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Time Travel: Double Your Fun

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Abstract

I start off by relating the standard philosophical account of what time travel is to models of time travel that have recently been discussed by physicists. I then discuss some puzzles associated with time travel. I conclude that philosophers' arguments against time travel are relevant when assessing the likelihood of the occurrence time travel in our world, and are relevant to the assessment whether time travel is physically possible.

1. You Don't Want to Know

Things are not going well. Last night I called my friend Jur in Holland and complained about living in this lawless country in which they don't even need warrants for wire-tapping. Turns out, my phone was wire-tapped. Long story short: I am sitting at Newark Airport, waiting for my flight to Guantanamo Bay. I don't handle that kind of prospect well. Suicide seems like a plan. No guns at hand though. Hm, I guess I will just have to build a time-travel machine when I get out. Then I will be able to travel back to just about here and now, and kill my younger self, thereby preventing my rather depressing future (see Figure 1). Not being a philosopher, I don't worry much about the coherence of this idea. Rather, I am musing about who else to take out while I am at it. Suddenly a crazed old man with a really bad limp appears out of nowhere with a gun pointed at me. Fear takes

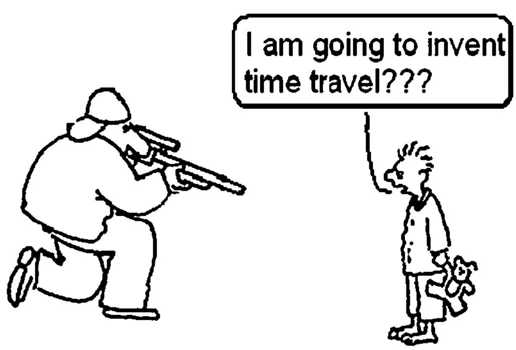

Fig. 1.

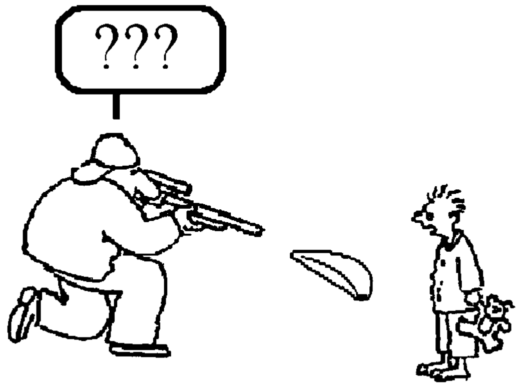

Fig. 2.

over and I start running. The old loon runs after me and tries to shoot me. However, his limp is a problem and he only manages to hit me in the leg. My guards wrestle him to the ground and take his gun off him. "You idiot" the old man yells at me, in a voice that sounds surprisingly familiar. Uh oh; I am getting that sick feeling at the pit of my stomach. The old man continues "I am you, you moron! Why did you run? I was trying to erase 40 years of hell!" Damn.

2. Banana Peels, Anyone?

Time travel apparently confers upon us the Stalinesque capability to re-write history and the Stalinesque desire to kill some of our closest relatives. As appealing as this might sound, it has been argued that there are problems with time travel. Some have claimed that time travelers have little or no freedom of action. Some have argued that time travel implies conspiracies of a type that we never see, so that we can safely infer that there is no time travel in our world. Some have even argued that time travel is flat out impossible (see Figure 2). The literature on time travel and its problems is voluminous, too voluminous. I will restrict myself to just a few remarks regarding some of the more entertaining time-travel arguments.

Let me start by indicating what I regard as the most interesting kind of time travel. That would be the kind where our time traveler, let's call him Jimmy, stays in one and the same world, and this world has a single, determinate and coherent, history. So no traveling to other worlds, no fading newspapers, and no messing around with truth. It would also be nice if, after traveling back in time, Jimmy affects things around him in much the same way that people normally affect things around them, and if no deus ex machina is needed to avoid logical catastrophe. So, preferably, no inexplicable memory lapses, no unusual impotence, and no fortuitous banana peels. Let's see whether we can have all that.

3. The Before and After

In 1971 Jimmy Hoffa is pardoned by President Nixon and released from jail. In 1975 Nixon reminds Hoffa that he owes him $300,000 for the pardon. Hoffa goes to see a mafia boss by the name of Anthony "Tony Pro" Provenzano. (As we will see in a minute, "Tony Pro" in fact just is Hoffa's older self.) "Tony Pro" gives Hoffa the $300,000 he needs. Hoffa hands the money over to Nixon, and gets into a time machine (provided to him by the Republican Party), so that he mysteriously disappears from the public eye. Hoffa travels back to 1964 and starts calling himself Anthony "Tony Pro" Provenzano. "Tony Pro," with the cooperation of Hoffa, manages to get the Teamsters union under the control of organized crime. "Tony Pro" agrees to pay Hoffa $300,000 in reward for his help. Later on in 1964 Hoffa is arrested and convicted of having illegal connections with organized crime. Eleven years later "Tony Pro" pays off his debt to Hoffa, and "Tony Pro" lives happily ever after.

One could argue that the above story is incoherent. For, on the one hand, according to the story Hoffa gives the $300,000 to Nixon *before* he travels back in time and starts to make that money (under the name of "Tony Pro"). On the other hand, according to the story Hoffa gives the money to Nixon *after* "Tony Pro" makes the money (with Hoffa's help). But one event can not happen both before and after another event.

There is a standard answer to this problem, namely the one given by David Lewis ("Paradoxes of Time Travel"). His suggestion is that in addition to the ordinary person-independent notion of time, "external time," one has to introduce the notion of "personal time." His idea is something like this. If Jimmy carries a watch with him on his travels, then his personal time is measured by that watch. If Jimmy is not carrying a watch then his personal time corresponds to the amount of time it would normally take him to age the amount that he has aged. If Jimmy is an immutable rock, then the rock's personal time is the time that *would be* indicated by a watch *were* the rock to have carried a watch. (Lewis doesn't make such an appeal to counterfactuals. Indeed, one might be squeamish about an appeal to counterfactuals. No need to worry: we will soon see that general relativity takes care of this problem.)

So, the proposed solution to our worry is that the money hand-over takes place *after* the money is earned in *external* time, but the money is earned after it is handed over in Jimmy's *personal* time. Indeed, it might seem that it is precisely this distinction between personal time and external time that allows one to speak of time travel in the first place. Time travel just amounts to a mismatch between personal time and external time. Problem is, this account ain't quite right. That is to say, it ain't quite right according to the best theory of space and time which we have, namely general relativity. To get a better grip on the issue let me say something about general relativity.

Let's start with the notion of personal time. One of the basic assumptions of general relativity is that every path P in space-time has a unique objective (space-time) length.[1] Moreover, one can show that when a (well-constructed) clock travels at less than the speed of light from space-time point A to space-time point B along path P, then the difference between what the clock reads at A and what it reads at B corresponds exactly to the space-time length of path P between A and B. (A path which is such that an object following it always travels at less than the speed of light, is called a "time-like" path.) Ignoring the fact that people are fat, there is a unique time-like path that any person traces out during the course of her life, her so-called "world-line." So we can identify a person P's personal time lapse between events A and B which lie on her world-line, with the space-time length of P's world-line between A and B. (Since it will turn out that we will not need to worry about how to extend someone's personal time to events that are *close* to her world-line, though not exactly *on* her world-line, I will not address that issue.)

Let's now discuss the notion of external time. General relativistic space-times typically can be completely sliced up ("foliated") into "time-slices," i.e. sliced up into mutually exclusive and jointly exhaustive sets of events where all events in the same set can coherently be considered to all occur simultaneously. However, typically there are many *distinct*, equally good, ways of doing this slicing. In short, there is no natural unique notion of "external time" in general relativistic space-times.

Now, this non-uniqueness problem doesn't quite scupper Lewis's account of time travel, at least not when it comes to *backwards* time travel. (I will return to the issue of *forwards* time travel at the end of this section.) For, typically, when two locations in space-time are situated in such a way that one can get from the one to the other while traveling at less than the speed of light, then all coherent time-slicings will agree as to which event occurs earlier and which later. So it seems Lewis can maintain that P travels *back* in time if there are two events, A and B, on P's world-line such that according to P's personal time A occurs before B while according to any admissible time-slicing A occurs after B.

But there is another problem. According to general relativity the very space-times that allow time-travel rule out the existence of even a single coherent global external time. Let me be more precise. There exist general relativistic space-times which contain "closed time-like curves" (looped time-like paths). For brevity, I will henceforth refer to "closed time-like curves" as "CTCs". Now, in such space-times there will also be time-like paths which do not quite form a loop, but which are close to forming a loop. Any object following such a path will travel at less than the speed of light and yet there will be events (or, at least, space-time locations) such that the object comes close to such an event on two separate occasions during the course of its life. This seems as good an instantiation of the notion of time travel as one could hope for. So I will call space-times with CTCs "time travel space-times."

Unfortunately, in time travel space-times there can be no coherent global external time. That is to say, a space-time with CTCs can not be completely

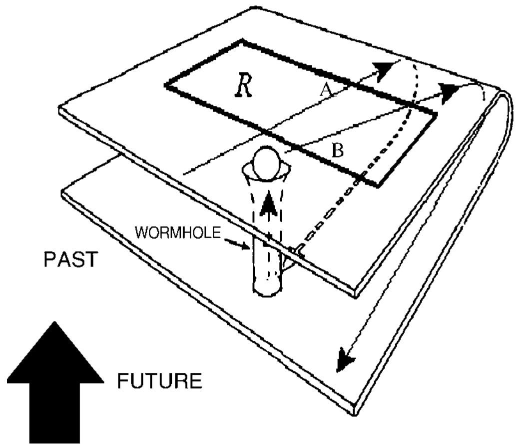

Fig. 3.

and coherently sliced up into an ordered series of times. (I will not prove this, but the example immediately below will illustrate why one can not slice time-travel space-times into time-slices.) So the best models that we have of backwards time travel in modern physics rule out the standard philosophical characterization of time travel. What to do?

Here is a suggestion. Suppose there is some (connected, 4-dimensional) sub-region R of space-time which one *can* slice up into time-slices, so that one can define an external time *confined to R*. Now suppose that there is a person whose world-line W partially lies in R. Then we can say that person P travels back in time if there are events A and B such that according to P's personal time A occurs before B while according to R's external time B occurs before A. Figure 3 shows an example: a ball time-traveling through a wormhole. The depicted space-time is constructed as follows. One starts with a temporally oriented Minkowski space-time; so there is an objective distinction between the future and past directions everywhere. One then "folds" this space-time, and adds a wormhole connection.[2] The wormhole connection allows time travel to occur, but it is also fairly obvious that the wormhole leads to a problem for the project of slicing the space-time completely into (non-overlapping) time-slices. For how should one extend a time-slice that hits one of the "mouths" of the wormhole?

Now, region R is just a (flat) rectangular part of the original Minkowski space-time, so R can be sliced up into time slices. If one can get from B to A while remaining in R and traveling at less than the speed of light, then, according to any allowable time-slicing of R, A occurs after B. But according to the ball's "personal time" event B occurs after event A, since one can get from A to B along the ball's world-line while always traveling in the future direction. So according to the suggested account of time travel, the ball time travels. So there exists a general relativistically acceptable notion of "external time," which, while being neither global nor unique, can be used to

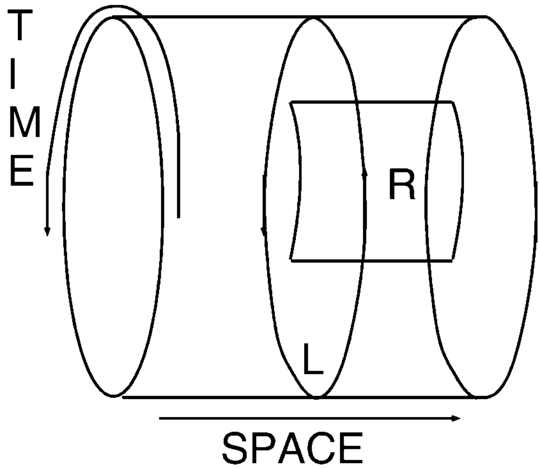

Fig. 4.

characterize when backwards time travel occurs. Great. There are just three minor issues to be cleared up, and then we can get on with a discussion of the mother of all time-travel paradoxes.

First minor issue: how should we apply the above account to the case in which a world-line L is a loop (see Figure 4)? The problem is that if a L is a loop one can not assign a personal time to each point on L which increases continuously in the future direction. Well, we can take care of this problem by saying that a person P with world-line L time-travels iff there exists some segment S of P's world-line L such that following S in the future direction will take P from a later slice in R to an earlier slice in R.

Incidentally, this example also shows that there is nothing nonsensical, or impossible, about two events occurring both before and after each other according to one and the same notion of time (whether personal or external). For instance, in the space-time depicted in Figure 4 one can get from any event to any other event while always traveling (at less than the speed of light) in the (locally determined) future direction of time. So there is a perfectly coherent sense in which an event can be said to occur both before and after some other event.

Second minor issue: I previously assumed that the space-time in question was temporally oriented. In fact, we can drop that assumption. For, suppose that we have a space-time that is not temporally oriented (perhaps not even temporally orientable), a person P following a world-line W, and a (4-dimensional, connected) sub-region R which we have sliced into time-slices. Then suppose we arbitrarily choose a direction of increasing personal time on W and a direction of increasing external time in R such that the two agree on the direction of time where both are defined. Then, if there are events A and B such that P's personal time and R's external time disagree as to the temporal order of these events, we can say that P travels back in time.

Third minor issue, what about forwards time travel? Well, I am not sure that in relativistic space-times there can be any clear notion of forwards time travel. According to (special and general) relativity two clocks that travel along different world-lines from space-time point A to space-time point B will, almost always, measure different time intervals between A and B no matter what the structure the space-time has. Indeed, typically, given any two time-like related space-time locations A and B one can, by a suitable choice of path make the time interval measured by a clock traveling along that path from A to B as small as one likes. (This is the essence of the "twin paradox" in special relativity.) So, on a fairly natural characterization of what it is for there to be forwards time travel, forwards time travel would be ubiquitous, too ubiquitous to be interesting. Now, this is hardly a rigorous argument that no decent notion of forwards time travel can be dreamt up. Indeed, I wouldn't be surprised if, when one restricts oneself to cases where there is a topological difference between the paths, one can give a precise and intuitively correct characterization of those paths which correspond to forwards time travel and those which don't. But one surely does not want to restrict attention only to cases in which there are such topological differences. In any case, I will not pursue this issue. The more interesting puzzles regarding time travel concern backwards time travel, not forwards time travel.

4. Fixing Your Grandfather

Suppose you travel back in time and try to kill your grandfather before you were born. Setting aside inter-possible-world travel, miraculous resurrections, and other cop-outs, logic dictates that you will fail. You will slip on a banana peel, a grain of sand will jam the gun, you will change your mind, you will have an epileptic seizure, . . . However ingenious and persistent you might be, you will in fact not succeed. This predictable ineptitude on the part of time travelers brings up a few issues.

One issue is whether it shows that time travelers are modally incapacitated: not only do they in fact not kill their grandfathers, they *couldn't* have. I will discuss that issue in section 6. In the current section, for the most part, I will confine myself to the epistemic question whether the remarkable survival skills of our ancestors suggests that it is unlikely that there is time travel in our universe. At the end of this section I will briefly discuss the claim that the grandfather paradox shows that (it is likely that) time travel is physically impossible.

There is a simple argument that the grandfather paradox implies that it is unlikely that time travel occurs in our universe. We know that if there are time travelers they will fail to kill their ancestors before they are born. This requires bizarre coincidences such as banana peels lying around in just the

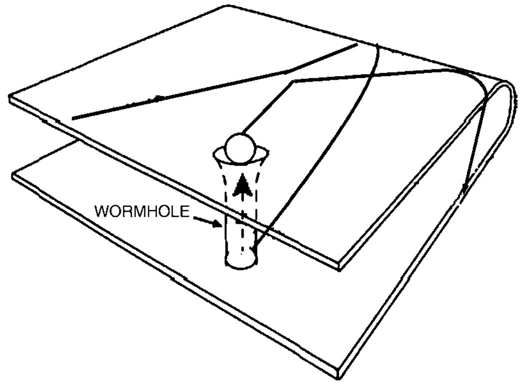

Fig. 5.

right spots. But it is implausible that our world is set up in such a conspiratorial way. The problem, moreover, concerns not just murderous time travelers. Any attempt whatsoever on the part of any time traveler to do something that is inconsistent with what she knows to have happened must result in failure. Indeed, even whether she knows it or not is immaterial. It seems then that a divine pre-established harmony, a harmony between the initial conditions of the universe and its time-travel structure, is needed to avoid paradox. This requires bizarre and implausible constraints on initial conditions in time-travel worlds. So our universe likely does not have a time-travel structure.

Let's return to the case of billiard ball wormhole time travel in order to make this argument more precise. Suppose that the ball initially is cued up so as to go into the wormhole at such an angle that it will come out of the wormhole so as to collide with its earlier self and thereby prevent itself from going in the first place (see Figure 5). Then, if it goes in, it will come out and prevent itself from going in. Contradiction. But if it does not go in, then it will not come out, so, given the way that it is cued up, it will go in. Also a contradiction. So we have a paradox. It seems that the only way we can avoid paradox is to disallow the ball being cued up in such a way, i.e. we must impose bizarre constraints on initial conditions.

However, we have overlooked something. The very initial condition that we were worried about could produce a "glancing blow collision," i.e. a collision which sends the ball into the wormhole at exactly the right angle for it to come out and deliver itself that "glancing blow" (see Figure 6). While philosophers of time have been yammering on about banana peels, physicists have been calculating whether such "glancing blow" solutions always exist. Echeverria, Klinkhammer, and Thorne found a large class of initial conditions which they showed to have consistent glancing blow continuations. While they could not rigorously prove it, they made it very plausible that every initial trajectory has a consistent continuation.

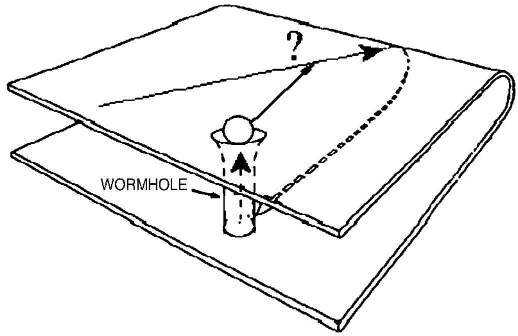

Fig. 6.

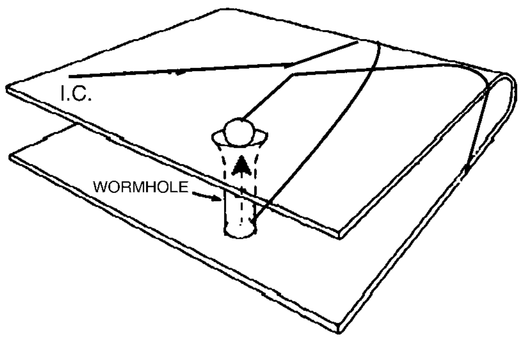

Fig. 7.

Various cases other than billiard balls traveling through wormholes have been examined by physicists. In most of the examined cases the possibility of time travel turned out to impose no constraints on initial conditions, though in some cases it did. (See Arntzenius and Maudlin for some examples and references.) However, the cases were idealized (else they would not be tractable), and it is hard to conclude anything with much certainty about the actual world.

Perhaps more interesting is that physicists found the opposite problem from that of looming inconsistency: they found looming non-probabilistic indeterminism. That is to say, initial conditions typically fail to determine a unique continuation in time-travel worlds. For instance, consider our ball again, and suppose that the ball is initially "aimed" so as to miss the wormhole altogether. One possible continuation of that initial condition is that, indeed, it never enters the wormhole (Figure 7). Another possible continuation of that very same initial condition is that a collision with its "older self" sends the "younger" ball into the wormhole at exactly the right angle so as to come out and produce that very collision (Figure 8).

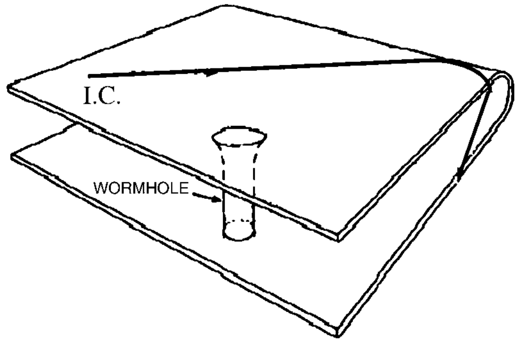

Fig. 8.

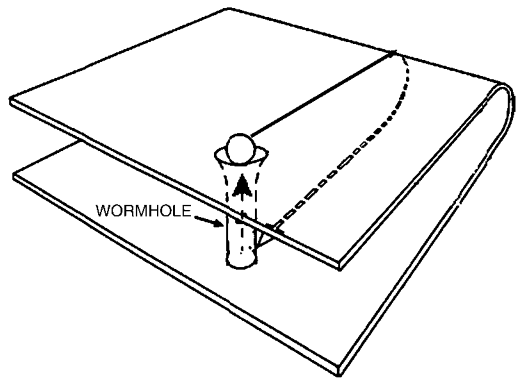

Fig. 9.

Perhaps even more disturbing is that there can be billiard balls whose world-lines form a simple loop through the wormhole (Figure 9). This means that even an initial vacuum does not have a unique future, since balls can appear "out of nowhere," or rather, out of a wormhole.[3] (Note that the depicted scenario does not violate conservation of mass-energy. Conservation of mass-energy is a local law in general relativity, and it can be everywhere satisfied even in cases where world-lines form a loop.) This kind of possibility obviously leads to rampant indeterminism. Boy, oh, boy, time travel seems to be even stranger than we already thought.

I need to make one final cautionary remark before discussing whether all of this might add up to an argument against the likelihood of time travel in our world. I have been suggesting that it would be nice if at all times (on all time-slices) prior to the relevant time-travel possibility one can freely specify initial conditions, and any possible complete set of such initial conditions determines a unique history. But, hang on, didn't I claim earlier on that one can not slice a time travel space-times into time-slices? Yes, I did, but in certain time-travel worlds one can get something very close to the desired time-slices. For in certain time travel space-times there exist inextendible smooth space-like surfaces S such that every inextendible smooth time-like line L that exists to the past of S must pass through S once and only once. For instance, in the example that we have been discussing so far: an infinite space-like line on the "top shelf" in front of the wormhole mouth will be such a space-like hyper-surface. So, in such cases we *can* make sense of the notion of "initial conditions": it's the conditions on such a surface S. It would be nice if one could freely specify initial conditions on such surfaces, and it would be nice if any complete set of initial conditions on such a surface would determine a unique history.

Unfortunately, it is also true that in many time travel space-times there are no such surfaces. For instance the first time-travel space-time that anybody ever dreamt up, namely Gödel space-time, contains no such surfaces. This makes the business of constraints and indeterminism harder to discuss in such cases. However, there are questions that can be asked even in such cases. For instance, one can ask whether initial conditions on inextendible space-like surfaces in certain sub-regions (such as region R of my first example) are freely specifiable (in the sense that any set of initial conditions can be extended to a solution over all of space-time.) Indeed, there exist various sensible questions that we can ask about constraints on initial conditions, about indeterminism, and about global conservation laws regarding just about any time-travel world.

But, should we care about the answers? That is to say: if we were able to figure out whether constraints and/or indeterminism and/or global conservation failures obtain in, say, the most plausible time-travel models of our universe, should this affect how likely we take it to be that our universe has a time-travel structure?

Here is an argument that such discoveries should affect our estimate of the likelihood that our universe is a time-travel universe. We have in fact not seen any bizarre constraints on initial conditions nor any indeterminism (at least no indeterminism of the time-travel variety), nor billiard balls coming out of nowhere. Hence, by induction, it is unlikely that our universe contains any such phenomena. So our universe probably does not have a time-travel structure.

Is this a good argument? Well, suppose there just hasn't been any time travel yet (near us). That would explain why we haven't seen indeterminism or billiard balls popping out of nowhere. So if time travel hasn't happened yet, then the only argument we have left against the likelihood of time travel in our universe is that we haven't seen any bizarre constraints on initial conditions. But even that argument doesn't seem very good. For physicists' work on time travel makes it plausible that if time travel imposes any constraints on conditions prior to the time travel, they aren't easily recognizable constraints. For instance, it's not as if the existence of later time travel rules out the earlier existence of cows. Indeed, depending on what the time-travel structure in question exactly is, and depending exactly on what the dynamical laws are that govern the elementary constituents of our world, if there are any earlier constrains imposed by later time travel, we probably would not be able to figure out from the dynamics and the time-travel structure exactly what the constraints are, and even if we could, the ruled out initial conditions would probably be some totally crazy set of dispersed points in state space, so that even if we knew exactly what the constraints were we couldn't even tell whether they obtained.

Let's take a step back. OK, so we wouldn't *know* whether they obtained, but still, bizarre constraints on initial conditions surely make for an ugly and implausible theory. Isn't it much more plausible that our world does not have a time-travel structure rather than that it does and there are crazy constraints on initial conditions? The fan of time travel might respond: what are you whining about? If the laws of development plus the time-travel structure of space-time logically entail crazy constraints on initial conditions and/or indeterminism, well, then we have as good an explanation as we are ever going to get of the existence of the crazy constraints/ indeterminism. What more do you want?

In order to try to resolve this debate let's examine an analogous case. One can show that the existence of infinitely many particles in Newtonian collision theory leads to similar problems. That is to say, certain initial conditions for infinitely many particles must be ruled out in Newtonian collision theory because they lead to inconsistency with the laws of collision after a finite time. Moreover certain initial conditions lead to indeterminism in Newtonian collision theory. So if one didn't already know that Newtonian collision theory is false, then the mathematical discovery that Newtonian collision theory has such, previously unknown, ugly features, it seems to me, should lower one's degree of belief that Newtonian collision theory is true. So, one then would have reason to look for a plausible improvement of Newtonian collision theory which gets rid of these problems. Some candidates for such an improvement would be:

a) the addition of a new law which just forbids the existence of infinitely many particles;
b) an argument that these problems do not exist when we adopt a more realistic model in which particles interact via fields rather than via contact collisions;
c) an argument that these problems go away when one makes Newtonian collision theory relativistic; and
d) an argument that these problem go away when one quantizes Newtonian collision theory.

Similarly, it seems to me that if one were to discover that time travel in general relativity implies the existence of constraints on initial conditions and/or indeterminism and/or violation of global conservation laws, then one has reason to search for a new argument within general relativity, or an improvement of general relativity, which shows that time travel space-times are pathological, or even physically impossible. Here are some candidates:

a) an additional law which simply forbids the existence of time travel space-times;
b) an argument that some plausible conditions, which may or may not be elevated to the status of laws, implies that time-travel wormholes can not be formed, or are extremely unlikely to form (e.g. because time-travel solutions are of measure 0 in the solution space);
c) an argument that these problems go away in quantum theory; and
d) an argument that these problems go away in quantum gravity.

For instance, Stephen Hawking and Frank Tipler have given arguments of variety b. David Deutsch has given an argument of type c. Cassidy and Hawking have give an argument of type d. See also Earman, Smeenk, and Wütrich for further discussion of this topic, and further references.

In short, it does seem to be of epistemological interest to examine whether time travel, in something like our universe, implies indeterminism and/or constraints on initial conditions and/or violations of global conservation laws. For it could guide our search for the best theory of the world.

5. Area 51

We haven't seen any yodeling barracudas pop out of wormhole mouths. To paraphrase Stephen Hawking: "If time travel occurs in our universe, why aren't they visiting us? What are we, chopped liver?" Here are a few possible explanations for why time travelers appear not to have visited us.

Reason 1: We have to take the History Channel more seriously. The wormhole mouth is in area 51, Nevada, and we just keep ignoring them. Can you imagine their frustration? By now (sic!) they have given up on the whole thing.

Reason 2: In the wormhole case time travel is only possible once the right kind of wormhole exists, and then one can, at best, travel back to the time at which the wormhole was formed. And time-travel wormholes don't exist yet (near us).

Reason 3: Time travel occurs all over the place, but wormholes have Planck-length diameters. It is hard to squeeze a yodeling barracuda through there.

6. Does Time Travel Cause Impotence?

Time travelers do not kill their grandfathers before they are born. But could they have done so? Barring resurrections and other cop-outs, it seems they could not, since this would lead to logical inconsistency. In this section I will discuss whether time travelers indeed suffer from such modal impotence.

The standard answer to worries about impotence comes from David Lewis (*Counterfactuals*). His view is that there are no absolute, context independent, facts as to what one can do and what one can not do. More precisely: the truth conditions for claims such as "P can do X" are context dependent. What one can do and can not do, on Lewis's view, depends on which facts one holds fixed and which one varies when assessing what possibilities there are. Context determines which facts it is appropriate to hold fixed and which it is appropriate to vary. For instance, there is a sense in which I can now jump out of my window: my ankle sprain has healed, so it is compatible with my current (coarse) physical state that I jump. There is also a sense in which I can't: my depression has subsided, so it is not compatible with my current mental state that I jump. My physiotherapist is interested in what I am physically capable of, my psychiatrist is interested in what I am mentally capable of. When the time traveler possesses a gun and is standing in front of his grandfather he can kill him in the sense that this is compatible with the coarse local facts that he do so. But, holding fixed the fact that it is *his grandfather* (and that resurrections do not occur, and . . .) the time traveler can not kill him.

Kadri Vihvelin has objected to Lewis's account. She thinks that in the ordinary sense of "can" the time traveler can not kill his grandfather, and that this is not, in any reasonable sense, context dependent. Her argument is as follows.

(1) If person P can do X, then if P were to try X, P would (or at least might) succeed.

(2) If a time traveler were to try to kill his grandfather (repeatedly), he would fail (repeatedly).

Therefore

(3) A time traveler can not kill his grandfather.

Ted Sider has responded that there are cases in which P can do X, yet, in certain contexts at least, the counterfactual "Were P to try to do X, P would succeed" is false. Here is why. First consider the counterfactual "Had Harry been a permanent bachelor and had he tried to get married he would not have succeeded." This counterfactual seems true because the "permanent bachelorhood" of Harry is part of the counterfactual condition. Now suppose that we all know that Harry in fact was a permanent bachelor, and we consider the counterfactual "Had Harry tried to get married he would not have succeeded." Is it true? Sider argues that in certain contexts it is true, namely contexts in which it is appropriate to hold Harry's bachelorhood fixed when evaluating the counterfactual. Now, it may be that such contexts are unusual in normal cases, however, Sider argues that in the case of a time traveler it is not so odd to hold fixed the fact that he fails to kill his grandfather. It is, after all, *his* grandfather.

John Carroll has claimed that Sider's argument is not quite enough to defeat Vihvelin. Carroll agrees with Sider that there are contexts in which it is true to say "Were Harry to try to get married he would fail." But Carroll claims that in that very same context it is also true to say "Harry can not marry." For otherwise the conjunction "If Harry were to try to marry he would fail, though Harry can marry" would come out as true. And this conjunction surely isn't true. So, according to Carroll, in a context in which it is true to say "If Jimmy were to try to kill his grandfather he would fail" it is also true to say "Jimmy can't kill his grandfather." However, according to Carroll, this makes Jimmy no more impotent than our unfortunate permanent bachelor.

What do I think? I agree with Carroll's assessment, except for a couple of caveats. My first caveat is that it seems to me that time-travel contexts make counterfactuals hard to evaluate. The standard explanation of why we (typically) hold the past fixed (except maybe for a "little miracle") but do not hold the future fixed, when we counterfactually vary the present, relies on the existence of the so-called "trace-asymmetry." The "trace asymmetry" consists in the fact that the future typically contains (multiple) "traces" of the past, while the past typically does not contain "traces" of the future (Lewis, "Counterfactual Dependence"). This "trace asymmetry" in turn, might be explicable in terms of the increase of entropy in our universe (Albert and Loewer). The problem is that time travel is not typical. The memory of a time traveler contains, in a clear sense, "traces" of the future. Moreover, entropy can not behave as usual in time-travel worlds. For instance, if someone (something) is stuck on a time-travel loop, then he (it) can not have a continuously increasing entropy in the (local) forwards direction of time. These two facts make it especially hard to evaluate counterfactuals in time-travel contexts. Be that as it may, Carroll's conclusion that a time traveler is no more impotent than a permanent bachelor still seems right, or as right as such a claim can be.

My second caveat is that it seems to me that this whole debate about impotence does not have much significance. That is to say, whatever verdict about Jimmy's impotence one settles on, it should affect neither one's assessment of the likelihood of time travel in our universe, nor one's assessment of the possibility of time travel. Sider suggests the opposite: he suggests that if Vihvelin were right, it would be reasonable to conclude that time travel is impossible, or at least, that there are strange shackles on the time traveler. So Sider thinks that it is quite important to show that Vihvelin is wrong.

I fail to see the significance. Our grounds for claims about Jimmy's putative impotence are just ordinary, non-modal, facts, plus some judgments about distances between possible worlds (or something like that). It is hard to see how judgments about distances between possible worlds could have any relevance regarding the logical, metaphysical or physical possibility of time travel. And it is hard to see how such judgments could have any relevance regarding our assessment of the likelihood of time travel in our world. Of course, the non-modal facts could give us reason to think time travel is unlikely, or even that it is physically impossible. But a detour through modal facts about Jimmy seems at best an unnecessary detour, and, at worst, a confusing and misleading detour. Surely the real, underlying, argument has to be that repeated failures to kill grandfathers are implausible, whatever this might imply about the impotence of time travelers.

Well, how about this last argument? I have already agreed that if time travel implies indeterminism, yodeling barracudas, and/or constraints on initial conditions, then this does give us reason to think time travel unlikely. But what if time travel, in any world similar to our world, does not have those implications? Does the implication of repeated assassination failures alone not already provide us with plenty of reason to think time travel unlikely?

To assess this claim let us once again return to the billiard ball case. Suppose we keep trying to shoot the billiard ball into the wormhole so that it will come out at an earlier time so as to prevent itself from going in. Each time we try this the ball damn well gets deflected in such a way so as to go in the wormhole and then come out the wormhole so as to cause this very deflection. Is this strange? Yes. Is the full trajectory of the ball inexplicable, or even hard to explain? No. The motion of the ball at all times has the usual local cause. Does the sequence of "glancing blows" constitute a sequence of unlikely coincidences? Well, I am not quite sure how the notion of "coincidence" applies to such cases. But it seems clear that the sequence of "glancing blows" do not provide any reason to think time travel unlikely (or impossible), if one did not already think so. To be more precise: if one were to know that time travel imposes no constraints on initial conditions, then it would seem wrong to claim that the fact that in a time-travel world the ball always comes out of the wormhole at the required angle is a reason to consider time travel more unlikely than one already thought it was.

Similarly, my limp is a perfectly good explanation of why I hit my leg rather than my head when I attempted to assassinate myself. Even *repeated* failures to assassinate one's grandfather do not constitute an argument against the likelihood of time travel.

7. *Teach Your Parents Well*

Jimmy's father taught him how to build a time-travel machine. So Jimmy asked him: "how do you know how to build one?" "Oh," said Jimmy's father, "I got it from you. You are going to time travel back to my youth just to tell me how to do it."

Some people are perturbed by circular explanations. But what do you expect? Circular time, circular causation, circular explanation. Get used to it.

8. *Just Say No*

If you allow me, I will end on an autobiographical note. I am still in Guantanamo Bay. Except for the occasional visit from a yodeling barracuda, life has not been pleasant. The crazy old guy who tried to kill me, allegedly my older self, apparently also got locked up somewhere in Guantanamo Bay. The Feds figured he was trying to silence me before I gave away the names of my terrorist friends, so they are brutally interrogating both him and me. My hope is that the old fool is a clever imposter, or at least, that he has come from some different possible world. In any case, I firmly intend to make something like that true by not acquiring any weapon of any sort when I get out. I have to admit, though, that I do get occasional bouts of homicidal rage directed at the idiot that shot me. What was he thinking? Oh well, I should let it go. Meanwhile, I have some advice for you (assuming this letter ever gets anywhere): don't even *think* about traveling in time. It ain't nothing but trouble.

Short Biography

Frank Arntzenius's main interests are philosophy of physics, foundations of decision theory and probability theory, and metaphysics. He did an undergraduate degree in physics in Holland, and then did a Ph.D. in Philosophy of Science in England. After that he has been at Pittsburgh University, Harvard University, the University of Southern California, and Rutgers University. Currently he is working on three (count 'em!) books: one on time and space in modern physics, one on decision theory, and one on paradoxes. He has managed to avoid receiving any honors or grants, and takes it that teaching is the only useful thing he does.

Notes

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[1] The space-time length of a path is determined by the space-time metric along that path.

[2] The folding does not affect the intrinsic structure of the Minkowski space-time, i.e. its metric, curvature, topology etc. The only reason I depicted a "folded" space-time is that it makes the wormhole connection easier to draw. Of course, the addition of the wormhole *does* affect the structure of the space-time. For one thing, it changes the topology of the space-time, for another, it adds CTCs.

[3] I am ignoring the issue as to why a vacuum space-time would develop a wormhole connection.

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