Causal Loops in Time Travel

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Contents

Abstract

In this paper I analyze the possibility of time traveling based on several specialized works, including those of Nicholas J.J. Smith ("Time Travel", The Stanford Encyclopedia of Philosophy"), (Smith 2016) William Grey ("Troubles with Time Travel"), (Grey 1999) Ulrich Meyer ("Explaining causal loops"), (Meyer 2012) Simon Keller and Michael Nelson ("Presentists should believe in time-travel"), (Keller and Nelson 2010) Frank Arntzenius and Tim Maudlin ("Time Travel and Modern Physics"), (Arntzenius and Maudlin 2013) and David Lewis ("*The Paradoxes of Time Travel*"). (Lewis 1976) The paper begins with an introduction in which I make a short presentation of the time travel, and continues with a history of the concept of time travel, main physical aspects of time travel, including backward time travel in general relativity and quantum physics, and time travel in the future, then a presentation of the grandfather paradox that is approached in almost all specialized works, followed by a section dedicated to the philosophy of time travel, and a section in which I analyze causal loops for time travel. I finish my work with conclusions, in which I sustain my personal opinions on the time travel, and the bibliography on which the work is based.

Keywords: time travel, causality, causal loops, temporal paradoxes, grandfather paradox

Introduction

Time travel involves traveling in a time different from the present, in the past or in the future, basically without a space move with reference to a local coordinate system. Time travel can be made by a material body that may or may not be a living being, and for which a special device called the time machine is usually used.

Time travel is a recognized concept in philosophy and science, but whose scope is highly disputed, giving rise to numerous paradoxes in both philosophy and science. Time travel is considered by some accepted both in general relativity and quantum mechanics, but there is a unanimous consensus that it is not feasible with current technology. (Hawkins 2010) The raised issues are different for the time travel in the past compared to the time travel in the future.

Note that the following aspects are not considered to be time travel: sleep, cryogenic freezing, virtual reality simulator, crystal ball predictions, isolation, time zone change, etc.

The most well-known definition of time travel is given by Lewis: (Lewis 1976, 145–46)

"What is time travel? Inevitably, it involves a discrepancy between time and time. Any traveller departs and then arrives at his destination; the time elapsed from departure to arrival…is the duration of the journey. But if he is a time traveller, the separation in time between departure and arrival does not equal the duration of his journey.…How can it be that the same two events, his departure and his arrival, are separated by two unequal amounts of time?…I reply by distinguishing time itself, external time as I shall also call it, from the personal time of a particular time traveller: roughly, that which is measured by his wristwatch. His journey takes an hour of his personal time, let us say…But the arrival is more than an hour after the departure in external time, if he travels toward the future; or the arrival is before the departure in external time…if he travels toward the past."

Another definition of time travel (Arntzenius 2006) (Smeenk and Wüthrich 2011) equates it with the existence of the closed timelike curves (CTC), a Lorentzian manifold of a material particle in spacetime returning to its starting point.

Some authors accept the existence of two temporal dimensions, (Meiland 1974) and others consider scenarios with multiple "parallel" universes, each with its own four-dimensional spacetime. (Deutsch and Lockwood 1994) But the question is whether a travel in another temporal dimension or into another parallel universe is indeed a travel in time or a virtual one.

Examining the possibility of returning back in time in a hypothetical universe described by a Gödel metric, led Kurt Gödel to assert that time could be a kind of illusion, (Yourgrau 2005) just another dimension as space, resulting in a 4-dimensional "block".

History of the concept of time travel

Egyptian thinker Ptahhotep (2650-2600 BC) said: " Follow your desire as long as you live, and do not perform more than is ordered, do not lessen the time of following desire, for the wasting of time is an abomination to the spirit... " (Bartlett 2014)

The Incas regarded space and time as one concept called *pacha*. (Atuq Eusebio Manga Qespi 1994)

Ancient philosophy has had two different time-related concepts: the followers of the Greek philosopher Heraclit think that the world is a continuous stream, whereas those of the Parmenid's metaphysics claim that truth and reality are stable and eternal. Based on these metaphysical concepts, McTaggart developed an argument for the non-reality of time that has become a common starting point for discussion of his nature. (Lewis 1976) Only the Parmenian philosophy, according to which the past, present and future are as real as the present, can accept journeys in time. (Grey 1999)

Aristotle argued that changing the past surpasses even the power of God. For this reason, "no one thinks of the past, but of what is future and can be different." (Aristotle 1941)

In Hindu mythology, *Mahabharata*, there is the story of King Raivata Kakudmi, who travels to heaven to meet the creator of Brahma and is surprised to find out when he returns to Earth for many centuries.

The Buddhist Pāli Canon states that Payasi Sutta says of one of Buddha's disciples, Kumara Kassapa, that he told him that "in the Heaven of Thirty-Three Devas, time passes at a different pace, and people live much longer. 'In our century; one hundred years, only one day, twenty-four hours would have passed for them.'" (Chattopadhyaya 1964)

Medieval philosophers and theologians have developed the concept of a universe with a finite past with a beginning, now known as temporal finiteism. (Craig 1979)

General relativity suggests that a proper space-time geometry or certain types of movement in space can allow time travel if these geometries or movements are possible. (Thorne, Braginsky, and Ginzburg 1994) The possibility of time-closed curves (worldines that form loops enclosed in space), such as Gödel space-time, for which there are solutions to general relativity equations, would allow the travel in the past, but the plausibility of solutions is uncertain.

For time travel, it is necessary to travel faster than the speed of light, as in the case of cosmic strings, wormholes, and Alcubier metrics. (Gott 2002) Hawking formulated the chronological protection conjecture, suggesting that the fundamental laws of nature do not allow the time travel, (S. W. Hawking 1992) but a clear decision can only be taken in a completely unified theory of quantum gravity. (Stephen W. Hawking et al. 2003)

Wormholes are a hypothetically curved space-time, allowed by Einstein's field relativity equations. (Visser 1996) Time travel is possible in this case if one end of the wormhole is accelerated to a significant fraction of the speed of light and then brought back to the point of origin. Alternatively, a single wormhole entry can be used to move it in the gravitational field of an object that has a higher gravity than the other input and then returns to a position near the other input. In both cases, the dilation of the time determines that the end of the wormhole that has been moved is less than the stationary end.

The construction of a traversable wormhole would require the existence of a negative energy substance, and a distribution of energy that violates different energy conditions, but time travel would still be possible due to the Casimir effect in quantum physics. (Visser, Kar, and Dadhich 2003)

In the case of a signal with a speed less than or equal to the speed of light, the transmission occurred prior to reception. If the speed is higher than the speed of the light, the signal is received before it is sent. (Jarrell 2006) It can be said that the signal has shifted back in time (tachyon anti-phone). (Kowalczyński 1984)

In quantum mechanics there are phenomena such as quantum teleportation, the Einstein-Podolsky-Rosen paradox, or quantum inseparability that could allow time travel. Bohm's interpretation assumes that some information is instantly exchanged between the particles to keep the correlations between them, (Goldstein 2017) effect called Einstein's "spooky action at a distance." But modern theories do not allow time travel due to the conservation of causality.

Everett's multiple worlds in quantum mechanics provide a solution to the paradox of the grandfather, involving the traveler's idea of time arriving in a universe different from the one he comes from; but in such a case, this is not a "real-time" journey. (Arntzenius and Maudlin 2013)The accepted interpretation of multiple worlds suggests that all possible quantum events can appear in mutually exclusive histories. (Arntzenius and Maudlin 2013) Stephen Hawking argues that every traveler should experience only one self-consistent history, so that time travelers stay in their own world rather than travel to another. (S. Hawking 1999)

Daniel Greenberger and Karl Svozil proposed a quantum model for the timeless paradox: (Greenberger and Svozil 2005) the past observed today is deterministic (only one possible state), but the present observed in the past has many possible states until the actions (inevitable) cause them to collapse into one state.

The travel in the future presupposes the expansion of time, a direct consequence of the inversion of the speed of light, (Ferraro 2007) by moving at relativistic speeds or by the effects of gravity. (Serway, Beichner, and Jewett 2000)

Grandfather paradox

The most well-known example of the impossibility of traveling in time is the grandfather paradox or self-infanticide argument: (Horwich 1987) a person who travels in the past and kills his own grandfather, thus preventing the existence of one of his parents and thus his own existence. A philosophical response to this paradox would be the impossibility of changing the past, (Swartz 2001) like Novikov self-consistency principle (if an event exists that would cause a paradox or any "change" to the past whatsoever, then the probability of that event is zero, thus it would be impossible to create time paradoxes). The paradox involves any action that changes the past. (Smith 2016)

Grandfather paradox is presented in many ways: physicist John Garrison presents a variation with an electronic circuit that sends a signal through a time machine that decays alone and receives the signal before sending it, (Garrison et al. 1998) and the self-infanticide paradox involves returning to time and killing one's own person while he was a child. (Horwich 1987)

From a logical point of view, the paradox is a logical contradiction: if an event has taken place in some way, there is no possibility that the event has occurred otherwise. (Swartz 2001) Bradley Dowden argues that the possibility of creating a contradiction excludes travel in the past.

An approach to this paradox is a parallel universe: when the time traveler kills his grandfather, he kills in fact a parallel version of his grandfather, and the original universe of the time traveler is unchanged; in other variants, the time traveler tries but fails to kill his grandfather.

According to Novikov self-consistency principle, physics in or near closed timelike curves (time machines) can only be in accordance with the universal laws of physics, and so only coherent events can occur. Novikov used the example given by Joseph Polchinski for his grandfather paradox to show how this system can be solved in a coherent way that avoids the grandfather paradox, although it creates a causal loop. (Lossev and Novikov 1992) Hawking states as follows:

"By traveling in a space ship on one of these closed timelike curves, one could travel into one's past. This would seem to give rise to all sorts of logical problems, if you were able to change history. For example, what would happen if you killed your parents before you were born. It might be that one could avoid such paradoxes by some modification of the concept of free will. But this will not be necessary if what I call the chronology protection conjecture is correct: The laws of physics prevent closed timelike curves from appearing." (S. W. Hawking 1992)

Lewis' own solution to this problem has been widely accepted: the traveler may enter the past without killing his grandfather, but we still have a contradiction: for he can do it and cannot do it:

” Could a time traveler change the past? It seems not: the events of a past moment could no more change than numbers could. Yet it seems that he would be as able as anyone to do things that would change the past if he did them. If a time traveler visiting the past both could and couldn’t do something that would change it, then there cannot possibly be such a time traveler.” (Lewis 1976)

Grandfather's shooting is compossible with the facts about his weapon, his formation, his mood, and so on, but it is not compossible with other facts, such as the fact that his grandfather did not die this way. Thus, "murder" is true in a sense (relative to a set of facts) and false in a different sense (to another set of facts), but there is no sense in which it is both true and false. So, there is no contradiction here - just an ambiguity. (Smith 2016)

The philosophy of time travel

Newton supported the idea of absolute time, unlike Leibniz, for which time is only a relation between events and cannot be expressed independently, a statement in concordance with the relativity of space-time. (Crisp 2007)

Eternalism claims that the past and the future exist in a real sense, (Crisp 2007) going to the idea that time is a dimension similar to spatial dimensions, that future and past events are "present" on the axis of time, but this view is challenged. (Maudlin 2010) On four-dimensional vision, the universe is an existing space-time topology, containing everything that has happened, everything that happens and everything that's going to happen. It follows that there is no singular moment to be considered as insignificant as present. (Keller and Nelson 2010) Time travel is possible if the four-dimensional vision including the time is correct, but it is not possible if presentism is true. William Godfrey-Smith says that "the metaphysical image underlying the discussion of time travel is that of the universe block, in which the world is conceived as extended in time as it is in space." (Godfrey-Smith 1980)

Prezentism claims that the future and the past only exist as changes, and they do not have a real existence of them, there is only the present. Thus, time travel would be impossible because there is no future or past. (Crisp 2007)

"Relativized presentism" admits that there are infinite reference frames, each of them having a different set of simultaneous events, making it impossible to distinguish a single "real" present and therefore all events in time are real - blurring the difference between presentism and eternalism - each frame of reference exists in its own reality.

According to the philosophical theory of composability, if the past *exists* in a certain way, it is not possible for it to be different. What can happen in the past is limited to what has happened, to prevent logical contradictions. (Lewis 1976)

A traditional realistic position in ontology is that time and space have existence apart from the human mind. Idealists, by contrast, deny or doubt the existence of independent mind-set objects. Some anti-realists, whose ontological position is that there are objects outside the mind, doubt however of the independent existence of time and space.

There was also a debate between the definition of space and time notions as real (absolute) objects or simple orders of real (relational) objects, backed by Isaac Newton and Gottfried Leibniz respectively (the principle of sufficient reason and identity of indiscernibles).

The conventionalist position states that there is no fact about matter, everything is decided by convention. Thus, Henri Poincaré argued that the geometry applied to a space was decided by convention.

A solution to the problem of the direction of time has a metaphysical vision, in which the direction of time results from an asymmetry of causality. A second family of solutions to this problem finds the existence of the direction of time as being related to the nature of thermodynamics (entropy). A third type of solution claims that physical laws are not symmetrical in the sense of reversing time.

Endurantism states that for an object to persist over time, it must exist completely at different times. Perdurantism claims that for a thing to exist in time, it must exist as a continual reality, considering an ensemble of all its "temporal parts" of existence.

According to the Heraclitean metaphysical conception, there is no field of the fact of a determined future, no inhabitant of the future, though it will exist. And the past is considered fixed and determined and can not be changed. The travel to the future in this context would be excluded, because we simply do not go anywhere.

Causal loops

There is, among some scientists and philosophers, the idea that any theory that would allow the time travel would introduce causal issues. (Bolonkin 2011) These types of temporal paradoxes can be avoided by the Novikov self-consistency principle or by a variation in the interpretation of many worlds with interacting worlds. (Everett 2004)

The classic argument against backward causality is the *bilking argument*. (Horwich 1987) If an event A causes a previous event B, bilking recommends an attempt to de-correlate A and B, that is to bring A in cases where B did not occur and prevent A in cases where B occurred.

A causal loop is a sequence of events (actions, information, objects, people) (Lobo and Crawford 2002) where an event A causes another event B, which determines the first event A. (Rea 2014) At such events in spacetime their origin can not be determined. (Lobo and Crawford 2002) Events that form a loop must not be the complete causes of each, nor the complete effects of another. In a causal loop there may be secondary causes or external events. If there are no such causes or events, it is said that the loop is *causally isolated*.

Backward causality presupposes a closed ontological future - a metaphysical time position usually called eternalism, a specific form of non-presentism. (Faye 2001)

Backward time travels determine causality loops? Hanley (Hanley 2004) asserts that there can be a backward time travel and a reverse causality without any causal loops. (S. W. Hawking 1992) Monton (Monton 2009) criticizes Hanley's example but agrees with his statement.

The world in which we live has, according to David Lewis, a Parmenidean ontology: "a manifold of events in four dimensions," and the occupants of the world are the 4-dimensional aggregates of the stages - "temporal lines". (Lewis 1976) However, the time traveler is not like other aggregates; "If he travels to the past it is a zigzag line." (Lewis 1976) There may also be broad lines that are travels in the future. This Parmenidean world of temporal stages immediately removes the "no destination" objection to the time travel. Four-dimensional geometry provides the means to record the travel of the time traveler.

Many believe that causality loops are not impossible or unacceptable, but only inexplicable. There were two main types of response to this objection. Lewis (Lewis 1976) accepts that a loop (as a whole) would be inexplicable, such as Big Bang or the disintegration of a tritium atom, but it is just strange, not impossible. Similarly, Meyer (Meyer 2012) argues that if someone asks for an explanation of a loop (as a whole), the fault would fall on the person who asked the question, not on our inability to answer. Another answer, Hanley, (Hanley 2004) is to deny that (all) causality loops are inexplicable. Mellor (Mellor 1998) believes that in such loops the chances of events will not be related to their frequencies, according to the law of the large number. Berkovitz (Berkovitz 2001) and Dowe (Dowe 2001) argue that Mellor fails to establish the impossibility of causality loops.

The causal loops in backwards time travel involve events that appear to "come from nowhere," (Smith 2016) paradoxical "self-existent" objects or information, resulting in a *bootstrap paradox*. (Toomey 2007) A time traveler who steals a time machine from the local museum to make a journey in time and then give the machine same time to the same museum at the end of the travel (that is, in the past); in this case, the car itself is never built by anyone - it simply exists. (Everett and Roman 2012) Everett gives an example of an *informational paradox*: a time traveler copies a mathematical demonstration from a manual, then travels back in time to meet the mathematician who firstly published the demonstration, the mathematician simply copied the demonstration at one time before the publication, in which case the information in the demonstration had no origin. (Everett and Roman 2012) Or an *ontological paradox*: (Smeenk and Wüthrich 2011) Kelley L. Ross (Ross 2016) gives the example of a physical object whose world line or history forms a closed loop over time where there may be a violation of the second law of thermodynamics: a clock is given to a person, and 60 years later the same clock is brought back in time and given to the same person. Ross states that the entropy of the clock will increase, and the clock transmitted back in time will be more worn out with each repetition of its history.

Andrei Lossev and Igor Novikov have named such objects without origin *Jinn*, with the singular term *Jinnee*. (Popper 1985) An object that makes the circular passage through time must be identical whenever it is returned to the past, otherwise it would create an inconsistency.

Krasnikov writes that these paradoxes always involve a physical system that evolves at a stage in a way that is not governed by its laws. He does not find this paradoxical and assigns the problems regarding the validity of the time travel to other factors in the interpretation of general relativity (Krasnikov 2002)

General relativity allows some solutions that describe universes that contain closed timelike curves, or world lines that lead to the same point in space. (Gödel 1949) Igor Dmitriyevich Novikov said about the possibility of closed timelike curves (CTCs) that only self-regulatory travels would be allowed. (Novikov 1983) He suggested the *principle of self-consistency*, which says that *the only solutions to physics laws that may appear locally in the real universe are those that are self-consistent at a global level*. Novikov's opinions are not widely accepted. Visser sees the causal loops and Novikov's self-consistency principle as an ad-hoc solution and assumes that there are far more detrimental implications of time travel. (Nahin 1999) Krasnikov finds no inherent fault in the causal loops but finds other problems with time travel in general relativity. (Krasnikov 2002)

Ulrich Meyer states that saying causality is mysterious is to say that it is always inexplicable, and he do not think it is right. The causality curves may admit all the explanations that they might reasonably require. (Meyer 2012) Asking for all events, including those in the causal loops, to be explicable, is to support Leibnitz's *principle of* *sufficient reason* (PSR)[1], but there are different ways of understanding this principle, such as PSR reading as a causal principle: (Meyer 2012).

One version would be that *each event has a sufficient reason*, PRS1, (Schlesinger 1995) which implies inference at the best explanation. This version often leads to infinite chains of events where each event is caused by the previous, *ad infinitum* (such as standard classical mechanical models where all events at a given moment are caused by events from a previous time, which, in turn, are caused by events at a previous moment, and so on), (Meyer 2012) also valid for causal loops. PRS1 requires that each event has a causal explanation, not that the chain of explanations ends somewhere. But PRS1 is not exactly what Leibniz had in mind when he developed the principle of sufficient reason in *De rerum originatione radicali* (1697):

"Let us imagine that the book of the elements of geometry has always existed, one always copied from another; it is evident that, even if a reason can be given for the present book from a past one, from which it was copied, nevertheless we shall never come upon a full reason no matter how many past books we assume, since we would always be right to wonder why such books have existed from all time, why books existed at all, and why they were written in this way. What is true of books is also true of the different states of the world; for a subsequent state is in a way copied from a preceding one (although according to certain laws of change). And so, however far back you go to earlier states, you will never find in those states a full reason why there should be any world rather than none, and why it should be such as it is." (Leibniz 1956)

By its very nature, a complete reason could not be a causal reason and would therefore overcome what is in question in PRS1.

The second interpretation of the principle is: *There is a sufficient reason why the whole world is as it is* (PRS2):

"... we might be able to explain the existence of a time machine at t_1 in terms of the existence of a time machine at t_2, but thisdoes not appear to explain why there is a time machine at all. But if we take this worry seriously then we should also worry about, say, why it is that there are electrons. We can easily explain this causally, in terms of the laws of nature and the fact that there were electrons 5 minutes ago. But then the question arises why those earlier electrons existed, and we are quickly led into an infinite regress of causal explanations that never succeed in giving a full reason for why there are any electrons at all." (Meyer 2012)

PRS2 has the undeniable consequence of excluding contingent truths, resulting that PRS2 "is false and that requests for full explanations are misguided." (Meyer 2012) It follows that if the laws of nature co-operate, then the events that form a loop can be explained causally. Asking for a more detailed or "complete" explanation of the causal loop is asking for something that is impossible. "In this case, the blame would fall on the person asking the question, not on our inability to answer it." (Meyer 2012)

Causal priority (certain sequences of related events) may be different from temporal priority (total events). If the cause was later than the effect, then the cause should be unstoppable. But, in general, we can intervene in the world to provoke or prevent contingent incidents. If the cause of an event is in the future, then such interventions are subject to clear constraints, and in some cases it will prove impossible. (Grey 1999)

Simon Keller and Michael Nelson (Keller and Nelson 2010) state that there is no premise of a preferential specificity involved in any argument, so that there is no special issue for time travel in terms of presentism.

Wheeler and Feynman (Wheeler and Feynman 1949) were the first to argue that the fact that nature is continuous does not involve causal paradoxes.

Conclusions

One of the backward time traveler's themes is when he turns out to be his own parent, (Ayer 1956) or even both his own parents in the event of a change of sex of the time traveler. The idea of time travel is bizarre from a Heraclitean metaphysical perspective. (Grey 1997) The concept of time is traditionally based, making an analogy with space, on an extra feature, the asymmetry. The past is fixed (the field of the past events, determined), the future is fluid (expressions of the same Heraclitean metaphysical intuition). If time is assimilated with the "directions" given by thermodynamics, cosmology and psychology, the reversal of time makes sense. But if the passage of time is the updating of the possibilities, the reversal of time would imply the absurdity of the "re-potentialization" of the past. ((Grey 1999), see also (Čapek 1961)) The past is not potentiality. What will be is not yet determined. The future is inactive in that it is not yet active, and therefore has potential, unlike the past that has been active and has no longer potential.

From a Parmenidean perspective, the existence of alternative chronological order, designated as "personal" and "external" time in Lewis' analysis, (Lewis 1976) is not sanctioned by the alternative measurements of physics. This temporal dualism between experimental time and physical time has a Cartesian resonance.

Frank Arntzenius and Tim Maudlin consider (Arntzenius and Maudlin 2013) that most of the contradictions that appear for time tavel are logically incoherent: the past cannot be "changed" (for presentism there is no past or future, so there is no such "destination"). But if the only imposed requirement is the logical coherence, it is easy to overcome these aspects. It is possible to develop a coherent time travel scenario, in which everything happens only once and in a coherent way. But logical coherence is a very poor condition. From a physical point of view (the universal validity of certain fundamental physical laws and the non- constraint of the physical state on a surface preceding the region of the time travel), the time travel is also considered possible. Problems appear metaphysically because of the nature of time itself.

Noteworthy that, although there is a focus on just one specific event (in the grandfather's paradox, for example, only on grandfather's death), this approach is considered erroneous. Analysis of ONE SINGLE event is wrong, when in fact there are countless simultaneous events connected with the same time travel. And the past is more than just events. It includes absolutely all matter and energy at various times, and their subsequent evolution. Changing the past does not just mean grandfather's death. It involves all the other exchanges of matter in the future subsequent to the past one, and the spatial displacement of matter that occupies the space now occupied by the time traveler.

Also, there is no clear delimitation between a person and the environment (there is a permanent exchange of matter, even the air in the lungs, clothing, the dust on clothes, etc.) according to the theory of dynamic systems interacting with the environment. (Beer 1995) In a time travel, it is impossible to avoid an exchange between matter arriving with the time traveler (air, dust, etc.), so there is a contradiction to the law of matter conservation, which can be created or disappeared in infinite, correlated with the law of energy conservation.

Finally, I sustain that no paradox exists in reality. The existence of the paradoxes is due only to our erroneous and/or incomplete information about space and time concepts, and the limits of language and the way in which we express and conceive the phenomena.

The only serious proof of the possibility of time travel would be a demonstration of its timeliness. If we agree that currently there is no time travel, the assumption that there would have been implies the postulate of a substantial timeliness difference.

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Notes

[1] The principle of sufficient reason states that everything must have a reason, cause or motive (Rescher 1991)