Time-Travel and Topology
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Time-travel and Topology

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1. A Problem about Time-travel and Backward Causation

Is time-travel possible? Like most intriguing problems that lie within the shared locus of physics, metaphysics and logic, this question admits of many interpretations, each of which engenders a different line of research. At its most anemic, the issue can be just: Is it possible to tell a story about travel into the past that contains no explicit contradictions? Under the stimulation of physical concerns it may develop into a more challenging problem: Do the laws of physics, as best we understand them, admit of solutions that contain closed time-like curves? And next: Would it be physically possible for a massive object to travel along one of those curves into its own local past? Then: Are the known facts about our universe consistent with it being such a world? And finally: Is time-travel in our universe technologically possible? When prodded in this direction our original question arrives at last on the drawing boards of the engineers, having passed successively through the precincts of the theoretical physicists, the mathematicians, and the astronomers. The most famous result in this research program is that of Gödel (1949), which shows that there exist solutions of the General Relativistic field equations that contain closed time-like curves through every point. David Malament (1985) has advanced our understanding of these solutions by endeavoring to calculate the minimal acceleration needed for time-travel in such a world.

I have remarked this research program only to salute it and wave good-bye. Although it embodies one fascinating way to construe our original question it is not of immediate interest for this essay.

When pushed in a more metaphysical direction, the problem of time-travel, rather than inspiring calculations of fuel consumption, seems to yield paradox. If we could travel into our local past- by whatever means- we could influence that past. Indeed, we could send into that past devices whose usual, reliable effects we know not to have occurred. Most famously, I could put a ticking atomic warhead into my own great-grandmother's hope chest. We know that no such warhead actually exploded. But, it seems, nothing could be expected to prevent the explosion if the warhead were there. So there must be a problem in the original supposition that I could send it.

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The great-grandmatricide scenario combines two distinct sorts of difficulties. The first arises from our reliable knowledge of the past. In this guise, the fact that my great-grandmother is the intended victim has no bearing on the case. We know that no atomic explosion took place which killed my great-grandmother, but also that none demolished Versailles in 1803 or interrupted the 1939 World Series or incinerated Bejing in 1481. A functioning warhead could not be sent anywhere in the recent past and function since that would be inconsistent with what we know about the recent past. Absent any grounds for thinking that something would always prevent the warhead from functioning we might infer that the possibility of free travel into the past must not exist.

This facet of the great-grandmother puzzle has several weaknesses. It depends upon assumptions about the reliability of our knowledge of the past. More importantly, it seems to require some inference from the fact that an event did not happen to the claim that it could not have happened. The relative paucity of atomic explosions in the past does not ensure that future military strategists won't have such options available, only that they won't exercise them if they have them. No paradox here.

The second facet of the great-grandmother scenario is one that does lend an air of paradox. If I do succeed in killing my great-grandmother then I will not have been born and so could not succeed. One side of the paradoxical condition obtains. The other side, though, is much weaker. To have a true paradox we must arrange things so that if I don't succeed in killing her, I will succeed. That is, we need a situation in which the only event that could foil my attempt would be my great-grandmother's premature death. But this seems a very unlikely state of affairs. After all, all sorts of things could happen to stay the hand of murderous intent. Here is David Lewis on an attempted grand-patricide: "Perhaps some noise distracts him at the last moment, perhaps he misses despite all his target practice, perhaps his nerve fails, perhaps he even feels a pang of unaccustomed mercy " (1986, p. 76), a list expanded by Paul Horwich: "Someone out to kill his early self might get distracted, the gun could jam, or a brilliant surgeon might be on hand to remove the bullet from the infant brain " (1987, p. 121).

These *deus ex machina* results may well seem very unsatisfying, and they will come in for more notice shortly. For the moment we should only remark that the circumstances always act to thwart the killing. For if success is logically impossible then failure, however baroquely contrived, must occur.

If we want to focus on more nearly paradoxical situations we should not consider cases of attempting to bring about events that did not happen, for we *know* how such attempts must end. We should rather focus on cases which appear to have no acceptable resolution. Such allegedly paradoxical cases would employ devices which detect backwards-directed effects and act to prevent the cause if and only if the effect is found. One such mechanism is described by John Earman:

> consider a rocket ship which at some space-time point x can fire a probe into the past lobe of the null cone at x. Suppose that the rocket is programmed to fire the probe unless a safety switch is on and that the safety switch is turned on if and only if the 'return' of the probe is detected by a sensing device with which the rocket is equipped (1972, pp. 231-232).

Unlike the great-grandmother case, in which we know how the attempt must end, the paradoxical machine is supposed to admit of no acceptable result. The probe is fired if and only if it isn't detected and it is detected if and only if it is fired. Something has to give, and the most vulnerable premise seems to be the assertion that the probe could be launched into its own past in the first place.

Of course, *deus ex machina* resources are still available. Perhaps someone breaks the sensor so that it can't detect the probe's return, or sets the safety switch even in the probe's absence, or destroys the probe after it is launched. But why can't the rocket exist in an otherwise empty region with no interlopers around? Ultimately, a consistent solution that still admits of time-travel apparently must resort either to conspiracies or to miracles. *Conspiracies* require the initial conditions of the universe to be constrained in unexpected ways. For example, every region in which a return journey by a murderous individual into the past occurs might be nomically constrained to also contain a brilliant neurosurgeon, or some other protective agency. *Miracles* would resolve threatened paradoxes not by constraining initial conditions but by suspending the laws of physics themselves. Even if saboteurs don't disable the rocket's sensors, paradox could still be avoided by supposing that the probe returns yet the rocket, though not tampered with, fails to detect it. It fails not through any defect of construction but because the laws of physics themselves go on holiday. Light refuses to propagate along null trajectories, charged particles ignore electric fields, free quarks wander out of nuclei. Clearly, by such expedients paradox can be evaded.

The fundamentally unsatisfying feature of the employment of conspiracies and miracles is that we have absolutely no principles governing when or how the miracle or conspiracy will appear. *Something* will prevent the assassination. Does it do so by saving the shot victim, deflecting the bullet, distracting the assassin, or perhaps by preventing the time-travel in the first place? Who is to say?

Miracles and conspiracies are logically possible and they can certainly rid tales of time-travel of incipient paradoxes. If all one wants of possible time-travel is the possibility ensured by such means then little more need be said. But there is a more interesting physical question. Miracles and conspiracies are rejected in serious physical inquiry. To admit miracles is to abandon the search for universally valid laws. Conspiracies are not so directly repugnant, but are still unacceptable refuges. The uniformity of the background microwave radiation might be "explained " by a law imposing uniformity on initial conditions, but no cosmologist would descend to such depths. We might also cite the question of locality in quantum mechanics: any actual experimental results in a Bell-type correlated pair experiment can be accounted for in a local deterministic way if we allow conspiracies. In such a theory there must be many possible measurements which- had they been made- would have falsified quantum mechanics. But we need only add the conspiratorial condition that we always happen to make the measurements which are in accord with the quantum mechanical predictions. Again, such a theory is logically possible, but is not physically interesting.

So we now have a relatively clear question to ask. Is time-travel possible without the expedient of miracles or conspiracies used to avoid paradox? Must a device such as Earman describes lead to paradoxical results if *deus ex machina* resolutions are barred?

2. The Solution of Wheeler and Feynman

Our question is not yet completely precise. We would first have to specify the physical laws and the exact construction of the device to know whether a consistent operation of the machine in accordance with the laws and design specifications is possible. But for a wide class of physical laws a resolution to this problem has been claimed. The resolution was advanced by John Wheeler and Richard Feynman when presenting their theory of electro-dynamics in terms of advanced and retarded potentials (Wheeler and Feynman 1949, p. 427-8). Their suggestion has not, I think, received sufficient attention in the philosophical literature.[1] Wheeler and Feynman claim that for any set of physical laws that are *continuous* a satisfactory resolution of the allegedly paradoxical situation will exist, a solution requiring no miracles or conspiracies. Let us briefly review their claim, using an example devised by C.J.S. Clarke for this purpose (1977, pp. 102-3).

Consider a proposed paradoxical device that consists of a box containing a gun, a target, and a shutter . The shutter, when closed, prevents the bullet from escaping the box. The shutter closes if and only if the target is struck by a bullet. This box is to be sent into its own past, aimed at its former self, and fired (see figure 1). The paradox is supposed to

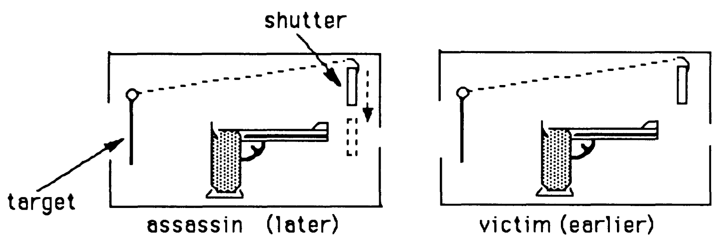

Figure 1

follow: if the shutter on the assassin box is up then the victim box will be hit, causing its shutter at a later time to be closed. If the shutter on the assassin box is closed then the victim box will not be hit, so its shutter will remain up. But the victim box at a later (proper) time is the assassin box, so both possibilities require the assassin shutter to be both open and closed. Graphically, we may represent the situation as in figure 2.

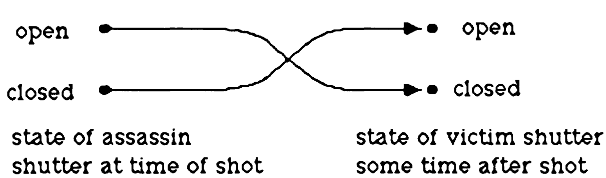

Figure 2

Wheeler and Feynman begin by noting that such a discussion presupposes that the shutter can exist in only two discrete states, up and down. But classically there is actually a continuum of states physically available to it, a continuum that connects these two extremes. Thus we should really represent the possible states of the assassin and victim boxes by line segments (figure 3). Under the assumption that the laws

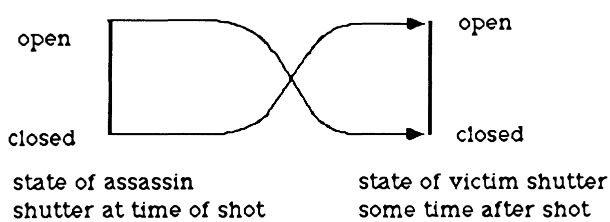

Figure 3

governing the time evolution of the system are continuous, the mapping from the state of the assassin box to that of the victim is also continuous. So as we move from the extreme up position to the extreme down position in the domain of the mapping the image point in the range must move continuously from down to up. Clearly, at least one equilibrium point must be passed, providing the consistent solution to the problem (figure 4). In the solution the bullet glances off the partially lowered shutter causing it to just nick the target, which causes the shutter to be only partly closed at the time of the shot.

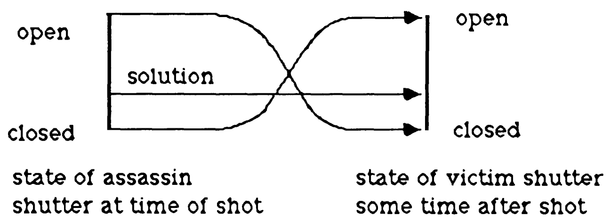

Figure 4

Such an event may seem amazing, even miraculous, but neither miracles nor conspiracies (as we have defined them) have been invoked. The device works exactly in accord with design specifications and with no outside interference, yet paradox is avoided. The only assumptions we have made are those of the continuity of the states of the shutter, bullet and target and the continuity of the dynamical laws. If these are granted, we can make the mechanism as complicated as we like, attempt to provide any failsafe, add human observers, but will still have the same result.[2] For only continuity has been appealed to in deriving the result.

What can we infer from this analysis? Wheeler and Feynman present the solution and conclude that backward causation need imply no paradoxes. Clarke is quite explicit about the adequacy of the analysis: "The general features of this situation are applicable to all paradoxical arrangements. At a local level the ordinary equations of physics can be written down. They then must be solved in a global context which is abnormal " (1977, p. 103). The availability of such a solution in all cases would eliminate any criticism of time-travel or reverse causation based in paradox.

This result would render some arguments in the philosophical literature powerless. Consider the conclusion Earman draws from his example:

> The existence of closed timelike or null curves imposes consistency conditions on any equations governing the time development of some physical system; in typical cases, these conditions are very severe indeed, and may exclude all save a single physically interesting solution. But in our universe, such conditions do not seem to prevail- we have not discovered any restriction of 'initial data' other than those already implied by known laws (e.g., Einstein's field equations); so from local observations we may form reasonable opinions about the global structure of space-time- in this case the opinion that no closed timelike curves pass through our region of space-time. (1972, p. 233)

In short, paradoxical devices mean that time-travel and backward causation imply conspiracies. But we don't see any conspiracies in fact, so time travel must not exist around here. Paul Horwich's recent book contains a chapter which is sympathetic to the possibility of time-travel, but he also accepts that conspiracies may be needed to block paradoxical results (1987, pp. 123-125). But if Wheeler and Feynman are right, Earman and Horwich have been misled. *Any* initial data can be continued to a consistent global solution in these cases.

Is Wheeler and Feynman's argument conclusive? In fact it is not, but we must go to some lengths to circumvent it. Paradoxical devices can be designed, but not so easily as one might think.

Let's return to Clarke's example. Clarke suggests that the continuity of the laws alone guarantees the existence of a consistent solution to the problem. Continuity, though, is only one part of the story. We are considering a continuous map from the state of the assassin shutter, which can be anywhere between up and down, between 1 and 0, to the state of the victim shutter some time after the shot (as long after as it takes from the victim to return in time and become assassin). The consistency requirement is that the two values be equal, since the time-advanced victim is the assassin. The existence of an acceptable solution follows from a fixed-point theorem: any continuous map from the region between 0 and 1 into itself must contain a fixed point, a value mapped onto itself. Such fixed-point theorems are extremely powerful and cover a wide range of cases. But they are not universal. Any continuous map from a closed line segment into itself or from a closed disk into itself must contain a fixed point, but a continuous map from a ring or a torus onto itself need not. So details about the topological features of our device are of central importance for the applicability of the Wheeler-Feynman argument.

To take the simplest case, suppose our device contains only one degree of freedom, like the shutter position in Clarke's mechanism, or (presumably) the output of the sensor in Earman's. If that degree of freedom varies between extremes along a simple line segment a solution will always exist. But if the degree of freedom varies in a space that is not topologically simple, the Wheeler-Feynman argument may break down.

We begin to design our paradoxical device by modifying Clarke's mechanism to have a cylindrical target as in figure 5. The target must be very densely packed with sensors- so densely that any bullet impacting in the shaded region will squarely hit many sensors. It may, of course, also strike some sensors only a glancing blow, but this will have no important consequences, as we will see. We send the device on a nearly closed time-like trajectory so that the gun of the returning mechanism sits in the middle of the target of its younger self. At that point the gun is programmed to fire (figure 6). Our target still has edges, at the top and bottom of the cylinder, but the edges no longer come into the analysis. In Clarke's device one could not avoid solutions in which the bullet delivers only a glancing blow to the target since in some states the bullet hits, in others it misses, and there is a continuous transition between. But in all of the cases in the new device the bullet will hit somewhere in the shaded region of the target. It would be nice to ensure this by constraining the gun only to rotate in the plane of the cylinder's cross-section, but as we will later see this is impossible.

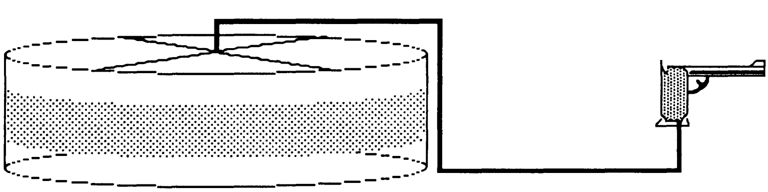

Figure 5

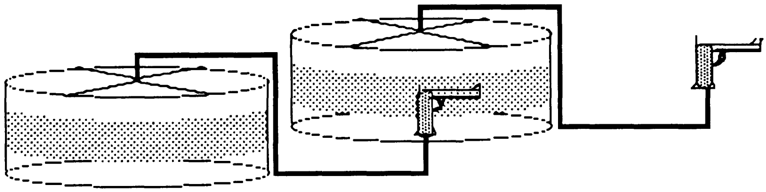

Figure 6

We wish to program the device with the following instructions: if a bullet hits the target at any point θ, point the gun to aim at θ + 180°. That is, we wish to effect the following map from the state of the assassin gun to the state of the victim gun at some time shortly after being shot (see figure 7). This map contains no fixed points, and hence no consistent solutions.

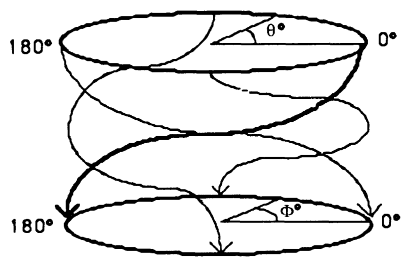

Figure 7

It is not so easy to manage this feat as it first seems. How are we to instruct the device to get from its initial state at 0° to θ + 180°? Suppose we constrain the gun to rotate in the plane. We tell it to rotate to θ + 180° either clockwise or counterclockwise, whichever is shorter. Then if the bullet strikes at exactly 0° the machine will be paralyzed. Unable to decide between rotating clockwise or counterclockwise the gun will remain frozen at 0°, thus firing at exactly the right place.

This fortuitous result may appear to be an artifact of our programming strategy, but in fact if the gun is constrained to rotate in the plane, *any* program for getting it from 0° to θ + 180° will suffer a similar fate. This follows from the topology of the situation.

Let us represent the state of the pair victim-and-assassin considered as a system. Since the state of each member of the pair is described by a point in a circular state space the state of the system is represented by a point on the torus (figure 8). The position of the victim gun is represented by the angle Φ, that of the assassin by q. At the moment the bullet is fired we know only that the state of the composite system will lie in the ring R. The victim gun begins pointing at 0°, the assassin gun can be in any state as far as we now know. After the requisite time, when the victim returns as attacker, the consistency condition is that the state of the "composite " system must lie along the line S, the set of points where $\Phi = \theta$ (figure 9). θ still represents the position of the assassin gun when fired, Φ the state of the victim gun generated from the position of impact of the bullet and the laws of time evolution. If the gun is constrained to move in the plane, then the state of the composite system must always remain in the torus. The possible time evolutions of the system after the bullet is fired will then be represented by a continuous deformation of the ring R that keeps the ring in the torus.

But no matter how we deform R, it must obviously always intersect S somewhere. So any continuous laws governing the time evolution of the device will again contain a consistent solution. We know where we want the gun to point (θ + 180°), but no mechanism that always turns the gun in the plane can guarantee that it will get there.

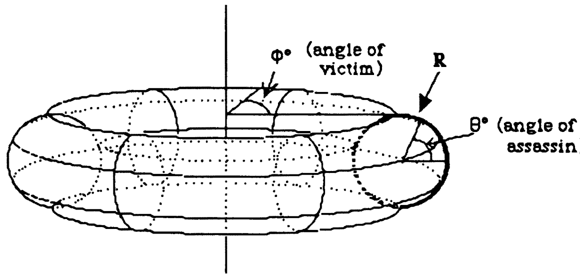

Figure 8

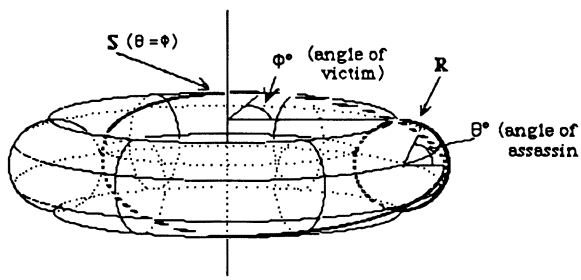

Figure 9

We seek a continuous time evolution that will take the ring R into the curve T (figure 10)- a curve that nowhere intersects the solution locus S. No such evolution exists which remains in the torus since R and T are topologically inequivalent, but one does exist if we are allowed to leave the torus. This means that the gun must be allowed to swing out of the plane.

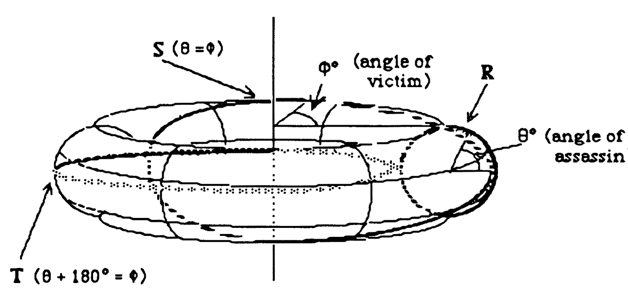

Figure 10

We finally have a truly paradoxical device. It is depicted in figure 5 and operates as follows. When a bullet hits the target at a position q the sensors struck send a command to move the gun so that it points towards θ + 180°. The gun will not move in the plane but along the paths depicted in figure 11. We may suppose that each sensor at θ controls an electro-magnet that slides along the path from 0° to θ + 180°. Since many of the sensors will be hit solidly by the bullet, a large number of magnets will be turned on and travel to θ + 180°, pulling the gun in tow. Some sensors may be hit marginally, causing their associated magnets to be only partially activated, but their effect will be overwhelmed by that of the fully functioning magnets. If all of the magnets are programmed to complete their journey in a minute, a minute after the bullet strikes the victim gun will be pointing to θ + 180°. So if we send the device on a journey into its own past, a journey designed to place the gun in the center of the target of its former self and fire, and if the return trip takes more than a minute in the proper time of the mechanism, we finally get a paradoxical result. There is no consistent solution in this situation even though the laws and operation of the device are completely continuous.

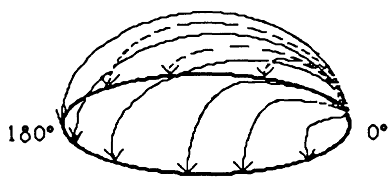

Figure 11

3. Quantum Mechanics to the Rescue?

So far we have traced out the implications of backwards causation or time-travel for any device that admits of a continuous range of states and is governed by continuous, deterministic laws. It is natural to wonder what changes in the analysis would be occasioned by taking quantum mechanical considerations into account. This discussion must be sketchy since we cannot present in full detail a quantum mechanical description of a system such as we have designed. But some useful conclusions can be drawn.

At first glance, quantum theory would seem to make things much worse for the Wheeler-Feynman strategy. Their argument depends vitally on the continuity of states of the device and of the laws of dynamic evolution. But quantum mechanical systems may not admit of a continuum of physically possible states. Furthermore, it is not entirely clear whether the laws of evolution will be continuous. The Schroedinger equation is, but the mechanism of wave collapse, if any such process occurs in nature, is at present entirely unknown.

Clarke notes, however, that the adoption of quantum mechanics is a two-edged sword: "It is of no avail to replace the mechanical gun and target by a quantum mechanical decaying atom and Geiger counter, for example. What one might gain in discreteness one loses in indeterminacy: even if the shutter were to close fully, there would still be a finite probability of the emitted particle tunnelling through it and so triggering the counter" (1977, p. 103-4).

We have been assuming that we can predict with accuracy how the device will function in various conditions. But perhaps quantum mechanics provides a loophole: the bullet could tunnel through the sensors without triggering them, or could be refracted upon leaving the gun barrel and hit 180° away from where the gun is pointing, or... It would be impossible to catalogue all of the strange results that could occur consistent with the quantum mechanical laws.

But this appeal to quantum mechanics entails even worse consequences than the acceptance of conspiracies. For quantum mechanics does not simply list the possible dynamical evolutions open to a system, it also assigns probabilities to them. And since our machine is a normal macroscopic device, we know that the probabilities assigned to classical or nearly classical evolutions will be unimaginably close to 1. Bizarre events are quantum mechanically possible, but highly improbable.

So what would it mean to say that *whenever* a paradoxical device is built one of the highly improbable events would occur? That would just be to say that quantum mechanics is false. The long run frequencies associated with the operation of such devices *could not* (not merely might not) even vaguely approach the predictions of quantum mechanics. And although the connection between probability, propensity, and frequency is debatable, it seems safe to say that if a theory assigns a high probability to an event that is nomically constrained not to occur, that theory has failed.[3]

If time-travel is possible for objects with basically the same physical characteristics as guns and sensors then we must accept nomically ordained conspiracies. Not every sort of data can be put on a space-like hypersurface that predates the time travel because not every set of such data will have a consistent continuation on the space-time manifold. Initial conditions that would give rise to devices like that of figure 5 executing trips into their own past and firing on themselves must be ruled out. We have no principle telling us how they are to be ruled out, for this constraint arises from no usual law. Such conspiracies are the minimum price one must pay for time-travel.

4. Is the Price Too High?

What attitude should one take to this result? Three, at least, are possible: the metaphysically liberal, the metaphysically conservative, and the empirical. For the metaphysical liberal the answer to our original question is clearly affirmative: time-travel is possible. True, there are certain things that we cannot do if we can send things back in time. We cannot construct devices such as that of figure 5, send them back, and have them function according to design specifications and without outside interference. This will be either because we are prevented sending them back (conspiracy), or they won't function (miracle) or they are always interfered with (conspiracy). But conspiracies and miracles are possible, hence so is time travel.

The metaphysical conservative would argue that a world with conspiracies or miracles is so radically unlike our world as not to be, in an interesting sense, a possibility accessible to us. Our world seems to be governed by laws that can be formulated as local differential equations, laws that either dictate or highly constrain the future state of the world given its present state. Any attempt to formulate a principle governing conspiracies would violate these requirements. The need for a conspiracy can only be discovered from global, not local, considerations. And the form of the conspiracy is, as far as we can deduce, entirely arbitrary. It is hard to imagine a law of the form: There must be *something* that prevents the gun from firing.

Finally, the empirical approach sidesteps the thorny problem of metaphysical possibility in favor of a simpler question: not whether time-travel is possible but whether it is actual. This seems to be Earman's tack in the passage cited above. Having concluded that time-travel imposes restrictions on initial data, Earman remarks that we have not discovered any such restrictions, and concludes that no closed time-like curves pass through our region of space-time.

Earman's inference depends on two tacit premises. First he assumes that the restrictions on initial data would have to be *salient* and second that they would be *severe* . Salience is a matter of how noticeable the restrictions would be outside of the incipient paradoxical situation itself. It is hard to address the question of salience exactly because we have no principle governing the nature of the conspiracy. But one could imagine microscopic conspiracies, involving very subtle correlations between a widely scattered collection of particles. Just before the gun is to fire the particles coalesce into (say) a small wad of chewing gum and jam the trigger mechanism. Before the critical moment, though, there might be nothing macroscopically odd about the situation. So if there actually are constraints on initial conditions which derive from the existence of backwards causation or time travel, we have no positive reason to feel confident that those constraints would be obvious.

Severity concerns not the nature of the conspiracies but their number. Roughly, we would like a measure of severity to be a measure of the space of initial conditions which are forbidden by consistency conditions. Since we have no *a priori* measure over the space of initial conditions, no precise quantification of severity is available. Still, our argument sheds some light on the question of severity, at least with respect to conspiracies required to avoid paradox.

We have seen that if the physical laws are continuous, paradoxical situations are rather hard to come by. Merely positing a reciprocal causal dependence of the past on the future does not make self-defeating causal loops inevitable, or even likely. Indeed, very general topological conditions must govern the causal situation in order for paradox to occur. These topological conditions are quite unlikely to arise spontaneously or inadvertently. It is hard to imagine that an object with just the sort of structure needed would arise except by conscious design. So conspiracies needed to avoid paradox would be required in only so many cases as there are of people trying hard, and with some sophistication, to create paradox. Even if such conspiracies are salient, then, it is unlikely that we would happen to meet with them frequently enough to arouse our curiosity.

Of course, restrictions on initial data, or data on a space-like hypersurface, may arise from sources other than threats of paradox. If spacetime is like a cylinder, closed in the time-like direction, then only very special data on a Cauchy surface will yield a consistent solution since the fields and particles must evolve so as to return to the same state after the characteristic period. Such restrictions arise from the topology of the spacetime and could be analyzed only through a close consideration of the laws of evolution. Our considerations have been much more general and cover a wider variety of cases. Space-time, for example, may be topologically simple but paradox still threaten due to backward causation. This is the case that worried Wheeler and Feynman, not a case of time-travel. To generate the paradox without time-travel we could build a device with a gun sitting in the middle of the cylindrical target. The sensors in the target are connected to a transmitter that would send a signal into the past, commanding the gun to point to $\theta + 180°$. Again, no consistent operation of the device is possible.

If we seek all of the restrictions on initial data that might result from time-travel our investigation has been by no means exhaustive. We can conclude, however, that causal paradox, the possibility of mechanisms whose structure admits of no consistent operation, is unlikely to be a frequent problem demanding conspiracies. Therefore empirical considerations arising from causal paradox will not rule out time-travel even in our region of the universe.

On the other hand we have discovered, *contra* Wheeler and Feynman, that continuity considerations alone cannot solve all threatened paradoxes. If time-travel is possible for humans or if backward causation can be used to send signals, then conspiracies must prevent the construction and operation of devices which would be permissible according to all other laws of physics. Such conspiracies would constitute a radical departure from our present understanding of physical law and physical constraints.

Wheeler and Feynman begin their discussion of the paradox of advanced action remarking that a physical theory, even when describing idealized conditions, "must be self-consistent" (p. 427). From their ensuing discussion it is clear that they mean that a solution to the threat of paradox must arise naturally from within the theory itself, not by the simple expedient of stipulating that troublesome experimental arrangements are to be proscribed as initial data. Their continuity argument is an ingenious attempt to derive such a solution without *ad hoc* assumptions. However, they generalize too readily from a single example: continuity alone does not ensure consistency. So by their own standards, the physical theory they present would not be acceptable. Similarly, Godel took the possibility of paradox as an objection to his solution of the field equations, and showed on good physical grounds that a device like that which we have envisaged could not be sent on a trip into its own past. Of course, in so responding to the threat Godel also forecloses time travel as it is usually understood. Every closed time-like curve in his model is an ignis fatuus for the aspiring autoinfanticide.

Standards of metaphysicians are much more vague than those of these physicists. Philosophers often do not feel obliged to show that paradoxes are resolved by some natural mechanism that arises from a hypothesis, but instead rest content with appeals to *deus ex machina* scenarios. This promotes hypotheses that are less rather than more detailed in structure, and hence less liable to falsification. It also produces a less satisfying result. Lewis's appeal to conspiracies in the avoidance of paradox is not nearly as stimulating as Wheeler and Feynman's project. Lewis is content to argue that time-travel is not *per se* impossible while Wheeler and Feynman attempt to show exactly how backward causation is possible.

The gap between the standards of the philosophers and those of the physicists is worthy of some reflection. Kripke has taught us that metaphysical possibility is tied to actual facts much more closely than had been appreciated. The closer metaphysical possibility approaches to physical possibility, the more one should feel obliged to provide detailed physical considerations to defend metaphysical claims. For to show that time-travel is possible in situations whose nomological structure is radically different from that of our universe is not to show that time-travel is possible for us.

Notes

[1]Mary Hesse cites the paper (1962, pp. 283-4), but dismisses the argument rather summarily. C. J. S. Clarke, in contrast, considers Wheeler and Feynman to have completely resolved all paradoxes, at least in the classical domain (Clarke 1977, pp. 102-3). Earman briefly notes the argument (1972, p. 235) objecting to the assumption of continuity as "brazen". Paul Horwich's recent book (1987) contains no discussion of it.

[2]Wheeler and Feynman stipulate that human agencies must be eliminated (1949, p. 427), but so long as human bodies are governed by the same laws, their addition will not affect the argument. The only assumption used is that the laws be continuous and so effect a continuous map from domain to range.

[3]The picture suggested by Clarke's comments- that nature always chooses the result that is quantum mechanically permissible and that avoids paradox- also seems to allow circumvention of the no-Bell-telephone theorems. All we need to do is set up an EPR-type experiment with, e.g., correlated electron pairs and spin analyzers set in the same direction. On the "send " wing of the experiment I have a paradoxical device which will be set in action if a switch is thrown. By coupling the switch to the up-outcome on the analyzer I can virtually assure that my electron will be down, since the down result avoids paradox. Because the pairs are strictly anti-correlated, this means I can also control the result on the other wing. By alternately coupling the paradoxical device to the up and down results on my end I can send a super-luminal message.

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