The Time Travel Paradox and the Process of World State Progression

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Abstract

This paper investigates the theoretical possibility of time travel, in view of the assumed physical properties of the world. We analyze to what extend the apparent impossibility of changing the past, as concluded from the time travel paradox, can be derived from physics-based considerations. Of particular importance are assumptions about the overall process of state progression of the world, which is a subject in the physics literature that is frequently touched upon only implicitly. Moreover, there does not seem to be an explicit and generally agreed-upon theory regarding the state progression of the world. In this paper, two rules with respect to the world's state progression are proposed, and alternatives to the proposed rules are discussed.

Keywords: Time Travel, Space-time Topology, World State Evolution

1. Introduction

Many books exist that discuss the (possible) structure and geometry of space-time in the context of physics theories. In books about special relativity theory (SRT) and general relativity theory (GRT), considerations about the structure of space-time are inevitable. However, space-time's structure is also discussed in books with a broader scope in physics (see, for example, Maudlin (2012), Hawking (2001), Penrose (2005), and Penrose (2010)). In such literature on space-time's geometry, the possibility of time travel is often discussed as a subsidiary topic. In general, discussions on the possibility of time travel in the context of most assumed space-time geometries do not come to a clear conclusion. Therefore, time travel is ruled out by showing that assumptions for the possibility of time travel would result in logical contradictions. It is argued that if time traveling were possible, the following sample scenario would be possible:

1. Year 2005: Tom Meyer, a son of Tim Meyer, is born.
2. Year 2500: John Meyer, a successor of Tom Meyer, lives.
3. Year 2500: By use of a time travel machine, John Meyer "travels" to the year 2000.
4. Year 2000 (reached by time travel): John Meyer performs actions that prevent the birth of Tom Meyer

As a consequence of step 4. there can be no John Meyer in the year 2500 which contradicts 2. Thus, it is argued, assuming the possibility of time travel leads to a logical contradiction (i.e., the "time travel paradox" or "grandfather paradox") and, therefore, time travel cannot be possible. This argument is not convincing to the author due to the following points: (a) the logical contradiction may be the result of an imprecise, incorrect, or incomplete formulation of the time travel paradox; (b) if the logical contradiction indeed can be verified, it should be possible to derive it from physics-based statements or assumptions; and, (c) the possibility or impossibility of time travel cannot be discussed conclusively by looking only at space-time geometry.

The authors reservations seem to be shared by many philosophers. The paradox has been the subject of discussions in many papers in both physics and philosophy. From the point of view of logic (item (a)), most of these authors have concluded that the (apparent) logical contradiction does not necessarily rule out time travel (see, for example Artzenius and Maudlin (2009)). However, item (b) is also supported by a number of papers that look at time travel in the context of physics (see, for example, Earman, Smeenk and Wuethrich (2009)). In the end, the primary subject of most related papers is space-time geometry and topology.

While the author recognizes the value of the previous works towards a physics-based analysis of the possibility of time travel, his work on the subject demanded assumptions on a physics topic where present-day physics seems to include only vague and implicit assumptions.

In Section 4 two rules with respect to the "Process of World State Progression" are proposed that have a major impact on the possibility (or impossibility) of time travel. The author does not view these rules as the invention of new laws of physics, but sees the rules as implicitly assumed within many areas of todays physics theories. On the other hand, these rules, or some alternatives, have not (to the authors knowledge) been stated explicitly anywhere previously.

Because the paper investigates different possible variants on how time travel may be accomplished, it does not start with a clear definition of time travel. Nevertheless, some assumptions made for this paper have to be mentioned:

- The subject of this paper is time travel in the backwards direction only.
- The type of time traveling analyzed in this paper is not restricted to closed time-like curves (CTCs). Discontinuous trajectories (e.g., "jumps") are also considered. (However, the example where jumps are discussed is considered less desirable for other reasons.)
- The assumption of a "direction of time" is not an a priori assumption of the paper. However, Rule1 for the "Process of World State Progression" (see Section 4) may be viewed as implying a direction of time.

After the definition of declarative and functional descriptions (Section 2), this paper will describe a number of areas in which process-oriented, i.e., functional descriptions offer a chance for new concepts and solutions (Section 3). Arguably, purely declarative descriptions may be insufficient in principle for some of these "problem areas".

2. Space-Time Geometry, Topology and Related Attributes

The possible geometry and topology of space-time are major subjects of lectures and books on physics theories such as special relativity theory (SRT), general relativity theory (GRT), and string theory. Space-time topology considerations in relation to quantum theory (QT) can mainly be found where possible concepts for quantum gravity are discussed.

The discussions on space-time topology usually are not restricted to topology in the mathematical definition, but include discussions on concepts and attributes that are related to geometry such as metric, the direction of time, and singularities (e.g. black holes). With SRT and GRT, the possible trajectories of matter (in the presence or absence of external forces) are directly related to the geometry of space-time. As a subordinate idea when discussing the possible trajectories in the context of space-time geometry, the possibility of closed time-like curves (CTCs) are sometimes also discussed (see, for example Maudlin (2012), Hawking (2001), Penrose (2005), Penrose (2010) and Davies (2001)). Some authors restrict any discussion of the possibility of time travel to the feasibility of CTCs.

Another subject that is frequently addressed in the physics literature and which has some relation to the possibility of time travel, is "the direction of time" (see Horwich (1987) and Price (1996)). Physicists seem to be divided on the existence of a direction of time and if it exists, on the meaning and foundation of the direction. As mentioned above, Rule1 for the "Process of World State Progression" (see Section 4) may be viewed as implying a direction of time.

While the literature on the possibility of time travel in light of space-time geometry and topology has led to interesting findings, the main point of the present paper is to establish the assumptions upon which a complete discussion on the subject of the "process of state progression of the world" can be built. Depending on the type of assumptions made, this may very well have consequences for the space-time geometry and topology being considered.

2.1 Many Worlds

The "many-worlds interpretation of quantum theory" was proposed by Everett (see Everett(1957)) as a solution to the measurement problem of quantum theory. Some authors consider the assumption of many-worlds to create a possibility for time travel that avoids the time travel paradox (see Davies (2001), pages 108-112). Time travel to a parallel world may be a solution to a logical paradox, though a rather obscure solution. As mentioned in Davies (2001) "physicists seem to be divided about the desirability of time travelling to other worlds".

The many-worlds theory and time travel between worlds will not be considered any further within this paper aside from a remark made in Section 5.1.

3. The State Associated with Space-Time

Discussions on space-time geometry, topology and metric that do not include considerations of the (possible) content of space-time may be interesting for mathematicians, but with physics-related subjects, considerations of the content of space-time are often necessary as well.

In this paper, the content of space-time is called the "state" associated with space-time. This definition implies that the "world" is assumed to consist of a space-time (with a certain geometry, structure, and metric), and associated with each space-time point is a (possibly empty) state. With GRT and, to a smaller degree, SRT the geometry of space-time is intertwined with the state (i.e., the contents) of space-time. In SRT, the properties of Minkowsky-space define the causality relations among moving matter. In GRT, the distribution of matter and energy defines the structure and shape of space-time.

Whatever its exact definition and concrete realization might be, time travel must be imagined like normal travel as the movement of states from one area of space-time to another area of space-time. The special condition assumed in time travel is that the target area lies outside the future light cone of the start area. The state associated with a point or area of space-time may belong to matter or fields located at that space-time. Accordingly, the state comprises parameters that are assigned to matter (e.g. mass, momentum, and charge) or to a field. The state associated with a space-time point may also be empty. For the purposes of this paper a "world" is simply a collection of space-time points $x = (t, x_1, x_2, x_3)$ with state $\psi(x)$ assigned to each space-time point x.

4. The Process of World State Progression

The evolution of states in our world is the major subject of physics theories. Physics, i.e., the laws that describe the evolution of states, can be quite complicated. However, there ought to be some basic laws (i.e., some type of meta-laws) with respect to the overall "Process of World State Progression", and these rules have a major influence on the possibility of time travel.

Let us view the laws for the evolution of the state of the world (i.e., the laws of physics) as represented by a "physics-interpreter". The physics-interpreter acts upon the state of the world. The model described here assumes the continuous repeated invocation of the physics-interpreter to realize the progression of the state of the world. The physics-interpreter determines new states for the associated space-time points. In addition, the physics-interpreter may also modify the set of space-time points that compose the world. For example, space-time may extend or shrink. The physics-interpreter acts upon an in-world to generate an out-world.

Of particular interest for the purposes of this paper, are the possible changes in space-time with respect to the time component. In support of causality, the following rules with respect to the time coordinate of space-time are proposed for the application of the physics-interpreter:

- Rule1: The time coordinate of the space-time points belonging to the out-world is uniformly equal to the time coordinate of the in-world increased by some constant amount (e.g., 1).
- Rule2: Given that the in-world has consistently older time-coordinates than the out-world, a further result of applying the physics-interpreter to an in-world is that the in-world is discarded and replaced by the generated out-world.

The above two rules (or similar ones) are crucial to discuss not only the possibility of time travel, but also causality and concepts for the progression of the world state in general. Therefore, it is worth considering some statements that are either rephrasings or consequences of these rules.

4.1 Semi-formal Description

In Diel (2013) a somewhat more formal description of the evolution process of world W with state $\psi(x)$ at time t is described as follows:

```
worldEvolution( world W ) := {
W.t = 0; W.x1 = 0; W.x2 = 0; W.x3 = 0;
W.ψ = initialState;
Δt = timestep; \\ must be positive \\
DO UNTIL ( nonContinueState( W ) ) {
physicsInterpreter( W, Δt );
```

```
}
}
physicsInterpreter( W, Δt ) := {
tdt = W.t + Δt;
W = applyLawsOfPhysics( W, Δt );
discardAllSpacetimePointsWithTimeCoordinate( W.t < tdt );
}
with state parameters
world := { spacetimepoint ... }
spacetimepoint := { t, x1, x2, x3, ψ }
ψ := { stateParameter1, ... , stateParametern }
```

4.2 A less abstract (in fact, almost trivial) formulation of Rule1:

The evolution of the state of the world is accompanied by the whole world getting uniformly older.

4.3 A less abstract formulation of Rule2:

The past is lost aside from any memorized information and from the effects of the past on the present.
In Artzenius and Maudlin (2009) this is phrased “one cannot 'change' the past to be different from what it was, since the past (like the present and the future) only occurs once.”

4.4 Time travel to the past is impossible because the past no longer exists.

4.5 Direction of time

Rule1's proclamation that the time coordinate is always increased by a constant amount, may be interpreted as defining a direction of time. In discussions on the necessity for assuming a time direction (see, for example, Maudlin (2012), Penrose (2005) and Zeh (2012)), it is usually noted that the known laws of physics are all time-symmetric, i.e., they do not prefer a particular direction of time. However, as described in Diel (2013) this does not mean that the actual progression of the world evolution applies the laws of physics in a symmetrical way. The author claims that the progression of the world evolution rather adheres to Rule1 and the above described process . Replacement of Rule1 above by a rule that is time symmetric would seem rather arbitrary.

4.6 Light cones of SRT and GRT

The property of light cones in the Minkowsky-space of SRT that says that past and future light cones are non-overlapping, follows from Rule1 above.

4.7 Impact on Space-time Topology

The two rules stated above also have an influence on the type of geometry and topology that may be appropriate for a model of our world. The traditional view of SRT and GRT is that the space-time of our world has (3+1) dimensions, which allows for various types of topological spaces, such as, for example, a 3-sphere, S^3.

Leaving out 1 space dimension, the 2 space dimensions + 1 time dimension may be graphically represented as shown on the left hand side of Fig. 1.

The right hand side of Fig. 1 shows the situation when the above two rules for the "Process of World State Progression" are applied. Instead of a topological space that is continuously expanding in the direction of time, we have a series of "time-slices". Rule2 says that there always exists only a single time-slice. The old time-slice is discarded when a new one is generated. If, however, the extension of the world in the time dimension is always equal to 0, one may question whether this should be viewed as a dimension at all; at the least, the time dimension has quite different characteristics than the space dimensions. One possible argument for keeping a time dimension is that it makes sense to label the series of time slices by unique time coordinates. However, if this is the justification for the assumption of a non-zero extension of the time dimension and Rule2 is assumed to hold, it should be made clear that the state of the world of past time slices is empty.

When "time dimension" and "time coordinates" are discussed within this paper, it must be clarified that this always refers to the time represented by the time coordinates of the world's space-time, as opposed to the "proper time" known from SRT and GRT. Inclusion of the proper time in these discussions is outside the scope of this paper because it would not change the major conclusions of the paper (Note 1).

5. Alternatives for the Process of World State Progression

Although the above described rules for the evolution of the world seem to be in accordance with many implicit assumptions in various areas of physics, some alternatives are discussed in this section.

5.1 Old states are not discarded - the past remains in existence

Keeping past world states would seem to be a prerequisite for any time travel function. Let us assume that the past is retained in the form of a series of snapshots similar to a sequence of pictures contained in a movie. The follow-up question becomes this: what is the role and purpose of these world state snapshots with respect to the evolution of the world? Specifically, when and how may these snapshots become activated to play a role in the world's evolution? If the snapshots would never be used, their purpose (and existence) are highly questionable. Assuming that the snapshots are maintained just to enable time travel would be rather silly. Disregarding their oddness, there are two main alternatives recognized by the author for the way in which these potential past snapshots may be activated or used:

1. The snapshots remain permanently active, which means they are a permanent source for interpretations by the physics-interpreter. The continuous generation of new worlds at all stages of history would be the result. This is similar to the new worlds occurring in Everett's "many-worlds interpretation" of quantum theory (see Everett (1957)). In fact, such a scheme might be defined as an extension of Everett's many-worlds interpretation.
2. A modification of a past snapshot (e.g., as a consequence of a time travel function) automatically starts an update of the world by replacing all the snapshots that are younger than the modified snapshot up to the youngest (i.e., the present) state. In other words, changing the past would automatically and instantly result in a replacement of the present.

As intended, these two alternatives for keeping the past would enable time travel (forgetting for the moment about some other physical problems). Notice, however, that both alternatives for utilizing the past do not result in the time travel paradox. With the "many-worlds process" (alternative 1), the non-existence of Tom Meyer would occur only in newly generated parallel worlds, which would not be a problem for the "old" worlds. With the "automatic update of the present" (alternative 2), the paradox is avoided because the contradicting statements occurring in the example described in the Introduction are now produced in sequence. Facts that would contradict when assumed concurrently may cause no problem when they occur in a certain sequence. The sequence would now be as follows:

1. Year 2005: Tom Meyer, a son of Tim Meyer, is born.
2. Year 2500: John Meyer, a successor of Tom Meyer, lives.
3. Year 2000, resumed: John Meyer performs actions that prevent the birth of Tom Meyer.
4. Year 2005, updated: Tom Meyer is NOT born.
5. Year 2005-2499, updated: No successors of Tom Meyer exists.
6. Year 2500, updated: John Meyer (a successor of Tom Meyer) does not exist.

5.2 Non-uniform time progression

The assumption of a uniform time progression, in Rule1, is a slight simplification to ease the discussion. Support of invariance with respect to coordinate transformation and the possibility of curved space-time (as with GRT) may require more sophisticated assumptions instead. What is really required is that the world at any stage of the evolution has (almost) zero time-like extension. The evolution produces a series of time-slices (i.e., snapshots), but there is always just a single time-slice in existence. As a result of quantum uncertainties and quantum fluctuations a small non-zero time-like extension may be considered. However, this small extension is too small to enable a reasonable scheme for time travel.

5.3 Possible Closed Time-like Curves (CTCs) with GRT

As mentioned in Section 2, some authors (for example, Earman, Smeenk and Wuethrich (2009) and Manchak (2009)) equate the possibility of time travel primarily with the possibility of closed time-like curves (CTCs) in GRT.

In some cases these authors come to the conclusion that CTCs cannot be ruled out in GRT. This seems to be a contradiction to the findings described in Section 4. However, the apparent contradiction does not exist for two reasons:

1 Even if the laws of GRT do not rule out CTCs, this does not mean that a more complete consideration, that includes further aspects of physics, may not come to a different conclusion.

2 Even if CTCs were possible, this does not mean that a (meaningful) time travel is possible. A return to past (space-)time coordinates should not be viewed as time travel, if the state at the past (space-)time coordinate is no longer the old state (for example, if the state is empty).

5.4 Non-local States

In Section 3 it was assumed that the state of the world can be uniquely mapped to space-time points. The validity of this assumption may be questioned. For example, a model of the world that supports quantum entanglement may assume non-local states in support of the entanglement. Again, the assumption of only local states should be seen as a simplification to ease the discussion. The possibility of non-local states would complicate the description, but would not invalidate any of the conclusions (especially if uniform time progression is assumed).

5.5 Alternative Physics-Interpreter

It may be argued that the successive application of the physics-interpreter to evolve the state of the world together with the two rules for the world state progression presupposes a certain time concept. It is true that the model behind the "physics-interpreter" and the rules for its application imply a certain time concept (for example, that there is a direction of time). However, this is exactly their purpose. The plausibility of this time concept has to be judged on whether the rules are in agreement with (a) what we know about Nature and (b) the laws of existing physics theories. As mentioned already, the author sees the above-described rules for the evolution of the world as being in accordance with many implicit assumptions in various areas of physics.

6. Conclusions

The analysis of the possibility of time travel described in this paper has confirmed the author's belief that the possibility of time travel cannot be sufficiently addressed on the basis of space-time geometry and topology. Inclusion of considerations on the state of the world and, in particular, the overall progression of the state of the world resulted in new conclusions, which are as follows:

1 An analysis of the possibility of time travel requires some very basic assertions on the overall process for the progression of the state of the world. Although the need for such assertions has been detected in the context of considerations on time travel, they should be of general interest within physics. Existing physics theories contain implicit assumptions on the subject, <u>but an explicit and clear formulation of them would be desirable</u>.

2 The paper proposes two rules for the overall "Process of World State Progression" (see Section 4). In the case that these rules indeed reflect the physics for the overall "Process of World State Progression", <u>time travel would not be possible</u>.

3 Alternatives to the rules proposed by the author, that do not exclude time travel, are theoretically possible, although they are rather obscure (at least, the alternatives investigated by the author). The type of time travel that would be possible by these alternative rules would not lead to contradictions of the time travel paradox. This proves that <u>the time travel paradox does not in general imply the claimed contradictions</u>.

4 The Need for Functional Interpretations of Physics

The model and semi-formal description in Section 4 "The Process of World State Progression" is what the author calls a "functional description". A functional description explains the details, and the behavior of a function in terms of process steps and by reference to intermediate states. Let us call the alternative to functional description, where a function is described purely by a set of axioms (i.e., rules, laws, and equations) with respect to the function results, an "axiomatic description" (Note 2, Note 3).

With physics theories axiomatic descriptions are the preferred kind of descriptions because they are more compact, and more elegant than functional descriptions. Often the details of a functions intermediate states can be derived from the axioms (e.g., from differential equations) of a theory. For example, the equations of motion (and, thereby, the trajectory of a particle) can be derived from the Lagrangian together with the Euler-Lagrange equation. <u>Functional descriptions are required to describe non-trivial processes</u>, for example, processes with non-linear, non-unitary, or non-deterministic trajectories or other complexities, such as, interactions (Note 4).

The findings claimed in the present paper support the authors advocacy for functional descriptions. The proposed rules for the "Process of World State Progression" and the conclusions described above could hardly be derived from purely axiomatic considerations.

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Notes

Note 1. However, this may result in additional arguments for keeping the view of a time dimension (with non-zero extension).

Note 2. The term "functional description" is also used in Maudlin (1989) where also the advantages of functional descriptions are described.

Note 3. The term "axiomatic description" may be misleading to some readers, because with physics theories it is sometimes used in a more narrow sense.

Note 4. In Diel (2013) the author claims that the QT measurement problem will find a solution only by a functional interpretation of the QT measurement process.

Figure 1. Space-Time Models with (2+1) dimensions - (a) traditional model (b) with elimination of the past