

SPAC 205

From Space and Time to Space-Time: Understanding Relativity

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HB 227

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GOALS:

- To introduce you to Special Theory of Relativity (SR)
- To have you understand and appreciate the impact of SR on our deeply entrenched views about space, time, and motion

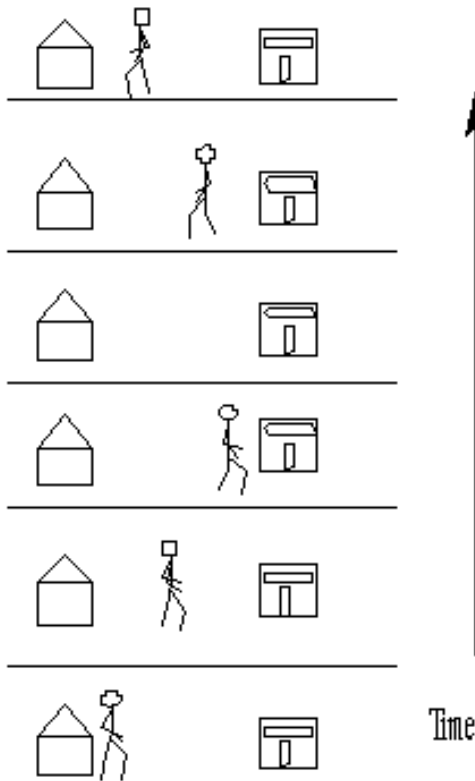
“The most beautiful experience we can have is the mysterious. It is the fundamental emotion that stands at the cradle of true art and true science. Whoever does not know it and can no longer wonder, no longer marvel, is as good as dead, and his eyes are dimmed. It was the experience of mystery—even if mixed with fear—that engendered religion. A knowledge of the existence of something we cannot penetrate, our perceptions of the profoundest reason and the most radiant beauty, which only in their most primitive forms are accessible to our minds: it is this knowledge and this emotion that constitute true religiosity. In this sense, and only this sense, I am a deeply religious man. . . I am satisfied with the mystery of life's eternity and with a knowledge, a sense, of the marvelous structure of existence—as well as the humble attempt to understand even a tiny portion of the Reason that manifests itself in nature.”



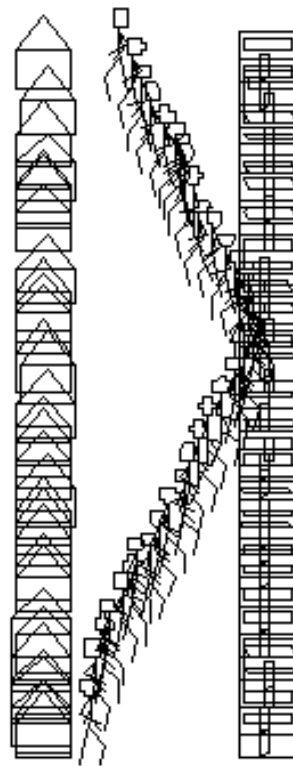
[A. Einstein, *Ideas and Opinions*, based on *Mein Weltbild*, edited by Carl Seelig. New York: Bonzana Books, 1954. pp. 10–11.]

Space-Time Diagrams

- A *space-time diagram*: A graphic representation of a physical phenomenon, such as motion, in four dimensions: three dimensions of space + one dimension of time
- Idealization: Leave only one (sometimes two) dimensions of space + one dimension of time
- A trip to a store (courtesy: Peter Bokulich):

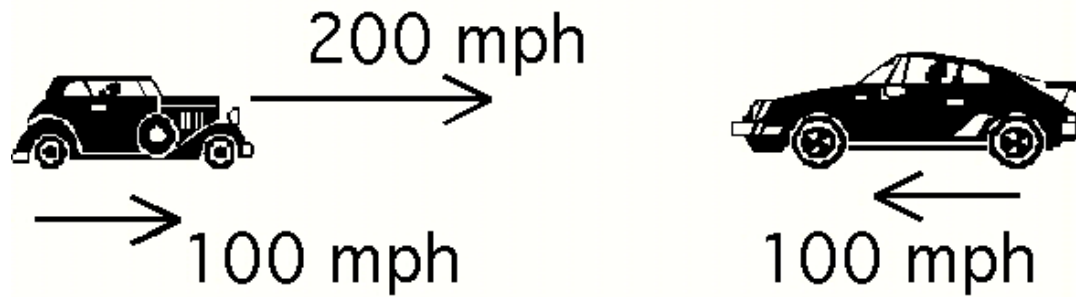


(a)

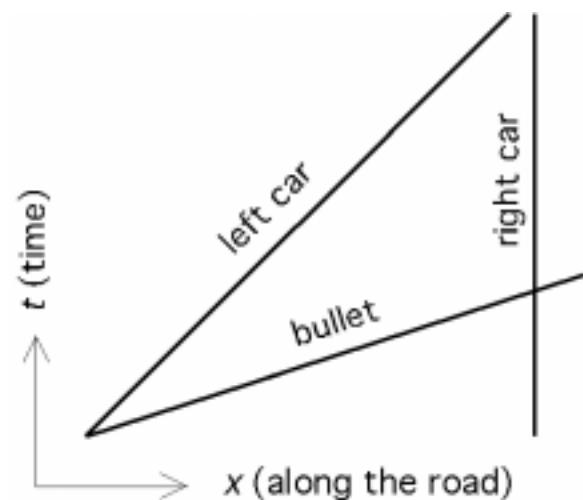
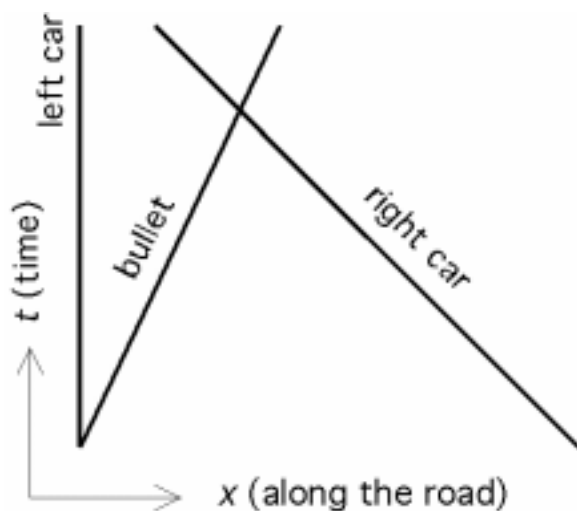
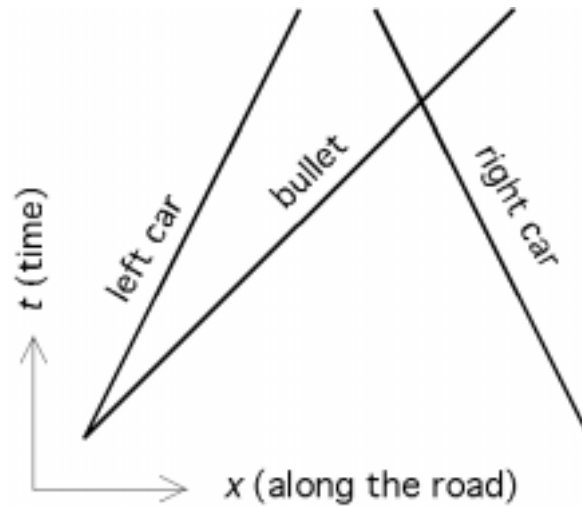


(b)

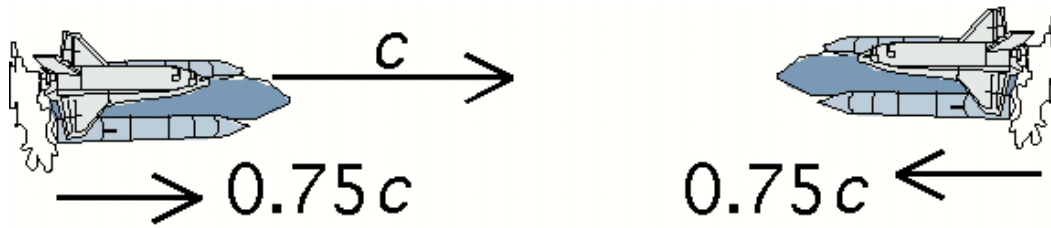
- Drive-by shooting: addition of velocities:



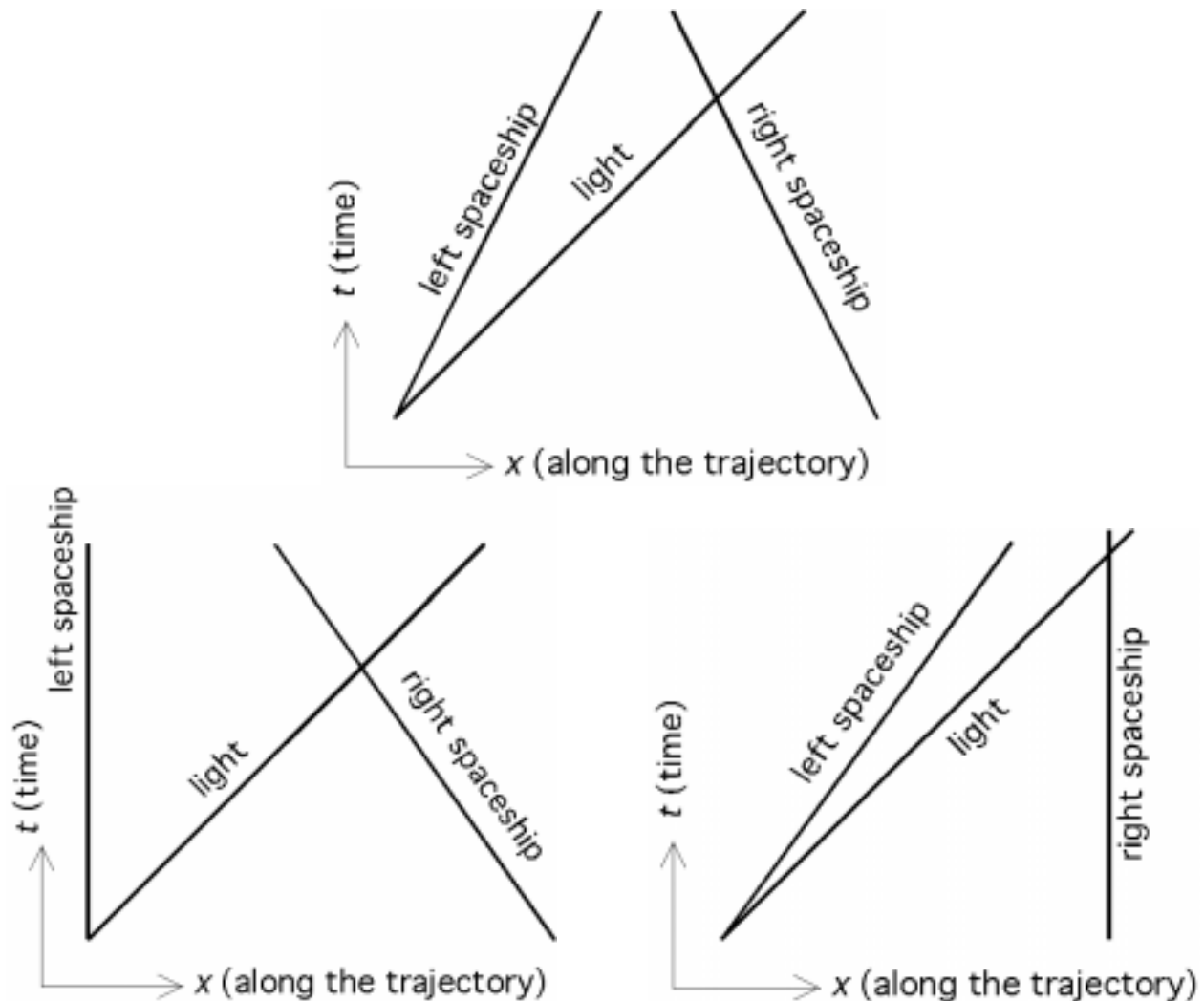
- Bullet velocity with respect to the left car?
- Bullet velocity with respect to a street observer?
- Bullet velocity with respect to the right car?



- Fly-by shooting: addition of velocities:



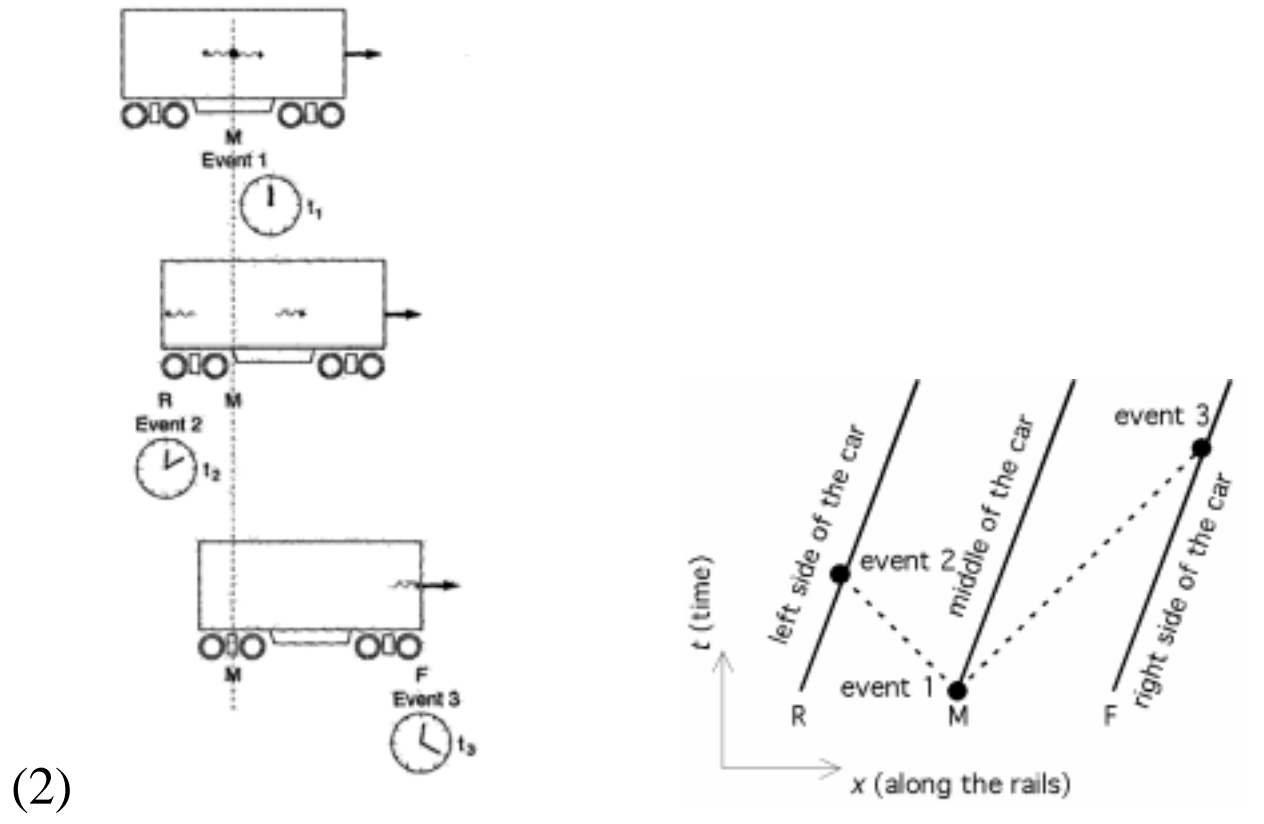
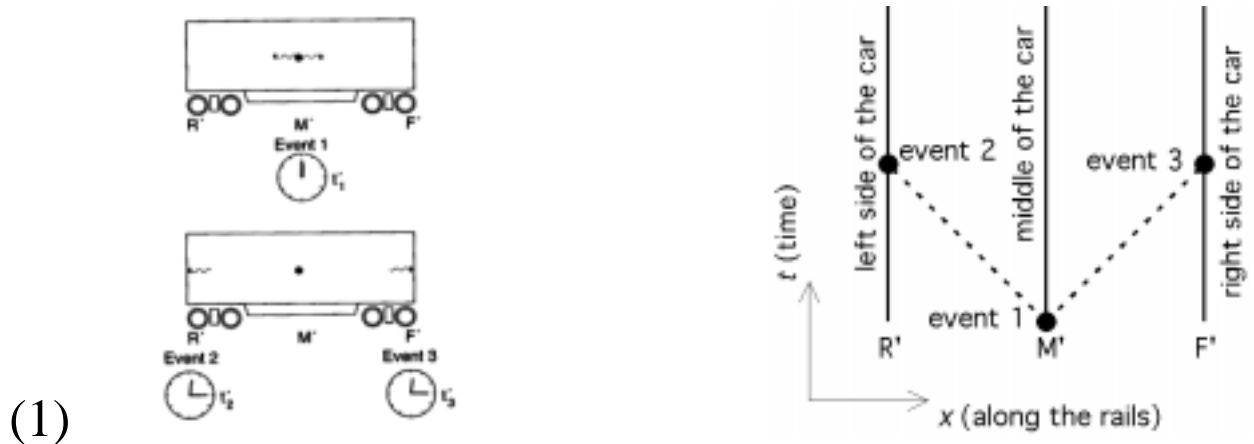
- Light beam velocity with respect to the left spaceship?
- Light beam velocity with respect to the cosmic observer at rest?
- Light beam velocity with respect to the right spaceship?



- The Einstein Train

Light flashes leave the middle of a train car and arrive at its ends. Question: Do they arrive simultaneously?

Answer: (1) **They do**, from the point of view of observers moving with the train; (2) **They don't**, from the point of view of ground observers.



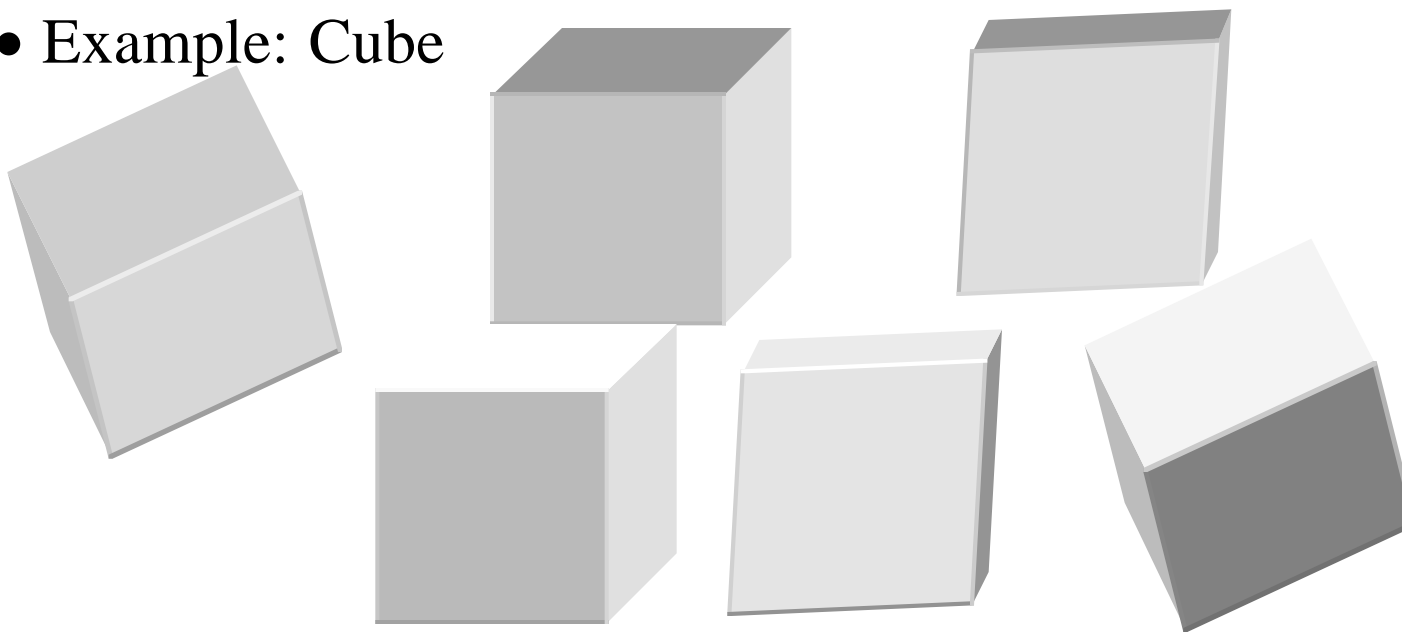
Lessons of Special Relativity

- We live in a four-dimensional world, the world of space-time.
- The spatial and temporal aspects of our world are inextricably mixed-up.
- This mixing-up explains the seemingly paradoxical results of relativity.
- Need to reshape your intuitions in such a way that these paradoxical results do not look counterintuitive anymore.
- Need to learn how to live in a four-dimensional world of space-time, how to think and visualize things in a spatio-temporal perspective.

Invariance (Objectivity) and Perspectivalism (Relativism)

- Perspectivalism: Any object or phenomenon in the world can be looked at from various perspectives. When so looked at, it presents itself in different ways. The result of observation is *relative* to a perspective.

- Example: Cube



- Invariance: There is something *permanent* standing behind all such changing images and perspectives.

The *three-dimensional* shape of the cube is *invariant*, hence *objective*

<p style="text-align: center;">Invariance \leftrightarrow Objectivity Perspectivalism (Relativism) \leftrightarrow Subjectivity</p>

Perspectives in Space-Time

- The Einstein Train: Is there a fact of the matter about which light ray arrived the first?
- Classical Physics: Of course, there is! Either the left ray arrived the first, or the right one.
- Special Relativity: NO! In one spatio-temporal perspective, the left ray arrived the first, in another they arrived simultaneously. In yet another perspective, the right ray was the first to arrive.
- Just as the cube presents itself in different ways in different spatial perspectives, the succession of events in the Einstein Train scenario looks differently in different *spatio-temporal perspectives*.

What *is* a “spatio-temporal perspective”?

- Different merely *spatial* perspectives can be easily associated with different positions (locations, vantage points) of different observers or with the changing position (location, vantage point) of a single observer.
- Different *spatio-temporal* perspectives (in the case of Special Relativity) are associated, not with positions of different observers, but with their different *velocities*.
- An observer at rest with respect to the train perceives the arrival of light signals as simultaneous. An observer standing still on the ground (and hence moving with respect to the train) perceives one of them occurring before the other.
- Question: Is there anything *invariant*, or *objective*, in the relativistic, spatio-temporal case? Are there any *facts of the matter* independent of the perspectives of various differently moving observers?
- Answer: YES!

- There is a fact of the matter about the intersection of the trajectory of the light signal with the end of the train. This is an *event* which occurs at a certain *space-time point*, that is, at a certain place in the universe and a certain time. It is invariant, hence objective.
- In an important sense, the *whole spatio-temporal diagram* representing the Einstein Train situation is also invariant—provided that we abstract from a particular assignment of spatial and temporal coordinates to the flashing, light ray arrival, and other events represented in the diagram. The assignment of particular space and time determinations is secondary; it is itself perspectival. But what these assignments are assigned to is not perspectival. It is invariant, hence objective.
- Perspectivalism (Relativism) is not something unique to Special Relativity. The interplay of the ideas of Perspectivalism/Relativism and Invariance has always had a role to play in physics, long before relativity. But SR has introduced a new *species* of Perspectivalism: the *spatio-temporal* Perspectivalism.
- Digression: This interplay between objectivity and perspectivalism is a very general phenomenon whose significance goes far beyond physics. It is present in any situation in which we have an interaction between the subject (who perceives something) and the object of his/her perception. There is something out there for us to perceive, something objective and invariant. But whenever we perceive it, the result invariably carries an imprint of some particular point of view, or perspective—just because there is a certain relation between the subject and the object. For example, a *cognitive* relation between the knower and what he or she gets to know, as in sciences. There is something out there, happening in the lab, and there is our interpretation of what's happening. Another example: an *aesthetical* relation between, say, a painter and what he depicts.