철학적 분석 34 (2016) pp.93-107

Time Travel in a World with Circular Time*

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According to the standard definition of time travel due to David Lewis, an object time travels if and only if the separation in time between departure and arrival does not equal the duration of its journey. After arguing that the standard definition of time travel is inadequate by discussing a world with circular time, I suggest a new definition of time travel that does not fail in situations involving circular time.

Subject analytic metaphysics, philosophy of time

Key words the standard definition of time travel, circular time, a rolled-up space-time, personal time, external time, David Lewis

* Received: Feb. 2, 2016 Revised: Feb. 29, 2016 Accepted: Mar. 1, 2016

1. Introduction

According to the standard definition of time travel due to David Lewis (1976: 145), an object time travels if and only if the separation in time between departure and arrival does not equal the duration of its journey. In this paper, I will argue that the standard definition of time travel is inadequate. I will show this by discussing a world with circular time. At the end of the paper, I will suggest a new definition of time travel.

The standard definition of time travel is due to Lewis, which comes from the attempt to resolve the paradox of time travel. Consider the following time travel story. A time traveler departs, he travels for an hour, and he arrives 100 years before his departure time. He travels only for an hour into the future. His arrival time is 100 years in the past. This seems paradoxical. How can one travel for an hour but arrive 100 years apart from the departure time? How can he travel into the future but arrive in the past? How can he arrive after the departure but arrive before the departure? Lewis's reply to this paradox is to distinguish between personal time and external time. Personal time is measured by objective physical processes that a person undergoes, and it is 'roughly, that which is measured by his wristwatch' (1976: 146).[1] External time is time itself. The time traveler travels for an hour in personal time but he arrives 100

1) Although Lewis says that personal time of someone is "roughly, that which is measured by his wristwatch", strictly speaking, this is not true. Personal time is measured by objective physical processes that a person undergoes. Given that personal time is defined as something that is measured by objective physical processes that a person undergoes, and given also that it is possible that his wristwatch works independently of this person's physical processes, it is wrong to say that personal time of someone is roughly measured by his wristwatch. I thank Cody Gilmore for an extremely helpful discussion on the concept of personal time.

years apart from the departure in external time. He travels into the future in personal time but he arrives in the past in external time. He arrives after the departure in personal time but arrives before the departure in external time.

Based on the distinction between personal time and external time, time travel can be defined as follows: an object time travels if and only if there is a discrepancy between personal time and external time in the journey. This is precisely what the standard definition of time travel says: an object time travels if and only if the separation in *external* time between departure and arrival does not equal the duration of *personal* time of its journey. Many philosophers such as Simon Keller and Michael Nelson (2001: 339), Bradley Monton (2003: 201), and Theodore Sider (2005: 330) accept the standard definition of time travel. Below, I will show that in some cases although there is a discrepancy between personal time and external time in the journey, they do not count as time travel.

2. Problems with the Standard Definition of Time Travel

Consider a world of rolled-up space-time. A rolled-up space-time can be described in the following way: for all integers n, points in Newtonian space-time (t, x, y, z) are numerically identical with points ($t+nd_0$, x, y, z), where d_0 is a constant (see Monton 2003: 200). In this world, time is circular. So, for any time t_i and any integer n, $t_i=t_i+nd_0$. Suppose that starting at t_1 and persisting in the forward direction through time for the duration of time d_0, an object comes back to its spatio-temporal starting point t_1, producing a closed timelike curve. Suppose d_0=10 years. So this object follows a closed timelike curve for 10 years and comes back to its starting spatio-temporal point. Is this journey time travel? According to the standard definition of time travel, it is time travel. In this scenario, the duration of the journey (10 years)[2] does not equal the difference between the departure and arrival time (0 years). Therefore, according to the standard definition of time travel, this journey is time travel (see Monton 2003: 201- 2).

However, it is difficult to consider the journey depicted in this scenario as time travel. This object progresses in the normal way through time. It never goes backward in time and it never jumps forward in time. This object goes in the forward direction through time at the rate of 'one-second-per-second', and this is just the ordinary way of persistence. It is never out of sync with the flow of time. Because of all this, I maintain that this object is not a time traveler. It just persists in the ordinary way and it happens to come back to its spatio-temporal starting point.

There is a more serious problem with the standard definition of time travel. The standard definition of time travel counts as time travel any object's journey in this world of rolled-up space-time. This is because in this world the time is circular. This implies that starting at t_1, m years after t_1 in the future is the same time as $d_0 - m$ years before t_1 in the past. In the above scenario, starting at t_1, 10 years after t_1 in the future is the same time as 0 years before t_1 in the past. Thus, the duration of the journey is 10 years and the difference between the departure and arrival

2) Remember that Lewis defines personal time as measured by objective physical processes that one undergoes during the journey. Also remember that the claim that it is measured by its 'wristwatch' is not true. When it is said that the duration of an object's journey is 10 years (that 10 years of its personal time has passed), it means that this object has undergone the sorts of change that *normally* occur to it (or to the objects of the same kind) during 10 years of external time in this world. It does not mean that its 'wristwatch' says 10 years have passed. See n.1 above.

time is not only 10 years (measured in one way) but also 0 years (measured in another way). Since 10 years do not equal 0 years, this journey satisfies the standard definition of time travel. Consider another object in the same world. Suppose this object persists for 3 years. The duration of the journey is 3 years and the difference between the departure and arrival time is not only 3 years (measured in one way) but also 7 years (measured in another way). According to the standard definition of time travel, this object's journey counts as time travel because the duration of the journey (3 years) does not equal the difference between the departure and arrival time (7 years).

The standard definition of time travel counts any ordinary persistence in this world as time travel. Take any object which persists for the duration of time d_m. For any d_m which is bigger than zero, d_m does not equal $(nd_0 - d_m)$ for some integer n, and this journey counts as time travel. According to this definition, everything is a time traveler in this world. This seems wrong. The reason why there is always a discrepancy between the duration of the journey and the difference between the departure and arrival time is not because every object in this world is a time traveler. It is because of the nature of its circular time. Circular time involves what Phil Dowe calls 'a collapse of the exclusive distinction between future, present, and past' (2009 : 650). For any time t_i, when it is present, it is not only present but also future and past. If a certain time is future, it is not only future but also past as well. If a certain time is past, it is not only past but also future as well. Therefore, a certain time t_i is not merely one of present, future, or past. It is all of the three, if it is present. If it is not present, it is both future and past. This explains why there is always a discrepancy between the duration of the journey and the difference between the departure and arrival time for any journey in this world. This shows that the standard definition of time travel is inadequate.

3. Problems with a Revised Definition

One might think that there is an obvious way to revise the standard definition of time travel. We can think of the following revised definition of time travel: an object time travels if and only if there is a discrepancy between personal time and every way of measuring external time in the journey. That is, an object time travels if and only if the separation in external time between departure and arrival that is measured in every way does not equal the duration of personal time of the journey.

The idea is as follows. In a world where time is not circular, there is only one way of measuring external time. Whenever there is a discrepancy between personal time and external time measured in this way, it is time travel. In a world where time is circular, external time can be measured in multiple ways. In this world, whenever there is a discrepancy between personal time and external time measured in all of these ways, it is time travel. Consider a time traveler who goes backward in time in this world where d_0=10 years. Suppose a time traveler departs, he travels for 1 year, and he arrives 7 years before his departure time. The time traveler travels for 1 year in personal time into the future. He arrives 7 years in the past in external time measured in one way and he arrives 3 years in the future in external time measured in another way. The duration of the journey is 1 year and the difference between the departure and arrival time is 7 years measured in one way, but also 3 years measured in another way. Also, in this world $t_1=t_1+nd_0$, so the difference between the departure and arrival time is $7+nd_0$ years and

$3+nd_0$ years. When d_0 is 10 years, this value is 17 years, 27 years, and so on, and also 13 years, 23 years, and so on, measured in other ways. None of these numbers equal the duration of the journey, which is 1 year. Since the separation in external time between departure and arrival that is measured in every way does not equal the duration of personal time of its journey, it counts as time travel.

As desired, this revised definition does not count the journey of an object following a closed timelike curve and coming back to its spatio-temporal starting point after 10 years where d_0=10 years. The duration of the journey is 10 years and the difference between the departure and arrival time is 10 years measured in one way and 0 years measured in other way. 10 years does equal 10 years. This journey does not satisfy the revised definition of time travel.

However, we can come up with counterexamples to this revised definition of time travel. Suppose that an object goes backward in time in a world with circular time where d_0=10 years. Suppose this object goes at the rate of 'one-second-per-second' for 5 years. This means that it takes this object one second in personal time to go the distance of one second in external time. It travels for 5 years and arrives 5 years before his departure time. It arrives 5 years in the past in external time measured in one way and it arrives 5 years in the future in external time measured in another way. The duration of the journey is 5 years and the difference between the departure and arrival time is 5 years measured in at least one way. Since the separation in external time between departure and arrival that is measured in both ways does equal the duration of personal time of the journey, it does not count as time travel. This seems wrong. This object goes backward in time. Going backward in time is a paradigmatic example of time travel.

Here is another counterexample. Suppose there is a time machine which goes in the backward direction through time at the rate of 'one-second-per-nine-seconds' (it takes this object one second in personal time to go the distance of nine seconds in external time) in a world with circular time where d_0=10 years. Suppose an object travels in this machine for 1 hour and arrives 9 hours before its departure time. This is time travel. Suppose an object travels in this machine for 1 month and arrives 9 months before its departure time. This is time travel. Now suppose an object travels in this machine for 1 year and arrives 9 years before its departure time. This is time travel. All of the three journeys are time travel. However, the revised definition of time travel counts only the first two journeys as time travel. In the last journey, the object arrives 9 years in the past in external time measured in one way and it arrives 1 year in the future in external time measured in another way. So the duration of the last journey is 1 year and the difference between the departure and arrival time is 1 year measured in one way. Since the separation in external time between departure and arrival measured in at least one way does equal the duration of personal time of its journey, it does not count as time travel. The revised definition of time travel provides the wrong verdict.

4. A New Definition of Time Travel

We should look elsewhere for a new definition of time travel. In the case of an ordinary persistence, an object is never out of sync with the flow of external time. It goes in the same 'direction' as external time and it goes at the rate of 'one-second-per-second', the same 'speed' as external time. However, when an object time travels, it goes out of sync with the flow of external time. Thus time travel involves at least one of the following two kinds of discrepancies. Either it goes backward in time or it goes ‘faster’ or ‘slower’ than time. In a world where time is not circular, both kinds of discrepancies can be captured by a discrepancy between personal time and external time in the journey. The problem is that in a world with circular time, these discrepancies, in particular the discrepancy between the ‘direction’ of the journey and the ‘direction’ of external time, cannot be captured by a discrepancy between personal time and external time. This is because the exclusive distinction between future, present, and past is collapsed in this world. This is why the standard definition of time travel cannot properly deal with time travel in a world with circular time. In order to capture both kinds of discrepancies in a world with circular time, we need something more than a discrepancy between personal time and external time. I suggest that in addition to a discrepancy between personal time and external time, we also directly appeal to the ‘direction’ of the journey.

Here is my suggestion for a new definition of time travel. In cases where an object goes in the forward direction through time, we assign a positive value to the separation in external time between departure and arrival. This means that, among every way of measuring the separation in external time between departure and arrival, we consider only those ways of measuring the separation in external time between departure and arrival which result in positive values. This is because we only want to measure the separation in external time between departure and arrival which goes in the forward direction through time and the forward ‘direction’ of the journey is represented by the positive values of its separation. But we should not consider all of those ways of measuring which result in positive values. Here is why. Consider an object which goes in the forward direction through time at the rate of 'one-second-per-six-seconds' (it takes this object one second in personal time to go the distance of six seconds in external time) in a world with circular time where d_0=10 years. It travels for 2 years in personal time and arrives 12 years in external time after its departure time. This is time travel. Since in this world, for any time t_i and any integer n, $t_i=t_i+nd_0$, if we consider all those ways of measuring the separation in external time between departure and arrival which result in positive values, we get 2 years, 12 years, 22 years, and so on. So, the duration of personal time of its journey (2 years) does equal one of these positive values (2 years). This shows why we should not consider all those ways of measuring the separation in external time between departure and arrival of the journey which result in positive values.

Here is another case which also shows this. Consider an object which goes in the forward direction through time at the rate of 'three-seconds-per-second' (it takes this object three seconds in personal time to go the distance of one second in external time) in a world with circular time where d_0=10 years. It travels for 15 years in personal time and arrives 5 years in external time after its departure time. This is time travel. Since in this world, for any time t_i and any integer n, $t_i=t_i+nd_0$, if we consider all those ways of measuring the separation in external time between departure and arrival which result in positive values, we get 5 years, 15 years, 25 years, and so on. So, the duration of personal time of its journey (15 years) does equal one of these positive values (15 years). This is a problem.

In order to deal with these kinds of cases, we need a stronger constraint when we consider ways of measuring the separation in external time between departure and arrival. Suppose an object travels in the forward direction through time at the rate of 'one-second-per-m-seconds'. This means that it takes this object one second in personal time to travel m seconds in external time. Then, if it travels for r seconds in personal time, this object arrives r×m seconds in external time after its departure time. Let us by stipulation define the 'original' separation in external time between departure and arrival of the journey as follows: the 'original' separation in external time between departure and arrival going forward in time = r×m seconds. The 'original' separation in external time between departure and arrival in the above cases is 12 years (2 years times 6) and 5 years (15 years times 1/3) respectively, so we only consider the way of measuring the separation in external time between departure and arrival which results in 12 years and 5 years respectively. None of these equals the duration of personal time of its journey (2 years and 15 years respectively). Then, when an object goes forward in time, time travel is defined as follows: an object time travels if and only if the 'original' separation in external time between departure and arrival does not equal the duration of personal time of its journey.

In cases where an object goes in the backward direction through time, we assign a negative value to the separation in external time between departure and arrival. This is because the backward 'direction' of the journey is represented by the negative values of its separation in external time between departure and arrival. Also, among them, we only consider the way of measuring which results in the 'original' separation in external time between departure and arrival, as in the case where an object goes in the forward direction through time. We can define the 'original' separation in external time between departure and arrival in a similar way as above. Suppose an object travels in the backward direction through time at the rate of 'one-second-per-m-seconds'. This means that it takes this object one second in personal time to travel m seconds in external time. Then, if it travels for r seconds in personal time, this object arrives r×m seconds in external time before its departure time. We by stipulation define the 'original' separation in external time between departure and arrival as follows: the 'original' separation in external time between departure and arrival of the journey going backward in time = −(r×m) seconds. Then, when an object goes backward in time, time travel is defined as follows: an object time travels if and only if the 'original' separation in external time between departure and arrival does not equal the duration of personal time of its journey.

According to this new definition, every journey going backward in time counts as time travel whether time is circular or not. This is because the duration of personal time of the journey is always either zero (in cases where time travel is instantaneous) or a certain positive value (in cases where time travel is not instantaneous), whereas the 'original' separation in external time between departure and arrival as defined above is always a negative value. The new definition of time travel counts as time travel the journey of an object going in the backward direction through time at the rate of 'one-second-per-second' for 5 years in a world with circular time where d_0=10 years. It also counts as time travel the journey of a time machine in this world which goes backward in time at the rate of 'one-second-per-nine-seconds' for 1 year in personal time and arrives 9 years in external time before its departure time, as desired.

Now consider an object which goes forward in time in a world where time is not circular. Consider first the case where time travel is instantaneous. An object departs and it instantaneously (in personal time) arrives 7 years (in external time) after its departure time. Since the duration of personal time of its journey (zero) does not equal the 'original' separation in external time between departure and arrival (7 years), this journey counts as time travel. Consider next the case where time travel is not instantaneous. An object departs, travels for 1 year in personal time, and arrives 7 years in external time after its departure time. Since the duration of personal time of its journey (1 year) does not equal the 'original' separation in external time between departure and arrival (7 years), this journey counts as time travel.

Consider an object which goes forward in time in a world where time is circular and d_0=10 years. Consider first the case where time travel is instantaneous. An object departs and it instantaneously (in personal time) arrives 7 years (in external time) after its departure time. In this world, there are infinitely many ways of measuring the separation in external time between departure and arrival which result in positive values. Among them, we only consider the way of measuring which results in the 'original' separation in external time between departure and arrival as defined above. Since the duration of personal time of its journey (zero) does not equal the 'original' separation in external time between departure and arrival (7 years), this journey counts as time travel. Consider next the case where time travel is not instantaneous. An object departs, travels for 1 year in personal time, and arrives 7 years in external time after its departure time. Again, in this world, there are infinitely many ways of measuring the separation in external time between departure and arrival which result in positive values. Among them, we only consider the way of measuring which results in the 'original' separation in external time between departure and arrival as defined above. Since the duration of personal time of its journey (1 year) does not equal the 'original' separation in external time between departure and arrival (7 years), this journey counts as time travel.

Consider finally an object which follows a closed timelike curve in the forward direction through time and comes back to its spatio-temporal starting point after 10 years in a rolled-up space-time where d_0=10 years. The duration of personal time of its journey is 10 years. The 'original' separation in external time between departure and arrival as defined above is 10 years. Since the duration of personal time of its journey (10 years) does equal this value (10 years), this journey does not count as time travel, as desired. I conclude that I have given a definition of time travel that does not fail in situations involving circular time, and hence that my definition is better than the standard one provided by Lewis.[3)]

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3) An earlier version of this paper was presented at the symposium on Philosophy of Mental Time held at Nihon University in January 2014, at the workshop on Current Trends in Analytic Philosophy held at Yonsei University in February 2014, and at the meeting of the Korean Association for Logic in July 2014. I thank audiences at these places for helpful and lively discussions. I also thank anonymous referees for their insightful and kind comments. I am most grateful to Ned Markosian, Bradley Monton, and Takashi Yagisawa for their helpful and detailed discussions and comments on an earlier version of this paper.

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