The Philosophical Quarterly *2008*
doi: 10.1111/j.1467-9213.2008.564.x

TIME TRAVEL WITHOUT CAUSAL LOOPS

By Bradley Monton

It has sometimes been suggested that backwards time travel always incurs causal loops. I show that this is mistaken, by describing worlds where backwards time travel occurs and yet no causal loops occur. Arguments that backwards time travel can occur without causal loops have been given before in the literature, but I show that those arguments are unconvincing.

I. INTRODUCTION

My thesis is that backwards time travel can occur without causal loops. Specifically, I shall show that assuming that backwards time travel ('time travel' for short) is logically possible, it is logically possible to have a world where time travel occurs and yet no causal loops occur.

To formulate this thesis more precisely, I need to distinguish two types of causal loops, *closed* and *open* causal loops. A causal loop occurs when some event *a* causes event *b*, and this event causes event *c*, and so on, until an event is caused which a cause of *a*. (There is no restriction on how many events occur in the loop, and whether a set of events counts as forming a causal loop is independent of whether causation is transitive.) A closed loop is one where *a* is the sole cause of *b*, *b* is the sole cause of *c*, and so on back to *a*. An open loop, by contrast, is one where, for at least two events in the causal loop *f* and *g*, *f* is *one* cause of *g*, but there is another cause of *g* that is not an event in the loop. In typical time travel stories, the causal loops that occur are open causal loops. For example, in a story where *S* gets plans for a time travel machine from someone, builds the machine, and then goes back in time to give the plans to *S*'s younger self, the plans are involved in a causal loop. But the event of the plans' being at some particular location in space and time is not the sole cause of the event of the plans' being at some other location in space and time further in the chain; other events play a role in the plans' being where they are.

The goal of this paper is to show that time travel can occur without open or closed causal loops. I shall give a simple (but contentious) argument for

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Published by Blackwell Publishing, 9600 Garsington Road, Oxford OX4 2DQ, UK, and 350 Main Street, Malden, MA 02148, USA

this thesis in the next section, and I shall give more complicated (but I hope less contentious) arguments for this thesis in the following section. These arguments will proceed by example: I shall describe (distant) possible worlds where time travel occurs, but where there are no causal loops. (At least, I shall argue that these worlds are possible under the assumption that time travel is possible; I shall be making this assumption throughout the paper.) In the final section, I shall consider an alternative argument, due to P.J. Riggs and Richard Hanley, for the thesis that time travel can occur without causal loops. They follow a different strategy from mine: their goal is to show that time travel without causal loops is physically possible, or at least is allowed in a possible world similar to ours but where time travel can occur. I shall show that this argument is unconvincing as it stands (but also that it can potentially be improved so as to succeed).

II. WHY THINK OTHERWISE?

Who thinks that time travel requires causal loops? D.H. Mellor is one.[1] He argues against the possibility of time travel by arguing against the possibility of causal loops; he explains that his argument against time travel works by 'ruling out the causal ... loops that cyclical time and backwards time travel need'. Jan Faye is another; he simply asserts that 'time travel involves a causal loop'.[2] David Lewis famously expresses uncertainty regarding the matter: 'Perhaps there must be loops if there is reversal; I am not sure'.[3] Murray MacBeath also tentatively endorses the thesis in question:

> Anyone who writes stories of time travel into the past will find it difficult to avoid telling loopy stories. Indeed, perhaps Lewis is right in his suggestion that the task might be impossible.[4]

Why do these philosophers think that time travel requires causal loops? While none of them has given a precise argument, the general line of thought can easily be reconstructed. In normal situations, events that occur at a certain time have a causal influence on events that occur at some later time. When time travel occurs, however, backwards causation occurs: an event *c* that occurs at a later time has a causal influence on an event *e* that occurs at an earlier time. It is natural to think that after that backwards

[1] D.H. Mellor, *Real Time* (London: Routledge, 1998), p. 131.

[2] J. Faye, 'Backward Causation', in E.N. Zalta (ed.), *The Stanford Encyclopedia of Philosophy*, http://plato.stanford.edu/archives/fall2005/entries/causation-backwards.

[3] D.K. Lewis, 'The Paradoxes of Time Travel', *American Philosophical Quarterly*, 13 (1976), pp. 145–52, repr. in his *Philosophical Papers*, Vol. II (Oxford UP, 1987), pp. 67–80, at p. 74.

[4] M. MacBeath, 'Who Was Dr Who's Father?', *Synthese*, 51 (1982), pp. 397–430, at p. 428.

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event, causal influences continue in the normal way. The event *e* that occurs at the earlier time will have a causal influence on an event which will have a causal influence on an event ... which will have a causal influence on the event *c*.

Time travel stories often appeal to this loopiness to make the story interesting. For example, in the two consistent time travel stories which David Lewis (p. 67) cites, Robert Heinlein's 'By His Bootstraps' and '–All You Zombies–', many causal loops occur. I shall give just two examples: in the first, the main character has a dictionary which he copies; he gives the copy to his younger self, and the younger self goes on to make a copy of that dictionary. In the second, the main character is both his father and mother. In fact, I know of no extant consistent time travel story which does not involve causal loops, and it may well be the case that such a story would not be interesting. But it does not follow that such a story is not possible.

III. THE ONE-PARTICLE ARGUMENT

In this section I shall describe a possible world, and I shall argue that this is a world where time travel occurs, but where causal loops do not occur. My description of this world will rely on the assumption that eternalism is true (where *eternalism* is the doctrine that the past, present, and future are all equally real, and there is no metaphysical difference between them, just an indexical one). I do not think that time travel can only occur in an eternalist world, though; I endorse the arguments of Keller and Nelson and Monton that presentism (the doctrine that only presently existing things and events exist) is compatible with time travel.[5] Since that issue is not relevant to the issue of whether time travel requires causal loops, I shall assume eternalism for simplicity.

Before I give my argument, I shall introduce a few concepts, starting with the concept of a *worldline* of an object. Without getting into the controversies over how best to understand the nature of a worldline, the rough and ready explanation is that the worldline of an object is the path that the object follows through four-dimensional space-time. Next, what I shall call *the personal time of an object* is a representation of the age of the object: an object's personal time increases monotonically as the object moves later, from its personal standpoint, from its creation. The concept of personal time is perhaps open to critique, but some concept like it is needed if one is willing

[5] S. Keller and M. Nelson, 'Presentists Should Believe in Time-Travel', *Australasian Journal of Philosophy*, 79 (2001), pp. 333–45; B. Monton, 'Presentists Can Believe in Closed Timelike Curves', *Analysis*, 63 (2003), pp. 199–202.

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to grant that time travel is possible. There needs to be some way of specifying that, for example, an object in 2008 is older than the same object in 2009 (where 2008 and 2009 are objective, 'external' times, and 'older' refers to the object's personal time). I shall not defend the concept of personal time further here, because it is not the point of this paper to argue that time travel is possible.

More argument preliminaries: I distinguish different types of time travel. I shall point out two different pairs of distinctions. Here is the first pair. *Discontinuous time travel* (also called *jump time travel*) occurs when the worldline of an object is discontinuous, stopping at some external time t_2 and instantaneously (from the standpoint of the object's personal time) restarting at some earlier time t_1. *Continuous time travel* (also called *slide time travel* or *Wellsian time travel*) occurs when the worldline of an object is continuous, and (out of the many parts of the worldline) there are at least two parts which are such that one of them exists at an earlier external time but has a later personal time than the other part. (I am assuming perdurantism for ease of exposition. Assuming that endurantism and perdurantism are equally compatible with time travel, none of my arguments hinges on what theory of persistence is the correct one.)

Here is the second pair of distinctions. Time travel can occur in a background space-time simply as a result of the motions of objects in the space-time. (For example, one could have a fixed Newtonian space-time, with objects moving forwards and backwards in time within the fixed space-time.) Alternatively, time travel can occur as a result of the structure of space-time itself. (For example, space-time can have a wormhole structure such that an object, always travelling forwards in time locally, can enter a wormhole and re-emerge at an earlier external time.) I shall show that all these types of time travel can occur without causal loops. My discussion will initially focus on a case of continuous time travel in a background space-time. Later I give an argument that holds for discontinuous time travel, as well as arguments for cases of time travel that occur as a result of the space-time structure.

With all this set up, my argument can proceed quickly. Suppose some world contains just one particle in it, and suppose that all physical interactions in the world happen via contact – there is no action at a distance in this world. Suppose that the particle continuously moves to the right, and the particle first travels forwards in time, then backwards, then forwards again. (In a space-time diagram, where time is represented by the vertical dimension, the worldline of the particle forms an *N* shape.) This particle never comes in contact with itself, and hence never interacts with itself. Moreover, this particle is the only particle in the world, so there is nothing else for it to interact with. In this world, time travel occurs, but there are no

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causal loops. There is nothing inconsistent about the world I have described, and hence it is possible for there to be time travel without causal loops. (An aside: if space-time regions themselves can participate in causal relations, as, for example, Tooley believes,[6] then the following point needs to be made: the world under consideration has a fixed background Newtonian-style space-time, with no wormhole-style loopiness, and hence the space-time regions are not themselves involved in a causal loop.)

I would be happy to stop here, but I can see how someone might object to the above argument. One might point out that the argument implicitly relies on a contentious substantivalist view about time. Such a view is most famously captured by Newton's slogan

> Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external.[7]

If such a view were correct, then my argument would make sense – time flows ever forwards, while the particle moves forwards and backwards in time. One can contrast this with a more relationalist view, where *time itself* is (at least in part) defined by the temporal evolution of objects. There are different relationalist views, and arguably none of them is completely satisfactorily worked out; for more details, see the discussions of Earman and Belot.[8] Without focusing on a particular version of relationalism, one can nevertheless appeal to the overall spirit of relationalism to suggest that my argument above is flawed. One can suggest that in a one-particle world, the direction of time is determined by the evolution of the particle in time. Hence it would be impossible for the particle to move backwards in time – as personal time goes, so goes external time.

One way to respond to this objection is to defend substantivalism. I shall not proceed in this way, because I intend my argument for the claim that time travel can occur without causal loops to be independent of the substantivalism/relationalism controversy. Instead, I shall give a different argument, one which will work even if relationalism is true. The idea behind this argument is to postulate that the world contains many particles, most of them travelling in the same temporal direction. On a relationalist framework, these particles establish what the direction of time is. In addition to all the forwards-time-travelling particles, there is one particle travelling backwards in time. I shall show that it is possible for this particle to travel backwards in time without producing any causal loops.

[6] M. Tooley, *Time, Tense, and Causation* (Oxford UP, 1997), pp. 260–6.

[7] I. Newton, *Scholium on Absolute Space and Time, Principia Mathematica.*

[8] J. Earman, *World Enough and Space-Time* (MIT Press, 1989), ch. 8; G. Belot, 'Rehabilitating Relationalism', *International Studies in the Philosophy of Science*, 13 (1999), pp. 35–52.

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IV. THE MANY-PARTICLE ARGUMENT

Imagine a world that contains exactly three types of particles, A-particles, B-particles and C-particles (all point particles). All interactions that take place between different particles happen via contact. The structure of space-time of this universe is a standard Newtonian-style one – if time travel occurs in this universe, it occurs simply because of the worldlines that particles follow, not because of any sort of curved space-time structure. The universe is divided into two spatial regions, region I and region II. The border itself is part of region II – region I includes all points to the left of the border, while region II includes the border and all points to the right of it. A-particles exist only in region I, B-particles exist only in region II, while C-particles exist in both regions. The C-particles can travel between the two regions unimpeded, and do not interact with particles of the other types – they are put in simply to forestall any worries that regions I and II are best considered as different universes. A force field prevents B-particles from crossing into region I. A-particles can cross into region II, but the moment they enter region II, they turn into B-particles. Otherwise the A-particles and B-particles do not interact at all. Finally, suppose that there are no causal loops in this world.

It may be helpful to give first my argument for the case of discontinuous time travel. Assuming discontinuous time travel is possible in general, I shall now show that discontinuous time travel is possible in the world described above. An A-particle can disappear at time t_2 in region I, and can reappear at earlier time t_1 in region II, as a B-particle. This is time travel, analogous to a person entering a time machine in Colorado in 2007 with amber hair and instantaneously (from the standpoint of the time traveller's personal time) emerging in Hawaii in 1987 with blue hair. But given the nature of this possible world, this time travel does not produce causal loops. Once the time-travelling particle is in region II, it is a B-particle, and hence cannot influence anything going on in region I. Thus I have provided a scenario where time travel has occurred without the existence of (open or closed) causal loops.

One might object: how could we know that the particle that appeared in region II at t_1 is the same particle as disappeared in region I at t_2? Would it not be more reasonable to postulate that the particle which appeared in region II is a wholly new particle? I have two responses here. First, the metaphysical question of whether the particle persists should not be confused with the epistemological question of how we can tell that the particle

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persists. But setting that aside, my second point is that I am assuming that discontinuous time travel is possible in general; it is not the point of this paper to argue for that possibility. Instead, I am just trying to show that assuming that discontinuous time travel is possible, it is possible for it to occur in such a way that no causal loops occur.

Perhaps one believes in the possibility of time travel, but not in the possibility of discontinuous time travel. Perhaps one believes that worldlines for particles have to be continuous. I shall now show that continuous time travel is also possible in the world under consideration.

Suppose that an A-particle heads towards the boundary between regions I and II, and at the very moment it reaches the boundary it simultaneously turns into a B-particle and starts heading backwards in time. Further, suppose that the world is such that this is the only A-particle that ever reaches the boundary. Suppose that while it is travelling backwards in time, its worldline follows the boundary, thus ensuring that it cannot interact with B-particles from region II (since they cannot reach the boundary) nor other A-particles that have turned into B-particles (since no other A-particle makes it to the boundary). At the moment when it stops travelling backwards in time, it moves from the boundary into region II. Here again we have a case of time travel without causal loops. The time-travelling particle is causally isolated from all the other particles in the universe while it is travelling backwards in time. Once it stops travelling backwards, the region where it started time travel is causally inaccessible, thus ensuring that no causal loop is produced.

(Some readers may wonder why I did not utilize laws of nature in stating my argument. While I could have, doing so would have introduced extra contentiousness, because of all the disputes regarding laws. For example, do the laws supervene on the occurrent facts? If so, what makes them different from mere regularities? If not, what is the truthmaker, if any, for the truth that the world has the laws it does? My argument works perfectly well without getting into these contentious issues. For any particular plausible thesis about laws of nature, I could give my argument in such a way that it is compatible with that thesis.)

So far, I have been discussing worlds where time travel occurs simply as a result of the worldlines that objects follow, not because of any sort of curved space-time structure. But I can give an argument to show that the latter sort of time travel can also occur without causal loops. Suppose some world contains no time travel that happens simply as a result of the worldline an object follows; in this world all the time travel which occurs does so as a result of the space-time structure. The world I have in mind evolves normally for some period of time, and then branches into two. After one

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year the branches recombine – in the sense that ideal clocks that travelled in branch A measured one year from the branching to the recombination, as did ideal clocks in branch B. During that one year period, the branches are not spatially connected, except for a single wormhole. An object that enters the wormhole is locally travelling forwards in time – the travelling occurs from branch A to branch B, and takes only a short period of time. The wormhole is attached to the branches in such a way that an object in branch A can enter the wormhole ten months after the branching (as measured by ideal clocks in branch A), and that object can emerge in branch B two months after the branching (as measured by ideal clocks in branch B). In the world I am presenting, a single object enters the wormhole. This object engages in time travel – a little later than ten months after the branching (from the standpoint of the object's personal time) the object can directly interact with objects only two months after the branching (from the standpoint of external time in branch B). But that object is not involved in any causal loop. Once in branch B, the object is causally isolated from branch A – it cannot interact with any object in branch A until the branches recombine. Thus the space-time structure of this world is such that it allows for time travel to occur without causal loops.

(If space-time regions themselves can participate in causal relations, as, for example, Tooley believes, this argument is nevertheless successful. No object can travel in a causal loop as a result of the wormhole in this world, thus demonstrating that the structure of the wormhole is such that the space-time regions are not involved in a causal loop.)

For completeness, I should also describe a world where discontinuous time travel happens as a result of curved space-time structure. The world can be like the one I described just above, except that no objects travel through the wormhole. An object in branch A simply disappears ten months after the branching, and reappears in branch B two months after the branching. Setting aside any problems with discontinuous time travel in general, this is again a case of time travel, but there are no causal loops involved.

I shall now mention two ways in which the various many-particle arguments given in this section are better than the one-particle argument given in the previous section. One virtue of the many-particle arguments is that they do not hinge on whether substantivalism or relationalism about time is true. If substantivalism is true, then the direction of time is determined by time itself, without relation to any of the particles. If relationalism is true, then the direction of time is determined by the vast majority of the particles, all of which travel in the same direction in time.

Another virtue of the many-particle arguments is that they describe worlds that are closer to our own. When philosophers contemplated the idea

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that time travel requires causal loops, they probably had in mind a world somewhat like our own, except that in it time travel is occurring. They probably did not have in mind a world with just one particle. So I have shown that time travel can occur without causal loops not only in an *outré* one-particle world, but also in many-particle worlds more like our own.

That said, the many-particle worlds described above are not *that* much like our world. Is there a way to show that time travel without causal loops is possible in a world like ours? I shall take up that issue in the next section.

V. AN EASY ARGUMENT?

One might think that the arguments given above are too convoluted. Is there an easy way to show that time travel is possible without causal loops? I shall very briefly consider a couple of arguments due to Tooley, and then turn to the main line of discussion, an argument due to Hanley.

Tooley presents a situation where *backwards causation* occurs without causal loops,[9] and one might wonder whether this counts as time travel. But in fact the backwards causation that Tooley describes is in no way backwards time travel. Instead, backwards causation occurs via the following sort of causal law: if location x has properties P and Q at time t, then this state of affairs causes a related location x–Δx to have P and lack Q at the earlier time t–Δt. As the reader can see, nothing is travelling backwards in time here.

A different argument of Tooley's perhaps comes closer to my argument: he describes a world with some objects engaging in causal processes that go one way in time and other objects engaging in causal processes that go the other way in time, where objects engaging in one type of causal process do not interact with objects engaging in the other.[10] It is simply not clear to me whether objects engaging in one of the types of causal process would count as time-travelling, and Tooley does not address the time travel issue.

I turn now to the main line of discussion. Hanley explicitly argues for the thesis that time travel can occur without causal loops. An argument similar to Hanley's is given by Riggs.[11] Hanley tells a time travel story which describes a world very like our own. He claims that his story is one where time travel occurs, but no causal loops occur. There are two ways of reading this

[9] Tooley, 'Backwards Causation and the Stalnaker–Lewis Approach to Counterfactuals', *Analysis*, 62 (2002), pp. 191–7.

[10] Tooley, *Time, Tense, and Causation*, pp. 64–8.

[11] R. Hanley, 'No End in Sight: Causal Loops in Philosophy, Physics, and Fiction', *Synthese*, 141 (2004), pp. 123–52, at p. 130; P.J. Riggs, 'A Critique of Mellor's Argument against "Backwards" Causation', *British Journal for the Philosophy of Science*, 42 (1991), pp. 75–86, at pp. 78–9.

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argument: the goal could be to show that time travel without causal loops is physically possible, or the goal could be to show that time travel without causal loops is allowed in the possible worlds most similar to ours but where time travel can occur. To focus my discussion, I shall assume that time travel in general is physically possible, and then I shall evaluate Hanley's argument for the claim that he has described a scenario where time travel has occurred without causal loops. I shall show that this argument is unconvincing as it stands, but I shall also suggest that the argument can potentially be improved so as to be a successful one. Hanley does not portray his argument as conclusive, so to this extent he and I are in agreement.

Leaving out the details, Hanley's basic story is that Max is born and grows up in Sydney, and then in 2000 time travels to New York in 1900. He does not father any children, and generally has little impact in New York before dying a few days after his arrival. Hanley remarks

> this is a story in which reverse causation obtains. But are any of the [New York] events causes of any of the [Sydney events]? This is doubtful.

He thus concludes that there is no causal loop in this story.

Hanley's conclusion here is unjustified. But before I give my argument, a minor confusion needs to be resolved. Some philosophers would hold that a causal loop could occur in Hanley's story, even if none of the New York events is a cause of any of the Sydney events. Specifically, those who believe that the causal relation is not transitive could hold this. Cei Maslen, for example, presents scenarios where causation does not appear to be transitive.[12] One could deny that any of the New York events is a cause of any of the Sydney events, but nevertheless hold that the event of Max arriving in New York is a cause of an event which is a cause of an event ... which is a cause of a relevant Sydney event (such as the event of Max entering the time machine). Here there would be an (open) causal loop, because of the causal chain that holds between the various events, even though it is not the case that the causal relation holds between every pair of events in the chain.

With that minor issue resolved, I turn to the main problem with Hanley's argument. The main problem is that the laws of physics of our world could very well be such that in Hanley's described time travel scenario causal loops will occur. In a universe governed by Newtonian physics, at least, there are events associated with Max's visit to New York that do causally influence events associated with Max's pre-departure life in Sydney. (It is hard to say whether this would be the case according to the true

[12] C. Maslen, 'Causes, Contrasts, and the Nontransitivity of Causation', in J. Collins, N. Hall and L. Paul (eds), *Causation and Counterfactuals* (MIT Press, 2004), pp. 341–58.

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fundamental theory of physics, because we do not have any completely worked out candidates for such a theory.) It is difficult to pick out exactly what events these are, without more detail to the story, but we should be confident that such events exist. I shall state a concise version of my argument for this claim now, and then fill in some details.

Under the assumption that the physics of the world is Newtonian, Max's arrival in New York exerted gravitational influence on some nearby particles, and this caused some of the particles to change locations. In 2000, some particles in New York – either the original affected ones or ones causally related to the original ones – were still in slightly different locations from where they would have been had Max not arrived. (This is what we would expect given Newtonian physics – more on this below.) It follows that in 2000 these particles in New York exerted a gravitational influence on the particles that composed Max's body in Sydney in a slightly different way from how they would have had Max not arrived in New York. Hence some of the particles in Max's body in 2000 would have been in slightly different locations had Max not arrived in New York in 1900. Thus there is a causal loop: the event of the particles in Max's body having a particular configuration just before he enters the time machine in 2000 is clearly a cause of the event of the particles in Max's body having a particular configuration when he arrives in New York in 1900, and there is a causal chain that goes from the event of the particles in Max's body having a particular configuration when he arrives in New York in 1900 to the event of the particles in Max's body having a particular configuration just before he enters the time machine in 2000. I conclude that Hanley has not given a story that is clearly one of time travel without causal loops.

That is the sketch of the argument; it is time to clarify and elaborate. First, it is worth pointing out that it need not be the particles in Max's body that are involved in the causal loop – as long as there is *some* sort of causal loop, Hanley's argument is unsuccessful. The loop could involve particles of Max's clothing, or particles of the time machine, or ..., and so on.

Another point: why did I say that given Newtonian physics, some particles in New York in 2000 were in locations different from where they would have been had Max not arrived? Well, I shall suppose for the moment that Newtonian physics is *bideterministic*. A theory which is *deterministic* is a theory where, given the history of the world up to some time, there is only one future allowed by the theory. A theory which is *backwards-deterministic* is a theory where, given the future history of the world starting from some time, there is only one past allowed by the theory. A theory that is *bideterministic*, then, is a theory which is both deterministic and backwards-deterministic. (As, for example, Earman makes clear, how exactly to characterize

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determinism and its cognates is contentious.[13] My account should be taken as merely rough and ready.)

Suppose now that two possible worlds have similar histories up to 1900, but one world has Max arriving in some particular configuration in New York in 1900, and the other world does not. (In the other world, either Max does not arrive at all, or he arrives in some different configuration.) Because of bideterminism, these worlds must have different futures – given a particular future, only one past is allowed by the theory, so these two different pasts cannot be compatible with the same future. It follows that there must be some sort of difference in the futures, given the difference in whether (or in what way) Max arrived in New York in 1900.

Given just the requirement of bideterminism, it could be that the differences would not include differences in the year 2000: it could be that the differences show up only after 2001, say. But Newtonian physics does not allow for that sort of action at a temporal distance: given two Newtonian worlds with different pasts, it follows that for every interval of time in the future, the worlds will be in different states. Thus, given one Newtonian world at which Max arrives in New York in the year 1900 in a particular configuration, and another world at which he does not, the two worlds will also be different in the year 2000.

It is natural to suppose that this difference would include differences in the locations of particles in 2000. In my concise argument above, I supposed that particles which have different locations in the different worlds include particles in New York. While this is a natural supposition, it does not actually matter where these particles are – regardless of where they are, they will have a gravitational influence on particles in Sydney, including particles in Max's body. The particles in Max's body would be differently influenced in the two possible worlds, and thus it follows that the event of the New York (or wherever) particles being arranged in a certain way in 2000 causally influences the event of the particles in Max's body having a particular configuration before he enters the time machine. Since the event of Max's body being the way it is before he enters the time machine has a causal influence on the event of Max's body being the way it is when he arrives in New York in 1900, a causal loop is established.

Above I supposed that Newtonian physics is bideterministic; in fact it is not. Contrary to standard textbook presentations, Newtonian physics allows for failures of determinism. For example, as John Norton describes,[14] an object can sit on top of a dome for an arbitrary length of time, and then can

[13] J. Earman, *A Primer on Determinism* (Dordrecht: Reidel, 1986).

[14] J.D. Norton, 'Causation as Folk Science', *Philosophers' Imprint*, 3 (2003), pp. 8–12, from http://www.philosophersimprint.org/003004/.

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roll off, where there is nothing causing it to roll off at that time. One could avoid a causal loop in a time travel story by appealing to this sort of indeterministic event: where normally one would have thought that event *f* causes event *g* in the causal loop, it could happen that the event of the object rolling off the dome pre-empts *f* from causing *g*, and causes *g* itself. This would be another argument for how time travel could occur without causal loops, but it is clearly not the easy argument Hanley had in mind.

Setting aside such exotic failures of determinism in Newtonian physics, I conclude that it is not easy to show that time travel can occur without causal loops in a Newtonian universe. It is, however, easier to show that time travel can occur without causal loops given a different theory of physics. Here are sketches of a couple of theories which just might hold for our universe. The true theory of physics could be such that the world has lots of indeterministic events, which prevent any long causal chains from occurring (analogously to how the object rolling off the dome pre-empts *f* from causing *g*). In such a world, one could engage in time travel without creating a causal loop, by, for example, discontinuously travelling so far back in time that no causal chain can be sustained from the time of one's arrival to the time of one's departure. Alternatively, the theory could be such that it allows for the events of some time between the time traveller's departure and his arrival to be the same, regardless of whether or not the time traveller arrives in the past. For example, the theory could be such that the events of 1950 all happen in the same way, regardless of whether or not Max arrives in New York in 1900. In such a world, Max could engage in time travel without creating a causal loop, since there is no causal chain of influence between Max's arrival in New York and the way the world is in 1950.

We do not know what the true fundamental theory of physics is, and we do not even have a fully worked out candidate for such a theory – the two most fundamental worked out theories we do have, quantum theory and general relativity, do not mesh together well. Thus it is hard to say whether our world is one where time travel could occur without causal loops (even assuming that time travel could occur at all in our world). Of course, the Max story is just a story, and I can tell the story however I like: I could specify that the physics of Max's world is such that time travel can occur without causal loops. To do this, I could utilize reasoning along the lines of the many-particle argument I gave in §IV above. But this would presumably involve a world where the true theory of physics is quite different from the true theory of physics of the actual world.

To sum up: it is an open question whether our world is one that allows for time travel without causal loops, even assuming that our world is one that allows for time travel at all. My conclusion is simply that under the

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assumption that time travel is logically possible, it is logically possible for time travel to occur without causal loops. Given that various philosophers have hypothesized otherwise, this conclusion is interesting enough.[15]

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[15] For helpful comments, thanks to an anonymous referee, Chris Heathwood, Brian Kierland, Melissa Joy Thompson and the students in my Fall 2006 time travel class.

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