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TIME

Time has frequently struck philosophers as mysterious. Some have even felt that it was incapable of rational discursive treatment and that it was able to be grasped only by intuition. This defeatist attitude probably arises because time always seems to be mysteriously slipping away from us; no sooner do we grasp a bit of it in our consciousness than it has slipped away into the past. This entry will argue, however, that this notion of time as something that continually passes is based on a confusion.

ST. AUGUSTINE'S PUZZLES

The apparent mysteriousness of time can make puzzles about time seem more baffling than they are, even though similar ones arise in the case of nontemporal concepts. St. Augustine, in his *Confessions*, asks, "What is time?" When no one asks him, he knows; when someone asks him, however, he does not know. He knows how to use the word "time" and cognate temporal words, such as "before," "after," "past," and "future," but he can give no clear account of this use. Trouble arises particularly from the form in which he puts his question: "What is time?" This looks like a request for a definition, and yet no definition is forthcoming. However, most interesting concepts cannot be elucidated by explicit definitions. Thus, to explain the meaning of the word "length," we cannot give an explicit definition, but we can do things that explain how to tell that one thing is longer than another and how to measure length. In the same way, it is possible to give an account of the use of the word "time" even though it is not possible to do so by giving an explicit definition. In short, this puzzle of St. Augustine's is not of a sort that arises peculiarly in the case of time. Beyond pointing this out, therefore, it is not appropriate here to go further into the matter.

Augustine was also puzzled by how we could measure time. He seems to have been impressed by the lack of analogy between spatial and temporal measurement. For example, one can put a ruler alongside a tabletop, and the ruler and the tabletop are all there at once. However, if one were to measure a temporal process, it would be done by comparing it with some other process, such as the movement of the hand of a watch. At any moment of the comparison, part of the process to be measured has passed away, and part of it is yet to be. It is not possible to get the thing to be measured in front of a person all at once, as one could with the tabletop. Moreover, if two temporal processes are compared—say, a twenty-mile walk last week with a twenty-mile walk today—they are compared with two different movements of a watch hand, whereas two different tabletops are compared with the same ruler. Augustine is led to see a puzzle here because he demands, in effect, that non-analogous things should be talked about as though they were analogous.

In any case, the two things are not, in fact, as non-analogous as they appear to be at first sight. If we pass to a tenseless idiom in which material things are thought of as four-dimensional space-time solids, the difference becomes less apparent. For in the case of the tables we compare two different spatial cross sections of the four-dimensional object that is the ruler with spatial cross sections of the two tables. Augustine seems to have been influenced by the thought that the present is real, although the past and future are not (the past has ceased to exist, and the future has not yet come to be); consequently, the measurement of time is puzzling in a way in which the measurement of space need not be (where the whole spatial object can be present now). This thought—that the present is real in a way in which past and future are not real—is part of the confusion of the flow or passage of time. This is not to say that presentism has not recently been intelligently defended, however implausibly, as by John Bigelow (1996). Apodeictic proof has rarely been possible in metaphysics, and we fall back eventually on trading plausibilities. One of the central objections to presentism is the difficulty it has in analyzing cross-temporal statements such as "Smith will have come before you have finished breakfast." Perhaps the most important objection relates to the explanatory value of four-dimensional space-time in relativity theory to be discussed below.

THE MYTH OF PASSAGE

We commonly think of time as a stream that flows or as a sea over which we advance. The two metaphors come to much the same thing, forming part of a whole way of thinking about time that D. C. Williams has called "the myth of passage"(Williams 1951). If time flows past us or if we advance through time, this would be a motion with respect to a hypertime. For motion in space is motion with respect to time, and motion of time or in time could hardly be a motion in time with respect to time. Ascription of a metric to time is not necessary for the argument, but supposing that time can be measured in seconds, the difficulty comes out clearly. If motion in space is feet per second, at what speed is the flow of time? Seconds per what? Moreover, if passage is of the essence of time, it is presumably the essence of hypertime, too, which would lead one to postulate a hyper-hypertime and so on ad infinitum.

The idea of time as passing is connected with the idea of events changing from future to past. We think of events as approaching us from the future, whereupon they are momentarily caught in the spotlight of the present and then recede into the past. Yet in normal contexts it does not make sense to talk of events changing or staying the same. Roughly speaking, events are happenings to continuants—that is, to things that change or stay the same. Thus, we can speak of a table, a star, or a political constitution as changing or staying the same. But can we intelligibly talk of a change itself as changing or not changing?

It is true that in the differential calculus we talk of rates of change changing, but a rate of change is not the same thing as a change. Again, we can talk of continuants as coming into existence or ceasing to exist, but we cannot similarly talk of a "coming-into-existence" itself as coming into existence or ceasing to exist. It is nevertheless true that there is a special class of predicates, such as "being past," "being present," "being future," together with some epistemological predicates such as "being probable" or "being foreseen," with respect to which we can talk of events as changing. Significantly enough, these predicates do not apply to continuants. We do not, for example, naturally talk of a table or a star as "becoming past" but of its "ceasing to exist." There is something odd about the putative properties of pastness, presentness, futurity, and the like, whereby events are supposed to change. One might conjecture that the illusion of the passage of time arises from confusing the flow of information through our short-term memories with a flow of time itself.

TOKEN-REFLEXIVE EXPRESSIONS. Leaving aside the epistemological predicates, we may suspect that the oddness arises because the words "past," "present," and "future," together with "now" and with tenses, are token-reflexive, or indexical, expressions. That is, these words refer to their own utterance. If italics are allowed to indicate tenselessness in a verb, then if one says, "Caesar *crosses* the Rubicon," the speaker does not indicate whether the crossing is something before, simultaneous with, or after the assertion. Tenseless verbs occur in mathematics where temporal position relative to a person's utterance is not even in question. Thus, we can say, "2 + 2 *is* equal to 4" not because we wish to be noncommittal about the temporal position of 2 + 2 as being 4 but because it has no temporal position at all.

The token-reflexiveness (or more generally the indexicality) of the word "past" can be seen, for example, if a person who said that a certain event *E* is past could equally well have said, "*E is* earlier than this utterance." Similarly, instead of saying, "*E* is present," he could say, "*E is* simultaneous with this utterance," and instead of "*E* is future," he could say, "*E is* later than this utterance." The phrase "*E* was future" is more complicated. It means that if someone had said, "*E* is future" or "*E is* later than this utterance," at some appropriate time earlier than the present utterance (the utterance which we now refer to as "this utterance"), he would have spoken truly. Thus, if we say that in 1939 the battle of Britain was in the future, we are putting ourselves into the shoes of ourselves as we were in 1939, when, given a certain amount of prescience, we might have said truly, "The battle of Britain *is* later than this utterance." Apart from this imaginative projection, we are saying no more than that the battle of Britain *is* later than 1939. Another way of dealing with this problem, one that is preferred by Michael Tooley (1997) would be to interpret the token reflexive expressions as referring not to utterances but to times of utterance.

It follows that there is a confusion in talking of events as changing in respect of pastness, presentness, and futurity. These are not genuine properties, which can be seen if the token-reflexiveness is made explicit. "*E* was future, is present, and will become past" goes over into "*E is* later than some utterance earlier than this utterance, *is* simultaneous with this utterance, and *is* earlier than some utterance later than this utterance." Here the reference is to three different utterances. However, if we allow simultaneity, being later, and being earlier as relations to times as well as events we could render the tensed sentence above by saying, "*E is* later than some time earlier than this utterance, *is* simultaneous with this utterance, and *is* earlier than some time later than this utterance." Also, the troubling sentence "Once there were no utterances" could go over to "There *are* times earlier than this utterance when there were no utterances." A failure to recognize the direct or indirect indexicality of words such as "past," "present," and "future" can lead us to think wrongly of the change from future to past as a genuine change, such as the change in position of a boat that floats down a river.

Nevertheless, there is probably a deeper source of the illusion of time flow. This is that our stock of memories is constantly increasing, and memories are of earlier, not of later, events. It is difficult to state this matter properly because we forget things as well as acquire new memories. With a very old man there may well be a net diminishing of his stock of memories, and yet he does not feel as if time were running the other way. This suggestion is therefore tentative and incompletely worked out. Possibly we confuse a flow of information through our short-term memories with a flow of time itself (Smart 1987). The subordinate question of why our memories are of the past, not of the future, is an extremely interesting question in its own right and will be answered in a later section.

TENSES. Not only words such as "past" and "future" but also tenses can be replaced by the use of tenseless verbs together with the phrase "this utterance." Thus, instead of saying, "Caesar crossed the Rubicon," we could have said, "Caesar *crosses* the Rubicon earlier than this utterance." For the present and future tenses we use "simultaneous with this utterance" and "later than this utterance." Of course, this is not a strict translation. If one person says, "Caesar *crosses* the Rubicon earlier than this utterance," that person refers to his utterance, whereas if another person says, "Caesar crossed the Rubicon," she is implicitly referring to her utterance. Nevertheless, a tensed language is translatable into a tenseless language in the sense that the purposes subserved by the one, in which utterances covertly refer to themselves, can be subserved by the other in which utterances explicitly refer to themselves.

A second qualification must be made. In the case of spoken language the token or "utterance" can be taken to be the actual sounds. In a written language the "token," the configuration of ink marks, is something that persists through time. By "this utterance" we must therefore, in the case of written language, understand the coming-into-existence of the token or perhaps the act of writing it. It has sometimes been objected that this account will not stand because "this utterance" means "the utterance which is *now*," which reintroduces the notion of tense. There does not seem to be any reason, however, why we should accept this charge of circularity. We have as good a right to say that "now" means "simultaneous with this utterance" as our opponent has to say that "this utterance" means "the utterance which is now." The notion of an utterance directly referring to itself does not seem to be a difficult one.

Tenses and their cognates may be seen to be indexical expressions. The truth conditions of sentences containing them cannot be given by translation into a nonindexical language. Nevertheless they can be given in a nonindexical *metalanguage*. The idea derives from Donald Davidson and is advantageous because there is a recursively specifiable infinity of sentences in a language but not of utterances or inscriptions. Equally with the token reflexive account it removes the mystery that one might feel about tenses and cognate expressions.

Tensers, such as Quentin Smith (1993), argue that the words "past," "present" and "future" refer to intrinsic properties of events, though Smith defines "past" and "future" in terms of "present." This makes him in a sense a presentist, though only a mild one as he does not deny the reality of the past and future. Davidson's suggestion for the semantics of tenses is to say that (say) "I will come" is true as (potentially) spoken by person *P* at time *t* if and only if *P comes* later than *t*. As Heather Dyke, in her doughty defense of the token-reflexive approach (Dyke 2002, 2003), has remarked, without the "potentially" (of which critics of modal logic may be suspicious) the Davidsonian schema comes out trivially true in cases where (say) "I will come" is not uttered by *P* at *t*. Perhaps one might reply that trivial truth is still truth and so harmless, or one might treat the Davidsonian schema as an idealization. Dyke has urged that one should abandon aspirations of the old token reflexive theory for a translation of tensed sentences into tenseless ones but argue that a tensed sentence states the same fact about the world as can be stated by a tenseless one. Thus she wants a semantics based on tokens of sentences, not sentences, and so abandons recursiveness. A similar appeal to the notion of "fact" is made by D. H. Mellor in his influential *Real Time II* (1998), where he says that ontology can be separated from considerations of semantics. Of course this metaphysical notion of "fact" has been thought problematic, as by Davidson himself. Nevertheless, the difference between the token reflexive account and the metalinguistic one is not of great ontological significance. Dyke contests arguments by Quentin Smith (1993), who has been an immensely prolific defender of the tensed notion of time.

DURATION. The philosophical notion of duration seems to be heavily infected with the myth of passage. Thus John Locke in his *Essay concerning Human Understanding* (1690) says that "duration is fleeting extension" (bk II, ch. 14, paragraph 1). In the early nineteenth century, Henri Bergson (1910, 1911, 1913) made the notion of duration (*durée*) central in his philosophy. According to him, physical time is something spatialized and intellectualized, whereas the real thing, with which we are acquainted in intuition (inner experience), is duration. Unlike physical time, which is always measured by comparing discrete spatial positions—for example, of clock hands—duration is the experienced change itself, the directly intuited nonspatial stream of consciousness in which past, present, and future flow into one another. Bergson's meaning is unclear, partly because he thinks that duration is something to be intuitively—not intellectually—grasped. Duration is closely connected in his thought with memory, for in memory, Bergson says, the past survives in the present. Here he would seem to be open to the objection, urged against him by Bertrand Russell in his *History of Western Philosophy* (1945), that he confuses the memory of the past event with the past event itself, or the thought with that which is thought about.

Even though the Bergsonian notion of duration may be rejected because of its subjectivism and because of its close connection with the notion of time flow or passage, there is nevertheless a clear use of the word "duration" in science and ordinary life. Thus, in talking about the duration of a war, we talk simply about the temporal distance between its beginning and its end.

MCTAGGART ON TIME'S UNREALITY. The considerations thus far adduced may well be illustrated by considering how they bear on John McTaggart Ellis McTaggart's well-known argument for the unreality of time, which was put forward in an article in *Mind* (1908) and in his posthumous *Nature of Existence* (1927). For McTaggart, events are capable of being ordered in two ways. First, they can be ordered in respect to past, present, and future. He calls this ordering of events "the *A* series." Second, events can be ordered in respect to the relations "earlier than" and "later than." He calls this "the *B* series." McTaggart then argues that the *B* series does not by itself give all that is essential to time and that the *A* series is contradictory. Neither leg of his argument can stand criticism. His reason for saying that the *B* series misses the essence of time is that time involves change and yet it always is, was, and will be the case that the Battle of Hastings, say, is earlier than the Battle of Waterloo. It has already been shown, however, that it is not just false but also absurd to talk of events' changing. The Battle of Hastings is not *sempiternally* earlier than the Battle of Waterloo; it simply *is* (tenselessly) earlier than it. The notion of change is perfectly capable of being expressed in the language of the *B* series by saying that events in the *B* series *differ* from one another in various ways. Similarly, the proposition that a thing changes can be expressed in the language of the *B* series by the statement that one spatial cross section of it *is* different from an earlier one, and the proposition that it does not change can be expressed by saying that earlier and later cross sections *are* similar to one another. To express the notion of change, we are therefore *not* forced to say that events change. Nor, therefore, are we forced into referring to the *A* series, into saying that events change (in the only way in which we can plausibly say this) in respect to pastness, presentness, and futurity.

Nevertheless, if we do retreat to the language of the *A* series, we can perfectly well do so without contradiction. Just as McTaggart erred by using tensed verbs when talking of the *B* series, he in effect made the correlative error of forgetting tenses (or equivalent devices) when talking of the *A* series. For the contradiction that he claimed to find in the *A* series is that because any event is in turn future, present, and past, we must ascribe these three incompatible characteristics to it; but an event cannot be future, present, or past *simpliciter* but only with reference to a particular time—for example, one at which it was future, is present, and will be past. If we restore the tenses, the trouble with the *A* series disappears. Unsuccessful though McTaggart's argument is, it provides an excellent case study with which to elucidate the relations between tensed and tenseless language.

SPACE-TIME

The theory of relativity illustrates the advantages of replacing the separate notions of space and time by a unified notion of space-time. In particular, Minkowski showed that the Lorentz transformations of special relativity correspond to a rotation of axes in space-time. He showed how natural the kinematics of special relativity can seem, as opposed to Newtonian kinematics, in which, in effect, we should rotate the time axis without correspondingly rotating the space axes. Since the theory of relativity it has become a commonplace to regard the world as a four-dimensional space-time manifold. Nevertheless, even in the days of Newtonian dynamics, there was nothing to prevent taking this view of the world, even though it would not have been as neat as it is in relativity theory. If we pass to the four-dimensional way of looking at things, it is important not to be confused about certain conceptual matters. Confusion will arise if the tenseless way of talking, appropriate to the four-dimensional picture, is mixed with our ordinary way of talking of things as enduring substances, "the permanent in change."

In ordinary language the word "space" itself is used as the name of a continuant. We can say, for example, that a part of space has become, or has continued to be, occupied. Space-time, however, is a "space" in a tenseless sense of this word, and because time is already in the representation, it is wrong to talk of space-time as itself changing. Thus, in some expositions of relativity it is said that a certain "world line" is a track along which a material body moves or a light signal is propagated. The body or light signal, however, cannot correctly be said to move through space-time. What should be said is that the body or the light signal *lies* (tenselessly) along the world line. To talk of anything's moving through space-time is to bring time into the story twice over and in an illegitimate manner. When we are talking about motion in terms of the space-time picture, we must do so in terms of the relative orientations of world lines. Thus, to say that two particles move with a uniform nonzero relative velocity is expressed by saying that they *lie* (tenselessly) along straight world lines that are at an angle to one another. Similarly, the recent conception of the positron as an electron moving backward in time is misleading because nothing can move, forward or backward, in time. What is meant is that the world lines of a positron and electron, which are produced together or which annihilate one another, can be regarded as a single bent world line, and this may indeed be a fruitful way of looking at the matter.

In popular expositions of relativity we also read of such things as "consciousness crawling up the world line of one's body." This is once more the confusion of the myth of passage and, hence, of the illegitimate notion of movement through space-time. It is instructive to consider how H. G. Wells's time machine could be represented in the space-time picture. A moment's thought should suffice to indicate that it cannot be represented at all. For if a line is drawn extending into the past, this will simply be the representation of a particle that has existed for a long time. It is not surprising that we cannot represent a time machine because the notion of such a machine is an incoherent one. How fast would such a machine flash over a given ten-second stretch? In ten seconds or minus ten seconds? Or what? No sensible answer can be given, for the question is itself absurd. The notion also involves the contradiction, pointed out by D. C. Williams in his article "The Myth of Passage" (1951) that if a person gets into a time machine at noon today, then at 3 a.m., say, that person shall be *both* at 3 p.m. today *and* at, say, a million years ago. There is nevertheless a more consistent notion of time travel though misleadingly so called. A person as a space-time entity might lie along a bent-back world line. It might curve back and then would go back to your great grandmother's time and then a bit forward while you saw your great grandmother. Paradox lurks because if the great grandmother had been shot you would not have existed. David Lewis has proposed a banana skin solution. Since you could not have shot your great grandmother some accident, such as your slipping on a banana skin or your pistol jamming, must have prevented you from harming her. One would wish, however, for a solution of the paradox by reference to the laws of nature.

Though D. H. Mellor ably defends the four-dimensional ontology in his *Real Time II*, he nevertheless says something that may puzzle four-dimensionalists—for example, that a person from birth to death, or a stone over a long period of time, is said to have a certain property at time *t*, but not that a mere time slice or temporal stage of the person or stone has the property. The puzzle is perhaps resolved if we note that Mellor thinks of the thing S as reidentifiable or a sortal as discussed by Peter Strawson. This is understandable because a child could hardly—and an adult could not easily—reidentify the mereological fusion of a bird, a bishop, and Mount Everest. Even so, the four-dimensionalist need not discern a difference between "S is A at *t*" and "S at *t* is A." The time slice may be referred to by reference to the salient four-dimensional object of which it is a slice. Mellor rightly stresses the importance for agency and practical matters of notions of reidentifiable sortals and for the determination of the strengths of beliefs and desires by a method originally due to F. P. Ramsey.

ABSOLUTE AND RELATIONAL THEORIES

Isaac Newton held to an absolute theory of space and time, whereas his contemporary Gottfried Wilhelm Leibniz argued that space and time are merely sets of relations between things that are in space and time. Newton misleadingly and unnecessarily expressed his absolute theory of time in terms of the myth of passage, as when he confusingly said, "Absolute, true and mathematical time, of itself and from its own nature, flows equably without relation to anything external" (*Principia,* in the Scholium to the Definitions of *Mathematical Principles of Natural Philosophy*). The special theory of relativity has made it impossible to consider time as something absolute;

rather, it stands neutrally between absolute and relational theories of space-time. The question as between absolute and relational theories of space-time becomes especially interesting when we pass to the general theory of relativity. According to this theory, the structure of space-time is dependent on the distribution of the matter in the universe. In most forms of the theory there is nevertheless a residual space-time structure that cannot be thus accounted for. A curvature is usually attributed to space-time even in the complete absence of matter, and the inertia of a body, according to this theory, depends in part on this cosmological contribution to the local metrical field and hence not solely on the total mass of the universe, as a purely relational theory would require.

Research on this question is still going on, and until it has been decided, Mach's principle (as Einstein called it), according to which the spatiotemporal structure of the universe depends entirely on the distribution of its matter, will remain controversial. But even if Mach's principle were upheld, it might still be possible to interpret matter, in a metaphysical way, as regions of special curvature of space-time. Graham Nerlich (1994) has given a striking and simple argument against those who, like Leibniz, defend relational theories by asking how one could tell whether everything had not doubled in size. He pointed out that this depends on the assumption that space is Euclidean. Relational theorists usually make the relevant relation that of cause and effect. If this is defined by the use of counterfactual propositions one may object that the murkiness or contextual nature of these contrasts with the absolute theory's reliance on the limpid clarity of geometry. Here I use "absolute" to contrast with 'relational' not as contrasted with "relativistic." An objection to a causal theory of time is that there could be uncaused events and that there are uncountably more space-time points than there are events. Michael Tooley separately assumes an ontology and topology of instants of time, but uses a causal theory to define temporal direction.

TIME AND THE CONTINUUM

An absolute theory of space-time, as envisaged above, need not imply that there is anything absolute about distance (space-time interval). Because of the continuity of space-time, any space-time interval contains as many space-time points as any other (that is, a high infinity of them); space and time do not possess an intrinsic metric, and there must always be an element of convention in definitions of congruence in geometry and chronology, as Adolf Grünbaum has pointed out (Grünbaum1973). This means that the same cosmological facts can be expressed by means of a variety of space-time geometries, provided that they have the same topological structure. (Topology is that part of geometry which treats only of those properties of a figure which remain the same however that figure is transformed into a new one, with the sole restriction that a point transforms into one and only one point and neighboring points transform into neighboring ones. Thus, the surface of a sphere and that of a cube have the same topology, but that of a sphere and that of an infinite plane do not.)

ZENO AND CANTOR. The continuity of space and time can be properly understood only in terms of the modern mathematical theory of infinity and dimensionality. Given the concepts available to him, Zeno rightly rejected the view that an extended line or time interval could be composed of unextended points or instants. (See Aristotle, *Physics* 231a20–231bl8 and *De Generatione et Corruptione*, 316al5–317al7.)

In modern terms it may be said that not even a denumerable infinity of points can make up a nonzero interval. Cantor has shown, however, that there are higher types of infinity than that which belongs to denumerable sets, such as the set of all natural numbers. Cantor showed that the set of real numbers on a line, or segment of a line, is of a higher type of infinity than is the set of natural numbers. Perhaps the right cardinality of "dimensionless points" *can* add up to a nonzero length. This answer is on the right track. Nevertheless, the cardinality of a set of points does not by itself determine dimensionality.

For example, Cantor showed that there is a one-to-one mapping between the points of a plane and the points of a line. However, a mathematical theory of dimension has been developed that accords with our intuitions in assigning 0, 1, 2, 3, and so on, dimensions respectively to points, lines, planes, volumes, and so on, and which also assigns dimensions to other sorts of sets of points. For example, the set of all rational points on a line has dimension 0. So does the set of all irrational points. In these cases an infinity of "unextended points" does indeed form a set of dimension 0. Because these two sets of points together make up the set of points on a line, it follows that two sets of dimension 0 can be united to form a set of dimension 1. Strictly speaking, it is even inaccurate to talk of "unextended points." It is sets of points that have dimension. A line is a set of points, and the points are not parts of the line but members of it. The modern theory of dimension shows that there is no inconsistency in supposing that an appropriate nondenumerable infinity of points makes up a set of greater dimensionality than any finite or denumerable set of points could.

The theory of the continuum implies that if we take away the lower end of a closed interval, what is left is an open interval, an interval without a first point. In fact, Zeno's premises in his paradox of the dichotomy do not lead to paradox at all but are a consistent consequence of the theory of the continuum. Motion is impossible, according to the paradox of the dichotomy, because before one can go from *A* to *B*, one must first get to the halfway mark *C*, but before one can get to *C*, one must get to the halfway mark *D* between *A* and *C*, and so on indefinitely. It is concluded that the motion can never even get started. A similar argument, applied to time intervals, might seem to show that a thing cannot even endure through time. The fallacy in both cases comes from thinking of the continuum as a set of points or instants arranged in succession. For if a continuous interval had to consist of a first, second, third, and so on point or instant, then the dichotomy would provide a fatal objection. However, points or instants do not occur in succession, because to any point or instant there is no *next* point or instant. Such considerations enable us to deal with Zeno's paradox of Achilles and the tortoise, in which similar difficulties are supposed to arise at the *latter* end of an open interval.

KANT'S ANTINOMIES. A related paradox is Kant's first antinomy, in his *Critique of Pure Reason* (1929 [1781]). As was shown by Edward Caird (1889) in his commentary on Kant's *Critique*, the antinomies (or paradoxes which Kant had constructed about space, time, and causality) were as important as Hume's skeptical philosophy in arousing Kant from his "dogmatic slumbers." Kant's first antinomy relates to both space and time; the concentration here is on *Critique* as it relates to time. There are two antithetical arguments. The first states that the world had a beginning in time, whereas the second, with equal plausibility, seems to show that the world had no beginning in time. The first argument begins with the premise that if the world had no beginning in time, then up to a given moment an infinite series of successive events must have passed. But, says Kant, the infinity of a series consists in the fact that it can never be completed. Hence, it is impossible for an infinite series of events to have passed away.

It can be seen that Kant's argument here rests partly on the myth of passage. Kant thinks of the world as having come to its present state through a series of past events, so that an infinite succession would therefore have had to be completed. Otherwise, he would have been just as puzzled about the possibility of an infinite future as about an infinite past, and this does not seem to have been the case. Just as the sequence 0, 1, 2 … can never be completed in the sense that it has no last member, the sequence ——, –2, –1, 0 cannot be completed in the sense that it has no first member. This is not to say, of course, that an infinite set need have either a first or last member. Thus, the set of temporal instants up to, but not including, a given instant, has neither a first nor last member. However, Kant is clearly thinking not of the set of instants but of a sequence of events, each taking up a finite time. The set of instants does not form a sequence because there are no instants that are next to one another. Kant's definition of infinity, besides being objectionably psychologistic, is clearly inapplicable to infinite sets of entities which do not form a sequence, such as the points on a line or a segment of a line. Concerning an infinite set of events which form a sequence, however, Kant is not justified in supposing that its having a last member is any more objectionable than its having a first member. There is a perfect symmetry between the two cases once we rid ourselves of the notion of passage—that is, of the one-way flow of time.

In Kant's antithetical argument, he argues that the world cannot have had a beginning in time, so that, contrary to the thesis of the antinomy, there must have been an infinity of past events. His reason is that if the world had begun at a certain time, all previous time would have been a blank and there would be no reason that the world should have begun at the time it did rather than at some other time. Previously, Leibniz had used the same argument to support a relational theory of time. If time is constituted solely by the relations between events, then it becomes meaningless to ask questions about the temporal position of the universe as a whole or about when it began. In an absolute theory of time (or of space-time) Kant's problem remains, but further discussion of it cannot be pursued here because it would involve a metaphysical discussion of causality and the principle of sufficient reason.

TEMPORAL ASYMMETRY

We have just seen that Kant was puzzled about the infinity of the past in a way in which he was not puzzled about the infinity of the future. Further, it has been suggested that the myth of passage had something to do with this inconsistency. If we reject the notion of passage, we find ourselves with a new, though soluble, problem. This is the apparent temporal asymmetry of the universe, which contrasts sharply with its large-scale spatial symmetry. For example, if we look out at the galaxies, they appear to be distributed evenly in all directions, and yet a time direction seems to be specified by the fact that they are all receding from one another, not approaching one another. On a more mundane level, the temporal asymmetry of the universe is forcibly striking in many ways. For example, there is nothing in our experience analogous to memory but with respect to the future. Nor is there anything like a tape recording or a footprint of the future—that is, there are no *traces* of the future. A memory is indeed a special case of a trace. This asymmetry about traces explains how we can be so confident about the past history of the human race and about the past evolution of living creatures, whereas it would be a bold person who would try to guess the political history of even the next hundred years or the organic evolution of the next few millions. The question "Why are there traces only of the past, not of the future?" is thus a fundamental one.

We must first rule out a purely verbalistic answer to this question. Someone might say that traces are always of the past, never of the future, because it is part of the meaning of the word "trace" that traces are of earlier, not of later, events. This would be to suppose that the earlier question is as stupid as the question "Why are bachelors always male, never female?" This account of the matter is not good enough. Admittedly, in the English language as it is, the expression "female bachelor" is a self-contradictory one. Nevertheless, it is easy to imagine a variant of English in which "bachelor" simply meant "not yet married person" and according to which spinsters could therefore be called "bachelors." For example, if one were to call a spinster a "female analogue" of a bachelor, then it is possible to silence the verbalistic objection to the question about why traces are always of the past, never of the future, by recasting it in the form "Why are there no future analogues of traces?"

TEMPORAL ASYMMETRY AND PHYSICAL LAWS. The temporal directionality of the universe or, at the very least, of the present cosmic era of the universe would therefore appear to be a deep-lying cosmological fact, which is not to be glossed over by verbalistic explanations. How is it to be explained? We must first dismiss the suggestion that the asymmetry lies in the laws of physics. The laws of classical dynamics and electromagnetism, as well as of quantum mechanics, are all expressed by time-symmetrical differential equations. In other words, if $f(t)$ is a solution to these equations, so is $f(-t)$. (Actually to take care of recondite matters, twenty-first century physicists believe not in T symmetry but in CPT symmetry, reversal of time, reversal of charge, and reversal of parity. P symmetry can be thought of as reversal in a space mirror just as C symmetry is a matter of thinking of an antiparticle as a backwards-in-time particle. So CPT symmetry can be thought of as a deeper form of space-time symmetry.)

It follows that if a cinematographic film were taken of any process describable by means of these laws and then run backward, it would still portray a physically possible process. It is true that phenomenological thermodynamics would provide a contrary case, because its second law does contain time explicitly. Thus, if someone put a kettle full of ice on a hot brick, that person finds that the system turns into one in which a kettle full of water sits on a cool brick. A film of this process cannot be reversed to show a process which is possible in phenomenological thermodynamics; we cannot have a system of a kettle filled with water on a cool brick turning into one in which the water has frozen and the brick has become hot. In spite of all this it must still be asserted that the laws of nature are time symmetrical. This is because phenomenological thermodynamics provides only an approximation of the truth (it is refuted by the phenomenon of Brownian motion, for example) and, more importantly, because the detailed explanation of the facts of which phenomenological thermodynamics treats at the surface level is to be found in statistical thermodynamics. Statistical thermodynamics bases itself on the laws of mechanics, which are time symmetrical.

According to statistical thermodynamics, the situation in which the water in the kettle freezes while the brick gets hotter is indeed a physically possible one, though it is an almost infinitely unlikely one. Why it is unlikely has to do not with the laws of nature themselves but with their boundary conditions. There is indeed a puzzle here, because if all the velocities of a closed system are reversed, what results is a configuration that, according to statistical mechanics, is as likely as the original one. Therefore, the process seen on the reversed cinematographic film should be as likely as the original one. The answer to this objection (the reversibility objection) lies in the fact that corresponding to a given macroscopic description (cold kettle on hot brick, say), there is a whole ensemble of possible microstates. It follows that though any microstate is as probable as any other, this is not so with macrostates, and given the information that a body is in a macrostate *A*, it is highly probable that it will turn into a macrostate *B* rather than vice versa if *B* corresponds to an ensemble of microstates which is vastly more numerous than the ensemble of microstates corresponding to *A*.

An analogy with a pack of cards will help to make this clear. Consider a well-shuffled pack of cards. Any order of the cards is as probable as any other provided that the order is precisely described. Given any one such order *P*, it is, of course, just as probable that in shuffling, *P* will turn into the order (call it *Q*) in which the pack is arranged in suits as that *Q* would turn into *P*. But if *P* is described simply as haphazard, there is a vast number of states other than *P* which are also haphazard. Thus, although a shuffling which turns *Q* into *P* is no more probable than one which turns *P* into *Q*, there are far more shufflings which turn *Q* into a state abstractly described as haphazard than there are shufflings which turn a particular haphazard state—say, *P*—into *Q*.

Suppose we started with our cards arranged in suits, the state *Q*. If we shuffled them, they would soon get into what we should call a well-shuffled state. Nevertheless, if we went on shuffling long enough, we should eventually get back to the unshuffled state *Q*. This illustrates the following interesting point. Let us for the moment toy with the almost certainly false cosmological hypothesis that the universe is a finite nonexpanding collection of particles without spontaneous creation or annihilation. Then, just as with our pack of cards, such a universe will eventually return to any given state. The universe will get more and more shuffled until we get the so-called heat death, in which everything is a featureless uniformity and will then become less and less disordered. In the era in which, as we should put it, the universe was getting less disordered, time would seem to run in the opposite direction to that in which it seems to run to us. (Thus, denizens of this era would still say that the universe was getting more disordered.) Indeed, there would be an infinite sequence of cosmic eras, much as is supposed in some Buddhist cosmologies, except that time would seem to run in opposite ways in alternate eras. In a sufficiently large view there would be temporal symmetry in this universe, though not on the scale of any single cosmic era. This is what makes the hypothesis of a finite nonexpanding universe philosophically instructive, even though it is probably contrary to fact.

TRACE FORMATION AND ENTROPY. It is now possible to deal with the formation of traces. Although a wide, relatively isolated part of the universe is increasing in its state of being shuffled, or, to use the more precise notion developed by physicists, in its entropy, subsystems of the wider system may temporally decrease in shuffling, or entropy. Thus, an isolated system, such as that consisting of a cube of ice in a beaker of water, may well have lower entropy than its surroundings. This reduction of entropy is bought at the expense of a more than compensating increase of entropy in the surroundings. There will, for example, be an increase of disorderliness in the system containing the coal and air that react chemically and drive the generators that provide the electric power that drives the refrigerator that makes the ice cube. (The system consisting of coal and oxygen is a more highly ordered one than is that which consists of the ashes and used up air.) Eventually the ice cube melts and becomes indistinguishable from the water in which it floated.

BRANCH SYSTEMS. The formation of a trace is the formation of a subsystem of temporarily lower entropy than that of its surroundings, and the trace is blotted out when the entropy curve of the subsystem rejoins that of the larger system. A footprint in sand is a temporarily highly ordered state of the sand; this orderliness is bought at the expense of an increased disorderliness (metabolic depletion) of the pedestrian who made it, and this extra orderliness eventually disappears as a result of wind and weather. Hans Reichenbach (1956) calls such systems of temporarily lower entropy "branch structures." It is an observable fact, and one to be expected from considerations of statistical thermodynamics, that these branch structures nearly all (in practice, quite all) go in the same direction. This direction defines a temporal direction for the universe or at least for our cosmic era of it.

On investigation it will be seen that all sorts of traces, whether footprints on sand, photographs, fossil bones, or the like, can be understood as traces in this sense. Indeed, so are written records. The close connection between information and entropy is brought out in modern information theory, the mathematics of which is much the same as that of statistical thermodynamics. A coherent piece of prose is an ordered part of the universe, unlike a completely random sequence of symbols.

It is possible that the formation of branch systems may be linked to deeper cosmological facts. Thomas Gold (1958, 1962) has argued persuasively that the formation of such a system is possible only because the universe provides a sink for radiation, and this is possible, again, only because of the mutual recession of the galaxies. It may therefore ultimately be the expansion of the universe that accounts for the direction of time. Beyond noting this interesting suggestion of a link between the small-scale and large-scale structure of the cosmos, we can for our present purposes take the formation of branch systems for granted without linking it to uncertain cosmological speculations.

POPPER'S ACCOUNT. The theory of branch systems outlined above has been developed rigorously by Reichenbach and Grünbaum, whose work partly goes back to that of Ludwig Boltzmann (1895). (A rather similar account of temporal direction has been independently given by O. Costa de Beauregard [1963].) We must now consider a different account of the direction of time, one that was conceived by Karl Raimund Popper.

Slightly changing Popper's example, consider a spherical light wave emitted from a source, as when a small electric bulb is turned on. Consider how this process would look in reverse. We should have a large spherical wave contracting to a point. This would be causally inexplicable. In order to get a spherical light wave coming in from the depths of an infinite space, we should have to suppose a coordinated set of disturbances at every point of a vast sphere, and this would require a deus ex machina. Moreover, this would still not provide the reverse of an outgoing wave expanding indefinitely. Thus, although the contracting wave is as much in accordance with the laws of optics as is the expanding one, it still is not compatible with any physically realizable set of initial conditions. Once more, as with the Reichenbach-Grünbaum solution, it can be seen that temporal asymmetry arises from initial, or boundary, conditions, not from the laws of nature themselves.

Popper's criterion of temporal direction does not shed light on the concept of trace, as does the criterion of branch systems. And traces, particularly memory traces, give us our vivid sense of temporal asymmetry in the world. It is also interesting that if we consider a finite but unbounded nonexpanding universe, a contracting spherical wave would be physically realizable. Just as an expanding series of concentric circles on the earth's surface which have their original center at the North Pole would become a series of circles contracting to the South Pole, so in a symmetrical, finite, but unbounded universe a spherical wave expanding from a center would eventually become a contracting wave, shrinking to the antipodal point of the point of emission. If we included the facts of radiation in our finite nonexpanding universe, we should have to suppose a finite but unbounded space, and Popper's criterion of temporal direction would become inapplicable. Including such facts would therefore also not conflict with our supposition of alternate cosmic eras in such a universe. In such a universe the Reichenbach-Grünbaum account of temporal direction for particular cosmic eras would still be applicable. There are still anthropocentricities to be brought to light, a task which has been impressively achieved by Huw Price in his book *Times Arrow and Archimedes' Point* (1996). He has clearly discussed the time symmetry (or one might say CPT symmetry) of microphysics. On the macro level, causation is at least in our cosmic era asymmetrical because the concept of it is closely related to that of agency and so to the temporal asymmetry of memory traces.

What is presented here is not an analysis of the ordinary language concept of earlier and later. This is learned to some extent ostensively, and we may perfectly well know how to use words such as "earlier" and "later" without knowing anything about entropy or branch systems. As Wittgenstein might have said, "We know the language game." Here the concern is with a deeper problem: what are the general features of the universe which enable us to play the language game? Indeed, if the universe did not contain traces, it would be impossible for there to be any thought at all. It should be noted that Mellor in his aforementioned book rejects the relevance of considerations of entropy and the like and relies on the notion of probability: the cause is an event that raises the objective chance of the event that is the effect. As mentioned above, Tooley also has a causal account. Even so, considerations of entropy could be needed to explain the asymmetry of causation on the macro level. On the micro level, causation is time symmetric and Price has neatly suggested defending locality, and perhaps hidden variables, in quantum mechanics and in the face of John Bell's well-known inequality, by means of backward causation. Curiously, according to Price, Bell had once considered such a solution but had rejected it for dubious philosophical reasons connected with the notion of free will.

COMPROMISE THEORIES

Storrs McCall and Michael Tooley have proposed theories that contain elements of both tensed and tenseless theories. Tooley, in his *Time, Tense, and Causation* (1997), worked out a sophisticated theory that is partly similar to one that C. D. Broad proposed in his *Scientific Thought* (1923). According to this view, only past and future are real and the universe is continually getting bigger as more and more of the future becomes present and past. Tenseless theorists will still see this as open to the objections to notions of time flow and of absolute becoming that were canvassed above. So also will they see McCall's theory according to which reality keeps getting smaller. McCall is inspired by the Everett-Wheeler interpretation of quantum mechanics. Space-time reality is like a giant poplar tree with branches corresponding to possible futures, with trunk, branches of branches, and so on, all pointing up in timelike directions. At every interaction between particles, branches (real possibilities) get lopped off. According to the tenseless theorist, reality must be like a stack of poplar trees, ordered according to the inclusiveness of the sets of branches. The mind boggles. Tooley's (though not McCall's) theory requires an absolute present and Tooley is bold enough to consider modifying special relativity. However, a reconciliation with special relativity could have been acquired at less cost as follows. The equality in all directions of the cosmic background radiation may give an approximation to a preferred frame of reference at each point of space. This will, because of the expansion of the universe, yield a curved hypersurface of cosmic simultaneity. Tooley defends his view of the increase of reality against the objection that it requires a hypertime. However, time travel is not like space travel because we may travel to a place, say the Taj Mahal, where we have not been before. The four-dimensional equivalent of a place is a timelike world-line, which in the example may intersect the world line of the Taj Mahal. The space of commonsense talk and of Newton's *Principia* is a continuant, not like the atemporal space of Euclid. Tooley's cutting off of the future may put in question the explanatory (as opposed to instrumental) value of full Minkowski space, though perhaps less so than presentism.

The tenseless four-dimensional account sits well with mereology, the theory of part and whole. Indeed some philosophical problems come out as easily as shelling peas when one goes four-dimensional. Consider Robert Louis Stevenson's story of Dr. Jekyll and Mr. Hyde, in which the personalities of the virtuous Jekyll and the criminal Hyde alternate in the one body. Mereology distinguishes three objects, the spatiotemporally scattered objects Jekyll and Hyde and the continuous fusion of these two. The problem is not one about identity, which is a clear notion in logic, but about "person" and the problems about these are more legal and psychiatric than philosophical.

CAUSAL THEORIES OF TIME

There are theories of the structure of time, or of space-time, that are based on the notion of causality. Objections to such theories have been made as follows (Smart 1987). How do we deal with points of space-time that are not occupied with events that are neither causes nor effects? Perhaps we could rely on causal connectibility and not on connectedness. Connectibility is a modal notion and so will not be liked by philosophers such as those influenced by W. V. Quine, who are suspicious of modality. In special relativity the notion of connectibility can be defined directly in terms of the geometry of Minkowski space by that of belonging in the same double light cone and then properties of space-time defined by axioms. Still, in face of the beautiful clarity of geometry we may prefer to characterize space-time directly, without trying to define the geometry by reference to causality. Tooley avoids these objections because he has an absolute theory of space-time and uses causality simply to define temporal direction. Possibly some of these objections make difficulty for Mellor who has a relational theory. However his notion of probability is that of objective chance and may depend on a theoretical posit and avoid modality. Tooley also needs a realistic theory of causality which some philosophers will find problematic.

TIME AND FREE WILL: THE SEA FIGHT TOMORROW

It is sometimes thought that the picture of the world as a space-time manifold is incompatible with free will. It is thought that if a single action of one's future actions exists (tenselessly) in the space-time manifold, then it is fated that the person will do this action; one cannot be free not to do it. To evade this conclusion, philosophers have sometimes been inclined to reject the theory of the manifold and also to deny that propositions about the future have to be either true or false. This view can be contested at several levels. First, the fact that this singular future action exists in the space-time manifold does not mean that the person is fated to do it, in the sense that the person comes to do it independently of what it was he or she does in the meantime. It will still be that person's choice. Second, the doctrine of the space-time manifold does not even imply determinism. Determinism asserts that the laws of nature connect earlier and later spatial cross sections of the manifold in a determinate way, whereas indeterminism denies this. Indeterminism is compatible with the theory of the manifold as such but is no friend to free will. Acting by pure chance is not being free. Third, it could be argued that free will is perfectly compatible with determinism anyway. On three counts, therefore, we may assert that the theory of space-time has, in fact, nothing at all to do with the question of free will.

Aristotle canvassed some of these matters in his well-known passage about the sea battle (*De Interpretatione*, ch. 9). Aristotle held that it is necessary that either there will be a sea battle tomorrow or there will not be, but that it is not necessary that there will be a sea battle tomorrow, nor is it necessary that there will not be a sea battle tomorrow. He held, however, that all present and past events are necessary, as are some future ones, such as an eclipse of the moon. It is clear, therefore, that Aristotle's notion of necessity here is not the modern notion of logical necessity. Nor by "necessary" can he even mean "predictable" or "retrodictable." Because past events, though not all retrodictable, may have at least left traces, perhaps Aristotle may have meant by "necessary" something like "knowable in principle." But how about past events whose traces have been blotted out? It is hard to give a coherent interpretation of Aristotle here, and certainly to try to give one would be to go into metaphysical subtleties not especially connected with time. Some commentators have interpreted Aristotle as saying that the proposition "There will be a sea battle tomorrow" is neither true nor false. It would seem, however, that this was not Aristotle's view.

Finally, it must be pointed out that the difference between past and future is misleadingly expressed by the common remark that we can change the future but not the past. It is true that we can affect the future and we cannot affect the past. We cannot, however, *change* the future, for the future is what it will be. If a person decides to take the left-hand fork in a road instead of the right-hand one, that person has not changed the future, for in this case the future *is* that person's going left. To talk of changing the future is indeed to relapse into talking of events changing and of the notion of passage.

See also Causal Approaches to the Direction of Time; Physics and the Direction of Time; Time, Being and Becoming.

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F. H. Bradley's argument for the unreality of space and time is given in his *Appearance and Reality*, 2nd ed., chap. 2 (Oxford: Clarendon, 1930). Henri Bergson's accounts of time and duration are given in his *Time and Free Will* (New York: Macmillan, 1910), *Matter and Memory* (New York: Macmillan, 1911), and *Introduction to Metaphysics* (London: Putnam, 1913). Bertrand Russell in his *History of Western Philosophy* (London: Allen and Unwin, 1945) gives a succinct criticism of Bergson. Like Bergson's, A. N. Whitehead's metaphysics took for granted a form of the myth of passage. His views are to be found especially in *An Enquiry concerning the Principles of Natural Knowledge* (Cambridge: The University Press, 1920), chaps. 3–6, and parts of *Process and Reality* (Cambridge: The University Press, 1929). See also V. C. Chappell, "Whitehead's Theory of Becoming," in *Journal of Philosophy* 58 (1961): 516–528.

SPACE-TIME

Hermann Minkowski's classic paper "Space and Time" can be found in *The Principle of Relativity*, a collection of papers by Einstein and others, translated by W. Perret and G. B. Jeffery, with notes by Arnold Sommerfeld (London: Methuen, 1923). Popular accounts can be found in A. S. Eddington, *Space, Time and Gravitation* (Cambridge: The University Press, 1920), and Moritz Schlick, *Philosophy of Nature*, chap. 7 (New York: Philosophical Library, 1949). Milič Čapek, in his *The Philosophical Impact of Contemporary Physics* (Princeton, NJ: Van Nostrand, 1961), criticizes the theory of the space-time manifold and defends the concept of becoming.

ABSOLUTE AND RELATIONAL THEORIES

A relational theory of space and time is defended by Leibniz. See especially his third and fifth papers in *The Leibniz-Clarke Correspondence*, edited by H. G. Alexander (Manchester: Manchester University Press, 1956) A brilliant argument against Leibniz is in Graham Nerlich, *What Spacetime Explains* (Cambridge, U.K.: Cambridge University Press, 1994). On space-time in the general theory of relativity see Adolf Grünbaum's paper "The Philosophical Retention of Absolute Space in Einstein's General Theory of Relativity" in *Problems of Space and Time*, edited by J. J. C. Smart (New York: Macmillan, 1964), and references given therein. Also see Graham Nerlich, *The Shape of Space*, 2nd ed. (Cambridge, U.K.: Cambridge University Press, 1994). The issue between three and four dimensionalism is thoroughly discussed in Theodore Sider, *Four-Dimensionalism: An Ontology of Persistence and Time* (Oxford: Clarendon, 2001).

TIME AND THE CONTINUUM

A good discussion of the paradoxes of Zeno will be found in Adolf Grünbaum, *Modern Science and Zzeno's Paradoxes* (London: Allen and Unwin, 1968). Since 1951 many articles on Zeno's paradox of Achilles and the tortoise have appeared in *Analysis*. See also V. C. Chappell, "Time and Zeno's Arrow," in *Journal of Philosophy* 59 (1962): 197–213; and Harold N. Lee, "Are Zeno's Paradoxes Based on a Mistake?" in *Mind* 74 (1965): 563–570. Also of interest is Paul Benacerraf, "Tasks, Super-Tasks and the Modern Eleatics," in *Journal of Philosophy* 59 (1962): 765–784. A useful account of Zeno's paradoxes is to be found in Kathleen Freeman, *Pre-Socratic Philosophers: A Companion to Diels, Fragmente der Vorsokratiker*, 3rd ed. (Oxford: Basil Blackwell, 1946).

Kant's antinomies about space and time occur in *The Critique of Pure Reason*. There is a translation of this book by Norman Kemp Smith (London: Macmillan, 1929). Zeno's and Kant's antinomies are discussed by Bertrand Russell in lectures 6 and 7 of *Our Knowledge of the External World* (London: W. W. Norton, 1922). See also C. D. Broad, "Kant's Mathematical Antinomies," in *PAS* 55 (1954–1955): 1–22. The commentary by Edward Caird, mentioned in the present article, is *The Critical Philosophy of Immanuel Kant* (Glasgow: J. Maclehose, 1889).

THE DIRECTION OF TIME

Besides Reichenbach's book *The Direction of Time* and the book by Grünbaum, *Philosophical Problems*, see especially Adolf Grünbaum's paper "Carnap's Views on the Foundations of Geometry" in *The Philosophy of Rudolf Carnap*, edited by P. A. Schilpp (La Salle, IL: Open Court, 1962), which, despite its title, contains a thorough discussion of the present problem, and Grünbaum's essay "The Nature of Time." See also Erwin Schrödinger's fine paper "Irreversibility" in *Proceedings of the Royal Irish Academy* 51 (1950): 189–195; and Norbert Wiener, "Newtonian and Bergsonian Time," which is chap. 1 of *Cybernetics*, 2nd ed. (New York: M.I.T. Press, 1961). Also see Ludwig Boltzmann, "On Certain Questions of the Theory of Gases," in *Nature* 51 (1895): 413–415. Reichenbach's book depends to a great extent on Boltzmann's ideas. There is a readable treatment of some of these issues in the final appendix of Schlick's *Philosophy of Nature*. A different solution to the problem is to be found in notes by K. R. Popper in *Nature* 177 (1956): 538; also vol. 178 (1956): 382; vol. 179 (1957): 1,297; and vol. 181 (1958): 402–403, in connection with which see the note by E. L. Hill and Adolf Grünbaum, in *Nature* 179 (1957): 1,296–1,297. See also O. Costa de Beauregard, "L'Irreversibilité quantique, phénomène macroscopique," in *Louis de Broglie*, edited by A. George (Paris, 1953). Grünbaum has examined Popper's view in his essay "Popper on Irreversibility" in *The Critical Approach to Science and Philosophy: Essays in Honor of Karl Popper*, edited by Mario A. Bunge (New York: Free Press of Glencoe, 1964). There are two beautiful articles titled "The Arrow of Time" by the cosmologist Thomas Gold in *La Structure et l'évolution de l'univers*, proceedings of the eleventh Solvay Conference, pp. 81–91 (Brussels: R. Stoops, 1958), and in *The American Journal of Physics* 30 (1962): 403–410. "The Direction of Time" by Max Black in his *Models and Metaphors* (Ithaca, NY: Cornell University Press, 1962), is written from the point of view that scientific considerations are irrelevant to the problem of the direction of time. D. H. Mellor rejects the relevance of considerations of entropy and statistical mechanics in his *Real Time II* (Cambridge, U.K.: Routledge, 1998). An absolutely outstanding discussion of temporal symmetry and asymmetry in which he identifies unrecognized anthropocentric confusions is Huw Price, *Time's Arrow and Archimedes' Point* (New York: Oxford University Press, 1996).

A readable discussion of the experiment by James H. Christenson, James W. Cronin, Val L. Fitch, and René Turlay, which suggests a possible violation of time symmetry in the laws of nature themselves, can be found in Eugene P. Wigner's article "Violations of Symmetry in Physics" in *Scientific American* 213 (December 1965): 28–42.

TIME AND FREE WILL: THE SEA FIGHT TOMORROW

On fatalism see R. D. Bradley, "Must the Future Be What It Is Going To Be?" in *Mind* 68 (1959): 193–208; Richard Taylor, "Fatalism," in *Philosophical Review* 71 (1962): 56–66, with the discussion on this by Bruce Aune in the same volume, pp. 512–519; and A. J. Ayer, "Fatalism," in his *The Concept of a Person and Other Essays* (London: Macmillan, 1963). On the sea battle see Aristotle, *De Interpretatione*, chap. 9. Extensive notes and a translation can be found in J. L. Ackrill's *Aristotle's Categories and De Interpretation,* vol. 1 of the complete works of Aristotle edited by Jonathan Barnes (Princeton; NJ: Princeton University Press, 1984). This passage has also been translated and discussed by G. E. M. Anscombe in "Aristotle and the Sea-Battle" in *Problems of Space and Time*. See also Colin Strang, "Aristotle and the Sea Battle," in *Mind* 69 (1960): 447–465. Many journal articles on the subject, following on D. C. Williams's interesting "The Sea-Fight Tomorrow," appear in *Structure, Method, and Meaning*, edited by Paul Henle, Horace M. Kallen, and Susanne K. Langer (New York: Liberal Arts Press, 1951). See especially the discussion note "Professor Donald Williams on Aristotle" by Leonard Linsky and the rejoinder by Williams in *Philosophical Review* 63 (1954): 250–255, and Richard Taylor, "The Problem of Future Contingents," and Rogers Albritton's reply in *Philosophical Review* 66 (1957): 1–46. The seventeenth-century English philosopher Thomas Hobbes also wrote on the sea-fight; see his *Works*, edited by William Molesworth, vol. 4, p. 277 (London: J. Bohn, 1839), and discussion by A. G. N. Flew, "Hobbes and the Seafight," *Graduate Review of Philosophy* 2 (1959): 1–5.

Other references are to Storrs McCall, "Objective Time Flow," in *Philosophy of Science* 43 (1976): 337–362; and his "A Dynamic Model of Temporal Becoming," *Analysis* 44 (1984): 172–176; and to McCall's book, *A Model of the Universe: Space-Time, Probability and Decision* (Oxford: Clarendon, 1994). Mellor's *Real Time II* was published in London in 1998. Michael Tooley's *Time, Tense and Causation* was published in Oxford in 1997. See also Michael Tooley, "The Metaphysics of Time" in *The Argument of Time*, edited by Jeremy Butterfield, pp. 21–42 (London: Oxford University

Press, 1999), and "Basic Tensed Sentences and their Analysis" in *Time, Tense, and Reference*, edited by Aleksander Jokic and Quentin Smith, pp. 409–447 (Cambridge, MA: MIT Press, 2003). John Bigelow defends presentism in his "Presentism and Properties," in *Philosophical Perspectives* 10, *Metaphysics* (1996): 35–52.

J. J. C. Smart (1967, 2005)

TIME, BEING, AND BECOMING

The major debate in the philosophy of time, being, and becoming is between defenders of the tenseless theory of time and defenders of the tensed theory of time. During the late twentieth century into the early twenty-first century, the tenseless theory of time was defended by such philosophers as D.H. Mellor, Graham Nerlich, and L. Nathan Oaklander. The tenseless theory implies that temporal features of events consist only of relations of simultaneity, earlier, and later than, and that all events are ontologically equal, regardless of when they occur. The tensed theory, which has many versions, is advocated by such philosophers as William Lane Craig, Quentin Smith, and Michael Tooley. The tensed theory of time implies that some or all of the words *past*, *present*, and *future* are needed to describe time, although what is understood by the words *future*, *present*, and *past*, or by their usage as parts of phrases or sentences (e.g., whether or not they express analyzable or unanalyzable concepts) is a matter that varies among tensed theorists.

THE OLD AND NEW TENSELESS AND TENSED THEORIES OF TIME

For most of the twentieth century, the debate was between defenders of the old tenseless theory of time and defenders of the old tensed theory of time, concerning whether or not tensed sentence tokens are translatable by tenseless sentences. If a tensed sentence token, call it S, such as the sentence token "John was running" can be translated by a tenseless token, such as "John is (tenseless) running earlier than S," then the tensed token S conveys no more temporal information than the tenseless token. Consequently, the defender of the old tenseless theory of time maintained that temporal properties and relations can consist only of the relations of earlier than, later than, and simultaneous with. Some of the main developers of the old tenseless theory are Bertrand Russell (1903, 1906, 1915)—Russell is the first twentieth century defender of the tenseless theory against the tensed theory of time—Hans Reichenbach (1947), J.J.C. Smart (1963, 1966), and Adolf Grünbaum (1973). Smart (1980) was also one of the main founders of the new tenseless theory of time.

Proponents of the old tensed theory of time argued that these sentence tokens cannot be translated. For example, "John (is) running earlier than S" does not convey the temporal information of whether John's running is past, present, or future. Because "John was running" conveys that it is past, this sentence token cannot have the same semantic content (or the same meaning, or express the same proposition) as the tenseless token, and therefore cannot be translated by the tenseless token. Some of the most influential defenders of the old tensed theory of time are C.D. Broad (1923)—who is the first twentieth century defender of the tensed theory and critic of the tenseless theory—A. N. Prior (1967, 1968, 1979), Richard Gale (1962, 1968), and George Schlesinger (1981).

In response to criticisms advanced by the old tensed theory of time, defenders of the tenseless theory largely accepted the argument of Gale and others that tensed sentence tokens cannot be translated by tenseless ones; however, the tenseless theorists now argued that the truth conditions of tensed sentence tokens are tenseless. For example, Mellor (1981) argued that the token S of "John was running" is not translatable by a token "John is (tenseless) running earlier than S", but is true if, and only if, John is (tenseless) running earlier than S. The new tenseless theory of time was in place by 1981, due primarily to the independent work of Mellor (1981) and Smart (1980) (see also Anderson and Faye [1980], Faye [1981], and Oaklander [1984]). The main developments and defenses of various versions of the new tenseless theory from the mid-1980s to the early twenty-first century were made for the most part by L. Nathan Oaklander, but also by Heather Dyke (2002a, 2002b, 2003), Robin Le Poidevin (1992, 2003), Graham Nerlich (1998), L.A. Paul (1997), J. M. Mosersky (2000), and others.

The emergence of the new tenseless theory in the 1980s inspired the new tensed theory of time, whose unifying theme was a criticism of the new tenseless theory and the development of ontologies for a tensed theory that were able to overcome the hurdles set by the new tenseless theorists. Criticisms of one of the two main versions of the new tenseless theory, Mellor's token-reflexive theory, appeared in Graham Priest's (1986, 1987) work, and criticisms of the two main versions of the new tenseless theory (Smart's and Mellor's) appeared in Smith's (1987, 1993) work.

The classification of the new tenseless theories of time into two versions, the token-reflexive version and