questions are quite specific to the study of space and time, although, as we shall see, treating them will often bring to light broader questions of metaphysics.

Time and Being

Consider, for example, the traditional doctrines connecting time and being. For some, it seemed intuitively obvious that only what existed now really existed at all. The future was not yet in existence and the past had ceased to exist. Only entities that existed at the present could be said, properly speaking, really to exist. For others, it was the past and present that were real and the future unreal. Here the intuitive idea was that the past and present, having already come into being or occurred, had a determinate reality. What they were like was a matter of hard fact. According to that idea, the future was a realm of that which had not yet come into being. It had no determinate reality at all. After all, following along the thought, if it was a determinate fact now that some future event had a reality, then how could it still be open as to whether the event would in fact occur? How could there be any room for deciding what our future actions would be, for example, if it was already the case now, and had always been the case, that what we would do tomorrow was already a determinate fact today? The issue here is not that of determinism, of whether or not past and present events fix, by their lawlike connections to other events, what future events will, in fact, occur. The issue is, rather, the claim that if future happenings had present and past reality (if it was a fact now that I would buy ice cream tomorrow), then there could be no sense in which the future was open to possibility at all.

Opposed to such intuitions were the views to the effect that any such alleged connections of time to being were mere illusions of language. Past, present, and future, it was argued, were equally real. We don't take it as grounds for denying reality to things that they are not here, where we are located, so why should we take it as grounds for denying their reality that they are not in existence when we are speaking or having thoughts about them? We would think it silly to claim, for example, that things behind us or at our location were real but that things in front of us lacked true reality, so why should we not think it equally absurd to posit reality to past and present but deny it to future realities?

Tied in with these issues are a number of others to which we will be able to direct only the briefest remarks. It is sometimes alleged that time is radically different from space: Whereas space can be correctly viewed from a kind of "perspectiveless" standpoint, an adequate understanding of the temporality of things requires a perspectival viewpoint. We could, it is argued, describe all of spatial phenomena in two—equally adequate—ways. We could assign all spatial locations some coordinate name and say where things occurred by specifying the locations in terms of this, perspectiveless, naming. Or we could specify where something happened in relation to "here," the place at which we are located.

If we try the same trick with time, we see a puzzle. Does the information provided by saying when things occurred, even in relation to one another, fully convey all the temporal aspects of what happened? Some say no. Suppose we give the date on which Julius Caesar died and the date it is now. Suppose we add the fact that the date of Caesar's death is earlier than now, taking "is earlier than" as a primitive relation among times. When we have said all of that, have we said all there is to be said, temporally, about Caesar's death? The claim that we have not rests upon the idea that when we say "Caesar died" or otherwise specify that Caesar's death is past, we are doing more than specifying that it occurred before 1989, say. That latter fact is "timelessly true," but the fact that Caesar *died* was not true before he did, even if the fact Caesar's death is (timelessly) earlier than 1989 is, in a sense, always true.

Couldn't we, though, capture the "pastness" of Caesar's death by saying that it occurred earlier than *now*? To be sure, it is replied, but now is the name of the *present* and in putting things that way we have reintroduced essential tensedness into our temporal description of things. Those who deny that there is anything essentially different between time and space in this regard reply that "now" is a word just like "here." The reference of such words, sometimes called token reflexives or indexicals, varies with their use. Each use of "here" refers to the place at which the speaker is located. Similarly each use of "now" refers to the time the utterance is made. Is there anything more mysterious to "Caesar died," beyond the fact that Caesar's death is (timelessly) earlier than 1989 and that it is *now* 1989, than there is to the fact that the supernova occurred some distance from the earth and *here* is on the earth?

Yes, responds the proponent of the view that there is something radically different about time that distinguishes it from space. Whereas things that exist in space elsewhere than here exist, things that don't exist now don't really exist at all. "Now" isn't a mere indexical, they insist; it is the term that picks out (at any time) that moment of time that is the moment at which things exist, which is of course, the present moment! So this debate about the essential tensedness of time reverts, once again, to the Augustinian intuition that only that which exists now exists at all, properly speaking.

Relativistic Considerations

It is clear that the radical restructuring of space and time into spacetime posited by the special theory of relativity must have a strong impact on this debate. What becomes of the claim that "only that which exists now truly exists," given that events that are simultaneous for one observer occur at different times for an observer in motion with respect to the first even if the two observers are momentarily coinciding? The very meaning of "now" has become problematic. At least it has become a relative matter of exactly which events are occurring "now."

Suppose two observers are coincident at event *e* but in motion with respect to one another. There will be events like event *a* that are after *e* for the first observer but simultaneous with *e* for the second. But then, how could we say that *a* is unreal for the first observer if *a* is real to the second observer at the time in question (being simultaneous with *e* for that second observer) and if the second observer is certainly real at event *e* for the first? The situation is even worse than that. An event in relativity can be later than event *e* or "absolutely later" than event *e*. We speak of "absolutely later" when the event, *b*, is after *e* and causally connectable to it by some signal traveling at or below the speed of light. For events like *a* that are not causally connectable to *e*, *a* will appear after *e*, simultaneous with *e*, and before *e* to different observers. But all observers will agree that *b*, which is absolutely after *e*, is after *e*. Yet it can still be the case that there is an observer whose life event *e'* is simultaneous (for him) with *b*, but such that *e'* is simultaneous with *e* for the first observer. So the first observer will declare the second observer's life at *e'* real at *e*, and the second observer will declare *b* real at *e'*. How then could the first observer think of *b*, in his absolute future, as unreal at *e*?

The arguments here are designed to convince the reader that accepting the spacetime of relativity makes a mockery of the traditional view that "only what is present now is real." It is argued that relativity is clearly compatible only with the alternative view that takes all events, past, present, and future, as equally real, just as we traditionally take all that goes on in space, wherever it is happening, as equally entitled to be called real. If past, present, and future are as relative to states of motion as the special theory of relativity takes them to be, how could we think of reality as varying with the temporal place of an event relative to the present event in the life of the agent concerned?

But, of course, it isn't that easy. The attempt to read off a metaphysical conclusion from a scientific theory requires more care than we have given it so far. One could, formally, hold to the old doctrines of the unreality of all but the present, even in the face of accepting relativity, simply by denying that "is real" is a fully transitive notion. If "is simultaneous" has the feature in relativity that *e'* can be simultaneous with *e* for observer one, *b* simultaneous with *e'* for observer two, but *b* *not* simultaneous with *e* for any observer (which feature it certainly does have), than why should we not relativize "is real to" in just the same way, so that although *e'* is real to *e* for observer one and *b* real to *e'* for observer two, *b* isn't real to *e* for anyone? So no observer at event *e* will ever declare *b* to be a real event no matter what his state of motion when he is coincident with *e*.

A more interesting response proceeds by seeking for the sources of the intuition that past and future are unreal in the first place. One motivation for that view, although by no means the only one, is the epistemic remoteness of past and future to the present. It is a common idea that the present is "presented" to us immediately in experience, but that what happened in past and future can only be known by inference from present experience (including such experience as "having the memory that such-and-such an event occurred"). As we saw in "How Do We Know the True Geometry of the World?" the ontological status of the inferred is frequently one that is placed in doubt. There are arguments designed to cast skeptical doubt on the adequacy of any claim to know the truth of a proposition whose truth can only be known indirectly and by means of an inferential process. *If* one bases the claim to unreality of past and future on their remoteness from the kind of knowability that the present has for us, then a way of holding on to the intuition that past and future are unreal in the relativistic context becomes evident.

When we looked at the foundations of relativity theory, we saw that it is based on a critical examination of our knowledge of events remote from us in space. It is on that critical argument that Einstein's original critique of the intuitive notion of simultaneity for distant events rested. Following out what is suggested by the remarks above suggests a metaphysical reading appropriate to relativity for someone who wants to hold to the view that past and future are unreal. It is to deny the reality of the else*where* as much as to the else*when*, taking as that which has genuine reality only that which is coincident with one's place-time as an observer. Now, to be sure, such a reduction of the real to a point in spacetime is even worse than retaining reality only for the infinitely thin moment of time that is the now. Needless to say, I am not advocating such a radical diminution in what we view as real. The claim being made, however, is that the impetus and the intuitions that lay behind the earlier irrealist attitude toward past and future can't be dismissed out of hand simply by pointing out the relativity of the notions of past and future to the state of motion of the observer in a relativistic spacetime. The reader interested in the questions of why anyone would hold to such dramatic irrealism about past and future in the first place and why, in the relativistic context, apparently sane people might be tempted to the even more radical irrealism about the elsewhere will have to seek out the more detailed works on these issues.

Substantivalism Versus Relationism

A topic with rather more substantial possibilities is the impact of relativistic theories on the debate between substantivalists and relationists that I introduced earlier. As we shall see, the issues here are multiple, subtle, and complex. But as we shall also see, it turns out, once again, that one must be wary of the tendency to infer a metaphysical view from the results of science prematurely. Trying to arrive at some philosophical conclusion concerning the existence and nature of space and time by examining what our best available scientific theories tell us about space and time is a worthwhile task. But it is one that requires a healthy dose of philosophical caution and prudence.

The relationists denied that one should posit space and time as entities in their own right, arguing that all that could be posited were the spatial relations material objects bore to one another and the temporal relations material events bore to one another. After the development of the special theory of relativity, it was commonly asserted that Einstein had finally fulfilled the Leibnizian relationist program. But these claims were very misleading. Although the special theory does tell us that some features of the world we once took to be absolute are really relative, this is not at all the same thing as saying that relationism is correct. In Newton's account of space and time, there is a definite, nonrelative, spatial, and temporal separation between any two events. In the theory of relativity, such separations are only relative to a choice of inertial reference frame and differ depending on the frame chosen. But such relativity has nothing to do with whether in order to account for observable phenomena, we must posit space and time or, now, spacetime, as structures over and above the material things and features of the world. It should also be noted in passing here that although special relativity turns some previously nonrelative notions into relative ones, it introduces new, nonrelative, features of its own. The spacetime interval separation between events is, in the special theory, an absolute relation between the events and is independent of any observer, as is the proper time elapsed along a specific path in spacetime from event to event.

If Newton's argument for a substantival view of spacetime, which he used with such great effect against Leibniz, was correct, then special relativity would seem to be a theory that posits a substantival spacetime as well. As we have noted, the distinction, so important in the Newtonian argument, between genuinely uniformly moving, inertial systems and absolutely accelerated systems holds up in the special theory of relativity. In the newer theory, the inertial frames are, as they were in the Newtonian theory, those in which no inertial forces are experienced. But they are also now distinguished by being the states of motion in which the optical round-trip experiments give their famous null results. The distinction between being really in accelerated motion or not, which is at the core of Newton's argument against relationism, remains in the special theory of relativity.

Does this mean that if we accept the special theory, we must accept the metaphysical position of the Newtonian antirelationist (with, of course, Minkowski spacetime, rather than Newton's absolute space, as the substantival spacetime structure)? Do we still need a "spacetime itself" relative to which absolute acceleration is acceleration and whose existence is posited as part of the explanation of the existence of inertial

forces and the optical effects that reveal absolute acceleration? Maybe, but once again it would be hasty to leap without further thought from a scientific theory to a metaphysical conclusion. Could we not find some way of reconciling special relativity with a relationist account of spacetime?

Perhaps. But the philosophical issues involved are complex, subtle, and problematic. There are arguments designed to show that the substantivalist's program of positing spacetime as an entity needed to explain the distinction between absolutely accelerated motions and those absolutely nonaccelerated is flawed and that the explanations offered are spurious. Inertial forces and the optical effects of acceleration are explained by reference to the acceleration of the laboratory with respect to the "inertial reference frames" of spacetime itself, these taking the place in special relativity of Newton's "space itself." But the spacetime structures themselves remain, in some sense, immune to direct observability, showing up only indirectly in terms of the causal effects of motion with respect to them. Can't we explain all that there is to explain without positing spacetime itself?

Now we can explain the differences in felt inertial effects in two laboratories by reference to their relative acceleration to one another. "But," says the substantivalist, "you can't explain why in one set of these frames no inertial effects are felt at all, the effects being felt only in the laboratories in acceleration with respect to these preferred laboratories. I," he says, "can explain why these frames are preferred. They are the ones unaccelerated with respect to spacetime itself." The relationist can counterargue by claiming that although he cannot explain why one set of these frames is preferentially inertial, he can simply take that as a "basic brute fact of nature" that simply doesn't ever get explained. After all, he can say, there must be some fundamental brute facts, so why not these? He goes on to argue that the substantivalist requires brute facts in any case. For the substantivalist, it is a brute fact of nature that acceleration with respect to the inertial geodesics of spacetime induces the inertial effects. So, the relationist claims, the substantivalist is no better off in explanatory terms than is the relationist, but the former must posit the mysterious entity "spacetime itself," which does no real explanatory work. And once again following Leibniz, the relationist will produce a series of arguments to the effect that the substantivalist view posits other facts, such as at which event location in spacetime a particular event occurs, that have no observable consequences whatsoever. So, continues the relationist, the positing of spacetime itself introduces "differences in theory without an observational difference." Such differences in theory were a puzzling feature of Newton's space itself.

There remain many other puzzling features on both sides of the argument. Indeed, as in any metaphysical debate in philosophy, the very terms in which the debate is being argued are highly problematic. Do we really understand what the substantivalist is claiming we must postulate in order to explain the observable phenomena? Do we really understand what the relationist is denying and what he is putting in its place? In particular, can we really fully understand on what the two approaches differ? I shall say just a little about these issues later.

Mach's Proposal and General Relativity

For the moment, though, let us return to the proposal of Mach that an alternative, relationistically acceptable, explanation of the famous inertial effects might be possible after all. Could we not assume that the inertial forces, and now the inertial optical effects as well, were the result of acceleration of the test apparatus not with respect to space itself or, in the relativistic case, with respect to the inertial geodesic structure of Minkowski spacetime but, rather, with respect to the cosmic matter of the universe? After all, in the theory of electromagnetism, we are familiar with magnetic forces that depend upon the velocities charged particles have with respect to one another. Could there not also be acceleration-dependent forces among bits of ordinary matter? If these forces depended very little on the separation of things from one another, but were highly dependent on the amounts of matter involved, couldn't it be possible to explain the inertial effects as the result of the acceleration of the test object with respect to what Mach called the "fixed stars," and what we would now speak of as the distant matter of the superclusters of galaxies that make up the cosmic matter of the universe?

Whereas special relativity doesn't provide a context suitable for Machian ideas, perhaps general relativity is more promising in this direction. After all, it deals with gravity, a long-range force. Newtonian gravity certainly couldn't provide the kind of long-distance, acceleration-dependent interaction Mach posited as responsible for the inertial effects, but perhaps when gravity is reconciled with relativity in the manner of the new curved spacetime theory of gravity, a Machian-type theory will result. Indeed, Einstein was certainly motivated by such hopes when he began the research that led to the general theory of relativity.

If Mach were right in positing that inertial effects are the result of the interaction of the test system with the remaining matter of the universe, what would be some consequences of this? First consider Newton's early remarks about what would happen in an empty universe. From the Newtonian point of view, a distinction between a spinning object and one not spinning should exist even if the test object were the only object in the universe. The spin would be revealed by the inertial effects on the test object generated by the absolute motion. Mach doubts that we should even think about empty universes. The universe is, he says, given to us only once, "complete with fixed stars intact." This might mean that we have no way of inferring from what we do observe to what would be the case in a radically different universe, or it might be the stronger claim that because the laws of nature are merely summaries of what does in fact occur in the world as it is, it is meaningless to talk about what would occur in a universe radically unlike

the actual one. Be that as it may, we can certainly ask of a theory like general relativity, which can describe gravity in many different kinds of possible worlds, if its predictions for an empty universe would, like Newton's, still make a distinction between absolutely rotating objects and objects not rotating, or whether that distinction would disappear in this world—without Mach's cosmic matter as the reference frame for absolute motion.

We would expect that in a Machian world the inertial effects generated on a test object would vary if the matter of the universe surrounding the object were radically modified, as the inertial effects are the result of interaction of test system and surrounding matter. Does the general theory of relativity predict that? It should make no difference if we spoke of an object in a Machian world rotating and the surrounding matter not or, instead, spoke of the matter rotating about the test laboratory, for, according to Mach, it is only the relative acceleration of test system and matter that determines the inertial forces detected. Is this what general relativity predicts? Finally, if Mach is right, it should be absurd to speak of the matter of the universe as itself in absolute rotation. If the effects of rotation in the test system are due to its motion relative to the cosmic matter, then it should be impossible for there to be effects owing to the cosmic matter itself's being in absolute rotation, for that would mean rotation of this matter with respect to itself, which is absurd. What does the general theory have to say about this?

Some early work with general relativity indicated Machian aspects of the theory. It is certainly true that what a test object in accelerated motion experiences will be dependent on the general distribution of matter in the universe, for in general relativity, absolute acceleration is deviation of motion from the local, curved, timelike geodesics of the spacetime. And because the overall curvature of the spacetime is correlated with the distribution of matter in the spacetime, radically changing the amount or distribution of cosmic matter will have an effect on inertial forces generated by local motion. Again, it can be shown in general relativity that an object that is itself at rest, but that is surrounded by matter in high rotation, will experience forces similar to those the test object would have experienced had it been put into rotation and the surrounding matter been at rest.

But if one looks further, the theory seems less and less one that Mach would have desired. Although inertial effects are modified by the changing distribution of external matter in the world, it is as though there was a basic inertial effect due to absolute rotation to which the new, modifying effects were added. In other words, even in a universe devoid of external matter, general relativity predicts a distinction between being in absolute rotation and not. To determine what spacetime is like in a general relativistic world requires the specification of boundary conditions for the spacetime, just as finding what an electrical field is like requires more than knowing what charges are present. The usual assumption made in general relativity, at least in open universes, is that spacetime far from matter is flat, Minkowski spacetime. A reasonable spacetime for an empty universe, then, would be just this flat, Minkowski spacetime of special relativity. But then, in such a world the old Newtonian distinction between the absolutely rotating and the not rotating would still hold up. Indeed, general relativity allows for even stranger empty spacetimes. Spacetime curvature has its own gravitational self-energy. So it is possible to have nonzero curvature in an empty universe, or for there to be regions of curved spacetime whose deviation from flatness is supported by no matter at all but simply by the self-energy of the curved spacetime region. Therefore, Mach's idea that in an empty world there would be no inertial effects doesn't hold up in general relativity.

Again, although matter spinning around an object generates inertial effects, the situation can be seen to deviate from what Mach would expect. If a test object is surrounded by two cylinders rotating with respect to each other and with respect to the test object, what one experiences in the laboratory will depend not only on the relative rotations involved but also on which cylinder is "really rotating," directly contrary to Machian expectations. Most dramatic of all was the discovery by K. Gödel that there are possible worlds consistent with general relativity in which all the matter of the universe is in rotation. It is not as if that matter were some gigantic, cosmic, spinning rigid sphere. That would be relativistically impossible. But in this world, an observer at any point whose laboratory was at rest with respect to the cosmic matter could perform an experiment to show himself that he was rotating along with all that matter. For each observer, there is a special plane. If the observer shoots out free particles or light rays along that plane, they follow spiral paths in the reference frame fixed in the cosmic matter. This indicates that this matter is in rotation, just as the path of a particle moving in a straight line out from the center over a phonograph record spinning on a turntable will mark a spiral groove on the record. So it is as if each observer could count himself as central to the spinning of the cosmic matter. For a Machian this seems absurd, but it is a possibility consistent with general relativity, once more revealing that theory's non-Machian aspects. (See Figure 2.10.)

Attempts to make general relativity more Machian exist. Some of the objections to a Machian interpretation of general relativity rest on the fact that the distribution of matter is not always sufficient to determine fully the structure of spacetime, hence, not adequate to determine fully what inertial effects of motion will exist. In universes that are always spatially closed, however, there is a tighter bond between the distribution of matter and spacetime structure, so that only one spacetime structure is compatible with the full distribution of matter. So, it has been proposed, the Machian version of general relativity is one where the spacetime has the appropriate closure. But this is a long way from Mach's hard-nosed relationism.

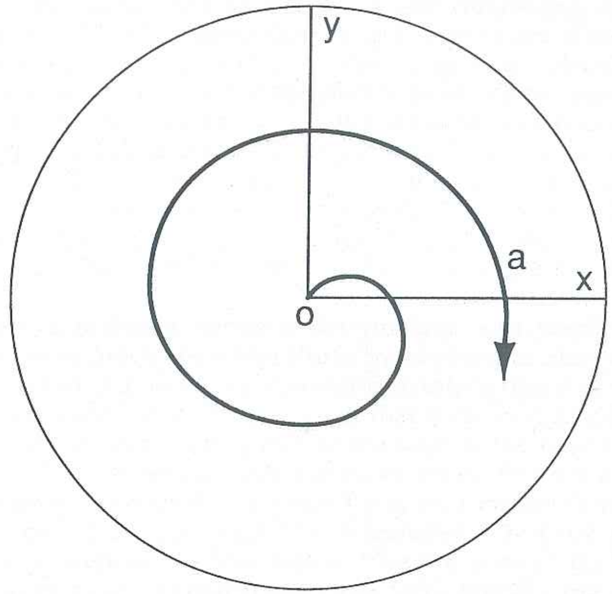

Figure 2.10 The absolute rotation of matter in the Gödel universe. In a solution to the equations of general relativity found by K. Gödel it is plausible to speak of the smoothed-out matter of the universe as being in "absolute rotation." What does this mean? At any point there is a plane with the following feature: Fix x and y coordinates in the plane so as to be at rest relative to the smoothed-out matter of the universe. Now send out from point o a free particle or light ray, a. In the coordinates at rest in the matter, the particle or light ray will trace out a spiral path as the particle or light ray moves away from o. If we think of the free particles and light rays as in straight-line motion relative to some "absolute" reference frame, it is "as if" the smoothed-out matter is rotating relative to that frame.

More on General Relativity and the Debate Between Substantivalists and Relationists

In fact there are aspects to the theory of spacetime in general relativity that make us begin to wonder whether the distinction between relationism and substantivalism, as they were traditionally understood, is coherent. We have noted that, in general relativity, the spacetime itself has mass-energy. But mass-energy is the characteristic basic aspect of matter as usually understood. Can we then talk about "relations among matter" versus "spacetime itself" if the distinction between matter and spacetime is itself problematic?

Even before the theory of general relativity presented the issues just discussed, it was clear that the distinction between substantivalism and relationism as traditionally understood was under stress. In the late nineteenth century, the concept of "the field" became essential in physics. In order to deal with the facts of electricity and magnetism, for example, it became necessary to add to the elements of nature items quite different from the material particles familiar from earlier physics. Entities such as the electric field are thought of as being extended over all space, with differing intensities at different spatial points. They have a dynamic evolution over time. Such physical "objects" as fields are essential to standard physical theory. But they are clearly a very different sort of thing from the localized material objects presupposed by the relationist. In many ways, they are more like the substantivalist's "space itself" than like ordinary material particles. When one considers how much one's view of what there is must change when fields are admitted into the physicist's picture of the world, it seems clear that the breakdown of the terms of the substantivalist-relationist debate had already begun with the introduction of field quantities into physics.

If we focus on a different aspect of general relativity, we see another way in which the existence of our fundamental theory of spacetime affects the traditional debate between substantivalists and relationists. The problem of determinism in physics is an enormously complex one. The eighteenth-century scientist P. S. de Laplace is famous for asserting that given the truth of the Newtonian mechanical picture of the world, a specification of the state of the world at one time determined its state at all future times, because the laws of nature generated from that state all the necessarily following states at later times. But everything about the issue of whether he was right, whether the world is really deterministic, becomes complex and problematic.

To begin with, there are some philosophical problems. As B. Russell pointed out, if we let the notion of "state of the world" be broad enough and the notion of "law of nature" be flexible enough, then determinism becomes a trivial doctrine, for no matter what the world was like, we could simply take the laws to be the statements saying which actual states followed which others. Let us suppose we have some way of avoiding such trivializations by demanding that genuine laws meet some stricter constraints. Many scientific problems come next. Even in Newtonian mechanics, there are problems with determinism. If we deal with point particles whose strength of interaction gets unlimited as the particles approach a zero separation, it becomes impossible to follow states deterministically through collisions of the particles. Again if we specify the world at a given time, the future may be influenced by a particle that "comes in from infinity" after that time, blocking the determination of the future by the full state at the time in question.

When we move first to special and then to general relativity with their new spacetimes, many more-complex issues arise. States of the world "at a time" are a relative matter in special relativity. In general relativity, it may not even be possible to slice up the spacetime of the world into "spaces at a time," so that the very notion of the state of the world everywhere at one time may no longer make sense. The pattern of possible causal influence in these theories is, of course, more complex than it was in the Newtonian theories, and the complexity of

the causal structure leads to important and interesting mathematical problems of trying to characterize which worlds are deterministic in which senses one can give to the term. In general relativity, another problem arises because of the possibility (and, often, inevitability) of singularities in the spacetime. The Big Bang at which our spacetime universe started (if it exists) is one such singularity, as would be those at the center of so-called black holes. These singularities are points of spacetime where curvature becomes infinite. Their presence in a spacetime blocks the ability to predict through them from earlier to later states of the world. Thus they introduce a form of indeterminism into the picture.

The very connection between determinism and predictability, assumed to mean much the same thing by Laplace, is also problematic. Does saying that the world is deterministic imply that it is predictable, at least in principle? Many have argued that such an implication doesn't hold. After all, determinism says that the state of the world at one time fixes, by the laws of nature, states at other times. But if we can't know the full state of the world at a given time, as a matter of fundamental principle, then the world might be deterministic but not predictable. Minkowski spacetime has this nature. The full state of the world on a space (relative to an inertial frame) may very well fix the state of the world on later spaces. But for any given observer, it may be the case that he will never be able to accumulate the information about the state of the world on any entire space-at-a-time, because the information he gets is what can causally reach him from the past, and this is restricted to what falls inside his backward light cone. That is, he can only gain information about events in the past that can be connected to him at the present by causal signals from the past. For this reason and, we shall see, for others as well, too immediate an identification of determinism with predictability is naive. However, if determinism and predictability are unconnected entirely, it becomes hard to solve the problem Russell posed for us of finding a way of restricting what can count as state and law so that the issue of determinism doesn't reduce to triviality.

In Chapter 3 we will return to the subject of determinism. There we will look at how the sensitivity of the development of a system to its exact initial conditions has led some to deny determinism in the world. What kind of deterministic world is it if even an infinitesimal change in the initial state of a system can lead to vast changes in its future development? In Chapter 4 we will explore some of the issues of determinism and indeterminism that arise in the even more radical context of quantum mechanics. There we will see why some have alleged that if quantum mechanics truly describes the world, determinism must be radically false.

But for the moment, I want to focus on an argument concerning determinism in the general theory of relativity, an argument designed to support a kind of Leibnizian relationism by claiming that if we interpret general relativity in a fully substantivalist way, we must take it to be an indeterministic theory—whose indeterminism is strikingly peculiar. Some of Leibniz's most telling arguments against substantivalism relied upon the supposition that each point of space was just like every other and each direction in space like any other. So the material world displaced in space from where it actually was would be qualitatively identical with the world the way it is. There would be no sufficient reason for it to be in one place in space rather than another. And the world would appear exactly the same to any observer, no matter where the material world was in space.

This is no longer true in general relativity, for spacetime can now have a structure that varies from place and time to place and time. Shifting the ordinary matter through spacetime would make a big difference in a world where curvature (the gravitational field) varied from spacetime location to spacetime location. But something like a Leibnizian argument can be reconstructed in which the shift of matter through spacetime is accompanied by a compensating shift in the spacetime structure itself.

A consequence of this is a problem noted by Einstein and called the "hole" problem. Let a small region of spacetime be empty of matter. Let the matter distribution and spacetime structure outside the region be anything you like. Then spacetime structures that appear to be distinct from each other in the hole are equally compatible, according to the laws of general relativity, with the nonexistence of matter in the hole and the distribution of matter and spacetime outside it. There is a way of reading this result that tries to explain it away as just saying that the structure in the hole can be described in terms of alternative coordinate systems. But if we take spacetime point locations seriously, surely part of the substantivalist reading of the theory, there is a way of reading this result that says that no matter how small the hole is, there are genuinely different spacetime structures in it compatible with the surrounding spacetime and matter structure. This is the new kind of indeterminism that, it is alleged, gets thrust upon one if one sticks to the substantivalist reading of the new theory of spacetime.

Clearly the discussion is not at an end. We have a long way to go before we have sorted out what the many distinct issues are between relationists and substantivalists of various sorts. And there are many aspects of the current physical theories of spacetime that must also be better understood. Until both the philosophical and the physical sides of the issues are made clearer and more precise, it will be impossible to say just what metaphysical reading best fits what current physics tells us about the space and time of the world. The issues here are important, for the theoretical arguments that underlie the critique of substantivalism and the advocacy of relationism, and the opposition to these arguments on the part of the substantivalist, are used in similar forms in other philosophical debates.

Summary

We have now seen that the problem of the kind of "being" to attribute to space and time has a rich history and a rich future. The basic metaphysical issues themselves have a complex and long-developing structure. Whether we are to view space, for example, as a substance existing over and above the material contents of the world, a set of relations among the material objects of the world, or something else entirely remains an open question. We have also seen that the issue of whether there is any sense in which spatiality or temporality is reducible to some other aspect of the world, such as a causal aspect, is also unanswered. Most important, we have seen that each revolutionary scientific advance in our understanding of space and time brings with it a new context in which the philosophical debates take place. Although the scientific achievements cannot by themselves fully resolve the metaphysical issues, any adequate philosophical treatment of the nature of space and time must do full justice to these scientific accomplishments.