# THE ORDER OF TIME

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## "NOW" MEANS NOTHING

What is happening "now" in a distant place? Imagine, for example, that your sister has gone to Proxima b, the recently discovered planet that orbits a star at approximately four light-years' distance from us. What is your sister doing *now* on Proxima b?

The only correct answer is that the question makes no sense. It is like asking "What is *here*, in Beijing?" when we are in Venice. It makes no sense because if I use the word "here" in Venice, I am referring to a place in Venice, not in Beijing.

If you ask what your sister, who is in the room with you, is doing *now*, the answer is usually an easy one: you look at her and you can tell. If she's far away, you phone her and ask what she's doing. But take care: if you look at your sister, you are receiving light that travels from her to your eyes. The light takes time to reach you, let's say a few nanoseconds—a tiny fraction of a second—therefore, you are not quite seeing what she is doing *now* but what she was doing a few nanoseconds ago. If she is in New York and you phone her from Liverpool, her voice takes a few milliseconds to reach you, so the most

you can claim to know is what your sister was up to a few milliseconds ago. Not a significant difference, perhaps.

If your sister is on Proxima b, however, light takes four years to reach you from there. Hence, if you look at her through a telescope, or receive a radio communication from her, you know what she was doing four years ago rather than what she is doing now. "Now" on Proxima b is definitely not what you see through the telescope, or what you can hear from her voice over the radio.

So perhaps you can say that what your sister is doing *now* is what she will be doing four years after the moment that you see her through the telescope? But no, this does not work: four years after you have seen her through the telescope, in her time, she might already have returned to Earth and could be (yes! this is really possible!) ten terrestrial years in the future. But "now" cannot be in the future . . .

Perhaps we can do this: if, ten years ago, your sister had left for Proxima b, taking with her a calendar to keep track of the passage of time, can we think that *now* for her is when she has recorded that ten years have passed? No, this does not work either: she might have returned here ten of *her* years after leaving, arriving back



where, in the meantime, twenty years have elapsed. So when the hell *is* "now" on Proxima b?

The truth of the matter is that we need to give up asking the question.[27]

There is no special moment on Proxima b that corresponds to what constitutes the present here and now.

Dear reader, pause for a moment to let this conclusion sink in. In my opinion, it is the most astounding conclusion arrived at in the whole of contemporary physics.

It simply makes no sense to ask which moment in the life of your sister on Proxima b corresponds to *now*. It is like asking which football team has won a basketball championship, how much money a swallow has earned, or how much a musical note weighs. They are nonsensical questions because football teams play football, not basketball; swallows do not busy themselves earning money; sounds cannot be weighed. "Basketball champions" refers to a team of basketball players, not to footballers. Monetary profit refers to human society, not to swallows. The notion of "the present" refers to things that are close to us, not to anything that is far away.

Our "present" does not extend throughout the universe. It is like a bubble around us.

How far does this bubble extend? It depends on the precision with which we determine time. If by nanoseconds, the present is defined only over a few meters; if by milliseconds, it is defined over thousands of kilometers. As humans, we distinguish tenths of a second only with great difficulty; we can easily consider our entire planet to be like a single bubble where we can speak of the present as if it were an instant shared by us all. This is as far as we can go.

There is our past: all the events that happened before what we can witness now. There is our future: the events that will happen after the moment from which we can see the here and now. Between this past and this future there is an interval that is neither past nor future and still has a duration: fifteen minutes on Mars; eight years on Proxima b; millions of years in the Andromeda galaxy. It is the expanded present.[28] It is perhaps the greatest and strangest of Einstein's discoveries.

The idea that a well-defined *now* exists throughout the universe is an illusion, an illegitimate extrapolation of our own experience.[29]

It is like the point where the rainbow touches the forest. We think that we can see it—but if we go to look for it, it isn't there.

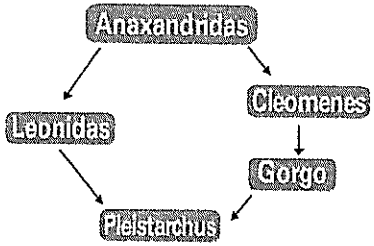


If I were to ask, "Are these two stones at the same height?" in interplanetary space, the correct answer would be: "It's a question that doesn't make sense, because there isn't a single notion of 'same height' throughout the universe." If I ask whether two events—one on Earth and the other on Proxima b—are happening "at the same moment," the correct answer would be: "It's a question that doesn't make sense, because there is no such thing as 'the same moment' definable in the universe."

The "present of the universe" is meaningless.

## TEMPORAL STRUCTURE WITHOUT THE PRESENT

Gorgo is the woman who saved Greece by realizing that a wax-covered tablet sent there from Persia carried a secret message concealed *beneath* the wax: a message that forewarned the Greeks of a Persian attack. Gorgo had a son called Pleistarchus, fathered by the king of Sparta, the hero of Thermopylae: Leonidas. Leonidas was Gorgo's uncle, the brother of her father, Cleomenes. Who belongs to the "same generation" as Leonidas? Gorgo, who is the mother of his son—or Cleomenes, who is the son of the same father? Here is a diagram for those who, like me, have difficulties with genealogy:

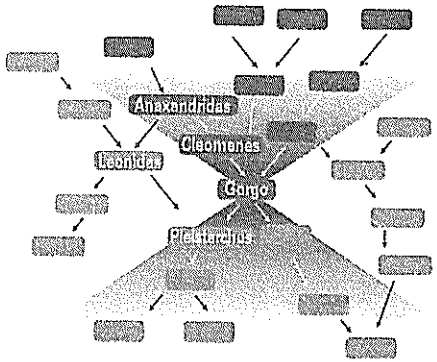



There is an analogy between generations and the temporal structure of the world as revealed by relativity. It makes no sense to ask if it is Cleomenes or Gorgo who is "of the same generation" as Leonidas, because there is no single concept[30] of "same generation." If we say that Leonidas and his brother are "of the same generation" because they have the same father, and that Leonidas and his wife are "of the same generation" because they have a son together, we must therefore say that this "same generation" includes Gorgo and her own father! The filial relationship establishes an order between human beings (Leonidas, Gorgo, and Cleomenes come *after* Anaxandridas and *before* Pleistarchus), but not between *any* humans: Leonidas and Gorgo are neither before nor after in respect to each other.

Mathematicians have a term for the order established by filiation: "partial order." A partial order establishes a

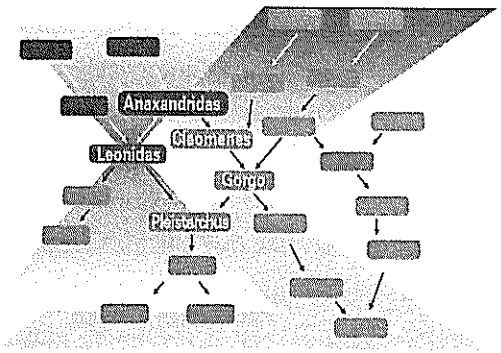


relation of *before* and *after* between certain elements, but not between any two of them. Human beings form a "partially ordered" set (not a "completely ordered" set) through filiation. Filiation establishes an order (*before* the descendants, *after* the forebears), but not between everyone. To see how this order works, we need only think of a family tree, like this one for Gorgo:




There is a cone-shaped "past" made up of her forebears, and a "future" cone comprising her descendants. Those who are neither ancestors nor descendants remain outside of the cones.

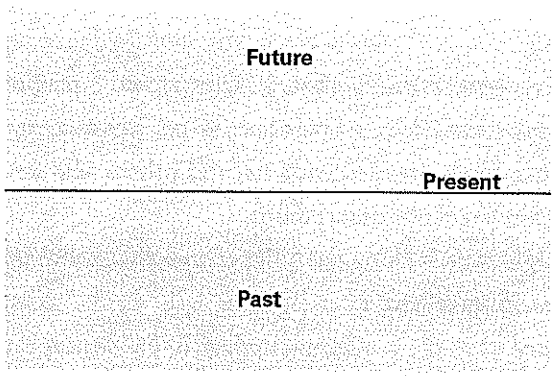
Every human being has their own past cone of ancestors and future cone of descendants. Those of Leonidas are shown below, alongside Gorgo's:



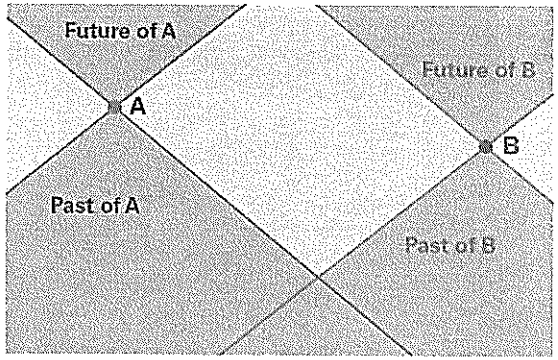

The temporal structure of the universe is very similar to this one. It is also made of cones. The relation of "temporal precedence" is a partial order made of cones.[31] Special relativity is the discovery that the temporal structure of the universe is like the one established by filiation: it defines an order between the events of the universe that is *partial*, not *complete*. The expanded present is the set of events that are neither past nor future: it exists, just as there are human beings who are neither our descendants nor our forebears.

If we want to represent all the events in the universe and their temporal relations, we can no longer do so with a single, universal distinction between past, present, and future, like this:






We must do so instead by placing above and below every event the cones of its future and past events:

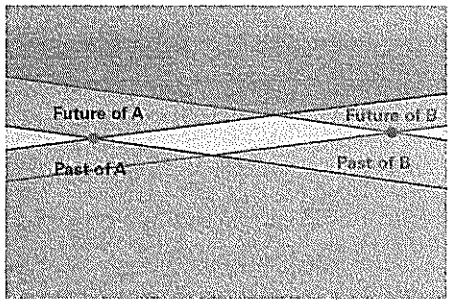



(Physicists have the habit in such diagrams, I don't know why, of placing the future above and the past

below—the opposite of how it is done in genealogical trees.)

Every event has its past, its future, and a part of the universe that is neither past nor future, just as every person has forebears, descendants, and others who are neither forebears nor descendants.

Light travels along the oblique lines that delimit these cones. This is why we call them "light cones." It is customary, as in the previous diagram, to draw these lines at an angle of forty-five degrees, but it would be more realistic to make them more horizontal, like this:

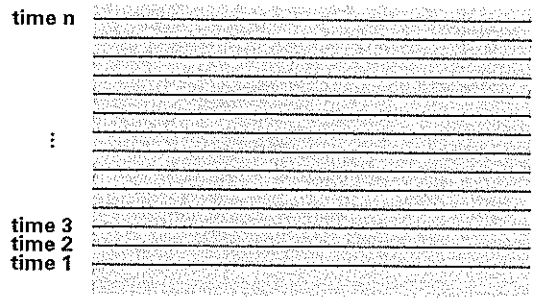



The reason for this is that, at the scale to which we are accustomed, the expanded present separating our past from our future is extremely brief (a matter of nanoseconds) and almost imperceptible, as a result of which it

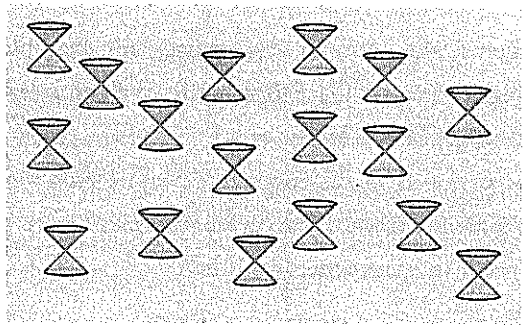


is "squashed" into a thin horizontal band we usually call "the present," without any qualification.

In short, a common present does not exist: the temporal structure of spacetime is not a stratification of times such as this:

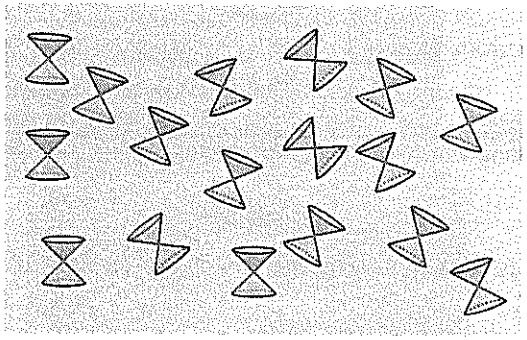



It is, rather, a structure made up entirely of light cones:



This is the structure of spacetime that Einstein understood when he was twenty-five years old.

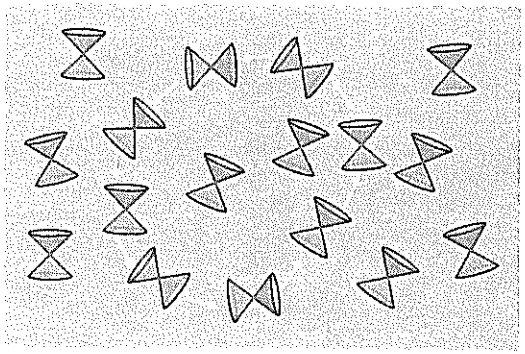
Ten years later, he comes to understand that the speed at which time flows changes from place to place. It follows that spacetime does not really have the order outlined above but can be distorted. It now looks rather more like this:



When a gravitational wave passes, for example, the small light cones oscillate together from right to left, like ears of wheat blown by the wind.

The structure of the cones can even be such that, advancing always toward the future, one can return to the same point in spacetime, like this:

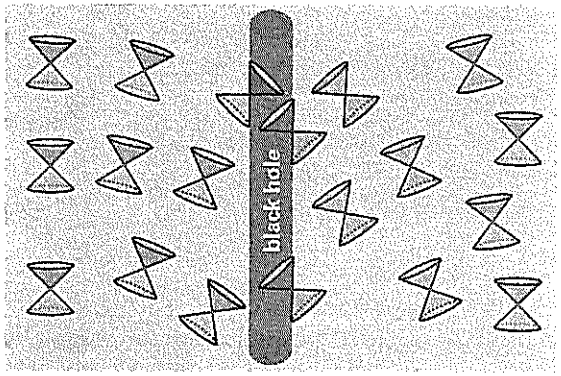




In this way, a continuous trajectory toward the future returns to the originating event, to where it began.*[32] The first to realize this was Kurt Gödel, the great twentieth-century logician who was Einstein's last friend, accompanying him on walks along the streets of Princeton.

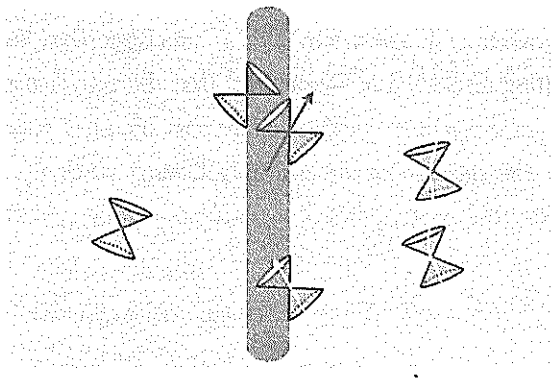
* The "closed temporal lines," where the future returns us to the past, are the ones that frighten those who imagine that a son could go on to kill his mother before his own birth. But there is no logical contradiction entailed by the existence of closed temporal lines or journeys to the past; we are the ones who complicate things with our confused fantasies about the supposed freedom of the future.

Near to a black hole, the lines converge toward it, like this:[33]




This is because the mass of the black hole slows time to such a degree that, at its border (called the "horizon"), time stands still. If you look closely, you will see that the surface of the black hole is parallel to the edges of the cones. So, in order to exit from a black hole, you would need to move (like the trajectory marked in dark gray in the following diagram) toward the present rather than toward the future!





This is impossible. Objects can only move toward the future, as in the trajectories outlined in the diagram in white. This is what constitutes a black hole: an inclination of the light cones toward the interior, marking a horizon, closing off a region of space in the future from everything that surrounds it. It is nothing other than this. It is the curious local structure of the present that produces black holes.

More than a hundred years have passed since we learned that the "present of the universe" does not exist. And yet this continues to confound us and still seems difficult to conceptualize. Every so often a physicist mutinies and tries to show that it isn't true.[34] Philosophers continue to discuss the disappearance of the present. Today, there are often conferences devoted to the subject.

If the present has no meaning, then what "exists" in the universe? Is not what "exists" precisely what is here "in the present"? The whole idea that the universe exists *now* in a certain configuration and changes together with the passage of time simply doesn't stack up anymore.