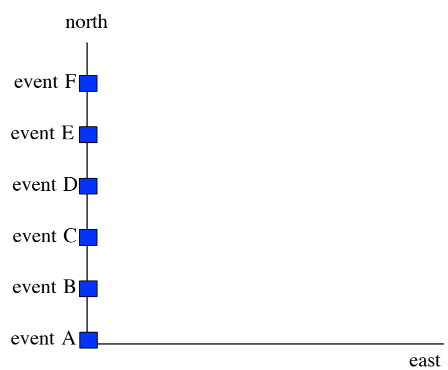
How Can Speed of Light Be Same in All Frames of Reference?

Scenario 1: Consider a vehicle (you're looking down on it) moving 100 mph directly north across a stretch of highway. What would you observe?

Looking strictly at the geometry, you would see no motion in the "east" direction with all the motion in the "north" direction.

NOTE: For the sake of simplicity, and to make things easier later on, I am going to identify each of the car positions shown as "events," and I'm going to define the "distance" between two events as an "interval."

Using that terminology, notice that the *interval* between *event A* and *event B* is the same as the *interval* between *event D* and *event E*.

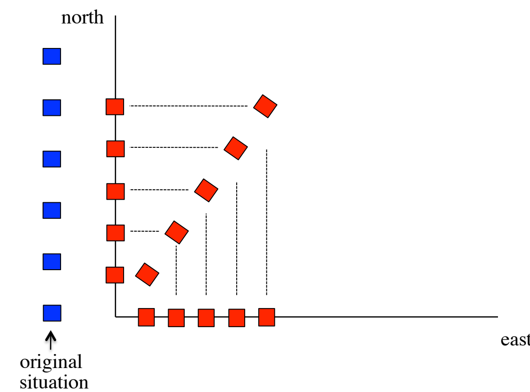


Scenario 2: How would things look if the car wasn't moving strictly due north but, rather, north-east?

In that case, the vehicle would still be moving with velocity 100 mph (which is to say, the intervals wouldn't have changed), but you would observe *less northerly motion*.

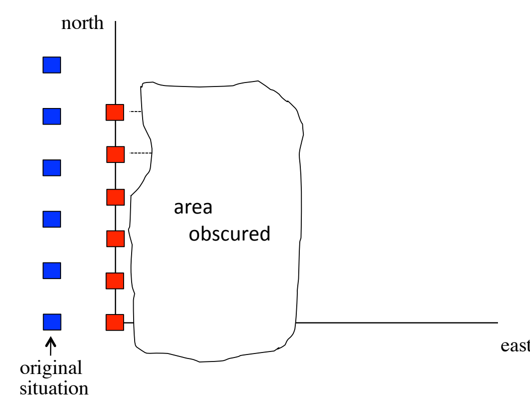
That is, the vehicle wouldn't go as *far* to the north (per interval) as it did *Scenario 1*.

That is, the vehicle wouldn't have traveled as far along the *northerly* axis as had been the case.



Put still differently, the rate of vehicle travel moving along the northerly axis would diminish. (Note that, for comparison sake, the blue cars show *Scenario 1's* outcome.)

What this additionally means, AND THIS IS HUGE, is that if *all you could observe was the northerly motion of the car*, the vehicle would have appeared to have SLOWED DOWN even though the vehicle's real motion wouldn't be any different for the driver than it ever was!

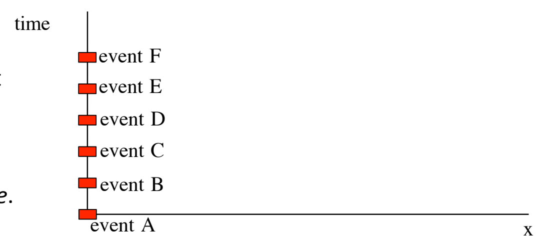


So let's switch gears and talk about Einstein's physics.

In relativity, TIME is a part of the fabric of space—it is one of the four SPACE-TIME coordinates, and it has every bit as much weight with respect to a body's changing motion as does the body's x or y coordinate.

What this means is that if we were to track the motion of, say, an ant constrained to move through time along the the x-axis only, we should find that the characteristics we observed with the northerly/easterly grid should hold for the time/spatial-position plot we generate for the ant.

Before we can look at our ant moving through *space-time*, though, there are several observations we need to make.



Observation 1: As was just pointed out, in this new scenario and its associated coordinate axes, our ant is moving through *space-time*. And paralleling our vehicle Scenario 1, the graph suggests that the ant is moving along one axis—the time axis—while not moving with respect to the second axis—the *x*-axis. (In fact, that might not be exactly what's going on, but that possibility will be fleshed out later.)

Observation 2: Just as was the case with Scenario 1, the *interval* between *event A* and *event B* is the same as the *interval* between *event D* and *event E*.

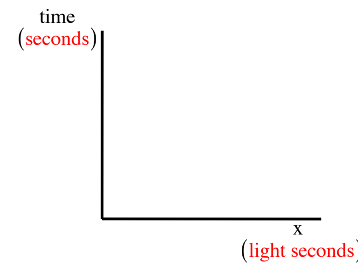
Observation 3: No properly trained student would graph the two-dimensional motion of Scenario 1 with the northerly-coordinate having the units of *kilometers* and the easterly-coordinate having units of *miles*. Units parity matters.

If we are going to treat *time* like a coordinate with the same properties as, say, an *x-coordinate*, we need *units parity* here, also. That is, we either need to find a way to give spatial coordinates *time-like* units or time coordinates *spatial-like* units. The way *relativity* does this is as follows:

DISTANCE can be measured with time-like unit if we define the distance light travel in one second as *one light-second*. Consequentially,

$$1 \text{ light-second} = 3\text{x}10^{8} \text{ meters}$$

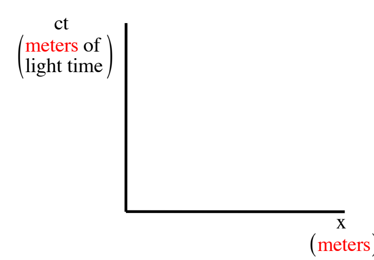
(a very large number). If we use this the time axis will have the units of *seconds* and the x-axis will have the units of *light-seconds*. Such a grid is shown to the right.



Alternately, TIME can be measured with distance-like unit if we define the time it takes light to travel one meter as *one meter-of-light-time*. Consequentially,

$$1 \text{ meter-of-light-time} = 3.33\text{x}10^{-9} \text{ seconds}$$

(a very small number). If we use this, the time axis will have the units of *meters-of-light-time* and the x-axis will have the units of *meters*. Such a grid is shown to the right.

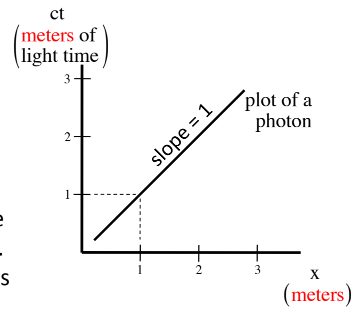


Note that "t" has the units of seconds and "ct" has the units of meters.

Bottom line: We are going to track the motion of our ant, constrained to move through time along the the x-axis, and we are going to execute that plot assuming that the coordinate's units are *meters*.

Observation 4: This has nothing to do with the ant, but it's important: What will the motion of a *photon of light* look like if graphed on our grid?

By definition, light travels one meter spatially in *one meter-of-light-time*, so the slope of that plot would be 1 (see sketch). (Kindly remember that a slope of 1 follows a path that is at 45° to the time axis.)



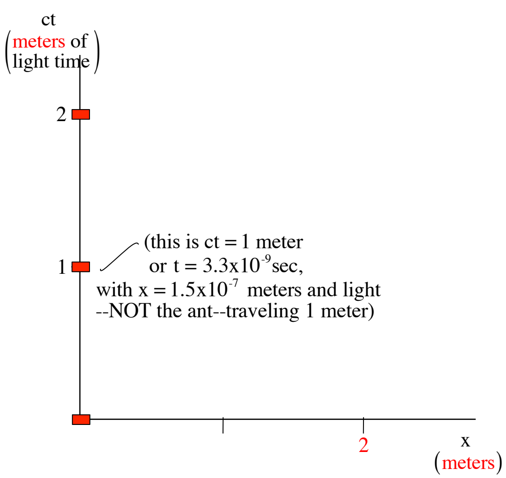
Observation 5: As nothing can go faster than the speed of light, there will never be a motion-plot on our grid that has a slope *less than 1*.

Observation 6: This is important. Notice that any object that has a plot slope a little above 1 is modeling motion whose velocity is *very near the speed of light*.

Observation 7: Because cars go, what, 100 mph (around 45 m/s) with ants moving a whole lot slower, and because 1 time-unit in *meters-of-light-time* is equal to $3.33\text{x}10^{-9}$ seconds, it makes sense that it will take lots and lots of these *time-units* for any object to travel 1 meter.

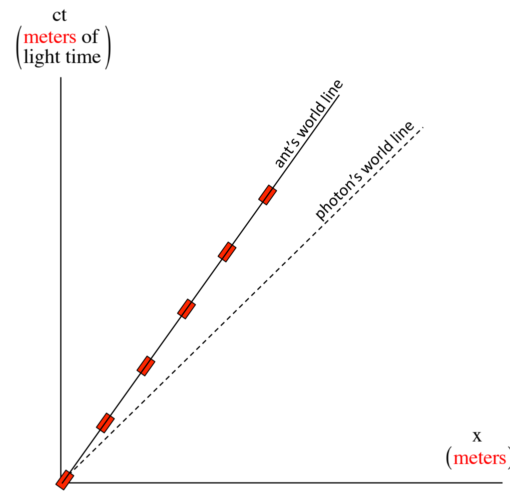
Put a little differently, the graph of ANY object that is moving with everyday velocities is going to have a slope that is so close to infinity that it will look as though the body is hardly moving along the x-axis at all.

In short, it will look like the graph shown above and to the right.



Observation 8: What that means is that if our ant is going to mimic our *Scenario 2'* vehicle situation on this grid, the ant can no longer be traveling at reasonable speeds. It now has to be moving REALLY, REALLY FAST . . . like, close to the speed of light.

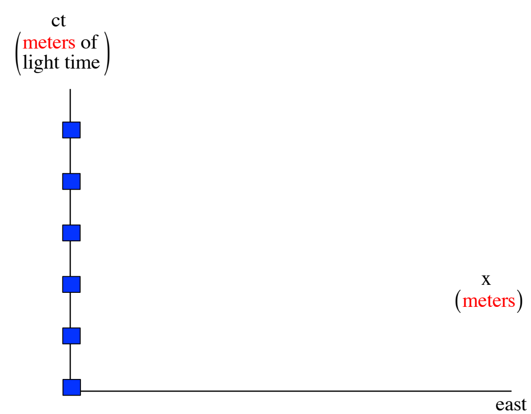
Fortunately, that's OK as the phenomenon we are trying to get a grip on only shows itself when objects are moving close to the speed of light.



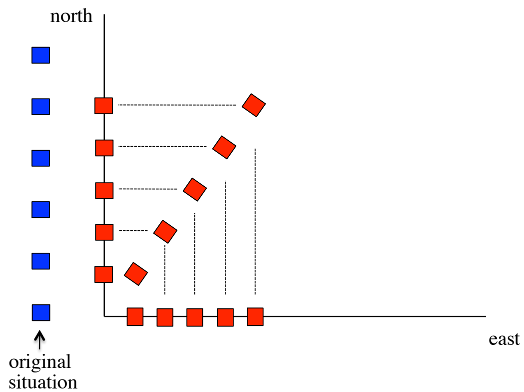
So let's take a run at this in the same way we did with our first circumstance.

In *Scenario 1*, it was observed that the vehicle's motion entailed equally spaced intervals that were proceeding along the vertical (northerly) axis.

With our ant, we still have equally spaced intervals that proceed along the vertical (time) axis. What's different here is that our interpretation of the motion. In the case of the ant, the ant appears spatially stationary (that, or it's moving really, really, really slowly) but is definitely moving through time.



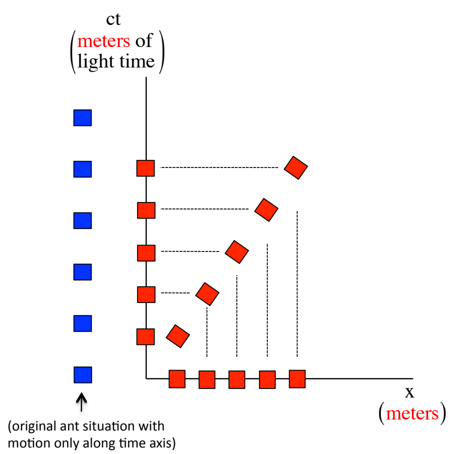
In *Scenario 2*, we kept the intervals spaced just as they were in *Scenario 1* (this corresponded to the vehicle continuing to move with the same velocity as before), but we angled the "motion" so that it was moving in both a northerly and easterly manner. The observation that we made was that even though the intervals hadn't changed, the vehicle's *northerly progression was now less than it was*.



With our ant, we will keep the intervals the same but, again, the interpretation will be different.

To begin with, for the angle to be a little above 45° as shown, the ant must be moving with a velocity close to the speed of light.

Second, the motion of the ant *along the time axis* is different than it was.



As viewed from the "outside," the rate of the ant travel along the time axis has diminished. THE ANT'S TIME APPEARS TO HAVE SLOWED DOWN.

This doesn't mean that the ant sees its world slowed down. The intervals are still the same for it, so it perceives time moving as usual.

What it means is that as viewed by someone who isn't in the ant's frame of reference, time in the ant's world (the projection of the ant's space-time motion onto the time axis) has slowed.