HAND-OUT FOR MOOC LECTURE 7

'TIME TRAVEL AND PHILOSOPHY'

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(Underlined titles correspond directly to sections of the lecture.)

Any inaccuracies, etc., do let me know and I will try to make corrections where possible.

0) Introduction – why a *philosophy* of time travel?

I thought one way to introduce you to metaphysics would be to offer a short introduction to a topic which is interesting, wide-ranging and growing in popularity.

My academic research is currently centred on philosophy of time travel and I'll be honest: I think time travel raises a fascinating set of problems. Time travel, whether as a source of problems in logic, metaphysics or physics, raises serious questions about time, causation, laws of nature, freedom, our identity as persons and even computation. (It's also the subject of some fine stories and films – see Appendix 2.)

Sections 1 to 5 below match sections of my lecture. Appendix 1 is more technical and tries to fill out the discussion I've had online with some of you about Kurt Gödel and relativity.

So let me stress at the outset that I really mean *time* travel: travelling to other times whether in the future or the past. Might such a thing be possible? If not, why not? But before tackling those questions, let's first consider this question:

1) What might time travel be anyway?

The best and most famous philosophical paper about time travel to date is:

David Lewis, 'The Paradoxes of Time Travel', *The American Philosophical Quarterly*, 13, 1976: 145-52. Reprinted in *The Philosophy of Time*, (editors Robin Le Poidevin and Murray MacBeath), (Oxford, Oxford University Press, 1993: 134-46). Online at:

http://www.csus.edu/indiv/m/merlinos/Paradoxes%20of%20Time%20Travel.pdf

David Lewis (1941-2001) believed that it is logically possible to travel in time – forward or backward. What does that mean? Lewis argued that some time travel journeys can be described without contradictions – that (to put it another way) time travel might take place in a possible world. (Maybe only a strange world though.)

To claim that time travel is logically possible is not to claim that it's metaphysically or physically possible – still less is it to claim that time travel is actually going on. I stress this because Lewis did not claim that time travel is physically possible or technologically possible or actual. One might accept Lewis's arguments and yet believe time travel cannot occur. As Lewis emphasises, a time travel world, even if possible, might be very unlike our world.

A Cautionary Tale: One day I got a bit fed up with being asked "If Lewis is right, where are all the time travellers then?" and I replied "We're very careful; we get a lot of training". A few unusual e-mails later, I came to regret that flippancy. (For the record: I am not a time traveller. I'm getting older but that is not the same thing …)

It's still remarkable if time travel is even logically possible. Showing that something is logically contradictory is a very powerful weapon in the philosopher's armoury – it's one thing to make a claim which is merely factually wrong but it's quite another to fall into contradiction. (Presumably if your view contradicts itself, then you're sunk.)

Lewis (1976, p. 145) offers this helpful definition of time travel:

> **What is time travel? Inevitably, it involves discrepancy between time and time. Any traveler departs and then arrives at his destination; the time elapsed from departure to arrival (positive, or perhaps zero) is the duration of the journey. But if he is a time traveler, the separation in time between departure and arrival does not equal the duration of the journey.**

So, on Lewis's definition, time travel requires a distinction between two ways of registering time – what we will call personal time and external time.

Personal time is time registered by the travelling object and should reflect changes in all processes travelling with the object. So a traveller's watch, accumulating memories, greying hairs, digestive processes, cellular decay (etc.) might all be registers of personal time. Note:

i) 'Personal time' does not mean that only people can time travel. The gradual rusting of a time-travelling iron bucket would be as good a register of personal time as any other.

ii) Time travel only occurs if all processes travelling with our voyager are affected – one does *not* become a time traveller simply by sleeping, hibernating or breaking one's watch.

External time is time registered in the world at large – by (e.g.) the movement of the tides, the Earth's rotation, the Earth orbiting the Sun, recession of the galaxies, etc.

So here's the crucial bit: if you are not a time traveller, any journey you take will have the same duration and direction in personal time and in external time. However, if you are a time traveller, your journey will be different viewed in personal time or in external time.

A time travel journey has different durations and/or different directions in external and personal time.

For forward time travellers, the journey's personal time has the same direction as external time but different duration. Suppose I travel from 2013 to 2163 in five minutes of personal time as measured by (e.g.) my watch and my memories. Then, by Lewis's definition, I have time-travelled into the future – my journey takes five minutes in personal time but 150 years in external time. Einstein's 1905 Special Theory of Relativity (SR) predicts such phenomena actually occur. To test such 'time dilation' experimentally, measure the decay half-life of a particle at rest (e.g. a π-meson) and then see how long it takes to decay when at high speed. Decay-times lengthen with velocity just as SR predicts.

For backward time travellers, the journey has *different directions* in personal and external time. Suppose I travel for five minutes of personal time but from 2013 to 1863. Here, my journey has positive personal duration (so it ends after it begins for me) but negative external duration – my journey ends 150 external years *before* it begins. Such directional discrepancy between personal and external time would make me a backward time traveller.

This next claim is controversial, but Einstein's 1918 General Theory of Relativity (GR) may allow backward time travel. In 1949, Kurt Gödel (1903-78) solved Einstein's field-equations for a world where it's possible to travel between any points in space and time. Quantum mechanics too may allow backward time travel. However, either way it doesn't look easy and the prospects for practical backward time travel are not looking too bright as of February 17th 2013. (Sorry if anyone is disappointed by that outcome – I know I am – but I would stress this is philosophy of time travel and not a guide to building a time machine.)

Given the personal/external time distinction, we've passed the first hurdle en route to seeing why time travel might be logically possible. The main focus from now on is on backward time travel. Why might backward time travel seem to present logical problems? How might these problems be addressed? These questions bring us to …

2) Grandfather paradoxes

The classic time travel paradox is the so-called 'Grandfather Paradox'. If you could travel backward in time, you could (supposedly) travel back to a time before one of your grandfathers became a parent and assassinate him, thereby preventing one of your parents from existing and hence preventing yourself from being born. So if your mission succeeded, you would not be there to carry out your mission. Paradox ahoy. One and the same person cannot both exist and not exist at the same time. (Like Lewis and most other philosophers, we will assume reality must be consistent.)

So the classic argument against backward time travel runs something like this:

i) If it is possible to travel backwards in time, it is possible to create contradictory states of affairs.

ii) It is not possible to create contradictory states of affairs.

iii) Therefore, it is not possible to travel backwards in time.

This argument is valid. It has the classic logical form 'Modus Tollens': 'If P then Q; not Q; therefore not P'. *Logically* the argument is impeccable. However, an argument guarantees the truth of its conclusion only if it is not merely *valid* but *sound*, i.e. it is a valid argument that contains only true premises. But is the above a sound argument? Lewis says 'No'.

Lewis would accept the validity of the above argument but he would deny its soundness on the grounds that one premise is false. In particular, Lewis's claim is that while statement ii) is true, statement i) is not true and therefore the argument has not proved its conclusion to be true. While Lewis did believe that it is impossible to create contradictory states of affairs, he did not accept that being able to travel backward in time would make it possible to create contradictory states of affairs.

Central to Lewis's argument is the claim that the above argument needs to be unambiguous about what 'possible' means and, as Lewis emphasises, the term 'possible' can mean different things according to context. Lewis argues that confusion follows if these different contexts are not kept clearly distinguished and that the Grandfather Paradox argument is guilty of precisely such confusion.

In order to assess what time travellers in the past (or anyone else) can and cannot do, we need to be clear about what sense of possibility we have in mind, and, in particular, we need to consider what is possible relative to a given set of facts.

Philosophers sometimes talk about 'compossibility', meaning by that possibility relative to some states of affairs, facts or circumstances. (This notion of compossibility is originally due to Gottfried Wilhelm Leibniz, 1646-1716.)

"To say that something can happen means that its happening is compossible with certain facts. Which facts? That is determined, but sometimes not determined well enough, by context" (Lewis, 1976: 143).

I don't have a problem with either of my (sadly late) grandfathers so for purposes of discussion, assume I am on a mission to remove from history somebody I do have a problem with, namely Adolf Hitler (1889-1945). Let's assume I travel from 2013 on a mission to assassinate Hitler in Vienna in 1908. I've done my homework and I think this juncture in history presents the best chances of success, i.e. Hitler's so-called 'Hunger Years' when he was eking out a living as an artist in Vienna. So I activate my machine and thereafter later moments of my personal time unfold in earlier external times – specifically in 1908.

Sidebar: lest all this talk of assassination seems a shade too violent, please feel free to imagine that I'm on some less bloodthirsty mission to the past, e.g. I am trying to make a paradoxical change in history by buying up Hitler's paintings and getting him to live out the rest of his life as a mediocre landscape artist. Preventing Hitler's actual career as Führer by this means would involve just as much of a contradiction as assassinating him. (Paradoxes do not come in sizes – so any such changes to history cannot be 'slightly' paradoxical or 'a bit' paradoxical.)

Let's suppose I can travel to Vienna in 1908. Can my mission succeed? Well, what counts as possibility varies according to the set of facts considered. There are some facts about the Vienna 1908 set-up which are compossible with success, e.g. Hitler isn't bullet-proof, my gun is working. However, relative to a bigger, more inclusive set of facts, there are other facts which are definitely not compossible with my succeeding, e.g. that my target doesn't die until 1945. Assuming death is a one-off operation, I cannot kill in 1908 someone who dies in 1945. BUT:

My being unable to succeed is not the same thing as my being unable to try.

On Lewis's analysis, backward time travel is consistent (i.e. logically possible) if the consequences of a traveller's actions are in place in the history whence the traveller departs. In other words, I can (logically at least) travel from 2013 to 1908 provided that everything I do in 1908 is consistent with the history whence I come.

A non-time-travel example (adapted from Lewis): can I speak (Scots) Gaelic? In one sense, I can: I have "got what it takes" in so far as I currently have a functioning larynx and have learned at least one language. But don't ask me for a recitation of any of Scotland's rich heritage of Gaelic verse because in another, more inclusive, sense, I can't speak Gaelic – alas I simply never learned enough of the words or the grammar. My speaking Gaelic is compossible with some facts about me but not with a more inclusive set. However there's no paradox here because the relevant senses of possibility vary according to the facts considered.

Another example: can I stop smoking? Well, in a sense, I can – relative to facts like: there are various support groups for people trying to quit smoking, various nicotine substitutes exist and I flatter myself I am not totally devoid of will power. So far, so compossible with my stopping smoking. But there's a logical problem with my stopping smoking: I can't *stop* smoking because I don't smoke. But stopping smoking *per se* is logically okay.

One more example – suppose you try to construct a Euclidean triangle with sides of the following lengths: 3 centimetres, 4 centimetres and 5 centimetres. That is logically entirely possible, if maybe difficult to achieve perfectly in practice in a lumpy, bumpy world like ours. However, *logic* forbids you constructing a Euclidean (my emphasis) triangle with sides of these lengths: 3 centimetres, 4 centimetres and 500 kilometres. The third length of side cannot be combined with both of the other two in a Euclidean triangle. But there's nothing logically funny about triangles. The task would be achievable given any two of the three lengths of side above but success is not compossible with all three of them taken jointly.

Now, let me emphasise that Lewis thinks backward time travel is logically possible even if there is only one history. (I'll mention many-histories time travel later on.) Again, this is not the same thing as claiming that backward time travel is *physically possible* in a single history. Maybe single-history backward travel is logically possible but physically impossible. (As we'll hear, some people have argued for something very like this conclusion.)

What this means is that in Lewis's model, backward time travel is still logically possible provided each moment in history happens only once. Backward time travel does not require one and the same moment to happen repeatedly – as if Vienna managed to get through 1908 without my presence and then (somehow) I travel back and make 1908 happen again, only differently with me there this time. Thinking that time travel must involve times happening 'again' is a (surprisingly common) mistake which has been dubbed by Nicholas J. J. Smith the "second-time-around fallacy" (in a fine 1997 paper).

Here's the thing: if travellers from the future (or the past) did not visit 1908 then there is nothing that later (or earlier) times can do to alter that fact. But if future travellers were present in 1908 then nothing later (or earlier) times can do can alter *that* fact either. (If I'm there, I'm there – if I'm not, I'm not. This sounds obvious but its implications run deep.)

Well okay, you may be thinking, maybe backward time travel is logically possible provided the history the traveller arrives in is consistent with the history the traveller departs from. But Lewis's analysis *might* seem to suggest that a time traveller is completely impotent in the past – constrained merely to observe.

Worse, it might seem as if time travel only makes sense if the backward traveller is only present in the past as a totally impalpable ghost, unable to affect anything in the past whatsoever. But this 'ghost traveller' idea actually rests on another mistake …

3) Two senses of change

It might sound as if consistency demands that time travellers in the past must be utterly powerless. Or to put it another way, surely a time traveller can't change the past without creating paradoxes? Well, just as the notion of possibility needs to be unpacked to prevent ambiguity, so too does the notion of change. In one sense, a time traveller can change the past – or maybe more correctly, in one sense, a traveller can have an impact on the past.

Change is another term prone to ambiguity in ordinary contexts. To adapt a point from Lewis, consider what might be called *replacement change* and *counterfactual change*.

An example of replacement change: an intact glass drops onto a concrete floor and shatters. So the intact glass is replaced by a mass of glass shards. Concrete objects suffer replacement changes all the time. (I spill my coffee and a full mug is replaced by an empty one. I sneeze and a completed jigsaw is replaced by a mess of separate pieces. You finish your homework and an unfinished assignment is replaced by a completed one.) There's a phase of history with an intact glass and then a phase featuring a smashed glass. But please note that nowhere in history are the intact and smashed phases superimposed.

Consider now the slightly more rarefied-sounding but actually pretty familiar notion of counterfactual change. With counterfactual change, we assess the impact that something makes by considering how events would have unfolded if that something hadn't occurred. A counterfactual (sometimes written 'contrary-to-fact conditional') expresses a relationship of consequence by taking as antecedent something that didn't in fact happen – for example, "If the internal combustion engine had not been invented, travel in the twentieth century would have been a lot slower". (A more mundane example: if my alarm clock hadn't gone off at the correct time this morning, I would have slept in.)

Another example: it's widely agreed (not least by the Duke of Wellington) that the outcome of the battle of Waterloo on June 18th 1815 was crucially affected by the arrival of a Prussian army under Field Marshall Blücher. Suppose it's true that without Blücher's intervention, the French forces would have triumphed. So we can assert the counterfactual conditional "If Blücher had been delayed, Napoleon would have won". Clearly Blücher's arrival had an impact, or to put it another way, Blücher's arrival changed the course of history. But changed *in what way*? Not by replacement – it isn't as if there was once a version of June 18th 1815 where Napoleon won at Waterloo and then Blücher's appearance (paradoxically) made the French victory go away so an Allied victory could take its place. Waterloo happened only once, ending in an Allied victory, but Blücher still changed its outcome.

Whither time travel in all this? Well, here's the important bit re: change:

Lewis thinks travellers in the past can only change history in the counterfactual sense, i.e. in the sense that history would have been different had the traveller not been present.

Lewis thinks travellers cannot make replacement changes in history. BUT, he says, *nobody* can make a replacement change to *any* moment in history, past, present or future. If I initially decide to have coffee with my lunch, only to change my mind and opt for peppermint tea, I have not thereby replaced an "Al has coffee" future with an "Al has peppermint tea" future. (These are the Earth-shaking decisions I wrestle with every day …) So replacement changes can happen to concrete objects but not to times. However, a time traveller in the past can nonetheless make a counterfactual impact and thereby (in a very real and important sense) be said to have changed history. (Note though my killing Hitler in 1908 would be a replacement change, and therefore impossible.)

Okay, let's try to construct a time travel story whereby the traveller has a counterfactual (i.e. non-replacement) impact on history. Suppose my time machine arrives in 1908 Vienna so close to my target that my arrival causes Hitler to leap backward, out of the path of an oncoming tram that would otherwise have ended his life. In this case, I would have made an impact on history but definitely not the one I would have wanted – in other words, my impact could be assessed with the counterfactual conditional "If I hadn't travelled back in time, Hitler would have died in 1908". So, if this sequence of events had played out, I would have been (albeit quite unwittingly and involuntarily) in part causally responsible for Hitler's rise to power. A very worrying thought for the aspirant time traveller … maybe you can have an impact in the past but your impact may not be a beneficial one at all. Travellers need not visit the past as ghosts but as concrete, fully-actual, living, breathing humans.

So travellers in a single history can help to make the past what it was without paradox, provided that their impact on past events is a counterfactual one and not one involving the replacement of past events.

"But surely", I hear you cry, "This does not exhaust the problems presented by backward time travel". Indeed not. Which brings us to ...

4) Causal loops

There's another kind of time travel example that poses problems that don't involve consistency but rather information and specifically the origins of that information. The cases in question involve what we'll causal loops.

A causal loop is an unusual kind of causal chain, namely a chain of events which loops backwards in time so that an event proves to be among its own causes. (Note this is not the same as a positive feedback loop, which involves normal causation throughout.)

In a causal loop, an event turns out to be (at least in part) a cause of itself.

Philosophers have often felt that such loops are philosophically intolerable. Perhaps unsurprisingly, Lewis disagrees … A couple of examples of causal loops:

i) Who writes *Hamlet*?

Imagine you travel back in time to 1588 equipped with a copy of Shakespeare's complete works printed in 2013. On arrival, you meet struggling young player, Will Shaxberd, (as he was *maybe* then calling himself) and you read Will the following lines:

> *What a piece of work is a man,*
> *How noble in reason,*
> *How infinite in faculty,*
> *In form and moving, how express and admirable …*

In short, you read Will a great soliloquy from *Hamlet*. (Specifically, from *Hamlet*, Act II, scene 2.) You then let Will copy all the contents of the Complete Works you've brought with you. Shaxberd (as was) duly arranges for his manuscript copies to be circulated to Elizabethan stage-companies, (maybe changing his name to the more familiar "Shakespeare" en route). The plays become popular, add to the canon of British drama and are reprinted until you obtain a Complete Works in 2013, which you take back to 1588 …

Now there seems to be no inconsistency here – no Grandfather Paradoxes or 'replacement changes' involved – yet there is something odd nonetheless. Even if this case is consistent, one might ask: but where does the information come from?

Or to put it another way, who writes *Hamlet*?

ii) A Self-Creating Time Machine (By Telephone)

Here's another example (freely adapted from Lewis 1976): you're sitting at home one evening when the telephone rings. You pick up the telephone and answer it, to hear an oddly familiar voice saying "Don't say a word. Write these instructions down and follow them to the letter". The instructions prove to be for building and operating a time machine.

You follow the instructions and the machine takes you into the recent past. On arrival, you dial your own 'phone number and, when an oddly familiar voice answers, you say into the receiver "Don't say a word. Write these instructions down and follow them to the letter" …

This story, even if we grant that it is consistent, prompts the question: How do you know how to build a time machine? Well, your later self knows how because you remember hearing the instructions as your earlier self. In turn, your earlier self knows how because of remembering being instructed by your later self. But where does the information come from in the first place? Perhaps surprisingly, Lewis's answer is: there is no answer.

"His earlier self knew how because his older self had been told and the information had been preserved by the causal processes that constitute telling. But where did the information come from in the first place? Why did the whole affair happen? There is simply no answer. The parts of the loop are explicable, the whole of it is not" (Lewis, 1976: 140.)

The instructions for building a time machine in Lewis's case (or *Hamlet* as above), in a real sense do not 'come from' anywhere – they simply are. Causal loops appear strange but are no worse from the point of view of ultimate explanation than any other kind of causal chain.

We have no complete explanation for any causal sequence (closed or linear) and we may just have to accept spontaneous creation of information in other cases. Explaining the existence of the whole loop may be a very different matter from explaining the existence of any loop-component. There seem to be only three possible forms a causal chain could take:

> i) Finite linear – causal chains that terminate in events that are causes but that do not themselves have causes
>
> ii) Infinite linear - each event has a cause, and those causes in turn have causes, and so on *ad infinitum*. The chain as a whole has no beginning.
>
> iii) Finite non-linear – the chain loops back on itself.

In the first case, we can only take the analysis of our chain back so far before we hit an event that is a cause but that itself has no prior cause. Physicists take very seriously the idea that there are such *ex nihilo* happenings, e.g. the emission of alpha particles or even the Big Bang that brought this universe into existence. The chain itself has no prior cause for its existence and taken as a whole appears inexplicable. (As Stephen Hawking put it, asking what came before the Big Bang is like asking what lies to the North of the North Pole. If you try heading North at the North Pole, you find yourself heading South …)

In the second case, we can pursue the chain of causes literally infinitely (i.e. every event has a cause distinct from itself stretching back forever) and never arrive at an 'Unmoved Mover' or 'Uncaused Causer' so again the occurrence of the whole chain is without explanation.

In the third case, the search for an earlier explanatory event leads right the way round the chain to the very event we started from. Again there is no explanation of the whole chain.

So Lewis does not try to address the causal loop problem by trying to explain where the information comes from. Instead, he offers a parity argument: granted there is no well-formed explanation for the existence of a causal loop taken in its entirety. However, exactly the same can be urged in the case of linear causal chains (finite or infinite).

On the face of it, this 'no answer' answer of Lewis's isn't very satisfactory. Surely we have stories for the origins of information and information just doesn't spring into being from nothing? Well, it's important to distinguish between asking where an *event* comes from and asking where *an entire chain of events comes from*. The first question is perfectly sensible but the second maybe less so. When it comes to explaining an event, we can usually appeal to some earlier event. I am alive now in part because of facts about my parents. Those facts in turn reflect facts about human evolution, the origins of the Milky Way and the history of the universe … But where does the whole chain come from? Lewis's point is that all three kinds of chain are equally mysterious when it comes to their ultimate origin.

Ultimately, a causal loop is no more (or less) hard to explain than any other kind of causal chain.

In connection with the material in this section, please see also Paul Horwich's 'On Some Alleged Paradoxes of Time Travel', *The Journal of Philosophy*, LXXII, 1975: 432-44. A paper which is very handy to read in conjunction with Lewis (1976), especially on causal loops.

5) Where next?

That completes my survey of Lewis (1976). However, there are lots of philosophical time travel questions we haven't discussed. Here are brief mentions of a few:

i) For one thing, time travel poses some interesting problems in persistence and identity. Consider the Lewis telephone call case again: here, we seemingly have two versions of the same person existing in different places at the same (external) time.

- How might time travel confer the power of bilocation?

Concrete objects cannot be completely located in more than one place at a time.

- **See Miller (2006) and Wright (2006).**

ii) Lots of interesting philosophical questions arise from the physics of time travel. What sort of physical laws might occur in a world that permitted time travel?

- **Physicist David Deutsch and philosopher Michael Lockwood argue that physically realistic time travel can only occur if there are many histories.**

They argue thus: backward-travelling systems face curious restrictions on their actions. In time-travel contexts, otherwise physically possible set-ups seem to yield impossible outcomes. (Guns that should normally be able to kill unarmoured people seem to fail of their normal function, etc.) This argument appeals to something like an 'Autonomy Principle': the causal powers of a physical system should reflect only local facts about that system and should not depend on the state of the universe as a whole. Therefore, Deutsch and Lockwood argue, the only way to keep time travel physically realistic is to imagine that backward time travellers must also make a transition into a different branch of history. So I can travel to 1908 and kill Hitler – the Hitler I kill resides in one branch and the Hitler from my history resides in another. No paradox because the Hitler who dies in 1908 and the one who dies in 1945 are distinct individuals in different branches.

- **But is travel between branching histories really time travel?**
- **See Deutsch and Lockwood (1994), Deutsch (1997), Sider (1997) and Lockwood (2005).**

iii) Stephen Hawking asked "If time travel is possible, where are the time travellers?"

- **Paul Horwich has argued that if backward time travel did occur, we would know about it because time travellers from the future would trail long chains of unlikely coincidences in their wakes.**

But maybe only very unreflective travellers would keep trying to assassinate the famous … and so unlikely output coincidences only follow from unlikely inputs.

- See Horwich (1987) and Smith (1997).

Iv) Work by philosopher John Earman suggests that if physical time travel mechanisms were constructed, they would be uncontrollable once completed.

- **Once one were constructed, it might be physically impossible to predict what a time machine would do.**

So (ironically) even if physics allows the construction of a time machine, it might not allow the device to be controllable …

- See Earman and Wüthrich (2008).

v) If physicists discuss time travel, they talk about closed timelike curves (CTCs).

- A CTC is a path through spacetime that returns to the very point whence it departed but which never exceeds the speed of light along the way.

So a CTC represents a physically possible pathway into the past.

- **Might CTCs exist in the real world or something like it?**

As above, in 1949 Kurt Gödel published a solution of Einstein's field equations that describe a remarkable universe governed by General Relativity. The model universes described by Kurt Gödel are infinite, rotating (in a technical sense) spacetimes with CTCs through their every point. In a Gödel universe, all of space and time are accessible. Alas, Gödel's infinite, rotating, non-expanding universe is rather unlike our apparently finite, non-rotating and expanding universe. (The Gödel universe's rotation is necessary for CTC-making.) (See Appendix 1 for more Gödel.)

However, it remains unclear whether the unification of General Relativity and quantum mechanics (the long-sought theory of 'quantum gravity') will allow CTCs. Hawking's 'Where are the travellers?' problem threatens some scenarios more than others. If our universe were an infinite, CTC-filled, Gödel universe, the observed absence of time travellers might be very puzzling. However, physicists also discuss localised CTC-generators, i.e. ways to make CTC-regions in otherwise normal spacetimes. A CTC-generator is not a vehicle like those familiar from fiction, but a region of curved spacetime. Local CTC-devices all have the feature that they facilitate access to the past only from the first moment when a CTC is generated. Suppose the first CTC-generator ever made comes on-line in 2015 – later times could use it to travel back to 2015 but no times before that could be accessed.

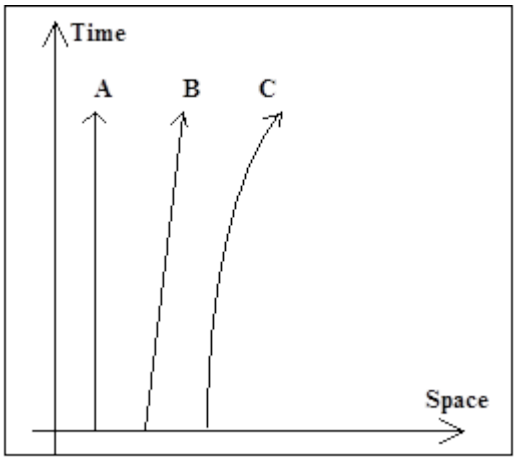
- So maybe time travel is possible but not just yet …

- See Hawking (1999) and Thorne (1994).

6) Appendix 1: Relativity, Kurt Gödel and the unreality of time

At the risk of over-extending this hand-out, some final thoughts on Gödel's argument from the possibility of time travel to the unreality of time. This section gets technical.

Part One: Relativity and Time Travel – An Exceedingly Brief Sketch.



Let's plot the career of some objects over time and space.

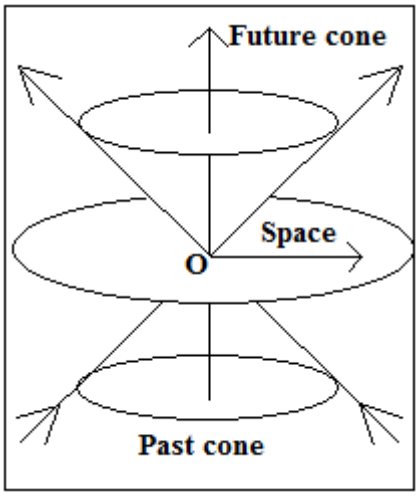
Left, three spacetime paths, or worldlines:

A is a straight line parallel to the time-axis, i.e. world-line of a particle at rest. No change in spatial location.

B is a straight line at a constant angle to the vertical time axis, i.e. world-line of a particle with constant velocity.

C is a curved path, i.e. world-line of an accelerating particle. Spatial displacement per unit time varies.

Hermann Minkowski (1864–1909) invented a useful schema for depicting events, where space has (usually two) horizontal dimensions and time a vertical dimension. In Minkowski's diagram, the possible paths of light-rays to and from any given point in spacetime form a pair of cones. The cones map where causal influences can go. Their sides are formed by light-ray paths and lie at 45° to both time- and space-axes.



Left, light-cones for a point 'O'.

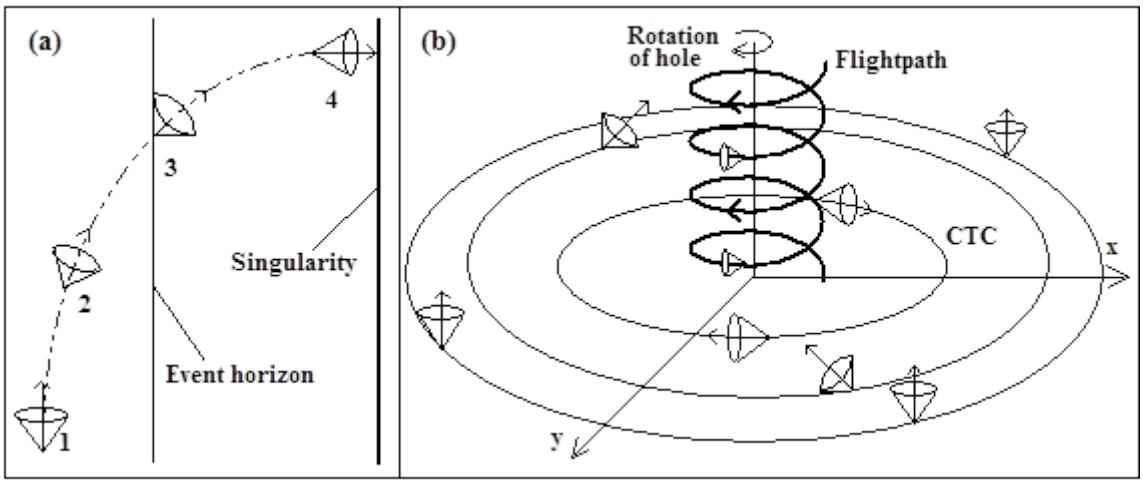
Spacetime paths are of three kinds: 1) time-like paths - those below the speed of light; 2) light-like paths - those taken by light-rays and 3) space-like paths, corresponding to (forbidden) faster-than-light journeys.

The past cone contains all points from which a signal could travel to O – i.e. all points that can affect O. The future cone contains all points that can be reached by a signal from O - i.e. all points O can affect. Points outside cones are 'absolutely elsewhere' – they can't interact with O and are in no set temporal sequence with O.

Note that the past and future cones meet only at O itself – they do not overlap. In SR's flat spacetime, all light-cones are aligned so past events can't be visited without travelling faster than light. However in GR, the mere presence of mass distorts spacetime. SR may be approximately true in (e.g.) empty spacetimes, but it's strictly false for spacetimes containing matter. All matter affects the alignment of light-cones, although usually only minutely: "In flat spacetimes light cones are always 'aligned' but in curved spacetimes they (generally) are not, and from that can come time travel to the past", (Nahin, 1999, p. 444).

GR also predicts something called *gravitomagnetism*, i.e. moving mass generates a gravitational field just as moving charge generates a magnetic field: "The mere presence of mass tips light cones, but the effect is unnoticeable in everyday life on Earth. A truly enormous mass density is required to tip nearby light-cones over so that their Future noticeably opens up towards the massive body", (Nahin, 1999: 444-5). Very large, dense and/or fast-moving masses tilt nearby cones until local and global time-axes diverge so the local future points into the global past.

Below (a): cone-tilting near a non-rotating black hole. (Only future cones shown.)



At Stage 1, spacetime is roughly flat, with little or no overall gravitational pull. However, at 2, the hole's presence starts making itself felt and local future cones are pulled away from their original orientation. At 3, a particle has to travel away from the hole at the speed of light in order to maintain constant distance from it. If a particle strays within this critical radius (or "event horizon") it falls inexorably into the hole. By 4, all future cones point towards the hole. The event-horizon prevents any signalling from 4 to 1.

However, not all dense masses might be inescapable: "If the massive body is set rotating, ... Future cones in spacetime open up both toward the body and in the direction of rotation", (Nahin, 1999: 444-5). Orbiting a swiftly-rotating ultra-dense 'Tipler Cylinder', you can explore light-cones which let you follow the local future into the global past. 'CTC' above marks the critical radius where a time-like journey into the local future returns to the very spacetime point whence it started. Alas, Tipler cylinders require the following features:

i) Surface-velocity ≥ ½ light-speed
ii) Matter which is roughly 10^{40} - 10^{80} times denser than an atomic nucleus
iii) Infinite length. (This last condition might be the <u>real</u> sticking point.)

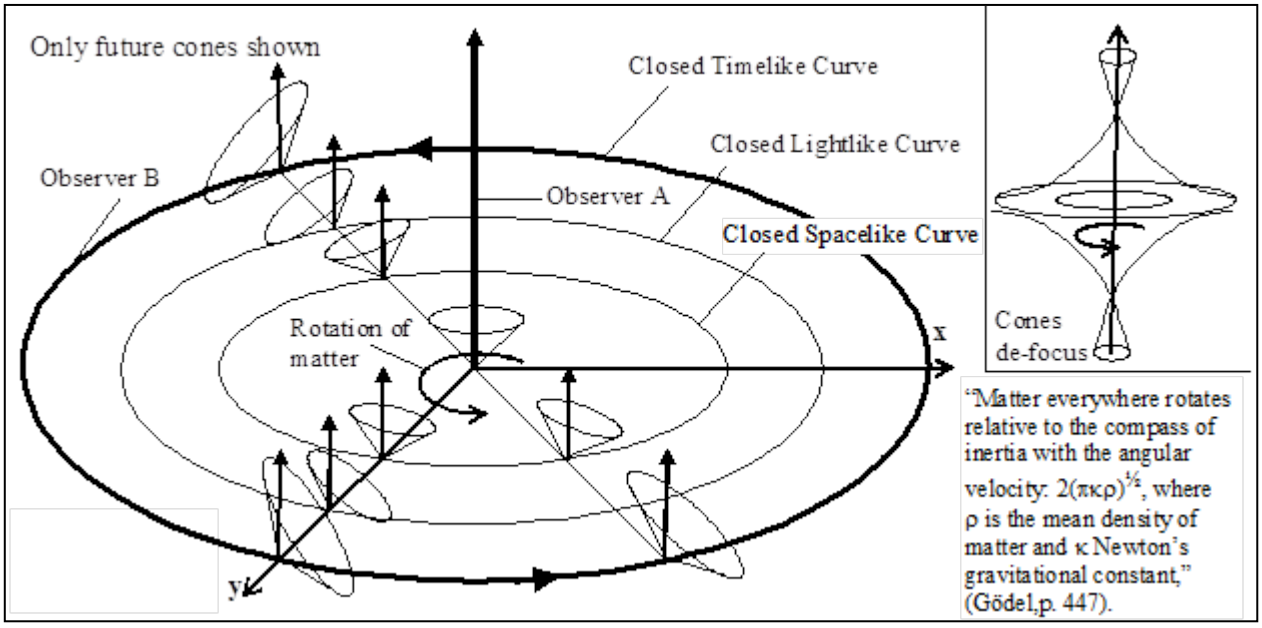
However, while the cylinder time-machine in Tipler's (1973) model is infinitely long, some physicists have speculated that finite objects might generate the same effect and that natural time-machines may exist as rapidly-rotating 'Kerr' black holes.

Part Two: Gödel's Universe: From Time Travel to the Unreality of Time.

Kurt Gödel's (1949) solutions to Einstein's field equations exhibit some striking properties. Notoriously, Gödel universes permit CTCs. Gödel worlds let a traveller journey into her own past, interact with her earlier self and return to her starting point, and thus allow "travel into any region of the past, present, and future, and back again", (see Nahin, 1999: 81).

Gödel (1949) describes an infinite spacetime filled with an idealised perfect fluid. (The distribution of galaxies, stars and dust-clouds in our world can be treated as such a fluid.) To prevent this fluid collapsing under the action of gravity, the entire contents of the material universe in Gödel's world are imagined as rotating. (This absolute rotation is not to be imagined as taking place about a privileged geometrical axis but about 'the compass of inertia' – there is no unique axis of rotation for Gödel's universe and any observer would seem to stand at the centre.)

In Gödel's universe, there is a critical radius around every point where rotation of matter both tilts light-cones and opens them out so that CTCs form. In any physically realistic universe, the critical CTC-radius is huge : "If our Universe were Gödelian, ... the critical radius would be 16 billion light-years" (Nahin, 1999: 492), so any backward time-journey would have to cover at least a hundred billion light-years.



Every light-cone "de-focuses" so the past or future of any point is the whole universe. Note observer A sees B's whole world-line as instantaneous and B will think the same of A. In effect A and B have time-axes which are at right-angles to each other.

Generally physicists accept that CTCs are a generic feature of Gödel's (and certain other) GR-compatible spacetimes. Furthermore, Gödel worlds have this 'time travel' property as a

result of intrinsic spacetime features which cannot easily be analysed away. Thus, CTCs in Gödel spacetimes reflect a real physical possibility within GR. A Gödel world is compatible with one of our best-confirmed physical theories, i.e. GR. So a Gödel world is a possible world in a strong sense – a Gödel world may be weird but it's governed by the same physical laws we believe govern our world.

Gödel thought GR's attendant possibilities for CTCs completed a revolution in our understanding of time that SR only began. However, possibility within even a very well-established scientific theory is not necessarily the same as possibility *tout court*. It is possible that two (or more) mutually incompatible theories could be empirically successful although presumably no more than one member of this set could be true. At present we have two candidates for fundamental physical theory which contradict each other over several issues, i.e. GR and quantum theory.

Gödel himself would almost certainly be unhappy with the label 'time travel world' if applied to one of his family of rotating universes. But surely any world which permits travel between any and all points in time and space features everything requisite for meaningful talk of time travel? Well, Gödel thought his rotating universes could be explored throughout by travellers and were full of CTCs, but he concluded this demonstrated not so much the possibility of time travel as the unreality of time.

Yes, Gödel believed the rotating universe in his (1949) did offer CTCs. However, these curves could not really be regarded as taking place in a world that has a truly temporal dimension. Hence Gödel didn't really believe in time travel *per se*, for the (rather unexpected) reason that he held that his results demonstrated that there is no objective correlate to what we ordinarily believe is time.

Gödel's reasoning was roughly thus: time must involve genuine becoming. Our intuition of time is of a process whereby objects pass from future non-existence, enter existence in the present and thereafter pass into non-existence in the past. Past, present and future differ with respect to existence and the passage of time thus involves a change in the status of things. All events are quite definitely not on a par when it comes to existence. The present is in some sense privileged. However, Gödel thought of CTCs as given all at once, complete spatiotemporal unities, to which no dynamic account of change or flow could be applied. But besides CTCs, Gödel worlds let different observers have orthogonal time-axes, like A and B above. Each observer would perceive the other's entire existence to be instantaneous, and Gödel universes afford no physical basis for saying either one is wrong.

Gödel thought his rotating worlds revealed something important about the nature of time. Gödel-worlds certainly differ from ours but they do so over what seem to be purely contingent matters, such as the amount of matter in existence and how that matter is distributed. These contingencies are not settled by physical law. Gödel thought time can

only be conceived as involving passage. The existence of time cannot be a matter of purely contingent properties like how matter happens to be arranged. So Gödel concluded his CTC-worlds suggest time has no real analogue. Hence calling CTC-travel *time* travel is a misnomer if Gödel is correct, since the 'time' co-ordinate in a Gödel world does not resemble what we think time is or must be.

Gödel thought the real lesson of his (1949) was that physics has revealed that reality is not temporal and there is no objective analogue to what we think is temporal flow. Time is thus 'ideal' in that time may be a pervasive feature of perceptions but it cannot have any existence in reality. Gödel held that reality is not ordered in a temporal series and does not contain anything like time as it appears in our intuitive concepts. However, unlike arguments against time from other philosophers, Gödel's argument for time's ideality does not appeal to logic but to physics. Gödel thought the ideality of time is a physical discovery.

A Gödel & Kant Sidebar: Gödel claimed his view of time was inspired by that of Immanuel Kant (1724 – 1804). In his *Critique of Pure Reason*, (second edition, 1787), Kant argued that beside the empirical (or phenomenal) world given to us through the senses, there is also the realm of things as they are in themselves, (the noumenal realm). Space and time are only properties of the phenomenal world, i.e. the world as it appears to us, and thus the noumenal world (the world as it is independent of the order of our experience) is not spatio-temporally ordered. So, Kant concluded, time is *empirically real* (i.e. real in the world of experience) but *transcendentally ideal* (i.e. has no mind-independent existence).

Gödel thought that time cannot *accidentally* possess the property of passing. Whether or not time possesses objective existence should not be a matter of accidental features like the distribution and/or quantity of matter in our world. Gödel thought the objectivity (or not) of time cannot be a mere function of how matter happens to be arranged. If our universe could have been a Gödelian universe then there is no necessity linking experience of temporal passage with objective time.

Gödel seemingly assumes our chief reason for believing in objective time is our experience of temporal passage. If temporal experience only contingently relates to time's existence we might experience a purely spatial dimension as though it were a temporal one. If we could have all the experiences that we now think are reliably indicative of temporal passage but in a world which completely lacked temporal passage, what reason would we have for believing that time is real? Shades here of Descartes' 'Evil Demon' thought experiment. Descartes (1596-1650) argued that we could have exactly the same experiences that we now regard as indicative of the existence of an external world even if no such world existed, (e.g. if we were being systematically fooled by an Evil Demon who controlled all our sensory inputs at once). Therefore, Descartes concludes, any certainty we have that an external

world exists cannot be derived from the unmediated evidence of our senses. Our evidence under-determines the metaphysical question of whether reality is as it seems.

To put Gödel's argument in Cartesian terms: if all our evidence that time exists could be the same in the absence of genuine temporal passage then our evidence does not entitle us to claim to know that time genuinely passes. If genuine and experiential temporal passage are only contingently related, this undermines our best (maybe only) reason for thinking time genuinely passes. Why else, Gödel asks, do we believe that time genuinely passes apart from our apparent experience of time passing? Gödel thought our intuitions are our most fundamental source of insight into the nature of time but even they only reveal the properties that time would (hypothetically) have if it did exist objectively; our intuitions alone in this case cannot establish the existence of the intuited entity. If time existed then it would necessarily have the form given to it in our intuitions; however, time does not exist and therefore no objective analogue of our experience of temporal passage exists.

A final sidebar: Computation and Gödel's Universe. Amongst the odd features of Gödel's universe is that therein, one observer can survey in a finite amount of time a process that takes an infinite time for another observer. This might allow odd ways of finding answers to some outstanding mathematical conjectures. For example, suppose you want to determine the truth-value of (e.g.) Goldbach's Conjecture that all even integers (> 2) are uniquely expressible as the sum of two primes. In Gödel's universe, you could launch a computer which is programmed to test Goldbach's Conjecture by exhaustion for all infinitely many even integers greater than 2 and yet observe the whole infinitely long calculation in a finite amount of your personal time. For more on such *Malament-Hogarth* (M-H) spacetimes, see Hogarth (2004) and Earman and Norton (1996). Informally, a spacetime is M-H if it contains a timelike curve with infinite proper time, the entirety of which lies in the causal past of a point in the spacetime. Please note though that while Gödel's universe is M-H at every point, most M-H spacetimes in the literature do not feature backward time travel.

Gödel's argument from CTCs to the ideality of time has been much criticised and not always well-understood. However, I recommend Savitt (1994) and three books by Palle Yourgrau (1991, 1999 and 2005 – all cited below), which although not always endorsing Gödel's conclusions, do treat Gödel's argument as one of serious consequence. Whatever else it may do, Gödel's argument poses a forceful dilemma between CTCs and genuine time.

7) Appendix 2: Some notable time travel fictions and films

Unlike most metaphysical topics, time-travel has drawn forth a large fictional literature too.

I used to think H. G. Wells or Mark Twain had invented time travel fiction with *The Chronic Argonauts* (1888) or *A Connecticut Yankee in King Arthur's Court* (1889). Well how wrong I was:

Special mention to Edward Page Mitchell (1852 - 1927), probably the first writer in English to pen an unequivocal time travel (and causal loop) story: 'The Clock That Went Backward' (1881). Also interesting is Page Mitchell's 'An Uncommon Sort of Spectre' (1879), with its ghost from the future. Both Page Mitchell stories are in a fascinating anthology edited by Chad Arment, called *About Time: The Forerunners of Time Travel and Temporal Anomalies in Science Fiction and Fantasy* (Coachwhip Press, Landisville, Pennsylvania, 2009). *About Time* also includes what may be an even earlier backward time travel tale, 'An Anachronism, or Missing One's Coach', published anonymously in the 1838 *Dublin University Magazine*. I must also acknowledge Enrique Gaspar's 1887 *El Anacronopete*, due to appear in the English for the first time soon as *The Time Ship: A Chrononautical Journey*.

Below are a few more stories I found interesting. I believe authors have the right to construct inconsistent fictions if they so wish and many of the following are not remotely Lewisian.

- Stephen Baxter, *The Time Ships*, (1995). Authorised centenary sequel to Wells' *The Time Machine*. (Many-worlds travel featuring not only Wells himself but Gödel too.)
- Ray Bradbury, 'A Sound of Thunder', (1945), reprinted in *The Golden Apples of the Sun*. Rock-solid classic 'change the past' tale and an intriguing meditation on historical contingency too. (With added dinosaurs ... and a crucial butterfly.)
- John Brunner, *Times Without Number*, (1962, 1969). My favourite 'temporal police force' story – intentionally inconsistent, to very clever effect. Unusually willing to consider time travel in terms of freedom, theology and salvation.
- Richard Cowper, 'The Hertford Manuscript', (1976), in Cowper's *The Custodians*. Offers a manuscript of 19th century authorship retrieved from the 17th century.
- John Crowley, 'Great Work of Time', (1989), reprinted in Crowley's *Novelty*. Pushes the notion of changing history as far as it can possibly go … and then further.
- Lester Del Rey, 'My Name is Legion', (1942), reprinted in *The Best of Lester Del Rey*. Perhaps the pinnacle of multi-location stories – also contains some advice on what to do with (the obviously then still-living) Adolf Hitler.
- Philip K. Dick, 'A Little Something for Us Tempunauts', (1974), reprinted in *We Can Remember It for You Wholesale*. Genuinely disturbing (to this reader at least) fusion of time travel and eternal recurrence.
- Stella Gibbons, 'The Other Side of the Medal' (1945). Time-slippage between Agincourt and the Great War. The Bowmen of Mons story from *their* point of view.
- Robert A. Heinlein, "__ All You Zombies __", (1953), reprinted in Heinlein's collection *The Unpleasant Profession of Jonathan Hoag*. Now a bit dated and in some respects regrettably of its time but justly famous for introducing 'Jane', the hermaphroditic, inadvertently self-fertilising and self-parenting time-traveller.
- Henry James, *The Sense of the Past*, unfinished but posthumously published in 1917. Reprinted in a fine edition in 2006 as part of *The Sense of the Past: The Ghostly Stories of Henry James*. One of the first stories of backward time travel.

- Michael Moorcock, *Behold the Man*, (1969), original version in *Moorcock's Book of Martyrs*. Centred on a remarkable feat of historical impersonation. (I say no more.)
- Audrey Niffeneger, *The Time Traveler's Wife*, (2004). Absolutely stunning depiction (made with complete consistency) of a life whose personal time is very convoluted indeed. Lewis might well have applauded this ingenious and moving tale.
- Christopher Priest, *The Space Machine*, (1976). Rumbustious fusion of *The Time Machine* with Wells' *The War of the Worlds*. Space + Time + Martians = Triumph.
- Christopher Priest, 'Palely Loitering', (1979), reprinted in Priest's magnificent collection *An Infinite Summer*. Poignant tale of revisited chances that also oddly anticipates real physical speculation about (e.g.) time-travel by Alcubierre warp-tube.
- Wilson Tucker, *The Year of the Quiet Sun*, (1970). Oddly convincing, Biblically-haunted, depiction of government-funded time travel used (and misused) as an instrument for short-range political forecasting.
- Mark Twain, *A Connecticut Yankee at King Arthur's Court*, (1889). Transmigration of epochs, no less – transplants a then-contemporary American to the British Dark Ages. Plants some palpable hits on King Arthur and all quite independently of Wells.
- H. G. Wells, *The Chronic Argonauts*, (1888). Fun but rather rough-and-ready first attempt at *The Time Machine* – an attempt which Wells later tried to suppress. Rather clunky but does contain one of the first causal loops in literature.
- H. G. Wells, *The Time Machine*, (1895). Maybe not *entirely* the original but still the best. Rather well filmed in 1960. My preferred edition is *The Definitive Time Machine*, editor Harry M. Geduld, (Bloomington, Indiana University Press, 1987). This splendid compendium contains all Wells' published versions and many drafts.
- Robert Westall, *The Devil on the Road* (1978). Compelling fantasy of time-travel by witchcraft between the 1970s and the 1640s. Amongst other highlights, has the most extraordinary use of time-travel bilocation I've seen. (And a wonderful time-cat …)

Likewise, here are a few time-travel films that seemed interesting to me too:

- *La Jetée*, (1962), written and directed by Chris Marker. Beautiful, haunting short film told almost (but not quite) entirely in stills.
- *12 Monkeys*, (1995), written by David Peoples and Janet Peoples, directed by Terry Gilliam, (inspired by Marker's *La Jetée*). Along with Audrey Niffeneger's *The Time Traveler's Wife*, perhaps the best fictional exemplification of David Lewis's classic analysis yet devised.
- *Primer*, (2004), written, directed and produced by Shane Carruth. Not at all Lewisian but thoroughly intriguing – watch it at least twice, ideally the second time with director's commentary, some string and a notepad handy.
- *Time Crimes (Los Cronocrimenes)*, (2007), written and directed by Nacho Vigalondo. Also thoroughly Lewisian, albeit to some very strange, *film noir-ish*, ends. Another "watch at least twice" job.

I am always in the market for more recommendations however.

(I confess I haven't managed to see *Looper* (2012) yet but I hear it's very good.)

8) List of references / further reading

The following is only a selection of works I would stress but, just as a guide, I've taken the liberty of underlining those works I think are particularly interesting / important / useful / relevant etc.

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