufficient reason entails that God would not actualize such a world. Indeed, all that follows from the combination of the principle of sufficient reason and the principle of plenitude is that *other things being equal*, world W_1 is better than world W_2 if W_2 contains a vacuum while W_1 does not, and therefore *other things being equal*, God would not choose to actualize W_2 over W_1. But other things might not be equal and W_2 might be preferable to W_1 because the greater simplicity and harmony of its laws outweigh its lack of plenitude. Leibniz apparently thought that such a situation is unlikely to emerge in God's preference ordering over possible worlds, but he was careful not to preclude it.

Can we then set aside the vacuum as a tangential issue, if not a complete red herring? In the most authoritative recent discussion of relationism Friedman (1983, chapter 6) thinks not, because he worries that the debate over substantivalism threatens to collapse if the world is a plenum. I will argue that his worry is misplaced, at least as regards one important form of substantivalism (see chapters 6 and 8). The real significance of the issue of the vacuum seems to me to be twofold. First, a plenum makes it easier for the relationist to maintain that absolutist models are representations of relational worlds, and second, if we look in the opposite direction, a completely empty universe is difficult for the traditional relationist to accommodate (see chapter 8).

7 Conclusion

Though cursory, our initial examination of the absolute-relational controversy affords a glimpse of how far flung, how complex, and how subtle the issues are. The glimpse also reveals what a folly it would be to wade directly into the controversy with the aim of emerging from the fray with a once-and-for-all resolution. Nevertheless, I will try to show how progress can be made by a judicious choice of lines of inquiry.[18] The most fruitful entry point, I will try to show, is theme (R1), the relational character of motion. To prepare for this entry, the next chapter is devoted to a study of various classical space-time structures.

Appendix: Newton's Scholium on Absolute Space and Time

Hitherto I have laid down the definitions of such words as are less known, and explained the sense in which I would have them to be understood in the following discourse. I do not define time, space, place, and motion, as being well known to all. Only I must observe, that the common people conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common.

I. Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.

II. Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies; and which is commonly taken for immovable space; such is the dimension of a subterraneous, an aerial, or celestial space, determined by its position in respect of the earth. Absolute and relative space are the same in figure and magnitude; but they do not remain always numerically the same. For if the earth, for instance, moves, a space of our air, which relatively and in respect of the earth remains always the same, will at one time be one part of the absolute space into which the air passes; at another time it will be another part of the same, and so, absolutely understood, it will be continually changed.

III. Place is a part of space which a body takes up, and is according to the space, either absolute or relative. I say, a part of space; not the situation, nor the external surface of the body. For the places of equal solids are always equal but their surfaces, by reason of their dissimilar figures, are often unequal. Positions properly have no quantity, nor are they so much the places themselves, as the properties of places. The motion of the whole is the same with the sum of the motions of the parts; that is, the translation of the whole, out of its place, is the same thing with the sum of the translations of the parts out of their places; and therefore the place of the whole is the same as the sum of the places as the parts, and for that reason, it is internal, and in the whole body.

IV. Absolute motion is the translation of a body from one absolute place into another; and relative motion, the translation from one relative place into another. Thus in a ship under sail, the relative place of a body is that part of the ship which the body possesses; or that part of the cavity which the body fills, and which therefore moves together with the ship: and relative rest is the continuance of the body in the same part of the ship, or of its cavity. But real, absolute rest, is the continuance of the body in the same part of that immovable space, in which the ship itself, its cavity, and all that it contains, is moved. Wherefore, if the earth is really at rest, the body, which relatively rests in the ship, will really and absolutely move with the same velocity which the ship has on the earth. But if the earth also moves, the true and absolute motion of the body will arise, partly from the true motion of the earth, in immovable space, partly from the relative motion of the ship on the earth; and if the body moves also relatively in the ship, its true motion will arise, partly from the true motion of the earth, in immovable space, and partly from the relative motions as well of the ship on the earth, as of the body in the ship; and from these relative motions will arise the relative motion of the body on the earth. As if that part of the earth, where the ship is, was truly moved towards the east, with a velocity of 10010 parts; while the ship itself, with a fresh gale, and full sails, is carried towards the west, with a velocity expressed by 10 of those parts; but a sailor walks in the ship towards the east, with 1 part of the said velocity; then the sailor will be moved truly in immovable space towards the east, with a velocity of 10001 parts, and relatively on the earth towards the west, with a velocity of 9 of those parts.

Absolute time, in astronomy, is distinguished from relative, by the equation or correction of the apparent time. For the natural days are truly unequal, though they are commonly considered as equal, and used for a measure of time; astronomers correct this inequality that they may measure the celestial motions by a more accurate time. It may be, that there is no such thing as an equable motion, whereby time may be accurately measured. All motions may be accelerated and retarded, but the flowing of absolute time is not liable to any change. The duration or perseverance of the existence of things remains the same, whether the motions are swift or slow, or none at all: and therefore this duration ought to be distinguished from what are only sensible measures thereof; and from which we deduce it, by means of the astronomical equation. The necessity of this equation, for determining the times of a phenomenon, is evinced as well from the experiments of the pendulum clock, as by eclipses of the satellites of Jupiter.

As the order of the parts of time is immutable, so also is the order of the parts of space. Suppose those parts to be moved out of their places, and they will be moved (if the expression may be allowed) out of themselves. For times and spaces are, as it were, the places as well of themselves as of all other things. All things are placed in time as to order of succession; and in space as to order of situation. It is from their essence or nature that they are places; and that the primary places of things should be movable, is absurd. These are therefore the absolute places; and translations out of those places, are the only absolute motions.

But because the parts of space cannot be seen, or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. For from the positions and distances of things from any body considered as immovable, we define all places; and then with respect to such places, we estimate all motions, considering bodies as transferred from some of those places into others. And so, instead of absolute places and motions, we use relative ones; and that without any inconvenience in common affairs; but in philosophical disquisitions, we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them. For it may be that there is no body really at rest, to which the places and motions of others may be referred.

But we may distinguish rest and motion, absolute and relative, one from the other by their properties, causes, and effects. It is a property of rest, that bodies really at rest do rest in respect to one another. And therefore as it is possible, that in the remote regions of the fixed stars, or perhaps far beyond them, there may be some body absolutely at rest; but impossible to know, from the position of bodies to one another in our regions, whether any of these do keep the same position to that remote body; it follows that absolute rest cannot be determined from the position of bodies in our regions.

It is a property of motion, that the parts, which retain given positions to their wholes, do partake of the motions of those wholes. For all the parts of revolving bodies endeavor to recede from the axis of motion; and the impetus of bodies moving forwards arises from the joint impetus of all the parts. Therefore, if surrounding bodies are moved, those that are relatively at rest within them will partake of their motion. Upon which account, the true and absolute motion of a body cannot be determined by the translation of it from those which only seem to rest; for the external bodies ought not only to appear at rest, but to be really at rest. For otherwise, all included bodies, besides their translation from near the surrounding ones, partake likewise of their true motions; and though that translation were not made, they would not be really at rest, but only seem to be so. For the surrounding bodies stand in the like relation to the surrounded as the exterior part of a whole does to the interior, or as the shell does to the kernel; but if the shell moves, the kernel will also move, as being part of the whole, without removal from near the shell.

A property, near akin to the preceding, is this, that if a place is moved, whatever is placed therein moves along with it; and therefore a body, which is moved from a place in motion, partakes also of the motion of its place. Upon which account, all motions, from places in motion, are no other than parts of entire and absolute motions; and every entire motion is composed of the motion of the body out of its first place, and the motion of this place out of its place; and so on, until we come to some immovable place, as in the before-mentioned example of the sailor. Wherefore, entire and absolute motions can be no otherwise determined than by immovable places; and for that reason I did before refer those absolute motions to immovable places, but relative ones to movable places. Now no other places are immovable but those that, from infinity to infinity, do all retain the same given position one to another; and upon this account must ever remain unmoved; and do thereby constitute immovable space.

The causes by which true and relative motions are distinguished, one from the other, are the forces impressed upon bodies to generate motion. True motion is neither generated nor altered, but by some force impressed upon the body moved; but relative motion may be generated or altered without any force impressed upon the body. For it is sufficient only to impress some force on other bodies with which the former is compared, that by their giving way, that relation may be changed, in which the relative rest or motion of this other body did consist. Again, true motion suffers always some change from any force impressed upon the moving body; but relative motion does not necessarily undergo any change by such forces. For if the same forces are likewise impressed on those other bodies, with which the comparison is made, that the relative position may be preserved, then that condition will be preserved in which the relative motion consists. And therefore any relative motion may be changed when the true motion remains unaltered, and the relative may be preserved when the true suffers some change. Thus, true motion by no means consists in such relations.

The effects which distinguish absolute from relative motion are, the forces of receding from the axis of circular motion. For there are no such forces in a circular motion purely relative, but in a true and absolute circular motion, they are greater or less, according to the quantity of the motion. If a vessel, hung by a long cord, is so often turned about that the cord is strongly twisted, then filled with water, and held at rest together with the water; thereupon, by the sudden action of another force, it is whirled about the contrary way, and while the cord is untwisting itself, the vessel continues for some time in this motion; the surface of the water will at first be plain, as before the vessel began to move; but after that, the vessel, by gradually communicating its motion to the water, will make it begin sensibly to revolve, and recede by little and little from the middle, and ascend to the sides of the vessel, forming itself into a concave figure (as I have experienced), and the swifter the motion becomes, the higher will the water rise, till at last, performing its revolutions in the same times with the vessel, it becomes relatively at rest in it. This ascent of the water shows its endeavor to recede from the axis of its motion; and the true and absolute circular motion of the water, which is here directly contrary to the relative, becomes known, and may be measured by this endeavor. At first, when the relative motion of the water in the vessel was greatest, it produced no endeavor to recede from the axis; the water showed no tendency to the circumference, nor any ascent towards the sides of the vessel, but remained of a plain surface, and therefore its true circular motion had not yet begun. But afterwards, when the relative motion of the water had decreased, the ascent thereof towards the sides of the vessel proved its endeavor to recede from the axis; and this endeavor showed the real circular motion of the water continually increasing, till it had acquired its greatest quantity, when the water rested relatively in the vessel. And therefore this endeavor does not depend upon any translation of the water in respect of the ambient bodies, nor can true circular motion be defined by such translation. There is only one real circular motion of any one revolving body, corresponding to only one power of endeavoring to recede from its axis of motion, as its proper and adequate effect; but relative motions, in one and the same body, are innumerable, according to the various relations it bears to external bodies, and, like other relations, are altogether destitute of any real effect, any otherwise than they may perhaps partake of that one only true motion. And therefore in their system who suppose that our heavens, revolving below the sphere of the fixed stars, carry the planets along with them; the several parts of those heavens, and the planets, which are indeed relatively at rest in their heavens, do yet really move. For they change their position one to another (which never happens to bodies truly at rest), and being carried together with their heavens, partake of their motions, and as parts of revolving wholes, endeavor to recede from the axis of their motions.

Wherefore relative quantities are not the quantities themselves, whose names they bear, but those sensible measures of them (either accurate or inaccurate), which are commonly used instead of the measured quantities themselves. And if the meaning of words is to be determined by their use, then by the names time, space, place, and motion, their [sensible] measures are properly to be understood; and the expression will be unusual, and purely mathematical, if the measured quantities themselves are meant. On this account, those violate the accuracy of language, which ought to be kept precise, who interpret these words for the measured quantities. Nor do those less defile the purity of mathematical and philosophical truths, who confound real quantities with their relations and sensible measures.

It is indeed a matter of great difficulty to discover, and effectually to distinguish, the true motions of particular bodies from the apparent; because the parts of that immovable space, in which those motions are performed, do by no means come under the observation of our senses. Yet the thing is not altogether desperate; for we have some arguments to guide us, partly from the apparent motions, which are the differences of the true motions; partly from the forces, which are the causes and effects of the true motions. For instance, if two globes, kept at a given distance one from the other by means of a cord that connects them, were revolved about their common centre of gravity, we might, from the tension of the cord, discover the endeavor of the globes to recede from the axis of their motion, and from thence we might compute the quantity of their circular motions. And then if any equal forces should be impressed at once on the alternate faces of the globes to augment or diminish their circular motions, from the increase or decrease of the tension of the cord, we might infer the increment or decrement of their motions; and thence would be found on what faces those forces ought to be impressed, that the motions of the globes might be most augmented; that is, we might discover their hindmost faces, or those which, in the circular motion, do follow. But the faces which follow being known, and consequently the opposite ones that precede, we should likewise know the determination of their motions. And thus we might find both the quantity and the determination of this circular motion, even in an immense vacuum, where there was nothing external or sensible with which the globes could be compared. But now, if in that space some remote bodies were placed that kept always a given position one to another, as the fixed stars do in our regions, we could not indeed determine from the relative translation of the globes among those bodies, whether the motion did belong to the globes or the bodies. But if we observed the cord, and found that its tension was that very tension which the motions of the globes required, we might conclude the motion to be in the globes, and the bodies to be at rest; and then, lastly, from the translation of the globes among the bodies, we should find the determination of their motions. But how we are to obtain the true motions from their causes, effects, and apparent differences, and the converse, shall be explained more at large in the following treatise. For to this end it was that I composed it. (Newton 1729, pp. 6–12)