Time travel could be possible, but only with parallel timelines

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Have you ever made a mistake that you wish you could undo? Correcting past mistakes is one of the reasons we find the concept of time travel so fascinating. As often portrayed in science fiction, with a time machine, nothing is permanent anymore—you can always go back and change it. But is time travel really possible in our universe, or is it just science fiction?

Our modern understanding of time and causality comes from general relativity. Theoretical physicist Albert Einstein's theory combines space and time into a single entity—"spacetime"—and provides a remarkably intricate explanation of how they both work, at a level unmatched by any other established theory. This theory has existed for more than 100 years, and has been experimentally verified to extremely high precision, so physicists are fairly certain it provides an accurate description of the causal structure of our universe.

For decades, physicists have been trying to use general relativity to figure out if time travel is possible. It turns out that you can write down equations that describe time travel and are fully compatible and consistent with relativity. But physics is not mathematics, and equations are meaningless if they do not correspond to anything in reality.

Arguments against time travel

There are two main issues which make us think these equations may be unrealistic. The first issue is a practical one: building a time machine seems to require exotic matter, which is matter with negative energy. All the matter we see in our daily lives has positive energy—matter with negative energy is not something you can just find lying around. From quantum mechanics, we know that such matter can theoretically be created, but in too small quantities and for too short times.

However, there is no proof that it is impossible to create exotic matter in sufficient quantities. Furthermore, other equations may be discovered that allow time travel without requiring exotic matter. Therefore, this issue may just be a limitation of our current technology or understanding of quantum mechanics.

The other main issue is less practical, but more significant: it is the observation that time travel seems to contradict logic, in the form of time travel paradoxes. There are several types of such paradoxes, but the most problematic are consistency paradoxes.

A popular trope in science fiction, consistency paradoxes happen whenever there is a certain event that leads to changing the past, but the change itself prevents this event from happening in the first place.

For example, consider a scenario where I enter my time machine, use it to go back in time five minutes, and destroy the machine as soon as I get to the past. Now that I destroyed the time machine, it would be impossible for me to use it five minutes later.

But if I cannot use the time machine, then I cannot go back in time and destroy it. Therefore, it is not destroyed, so I can go back in time and destroy it. In other words, the time machine is destroyed if and only if it is not destroyed. Since it cannot be both destroyed and not destroyed simultaneously, this scenario is inconsistent and paradoxical.

Eliminating the paradoxes

There's a common misconception in science fiction that paradoxes can be "created." Time travelers are usually warned not to make significant changes to the past and to avoid meeting their past selves for this exact reason. Examples of this may be found in many time travel movies, such as the "Back to the Future" trilogy.

But in physics, a paradox is not an event that can actually happen—it is a purely theoretical concept that points towards an inconsistency in the theory itself. In other words, consistency paradoxes don't merely imply time travel is a dangerous endeavor, they imply it simply cannot be possible.

This was one of the motivations for theoretical physicist Stephen Hawking to formulate his chronology protection conjecture, which states that time travel should be impossible. However, this conjecture so far remains unproven. Furthermore, the universe would be a much more interesting place if instead of eliminating time travel due to paradoxes, we could just eliminate the paradoxes themselves.

One attempt at resolving time travel paradoxes is theoretical physicist Igor Dmitriyevich Novikov's self-consistency conjecture, which essentially states that you can travel to the past, but you cannot change it.

According to Novikov, if I tried to destroy my time machine five minutes in the past, I would find that it is impossible to do so. The laws of physics would somehow conspire to preserve consistency.

Introducing multiple histories

But what's the point of going back in time if you cannot change the past? My recent work, together with my students Jacob Hauser and Jared Wogan, shows that there are time travel paradoxes that Novikov's conjecture cannot resolve. This takes us back to square one, since if even just one paradox cannot be eliminated, time travel remains logically impossible.

So, is this the final nail in the coffin of time travel? Not quite. We showed that allowing for multiple histories (or in more familiar terms, parallel timelines) can resolve the paradoxes that Novikov's conjecture cannot. In fact, it can resolve any paradox you throw at it.

The idea is very simple. When I exit the time machine, I exit into a different timeline. In that timeline, I can do whatever I want, including destroying the time machine, without changing anything in the original timeline I came from. Since I cannot destroy the time machine in the original timeline, which is the one I actually used to travel back in time, there is no paradox.

After working on time travel paradoxes for the last three years, I have become increasingly convinced that time travel could be possible, but only if our universe can allow multiple histories to coexist. So, can it?

Quantum mechanics certainly seems to imply so, at least if you subscribe to Everett's "many-worlds" interpretation, where one history can "split" into multiple histories, one for each possible measurement outcome—for example, whether Schrödinger's cat is alive or dead, or whether or not I arrived in the past.

But these are just speculations. My students and I are currently working on finding a concrete theory of time travel with multiple histories that is fully compatible with general relativity. Of course, even if we manage to find such a theory, this would not be sufficient to prove that time travel is possible, but it would at least mean that time travel is not ruled out by consistency paradoxes.

Time travel and parallel timelines almost always go hand-in-hand in science fiction, but now we have proof that they must go hand-in-hand in real science as well. General relativity and quantum mechanics tell us that time travel might be possible, but if it is, then multiple histories must also be possible.

More information: Barak Shoshany, Lectures on faster-than-light travel and time travel, *SciPost Physics Lecture Notes* (2019). DOI: 10.21468/SciPostPhysLectNotes.10

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