Travelling in Branching Time

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Miller (2005) and Miller (2008) argue that the branching picture of time is incompatible with the possibility of backwards time travel. In this paper I show that Miller's conclusion is based on a hidden assumption which, while generally plausible, is unwarranted if time travel is possible. Branching time is, after all, compatible with time travel as Miller characterises it.

1. Introduction

The *forward-branching account of time* (also *BT*, from now on; see Thomason (1970), McCall (1976), Belnap et al. (2001), MacFarlane (2003)) purports to give rigorous expression to the intuitive conception of time according to which, although the past is closed (i.e., there is only one way events have unfolded,) the future is very much open: it is possible that future events unfold in a variety of ways. This does not just mean that we do not know which of these ways will be the actual one; rather, the world is well and truly indeterministic as regards those various alternative ways. Take the weather tomorrow: it is possible that it rains in London, it is possible that it does not, and this is not just a reflection of our meteorological ignorance. Rather, nothing in the actual state of the world fixes whether it will rain or not. Nothing *now* makes it the case that events will unfold in either of these ways.

According to BT theorists[1], time can be informatively modelled as a tree – henceforth I shall call it the *branching time tree* or *BT tree*:

[1] What follows is more or less the common core to most extant BT accounts. In her exposition of BT, Miller appears to be following most closely the version presented in McCall (1996).

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- The past lies in the *actual* trunk (which only branches into the *no-longer-possible*, if at all.)
- The future of possibilities[2] lies in the *still-possible* branches ahead.
- The present is the lowest point which branches into several still-possible branches.

See figure 1 for an example of such a BT tree. With the passing of time, one still-possible branch becomes actual, and several still-possible branches become no-longer-possible. Now see figure 2 for a (merely possible!) next step to the tree[3]. Some terminology will be useful in what follows: a *history* is a non-branching path through the tree, from the root to the very top[4]; a *branch stretch* is a continuous proper part of a history – a shorter non-branching path.

[2] This is the turn of phrase used in Belnap et al. (2001) to remind us of the fact that, if indeterminism is true, there is no such thing as the future.

[3] For simplicity, I am considering discrete branching points, although, likely, time branches in a continuous manner if it branches at all. Another caveat: Miller, following McCall, does not recognise the existence of no-longer-possible branches; rather, those still-possible branches which fail to become actual simply cease to exist.

There are theoretical reasons to part company with these theorists at this point, and recognise, as I have been doing, a category of no-longer-possible branches. I believe that such branches, for example, are useful in analysing the notion of metaphysical possibility: at least very many metaphysical possibilities may be fruitfully thought of as quantifications of open future possibilities across times – such that it is metaphysically possible that *p* if there is a time t such that *p* is an open future possibility at t. Also, the fact that branches overlap straightforwardly explains that alternative possibilities (branches) might harbour the same individual – as opposed to mere counterparts. This is, I think, a promising avenue to the eventual naturalisation of *de re* modalities.

In any event, nothing of what I will be saying here depends on these admittedly programmatic ideas, and the reader who shares McCall's antirealism about no-longer-possible branches is encouraged to reinterpret me as merely pretending to refer to them.

[4] Histories can be formally characterised as maximal chains of the relation "earlier than" – see Thomason (1970). The intuitive characterisation just presented is clear enough for our purposes, though, and I will not tax the attention of the reader of this paper with the technical apparatus of branching tense logic.

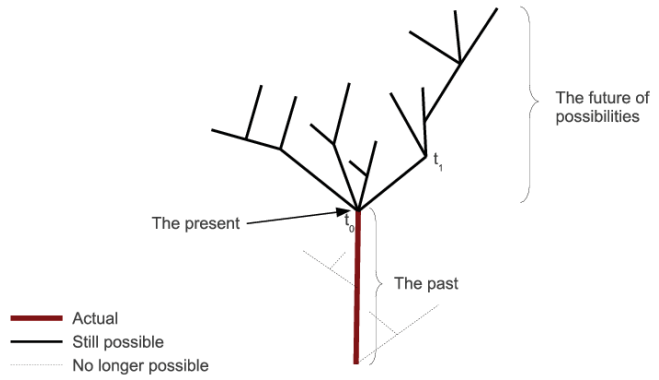

Figure 1: A Branching-Time Tree

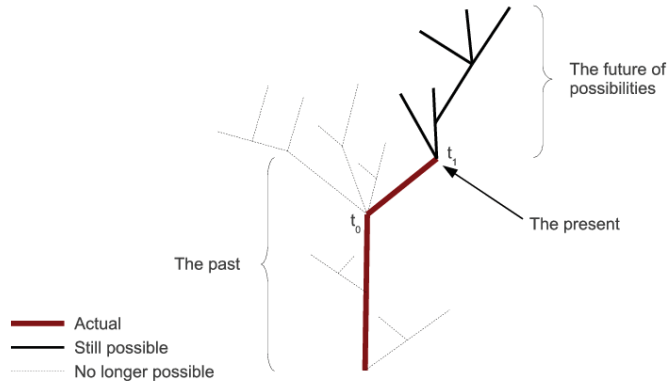

Figure 2: The following step

The way in which branches change of status, from still-possible to actual or no-longer-possible, seems to do full justice to the very natural conception of becoming as a matter of things that are still-possible turning into actual or no-longer-possible. BT accounts provide also compelling ways to analyse phenomena as disparate as objective probabilities (McCall, 1996), agency (Belnap et al., 2001) or causation (Xu, 1997).

On the other hand, Miller (2005) and Miller (2008) argue that BT is incompatible with backwards time travel. This, Miller claims, is bad news for BT, because our best physical theories do not rule out, and may even require, the existence of such time travel[5]. In what follows, I show that, *pace* Miller, BT is fully compatible with time travel as she characterises it.

I will first summarise, in section 2, Miller's argument for the incompatibility of time travel and BT. After that, I will provide the obvious rejoinder by the BT theorist – section 3. In section 4, finally, I suggest that Miller ignores this rejoinder because of her allegiance to a hidden assumption about admissible evolutions of BT trees. I argue that the possibility of time travel, precisely, makes this assumption unwarranted. Once we remove it, BT can be shown to have the resources to deal with time travel.

2. Miller's Incompatibility Argument

Miller argues that the following four propositions[6] are incompatible:

> **Miller1**: Necessarily, P is a genuine time traveller only if all of P's temporal stages are united by some causal relation;
> **Miller2**: It is not logically possible to change the past;
> **Miller3**: Time travel is logically possible;
> **Miller4**: Necessarily, our world has an objective present and an open future. (Miller, 2005, p. 225),

where by 'logically possible' Miller means something very close to what Chalmers (2002) calls 'negative conceivability': *p* is logically possible iff it cannot be ruled out a priori. Let me comment briefly on these premises: Miller1 is based on a plausible view of what individu-

[5] I take up briefly the question whether accommodating the possibility of time travel should be a *desideratum* for our theories of time in footnote 10.

[6] Taken *verbatim* from her (2005), in which she also considers a fifth proposition,

> It is not logically possible to travel from a non-existent location to an existent location.

which is needed in her criticism of other theories about time, such as presentism or the growing-block view. I will be concerning myself only with BT, and this fifth claim plays no role in the argument against this theory.

als are, according to which (when there is no time travel) earlier stages of individual participate in the causation of later ones. So, for example, a situation in which each "stage" is anihilated, and the subsequent "stage" created *ex-nihilo* would not provide adequate grounds for the existence of an individual[7]. Miller1 is the extension of this attractive view to the case in which there is backwards time-travel: talk of earlier and later stages is made problematic by the fact that some older stages of the traveller now happen earlier than younger ones, but we can and should retain causation among stages as a necessary condition for the presence of an individual.

Something like Miller2 is, again, very plausible: time sustains an asymmetry of influence in that we can bring about future events but cannot bring about past events[8]. This is in some tension with Miller3, of course; at least in the intuitive, Hollywood version according to which a time traveller – who, "the first time around" was absent from some past time – is free to mess with it and change it "the second time around". But there is another, less inept way to understand backwards time travel which is compatible with Miller2; according to this other way there are no "times around": if a time traveller happens to visit, say, the year 1900, she was there when the year 1900 was the present year. There is no changing the past[9].

Time travel does not seem a priori impossible, and this is all Miller needs for Miller3. One may wonder, though, whether we should really try to make our theory of time compatible with everything we are unable to rule out by a priori reasoning. Surely it is only metaphysical possibilities that should bother us? In any event, and for the

[7] Shudder quotes because these "stages" are not stages of anything.

[8] But see Kutach (forthcoming).

[9] What I have called the *Hollywood version* of time travel is, of course, best exemplified by the very entertaining *Back to the Future* series or, more recently, *Primer*. A recent film in which time travel is understood in the more apt way is *Timecrimes*.

In this film (and others, such as *12 Monkeys*) – I wouldn't like to spoil plots for you; if you haven't seen these films you may want to stop reading this footnote now – backwards time travel is conjoined with causal loops, such that the presence of the time traveller in the past somehow brings it about that he steps into the time machine in the future. I propose to steer clear of causal loops in this paper, though, as they add nothing to the discussion of Miller's argument.

sake of the argument, I will grant that we should care about upholding this claim too[10].

Finally, Miller4 intends to capture the common core in a number of theories about the nature of time. In particular, BT is rendered by Miller as

> **Miller4-Branching**: Necessarily, our world is a branching universe. (Miller, 2005, p. 229)

This is the version of Miller4 I will be focusing on. Miller4-Branching is intended as, and should be understood as, summarising a theory of branching time such as the one I have sketched in the introduction.

Now, the argument for the joint incompatibility of Miller1 through Miller4-Branching is the following:

> **Argument1**: Suppose that the present time is t1. Consider two histories which share t_1 and branch shortly after – see figure 3. In one of them, h_{Fred} , Fred is born at t_2 and travels back in time to t_1 at t_5; in the other, h_{Mary}, Mary is born at t_2 and travels back in time to t_1 at t_5. Accepting Miller3 implies accepting these time-travel scenarios as logically possible.

[10] Miller (2008) defends the stronger claim that physics may need the possibility of backwards causation – which is the controversial ingredient in backwards time travel. This would indeed provide more substantial grounds for a premise analogous to Miller3. The only argument provided for this stronger contention is Price (1994)'s interpretation of the Einstein-Podolsky-Rosen (EPR) paradox, which suggests that the measurement of one of the two entangled particles causes the (past) value of hidden variables.

This is not the place to discuss the merits of this solution to the paradox, but I'd like to draw the reader's attention to the following feature of the dialectics: Miller proposes backwards time travel as an argument against BT, and Price's solution to the EPR paradox as an argument in favour of time travel – assuming that all backwards time travel needs is backwards causation. But BT theorists have an independent solution to the EPR paradox available: one that simply relies on the EPR measurement probabilities being built into the BT tree itself – see McCall (1996, p. 94f), Belnap (1992, p. 416f).

So, for the possibility of backwards time-travel to count, in this dialectic situation, as an argument against BT, Miller would need to show that the BT solution to the EPR paradox is less compelling that the backwards-causation solution. This she has not done.

> **Argument2**: Now, given that t_1 is the present, and given Miller4-Branching, at t_1 both t_5/h_{Fred}[11] and t_5/h_{Mary}, which share the present moment, must be equally open possibilities – and therefore real. This, according to Miller, has the consequence that it is an open possibility that *Both* Fred and Mary travel back in time to t_1. (Miller, 2005, p. 230, my emphasis)

If this becomes actual, we seem to have *both* Fred and Mary visiting the present from their mutually incompatible futures – maybe getting to meet each other. Well, suppose that it does become actual, then:

> **Argument3**: Suppose that time goes by and, when we reach t_5, it is h_{Fred} and not h_{Mary} that has become actual. Then, given that in that branch Mary never starts existing, we are forced to conclude that the female "time-traveller" roaming around at t_1 could not be her – because the person at t_1 is causally disconnected from the Mary born in t_2/h_{Mary}, and as per Miller1, this is enough to count her out as a Mary-stage.
> **Argument4**: But (Argument2) she *was* here when we were at t_1: the past has changed by the time we reach t_5, contrary to Miller2.
> **Conclusion**: Miller1 through Miller4-Branching are jointly incompatible.

3. The Branching Theorist's Response

The key step in the argument is, obviously, Argument2. Is the BT theorist really forced to accept that both Mary and Fred could travel to the present time? An immediate response is that Miller is trading on an ambiguity between:

(1) [It is possible that Mary travels to the past] and [it is possible that Fred travels to the past]
(2) It is possible that [Mary travels to the past and Fred travels to the past]

We may simply point out that, from the fact that it is an open possibility that Mary travels back in time and an open possibility that Fred does, it does not follow that it is an open possibility that they *both* do – and only this second reading makes the four propositions incom-

[11] That is, what happens at t_5 in history h_{Fred}.

patible. This is, essentially, Belnap et al. (2001)'s reaction against Lewis's criticism of BT -see also Belnap y Green (1994, p. 382):

> The trouble with branching … is that it conflicts with our ordinary presupposition that we have a single future. If two futures are equally mine, one with a sea fight tomorrow and one without, it is nonsense to wonder which way it will be – it will be both ways… (Lewis, 1986, p. 207).

But it will *not* be both ways. It is not settled that there will be a sea fight tomorrow; it is not settled that there will not be; but it *is* settled that there will not [be and not be a sea battle tomorrow] – again, see Belnap y Green (1994).

Once we see this, we need to reconsider Argument2: we should not accept, after all, that at t_1 both t_5/h_{Fred} and t_5/h_{Mary} are open possibilities. Fred or Mary travel precisely to t_1, which means that in t_1 it is already a settled matter that any of them, or neither, do. Fred's and Mary's going back in time are in mutually incompatible branches, and this means that, e.g., Mary travelling settles that Fred does not travel and vice versa. Otherwise put: if the situation is one in which Fred is roaming about in t_1, this means that the event which causes his presence in t_1 – that is, his entering the time machine in t_5 – *will* happen. If, *per impossibile*, the situation is one in which both Fred and Mary are roaming about in t_1, this means, absurdly, that both possible – but incompatible – futures will happen.

To see how these options reflect on the BT tree, consider the situation that obtains *before* t_1, as depicted in figure 3. At t_0, it is genuinely indetermined whether Mary will travel back in time, Fred will, or the world branches to the right, away from any time travel. That last option would take the BT tree to the situation depicted in figure 4. Now, on the other hand, if time branches to the left, and given that left branches are time-travel branches, we simply cannot fix facts up to t_1 and leave the rest undecided – that is, figure 5 presents an unacceptable state for the BT tree. Rather, deciding t_1 is, *eo ipso*, deciding up to t_5 in the left branch. The two only other admissible evolutions for the BT tree from the situation in figure 3 are depicted in figure 6 – in which Fred travels – and figure 7 – in which Mary travels.

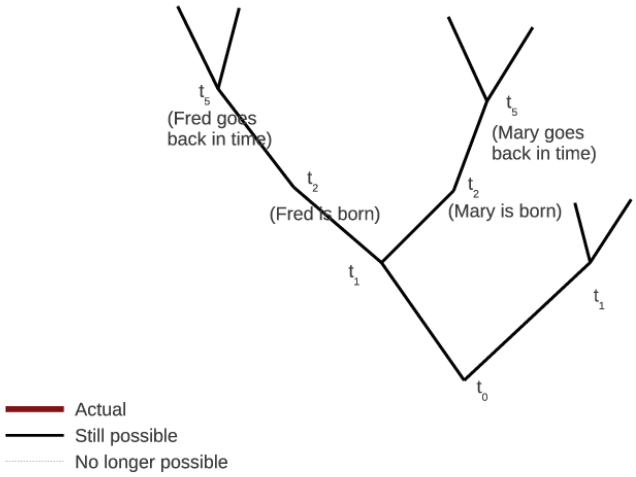

Figure 3: Before it All

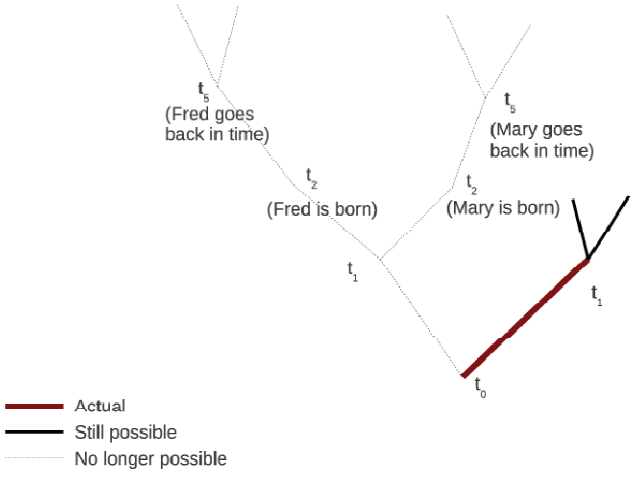

Figure 4: Away from Time Travel

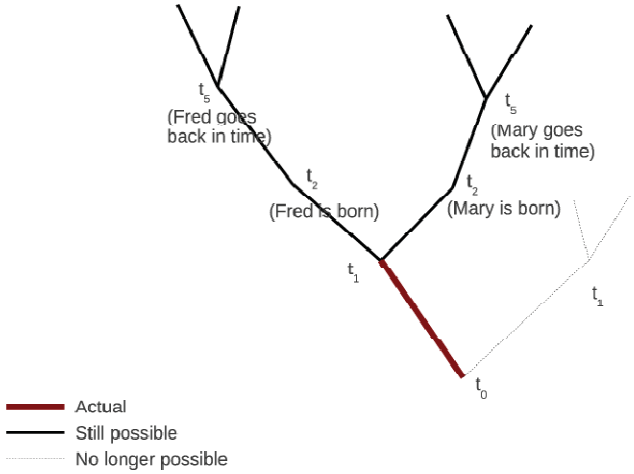

Figure 5: Undecided at t_1?

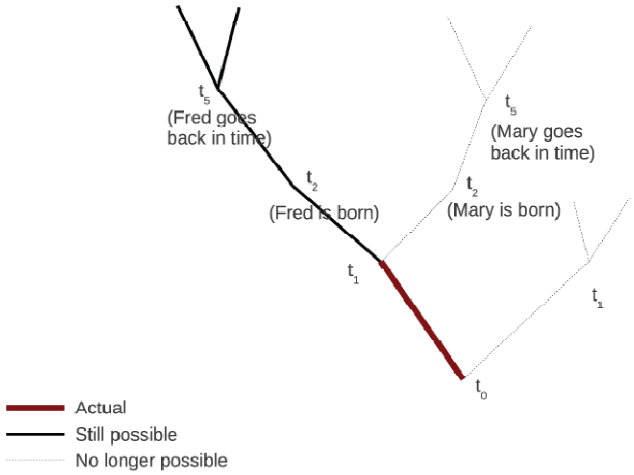

Figure 6: Fred travels back in time

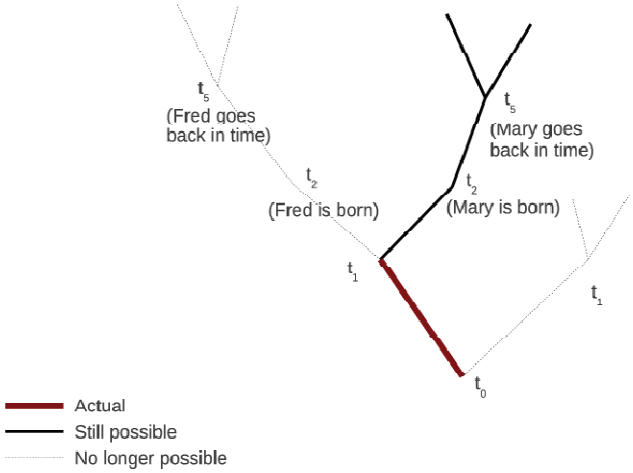

Figure 7: Mary travels back in time

The picture that emerges is fully indeterministic: there are times (e.g., t_0) at which it is open that Fred travels back in time, that Mary does or that no one does[12]. That is, it respects Miller4-Branching. It also obviously respects Miller1, 2 and 3. The conclusion is that there is no incompatibility between the branching time picture of time and backwards time travel.

4. Standard and non-Standard Prunings

This response is, I think, natural and compelling and, as the exchange between Belnap and Lewis shows, similar ones have figured in prominent literature about these issues. How come, then, that Miller chooses to ignore it? A reason may be that she believes time travel to make the response impossible. And, indeed, under a certain natural (but ultimately wrong) assumption of the way in which the BT tree evolves, the response in question is not available. It is easiest to introduce the assumption with an example. Consider a series of *n* coin tosses, happening at $t_0 \ldots t_{n-1}$ and assume that all of them are mutually

[12] Some such options are no longer open at t_1 but, I have argued, openness at t_1 is an unreasonable *desideratum*.

independent and each of them is truly indeterministic – see figure 8. After the first coin is tossed, a way the BT tree may look like is the one depicted in figure 9: the coin has landed heads – this has become actual – and its landing tails, together with everything that would have followed from its landing tails, has joined the limbo of the no-longer-possible, but *nothing else has*. Every course of events compatible with the coin having landed heads in the first toss is very much open. Another permissible evolution is the mirror image of figure 9: the coin lands tails and everything that would have followed from its landing heads (but nothing else) has joined the limbo of the no-longer-possible.

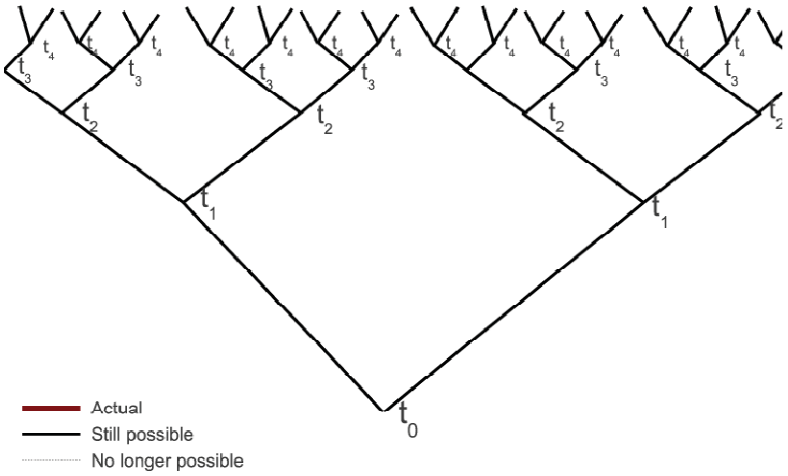

Figure 8: *n* coin tosses

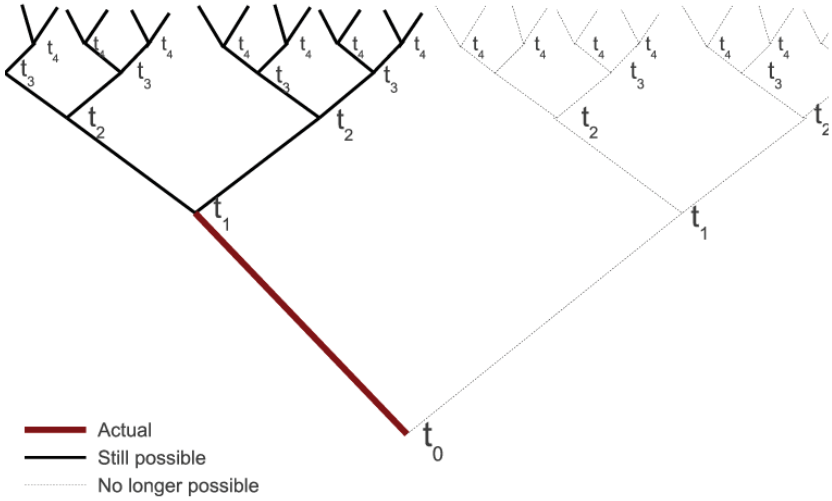

Figure 9: An acceptable next step

And any other kind of tree pruning looks very suspicious – indeed, looks non permissible. See, for example, figure 10: it is proposed that tossing the first coin has fixed the outcome of the fourth toss; besides, this influence has, somehow, jumped from t_0 straight to t_3 in an entirely mysterious way. The assumption (which I shall call Standard Tree-Pruning) is that this kind of entirely mysterious things simply do not happen:

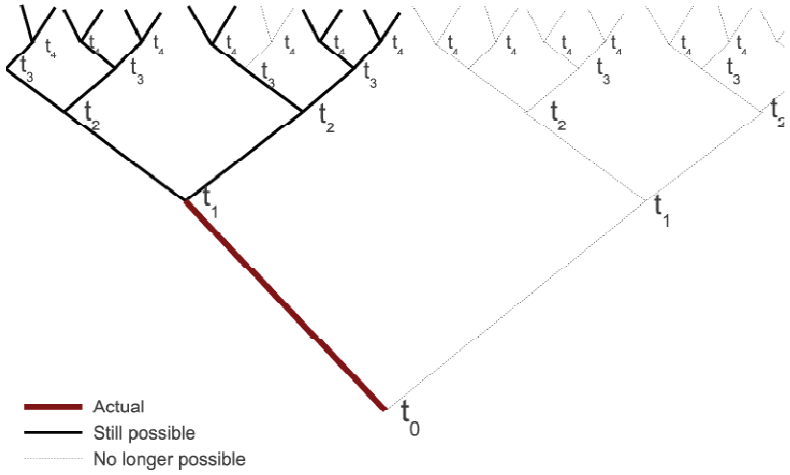

Figure 10: An uncceptable next step

Standard Tree-Pruning:
The only permissible kind of evolution for a BT tree with the present moment at t_0 has the following form:

- One (and only one) of the branches stemming from t_0 changes from still-possible to actual in the branch stretch going from t_0 to the next branching point. Above that stretch, everything remains as it is (i.e., still-possible).
- The rest of branches stemming from t_0 change from still-possible to no longer possible.

For another example, the transition from the BT tree depicted in figure 1 to the one depicted in figure 2 respects Standard Tree-Pruning. The intuitive idea is that, as the present travels up the tree, only sections of the tree connected to the present just left behind are "switched off"; having little regions here or there changing status, far away from the present moment, is not a possibility.

Now, it is easy to see that a BT tree evolution respecting this constraint cannot go from the situation in figure 3 to those in figures 6 or 7 without passing through figure 5. And accepting that the BT tree can be in this last configuration brings about the problems exploited in Miller's argument.

But it is equally easy to show that Standard Tree-Pruning is a sensible restriction on BT-tree evolution *only in the absence of backwards causal influence, or direct causal influence across disjoint times*. The tree evolves as it does because the events happening at a certain moment cause the events happening at the next moment, and causation obeys the following truism:

Causation:
If an event *a* at t_0 causes an event *b* at t_1 then:
- *a* is actual (as opposed to merely still-possible, or no-longer-possible)
- *a*'s causing *b* will make *b* actual at t_1 , and rules out possibilities in which not-*b* at t_1 (i.e., the causing commits all of those alternative, not-*b* branches to the no-longer-possible)

Standard Tree-Pruning is almost entailed by this truism. But just *almost:* you also need the principle that causal influence spreads only from a moment to its consecutive future moment. Or, more carefully – and in order to cover the case of continuous time, in which there is no consecutive future moment – you need causation to be *normal* in the following sense:

Normality:
An event *a* at t_0 causes an event *b* at t_1 *normally* iff
- t_0 is earlier than t_1, and
- For any time t_2 earlier than t_1 and later than t_0, *a* causes *b* by causing normally an event at t_2[13].

Causation does entail Standard Tree-Pruning if all causation is normal. It is also fair to say, I think, that the plausibility of Standard Tree-Pruning is derived from the plausibility of Causation plus the presupposition that causation is normal.

But now, time travel is the paradigmatic example of abnormal causation. For example, in Fred's (or Mary's) time-travel, causal influence jumps from t_5 to t_1 directly. Allowing for this kind of saltatory influence demands precisely foregoing the assumption that causation is normal, and leaves Standard Tree-Pruning unsupported. It is, then, unreasonable to demand of the BT theorist that she make room for (backwards or forwards) time travel while still honouring the Stan-

[13] Notice that this definition is recursive.

dard Tree-Pruning restriction. And once non-standard prunings are allowed, BT and time travel are, as I have shown, fully compatible.

5. Conclusion

Miller has tried to derive an incompatibility between backwards time travel and the branching picture of time from the fact that, according to the latter, all still-possible branches are ontologically on a par – and, among them, the (incompatible) branches in which two time travellers enter a time machine heading for the same past moment. This, Miller contends, forces the BT theorist to accept that two time travellers from incompatible futures could visit the same present moment, with obviously absurd consequences.

But, as I have argued, the possibilities countenanced by the BT theorist in cases of time travel only lead to absurdities under the further assumption that causation is normal – and, precisely, the causation involved in time travel is anything but normal. Once this is recognised, the BT theorist can simply point out that Miller is trading on a modal ambiguity, that between

(1) [It is possible that Mary travels to the past] and [it is possible that Fred travels to the past], and
(2) It is possible that [Mary travels to the past and Fred travels to the past.]*

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