Concept Check

Suppose I lock you in a spaceship. Can you tell whether or not the spaceship is accelerating, and if so, how?

Can you tell whether or not the spaceship is moving (at constant velocity), and if so, how?

Can you tell whether or not the spaceship is turning (at constant speed), and if so, how?

More serious question

I said that it means nothing to ask "am I moving or not?" All that has meaning is "am I moving relative to {you}?"

But wait: if when I move, my clock ticks slower, can't I just check, and if my clock starts ticking more slowly, I conclude "I must be moving"?

HOW DO YOU TELL IT'S TICKING SLOWLY?
You compare it to something else -- maybe you find your heart beats twice per clock-tick instead of only once.

But your heart is *just another clock*.

It also obeys the laws of physics.

If the laws of physics are *invariant* (w.r.t a *Lorentz transformation*), then my heartbeat takes the same number of (*my*) seconds no matter how fast I move – you think my clock ticks slower *and my heart beats slower*.

In fact, these *invariant laws of physics* must then actually mean that *everything really does happen more slowly* (as seen in someone *else*'s reference frame) when you are moving.

(Re-)Summary of the philosophy behind relativity

Einstein: **time is what a clock measures.**

distance is what a ruler measures.

How to build a clock?

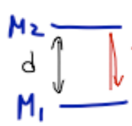
Find something which always takes the same amount of time (e.g., the Sun going around the Earth).

Einstein's proposal: light travelling a known distance (since we know the speed of light is constant!)

Question: how then do we base a ruler on physical laws??

Moving clocks tick more slowly

If the speed of light is the thing we know is constant, then let the "tick" of a clock be the time it takes light to go back and forth between two mirrors.



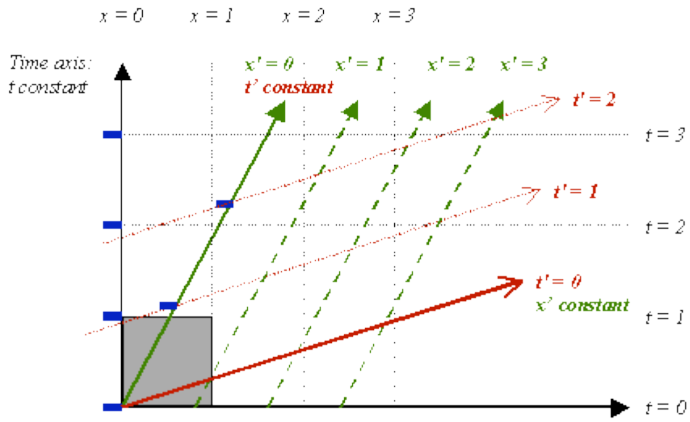
travels 2d at a velocity c; one "tick" is $\frac{2d}{c}$

the light in this moving clock needs to travel further, but still moves at c → the "tick" takes longer

IF SO, WHY DIDN'T ANY ONE NOTICE TILL 1905?!

c = 300,000 km/s. Even at 3600 kph (1 km/s), the base of that triangle is 300,000 times smaller than the height. The "correction" to Newton would be one part in 100 billion. Modern clocks confirm this!

Reference frames

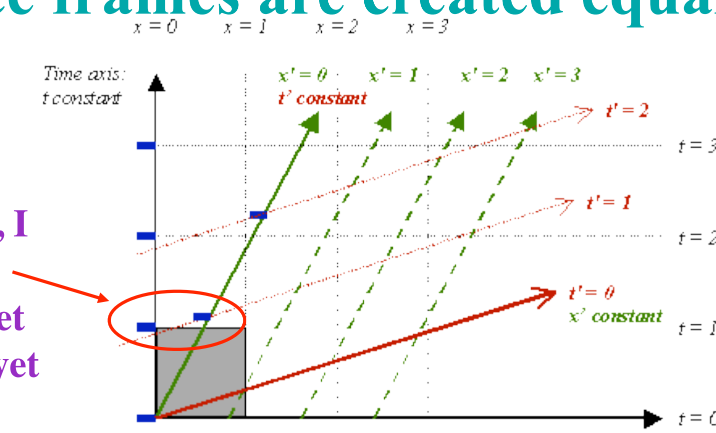


Even in classical physics, we might use different clocks, or rotate our axes. But time was independent of position, and all observers agreed on durations and distances.

In SR, we find that while clocks *at the same place* can be synchronized, and that distant observers *moving at the same speed* can share an entire reference frame, a clock which ticks once a second in a moving frame ticks less than once a second in a stationary frame (*time* is different in the two frames).

All reference frames are created equal

At t=1 (the first blue dot up my time axis), I think moving Sue's clock hasn't ticked yet (her first blue dot is yet further up).



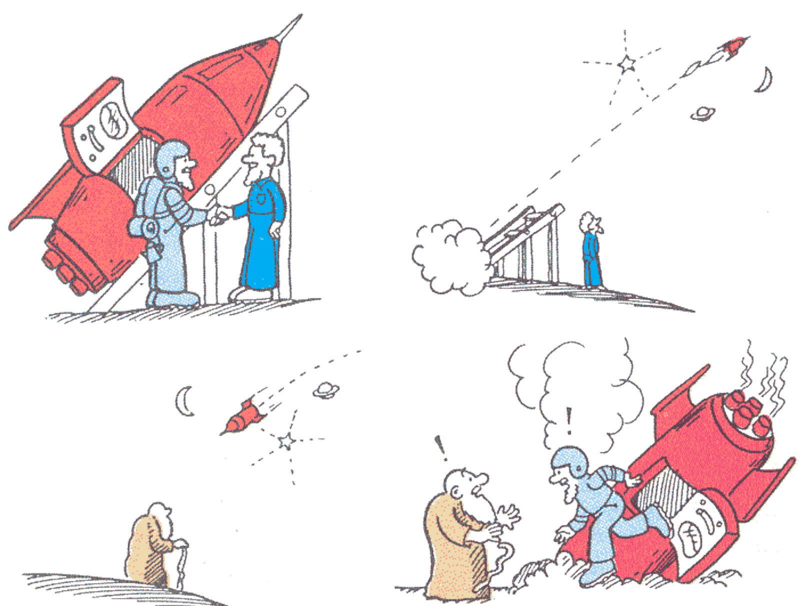
But at t'=1 (her first blue dot), *she* thinks *my* clock hasn't ticked yet (my first blue dot is yet further up than her "tilted" t'=1 axis). Relativity of simultaneity makes this okay.

At x=0, one of her clocks would tick before mine.

But at x'=0, one of my clocks would tick before hers.

In her frame, *my two clocks* aren't synchronized; in mine, hers aren't.

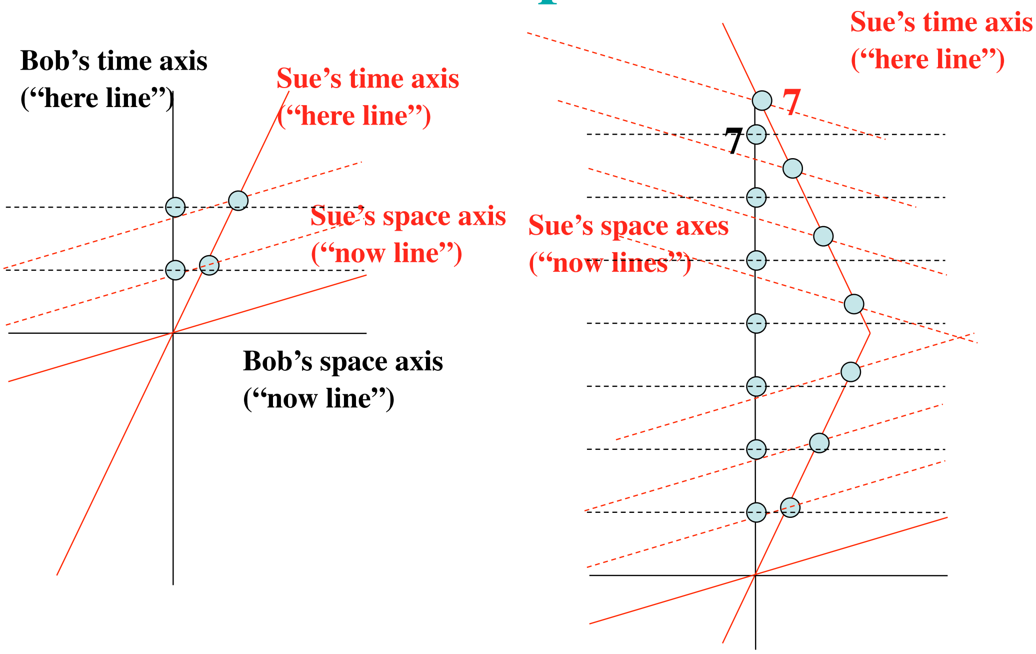
The twin paradox



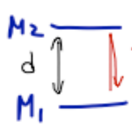
Could a returning spaceman really be younger than his twin?

What about all frames being equal? Doesn't he think the earthbound twin should be the younger one?

The twin paradox



Another problem with moving clocks...



travels 2d at a velocity c, one "tick" is $\frac{2d}{c}$

the light in this moving clock needs to travel further, but still moves at c
→ the "tick" takes longer

What if my light clock were moving *upwards* instead of sideways?

Comparing two clocks...

http://www.upscale.utoronto.ca/GeneralInterest/Harrison/SpecRel/Flash/MichelsonMorley/MichelsonMorley.html

So if your "vertical clock" and your "horizontal clock" are the same length, they will have the same tick rate (light travels at the same speed in all directions).

But a stationary observer would observe your horizontal clock to run even slower than your vertical clock...

Obviously, from *your* point of view, your two clocks still tick at the same rate.

From my (stationary) perspective, do your clocks tick at the same rate or not?

If I see your horizontal clock tick faster than I expect, but I know light travels at the same constant speed, what can I conclude?

Length contraction

Light *is our ruler*:
if it took the same time to traverse the horizontal and vertical clocks, *must* have travelled the same distance in both cases.

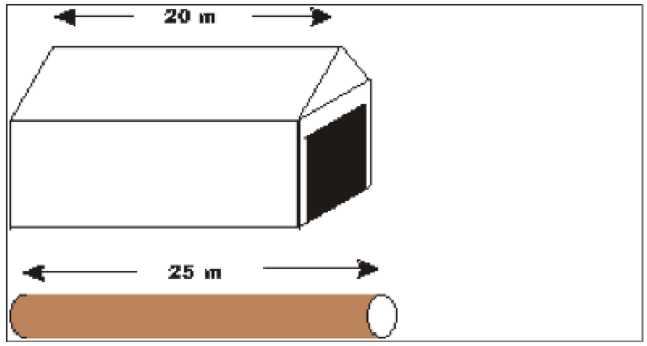
The same way moving clocks run slow,
moving metersticks get short –
but only along the direction of travel.

Once more: if we are moving relative to each other, then
***in my reference frame*, your clocks are slow and your rulers shrink;**
***in your reference frame*, my clocks are slow and my rulers shrink.**

Only by thinking about how measurements of space and time are connected (e.g., by light signals bouncing back and forth), and what this means about simultaneity et cetera, can we make this all consistent.

This is what Einstein means by "spacetime."

The Barn "Paradox"



When the pole moves at 0.7c, it looks short enough (in my reference frame) to fit.

But in *its* reference frame, it's the barn which is moving, so it surely doesn't fit!