MARKUS KLUTE: Welcome back to 8.20. In this section, we're going to talk about cause and effect and causality. And we do this with an example which talks about the good guys and the bad guys. There's always good guys and bad guys in the universe.

In this example, those two groups, they were fighting a war. And after some very long and grueling time, they were able to sign a peace treaty. So this happens in this story at year number 0. So in year 0, a peace treaty is signed. And the good guys, they go back to their families. They go back home to their planet. There's a spacecraft, which is able to go with a velocity of 0.6 times the speed of light.

The bad guys. That's the bad guys. And so they develop a faster-than-the-speed-of-light spacecraft to follow the good guys. And they succeed with the development of the spacecraft after four years. So they do. They follow the good guys. And in year number 5, the bad guys attack and destroy the good guys.

The challenge for you now is to explain the story and answer the following question. When and where does the attack happen, from the good guys' perspective? And when did the bad guys invent the spacecraft, from the good guys' perspective? You will see some surprising results in this analysis.

So please stop the video and try to work this out. I recommend drawing a space-time diagram in order to get to a good picture of what is actually happening here. If you do this, you find the space-time diagram here for the bad guys. So again, there's a number of important events. In year number 0, the peace treaty is signed. And then the good guys, they start traveling away at 0.6 times the speed of light. So what you see here is a world line of the good guys.

In year number 4, in the reference frame of the bad guys, they developed a spacecraft, and they keep following the good guys. And here in year number 5, the attack actually happens. So if you analyze this for the good guys, you find that the exposition, the position of the attack, is in their spacecraft. So let's figure out whether or not this is correct.

You find gamma and x_B minus v times t_B. If you put in the numbers, you find, luckily, the exposition is equal to 0. At what time did this event happen? Here, for the good guys, you find gamma times t_B minus v over c x_B. And again, if you put the numbers in, the attack for the good guys happens in year number 4.

But then the question is, when did the bad guys invent the spacecraft in the reference frame of the good guys? And if you put in the numbers, you find the invention actually happens in year number 5. So the attack happens before the spacecraft is invented in the reference frame of the good guys. And this clearly violates causality.

You cannot use a device which is not invented yet unless you travel faster than the speed of light. You travel in time. All right. I find this a really funny and geeky example. And the reason why this doesn't work out, why it's geeky, is that they travel faster than the speed of light.

So let me conclude this part of the section here with a concept question. We have an event A, and ask ourselves, can event A cause other events? So event A might be the invention of a spacecraft. Can event A cause event C, event D, or more than one event, like B and C or B and D?

Note that the time access here has units years and the x-axis has units light years. Again, stop your video here. Think about your answer. Maybe you draw in the space-time diagram in order to find the answer. And the answer, the correct answer, is C. Only event C can be caused, because only C lies within what we call the light cone of event A.

In order to impact, in order to cause an effect on any other event, the message needs to be traveling with speed smaller than the speed of light. So that means that, in order to reach event C, we can design a spacecraft, or we can send a light beam to this event or in this direction. And then just wait a little bit, in order to make any sort of impact on event C. We cannot travel faster than the speed of light, which would be necessary in order to reach event D. And you can also not go backwards in time, this message is, in order to reach event D.