

Instructions for Lab R1: Relativity of Simultaneity - The Train “Paradox”

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After each of the following sections, answer the related questions on your Lab Report Sheet.

A. Introduction:

You will use simulation software to view a hypothetical situation first described by Einstein. Suppose you are standing on the ground, watching a train traveling at high speed. Lightning bolts strike each end of the train. You observe that the two lightning bolts strike the ends of the train *simultaneously*. A person who is riding on the train, though, will observe that the two bolts did *not* strike the train at the same time. This strange result is an example of the fact that **simultaneity of events is a relative concept** (i.e., it depends on the frame of reference of the observer). In fact, the order in which events occur can depend on the reference frame from which the events are observed.

We define an **event** to be something that happens at a particular location (in space) at a particular instant (in time). We define a **reference frame** as a coordinate system (x-, y- and z-axes, for example), plus a set of identical, synchronized clocks spread throughout the coordinate system. Using the coordinate system, we can describe the position of any event according to that reference frame. To measure the time coordinate of an event that happens at a particular position coordinate, we use the clock located *at that same position coordinate*.

B. Opening the Software:

1. Click on the file START in the SPACETIME directory of your computer. Press the Esc key to get to the main menu of the software. Select option 1 (RUN SPACETIME), press Enter, and click on Ignore when you get popup box that says “The system can not open COM2 port.” Hit any key to reach the main screen of the simulation.

2. Once you are looking at the main screen, you need to load the Train Paradox simulation. To do that, press F5 to get a list of file commands. Select READ and hit Enter. You will see a list of all the simulation files that are available. Type TRAINING.STS (you will not be able to see what you are typing) and hit Enter. The train simulation should then open.

C. How to Read the Screen:

The screen in the SPACETIME software represents a “superhighway” along which objects move from left to right (or vice versa). The superhighway is organized into “lanes”; each lane is a horizontal strip of screen. Within each lane, all objects must travel at a specific velocity. The velocity for each lane (expressed as a fraction of the velocity of light) is indicated by the number on the far left side of the screen. Objects in the upper half of the screen travel to the right, with the speeds of the lanes increasing towards the top of the screen. Objects in the lower half of the screen travel to the left, with the speeds of the lanes increasing towards the bottom of the screen. The topmost (and bottommost) lanes are reserved for objects traveling at the speed of light. The lane in the middle of the screen is for objects that are stationary.

The screen currently shows how objects are observed from the reference frame of the stationary lane – we will call that the Ground Reference Frame. You are standing (at rest) in the exact

middle of the screen, at the position coordinate $x_G=0$ (we will use the subscript G for variables that refer to the Ground Reference Frame). Three digital clocks are located along your strip of the superhighway; you are located at the position of the middle clock. The train is represented on the screen by three clocks connected by rods. One clock is at each end of the train and one is at its middle. There is also a train passenger (not shown on the screen) at the middle of the train.

D. Animation vs. What You Would Actually See

Think of what you see on the screen as an animation that the computer constructs based on information (positions, times) about a series of events that happened. The information at each coordinate was recorded **locally**, i.e. by a data recording device and clock that sit at rest at that particular coordinate. After all the events have happened, the various data recorders send their data to your computer, which then draws the animation. Each screen of the animation is a “snapshot” of what happened, showing the positions of objects as observed *at one instant of time* (i.e. simultaneously) in the Ground Reference Frame.

In real life, the image that we see of an object is formed from light rays from different parts of the object that reach our eye at the same time. If different parts of the object are different distances from our eyes, we see the different parts as they appeared *at different times* ! Thus, in real life, you would not actually see the objects as they appear on the screen.

E. Recording Events as Viewed by Ground Observer:

To describe any event, we must specify three things: 1) what happens; 2) what the position coordinates of the event are, relative to a particular reference frame, and 3) what the time coordinate of the event was, according to the clocks in that reference frame.

If an event occurs, a vertical line appears on the screen at the position of the event. You can use that vertical line to determine the event’s position coordinate by using the horizontal scale across the center of the screen. You can find the event’s time coordinate in the upper right corner of the screen (or on any of the clocks in the Ground Reference Frame).

The simulation begins at the instant when you and the train passenger are side-by-side at $x_G=0$. At that instant, both your clock and the train passenger’s clock at that location read $t_G=t_T=0$ (we will use the subscript T for variables that refer to the Train Reference Frame). Also at that instant, your clocks that are located at the two ends of the train record that lightning bolts are hitting each end. The * symbols in the top and bottom lanes represent the flashes of light caused by the bolts.

Try moving time forward and backward, watching the train move. To move the simulation one time step forward or backward, use the up or down arrow keys. You can also use the Page Up and Page Down keys to move the simulation forward or backwards by larger time steps. Note that you, standing on the ground, do not move across the screen – you remain stationary in the center lane. Notice that the time reading of each clock changes as you move the simulation forward and backward. If you need to view objects that go off the screen, you can move the entire screen display to the left or right by using the left and right arrow keys. You can also reset the simulation to time = 0 by pressing the 0 key.

F. Recording Events as Viewed by Train Passenger:

Now you will view the entire simulation again, from a different reference frame. To do that, first press F6. A unique letter label will appear on every object on the screen. Press B to select object B, which is the train passenger. Finally, press J (for “jump”). You have now “jumped” to the Train Reference Frame – the screen now shows how objects are observed by the train passenger. The train is now in the stationary lane, while you are in a moving lane.

You may be puzzled that the sizes of objects on the screen are different than in the Ground Reference Frame. We ask that you accept for the time being that there are good reasons for those differences, and that the data provided by the software are correct. You will learn the reasons soon.

We hope you also recognize that the Ground Reference Frame clocks are *not* synchronized, according to the train passenger ! The simulation still begins, though, at the instant when you and the train passenger are side-by-side at $x_T=x_G=0$, and when your clock and the train passenger’s clock at that location read $t_G=t_T=0$. Since your clocks are not synchronized in the Train Reference Frame, though, one of the lightning bolts has already struck the train before the simulation begins ! In order to view the entire sequence of events from this reference frame, you will need to back up the simulation in time until you see the first lightning bolt strike the train. Do that before answering the questions for this part.