HAWKING ON GOD AND CREATION

by Robert J. Deltete

Abstract. Although full of talk about God, Stephen Hawking's recent best seller, *A Brief History of Time*, apparently has little use for the traditional notion of God as cosmic creator. More precisely, Hawking seems to reject the idea that we need appeal, any longer, to the notion of *creatio originans* (originating creation). The reason is that he has developed, over the last decade, a cosmological model that avoids any beginning to spacetime and the universe, and so eliminates the need for a cosmic beginner. I criticize Hawking's model in this essay, arguing that either it is not intended to be construed realistically or that, if it is, the model is highly implausible.

Keywords: Big Bang theory; general relativity; S.W. Hawking; quantum cosmology; time.

The singularity at the beginning of time should be viewed as a challenging puzzle, not a signal that we must give up.
—H.R. Pagels

Stephen Hawking's recent best seller, *A Brief History of Time,* is full of talk about God. The last paragraph of the work gives the flavor. Hawking has been discussing recent attempts by physicists to formulate a complete and unified physical theory. Such a theory would answer "the question of why it is that we and the universe exist. If we find the answer to that," he concludes, "it would be the ultimate triumph of human reason—for then we would know the mind of God" (Hawking 1988, 175).

This is heady stuff. It is difficult to read Hawking's words without getting goose pimples—no doubt the reason that the movie based on his book has him, in its final scene, typing them into his computerized voice synthesizer against the backdrop of a starry sky. But if we look more closely at his book, it would seem that Hawking has little need for God in the picture that he paints of the universe. In

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this essay I want to argue that the reasons he gives for thinking, apparently, that God is unnecessary are unconvincing.

I must begin by limiting the scope of my remarks. Hawking has said that, in fact, he leaves open the question of whether God exists (Hawking 1985b, 12). What he challenges as unnecessary is the need for any appeal to God as creator of the universe. The nature of this challenge, in turn, is limited—or may be. That is, he may leave room for an appeal to God as cosmic sustainer, and so for the traditional notion of *creatio continua;* in any case, several recent commentators have suggested this as a possibility (see Craig 1990, 474–76; Drees 1991, 389-90, 391–92; Davies 1992, 68–69). What Hawking denies is any need for God as a cosmic originator, that is, the traditional notion of *creatio originans*. More concretely, he rejects the idea that we need to appeal to God to explain the beginning of spacetime or the universe, since, appropriately understood, neither had a beginning (Hawking 1988, 116; referring to Hawking 1982). I propose to tackle Hawking on this limited field, so to speak, and to argue that he does not make a convincing case.

Limiting the playing field does not eliminate all of the difficulties, however. The main problem, as I see it, is the difficulty one has in determining whether Hawking intends his proposal about the universe in a realist sense, as a literal description of the way the world is, or only instrumentally, as an attractive mathematical model that has no origin. I think he is in trouble either way. But before I indicate my reasons for so thinking, and thus the general approach I shall be taking in this essay, I must mention a third possibility: This is that Hawking is merely teasing his readers, and that he does not intend anything that he has to say about God to be taken seriously. There is, admittedly, something to be said for this reading (see, e.g., Hawking 1988, 88). Still, most of Hawking's remarks on God appear serious in intent and, taken together, seem best construed as Carl Sagan reads them (Sagan 1988, x), that is, as seriously suggesting that his model eliminates any need to appeal to God as a cosmic originator. In what follows, therefore, I shall argue that if Hawking interprets his model instrumentally, which is his official way of construing physical theories, then he has no grounds for an ontological dismissal of the need for a beginning. On the other hand, if he does intend an ontological rejection of any need for a beginning, then he must interpret his model in realist sense; and such an interpretation, I argue, is highly implausible.

I should perhaps also make clear at the outset that I will not try to defend the antithesis of Hawking's proposal, namely, that it is necessary to appeal to God to explain the origin of spacetime and the universe. Instead, my critique is an internal one. To the question, Why such a critique? the proper response is twofold. First, while Hawking is a talented physicist, who has made original and important contributions to cosmology, his speculations about the theological implications of some of his *very* speculative cosmological work seem rash at best. But, second, and because of all the publicity *A Brief History* has received, Hawking is now probably regarded as *the* spokesperson for modern scientific cosmology. In fact, this is not the case; many of Hawking's professional colleagues disagree with him, both in detail and in orientation (see, e.g., Isham 1988 and Penrose 1987). Still, the general reading public's perception of the issues I shall address has likely been shaped by *A Brief History*—which was of course intended for general consumption—and by what its many reviewers have written about it. So an internal critique of Hawking's ideas seems worthwhile: It may encourage well-known scientists to be more responsible in their popular speculations and general readers to be more circumspect in their reception of them.

THE BIG BANG SINGULARITY

Let me begin by describing, very briefly, the cosmological problem Hawking's proposal is meant to address. Einstein's general theory of relativity (GTR) is about the overall structure of spacetime.[1] It is a geometrical theory that says that spacetime has a geometrical structure dependent on the mass-energy embedded in it. More precisely, the fundamental equations of the theory equate the curvature of spacetime to the mass-energy density of the universe. Few physicists doubt that Einstein's theory provides an accurate, realistic picture of the large-scale structure of the universe: Very natural solutions to Einstein's field equations predict an expanding or contracting universe; and the best current scientific evidence, from a variety of sources, indicates that the universe is expanding in a manner described by these equations (see Smith 1988, 40–41). If we run the expansion backward, however, in search of its origin, we encounter what is known as a *singularity,* a point of infinite mass-energy density and infinite space-time curvature. Indeed, the equations of general relativity, as applied to a "natural" universe, imply a singularity at its origin (see Hawking 1970 and Penrose 1974; also Hawking 1988, 115, 133, 173). Since $t = 0$ at the singularity, we may therefore say that time and the universe begin with the first event, the so-called Big Bang, from which the expansion ensues (Hawking 1988, 50).

This beginning suggests the need for a supernatural beginner, since it apparently had no natural cause. One author recently put it this way: "There is no doubt that, psychologically speaking, the existence of this initial singular point is prone to generate the idea of a Creator who sets the whole show rolling" (Isham 1988, 405). And, in fact, Hawking writes: "So long as the universe had a beginning, we could suppose it [also] had a creator" (Hawking 1988, 140–41).[2] But the situation is fundamentally different, he thinks, if it can be shown that time has no beginning, for then there was no first event and so no beginning to the universe. Can this be done? Hawking believes there are reasons for thinking that it can. His strategy is to avoid the singularity predicted by the general theory of relativity. If the singularity required in GTR-based Big Bang models can be avoided, there will be no boundary or "edge" to spacetime, and so no first event (no beginning) and no need for a Creator as beginner (Hawking 1988, 116, 139, 156–57).

Hawking has reasons for optimism. The main one concerns the status of GTR: Although few physicists doubt its reliability on a large scale, most (including Hawking) regard it as only a partial theory. More precisely, Hawking believes that "Einstein's idea that the gravitational field is represented by a curved space-time" will be part of any ultimate theory (Hawking 1988, 135; also 1984a, 336; 1984b, 357; and 1984c, 13). But like most physicists, he also thinks that GTR will break down near a singularity (Hawking 1988, 46, 50–51, 61, 122, 133, 148; Pagels 1985, 338; Wald 1992, 56–57, 92). Why? Because General Relativity is a classical theory that does not incorporate the small-scale effects described by quantum mechanics (QM)—" the other great partial theory of the twentieth century" (Hawking 1988, 51; also 1984b, 357; 1984c, 13; 1988, 11). At the scale of ordinary bodies, planets and galaxies, quantum effects are negligible for the most part; but at the scale of the very early universe, if a Big-Bang model of cosmic evolution is essentially correct, they should become hugely significant (Hawking, 1984a, 337; 1988, 50–51, 133, 139, 148).

What scale are we talking about? Physicists who believe that quantum mechanics can be applied to the whole universe generally think that quantum effects will dominate at the so-called "Planck scale," if not outside it (Davies 1983, 179–80; 1992, 62; Pagels 1985, 303–4; Gribbin 1986, 382). That is, they think General Relativity will break down when the universe is younger than 10^{-43} seconds and smaller than 10^{-33} centimeters in diameter. Hawking thinks this will happen (1982, 564, 566,; 1984a, 337, 355; 1985a, 2490; 1988, 51, 133, 167). He also thinks that quantum mechanics can be applied to the early history of the universe (Hartle and Hawking 1983; Hawking 1983, 1984a, 1987). Finally, he conjectures that combining GTR with QM to form a quantum theory of gravity will eliminate the singularity predicted by general relativity, and so any boundary or "edge" to spacetime and the universe and any need to have God start the cosmos rolling. He writes:

> In the classical theory of gravity, there are only two possible ways the universe can behave: either it has existed for an infinite time, or else it had a beginning at a singularity at some finite time in the past. In the quantum theory of gravity, on the other hand, a third possibility arises. . . . It is possible for space-time to be finite in extent and yet have no singularities that formed a boundary or edge. . . . [In such a theory,] there would be no singularities at which the laws of science broke down and no edge of space-time at which one would have to appeal to God or some new law to set the boundary conditions. . . . So long as the universe had a beginning, we could suppose it had a creator. But if the universe . . . [has neither] boundary or edge, it would have neither beginning nor end. What place, then, for a Creator? (Hawking 1988, 135–36, 140–41; also 1984b, 358, 1984c, 13–14 and 1988, 44, 50–51, 61, 115–16)

HAWKING'S PROPOSAL

The key to Hawking's proposal is an adequate quantum theory of gravity, which he admits we do not currently have (Hawking 1988, 12, 61, 133, 137). Still, he thinks that such a theory will have to include certain features that he has incorporated into his own proposal. So we need to have a look at these features before considering his hypothesis.

First, Hawking believes that an adequate theory of quantum gravity will have to incorporate Richard Feynman's "sum-over-histories" formulation of quantum mechanics (Hawking 1988, 133–35). The basic idea of this approach is that an elementary particle (an electron, for example) does not follow a single path between two spacetime points, and so does not have a single "history," but is rather to be conceived as taking all possible paths connecting these points. To calculate the probability of a particle's passing through any given spacetime point, one sums the wave amplitudes associated with every possible history that passes through the point. Histories represented by waves having equal amplitude and opposite phase mutually cancel, so that only a finite number of most probable histories remains. But in order to achieve this result, which eliminates intractable infinities, one must use imaginary numbers (i.e., quantities multiplied by the square root of negative one) for the values of the time coordinate in the path integral.

Here is the way Hawking describes the situation:

> When one actually tries to perform these sums, however, one runs into severe technical problems. The only way around these is the following peculiar prescription: One must add up the waves for particle histories that are not in

> the "real" time you and I experience but take place in what is called imaginary time. . . . That is to say, for purposes of the calculation one must use imaginary numbers, rather than real ones. . . . This has an interesting effect on space-time: the distinction between time and space disappears completely.

The resulting spacetime is simply a four-dimensional space in which there is "no difference between the time direction and directions in space" (Hawking 1988, 134; 1984b, 358; 1984c, 13).

A second feature that Hawking believes an adequate theory of quantum gravity must possess has already been mentioned. It is that the gravitational field must be represented, in the manner of GTR, by a curved spacetime. Combined with the first feature, this yields the following important condition: "When we apply Feynman's sum over histories to Einstein's view of gravity, the analogue of the history of a particle is now a complete curved space-time that represents the whole history of the universe." However, "To avoid the technical difficulties in actually performing the sum over histories, these curved space-times must be taken to be Euclidean. That is, time is imaginary and is indistinguishable from directions in space" (Hawking 1988, 135).

Hawking then proposes a model that he thinks is a good cosmic analogue of the path-integral history of a quantum particle. It is a compact four-dimensional Euclidean space analogous to the surface of a sphere, which is finite, but unbounded, and so possesses no initial singularity. Of course,

> if Euclidean space-time stretches back to infinite imaginary time, or else starts at a singularity in imaginary time, we have the same problem as in the classical theory of specifying the initial state of the universe: God may know how the universe began, but we cannot give any particular reason for thinking it began one way rather than another. On the other hand, the quantum theory of gravity has opened up a new possibility, in which there would be no boundary to space-time and so there would be no need to specify the behavior at the boundary. There would be no singularities at which the laws of science broke down and no edge of space-time at which one would have to appeal to God or some new law to set the boundary conditions for space-time. One could [instead] say: "The boundary condition of the universe is that it has no boundary."[3] The universe would be completely self-contained and not affected by anything outside itself. It would neither be created nor destroyed. It would just BE. (Hawking 1988, 135–36; also 44, 173. Cf. Hawking 1984b, 358; 1984c, 13)

Hawking stresses in all of his writings on quantum cosmology that his model is, thus far, merely a proposal, which must be tested to determine whether it "makes predictions that agree with observation" (Hawking 1988, 136–37; see also, e.g., Hartle and Hawking 1983, 2965; Hawking 1984a, 377 and 1987, 636). He also concedes that "the calculations are very difficult and have been carried out so far only in simple models with a high degree of symmetry." But the results, Hawking says, are "very encouraging" (Hawking 1984b, 358). Indeed, they are so encouraging that he is prepared to question the need for a creator. "So long as the universe had a beginning," he writes, "we could [also] suppose it had a creator. But if the universe is really self-contained, having no boundary or edge, it would have neither beginning nor end: it would simply be. What place, then, for a creator?" (Hawking 1988, 140–41).

ANALYSIS

It is difficult to evaluate Hawking's model from his popular presentations of it (Hawking 1984b, 1984c, 1988). How is the history of the universe analogous to the path-integral history of a quantum particle? What is the meaning of imaginary time? How is a four-dimensional Euclidean space supposed to eliminate an initial cosmic singularity? What does it mean to say that the universe just IS? To answer these questions, we need to look at the technical underpinnings of his popular summaries. This is no simple task since, as Hawking himself points out, the mathematics through which they are developed is complex. I shall therefore try to simplify, without misrepresenting, some of the technical ideas underlying his model. This will help us to understand better the implication of Hawking's proposal about the need (or rather lack of any need) for a creator and (in the next section) to evaluate it.

Let me begin with a few remarks on the "sum-over-histories" or "path-integral" version of quantum mechanics (QM), since this is the approach that Hawking would like to extend to quantum cosmology (Hawking and Hartle 1983, 2962; Hawking 1984a, 355; 1988, 113, 134–35).[4] The basic idea is to interpret the equation that describes the temporal evolution of a quantum particle in terms of the possible paths that it can take between two states. The mathematical formalism of the path-integral approach specifies the probability that a particle initially in a given state will later be found in another state, and also provides a means of reducing the number of possible paths that may be taken to a small number of likely ones. However, this procedure does not work unless one uses imaginary values for time in the equation expressing the state of the particle (Hawking and Hartle 1983, 2960; Hawking 1984a, 338–40).[5] Still, if there is also a classical description of the particle's path, it turns out that the likely quantum paths are very close to the classical one. Hawking uses this virtue of a path-integral approach to ordinary QM to guide

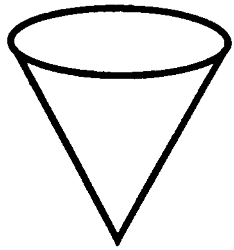

Figure 1.

his conjectures about quantum gravity, since very natural solutions to Einstein's field equations *do* give classical answers to questions about how the universe has evolved (see Hartle and Hawking 1983, 2966–67, 2969–71; also Hawking 1987, 631–33, 635, 642, 650; and Pagels 1985, 304).

Nevertheless, the attempted extension is both difficult and problematic (see Isham 1981 and Bell 1981). If one seeks to apply the path-integral approach to the universe as a whole, then the main task is to determine how the universe, rather than a particle, evolves in time. That is, one must determine how likely it is that, if the universe is in one state, it will later be found in another state. But time in general relativity is best understood as an internal parameter that is defined in terms of some property of the universe, such as average mass-energy density or curvature (see Isham 1988, 389–91, 396; also Hawking 1987, 648, 651; and Barrow 1991, 79–81).[6] To recover this feature of GTR in a quantum theory of gravity, therefore, one usually selects as a "time" parameter a "geometrical" property (such as radius or curvature), which depends on a "physical" variable (such as average mass-energy density) in the equation describing the state of the system. It is this choice that provides quantum-gravity theorists with an internal definition of time and its direction. The main result of any such choice, however, is that it is redundant to add external "time labels" to stages of the universe's evolution (cf. Isham 1988, 396–97; Barrow 1991, 85). Instead, the entire history of a quantum-gravity universe is coded (probabilistically) into a single mathematical entity—a so-called state-function of the universe (see, e.g., Hawking 1984a, 356; 1987, 636).

How would such a universe "look"? Well, a GTR universe is a curved four-dimensional spacetime comprised of a set of three-dimensional spaces that is, in turn, codetermined by whatever is needed to specify the arrangement of any mass-energy present. A

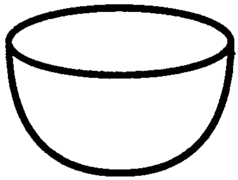

Figure 2.

spacetime diagram of such a universe may therefore look like a vertically oriented piece of pipe or segment of a garden hose, with an initial three-space at the bottom and a final one at the top. For quantum gravity theorists such as Hawking, however, the set of three-spaces will look more like a stack of pancakes. The "state-function of the universe" should then give the probability that, if the universe's state at a given internal time is one pancake, then its state at a later time will be another pancake. Some version of the "pancake" picture may be roughly appropriate for describing segments of spacetime far from its "origin"; but given cosmic expansion and the likely breakdown of GTR at very small dimensions, it will not be suitable as we approach the "origin." It might thus appear that these problems could be overcome by representing the spacetime diagram of (at least) the very early universe as analogous to an ice-cream cone (see figure 1), whose boundaries consist of a curved three-space and a single initial point. But this will not do either, since a singular point is not a smooth three-space, so that the function for computing how the universe evolved cannot be applied to it. What we have there is a singularity (see Isham 1989, 388–91; Davies 1992, 63–65).

How can this be avoided? Hawking's proposal is to suggest that we model the spacetime "origin" of the universe as a compact four-dimensional space, analogous to a partial sphere (see figure 2), whose boundary is a *single* three-dimensional space.[7] Notice that this spacetime diagram has no single point at its lower end, as would an ice-cream cone at its apex; rather, its surface is smooth. Hence, Hawking suggests, "The [initial] boundary condition of the universe is that it has no boundary" (Hawking 1988, 136 and elsewhere).

We know what largely motivates such a model: It is Hawking's deeply felt need to eliminate any initial spacetime singularity (e.g., Hawking 1987, 634–35). But on what grounds can he defend it? Two moves are essential. The first is to invoke the idea of "imaginary" time, that is, descriptions of time using numbers multiplied by the square root of negative one, which has the effect of eliminating any distinction between space and time dimensions (recall the passages from Hawking 1988, quoted earlier). More precisely, it changes the equations used to describe the curvature of a four-dimensional spacetime, so that there is no longer any difference between "spacelike" and "timelike" directions (see Isham 1988, 399; and Drees 1991, 393–94). This looks highly nonphysical—a problem to which I shall return. For now I note only that it allows Hawking to avoid, in his own model, the singularity at the apex of a conical model (see Hartle and Hawking 1983, 2969–70; Hawking 1984a, 355, 369–70; 1987, 634–35). Hawking's model, depicted in figure 2, has a single three-space as its boundary; the singular point has been eliminated by converting (via imaginary time) the compact four-dimensional spacetime into a compact four-dimensional Euclidean space. Because, moreover, the "surface" of the four-space is smooth, it has no point of "origin": it simply IS.

The second part of Hawking's defense strategy is to propose a state-function for the universe, which uses the path-integral method, but with some restrictions. For our purposes, the most important restriction is that Hawking limits the "paths" summed in the integral to the compact four-dimensional curved spaces with space and time having an equal status and with a well-defined three-dimensional boundary, as in figure 2 (Hartle and Hawking 1983, 2964–65, 2967–68, 2969–72; Hawking 1984a, 362–63; 1987, 634–35).[8] But the result of this restriction is that his "universal state-function" does not show the very early universe evolving. I can be more precise: For any three-space within figure 2, there is no other three-space, corresponding to an earlier (internally defined) "time," from which the universe may be said to have emerged. So the universe, too, just IS.

Does this mean, then, that time and cosmic expansion are illusory? No. Notwithstanding his use of "imaginary" time, Hawking's proposal still satisfies what is usually called the Wheeler-DeWitt equation, which describes the evolution of the physical variables in a "universal state-function" with respect to an internal choice of time (e.g., Hawking 1984a, 355, 357; 1987, 638–40).[9] But there are limitations to both: In the extreme quantum region (figure 2), the Wheeler-DeWitt equation cannot be interpreted in terms of such an evolution. Why not? Because as one approaches the extreme quantum region (that is, as the state of the universe becomes "more quantum mechanical" and departs more radically from the classical equations of general relativity), it becomes more difficult to say from within that one state preceded (or followed) another. Put differently, as the underlying equality of space and time begins to assert itself, it becomes impossible to interpret the physical variables as evolving. Thus, the ability to construct an internal definition of time breaks down and time "phases out." Conversely, as one moves away from the extreme quantum region (i.e., as the three-surface in figure 2 gets larger), the physical variables may be interpreted as evolving with respect to some internal time, and time "phases in."[10]

Hawking offers this analogy: "Time ceases to be well defined in the very early universe just as the direction 'north' ceases to be well defined at the North Pole of the earth. . . . The quantity we measure as time had a beginning, but that does not mean spacetime has an edge, just as the surface of the earth does not have an edge at the North Pole" (Hawking 1984b, 358; 1984c, 14; also Hawking 1988, 137–38). The analogy is not exact: the direction *north* does not "phase in" ("phase out") as one moves away from (approaches) the North Pole. But one can see his point: *North* does cease to be defined at the Pole. But one must also avoid being misled. The actual North Pole is determined by the earth's axis of rotation and so *is* physically special; but this is irrelevant to Hawking's analogy. The point of his analogy is twofold: First, that geometrically there are no special points on the surface of a sphere, so that it would be incorrect to think of the "south pole" in figure 2 as if it were special (the "origin" of the four-space); and, second, that for all points on the partial sphere representing the extreme quantum region, time is undefined.[11]

EVALUATION

If we now seek to evaluate Hawking's proposal, we must choose a level of entry. A high-level entrance would question some of the global assumptions on which the proposal rests. Let me mention some of them. One is the assumption that quantum theory can be extended from its natural home in the microscopic world to the universe at large. There are reasons for thinking that it can, notably the idea that on any realistic Big-Bang model the universe must once have been small enough so that quantum effects would dominate. But many theoretical physicists nevertheless have strong reservations about both the technical and the philosophical validity of such an extrapolation.[12]

There is also the assumption that quantum theory is adequate in its current form and that general relativity will need to correspond to it. This is a guiding belief of most quantum cosmologists, including Hawking,[13] but it has been vigorously disputed by a vocal minority (e.g., Penrose 1987, 34–36).

Another high-level assumption is the idea that, in any case, space and/or spacetime may be represented by a mathematical continuum, even at the tiny distances where quantum effects are expected to dominate. Hawking's proposal rests on this assumption, but other quantum-gravity theorists (e.g., Isham) believe that a viable theory of quantum gravity will probably require abandonment or radical revision of the simple (and familiar) idea of continuum spaces.

A further assumption of Hawking's research program is embodied in the belief, apparently well-founded, that Einstein's field equations *do* accurately describe the large-scale gravitational properties of the universe, and that an adequate theory of quantum gravity must recover solutions to these equations in the classical limit. But even this has been challenged (by, e.g., Feynman in Davies and Brown 1988, 200–201).

Finally, there is the assumption that the entire material content of the universe can be described accurately in the language of local, interacting quantum fields or the latest "best" theory of particle physics. This is a large assumption, given the recent rethinking of particle theory (see Davies and Brown 1988), which makes any proposal such as Hawking's tenuous at best.

Having noted the difficulties and disagreements at this level, however, I must say that I do not think it the appropriate level from which to launch a critique. The field of quantum cosmology is now too unsettled, too uncertain, and too rapidly evolving to draw much more than hasty conclusions from a global vantage. Recognition of this situation might therefore suggest a low-level entry, one that examines the details of Hawking's various models to determine how well they square with what is otherwise known about the universe (isotropy, expansion rate, density, etc.). But this seems *too* low a level from which to begin. Hawking is well aware of the simplifying assumptions that have gone into his own models and of the difficulties, put to the side in developing them, that would have to be addressed in a more adequate theory (see e.g., Hawking 1984a, 378). One would thus belabor the obvious to criticize the particulars of any given, provisional model. What to do? A recent commentator, who is both an expert in quantum cosmology and also sensitive to its possible religious implications, suggests this answer: "the broad conceptual ideas of quantum cosmology are more relevant for the science-religion dialogue than are the technical details of the theories themselves" (Isham 1988, 402).

With this advice in mind, it seems that the proper point of entry is to focus on several features of Hawking's proposal that are distinctive (if not uniquely so) of his approach. I shall concentrate on three of them: the "sum-over-histories" version of QM, the specification of a dynamical equation for describing the entire universe, and the appeal to imaginary time. These ideas are all essential to Hawking's research program, so that closer examination of them will offer insight into both its implications and the insubstantial basis for his belief, apparently, that a creator is unnecessary.

We must begin by noting a tension in Hawking's methodology. On the one hand, there is his "official position" on the goal of physical theory, which he states explicitly:

> I shall take the simple-minded view that a theory is just a model of the universe, or a restricted part of it, and a set of rules that relate quantities in the model to observations that we make. It exists only in our minds and does not have any other reality (whatever that might mean). A theory is a good theory if it satisfies two requirements: It must *accurately* describe a large class of observations on the basis of a model that contains only a few arbitrary elements, and it must make definite predictions about the results of future observations." (Hawking 1988, 9)

Later, appealing to this position, he denies that it is meaningful to ask about what is real (Hawking 1988, 139). But, on the other hand, Hawking's objectives seem clearly realistic in intent. "The eventual goal of science," he writes, "is to provide a single theory that describes the whole universe" (Hawking 1988, 10). And this goal, as he makes clear in his discussion of it (Hawking 1988, 11–13), is not simply a matter of recovering past observations and of predicting future ones. The goal is to understand how the world works and why it works the way it does. This realist objective—to "know the mind of God," as Hawking put it in the last paragraph of his book—sits uneasily with his instrumentalist "official position" on the goal of scientific theory. In what follows, therefore, I shall argue that if Hawking construes the essential features of his approach instrumentally, in accordance with his "official position," then he has no grounds for dismissing ontologically an origin to the universe or any need for an originator. If, however, his claim is ontological, then he must interpret his models realistically; and interpreted in this way, they are highly implausible.

Path Integrals in Cosmology. Consider, to begin with, the "sum-over-histories," or "path-integral," version of quantum theory. If Hawking construes this instrumentally, then his interpretation of spacetime must also be instrumental and, in consequence, so must his model. That is, the "no boundary" and "no beginning" conclusions, while features of his model, have no ontological import. Why? Because, as we have seen, the path-integral history of the universe is said to be analogous to the path-integral history of a quantum particle, and what is summed in a "cosmic path integral" are all the four-dimensional spaces with specific, well-defined three-spaces as boundaries. The "no-boundary" model depicted in figure 2 represents, in turn, a restriction of the class of four-spaces to a simple subclass of compact ones (e.g., Hartle and Hawking 1983, 2967; Hawking 1984a, 364). In this model there *is* no well-defined origin to time; but to dismiss an origin, and therefore any need for an originator, Hawking must construe realistically the path-integral approach on which the model depends.

Suppose one does this. Then what? The "paths" in ordinary quantum mechanics connect points in configuration space, an abstract entity. But the realistic backdrop for them is the flat spacetime of special relativity. What if one tries in a realistic manner, to extend to gravitiy, i.e., to general relativity, the path-integral version of ordinary QM? Then the corresponding backdrop is an infinite-dimensional manifold or "superspace" (Hartle and Hawking 1983, 2963; Hawking 1984a, 364; Hawking 1987, 640). The reason is the form of the Wheeler-DeWitt equation, of which Hawking's "universal state function" is a solution. Hawking is unable to solve this equation in its general form, so he restricts his applications of it to a finite-dimensional submanifold called a "minisuperspace" (Hartle and Hawking 1983, 2967–72; Hawking 1984a, 364–75; 1987, 640–45). This involves limiting the spaces included in the integral to the ones mentioned earlier, and the infinite number of degrees of freedom of the matter fields to a finite number. Still, the result is that he cannot construe the spaces of his models realistically unless he is also willing to interpret realistically the superspace of which they are a subclass. And this involves a large metaphysical commitment, which physicists should find extravagant and unfounded if the only reason for making it is to avoid an initial spacetime singularity (see Craig 1990, 481, 489).

Some physicists have another reason for making this commitment, however, since they are also prepared to embrace a strongly ontological version of the "many worlds" interpretation of the quantum formalism. Is Hawking prepared to do so? No; although he does seem to think that the "many worlds" approach, properly construed, is in some sense the right one (see Hawking 1983, 192–93; 1984a, 336–37). I shall discuss the construal he prefers in a moment, when I consider his interpretation of the wave-function of the universe. Here I note only that a strongly ontological version of the "many worlds" interpretation is itself so implausible that it does little to enhance the plausibility of a realistically interpreted superspace (see Deltete 1993). I conclude that Hawking does not have the space (literally) for his model to work.

The Universal State-Function. Turn, then, to his interpretation of the universal state-function. In general, Hawking has little patience with the "interpretation problem" in ordinary quantum theory, writing in one place that "my attitude toward those who argue about the interpretation of quantum mechanics is reflected in a paraphrase of Goering's remark: 'When I hear of Schroedinger's cat, I reach for my gun' " (Hawking 1984a, 337). But this will not do, as Hawking must know. Understanding what the wave-function of the universe asserts is crucial to evaluating his proposal. So how does he understand it? For usual quantum situations, Hawking claims, "the Copenhagen Interpretation of quantum mechanics is adequate" (Hawking 1984a, 336; also 1982, 563; 1983, 192). On his reading of this interpretation, a quantum system interacts with an external, classically described observer. Before measurement the state of the quantum system is a linear superposition of different eigenstates of the "observable" measured; but after measurement of one of the eigenvalues of the observable, the system "jumps to the corresponding eigenstate. This is the so-called 'Collapse of the Wavefunction' " (Hawking 1984a, 336; also 1983, 192). I note that the physical intelligibility of this application of quantum theory to individual systems is generally rejected by physicists who embrace the "Copenhagen Interpretation" of its formalism; but let that pass. Hawking certainly knows that his own reading will not work if one wishes to apply quantum theory to the whole universe.[14] So what is the proper interpretation for quantum cosmology?

Here Hawking must confront several difficult and contentious problems, well known to physicists more sympathetic to the problem of interpretation in ordinary quantum theory. To begin with, the usual statistical approaches to quantum mechanics incorporate a strict subject-object dualism between an observer (who makes the measurements) and the quantum system (on which the measurements are made). Such a dualism cannot be present in a naturalistic quantum cosmology, where there must be no references to measurements of the entire system by an external observer. In consequence, there also must be no appeal to any "collapse" of the state vector induced by measurement (see Bell 1981, 615–18). Moreover, there should be no reliance on an "ensemble" of universes and so, it would seem, no appeal to frequentist interpretations of probability. Finally, if Hawking wants a consistent, generally applicable interpretation, and not one designed merely to remove an awkward spacetime singularity, his interpretation must be able to recover ordinary quantum-statistical results when it is applied to sufficiently small subsystems.

This is a tall order, and it is unlikely that Hawking can fill it (see Bell 1981). If nothing else, his own preference for a Copenhagen reading of the quantum wave equation is hugely unpromising. What can take its place? In quantum cosmology, at least, Hawking's proposal is to limit the "many worlds" interpretation to specifying conditional transition probabilities. "In fact," he writes in one place, "I think that the Many Worlds Interpretation simply involves the use of conditional probabilities, that is, the probability that A will occur given B" (Hawking 1984a, 336). In a discussion of his model, Hawking elsewhere expresses the basic idea more formally, using a rule from the standard calculus of probabilities (Hawking 1987, 633). But it seems clear that *this* appeal to the many-worlds interpretation of QM cannot do for Hawking what is required of it. Consider a few of the major problems.

One is that Hawking's "universal state-function" only gives the probability that the universe will be in a given state, not the probability that it will be in that state *given* another (earlier) state. The point is important, so an example may help. The rule of probability on which Hawking relies yields the likelihood (for instance) of drawing a second king from a randomly shuffled deck of cards, given that one king has already been drawn and is not returned to the deck (cf. Hawking 1987, 637–38). By analogy (and in contrast), his state function just gives the probability that the universe is in the "second drawn king" state. But if we then ask what interpretation of probability might sanction such an inference, the answer is that there does not seem to be any: A subjectivist interpretation is absurd, a frequentist interpretation seems precluded (since Hawking does not resort to multiple worlds), and he has no basis for assigning a priori probabilities to states of the universe.

Moreover, even if we set aside the general (and pressing) problem of how Hawking interprets probability, it seems clear that his state-function cannot be regarded as giving a probabilistic distribution for many states of the universe. The reason, as we have seen, is that the "physical" variables in Hawking's state-function can only be interpreted as "evolving" outside the extreme quantum region when time "phases in." But what this suggests is that cosmological probabilities, like time, "emerge" from the formalism, so that in the extreme quantum region (figure 2) that function has *no* physical interpretation (cf. Isham 1988, 403).

Finally, there is perhaps a bit of irony in the expression Hawking gives for the ground-state values (in his universal state function) of the transition probabilities. As noted earlier, the quantum state of the universe, far from the extreme quantum region, should yield "almost classical" solutions. But Hawking's own model calculations suggest that his state-function does not correspond to a single solution of Einstein's field equations, but rather only to a linear superposition of many solutions (see Hawking 1984a, 369–75, 377–78). In short, what results, apparently, is just the problem of Schrödinger's cat writ large! I conclude that Hawking has no plausible realistic interpretation of his universal state function, and that, in consequence, he has no plausible reason for claiming that the universe just IS.

Imaginary Time. Consider, finally, Hawking's use of "imaginary" time. This is the most striking feature of his approach, but it is also the most problematic. Appeal to imaginary time is a commonplace in ordinary (special relativistic) quantum field theory, where it is regarded as little more than a mathematical trick that permits one to compute the path integral (see e.g., Barrow 1991, 91). Does the trick have any physical consequences, that is, does its use alter the physics of the situation? The usual answer is that it does not, although some physicists wonder why it works. Hawking agrees that the invocation of imaginary time in ordinary quantum-field theory *is* just a trick; for example, he writes in one place that "as far as everyday quantum mechanics is concerned, we may regard our use of imaginary time and Euclidean space-time as merely a mathematical device (or trick) to calculate answers about real space-time" (Hawking 1988, 134–35). But he also knows that there are large physical differences in general relativity between spaces in real time and those in imaginary time (e.g., Hawking 1982, 569; Coveney and Highfield 1990, 328–88). So we need to know how he understands the "trick" in quantum cosmology: Is it to be construed instrumentally or realistically?

The answer is that Hawking apparently wants it both ways. Here he is appealing to his instrumentalist "official position": "a scientific theory is just a mathematical model we make to describe our observations: it exists only in our minds. So it is meaningless to ask: Which is real, 'real' or 'imaginary' time? It is simply a matter of which is the more useful description" (Hawking 1988, 139). But if this is Hawking's position, then his model has no ontological import; and his claims to have eliminated an origin to the universe, and so any need for a creator, amount to little more than empty teases. One suspects that Hawking knows this since, on the other hand, he also suggests that (maybe) "so-called imaginary time is really the real time, and that what we call real time is just a figment of our imaginations." He explains his suggestion this way:

> In real time, the universe has a beginning and an end at singularities that form a boundary to space-time and at which the laws of science break down. But in imaginary time, there are no singularities or boundaries. So maybe what we call imaginary time is really more basic, and what we call real is just an idea that we invent to help us describe what we think the universe is like. (Hawking 1988, 139)

It is difficult to know what to make of this proposal, since Hawking immediately follows it with the "official" instrumentalist remark cited above.[15] Moreover, if he takes it seriously, it is not at all obvious what he is suggesting, since (in his philosophical speculations, at least) Hawking seldom uses language as carefully as one would like. The proper reply is therefore twofold. First, he must take imaginary time to be real, if not basic, if his model is to have ontological import. But this is enormously implausible if for no other reason than that it is largely opaque what that could mean. Hawking speaks casually of moving forward and backward in imaginary time, claiming that there is "no important difference" between the directions (Hawking 1988, 143–44). This suggests that imaginary time is symmetric and directionless, which would imply that the extreme quantum region is also directionless, so that the very early universe does not really evolve.

That conclusion is difficult to accept. It also brings me to my second point: Hawking's larger suggestion that imaginary time is basic, and that "what we call real time is just a figment of our imaginations," or a concept "we invent as part of a mathematical model to describe our subjective impressions of the universe," simply will not do. It would seem to render symmetric and directionless the real existence of the *entire* universe, and our experience of time and change illusory; for the time that Hawking suggests may be only an imaginary figment is the internal time that is "constructed" with reference to actually occurring processes (e.g., expansion) and real parameters (e.g., curvature). I can be more precise: "Internal time" is elsewhere said to be the "real time," which may be computed (outside the extreme quantum region) using the "trick" of imaginary time (Hawking 1988, 134–35; quoted above). But if "figment of the imagination" means "illusory," as it seems to in the passage quoted above, then internal time is illusory; and the processes and parameters on which it is based are illusory as well. In consequence, the "arrows of time" to which Hawking devotes lengthy discussions (see 1985a and 1988, chap. 9) are themselves nothing more than figments of our imagination.[16] I take this consequence of his suggestion to be a *reductio ad absurdum* of Hawking's larger "maybe." More generally, I conclude that his invocation of imaginary time cannot plausibly be construed to have realist import.

CONCLUSION

If we now draw together our recent conclusions, what do we find? I have sought to probe beneath the surface of Hawking's popular pronouncements, in an effort to reveal some of their technical bases; and I have tried to critique Hawking's proposal at neither too high nor too low a level. But I have also argued that several of the most basic features of his approach cannot withstand general examination. To take seriously the idea that Hawking's model has eliminated a beginning to spacetime and the universe, and so any need for a creator, we need a plausible way of construing realistically the path-integral version of quantum theory as applied to cosmology, Hawking's own quantum state function for the universe, and his appeal to imaginary time. But, as we have seen, Hawking does not interpret any of these basic features of his approach to quantum cosmology in a plausible, realistic manner. I therefore conclude that he has not defended adequately the provocative implication of his mathematical models that a creator is unnecessary.

NOTES

1. Good recent nontechnical accounts are available in Schwinger (1986), Will (1986), and Wald ([1978] 1992).

2. Indeed, Hawking apparently once told an interviewer: "If there is an edge, . . . then you would really have to invoke God" (reported in Peters 1989, 54).

3. Hawking is evidently facinated by (and pleased with) this result. The reason is that he thinks there should be a simple "law" governing the boundary conditions of the universe, just as there are (or will be) simple laws governing its dynamics (Hawking 1988, 10–11, 123). Otherwise, the universe's initial conditions are arbitrary, or inputs from outside (see, e.g., 1984b, 358). The same statement thus recurs in many of his writings on quantum cosmology (e.g., Hartle and Hawking 1983, 2975; Hawking 1983, 571; 1984a, 337; 1984b, 358; 1984c, 13; 1987, 635). In fact, he recently conjectured that "the no-boundary proposal, like the big-bang, will become one of the background assumptions of cosmology" (Lightman and Brawer 1990, 397).

4. See Feynman and Hibbs (1965) for a lucid, but technical discussion. Less mathematically demanding introductions include Feynman (1985); Gribbon (1986, 129–49); and Gleick (1992, 229–31, 246–51, 254–55). The possible cosmological import of the path-integral approach is discussed in Barrow (1991, 86–88).

5. More technically, the oscillatory integral in the sum-over-histories approach does not converge unless one rotates the time variable to imaginary values in the complex plane.

6. The reason is this: The four dimensional spacetime of a GTR universe may be decomposed into "space-like" and "time-like" intervals, but GTR requires no unique way of doing this. More precisely, there is no unique decomposition of the four-dimensional spacetime of a GTR universe into one-parameter three-spaces, where a single parameter represents "time." The decomposition cannot be done in just any

way (e.g., it has to respect the separation conditions of special relativity), but it can nevertheless be done in many ways (see Drees 1991, 379-80; and Barrow 1991, 86, 88). In this sense "time" is a "construct" that depends on the choice of decomposition.

7. See Hartle and Hawking (1983, 2969), Isham (1988, 398), Davies (1992, 66), and Barrow (1991, 90), for versions of my second diagram. The radius of the three-space is of roughly the same order of magnitude as the Planck length, that is, 10^{-33} cm.

8. Some restrictions are necessary, since not all "stacks" of three-spaces yield anything resembling a spacetime, and of those that do only some recover the predictions of GTR (see Isham 1988, 397; Drees 1991, 380; and Barrow (1991, 80-81, 86-87). Hawking includes only "stacks" that promise to recover, outside the limits of figure 2, the classical predictions of GTR. For his defense of the choice of compact metrics, see Hartle and Hawking (1983, 2965-66), Hawking (1984a, 362-63, 376-77, and 1987, 635-36).

9. The Wheeler-DeWitt equation seeks to extend to gravitational effects the Schrödinger wave equation of ordinary QM. Hawking's "universal state-function" is a solution to this equation.

10. In his popular summaries, Hawking writes of time being "smeared out" in the extreme quantum region (Hawking 1984b, 358; 1984c, 14; 1988, 139), as does Davies (1992, 63), who also speaks of time "emerging from" space (66) and of time "turning into" space (63). The same language is used by Gribbin (1986, 385). Barrow is even more graphic: As one exits the extreme quantum region, "the conventional notion of time as a distinct concept to that of space begins to crystallize out. Conversely, as one approaches the beginning, . . . the conventional picture of time melts away and time becomes indistinguishable from space . . ." (Barrow 1991, 91).

11. It may look as if rotating figure 2 through some angle (thereby making another point on the partial sphere the "south pole") would affect the model, but it does not, since the figure is drawn on a piece of paper, which provides an orienting (but also misleading) coordinate system (see Davies 1992, 67). Instead, one should try to imagine figure 2 with no background space.

12. The idea of "quantum cosmology" is inimical to physicists whose view of QM is primarily instrumental; but there are also enormous technical difficulties in constructing a coherent and consistent QM theory of gravity (see Bell 1981 and Isham 1981). The current favorite for combining general relativity and QM is superstring theory, but it is not at all clear whether this will work (see Davies and Brown 1988). More to the point, Hawking states that GTR and QM "are known to be inconsistent with each other—they cannot both be correct" (Hawking 1988, 12); but his own proposal would join them.

13. Something like the correspondence approach of Niels Bohr seems essential to Hawking's project. Just as Einstein sought a theory of gravitation that corresponded to Newton's in the limit of weak fields, so Hawking (not unreasonably) seeks a quantum theory of gravity that corresponds to Einstein's classical theory outside extreme quantum regions such as that occupied by the very early universe. See Hawking (1987), 631-633, 635, 642, 650; also Pagels (1985), 304.

14. Unless, of course, one is prepared to appeal to God to "collapse" the wave-function of the universe—that is, to make God the "Ultimate Observer,"—which Hawking does not wish to do (see Coveney and Highfield 1990, 133, 327-55).

15. Elsewhere, Hawking is even more provocative: "If you take a positivist position, as I do, questions about reality do not have any meaning. All one can ask is whether imaginary time is useful in formulating mathematical models that describe what we observe. This it certainly is. Indeed, one could take the extreme position and say that imaginary time was really the fundamental concept in which the mathematical model should be formulated. Ordinary time would be a derived concept that we invent as part of a mathematical model to describe our subjective impressions of the universe" (June, 1989; cited by Coveney and Highfield 1990, 145).

16. Hawking argues, for example, that our "psychological arrow" of time (how "we feel time passes," our sense of before and after) is "determined by" a "thermodynamic arrow" (the increase of entropy or disorder) (Hawking 1988, 145, 147). But if the

psychological arrow is illusory, then it would seem that the thermodynamic arrow is too. Hawking does not want to say that (see 144, 146, 149), but his suggestion that imaginary time is both real and basic seems to commit him to it. Put differently, Hawking elsewhere claims that "time is just a coordinate that labels events in the universe" (Hawking 1987, 651); but if this "labeling" is not an objective ordering, then the processes and parameters on which it is based are unreal.

I note that this internal critique seems cogent regardless of whether one thinks that there is an absolute ordering of events, determined by a moving "now" (the position of an A-theorist), or whether one thinks that time is an internal construct (the position of a B-theorist). See Horwith (1987, ch. 2) and Craig (1990, 484–85).

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