

HAWKING'S HISTORY OF TIME: A PLEA FOR THE MISSING PAGE

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One of the outstanding achievements of recent cosmology has been to offer some prospect of a unified explanation of temporal asymmetry. The explanation is in two main parts, and runs something like this. First, the various asymmetries we observe are all thermodynamic in origin – all products of the fact that we live in an epoch in which the universe is far from thermodynamic equilibrium. Second, this thermodynamic disequilibrium is associated with the condition of the universe very soon after the Big Bang – the essential point being that in the rapidly expanding universe of the time, gravity is able to create organisation much faster than other processes can destroy it. The stars, galaxies and other forms of organisation we find in the present universe are all products of this early period. Such concentrated energy sources themselves make possible the kinds of asymmetric phenomena with which we are most familiar, such as life itself.

If this explanation proves to be right it will surely rank as one of the most impressive achievements in the whole of natural philosophy. Where else do we find this breathtaking scale, this extraordinary conjunction of fundamental physics, the first moments of Creation, the possibility of life and the basic character of human experience? And it is very much a contemporary achievement: even if its roots go back on one side to the investigation of time asymmetry in nineteenth century statistical mechanics, and on the other to Hubble's discovery in the 1920's of the expansion of the universe, the body of the picture has only begun to be filled in in the last twenty or thirty years. This fascinating story has recently been given some well-deserved publicity in Stephen Hawking's best-seller, *A Brief History of Time* (Bantam, 1988) – well-deserved, not least, because Hawking himself is responsible for a considerable part of the story as it presently stands.

Hawking's book is a clear and exciting guide to the recent search for a cosmological understanding of temporal asymmetry – a scientific thriller. Despite its merits, however, I think it commits one of the worst sins of that literary genre. The last pages offer us a surprising denouement, but fail to explain its most puzzling aspect. It is as

if we are assured that the butler did it, without being told how he overcame the evident obstacles (the fact that he was already incarcerated in Wormwood Scrubs at the time, for example). If the omission goes unnoticed by the casual reader, it is simply because he or she has not been told enough of the story to see that the climax is so surprising. Such a reader is doubly deprived, for mystery is the heart of a good detective story.

In the case of the story of cosmology and temporal asymmetry, the mystery lies in the fact that the attempt to explain thermodynamic asymmetry in terms of the expansion of the universe from the Big Bang seems to lead to an inevitable and unpalatable dilemma. I'll describe this dilemma in a moment. In effect, it's rather as if the clues point overwhelmingly to two possible suspects, but one turns out to have a perfect alibi and the other to have no possible motive. We can see perfectly well what the two possible solutions are, but individually they both seem untenable. Hawking's popular account of his own contribution serves to mark this dilemma, in that he describes how he was led to change his mind about which of the possible conclusions is the right one. In the process, however, he appears to gloss over the difficulty that has long plagued the conclusion he finally opts for. So it is not clear whether he has found some way around this difficulty, or whether he has perhaps overlooked it. Either way, some clarification seems in order.

The dilemma stems from the fact that the universe may not always expand. If the density of matter is sufficiently great, gravity will eventually reverse the expansion, and the entire universe will collapse to a black hole. What would then happen to entropy? Would entropy decrease as the universe contracted? Or would it go on increasing, to reach its maximum value in the final singularity? Both answers have seemed unsatisfactory, though for quite different reasons.

The problem with the former answer is that it seems to entail that all the ordinary time asymmetries would be reversed as the universe begins to contract. The universe would enter an age of miracles. Radiation would converge on stars, apples would compose themselves in decompost heaps and leap into trees, and humanoids would arise from their own ashes, grow younger, and become unborn. These humanoids wouldn't see things this way, of course. Their psychological time sense would also be reversed, so that from their

point of view their world would look much as ours does to us. The difficulty really lies in managing the transition. They lie in our future, as we lie in theirs. Various sorts of paradoxes seem to arise in the middle. I won't try to describe these problems here. (Interested readers may consult P. C. W. Davies, The Physics of Time Asymmetry, Surrey University Press, 1974, particularly sections 4.5, 5.6 and 7.4; and R. Penrose, 'Singularities and time-asymmetry', in Hawking and Israel, (eds.), General Relativity: An Einstein Centenary Survey, Cambridge University Press, 1979, pp. 581-638, section 12.2.6.) For the moment let me simply note that we can't avoid the problem by supposing (as on present evidence may well be the case) that the universe never contracts. Even if the universe as a whole never re-collapses to a singularity, there is now a very strong case that parts of it do, as certain massive objects collapse to black holes. Does entropy decrease in these cases? If we say that it does, the same sorts of paradoxes seem to arise.

What then of the alternative answer, namely that entropy does not decrease as one approaches a future singularity (either the collapse of the universe as a whole, or the collapse of some part of it)? The problem with this answer is that it makes it mysterious why entropy does decrease in the other direction, as one approaches the singularity at the beginning of the universe. The difficulty stems from the time-symmetric character of the physical theories involved. If these theories imply that entropy was low in the region of this initial singularity, then in virtue of their time-symmetric character, it seems that they should also imply that entropy will be low towards a final singularity – i.e., that entropy decreases as the universe contracts. So if we reject that option, we seem forced to conclude that physical theory does not explain the low initial entropy of our universe. We can't explain temporal asymmetry, in other words, but simply have to accept it as an extra-theoretical 'initial condition'.

This then is the dilemma: either we have to admit reversal of the thermodynamic arrow of time in the case of local or universal gravitational collapse; or temporal asymmetry turns out to be inexplicable after all, since we can't account for the low initial entropy of the universe as a more or less inevitable consequence of our best physical theory of the universe as a whole. The dilemma is particularly acute for Hawking, for he

has an additional reason to avoid resorting to unexplained boundary conditions. For him their effect is not simply to make time asymmetry inexplicable. They also conflict with the spirit of his 'no boundary proposal', namely that one restrict possible histories for the universe to those that 'are finite in extent but have no boundaries, edges, or singularities.' (BHT, p. 148)

Hawking describes how initially he thought that this proposal favoured the former horn of the above dilemma: 'I thought at first that the no boundary condition did indeed imply that disorder would decrease in the contracting phase.' (BHT, p. 150) He changed his mind, however, in response to objections from two colleagues: 'I realized that I had made a mistake: the no boundary condition implied that disorder would in fact continue to increase during the contraction. The thermodynamic and psychological arrows of time would not reverse when the universe begins to contract or inside black holes.' (BHT, p. 150) In an earlier article in New Scientist (9 July 1987, pp. 46-9) Hawking describes his change of mind in this way: 'I then realised that although it was possible for the Universe to contract back to a smooth and ordered state, it was much more likely to contract to a very disordered state, because there are so many more disordered states. Thus the thermodynamic arrow of time will not reverse. It will continue to point in the same direction.' (p. 49)

This change of mind enables Hawking's proposal to avoid the difficulties associated with reversing the thermodynamic arrow of time. What is not clear is how he avoids the alternative difficulties associated with not reversing the thermodynamic arrow of time. That is, Hawking does not explain how his proposal can imply that entropy is low near the big bang, without equally implying that it is low near the 'big crunch' (or in a black hole). The problem was to get a temporally asymmetric consequence from a symmetric physical theory. Hawking suggests that he has done it, but doesn't explain how. Readers are entitled to feel a little dissatisfied. As it stands, Hawking's account reads a bit like a suicide verdict on a man who has been stabbed in the back: not an impossible feat, perhaps, but we'd certainly like to know how it was done.

To my admittedly unqualified eye, there seem to be three possible resolutions of this mystery. The first, obviously, is that Hawking has found a way round the difficulty, but hasn't told us what it is. I think that the easiest way to get an idea of what he would have to have established is to think of three classes of possible universes: those which are smooth and ordered at both temporal extremities, those which are ordered at one extremity but disordered at the other, and those which are disordered at both extremities. If Hawking is right, then he has found a way to exclude the last class, without thereby excluding the second class. In other words, he has found a way to exclude disorder at one temporal extremity of the universe, without excluding disorder at both extremities. Why is this combination the important one? Because if we can't exclude universes with disorder at both extremities, then we haven't explained why our universe doesn't have disorder at both extremities – we know that it has order at at least one temporal extremity, namely the extremity we think of as at the beginning of time. And if we do exclude disorder at both extremities, we are back to the answer that Hawking gave up, namely that order will increase when the universe contracts.

Has Hawking shown that the second class of universal histories, the order-disorder universes, are overwhelmingly probable? If so, then he hasn't yet explained to his lay readers how the trick was turned. What seems clear is that it can't be turned by reflecting on the consequences of the no boundary principle for the state of one temporal extremity of the universe, considered in isolation. For if that worked for the 'initial' state it would also work for the 'final' state; unless of course the argument had illicitly appealed to temporal asymmetry, in applying some constraint to the 'initial' state that it didn't apply to the 'final' state. This is an important point. When we're trying to explain temporal asymmetry, we are not allowed for example to put any weight on the idea that the Big Bang occurs at the start of the universe. After all, how could we tell that we aren't mistaken, and that the Big Bang isn't really the finish of the universe? We must assume that the truth of the matter is that it is neither, and that our ordinary inclination to treat it as the start is just one manifestation of the temporal asymmetry we're trying to explain.

Hawking thus needs an argument that excludes disorder-disorder universes (i.e., universes with high entropy at both temporal extremities), without also excluding order-disorder universes (or, what comes to the same thing, disorder-order universes). The above point suggests that it is impossible to get such an argument from the no boundary proposal (or indeed from any other time-symmetric physical theory), simply by reflecting on its consequences for one temporal extremity. In virtue of the underlying theoretical time symmetry, a consequence for one extremity is also a consequence for the other. What is needed is therefore some more general argument, to the effect that disorder-disorder universes are impossible (or at least overwhelmingly improbable). It needs to be shown that almost all possible universes have at least one ordered temporal extremity – or equivalently, at most one disordered extremity. (As Hawking points out, it will then be quite legitimate to invoke a weak anthropic argument to explain why we regard the ordered extremity thus guaranteed as an initial extremity. In virtue of its consequences for temporal asymmetry elsewhere in the universe, conscious observers are bound to regard this state of order as lying in their past.)

That's the first possibility: Hawking has such an argument, but hasn't explained to his lay public what it is. As I see it, the other possibilities are that Hawking has made one of two mistakes. Either his no boundary proposal does exclude disorder at both temporal extremities of the universe, in which case his mistake was to change his mind about contraction leading to decreasing entropy; or the proposal doesn't exclude disorder at either temporal extremity of the universe, in which case his mistake is to think that the no boundary proposal does away with the need for initial conditions in explaining temporal asymmetry.

The former mistake would be a more pleasing outcome than the latter. For one thing, it would restore the appealing symmetry in time, which Hawking says he originally saw as one of the attractions of the no boundary proposal – a symmetry which is lost if contraction needn't lead to decreasing entropy. More importantly, it would mean that Hawking's explanation of time asymmetry would still be intact – a much happier

conclusion than the latter possibility, the discovery that the no boundary proposal simply fails to deliver its promised benefits, at least in this respect.

What is more, the former mistake might itself have a nice explanation, in terms of the temporally asymmetric character of our ordinary view of the world. One of the manifestations of this ordinary asymmetry is that we regard it as 'natural' for physical systems to be governed by initial constraints, but as highly unnatural for them to be governed by final constraints. We expect events to be determined by their past, but not by their future. Accordingly, we find it much easier to make sense of a universe evolving 'from' tightly constrained initial conditions, than of it evolving 'towards' similarly constrained final conditions. So it would seem odd to say that the universal histories whose discovery led Hawking to change his mind about entropy in the contracting universe – those histories that start with order and finish with disorder – are excluded because they violate a final condition stemming from the no boundary condition. It seems miraculous that the course of the universe at a particular time could be bound by conditions many billions of years in the future.

However, this seeming oddity is surely just a manifestation of our ordinary asymmetric way of looking at time. If we look at things from an atemporal perspective, as we need to if we are to explain temporal asymmetry in a non-circular way, then the oddity vanishes. As I noted earlier, from this perspective it makes no more sense to say that the universe really 'begins' at one temporal extremity and 'evolves' towards the other, than vice versa. So initial and final constraints stand and fall together. If we're entitled to one then we're entitled to the other.

To pay lip service to the need for such an atemporal perspective is one thing, however; to be faithful in practice is quite another. This being so, it is conceivable that Hawking's concession to his colleagues does rest on a breach of faith at precisely this point – on a failure to insist that final constraints are as legitimate as initial constraints in narrowing the class of possible world histories. To show that entropy decreases in a re-contracting universe, we don't need to show that the initial constraints themselves entail that entropy behaves in this way – that they themselves so restrict the class of possible

histories of the universe. We only need to show that the initial and final constraints jointly restrict the possible histories in the appropriate way. Given that much, and of course a plausible argument for both the initial and final constraints, there's nothing mysterious going on. Only a lingering attachment to the ordinary asymmetric perspective makes this use of final conditions look in any way suspicious. (It is true that there is still the mystery of what happens 'at the changeover', when entropy changes direction. But Hawking presumably regards this as a surmountable problem, since he was earlier prepared to advocate this view.)

It may be unfair of me to suggest that Hawking's concession to his colleagues might rest on this sort of conceptual mistake. If so, I apologise, and can only say in my defence that I'm a philosopher, and philosophers and physicists have a longstanding tendency to under-estimate one another. (The tendency is illustrated by Hawking's own gentle dig at twentieth century philosophy in the concluding pages of A Brief History of Time). But I don't think that it is unfair to claim that there is a tantalizing gap in Hawking's popular account of his endeavour to explain the asymmetry of time. I'll happily accept Hawking's verdict, and go back to the analysis of language (or whatever we philosophers do these days), if only he will tell us how the butler pulled it off.

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