ULTIMATE PARADOXES OF TIME TRAVEL

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Abstract. We briefly present some paradoxes of time travel, and discuss their possible solutions. We also analyze the epistemological status of the Principle of Self-consistency.

1. Introduction

One of the most perplexing aspects of General Relativity is that its field equations have solutions that allow the existence of closed time-like curves (CTCs). CTCs are space-time trajectories such that a particle can traverse them, always moving towards its own future, and intersect itself in the past. Such a situation corresponds to what science-fiction writers have called "time travel". A time machine is a device that can generate or use a special energy-momentum distribution to distort the geometric structure of space-time to the level at which CTCs are formed (strong time machine) or allowed (weak time machines) to some physical systems ("time travelers").

The most studied solutions of Einstein field equations that allow CTC formation are wormhole space-times. [1] If a wormhole exists, then it can

[1]For a discussion on wormhole features and observational bounds see the work by Torres and Romero (2000) in this volume.

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be converted into a time machine through the relativistic motion of one of the mouths, or using strong gravitational fields in order to induce large redshifts (e.g. Morris et al. 1988, Novikov 1989).

2. Against time machines

The opponents of time machines are legion. To many people time machines appear to be hideous devices that unlock the door to all kind of ontological bizarrerie. However, since CTCs are naturally expected in General Relativity, if we are going to take seriously this theory we should also take seriously the possibility that CTCs can actually occur in the Universe, and then explore their consequences as far as our theoretical knowledge allows it.

The opposition to time machines has adopted two main forms. First, through the chronology protection conjecture (Hawking 1992): Nature abhors time machines and they are not physically feasible: always that a CTC is near to be formed, some laws of nature produce a situation that destroys the machine. The main mechanism to enforce chronology protection is the back-reaction of vacuum polarization fluctuations (see Earman 1995 for a discussion). However, it has been recently shown, and admitted by Hawking and followers (Cassidy & Hawking 1998), that this mechanism can fail in creating an effective protection.

In second place, chronology protection has been sought in the apparent logical paradoxes produced by time travel. The best known case is the "grandfather paradox": I go to the past, and in a bloody impulse I kill my own grandfather before he had the opportunity to meet my grandmother. Where am I from then?[2] This kind of paradoxes have been used to claim that time travel is illogical.

At this point a semantic note on the word "paradox" is required. A paradox can be:

1. An apparent logical situation that actually is not.
2. An apparent illogical situation that actually is perfectly logic.

It has been argued (e.g. Friedman et al. 1990) that the paradoxes just point out the existence of "consistency constraints" in the laws of Nature. With such constraints all time travel paradoxes would be of class 2. More specifically, it has been proposed the following

PRINCIPLE OF SELF-CONSISTENCY (PSC): The only solutions of the laws of physics that can occur locally in the real Universe are those which

[2]The reader interested in ALL kind of time paradoxes should run to see the fascinating book by Nahin 1998, by far the most comprehensive work on the subject.

are globally self-consistent.

This mean that I cannot kill my grandfather (a local action) because in the far future this would generate an inconsistency with my birth. Other way to state this is that I cannot kill my grandfather because nobody killed him in the past. Just consistent histories can develop in the Universe. In a series of papers (e.g. Echeverría et al. 1991), the application of the Principle of Self-Consistency has been used to shown that in different physical (simple) situations no paradoxes arise at all.

3. What is the epistemological status of the PSC?

What is this principle of consistency? Is it a law, like Einstein field equations or the Newton's laws? Is it tautological, i.e. it has not a factual content? Does it refer to our capacity to understand a logical world?.

We think that the PSC is not a physical law, in the sense that it says nothing on the kind of entities that populate the Universe. Its reference class is not a class of individuals, the ontological furniture of the world, like it is the case for the usual physical laws. We propose that the PSC is a metanomological statement (Bunge 1961), like, for instance, the principle of covariance. This means that the reference class of the principle is not formed by things, but by laws. The usual laws are restrictions to the state space of a physical system. Metanomological statements are laws of laws, i.e., restrictions on the global network of laws that thread the Universe.

Earman (1995) has suggested that the requirement of self-consistency must be considered as a new law. This can be objected through the simple determination of the reference class of the principle. In order to accomplish this, the principle should be translated to logical notation and the dominion of the bound variables in the logical quantifiers must be determined (for details see Romero & Torres 2000). When this is done it becomes clear that the principle deals just with laws. The requirement of consistency constraints is then pointing out the existence of deeper level super-laws, which enforce the harmony between local and global affairs in space-time.

4. Self-existing objects trapped in CTCs?

Although the PSC eliminates grandfather-like paradoxes, other highly perplexing situations remain. The main of these situations is the possibility of an ontology with self-existing objects. Here there is a graphic description of one of such objects: I have a book and I give it to a friend of mine saying: "Would you be so kind as to keep safe this book a whole year and return it to me at this same day and hour, next year". "Sure!" says my friend, and a year later gives me back the book. Then, I take the book, run into my

time machine, appear a year before in front of my friend and say: "Would you be so kind as to keep safe this book a whole year and return it to me at this same day and hour, next year".

Who made the book?. It seems to be trapped in a time loop. There are not inconsistencies to be avoided: every local action is consistent with the global loop. There is no causality violation, no lawless trajectories, nothing but a book never created, never printed, but, somehow, existing in space-time. It has been suggested that if time travel is unavoidable, then we should accept an ontology of self-existing objects (Nerlich 1981). They just are out there, trapped in space-time. There is no sense in asking where they come from.

The acceptance of such a bizarre ontology proceeds, we believe, from an incorrect application of the PSC. It is usually discussed within the framework of General Relativity, but actually it encompasses all physical laws. What should be demanded is total consistency, and not just consistency in the solutions of Einstein or other field equations.

In order to show this, we have taken into account thermodynamic effects when considering CTCs in wormhole space-times. We have specifically shown that any real fluid increases its entropy when traveling in a casual loop threading two wormhole mouths (see, again, Romero & Torres 2000 for details). This means that the state of the system changes along the loop, and then that the loop cannot be consistently closed, because initial and final states do not match. The PSC therefore rules out these trajectories in space-time. There cannot be self-existing objects by the same reason that there is no grandfather paradox: global consistency must be fulfilled in the Universe.

5. Conclusions

Time travel is not only a justification to let fly our imagination. It can be a powerful tool to probe the deep levels at which the laws of nature are led to their most extreme manifestations. It is a conceptual instrument that can allow us to clarify not only the very foundations of General Relativity, but also the complex relations among the different theories we use to describe the Universe in which we live.

We have described here how certain apparent paradoxes originated by time travel can be conveniently dissolved. In particular, we are not committed to accept an ontology of self-existing objects if we take seriously the possibility of formation of traversable CTCs. There remain, however, some important epistemological issues arisen from information flux to the past. But this is a different story, that will be treated elsewhere (Romero & Torres 2000).

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