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The Philosophy and Physics of Time Travel: The Possibility of Time Travel

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1. Introduction

Time is mysterious. Philosophers and scientists have pondered the question of what time might be for centuries and yet till this day, we don't know what it is. Everyone talks about time, in fact, it's the most common noun per the Oxford Dictionary. It's in everything from history to music to culture. Despite time's mysterious nature there are a lot of things that we can discuss in a logical manner.

Time travel on the other hand is even more mysterious. It's a subject that captured the interests of great writers like H.G. Wells and Mark Twain and has been the premise of T.V. shows and movies. Everyone would love the idea of getting on Doc Brown's DeLorean and taking a blast to the past but it isn't as simple as science fiction would put it.

In this work, I explore the nature of time and take a side on several fundamental questions about it. I then explore a model of time that I created based on my research which allows for the possibility of time travel. I don't believe that this model accurately models time (or is complete) but in my opinion, this would be the best model that avoids a lot of paradoxes of time travel assuming time travel is possible. Finally, I explore several paradoxes of time and explain how my model of time could solve them to a certain extent.

2. The Concept of Time

(This section is based on the works of Tannenbaum et. al 1958)

Tempus Fugit is the Latin phrase for time flies, the situation that we are all too familiar with. We live our lives by the clock. Time has become an integral part of our lives; it controls when we wake up, what time we have to be at a particular place and even when we decide to die for the sake of our country. How did we come to "measure" time? Who decided how we measured time? Why is it that when it is 6:00 a.m. in New York it is 12:00 p.m. in Paris?

Primitive humans' first division of time was light and darkness (i.e. day and night) but they eventually realized that smaller periods of time were needed to organize their daily life. In most parts of the modern world this division of the day is in twenty-four equal parts (hours). This division came about from the Babylonians who used a number system based on twelve. The system was adapted by the Greeks and the Romans and eventually passed down through medieval Europe to the modern Western civilization. For convenience, the hour was divided into sixty equal parts (minutes) and each minute was divided in sixty equal parts (seconds). In 1884, an international conference was held in Washington D.C. where representatives of many governments decided that the meridian line that passed through the observatory in Greenwich should be the initial meridian and approved a plan to divide the entire world into fifteen degree widths resulting in twenty-four time zones. Therefore, when it is 6:00 a.m. in New York it is 12:00 p.m. in Paris.

Measuring the passage of time required a great deal of insight and innovation. Before the invention of mechanical clocks, time was measured using a variety of methods. Greeks and Romans used brilliant stars such as the Big Dipper constellation to tell time. Many ancient civilizations used water, sand and fire to tell time, such as one-hour candle clocks, fire alarm clocks (used by the Chinese), sand hour glasses and water-based Clepsydras (used by the Egyptians). Eventually, in the 1200s mechanical clock tower systems started to grow and, as time passed, improved in ways such as switching from man power to electrical power. Portable forms of time keeping such as Nuremberg eggs (similar to a pocket watch) started growing and after a while, wristwatches gained popularity after World War I. Finally, time keeping came to a point where we tell time using many ways including using cellular devices. While measuring time is useful, would it be useful without putting it in context (such as what day it is)?

Time was and still is being put into context using calendars. After centuries of progress, from the Egyptian Calendar to the Biblical Hebrew Calendar to the Julian Calendar, we ended up with the calendar used by many nations today, the Gregorian calendar. History has shown us that the process of standardizing time had caused riots and the spilling of blood such as during the French Revolution when the government forced people to use the “Calendar of Reason” which had 12 months of 30 days and left behind 5 days to honor poor people. Eventually over the passage of history we ended up with the system of time you and I are familiar with. While we know how to measure time and utilize it to organize our daily lives, we still find it difficult to answer a deceptively simple question: what is time?

3. What is Time?

You cannot see, hear or touch time but you feel it flow. You intuitively have a sense of what time it is. For example, you know it’s almost dinner time without looking at the clock. But there are many questions you could ask: what is time? Does it really exist? Is it just a series of events? Is it linear? Does time have a beginning or an end? In this section I will try to give you, the reader, a general idea of what time is and how I view time. The discussion of time could be hundreds of pages long but I will briefly introduce you to only a few concepts of time discussed by academics that I believe are relevant to the discussion of time travel. I discuss eight different concepts related to time in the given order: classifications of time, subjectivity and objectivity of time, time and change, the beginning and end of time, the topology of time, continuity of time, flow of time and finally, the arrow of time. I ordered these concepts as stated because I believe that there is a logical question you could ask that connects one concept to the next.

I. Classifications of time

Time can be classified as physical, psychological and biological. Biological time is captured by the internal clocks within various organisms such as the rhythm of one’s heartbeat. Psychological time is how we experience time such as how we feel as if time passes fast in moments of excitement. Physical time is the time that is used in physics and the time that our clocks measure (Dowden 2016). While physical time is what this paper mainly concerns itself with, I believe it is important to have a brief understanding of psychological time.

The reason why we feel the continuity of time is because our brain process events such that we experience a scenario. For example, if you make a cheese burger you first make the burger then cook it and finally assemble the burger. You remember it in a order, i.e. as a scenario. The brain takes a short amount of time to interpret events and puts the events in context for you. If you touch your toe and your head at the same time, it is interpreted as if both events happened at the same time even though it may have taken longer for the signal from the toe to reach the brain. According to philosopher Craig Callender, this "now" experience for two simultaneous events must be less than 250 milliseconds (Dowden 2016). Similarly, the processes in the brain cause the "time dilation effect" where a short period of time may feel longer. For example, a person would remember a car crash vividly as if it happened for a longer period of time even if it lasted only a second or two. Given the role of neurological processes in our experience of time, one may come to believe that time is mind-dependent (subjective) but is time subjective or is it objective?

II. Subjectivity and objectivity of time

Questioning whether time is subjective or objective is similar to questioning whether time is real or a man-made construct. I would argue that time is objectively real. One argument for this is the fact that many people can chronologically organize events. For example, everybody would agree that Isaac Newton was first born, then he made great scientific discoveries and then died. No one would argue otherwise (Dowden 2016). Hence, time is recognized intersubjectively by many people and it is not merely subjective. Another argument for the objectivity of time is the fact that events have occurred before the presence of organisms of consciousness and the fact that events will occur after the end of life; these events must occur at some time and that time would be objective time (Dowden 2016). A subjectivist would disagree on the second argument by stating that consciousness is required to experience time and as a result time cannot exist without a mind to perceive it. Hence, the subjectivist would claim that it makes no sense to say that events occurred before the creation of time and will happen after the end of time. A subjectivist would argue that time is a series of events that occur and it is a man-made construct (personal communication – Pieranna Garavaso). So, does that mean time is a series of events as subjectivists claim or can time exist without events to fill it?

III. Time and change

An event is a change. If you eat an apple, you changed the nature of the apple. The action of eating the apple is in itself a change. So, time passes as change occurs. Is time dependent on change or is it independent of it? This is a subject of debate within the philosophical community. Reductionists (also called Relationists) believe that time is dependent on change. Imagine a world where you are the only thing existing and you are breathing and moving around. If you weren't present, the world would simply be emptiness and for a Reductionist, time would not pass since nothing is happening and no change is happening. For the reductionists, if there is no change there is no time, change is a necessary condition for time and in other words, time requires change. Reductionists believe time is temporal relations between events so a period of empty time is incomprehensible for them (Markosian 2002). On the other hand, Platonism (also called Substantivalism and Absolutism) is the belief that time without change is possible (Markosian 2002). A Platonist believes that time would pass in an empty world despite you not being present. A problem with the Platonist view is that there could be long periods of empty time, in other words time freezes in the sense that time passes but nothing happens. I support the Platonist view of time and since this is the view that I will hold throughout this paper, I will take some time to defend the view.

One of the best literature available to support the Platonist view of time is Sydney Shoemaker's "Time Without Change". In his paper, Shoemaker creates a world of three regions: A, B and C where every third year A freezes, every fourth year B freezes and every fifth year C freezes. By basic arithmetic that would mean that every twelfth year A and B freeze at the same time, every fifteenth year A and C freeze at the same time, every twentieth year B and C freeze at the same time and finally every sixtieth year all three regions freeze at the same time. Shoemaker defines a freeze as a complete halt of processes where there is "no motion, no growth, no decay", and so on. Each freeze would last a single year. The freezing of all three regions is a "total freeze" while the others are "local freezes". During a local freeze, individuals of other regions cannot pass into a frozen region but they can observe the time period for which the freeze lasts (Shoemaker 369-371). Given this thought experiment, it can be concluded that the inhabitants of the world described by Shoemaker have grounds to believe that time could pass without change in the sense that the inhabitants of the separate regions, after having witnessed mathematically regular local freezes in the other regions, may have inferred that every sixty years the three regions froze together; although by definition, they may not directly experience it.

In his paper, "Time and Change", Michael Scott pointed out objections to Shoemaker's argument and defended Ludwig Wittgenstein's proposal that given the present concept of time, time without change would be senseless (213). He pointed out difficulties in Shoemaker's arguments such as how processes could start again from a total freeze and how individuals could possibly create a universal calendar in Shoemaker's world without allowing the possibility for time without change (this would mean that the people in Shoemaker's world would create a calendar that ignores the frozen years such that they would not realize a freeze actually occurred) (Scott 217). Clearly, there are good arguments for the Reductionist and Platonist view of time and I will let you, the reader, decide which one to choose for yourself and not delve on the subject any further because it is not the major concern of this paper. I will maintain a Platonist view of time, i.e. the view that time passes without change. One of the bigger reasons I support the Platonist view is because of the question of the beginning of time: does time have a beginning? If so, did time pass before said beginning?

IV. The beginning and end of time

The universe began from an infinite density of matter called a singularity. A rapid expansion of the matter in this singularity (the Big Bang) created the universe as we know it. Scientists such as Stephen Hawking claim that real time began with the Big Bang. In one of his lectures titled "The

Beginning of Time", Hawking stated "Since events before the Big Bang have no observational consequences, one may as well cut them out of the theory and say that time began at the Big Bang." (qtd. in Hawking, "The Beginning"). Here, Hawking implies that talk about time before the Big Bang is senseless because there is nothing to observe nor anyone to do the observing; this view is like that of a subjectivist. I believe it is important to talk about it because it may help us understand the very nature of time. While Hawking has a point, he cannot deny that time could have existed before the Big Bang. Hawking talks about how, if General Relativity is correct, time must have a beginning (which he believes is the Big Bang). He also introduces a concept from the Quantum theory called "imaginary time" which is just as real as "real time" but not what we experience. Imaginary time is the time before the Big Bang but it isn't as real as the time we experience now because it is simply imaginary (as no time existed before the Big Bang) (Hawking, "The Beginning"). He states that real time would have a beginning which would be the Big Bang. While physics may only be concerned with real time, I am concerned simply with the concept of time and I believe that imaginary time is as real as real time and that time existed before the Big Bang. The difference between Hawking's views and mine goes back to the relationship between time and change and the subjectivity/ objectivity of time. Hawking believes that time is subjective and requires change. So, since there was no conscious mind to observe time before the Big Bang and that nothing happened before it, time before it is imaginary. I hold the view that time does not require change and that time is objective (it will pass without a conscious mind to perceive it) and therefore both imaginary time and real time is simply time. This is what I mean when I claim that there is no need for a separation of time into imaginary time and real time. Objectivists believe that time is objectively real and the concept of imaginary time takes away the objectivity. This another reason why I believe that time shouldn't be separated as real and imaginary. Since I believe that time existed before the Big Bang, a logical question you could ask me is whether I believe that time had a beginning at all? You could also ask me a related question, does time have an end?

I believe that time does not have a beginning nor an end because it is not related to change. The great philosopher, Aristotle (who held a reductionist view of time) argued that if there is a first moment of time then in order to count that moment it has to come between an earlier and later period of time. This contradicts the fact that there would be a first moment of time. Therefore, time does not have a beginning. Aristotle makes a similar argument to conclude that time does not have an end (Markosian 2002). For some, Aristotle's argument does not seem satisfactory because it seems like a circular argument (since it assumes that time is infinite in the first place) but it makes intuitive sense to me that time would exist without anything (events) being present and thus, time would not have a beginning or an end. Although Aristotle is a reductionist, his beliefs of time and change is not directly related to his ideas on the beginning and end of time, so, I can accept his viewpoint on the beginning and end of time without accepting his reductionist view. If I believe that time has no beginning or end, it raises the question of how I would represent time; more specifically what is the topology of time?

V. *The topology of time*

The discussion into the topology of time would lead to a lengthy discussion, so instead I will pose several questions related to it (including some open-ended ones) and give the reader my position on them. The first fundamental question on topology would be whether time is linear or circular or whether it could have any other shape? If time was circular the future would also be the past and it would come down to the question of whether you believe in rebirth. In that case would you go through the circle of time once or infinite times (i.e. would you be born infinite times?). In physics, time is usually a linear continuum of instants. I believe that time is as described in physics. You could then ask the question of whether this line of time can be branching? I believe it could (I discuss this later). You could also ask whether this time is one dimensional? For this paper, I hold the viewpoint that time is one dimensional but there are equally good arguments for two dimensional and higher dimensional time such as in the study of cosmic strings. Since I believe that time has no beginning or end, the line of time has no beginning or end. So, the topology of time that I will hold is that time is an infinite, straight (linear), continuous line that may have branches at particular temporal instants. I will maintain that time is continuous in my definition for the topology of time but it would work just as well if time is discrete. In the next section I discuss why I prefer continuous time.

VI. The continuity of time

Continuous time is analogous to real numbers while discrete time is analogous to integers. For the purpose of this paper I believe that it does not matter whether time is discrete or continuous as long as time could be discussed in terms of temporal instants. I believe that a temporal instant or temporal part is as Bertrand Russell defined in 1929,

> X is an instant if and only if X is an exhaustive class of mutually overlapping events
>
> Event E is at instant X if and only if E is a member of X. (qtd. in Dowden 2016)

To loosely understand Russell's definition, let X be all the events (by "all events" I mean everything happening in this universe or the multiverse) that happen in one second. Then X would be an instant. Let E be the event you are participating in at the second X, then event E occurs at instant X. Both discrete and continuous time can be divided into temporal instants based on this definition. You could consider second, millisecond or picosecond intervals depending on the event you want to describe.

Personally, I prefer to believe that time is continuous because if time is discrete it would have to be analogous to a sequence of integers which means it would have to have a smallest possible value. Physicists prefer this smallest time to be the Planck time of 10^{-43} seconds (Dowden 2016). Continuous time would remove the necessity of having a smallest possible time interval. Continuity of time would make sense to some because it represents a flow, like the flow of time but does time flow?

VII. The flow of time

We feel that time flows but there are philosophical disagreements about whether time flows and it is directly related to McTaggart's argument against the reality of time. In his argument, McTaggart introduced two series called A series and B series to order positions in time. In order to understand this let's consider the following scenario,

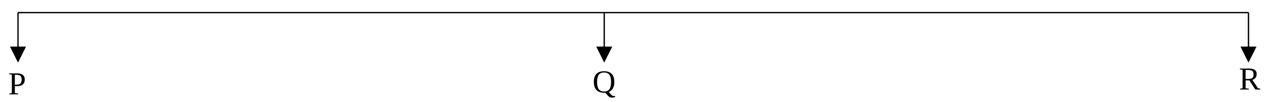


Figure 1

P, Q and R are three events in time where P is in the past, Q is in the present, R is in the future, and each event is a day apart. According to McTaggart's A series, P, Q and R can be ordered according to their possession of properties. That means P is a day in the past, Q is in the present and R is a day into the future. According to the B series P, Q and R can be ordered by two-place relations. That means P is one day earlier than Q, Q is one day earlier than R, R is one day past Q, R is two days past P, etc. While the difference between the A series and B series is subtle, it has philosophers divided into two camps questioning the reality of time, A theorists and B theorists.

There are two theses for the A-theory,

1. Any event's being in the past, present or future is an essential, objective property of the event.
2. Events can undergo McTaggartian change (also called secondary or second-order change).

To understand these theses, consider the scenario below (the time difference between D_1 and D_2 is one day, D_2 and D_3 is one day, etc.),

Figure 2

Let D_1 be the present and let Q be an event that is going to happen a day into the future at D_2. After a day passes, Q is in the present. Another day later (at D_3), Q is a day in the past and finally another day later (at D_4), Q is two days in the past. With each moment that passes, Q becomes further and further past. This "change" is known as the McTaggartian change. Note that the event itself does not change; for example, if Q was the day President John F. Kennedy was shot, it remains a fact that Kennedy was shot on November 22, 1963 (neither A theorists nor B theorists disagree on this) but for each second that passes, November 22, 1963 goes further and further into the past. Given the belief that time and events are undergoing constant McTaggartian change (such as events becoming more and more past), you can conclude that time flows and it is objectively real. This is the A theorist argument but B theorists conclude otherwise.

B theorists disagree with both theses of the A-theory and claim that time flow is subjective. Consider the scenario in Figure 2 again, Q is a day in the future in relation to the day D_1, Q is two days into the past in relation to the day D_4, etc. Clearly, it can be seen that Q is subjective. If you consider the assassination of Kennedy, it is in our past but it is in the future of a person living in November 21, 1963. Thus, you can conclude that time does not flow, it only appears to flow and it is only subjectively real. I hold the view of the B-theorists and I support it because it makes sense according to physics as well.

If time flows, what is the rate of flow of time? The answer would be (for example) one second per second which is simply, one. This doesn't make sense because this is not a coherent rate. This is one reason why time flow is not real according to physics. According to Einstein's theory of special relativity there is no global present. Consider the situation of a ball on top of a moving train. If I stand outside at a fixed position as the train passes, the ball changes its position relative to my fixed position but if I were standing right next to the ball on the train, it would not change its position relative to me. Notice the similarity of this argument with the B theorist argument for the scenario in Figure 2. An event being present at a particular time is a property of the event and it subjectively changes with respect to the time being considered. Therefore, time does not flow; it is simply a phenomenon of the mind (note that I'm claiming that the "flow" of time is a phenomenon of the mind not time itself which I believe is objectively real). This phenomenon of the mind still creates the feeling that time moves forward, so you could ask the question of whether time "flows" forward?

VIII. The Arrow of time

In the old nursery rhyme, the king's men couldn't put Humpty Dumpty back together again or could they have? What if the direction of time could reverse and you could make a whole egg from a cracked egg? Why does time seem to "flow" forward? The answer is "the arrow of time". Time's arrow is not a feature of time but a feature of processes happening in time (Dowden 2016). Time can move backward and the laws of classical physics will remain consistent. This means that even if a whole egg is made from a cracked egg, by the known laws of classical physics, it would not be impossible (since the laws are time reversible). It is because we believe that the process of going from a whole egg to a cracked egg is the natural order, time moves forward. In other words, the arrow of time is the feature of how events are occurring in a logical forward order in time but there is no solid explanation as to why time moves forward like this.

Most physicists prefer the explanation that since entropy increases in the forward direction of time, by the second law of thermodynamics, time moves forward and things have moved forward in time since the Big Bang. Simply put, entropy is the measure of disorder of a system; a gas has a higher entropy compared to a solid because it runs all over the place (disordered). So, entropy naturally increases from low to high (a more accurate but complicated definition of entropy was defined by Ludwig Boltzmann in terms of micro-states). The Big Bang is said to be in a low entropy state and as time passed the entropy increased (so the past has a lower entropy than the present or future). So, because of entropy, could we conclude that time's arrow is forward?

There is no classical physics law that reveals time's arrow. In fact, all fundamental laws of classical physics are time symmetric which means the laws of physics would agree for a whole egg being made from a cracked one. For example, James Clerk Maxwell's equations of electromagnetism predicts the existence of radio signals but cannot predict whether the radio detects the signals before or after they are transmitted from the radio station (even though it makes sense that the signals were received by the radio after transmission). A paradox by Joseph Loschmidt pointed out an issue with Boltzmann's explanation of entropy to determine the direction of time. He pointed out that if you did not make the presupposition of the truth of the second law of thermodynamics you would not be able to predict that the past was of low entropy.

Since we know for a fact that the past was of low entropy, most physicists state that it is necessary to adopt the Past Hypothesis which states that the Big Bang was in a state of low entropy. This need to adopt a hypothesis without any explanation seems unsatisfactory. There are many responses to explain the need for the hypothesis. The one that I find myself attracted to is a more radical explanation from the multiverse (also called many-word) interpretation of quantum mechanics which states that out of the many universes with different initial entropies our universe ended up having a Big Bang with a low entropy. So, while the laws of physics are unable to explain time's arrow and while it is physically possible for processes to reverse and time's arrow to change direction it is very unlikely to happen because the probability for something to go to a state of lower entropy is slim. For this paper, I will maintain that the second law of thermodynamics is an iron clad rule and every universe of the multiverse follows this rule and thus, has a forward arrow of time.

Answering the simple question of "what is time?" is arduous because there are many places where physicists and philosopher alike disagree on. I've hopefully clarified my stance on many different issues of time where physicists and philosophers are divided to you, the reader. Fortunately or unfortunately, the discussion of time does not end here; there is one huge division among philosophers and physicists of time in relation to the dimensions of space that needs to be discussed. I shall call this division the ontological divisions of time.

4. Ontological divisions of time

On the previous section, the question of whether there is a difference between the past, the present and the future was brought up. This is really a question of reality; is the present more real than the past or the future? Philosophers are divided on this ontological division of time. There are three main divisions of philosophers on the reality of the past, present and future, namely, presentism, the growing past and eternalism.

Presentism is the belief that only present objects exist. More specifically, presentists hold the view that only objects that exist at the present temporal part are real. A presentist would maintain that the past and future are not real. To understand presentism, consider a clay vase. For a presentist, the clay vase that you would see now is real but the clay before it was molded into a vase is not real or the clay vase a moment later into the future is not real. There are two issues with the view of presentism. The first is whether propositions about the past are true. Consider the clay vase, a question to ask a presentist is what makes it true that the vase was in fact molded from clay? The second issue is how presentism can account for causation; how can a presentist account for the fact that the clay is made from the gradual weathering of rocks over time? (I will not consider the solutions that presentists give here for these two issues in this paper). Some theorists, who support the A theory of time, are usually attracted to presentism while others are attracted to the growing past theory.

The growing past theory (also called the growing universe theory) argues that in addition to the present the past is also real. They also claim that the past is growing bigger all the time and agree with presentists in claiming that the future is not real. Both presentists and growing past theorists agree on the fact that the future is undetermined. This is a view that defenders of eternalism disagree on.

An eternalist does not believe that the past, present or the future should receive a special ontological status of being "real". Eternalists don't deny that events in the past, present or future are real they simply believe that there is no objective ontological difference between them. They believe classifying one (of past, present or future) as being more real than the another is a subjective classification. I endorse the view of eternalism and therefore I will go into some detail about it to make sure there is a clear understanding of my viewpoint.

An eternalist (at least an eternalist like me) believes in the block-universe theory and four dimensionalism associated together. To understand the ontological view of time I hold, first, it is important to understand what I believe is the nature of fundamental objects in the universe. Since I agree with four dimensionalism, I believe that fundamental objects are four-dimensional instead of three-dimensional where three of the dimensions are space and the other dimension is time. The block-universe theory helps visualize this by stating that the universe is a block that is four-dimensional. Since I believe that time has neither a beginning nor an end and that space can essentially be treated as infinite, this block is an infinite four-dimensional block (infinitely large along all dimensions). Along the dimension of time of the block, for an eternalist, there is no distinguishable past, present or future. Now, if I take an object in this block within a time period of one second of its existence, there would be an infinite number of temporal parts (time-slices) because I believe that time is continuous. Therefore, I hold the view that objects in four-dimensions are perduring.

A perdurantist believes that objects persist in time by the virtue of their temporal parts. For example, consider the time stream below,

T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}

Figure 3

For a perdurantist, you exist in all ten parts of the time stream above but only the current part is present at any one time of your existence. Imagine yourself giving a three-paragraph speech where you are on the second paragraph at time T_5; that means time T_4 is probably the temporal part of you reading the first paragraph and maybe at time T_{10}, you are reading the third paragraph. The you at the current moment (T_5) is reading the second paragraph. The whole of you is the combination/sum of all these moments in time or temporal slices of your existence. The group holding the opposing views to that of perdurantists are called endurantists. Endurantists believe that an object exists in its entirety at every time at which it exists and don't believe in temporal parts. Many objections can be raised against perdurantism, four dimensionalism and eternalism such as having infinite temporal parts being a problem and the Heraclitus Paradox, which states that you cannot step into the same river twice because the water is different the second time (because it is in a different temporal part). The paramount objections are free-will, truth values and personal identity. I will not dwell into these objections in this paper but I will support my ontological view of time with one more viewpoint.

Most physicists (at least the ones who study time) advocate eternalism. They do so because of Einstein's theory of special relativity which states that if person A travels at a significant fraction of the speed of light while person B remains at rest, an event of person B's present could be in the future for person A (because their personal clock runs slow). If you hold the view of a presentist or growing-past theorist, whose present would be real (A or B's)? You would have to claim one present is real over the other. An eternalist would claim that if two events are simultaneous at some frame of reference then both events would be real because it would make no sense to give one event a special status of being "real".

Now that I have defined my view of time as clearly as I can, it is time to move on to the main point of this paper: the possibility of time travel.

5. What is time travel?

In 2065, Doctor Who steps into the TARDIS and after five minutes arrives in 1965 to pick up Susan. You may be familiar with the British television series *Doctor Who* with its take on time travel using a police box or you may have read H. G. Wells infamous book, *The Time Machine* or you may have seen movies like JCVD's classic, T*imeCop* or the 2014 fantasy/thriller, *Predestination* starring Ethan Hawke. One way or another you may have had some exposure to the great world of the science fictional time travel. But is time travel fiction? In order to explore and understand time travel, I must first set the foundation of what time travel is.

The definition of time travel that many philosophers agree with is the one stated in David Lewis' article from 1976, "The Paradoxes of Time Travel",

> What is time travel? Inevitably, it involves a 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 his journey. He departs; he travels for an hour, let us say; then he arrives. The time he reaches is not the time one hour after his departure. It is later, if he has traveled toward the future; earlier, if he has traveled toward the past. If he has traveled far toward the past, it is earlier even than his departure. (qtd. in Lewis 145)

Essentially Lewis' definition states that you need to travel for a long time in a short time. Simply put, if you consider the Doctor Who time travel situation described before, the Doctor travels for a mere five minutes but arrive a hundred years in the past; the time he travelled is shorter than the time that passed. A common time travel situation in physics comes from Einstein's theory of special relativity. A time traveler enters a rocket that is able to travel close to the speed of light and he travels for a few months and returns to Earth. Because of relativistic effects the Earth is a few hundred years into the future when the time traveler returns. If time travel is as described by Lewis, is sleep a form of time travel?

You fall into a deep REM sleep and wake up eight hours later but you feel as if only one hour passed. You might be tempted to say that based on Lewis' definition it is time travel but that is not the case. The fact that you felt that only an hour passed is a state of your mind, so it isn't time travel. Similarly, waking up after a coma or a cryogenic state are not forms of time travel because you did not journey for a shorter period of time (Smith, "Time Travel").

Time travel is a seriously discussed subject in philosophy and a subject of interest for many physicists. Is time travel possible? This is the subject of the next few sections of this paper.

6. Time travel in physics

Do the laws of physics allow us to travel some 100 years into the future to see flying cars or to the past where we could see dinosaurs? Physics allow us to travel to the future but we don't know whether it allows us to travel to the past. Einstein showed us using his famous relativistic laws that we could travel to the future but we are far from doing it in significant time periods today because we don't have the technology. Travelling to past, according to physicist Kip Thorne "…is likely controlled by a set of physical laws that we do not yet understand at all well…" (qtd. in Thorne). What Thorne implies is that the answer could lie in the "theory of everything" that unifies quantum gravity and relativity. In this section of this paper I will explore how physicists have explored the concept of time travel in different ways.

I. The Twins Paradox and time travel to the future

In order to understand the Twin's paradox, first, I will introduce Einstein's theory of special relativity. Second, I will introduce you to the concepts of timelike, spacelike and lightlike separations. Third, I will introduce you to the concept of relativistic time. Finally, I will introduce the Twins Paradox. For clarity, I have decided to exclude most of the math.

In one of his papers published in 1905, Einstein presented the special theory of relativity which includes two postulates. First, the laws of physics remain the same in every reference frame at constant velocity. Second, the speed of light is constant (usually denoted by "c") at every reference frame; it is 299 792 458 ms^{-1} to nine significant figures (Gott 41). A reference frame is a position in a coordinate system, if I hold a laser at point A and you are watching from a jet about 5 km away, the laws of physics for the laser would be the same whether it is observed at my position or yours and the laser travels at the constant speed of light as observed by me or you. While the laws of physics remain the same, there is one crucial mathematical difference between your position and my position in space-time.

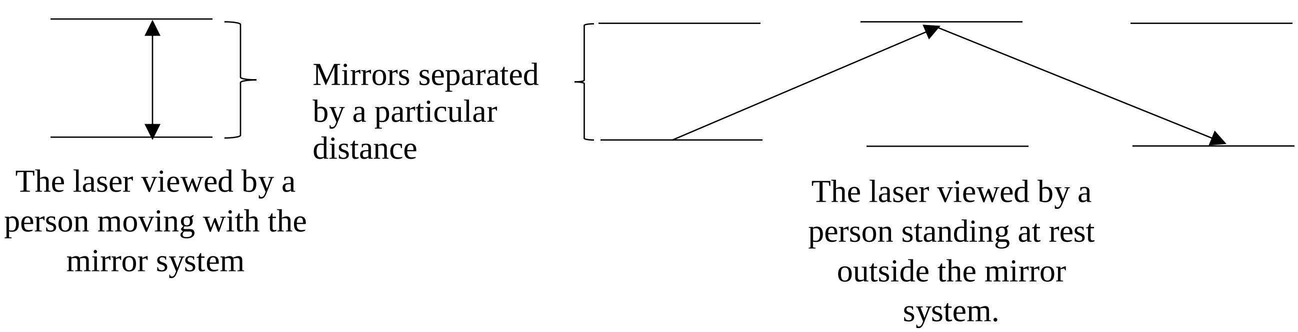
Space-time is four dimensional but the three dimensions of space and the dimension of time have different mathematical signs associated with them (Gott 54). To make things simple, we must consider separations in space and time in terms of units which make the speed of light 1. The speed of light could be considered in the units of 1 foot per nanosecond. Consider the following scenario: suppose while travelling at 60 percent the speed of light in a space ship, I fire a star trek - like Phaser gun at a mirror in the spaceship which reflects the fired beam. Suppose a camera at rest outside the spaceship is recording the event. The camera records that the two events are separated by 60 feet and 100 nanoseconds in time. But I see the Phaser bullet firing and returning to the original position to be two events separated in space by 0 feet and 80 nanoseconds in time.

In this case, the camera and I would disagree on the event of firing the Phaser in both space and time. But we would agree on the square of the separation in space minus the square of the separation in time. So,

Me: $0^2 - 80^2 = -6400$
Camera: $60^2 - 100^2 = -6400$

The answer would be the same for several different reference frames observing the same event in space-time. Since the quantity is negative we say that the two events (One event is that I perceive the laser to be at the same point and the other is that you perceive it as if it changes position) have a timelike separation which is when events have a greater separation in time than in space. If the value was positive, it would be a spacelike separation where the events have a greater separation in space than in time. Finally, if the value was zero, the events are connected by a light beam and it would be a lightlike separation (Gott 55). We can see that there is an agreement of the separations in space-time but why is this the case? The answer is because moving clocks appear to run slow (also called time dilation).

Einstein's theorems tell us that time is relativistic but what does this mean? Consider the following scenario where you reflect a laser beam between two moving mirrors,



4.1 *4.2*

Figure 4

If you do a calculation on the two systems above (similar to the train situation described in the time section), you would find out that it would take longer for light, as viewed by the person standing outside the mirror system, to bounce between the mirrors (I will not go over the mathematics for clarity). If you are moving with the mirror as shown in 4.1 the light takes a shorter period of time compared to 4.2. The only thing that changes between 4.1 and 4.2 is your position in space. This is why moving clocks appear to run slow and why time is said to be relativistic (relative to a frame of reference). At very high speeds (a significant fraction of the speed of light) the effect of time dilation is greater. This relativistic character of time allows a person to take advantage of it and travel to the future.

The twin paradox explains how a person can exploit the relativistic nature of light to travel to the future. There are two twin sisters called Eartha and Astra. Eartha remains on Earth while Astra decides to take a rocket to Alpha Centauri at 80 percent of the speed of light. When Astra returns, Eartha has aged 10 years but Astra had aged only 6 years (Gott 67). Why? Explaining this would take a bit of rigorous math but I will put it in simple terms. Eartha remains at a constant velocity on Earth satisfying the first postulate of Einstein's theory of special relativity but Astra accelerates to a speed of up to 0.8c ms^{-1} in her rocket and decelerates when she arrives at Alpha Centauri, then she accelerates again to 0.8c ms^{-1} and changes direction to return back to Earth. Astra does not satisfy the first postulate and she also travels at an enormous speed causing her clock to appear as if it runs slow. As a result, Astra travels 4 years into the future (Gott 68), since the time travelled is less than the time passed in Eartha's reference frame.

Time travel to the future has been achieved in small time scales. For example, astronauts in the ISS have aged slower in tiny scales due to something called "velocity time dilation" and the time for them passes a bit slower. Time travel to the future in scales as big as the twin paradox has not been achieved. This kind of travel to the future sounds as simple as building a rocket but the engineering aspects are beyond current human ability. The fuel and materials required to build a rocket that can travel close to the speed of light is not simple. Time travel to the future is theoretically possible but that is not the case for time travelling to the past.

II. Time travel to the past

There was a young lady called Bright
Who could travel far faster than light;
    She set off one day,
    In a relative way,
And returned home the previous night. (qtd. in Gott 76)

This poem by A. H. R. Buller embodies the main feature of many time travel theories to the past as explained in physics: the rules of time travel should agree with known physical laws such as Einstein's general relativity. A majority of physicists agree that the laws of physics are consistent with time travel to the future but there aren't many who agree with time travel to the past. In this section I will explore three theories that have been proposed by great minds in the world of physics that challenges us to seriously think about time travel to the past.

- Cosmic strings

In many proposed theories of "the theory of everything" that is supposed to explain all the laws of physics, thin strands of high-density materials left over from the early universe are mentioned. These strands of material are known as cosmic strings. Cosmic strings have no ends and are infinitely long structures like an infinite spaghetti or a closed loop like a Spaghetti-o (Gott 93-94). Cosmic strings are like stretched rubber bands that are under high tension – about 10 million billion tons per centimeter – and narrower than an atomic nucleus (Gott 94). Given their massiveness (heaviness), cosmic strings can warp space-time. Richard Gott, a theoretical physicist studying cosmic strings, introduced a cosmic string model (based on his exact solution to Einstein's equations) that allows time travel.

Since cosmic strings are massive they create an incredible amount of gravity and because of this the space-time around a cosmic string looks like a pizza with a slice cut out as shown in Figure 5 where points A and B are connected to form a cone-like shape. Light would travel through the geodesic path of the cone which is from A to the vertex of the cone then to B. This creates an interesting opportunity for time travel where you could travel directly from A to B which would allow you to beat light to B. Since you beat light (it is important to note that you didn't travel faster than light; you took a shortcut) you have time traveled to the future ("Through The Wormhole - Is Time Travel Possible?"). Your departure and arrival had a spacelike separation. If this model is improved upon by adding two cosmic strings parallel to each other time travel to the past would be possible.

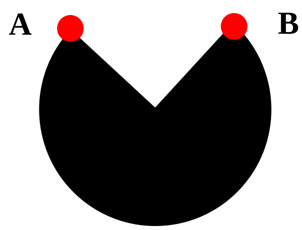


Figure 5

If there were two cosmic strings close and parallel to each other it would create a space-time around the cosmic strings similar to Figure 6 where A and B (call this point V_1) and C and D (call this point V_2) are joined together to form another shape similar to a cone. Let's say you have two planets at V_1 and V_2, if you take the shortcut from V_1 to V_2 and back to V_1 you'd be able to arrive at the same time you left (because you beat light on the round trip) ("Through The Wormhole - Is Time Travel Possible?"). You have time travelled to the past!

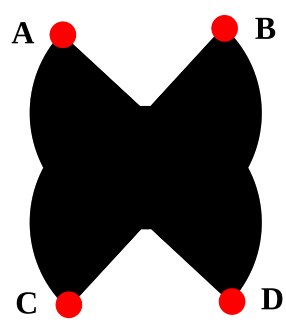


Figure 6

Cosmic strings are only a theory at this point and discovering one might take a while. To time travel to the past you would need two cosmic strings close and parallel to each other. The odds of finding such a system is low. There is also the concern that the two cosmic strings travelling at high speeds could create a black hole ("Through The Wormhole - Is Time Travel Possible?"). Finally, the engineering capabilities of creating a spaceship to withstand the immense gravitational effects of the cosmic strings is something only a supercivilization could achieve.

- Wormholes

A wormhole is a space-time tunnel connecting two locations or as a pioneer of the idea of wormholes, Kip Thorne, describes it: it's a "hypothetical tunnel through hyperspace" connecting one location to another (Thorne). A wormhole is very similar to portals opened by the portal guns in the Portal game series; when looking into the hole of one side of the wormhole, it allows you to see a distorted image of what's on the other side of the wormhole. A wormhole is simply a shortcut. For example, if I have a wormhole connecting my room to the front of the Whitehouse, I could travel 5 m in distance and get to the Whitehouse which is 500 miles away from where I am. I'd also be able to see a distorted image of the Whitehouse if I look at the wormhole in my room. A wormhole would look like the image in Figure 7.

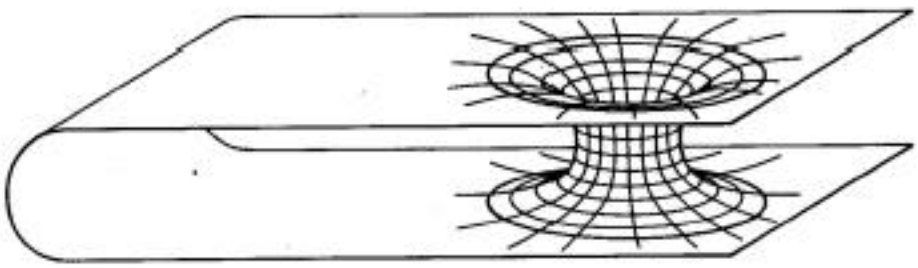


Figure 7 (Thorne, "Wormhole")

In the figure above the universe is the two dimensional sheet and the wormhole connects one part of the sheet to another. While wormholes seem like the perfect time travel phenomenon, it is still unknown whether the laws of physics permit wormholes. If wormholes do exist, they are smaller than atoms ("Through The Wormhole - Is Time Travel Possible?"). If that's the case, how can a ship travel through a wormhole? The wormhole would have to be stretched open.

In order to open wormholes up gravitationally repulsive forces are needed, i.e. exotic matter (Thorne). Exotic matter would be matter with negative mass and negative energy density that can warp space-time (Hawking, "Space"). The quantum mechanical uncertainty principle allows exotic matter. The uncertainty principle tells us that the speed (more accurately momentum) and position of a particle cannot both be accurately defined. The uncertainty principle can also be applied to fields such as electromagnetic fields. An electromagnetic field cannot be exactly zero in a vacuum because it would mean that the position and speed must be known, and that would violate the uncertainty principle. Instead there are tiny vacuum fluctuations or virtual particles which is the exotic matter (Hawking, "Space"). Exotic matter has been proven to exist in laboratories by producing small amounts in the "Casimir Vacuum" and "Squeezed Vacuum". While exotic matter exists there are some problems that we would have to overcome to open wormholes.

The first problem with wormholes is accumulating enough negative energy to open them up. There is currently no solid way in modern physics to capture enough negative energy (Thorne). The second problem is the self-destruction of wormholes. Wormholes have travelling vacuum fluctuations in them and when you travel from one end to the other, these vacuum fluctuations could have already flowed to the other side resulting in an explosion of the wormhole. Just like cosmic strings, wormhole based time travel would only be possible by a supercivilization.

- Closed Time-like Curves (CTCs) and the Multiverse

In Einstein's general relativity, space-time is four dimensional. Imagine the Earth rotating the Sun; if we ignore the thickness of the Earth and imagine a two-dimensional Earth-Sun system moving forward in time, the Earth's movement along the time axis would be a helix. This is Earth's worldline (Gott 10). Our worldline would look like Figure 8 - an intricately curved worm (Deutsch 69). Since nothing can travel faster than light, the worldline of light is drawn at a 45° angle spreading in all directions. This forms a cone which no physical object's worldline can go beyond. Worldlines that fit inside the light cone are said to be time-like (Deutsch 69-70)

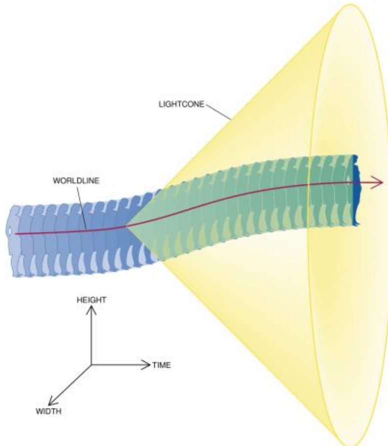


Figure 8 (Deutsch 69)

If space-time becomes so distorted that it forms a closed loop, then a CTC would form where the worldline is time-like all around (Deutsch 70). CTCs would allow us to visit events of our past by travelling along the loop exactly. The intersection of the loop shown in figure 9 is where one would meet their past self in a CTC. The CTCs allow for yet another radical possibility of time travel to the past.

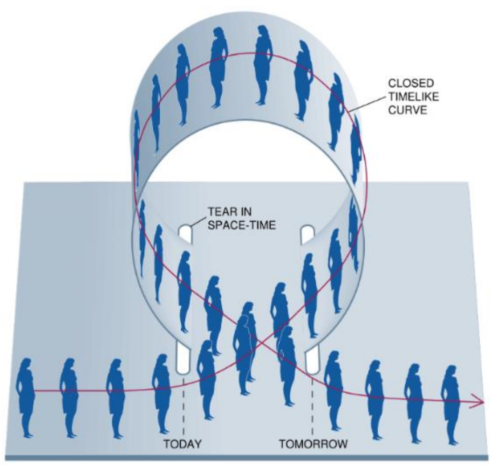


Figure 9 (Deutsch 71)

The wavefunction collapse in quantum mechanics allows for a controversial interpretation called the many-universes (also called many worlds) or multiverse theory. Proposed by Hugh Everett III in 1957, this interpretation claims that physical reality is a collection of universes (Deutsch 72). If something is a physical possibility, then according to the multiverse theory there is a universe where it has happened. For example, there could be a universe where there was no world war I or II. If CTCs exist, then the universes in the multiverse could be connected by CTCs (Deustch 73). So, if time travel to the past happens, we would be travelling to a different universe in the multiverse. While this sounds mind-bogglingly amazing, there is no proof for the existence of CTCs yet but reasonable convincing theories have been presented by theoretical physicists.

While CTCs much like cosmic strings and wormholes sound intriguing, we would need to find one and build a time machine that can travel through them: an engineering marvel beyond current human ability.

III. Time travel and engineering challenges

For a civilization to time travel via wormholes or the cosmic string model you would need a spaceship that can withstand immense gravitational fields and travel at a significant fraction of the speed of light. In his book, *Time Travel In Einstein's Universe*, Gott details creating a matter-antimatter rocket that could travel at 99.9992 percent of the speed of light (Gott 35) but antimatter costs billions of dollars to make with current technology and it may take years to obtain a reasonable amount of it. While we may not be currently equipped with the technology, scientists are working on projects that may eventually lead to advances making the dream of time travel closer each day (one such project is the Breakthrough Starshot project). While time travel is far from reality today, it hasn't stopped physicists and philosophers from questioning and rigorously exploring its possibility.

7. A possible model of time

Before moving into the philosophical discussion of the possibility of time travel, I will present to you my model of time. The model is presented below in Figure 10.

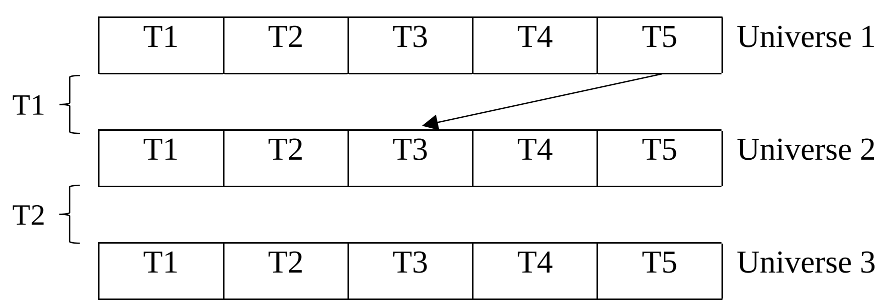


Figure 10

My model of time involves the multiverse and in this model, I will assume that the second law of thermodynamics is an iron clad rule for all universes. This means time reversal is not possible because entropy decreases which according to the second law is not possible. So, the only way to travel to the past is to travel forward in time. So, time travel to the past in this model will involve CTCs similar to David Deutsch idea. Time travel to the future would be relativistic time travel. This means there are two different ways to travel in time. This conclusion means that another assumption that time would not be symmetric is made. I have not discussed the symmetric nature of time in detail but the idea is that entropy increases over time and thus, each temporal part in a time stream has different entropies (personal communication – Michael Korth).

To understand this model better, consider Figure 10. I have presented three universes each with five temporal parts corresponding to a particular time. When a time traveler starts his time machine, he ends up in a different parallel universe if he travels to the past but, remains in the same universe if he travels to the future. In Figure 10, the arrow's end indicates the temporal position in Universe 1 when the time traveler starts his machine and travels to the past and the head of the arrow indicates what time he arrives in Universe 2. Note that the universes are separated by a single temporal distance, this separation is the time taken for the time traveler to travel to Universe 2. The time traveler has travelled three temporal parts backward in the time of one temporal part: he has time travelled to the past.

When the time traveler travels to the past he never ends up in the same universe but when travelling to the future he would. In order to get out of a paradox (discussed later), I will make another assumption similar to Nicholas Smith (discussed later); consider the situation of a time traveler travelling to Universe 2 from Universe 1. Let T5 be the present; the time traveler travels to the past of Universe 2 and changes something in it. Since I take an eternalist view of time, I will claim that this had already happened in the past of Universe 2, so it is consistent with the history of Universe 2.

For clarity, I will recap the assumptions for this model,

1. Time is not symmetric.
2. All universes in the multiverse follow the second law of thermodynamics.
3. The time machine can distort space time to create a CTC to any point in the past, thus allowing travel to the past. The time machine can also travel close to the speed of light to travel to the future.
4. If a time traveler interacts with the past of a universe, it is consistent with the history of that universe.
5. These are the assumptions about time I made in sections 3 and 4,

    - Time is objectively real
    - Platonist view - time passes without change
    - Topology of time – time is infinite, continuous, linear and has no beginning or end
    - McTaggart's B-theorist view - time does not flow and the flow is only subjectively real
    - Time has a forward arrow
    - Eternalist view of time – block universe and four dimensionalism associated together and perduring nature of objects.

8. Time travel in philosophy

As you've read before, time travel to the future is not that controversial, it is time travelling to the past that is controversial. So, in this section I will cover three issues related to time travelling to the past as discussed by philosophers.

I. Grandfather's Paradox

Mary's maternal grandfather never treated her well; he was abusive and showed her no respect. Mary grew up to despise him. She despised him so much that she was homicidal. She had planned to kill her grandfather on one beautiful Sunday, right after church but she missed her opportunity because her grandfather died of a heart attack the day earlier. Months later she joined the Marines and trained well in many lethal techniques and was a first-rate sniper who never missed a single shot in her career. A year later she came across a time machine. She used the time machine to travel 60 years to the past with the intention to murder her grandfather. At this time, her grandfather was a young man in his mid-twenties and hadn't even met Mary's grandmother. Mary observed her grandfathers every move for weeks and studied his habits and schedule. On one clear day, which was neither too hot nor cold and with just a slight breeze that couldn't blow an ant away, Mary decided to kill her grandfather. She bought a sniper rifle and positioned herself on top of a building right across her grandfather's regular coffee shop. He showed up at precisely the same time he always showed up at, 9:00 a.m. and he sat outside in clear sight of Mary. Mary took her time and aimed the sniper rifle straight at her Grandfather's head and pulled the trigger. Did she succeed in killing her grandfather? If she did, she wouldn't have been born in the first place because her grandfather would still have to meet her grandmother who would give birth to her mother. Mary wouldn't have been born and if that's the case how could she travel back in time to kill her grandfather? Here we have the infamous grandfather's paradox. Let's put aside the difficulty of creating a time machine and focus on the issue that comes later, where Mary has every single opportunity to change the past. The question is whether she can do it.

As I said previously, Mary has never missed a single shot in her life, she is well trained and is the best of the best. Let's also make it a fact that Mary is using a 50-caliber, semi-automatic sniper rifle that can fire up to ten shots which means she has ten tries to kill her grandfather. You could say that there is no way that Mary would miss shooting her grandfather at such a close range with ten tries. Given these set of facts, Mary successfully kills her grandfather. On the other hand, we know for a fact that her grandfather lived and it is impossible to change the past. Given these set of facts, Mary is unsuccessful in killing her grandfather. David Lewis brought forth this argument that given one set of facts, Mary kills her grandfather and given another she doesn't (Lewis 150). Lewis claimed that the fact that Mary kills her grandfather remains in the larger set of facts that Mary did not kill her grandfather (Hunter 2016). To understand this concept better, consider this, we know for a fact that Mary did not kill her grandfather because Mary was born and her grandfather did not die at least until he was in his mid-80s. This is a larger fact. The other smaller fact is that Mary could kill her grandfather because she has the talent but the larger fact has superiority because we *know* her grandfather lived. So, if Mary travels to the past to kill her grandfather there is larger set of facts that contains a contradiction which is impossible, so Mary does not kill her grandfather (Lewis 152). History remains consistent. So, because Mary cannot kill her grandfather, some may be led to argue that Mary cannot even travel to the past. Paul Horwich argues otherwise.

Horwich claims that there is a difference between influencing the past and changing the past (435). When Mary kills her grandfather, she runs the risk of changing the past, i.e. her mother is never born and in turn she's not born, but Mary could still time travel to the past and interact with things. For example, Mary could go to the store and buy a sniper rifle. Horwich claims that having the assumption that Mary could not buy the rifle because she was not present in the past does not follow that she couldn't have been there. In other words, the fact that someone did not do something does not mean that they couldn't do it (Horwich 435). Horwich, like Lewis, would still maintain that Mary would not be able to kill her grandfather because that would mean she changed the past in larger sense, which is logically impossible. History remains consistent. So, by his argument, Horwich maintains a view that time travel is improbable. Nicholas Smith criticizes this view of Horwich (and Lewis) to make a bold claim that time travel to the past is possible.

Smith's arguments are quite complicated but I will briefly outline them. Smith claims that time travelers can change the past but they cannot do anything contradictory (Smith, "Bananas" 366). The argument seems similar to Horwich but with a major difference. If Mary shoots her grandfather she would miss because of various reasons. For example, her rifle could jam or the bullet could hit a bird that flies by. He claims that there would be many "coincidences" that would prevent Mary from shooting her grandfather and he also goes on to claim that the coincidences are not in fact coincidences but things that have already happened in the past. That means if Mary travels to the past to kill her grandfather she had already done so and has failed to kill her grandfather because of the coincidences. One might argue that so many coincidences couldn't occur but Smith writes this interesting story to dissolve that argument,

> Suppose that several years before I was born my parents were booked on a train that ended up travelling past a leaking nuclear facility, causing everyone on board to become sterile. It is somewhat of a coincidence that they missed the train because the ferry they were taking to the station was delayed by fog. Suppose that had my grandmother decided to visit Benny rather than Lenny one day when she was a little girl, she would have perished in the fire which killed Benny. It is quite a coincidence that she was annoyed with Benny that day because the latter had spilt ink all over her collection of cigarette cards the day before. Suppose that had my father been driving into work as usual one day, he would have been crossing the local bridge at the moment it was hit by a ship. It is a coincidence that my father stayed at home that day to look after his brother, who had contracted food poisoning after eating a fish won in a raffle. Now suppose someone were to argue that my birth requires the occurrence of all these coincidences. (qtd. in Smith 375)

The extraordinary circumstances of his birth (if it had happened so) is a fact. The string of coincidences become a part of the past. Therefore, by Smith's argument, Mary would fire all ten shots at her grandfather and still miss due to a string of coincidences. History remains consistent.

Smith's view is radical but my view of time would allow something even more radical: Mary would successfully kill her grandfather.

Quantum entanglement is when two quantum systems physically interact with each other and then separate (Smith, "Time Travel"). This is where the idea of the multiverse comes from: one universe splitting into two. If the multiverse exists, Mary would be able to successfully kill her grandfather in at least one of the universes. According to the model of time I presented, the task would be as shown in the figure below.

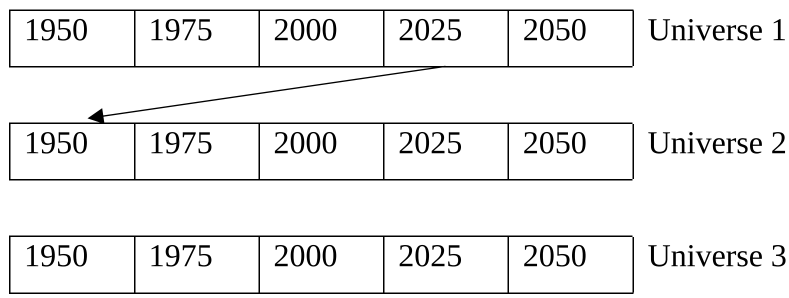


Figure 11

In Universe 1, the past has no record of Mary even attempting to kill her grandfather. In Universe 2, Mary's grandfather was killed by a bullet to the head and thus Mary was never born in that universe. In Universe 3, someone attempted to take the life of Mary's grandfather but failed. Like the universes in Figure 11 there are infinitely many more because the multiverse should allow any reasonable outcome. Let's say that Mary got into the time machine in 2025 and travelled back to 1950 to kill her grandfather. The past in Universe 1 where Mary got into the time machine has no record of Mary's attempt to kill her grandfather but the past of Universe 2 and 3 does, so she ends up in either Universe 2 or 3. If Mary succeeds in killing her grandfather she remains in Universe 2 but if she doesn't, time branches out and she ends up in Universe 3. So there's a universe where Mary kills her grandfather and there's a universe where she doesn't. The history of Universe 1 where Mary was originally from and the history of the other universes remain consistent and there is no paradox. The cost of solving the paradox however is having an unimaginable number of universes with every possible outcome; one might say it's a cheat but if the current knowledge of quantum physics allows it, why not?

II. Personal Identity

Back to the scene where Mary finds a time machine and decides to kill her grandfather. Moments before entering the time machine, Mary realizes what she has become: a monster thirsty for revenge. Mary finds it difficult to keep herself together so she buys a gun and puts a gun to her head and tries to pull the trigger. She couldn't do it. She realizes the time machine has provided her with an opportunity, the chance to kill herself by travelling to the past and pulling the trigger on her past self. She travels back twenty years to the past where she's only an eight-year-old. She's in front of her younger self, face to face. Let's pause here to ask the question that this section concerns about: Is older Mary (whom I shall refer to as $Mary_1$) and younger Mary ($Mary_2$) the same person or two people?

David Lewis holds the view that both $Mary_1$ and $Mary_2$ are the same person. He does this by differentiating between personal time and external time. Consider the relativistic property of time and picture the following situation. You stand in a room with only a clock on a wall and you also have a wristwatch which is perfectly in sync with the clock on the wall. You travel at a significant fraction of the speed of light around the room for five minutes and your wristwatch says that only five minutes passed. The clock on the wall tells you that five hours has passed. The time displayed by the wristwatch is personal time while the time displayed by the clock on the wall is external time. This thought experiment is only a simple model of the difference between personal time and external time. According to David Lewis, when $Mary_1$ is in front of $Mary_2$, there are two Marys in external time but it is the same Mary in two temporal moments in personal time (perdurantist view). So, there aren't two people but one person connected in personal time in the forward direction (Lewis 147). Horwich holds a similar opinion about assigning proper time (his version of personal time) to Mary (Horwich 434). The problem of personal identity is well solved if we assume an eternalist (or growing past theory) view of time as shown by Lewis and Horwich but if you also believe in the multiverse (as in the model I presented) personal identity is a bit complicated.

When Mary travels back in time in the multiverse, she travels to a past in another universe which means she would meet a different Mary. That means $Mary_1$ and $Mary_2$ are unique people. But Mary could also be the sum of all her appearances in the multiverse (Hunter 2016). If $Mary_1$ and $Mary_2$ are in fact unique in the multiverse, then according to the discussion in the grandfather's paradox Mary does not kill her own grandfather but a different version of her grandfather. Personal identity in the multiverse is something that I haven't been able to reach a conclusion about but I seem to find myself leaning towards the view that the Marys in different words in the multiverse are unique (which certainly created issues!).

III. Autoinfanticide

Let's consider the point where $Mary_1$ meets $Mary_2$. $Mary_1$ has her gun on her younger self's ($Mary_2$'s) head at point blank range. Can Mary kill her younger self? In philosophy, killing your younger self is called autoinfanticide and philosophers take multiple views on its physical and metaphysical possibility. The easiest solution to autoinfanticide could be the multiverse (as in the model presented). Mary travels back in time and kills herself in another universe but that would bring us back to the same problem of personal identity, did Mary kill herself or a different Mary in another universe? It may seem logical to most that it is impossible for Mary to kill her younger self because that would mean she would cease to exist but a fatalist mistake is being made here.

A fatalist believes that if something is true in the present then it would happen in the future (Vihvelin 316). Let's say that you resolve to go to the gym on January 1st and work out. You have the means such as a gym membership, the workout plan and the equipment at the gym. So, based on these facts it is true that you would go work out on January 1st. This still doesn't mean that you couldn't go back on your resolution and stay home, eat chips and binge watch a TV series. This is similar to Lewis' argument on the grandfather paradox: in one sense, it's true that Mary can commit autoinfanticide but in the other it's not. Kadri Vihvelin holds the view that autoinfanticide is logically possible but physically impossible.

Vihvelin's argument rests on the fact that counterfactuals stack up. Imagine that you are a short person who does not play basketball and you claim "If I were tall, I'd play basketball." This is a counterfactual because you are not tall and you would never be. So, your statement would never be a fact. Vihvelin argues that just because Mary can kill her younger self does not mean she will because she would cease to exist (Vihvelin 321). The only worlds where that would be possible is a word where resurrection is possible but that is not the world we know, so it is physically impossible to commit autoinfanticide but logically possible (Vihvelin 321). G.C. Goddu and John W. Carroll, unlike Vihvelin, seem to hold the view that autoinfanticide is both logically and metaphysically possible.

Goddu's view of committing autoinfanticide rests on changing the past. He creates his own model of time where he introduces the concept of hypertime. When a time traveler travels to the past he travels in a branching time stream called hypertime and this hypertime becomes the normal universal time (Goddu 21-22). That means a time traveler's arrival to the past changes the past and rewrites the time stream similar to writing over a cassette tape. So, you could literally kill yourself and live to tell the story. Goddu's idea is bold but unreasonable because it means erasing what has already happened. Carroll's views seem a bit reasonable but he only goes over several case studies of how autoinfanticide would be possible. One of his case studies is where Mary travels back in time to poison her younger self, the poison is so slow acting that Mary dies after poisoning her younger self (Carroll 182). While Carroll's arguments are well thought out it does not prove beyond doubt that autoinfanticide is possible.

9. Conclusion

Throughout this paper, I tackled a lot of concepts/ ideas related to both time and time travel. Time and time again (pun intended), I have returned to these concepts and tried to come up with a perfect model that would seem reasonable. The model I came up with has too many assumptions since it was created in a way to avoid many paradoxes. Nonetheless, my original goal was to come up with a model that took concepts debated by many philosophers and scientists to show the possibility of time travel no matter how unlikely it may be.

There is a constellation of questions that one could ask about time and time travel that would continue to remain unanswered. Maybe the answer to all these questions lie in the reconciliation of quantum mechanics and general relativity or maybe asking these questions could be a waste of time because the concept of time is subjective. Whatever the truth maybe, for now, time travel is a possibility.

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