A COMPARATIVE ANALYSIS OF DAVID LEWIS' MODAL REALISM AND EVERETT'S MANY WORLDS ON CLOSED TIMELIKE CURVES AND TIME TRAVEL

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INTRODUCTION

In this paper, I aim to explore the metaphysics involved in time travel by examining the prospect of changing the past. In breaking down the notion of time travel there are key areas in which one's views must be established. Firstly, there are a number of models we can have on *time* itself. I will aim to establish two theories which I take to adopt a shared perspective on this particular metaphysics. Once this question has been answered, the second which arises is whether such a model allows for 'changing the past'. In answering this, the views which I shall discuss will prove to be essential towards notions of consistency in causality. I will in the first sections (**I,II**) of this paper describe what we might take to be paradoxical consequences of time travel. Setting up these cases I will begin to see how they can fit into the theories I will later discuss. Importantly, I will highlight some of the physics in section **II**, which should encourage us to further analyze the implications of the troubling paradoxical scenarios such as the grandfather paradox. David Lewis (1976) argued that time travel must maintain consistency, and crucially, that even if time travel were possible; we would not be able to change the past. His arguments are supported by his views on causality, time, and perhaps most significantly for this paper; modal realism. By examining Lewis' metaphysical picture in **III.** I aim to show that he holds a crucial assumption on physics. I hope to highlight this assumption by a conflicting view in section **IV.** Everett's Many Worlds interpretation holds many similarities to Lewis' views with regards to time, global determinism, and the ability to establish tenseless statements across worlds. However, the mechanism by which these worlds exist is something which I argue the Everettian picture is able to do more fully. In comparatively analyzing these two views in **V.** I will show that Lewis can offer us a better understanding of how the metaphysics of time travel can exhibit in the many worlds view. From adopting a temporal framework towards these theories, specifically an eternalist framework, I hope to expand the limitations of such a framework on a single timeline. The modal worlds structure has afforded a comprehensive metaphysics with regards to time travel; that is, with regards to change and consistency in a four dimensional 'block world'. I hope that through applying this metaphysics on the quantum mechanical many worlds model, I can show that we are afforded with a potentially more comprehensive state through which time travel may be explored further.

I. TIME TRAVEL AND PARADOXES

According to a definition by David Lewis (1976) a person is a time traveler *iff* one's personal time does not match external 'objective' time. For example, if we travel to the future, one's journey is time travel *iff* one's personal journey to the future is *shorter* than that of the external duration. Likewise, one travels to the past if the external time is earlier than that at the beginning of the journey (Fletcher, 2022)[1]. The distinction of personal vs external time is not an extra dimensional one, that is, the above view does not pose that there are two dimensions of time ie. one personal and one external (Lewis 1976).

The common-sense story of time travel goes as follows: Person A steps into a time-machine and Person A appears in a time prior to entering the time-machine. Further, the time traveler enters her same world but earlier in time; if she entered the time-machine in the year 2022 she could travel to the year 1910. Upon arriving at this earlier year, the time traveler is able to see that nothing had changed, the newspaper which was being delivered at 9am on Sunday morning on October 23 1910 becomes delivered exactly at the same time and the time traveler can curiously observe these historical set of events in real time. But the traditional time traveler is not only able to observe history first hand, but is able to actively interact with it, talk to people, displace objects, and so on. Perhaps the time traveler went back to kill a baby who would later

[1] The complications associated with this particular definition of time travel is something I will focus on later in the paper.

become a vicious dictator, or to kill her abusive grandfather, the time traveler will then alter history and prevent the dictator's actions or her grandfather's later abuse. At least so the fictional narrative is usually played out. However, If one killed their grandfather early in life, their father would not be born and so neither the time traveler; how could the traveler later make their journey to perform the act?

There is a different type of product that can arise from time travel—for example: let's say I went back in time to visit a painter who is just starting out in the profession, what the painter doesn't know is that he will become incredibly famous for his work. However, on my time travel journey, I bring photographs of his future paintings which I show to the painter, telling him that these are his most famous future works and that I am a time traveler he should trust. Before I leave, the painter steals my photographs and spends the rest of his life meticulously copying them. Now, it seems the source of the great paintings come from… where? Who? It seems that in the painters loop described above, the information that seeds the creation of the paintings comes without a genuine global source. However, if we try to question each participant, each will give a genuine response to the source of their action, yet 'globally' we are perhaps confused. That is, the time traveler will easily explain where they got the pictures from, likewise the painter will easily explain where he got the pictures from, and so on and so forth. The apparent loop that results from such an investigative sequence could be illusory; global sources are perhaps too much to ask. Let me quickly sketch another concerning example of time travel as shown in Harry Potter: The prisoner of Azkaban. In the book, Harry is being attacked by dementors when suddenly from across a lake a figure appears in the dark which casts a powerful spell thereby saving Harry. However, what Harry later finds out is that it was himself in the future saving him, he later proceeds to perform the act of saving which he benefited from earlier. When asked by his friends how he was able to perform such a difficult spell which saved himself, Harry responds by saying "because I had done it before". Similarly here, Harry's conviction towards his self belief stems from a loop without a 'global source' (for lack of a better phrase). Although these stories come across as 'weird', for the purpose of my topic of discussion, I will not focus on these too much. As I will show later, such 'causal loops' pose little difficulty for the view I shall later sketch. Since each event in the causal loop story has a genuine cause, we can argue it is unproblematic. Instead, I will focus on the grandfather paradox-like difficulties of time travel.

Consider again the time traveler who wants to kill her abusive grandfather while he is still a child, if she does, her father would never be born and so the time traveler wouldn't be born either. How could she then step into the time machine in the future if she was never born? Consider killing the to-be dictator baby, if the time traveler manages to kill the baby, the dictator never becomes anything, so how might the time traveler know about the dictator in the future if he never became a dictator? Known as the "grandfather paradox" it is usually the first objection to being able to influence the past, as doing so would lead to a paradox where whatever action is done in the past by the time traveler would prevent that action from being motivated in the future, and therefore the motivation of the time traveler prior to entering the machine should already be canceled out by… herself? Authors such as Thom. P argues this as a reason for the *logical impossibility* of time travel. David Lewis (1976) famously argues against this objection to time travel by highlighting that while some restrictions might prevent the time traveler from killing her younger grandfather, she isn't strictly logically unable to do so, as there is a difference between something one 'can' do and what one is logically unable to do. He argues therefore that time travel is *logically* possible. I will unpack and examine Lewis' argument for this following the next section of this paper and show why there is a potentially more attractive alternative to his view. I will now quickly examine the physics which encourages us to examine time travel further.

II. CLOSED TIME-LIKE CURVES

II.I. THE PHYSICS

On one hand there are the metaphysical questions with regards to individuals traveling through time; what decisions can a person make when attempting such a journey? Can the time-traveler have free will? And what relationship does an individual have with regards to the objects around them (personal versus external time)? On the other hand we have the physics which must be dealt with so as to give us a direction or potential motivation for these questions. In looking at the physics, I shall for a moment discard the idea of a person traveling through time and instead look at simple objects like a bowling ball or even particles.

In general relativity the Einstein field equations describe curvature to spacetime as indicated by previous notions through special relativity. For these equations there are different sets of solutions which give unique curvatures for given inputs if you will. Simplified versions of the equations shown below:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu} \quad , \quad G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu},$$

$$R_{ab} - \tfrac{1}{2} R g_{ab} - \Lambda g_{ab} = 8\pi G / c^4 \; T_{ab}$$ [2]

Normally given our understanding of the spacetime curvature the solutions provide outputs with implications on space-time which is quite extraordinary. For example, equating gravity with acceleration combined with special relativity indeed have metaphysical implications on *time* which at first hand might seem worrisome, yet these are experimentally confirmed to agree with what is predicted. Special relativity gives us

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[2] Λ cosmological constant, G Newton's gravitational constant, and c the speed of light

the possibility to travel forwards in time *relative to some other object* through no difficulties at all, simply go for a run while your friend sits and waits for you to come back and less time will have elapsed for you than you stationary friend (although very minimally different of course). Imagine going close to the speed of light, a little over 80% and you will find that time passes (*that is, as measured on a personal wrist watch*) twice as quickly for your stationary friend compared to you. Likewise, place yourself in a significant gravitational field and the same effect will happen. Problems of forward time travel, in this wrist-watch, sense give little problems but importantly highlight the conjunction of spacetime curvature and the passing of time[3]. Considering what I previously mentioned, certain solutions which assume structures in our universe can give significant differences to the results of those equations; the Gödel metric is certainly one of these. A striking feature of this solution is the existence of closed timelike curves (CTCs), which are *piecewise timelike curves* that "close" back on themselves such that two distinct parameter values map to the same atomic event (Fletcher, 2022)[4]. Although assuming very exotic configurations of our universe (ie. a non-expanding, rotating universe), the Gödel solution to the field equations give rise to structures in which objects can return to their previous time indices, essentially by traveling forwards in time ending up in the past.

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[3] There are subtleties here with regards to the measure of an external vs personal time as previously mentioned in the definition of a time traveler. Assuming a personal time is measured by one's wristwatch, the forward time travel here is relative to some 'stationary' external environment against which the personal time is measured.

[4] Fletchers (2022) definition goes as follows: "Duration γ is timelike iff then $|\gamma|$ represents the *duration* of the events in $\gamma[I]$. (This postulate is sometimes called the *clock hypothesis)* Length γ is spacelike iff $|\gamma|$ represents the *length* of the events in $\gamma[I]$" where γ is some specified spacetime curvature.

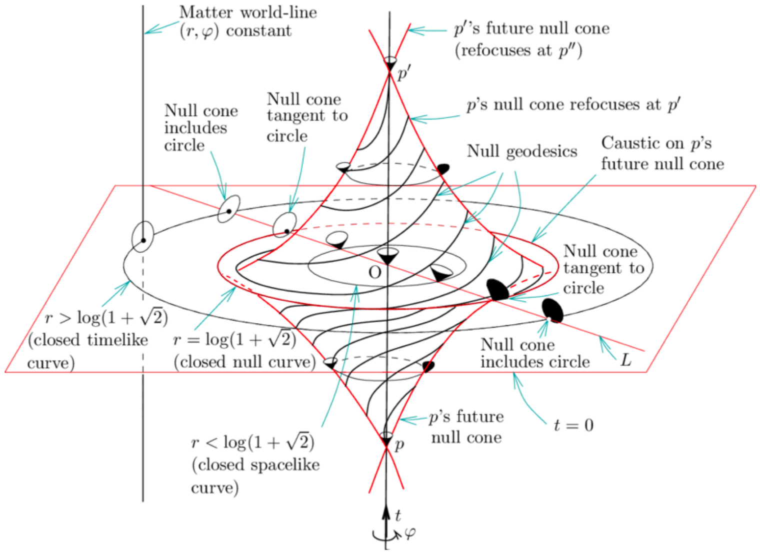

Figure 1: A visual of the Gödel Metric

Considering the conditions for a non expanding universe, we have reason to believe the Gödel metric is in reality at least very difficult to come across, having observed the redshift doppler effect of distant galaxies indicating an expanding universe at a particular increasing rate. Nonetheless, the importance for my paper here lies not in whether it empirically marries our current observations, but rather, that the physical possibility for such a universe is not beyond metaphysical reach, perhaps even we can imagine a possibility for an intelligent species to manipulate the physics so as to give rise to these curves as Callendar says: "The discussion above (Gödel CTCs) shows that time machines are physically possible in the weak sense that there are spacetime geometries that instantiate a time machine" (2011). Although the physics of CTCs deserve more significant attention, for the scope of this essay, I have outlined their plausibility to highlight the need to look further into the potential consequences of such structures. There are difficulties which arise in attempting to match CTCs with the Lewisian sense of time travel. That is, as mentioned earlier, Lewis defines a time traveler as one which de-synchronizes with external time; relativistic physics do not generally make this distinction[5]. However, many different modifications on relativistic spacetimes exist to allow for this distinction each deserving their own discussion (See for example: Fano and Macchia 2020, Fletcher 2022, and Daniels 2014).

II.II. PARADOXES OF CTCs

Initially there are some paradoxes with CTCs, solutions to these are usually framed as consistency constraints and remain a contested topic for time violations. I. D. Novikov (1992) highlights a number of ways in which causal relations in CTCs may be consistently formulated without producing what we take to be paradoxical outcomes. Lets first look at one of these causal paradoxes to then see how Novikov offers a consistent solution. Imagine a bowling ball which is approaching a CTC, upon arriving it follows its trajectory through the CTC and appears earlier in its temporal past, meeting itself, makes contact, knocks its past self off course so as to prevent itself from entering the CTC in the first place, how then might it have knocked itself of course? Clearly here we have another case similar to the Grandfather paradox, although a more physical example. These outcomes are known as casually inconsistent and many physicists advocate for such scenarios to be physically restricted through a law like Consistency Constraint (Penrose and Hawking for example). Whether or not we ascribe 'lawhood' to such a principle remains up to debate, however, considering the possibility of formulating these physical setups, avoiding causal inconsistency is taken by many as a possible law on a similar foot as the second law of thermodynamics for example. So what does a consistent solution look like? Novikov (1992) sketches a number of these and instead of going through each I will sketch the most simple one:

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[5] Something which could bear weight on the question at hand here is the substantival versus relationalist debate with regards to space. That is, whether spacetime structures are inherently 'real' in the ontological sense, or whether these are emergent properties from relations between objects. A further discussion on the General Relativistic approach with regards to personal/external time in substantival/relational ontology is a topic for another paper.

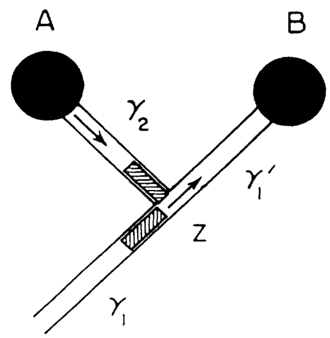

Figure 2: Self-consistent motion of a piston in a tube (Novikov 1992)

In this example we have a piston going through a tube towards CTC B to reappear at CTC exit A where it interacts with its former self. Unlike the paradoxical case where the piston stops itself from entering completely, the piston exiting at A slows down its former self through the interacting friction, allowing itself to travel to B and so on[6]. I find that the consistency case like the mentioned example shows us something important with regards to how we might have initially dismissed time travel from the perspective of asymmetric temporal causation requirements. Even in cases of a shared temporal timelines (ie. a non branching view) we are able to find clues which might lead us to deal with objections to time travel. However, a great question remains unexamined, are consistency constraints like Novikov's doors to *changing* the past? We seem to observe there being some casual interaction between the "two" pistons; yet, does it change the past? David Lewis aims to provide an answer to the above question, this I will now look at further.

[6] I reserve a detailed outline of the mathematics that prove this consistency here (see Novikov 1992).

III. DAVID LEWIS: MODAL REALISM AND TIME TRAVEL

Having looked at some of the physics encouraging us to examine time travel further, I will now look at how differing metaphysical views on 'time' will influence the relevant metaphysical difficulties. I will quickly look at presentism to show how David Lewis' view contrasts this view, to then examine his view with regards to time travel and changing the past.

III.I. PRESENTISM AND GROWING BLOCK

If one subscribes to the idea of an open future, in the sense that events in the future are not *actualized* or yet *real* while allowing time-travel, one has to reconcile with that of a future event being *actual* (holding a real truth value) yet somehow *not actual* (i.e. lacking a truth value: an obvious contradiction)[7]. For if the time traveler steps into time machine at t5, exits at t1 and decides to displace a body (whatever object in the world the time traveler finds itself in) within the world at t2 the explanation for the movement at t2 can only be accounted for through the events at t5. From such reasoning, maintaining at t3 that t5 is open, in the previously described sense, seems contradictory. Authors like Miller (2005) use this as an objection towards the possibility of time travel in an open universe. The same argument can be made for a "growing block" open future view. The intricacies of why we should or should not believe in an open future deserves its own discussion. Some argue that the indeterministic physics found through quantum mechanics for example should motivate an *actuality evolution* or *becoming*. There are a number of responses to this which I will not go through—simply put, It is possible to

[7] Lewis in his 1980 paper on probability defines this slightly differently in a more subjective sense, this definition will become an apparent assumption in his ontology which we shall see later in this paper. He says: "The past, unlike the future, has no chance of being any other way- than the way it actually is. This temporal asymmetry of chance falls into place as part of our *conception* of the past as "fixed" and the future as "open"- whatever that may mean"

establish an eternalist picture with indeterminate physics. Regardless, the presentist argues that *only the present* exists[8], the objection then goes; to what 'location' in time could the time traveler possibly travel to if that past time does not exist anymore? Known as the *no destination argument* it might seem to punch a blow to the presentist who wants time travel. However, for the scope of this paper, I will not go further into this area. Presentism indeed offers an interesting discussion on time travel, but what I intend the above outline to offer is to *contrast* from David Lewis' view on time (ie. his 4D eternalist block view) and associated argument regarding time travel.

III.II. LEWIS': ETERNALISM, MODAL REALISM, AND TIME TRAVEL

Lewis (1976) held a view that events in history were fixed and immune to interference or *change*. Consequently, any attempts aimed at altering things from the past, like causing their grandparents' death by meddling with past occurrences, would be fruitless: self-consistency rules, similarly to the Novikov constraint sketched earlier, naturally prevent changes to a 'past'. That is, on Lewis view, the world and what we call temporal events, are all fixed and actualized in the 4D block. In this block, objects are 4D worms which can be causally linked through counterfactuals. However, no real *change* occurs at some given time, rather these worms are merely in different relative configurations through time and as humans these differences are observed as an illusory form of change. I have created a visual below:

[8] See for example Saunders 2022 and Maudlin 2002 for a more detailed outline on this view of presentism

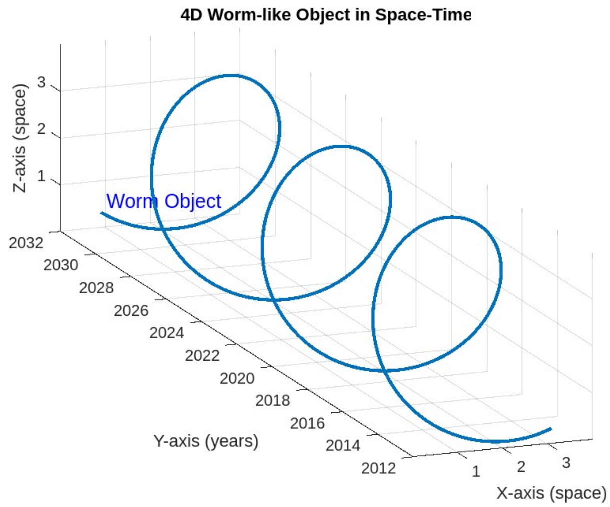

Figure 3: 3D visualization of a 4D object through time[9]

When it comes to the Grandfather Paradox, Lewis (admittedly similar to Novikov) has a distinct perspective that emphasizes logical consistency in time travel. As seen above, the four dimensional view on time has a crucial consequence on causality and change. That is, in moving between slices of such a block, events are merely illusory as viewed through experience. That is, an object does not 'move' through space, the object is fixed in space—causality is merely represented in a counterfactual sense. A ball bouncing off the floor is already in contact with the floor, in the four dimensional sense, prior to hitting it in the experiential three dimensional sense. We explain the bouncing of the ball by looking at possible worlds in which the floor does not exist and thereby say the floor 'caused' the ball to bounce. With regards to time travel, the four dimensional block view ensures that events which are connected through the time traveler were already fixed as such. By structuring time in this eternalist B-series (earlier than, later than) configuration, time travel is not impossible, since we can logically establish causal consistencies in objects moving in whichever direction we may want (Lewis, 1976).

[9] This particularly simplified graph aims to show an object which is configured in different spatial locations through the time dimension

Preserving consistency with previous occurrences despite moving backward or forward allows for established past evolutions not getting disrupted without losing any inherent consistency; ensuring no one can assassinate their own grandparent unless upholding consistency within the chronology.

So far I have outlined Lewis' view without explaining a central claim; his modal realism. In *On the Plurality of Worlds* (1986) Lewis outlines his metaphysical account on possible worlds which is essential to understanding his claims regarding time travel. Lewis posits that there are an infinitude of spatio-temporally disconnected possible worlds, existing as true genuine worlds. These worlds exist in identical ways to our own, that is, as equally real. The worlds merely differ slightly from the next, allowing us to make statements such as 'close worlds' those which differ slightly, and 'distant worlds' those which differ more drastically (Lewis, 1973). When we say something is 'possible' in Lewis' view we refer to their occurring in *some possible world.* Comparatively, when we say something is impossible, or necessary, we say it holds true in *all possible worlds.* In his own words:

> "*There are so many other worlds, in fact, that absolutely every way that a world could possibly be is a way that some world is. And as with worlds, so with parts of worlds: absolutely every way that a part of a world could possibly be is a way that some part of some world is. Therefore, every possibility, in every respect, is realized. Actuality is just one of the ways that a world can be; to be actual is to be just this way, the way the world is."*

The view above with regards to time travel has implications on a number of dimensions. Possibly unlike the view I will later sketch, Lewis' multiple worlds are not traversable, a time traveler must remain in his own world, thereby identity and freedom is tensed in the sense that you, *as in the one reading this*, belongs to the one world you are in and cannot exist elsewhere. However, there are copies of yourself which exist, thereby offering a semi tenseless identity and existence theory. You can be regarded as the totality of worlds in which you exist. Nonetheless, your story is fixed and any time travel must cohere in similar fashion to that of Novikov's consistency principle. However, statements such as, "it is impossible to kill my grandfather" are statements about all possible worlds, and so Lewis concludes the statement is flawed. In *The Paradoxes of Time Travel* (1976) Lewis states, on the grandfather paradox, that statements about events are *compossible* with a rich set of facts, including his plans, rifle, and also the fact that *grandfather did not die*. That is, the time traveler Tim's compossible set of facts includes his grandfather fathering Tim's father who fathered himself. Relative to these facts, Lewis says, Tim cannot kill grandfather; "There is the simple fact that Grandfather was not killed. Also there are various other facts about Grandfather's doings after (time traveler's arrival) and their effects" (1976)[10]. According to Lewis, objects exist through all 'time'. That is, as 4D worms. The passing of time is an illusory experience and change is nothing more than 'observing' relative differences between 4D objects, using counterfactual claims in line with the modal argument to explain causation (1973).

From looking at the Lewisian metaphysics, 'changing the past' is a flawed statement. The composite set of events which appear to occur in a slice are simply a time-tensed perspective from one frame to another in the already static 4D block. Time travel in this sense involves no change. The modal worlds which exist in Lewis view also serve towards this purpose. There are consistency constraints upon the time traveler, yet we find that statements across worlds that are tensless ie. "It is impossible that my grandfather dies" is not strictly true since there are worlds in which such occurrences may be within the configurations of the block. To clarify his view, causes must not strictly precede their effect, allowing for his consistency restricted time travel, we can establish counterfactual dependence through both directions, to simply posit that a cause must precede the effect is akin to rejecting *apriori* "certain legitimate physical hypotheses

[10] This particular argument is here simplified for the scope of this essay; a further discussion on causal dependence and counterfactual logic is outlined in detail in *Causation* by David Lewis (1973) on pages 564-567.

that posit backward or simultaneous causation" (1973)[11]. There are a number of complications I have skipped over here for the scope of this paper, such as the intricacies of causal dependence in Lewis' view. In conclusion, Lewis argues that while it is metaphysically *possible* for a time traveler to kill their grandfather prior to your fathers birth, such causally linked events must be consistent with the time traveler 'later' stepping into the time machine (for example, the grandfather is later resurrected).

IV. THE BRANCH VIEW

The discussion has so far largely been compromised on considering a singular timeline let us now look at another type in which we have several timelines in the same 'world'.

IV.I ACTUALITY BRANCHING AND TIME TRAVEL

What about a branching universe? There are several different versions and I will look at one of these here then later sketch what I take to be a more robust version of the branching view. Firstly, let's consider a commonly sketched branching view: at each moment there is a set of ontologically real possible outcome branches or worlds which, although not *actual*, are ontologically real prior to the present evolving into the actual - at the point of splitting an *actuality* is 'selected' and the unrealised worlds/branches 'drop of' and seize to be ontologically real[12]. In this particular set up, as sketched by Miller (2005) and others, the branches drop off, that is, seize to exist; either this is to hold the future as open, or to privilege one timeline as real. It seems that in the case of a time traveler going to t1 we can have at t3 knowledge about which branches remain and which drop off towards t5—from this, the sketched view runs into similar problems as the previously outlined open-future examples. Clearly there are some assumptions that need

[11] There are a number of objections towards backwards causation, Ryan Wasserman (2017) highlights some of these, such as: a causal theory of time, the Humean objection, the immutability of the past (concerning the changing of the past as impossible) and more. These deserve their own discussion, but unfortunately fall outside the scope of this paper.

[12] This is crucially different from Lewis' modal worlds which do not interact through some branching mechanic

to be dropped—in my view one of these assumptions is the 'open future hypotheses'. The examined view that branches serve to provide some wider array of possible actuality that later drop off seems to do so without much convenient purpose. What mechanics deliver the selection of these possibilities? There are two apparent difficulties: (1) Branches for no reason: if the evolution forwards in time, in this branching sense, privileges one actuality which selects from multiple branches, what purpose do these branches metaphysically serve to provide? And (2) by which mechanism is this 'actuality selection' governed by? In light of these unanswered questions I shall instead move to a more robust branching view.

Let us set aside questions regarding an open or closed future for now and instead grant that we can avoid causal paradoxes in a branching universe for the following reason: Unlike setups which contain one world line, a branching world line can avoid the difficulties arising from causal paradoxes since in a branching universe, the future we change from our actions within our past-time journey will simply be *another* future ie. branch. For example, if I go back and kill my grandfather, the future that evolves without my grandfather will be *world b* whereas the world in which my grandfather lives remains in *world a*. Considering the causal structure with regards to these split time-lines we can avoid the consequences arising in the grandfather paradox.

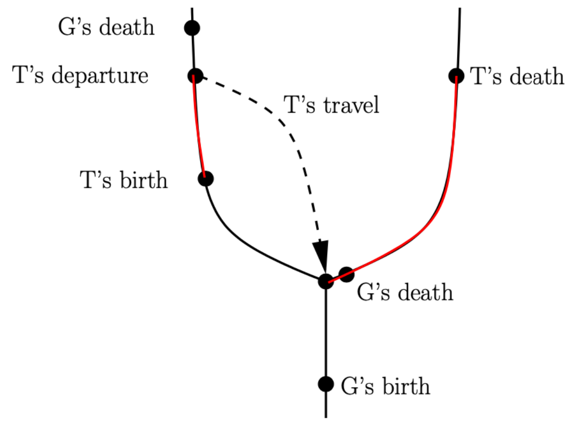

Figure 5: Branching time travel; red indicates the time-traveler's occupied regions

A common objection to the above branching view is that the time-traveler's 'original' past does not change; the world in which her grandfather continues to live persists. From this, the time-traveler does not really change the past—she only occupies a different branch, this objection I find difficult considering how we might otherwise deal with branching in our future evolutions on certain views of quantum mechanics, I'll get to this later. Another objection to the branching view is the location to which the time-traveler arrives at. That is, as soon as the time traveler arrives, she is no longer on the same branch as her original past, and therefore, she supposedly hasn't traveled to her past at all, but merely some other world. As Nikk Engham puts it, the time traveler "may as well have stayed at home and just created a simulacrum of [her] grandfather to kill instead" (2012). I take this alternative objection as quite incomplete and deserving of further discussion; as the time traveler will nonetheless have traveled to a *genuine, naturally occuring* world, a simulated grandfather or world would be quite different ontologically and metaphysically from a genuinely branched world. If the reader is unconvinced of this difference, consider the requirements of such a simulacrum: it must contain all histories as a genuine world, including the matter evolution and energy in that universe, to 'simulate' this would be to somehow create energy from nowhere.

Further, such a simulated copy would not be an instantaneous copy from what the objecting individual might call 'actual past'. The branched grandfather is intimately connected with the trunk-world, the simulated copy is a simulated creation without all the physical configurations of a genuine world. If such a simulation would be complete it must contain the full causal chain of events as in your actual grandfather's history. However, if we trace your grandfather's causal events versus the simulated, we find that the simulated grandfather has a distinct causal chain leading up to his creation compared to a genuinely branched grandfather. The only escape for such a 1:1 metaphysical correspondence between a genuine world (arising from branching) and a simulated world containing grandfather, would be if the simulated world arose from the same physics; i.e a recreated big bang (including what came before it), formation of the earth, etc. If so, then I lay down my objection and grant the simulated grandfather is identical to a genuinely branched grandfather. I will come back to a branching world view later. For now I will look at some of the physics that might motivate a branching world view.

IV.II EVERETTIAN INTERPRETATION OF QUANTUM MECHANICS

Discussing physics so far has largely been through a classical perspective. Quantum mechanics largely differs from these less problematic notions of definite states and Newtonian interactions. In Quantum Mechanics we might be led to adopt an entirely different metaphysical picture which could influence our view on the outcome of time travelers. There are a number of 'interpretations' of quantum mechanics and each deserve significant philosophical attention—however, in this paper I will focus on one which has a particularly relevant metaphysics for the possibility of time travel. The interpretation in question is the Everettian Many Worlds view.

Although the extraordinary metaphysical baggage hinted at in its name should leave us worried, we are led to this interpretation not by mere philosophical intrigue but rather from the many issues in quantum mechanics the view can resolve.

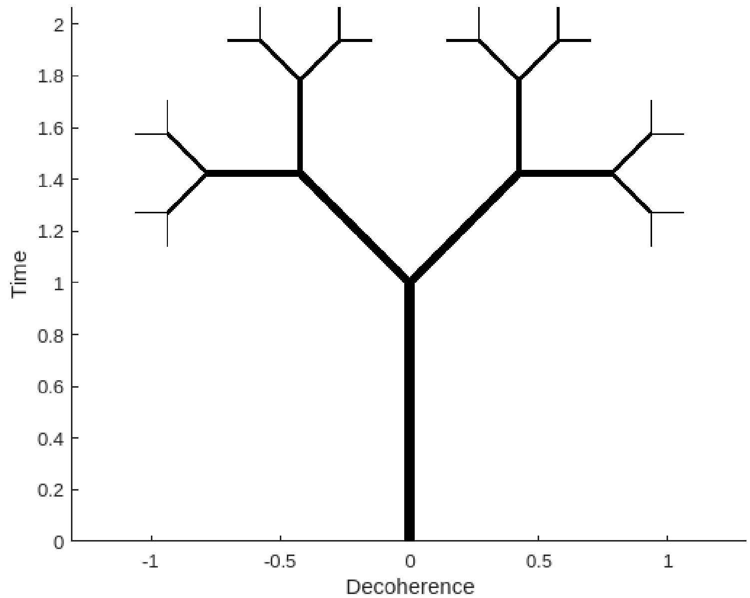

Figure 6: Crude visualization of Everettian Branching[13]

In quantum mechanics there are a number of states in which for example a particle exhibits at the same time, this is known as superposition, and such exotic states drastically differ from our usual conception of definite and defined states we encounter in the classical world. Therefore, a large mystery in quantum mechanics lies at the intersection of a particle going from a superposition state to a definite classical state. Unlike the many worlds interpretation, this transition can only be described by adding new physics, one that is quantum mechanics, and one that is classical mechanics on

[13] This simplified visualization is potentially misleading—for the purposes of this paper I am to provide the visualization for readability. A number of different interpretations of the 'branching' or 'world' structure exist. For example, the *subjective uncertainty* interpretation of the everettian worlds posits that these are always separated and that only when a quantum measurement is made can one relieve the uncertainty of which world one inhabits; this is crucially different from a branching picture where worlds are connected to their shared 'trunks'

quantum mechanics. However, the many worlds interpretation does not 'add' to the physics itself, rather it keeps the pure quantum state wave function globally and instead through decoherence physics 'sorts' parts of the wave function into preferred states that appear classically in the way we humans observe it. However, what comes with this view is that a superposition state of for example an up/down spin particle, is that upon interaction with the environment, not only is up measured, but there is a different world in which down is also measured. Simply put, the interference between pointer states such as up or down (if we are talking about spin), tend to zero, while the two 'classical' states get more and more superselected through what is known as environment selection in the preferred basis of the observed classical states. Description of this process is outlined below

Take again a pure state spin superposition state as modeled by the wave function $|\psi\rangle$:

$$|\psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle$$

From it we get a density matrix as follows:

$$ps = \begin{pmatrix} |\alpha|^2 & \alpha^*\beta \\ \beta^*\alpha & |\beta|^2 \end{pmatrix}$$

The diagonal terms represent the pointer state values of the wavefunction (the classically observed states of up or down spin for example) and the off-diagonal terms the interference between the *pointer* states, the union of this full matrix is known as the superposition state of up/down. Now let's interact the system with the environment through the Hamiltonian:

$$H_{S\varepsilon} = \sigma_S^z \sum_k gk\sigma_k^z$$

As the state interacts with the environment and entangles appropriately with the the preferred basis get a density matrix as follows:

$$ps = \begin{pmatrix} |\alpha|^2 & 0 \\ 0 & |\beta|^2 \end{pmatrix}$$

The ‘classically observed states’ in the diagonal are the two separate world branches. The zeros in the off diagonal are the ‘washed out’ interference between the pointer states. To note; this particular illustration is potentially misleading, and crucially so for this paper. That is, the interference terms do not become zero, rather they asymptote towards zero. For this paper this is crucial as it highlights the worlds are still physically connected through their *non-zero interference*.

The many worlds that therefore branch from interacting with emergent worlds are all in the same *global wave function*. You exist not merely in this ‘world’ but rather all which include your composition and have branched from quantum interactions. Again, the ‘many worlds’ here is not a philosophical fancy, but rather an emergent phenomenon towards which we might be led reluctantly by the number of other philosophical issues the view resolves[14].

Compared to the branch view that I have discussed earlier, this branching view drastically differs. There is no privileged *actuality*, in fact the branches dont metaphysically differ in any way except for perhaps their likelihood of occurring[15]. These branches are indeed multiple worlds, but unlike the modal worlds in Lewis' view, these are physically connected in the same ‘greater world’ through a systematic entanglement mechanic.

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[14] The problems the Everettian picture resolves is a topic for another paper, these include; entanglement action at a distance, and the two fold description of quantum mechanics as outlined previously.

[15] Probability in the Everettian Interpretation is another significant debate in and of itself, which I will not address here. In short the debate highlights the following: (1)If you have two quantum states with different probabilities of occurring yet (2) both equally occur in different worlds, then (3) what is the meaning of probability?

IV.III LANGUAGE USE IN AN EVERETTIAN WORLD

If timelines and 4D blocks branch, there is a more complex form of relationship between tensed and tenseless utterances. Tensed sentences can no longer be simply related to a tenseless counterpart based on linear progression of time; instead, truth values depend upon which branch of reality they arise from. The accuracy of statements requires a particular change in the evaluation of statements. A model where branches hold different degrees of truth value (depending on their distribution in the deterministic wave function), we must adopt a branching Everett semantic—In doing so, statements about future events are not purely with reference to one timeline: as these will branch. Adding to our conditions for truth Moreover, according to Wallace's study on temporal models (which distinguishes combining both essentially-tensed and branching-time tenseless viewpoints), therefore, possibility can be framed by postulating the very structures which contain the histories and future evolutions of branches. He says: "It is possible p holds true exactly when 'p' correctly matches some given history set containing p" (Wallace, 2005). The important takeaway from the argument above is the recognition of the temporality's role in underpinning semantic meaning in combination with the branching of quantum mechanics' many worlds interpretation. In doing so, paradoxes such as the grandfather paradox become resolved as it is true you will have killed your grandfather even if on a different branch than your original; the argument highlights both a semantic and ontological revision of tenseless logic and identity.

Therefore, let's consider the time traveler. In making a journey to a B-series past configuration or branching trunk, a time traveler would generate a newly distinct branch and world upon arrival. In this sense, the time traveler occupies an entirely distinct timeline from the original. However, in sharing the same 'trunk'. From the semantic discussed above, statements about future slices would be tensed with regards to the newly occupied branch, while also tenselessly referring to the original branch. The formulation involves altering our usual notion of truth value with regards to events in the 4D block. The argument which I take Wallace to put forward is that we are selecting a particular scope with regards to an occupancy within a specific branch when making general truth statements. Similarly to Lewis modal worlds, simply occupying a particular branch does not mean excluding the truth values of other branches, as these may have different configurations.

According to the Everettian theory and associated branching semantics, time does not follow a linear structure but rather branches out with each moment thereby creating new timelines (Wallace, 2003). An individual traversing time in such an intricate universe would, by their casual interference engender a distinct reality which, counterfactually, would not have evolved otherwise. Differently put, supposing someone were to voyage this kind of intricately-constructed many-worlds, it follows that every action made by them will have repercussions so far-reaching as to result in alternative realities completely different and apart from what existed previously before said individual interceded into the past (in the tensed time sense, such distinct realities already exist in the block tenselessly). This approach effectively removes all notions of self-causality loops, like the painter's paradox, as every action taken transports one onto another branch within reality's vast network; removing the idea behind backward causation and instead where actions have vastly differing outcomes depending on which respective branch is being considered.

As mentioned earlier in this discussion, an identity objection arises in the form of the time traveler not ‘genuinely’ altering the past, which I shall now attempt to address.

In the framework of Everettian semantics, personal identity is contingent upon both time and a specific reality branch. Rather than an uninterrupted singular self, multiple versions of oneself would exist in distinct branches of reality. To determine personal identity within this system requires assessing historical context as well as temporal truth values for sentences containing tense markers. The self exists relationally; its definition established by interactions with other entities present in the same reality branch it occupies. This differs from conventional views on personal identity which consider it to be a continuous and non-relational entity-based view rather than one that allows for diverse realities (How this differs from Lewis' modal worlds will be discussed in the next section). The latter view resulting in distinctly separate selves existing simultaneously across various *connected* parallel universes or instances thereof under Everett's many-worlds theory; accounting plurality while maintaining coherence between them all at once through quantum superpositions preserving entanglement relationships throughout all conceivable potential histories contained alongside their corresponding probability amplitudes. Expressed mathematically according to the Schrödinger equation as outlined previously, consequential states update dynamics over time passing forward into the future.

With these considerations in mind, adopting a new form of semantic identity in the many worlds view, It seems we have some foundation to challenge the "no-genuine branching time traveler". That is, if we consider the identity of individual A, it seems in an Everettian universe, if assumed, A is the collection of worlds in which A occupies (how this compares to the modal worlds in Lewis will be outlined in section **V.**). I now want to outline the stage from which we might further discuss time travel in many worlds. I will begin doing this through outlining the metaphysics. After doing this, I will highlight how the many worlds view and Lewis view compare.

IV.IV. DEUTSCH'S MANY WORLDS MODEL

David Deutsch is a proponent of time travel through many worlds. I will show why Deutsch's particularly distinct formulation of the many worlds view highlights both a concern with regards to maintaining the pure quantum reduction characteristic, but also an intriguing escape for the Everettian.

His thoughts on traversing between parallel universes are sometimes overlooked because they seem to initially reflect the pure state structure of the Everett interpretation. However, I and others like Dunlap (2016), argue that such a correspondence would mean that a time traveler would not be able to do anything more than on Lewis model. The reason stems from how the wavefunction must remain valid. That is, interfering with itself in the pure state sense must ensure consistency akin to a single time-line sense. Interfering with itself would entangle the wave function and influence the branch that was initially used as an entry point (the same paradox predicament of classical mechanics). To solve this issue, said traveler would need access into another existing branch where at least one version of themselves *already exists during time slot t=1* (Deutsch and Lockwood, 1994). However, according to the standard interpretations of the Everett Interpretation, such extra branches do not exist.

Deutsch often uses the concept of parallel existent worlds. However, it must be noted that Deutsch acknowledges his use of parallel worlds as only an "approximation" of the Everettian picture and that it should be philosophically used with caution (Deutsch and Lockwood, 1994 and Dunlap 2015).

Since the Dutch-CTC (D-CTC) model does not purely resemble the many worlds interpretation, it can potentially mislead us, I shall now show why. Deutsch's model is a metaphysically unique approach to many worlds; that is—"he is a realist about the existence of many parallel worlds that differ from many worlds" (Dunlap, 2016). Here Deutsch asserts the existence of a multitude (infinite) of parallel universes where worlds endure interminably and share indistinguishable congruent pasts.

The D-CTC model operates necessarily on this perspective and therefore regards parallelism as a quintessential principle in reconciling the contradictions found in CTCs and time travel. The grandfather paradox is resolved since the time travel is to another world, allowing the traveler to kill their counterpart *without altering their own past*

(Dunlap, 2016). For Deutch's view, parallelism is central to his solutions for resolving paradoxes, yet crucially is distinguished from the traditional Everettian view. He says the following:

> "*If the classical space-time contains CTCs, then, according to quantum mechanics, the universes in the multiverse must be linked up in an unusual way. Instead of having many disjoint, parallel universes, each containing CTCs, we have in effect a single, convoluted space-time consisting of many connected universes. The links force [the time traveler] to travel to a universe that is identical, up to the instant of her arrival, with the one she left, but that is thereafter different because of her presence.* " (Deutsch in Dunlap 2016)

We can see from the described formulation of the Everettian mechanics that time travel becomes loosely restricted. Perhaps suspiciously unrestricted, as paradoxes like killing your grandfather have basically zero consistency requirements. Conversely this can be seen as a win for the aspiring time traveler. However, in doing so, if we agree with Deutsch, we adopt an exotical extra-metaphysical addition to the Everettian (as if it wasn't already so). This analysis is not intended to argue against Deutch's view. The purpose is to inform the reader of the relevant assumptions being made in my paper and additionally dispute the notion that quantum mechanics and purely Everett can alone resolve the Grandfather Paradox, something this paper could have initially hinted at. While it seemed at first the Everett interpretation offers a clean solution akin to the branching form in **figure 5**, this is misunderstood. The particular structure of Deutsch is fairly more complicated than sketched in this paper. For this reason, his views deserve more analysis and philosophical maturity.

With the views discussed so far, how branching time and time travel can resolve some paradoxes, and how quantum mechanics could get us there and where it ultimately fails to do so all the way, I wish to compare the Everettian and Deutsch view to Lewis' modal view. As we shall see, the branching semantics of the many worlds allow us to describe identity in a physically connected whole. However, unlike what we had hoped for, altering the past must be similarly restricted as sketched by Lewis for us to adhere to the physics which give rise to the many worlds view.

V. MODAL REALISM VS EVERETTIAN WORLDS ON TIME TRAVEL

V.I. TIME

When comparing the many-worlds view to the Lewis view of time travel, several key differences emerge. In accordance with the theoretical framework introduced by David Lewis, transportation through time occurs within a solitary and internally coherent timeline. In this configuration, events of past occurrence may be influenced to an extent by actions taken on behalf of time travelers; however, such interventions are unable to lead to any alterations that could generate paradoxical outcomes. The Lewis view maintains a single, continuous personal identity for the time traveler, whereas the many-worlds view allows for multiple, distinct versions of the time traveler to coexist within different branches of reality and crucially, time. However, the aim here is to find differences which may help us lead to a favorable framework to the other. What has largely been the case throughout this essay is that the multitude of timelines suggested by the Everettian can offer us a way to escape paradoxes and genuinely change the past. However, like with Lewis, the Everettian is similarly constrained. That is, unless we adopt the D-CTC as outlined above, we must be limited to the self consistency constraints which Lewis adopts. So why then should we not adopt the D-CTC model and defeat Lewis modal worlds and conclusions regarding time travel? This leads me to my next point regarding the differences in the ‘worlds' between Lewis's modal worlds and Everetts branching worlds. I shall argue that by adopting a D-CTC model we lose another feature of the Everettian which is perhaps the most attractive in this contextual discussion.

V.II. MODAL VERSUS QUANTUM WORLDS

There are a multitude of comparisons that can be made between Lewis-worlds (L-worlds) and Everett-worlds (E-worlds), ontological commitments, epistemic implications, criteria for individuation of these worlds, and more. For the scope of this paper I will focus on Nature of Origin and Existence; associated ontological commitments and the resulting implications on time travel.

It must be noted that the motivations for the two views result from distinct sources; in Lewis, his modal realism commits to possible worlds for purposes related to modality which can counterfactually support truth conditions of statements regarding possibility and necessity. Comparatively, the E-worlds are largely motivated by an attempt to reduce the ontology of our physics to pure state quantum mechanics (I.e. the wavefunction). The worlds in this sense are instead an emergent phenomena resulting from the minimalist approach to avoid the need for extra-physics in collapse dynamics. Similarly, however, is that the worlds in both pictures are all 'real' and existent. There are therefore tenseless consequences which arise from both. In measuring a quantum state the tenseless utterance "It is false that I will observe spin up" Is both true and false in L-worlds and E-worlds. That is, in E-worlds it is true that there will be two resulting worlds; one in which spin up is observed and one in which spin down is observed. Similarly, in L-worlds, there is a world in which spin up is observed and vice versa. As a result of this *tenseless scope* present in both views, statements and events must be tensed to the specific world considered. There is another slight possible difference between the two worlds, Lewis modal worlds can be any possible state, here 'possible state' means something else in the Everettian picture. 'Possible state' in the Everettian picture must nonetheless be part of the total state space of the global wave function; this does not engender the same possible worlds as in Lewis. That is, on modal worlds in Lewis, he even goes as far as describing possible modal worlds in which the physics itself is different. For example, in *Causation* 1973, Lewis says: "We should not take it for granted that a world that conforms perfectly to our actual laws is *ipso facto* closer". The possible worlds in Everett conversely must adhere to the same laws shared by the 'global wavefunction'.

VI.III ON TIME TRAVEL AND CHANGE

As previously noted, there is zero change in the Lewisian 4D block of time and possible configurations, as the 'events' within it are fixed. Further, we have an infinite set of these static worlds who are spatiotemporally separated. Possible worlds in this sense are also not traversable. Because of this metaphysical separation, there is no way in which an event which has occurred, could be any other possible evolution; indeed, to have it so would be to experience a *different* modal world. What we observe as change, is merely illusory in this sense; what is experienced is fixed to the world inhabited. While this ensures consistency, and does so similarly in the Everettian picture, I will show that a similarly fixed structure in D-Everett can help us rid of the (more)limited *experience* in separated modal worlds in time travel.

As discussed previously, Identity in the Everettian picture allows for describing a tenseless, *physically connected* totality of an individual. To time travel indeed would be to occupy a different branch which also fulfills a consistency criteria akin to a Lewis world. However, the set of events a time traveler could potentially experience while making such a journey is far greater. Indeed, if such branches are physically connected, and traversable in the experiential sense (i.e. the time traveler can move between the consciousness of himself or his branched counterparts, then the set of experience vastly increases. As shown earlier, killing your grandfather becomes entirely possible—having moved 'worlds' within the wider connected world (the set of all connected branches), the time traveler is able to ensure consistency on her original branch and be part of the casual story of another. Although change is similarly non-existent here, there is more 'freedom' for the time traveler in the weak epiphenomical sense. However, as mentioned earlier, such excursions must require us adopting the D-CTC model, which as we have seen, goes beyond the traditional Everettian and quantum mechanical picture. It is unclear whether the D-CTC model allows for us to describe the parallel configurations as similarly connected as in the traditional quantum mechanical picture and as such more work needs to be done.

VI.IV. OBJECTIONS AND RESPONSES

OBJECTION 1: It still remains that a branching world time-traveler is not genuinely traveling to their past, since they enter another branch upon arrival.

RESPONSE 1: By adopting a relational view of personal identity, one that allows for diverse realities and multiple versions of oneself, we can better address the "no-genuine branching time traveler" objection. In this framework, when a time traveler enters a new branch, they are still part of the collection of selves that constitute their identity. As a result, they share a *connected* (unlike modal worlds) *common origin and history* with their counterparts in other branches, even if the specific circumstances of each branch differ. Considering this approach to personal identity, time travel in a branching universe can still be seen as genuine time travel. When a time traveler goes back in time and enters a new branch, they are interacting with a *connected version* of their past that is tenselessly part of their broader identity, which spans across the many branches in the same broader world. This redefinition of personal identity in the context of the Everettian Many Worlds Interpretation as highlighted by Wallace analysis in section **IV.III.** helps address the objection and provides a foundation for discussing time travel in many worlds. However, as mentioned previously, this relies upon whether you accept a similar identity picture in the Deutsch-Everettian and D-CTC model, which admittedly Wallace does not include.

OBJECTION 2: The Everettian D-CTC model poses parallel worlds, how these any different to the L-worlds?

RESPONSE 2: There are three different ways to respond to this objection which I take to highlight key differences, I have outlined three below:

A. The origin and nature of parallel worlds: In the Everettian D-CTC model we have a structural process to describe the distinction between worlds with regards to their counterparts. Worlds in the Everettian D-CTC emerge as a result of the branching process that occurs due to quantum decoherence and environment entanglement. The totality of worlds share a common history throughout the entire 4D block; thereby making them, in a sense, more closely connected due to their *shared past*. Conversely, the worlds of modality that Lewis presents are spatio-temporally, entirely distinct realities, each one being separate possibilities in which our world exists. The worlds in Lewis do not, crucially, share a common history or posit some branching process. There is no connection between the modal worlds in the 4D block—such connections wholly exist in the everettian picture.

B. Interaction between the parallel worlds: The Deutsch's D-CTC model allows for an interaction between the worlds. A given 'time traveler' transfers to a parallel world that shares an identical history up to their arrival point (Dunlap, 2016), actions in this newly arrived world do not affect their original world. This system resolves paradoxical outcomes which by not violation of consistency principles as otherwise strictly limited in the modal model. In contrast, Lewis's modal worlds are completely isolated from each other, and interaction between them is not allowed.

C. Identity and counterparts: In the Everettian model, as discussed in IV.III., identity is tenselessly *tied* to the decoherence process. In this sense, *counterparts* share a history and wavefunction throughout their 'separation', a tensed identity here is more arbitrary and conventional in the physical sense. Compared to modal worlds identity, is more continuous; counterparts in modal worlds are only considered as either more similar or different. Therefore, the connection between counterparts' identities in the Everettian context is more 'direct'. In Lewis's modal realism, however, counterparts are more akin to being analogous; if we are to describe them in the tenseless sense.

CONCLUSION

In this paper I hope to have examined two drastically different ontological systems on time, time travel, and change. I have looked at David Lewis modal realism and the Everettian interpretation of quantum mechanics; two views which although motivated for different reasons have given similarities for a comparative analysis. That is, since multiple worlds are part of the ontology for both theories, looking at how their systems have dealt with identity and change. Since there are hints (depending on who you ask) in our physics, namely closed time-like curves through exotic solutions like the Gödel metric. There are other prospects for physics motivated time-travel which I have purposefully excluded for the scope of this paper, for example Einstein-Rosen Bridges, also known as a wormhole in general relativity. These should lead us to examine time travel further. The following examination has forced us to adopt a temporal stage in our metaphysics through which identity, self location, and change can be discussed. For the reason of setting this stage, I briefly discussed different views on time in **III.I**, I believe there is also much more needed discussion excluded for the limited scope; different temporal models drastically influence our prospects; luckily there is much literature on this**.** I believe that Lewis' as well as Novikov's *eternalist* and, closely associated, consistency view has afforded us with a model for 'change' and prospect of 'changing the past' in time-travel which I hope to have applied to the Everettian picture. Since the Everettian picture offers us a deterministic theory, I have assumed that an eternalist metaphysics can be unproblematically applied, this is also a significant debate which I have omitted. I have in this paper made significant assumptions with regards to determinism and probability theory in both classical and quantum mechanical physics. I admit that there are significant disparities between these interpretations that could influence our time-ontology; I hope to have at least provided the perspective of one of these deterministic models. As mentioned briefly in **IV.II.**, there are a number of further interpretations on the actual worlds/branching structure in the Everettian picture. I have largely assumed a limited perspective on this particular model, I.e. the tree-esque branching model. Further insight could be potentially around how other everettian models compare to Lewis modal realism, such as the subjective uncertainty models that can be formulated in both a splitting and *divergence* worlds sense (As outlined by Greaves 2007 for example). I hope to have shown, the standard reduced Everettian framework fails to add anything new to the Lewisian picture in some sense. This conclusion is motivated by the findings of Dunlap highlighted in section **IV.IV.** Instead I have looked at a different version, the Deutsch Everett CTC. Nonetheless, the particular scope of this paper has offered an additional consideration on the physical consistency constraints around CTCs and time travel.

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