1.3: Events and Intervals Alone!

tools enough to chart matter and motion without any reference frame

Surveying locates a place

In surveying, the fundamental concept is **place**. The surveyor drives a steel stake to mark the corner of a plot of land — to mark a place. A second stake marks another corner of the same plot — another place. Every surveyor — no matter what his or her standard of north — can agree on the value of the distance between the two stakes, between the two places.

Every stake has its own reality. Likewise the distance *between* every pair of stakes also has its own reality, which we can experience directly by pacing off the straight line from one stake to the other stake. The reading on our pedometer — the distance between stakes — is independent of all surveyors' systems, with their arbitrary choice of north.

More: Suppose we have a table of distances between every pair of stakes. That is all we need! From this table and the laws of Euclidean geometry, we can construct the map of every surveyor (see the exercises for this chapter). Distances between stakes: That is all we need to locate every stake, every place on the map.

Physics locates an event

In physics, the fundamental concept is **event**. The collision between one particle and another is an event, with its own location in spacetime. Another event is the emission of a flash of light from an atom. A third is the impact of the pebble that chips the windshield of a speeding car. A fourth event, likewise fixing in and by itself a location in spacetime, is the strike of a lightning bolt on the rudder of an airplane. An event marks a location in spacetime; it is like a steel stake driven into spacetime.

Every laboratory and rocket observer — no matter what his or her relative velocity — can agree on the spacetime interval between any pair of events.

Wristwatch measures interval directly

Every event has its own reality. Likewise the *interval* between every pair of events also has its own reality, which we can experience directly. We carry our wristwatch at constant velocity from one event to the other one. It is not enough just to pass through the two physical locations—we must pass through the actual *events;* we must be at each event precisely when it occurs. Then the space separation between the two events is zero for us — they both occur at our location. As a result, our wristwatch reads directly the spacetime interval between the pair of events:

$$\begin{aligned}
(\text{interval})^{2} &= \begin{bmatrix}\text{time}\\ \text{separation}\\ \text{(meters)}\end{bmatrix}^{2} - \begin{bmatrix}\text{space}\\ \text{separation}\\ \text{(meters)}\end{bmatrix}^{2} \\
&= \begin{bmatrix}\text{time}\\ \text{separation}\\ \text{(meters)}\end{bmatrix}^{2} - [\text{ zero }]^{2} \\
&= \begin{bmatrix}\text{time}\\ \text{separation}\\ \text{(meters)}\end{bmatrix}^{2} \qquad\qquad [\text{wristwatch time}]
\end{aligned}$$

The time read on a wristwatch carried between two events — the interval between those events — is independent of all laboratory and rocket reference frames.

More: To chart all happenings, we need no more than a table of spacetime intervals between every pair of events. That is all we need! From this table and the laws of Lorentz geometry, it turns out, we can construct the space and time locations of events as observed by every laboratory and rocket observer. Intervals between events: That is all we need to specify the location of every event in spacetime.

''Do science" with intervals alone

In brief, we can completely describe and locate events entirely without a reference frame. We can analyze the physical world — we can "do science" — simply by cataloging every event and listing the interval between it and every other event. The unity of spacetime is reflected in the simplicity of entries in our table: intervals only.

Of course, if we want to use a reference frame, we can do so. We then list in our table the individual northward, eastward, upward, and time separations between pairs of events. However, these laboratory-frame listings for a given pair of events will be different from the corresponding listings that our rocket-frame colleague puts in her table. Nevertheless, we can come to agreement if we use the individual separations to reckon the interval between each pair of events:

$$(\text{ interval })^2=(\text{ time separation })^2-(\text{ space separation })^2$$

That returns us to a universal, frame-independent description of the physical world.

When two events both occur at the position of a certain clock, that special clock measures directly the interval between these two events. The interval is called the **proper time** (or sometimes the **local time**). The special clock that records the proper time directly has the name **proper clock** for this pair of events. In this book we often call the proper time the **wristwatch time** and the proper clock the **wristwatch** to emphasize that the proper clock is carried so that it is "present" at each of the two events as the events occur.

In Einstein's German, the word for proper time is *Eigenzeit*, or "own-time," implying "one's very own time." The German word provides a more accurate description than the English. In English, the word "proper" has come to mean "following conventional rules." Proper time certainly does not do that!

Question and Answer

Hey! I just thought of something: Suppose two events occur at the same time in my frame but very far apart, for example two handclaps, one in New York City and one in San Francisco. Since they are simultaneous in my frame, the time separation between handclaps is zero. But the space separation is not zero-they are separated by the width of a continent. Therefore the square of the interval is a negative number:

$$\begin{aligned}(\text{ interval })^2 &=(\text{ time separation })^2-(\text{ space separation })^2 \\ &=(\text{ zero })^2-(\text{ space separation })^2 \\ &=-(\text{ space separation })^2\end{aligned}$$

How can the square of the spacetime interval be negative?

Answer

In most of the situations described in the present chapter, there exists a reference frame in which two events occur at the same place. In these cases time separation predominates in all frames, and the interval squared will always be positive. We call these intervals **timelike intervals**.

Euclidean geometry adds squares in reckoning distance. Hence the result of the calculation, distance squared, is always positive, regardless of the relative magnitudes of north and east separations. Lorentz geometry, however, is richer. For your simultaneous handclaps in New York City and San Francisco, space separation between handclaps predominates. In such cases, the interval is called a **spacelike interval** and its form is altered to

$$(\text{interval})^2=(\text{ space separation })^2-(\text{ time separation })^2 \qquad [\text{when spacelike}]$$

This way, the squared interval is never negative.

The *timelike* interval is measured directly using a wristwatch carried from one event to the other in a special frame in which they occur at the *same place*. In contrast, a *spacelike* interval is measured directly using a rod laid between the events in a special frame in which they occur at the *same time*. This is the frame you describe in your example.

Spacelike interval or timelike interval: In either case the interval is invariant - has the same value when reckoned using rocket measurements as when reckoned using laboratory measurements. You may want to skim through Chapter 6 where timelike and spacelike intervals are described more fully.

Note

- Surveying locates a place
- Physics locates an event
- Wristwatch measures interval directly
- "Do science" with intervals alone
