

First, some practical matters

- (1) A proposed title for your term paper should be emailed to your TA for approval by 3 November (I will post some sample suggestions)**

It should critically examine a scientific topic which builds on material we have discussed in class, but going either further or deeper than we have during the course. It is expected that you will consult a range of published sources, and use proper footnotes (or endnotes) and a complete bibliography. The paper should demonstrate your ability to analyze conceptual questions about the science critically, making logical arguments and *distinguishing areas where reasonable people could differ from those where the answer is more or less clear-cut.*

- (2) An outline or preliminary bibliography should be submitted for approval by 17 November**

- (3) Start working on the paper early. It will be due the last week of class.**

The Barn “Paradox”

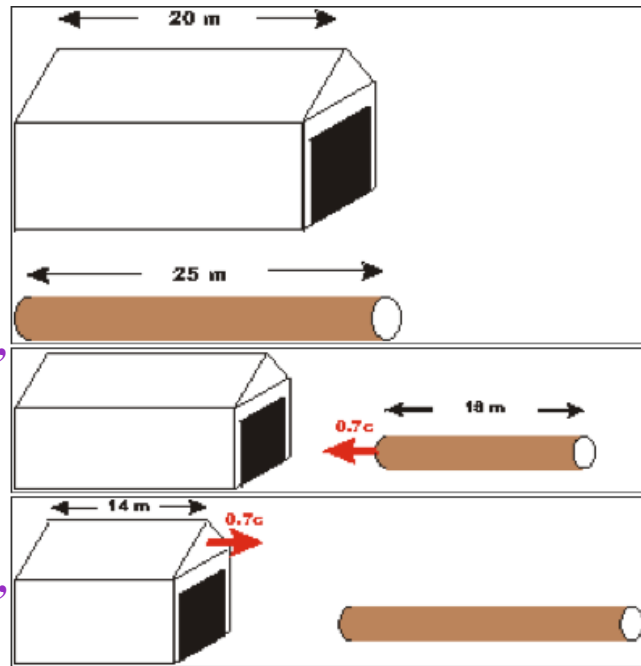
Niels Bohr:

**“How wonderful that we have met with a paradox.
Now we have some hope of making progress.”**

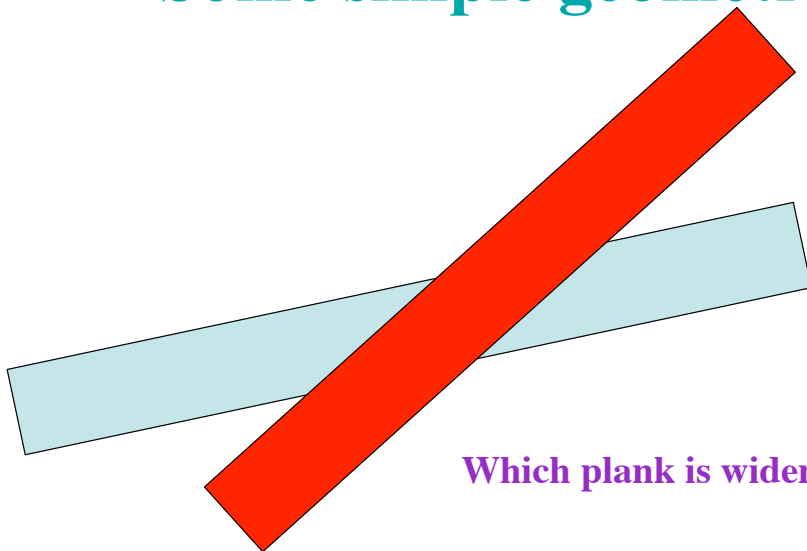
The Barn “Paradox”

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!

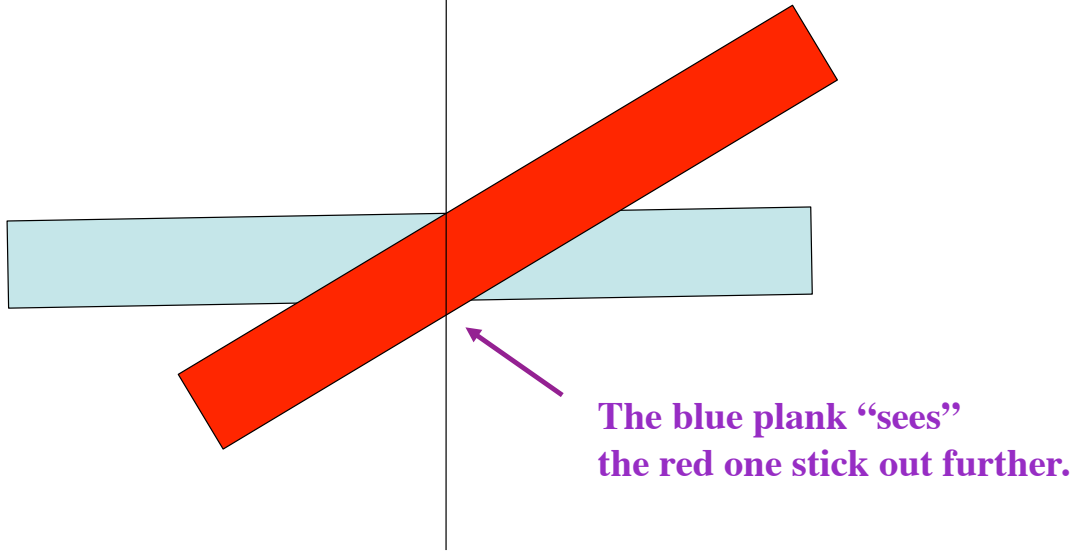


Some simple geometry



Which plank is wider?

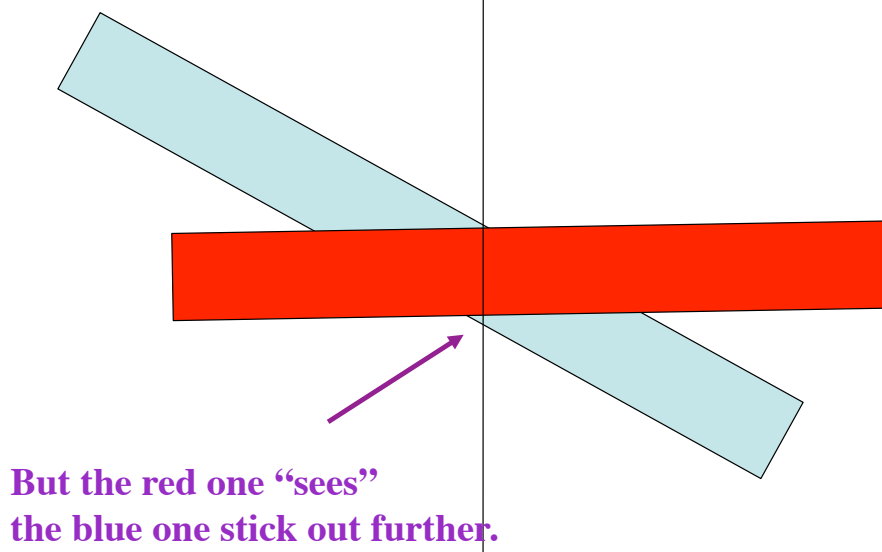
Some simple geometry



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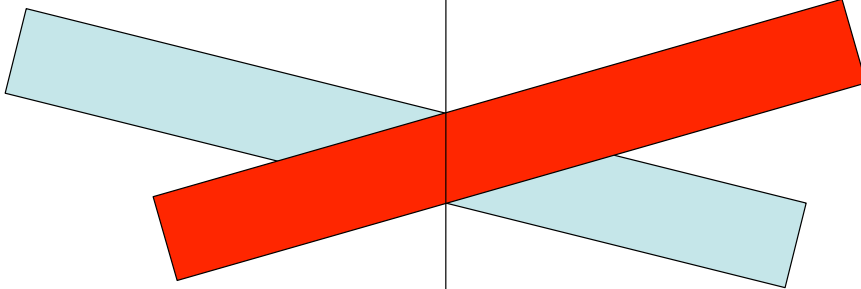
Some simple geometry



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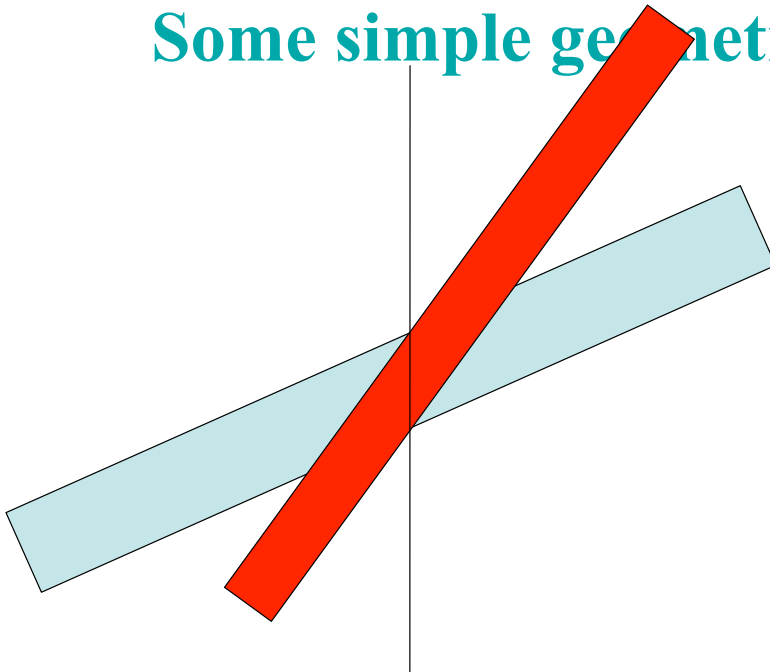
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Some simple geometry



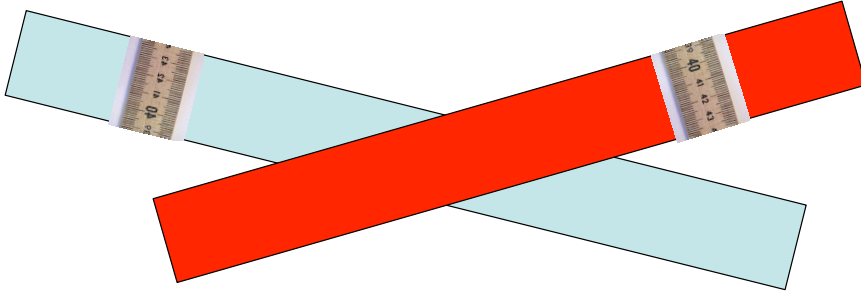
If we choose to look at them this way, they seem the same...

Some simple geometry



But that doesn't mean anything; we could always draw *some* line that makes any two planks "look the same" this way.

Some simple geometry



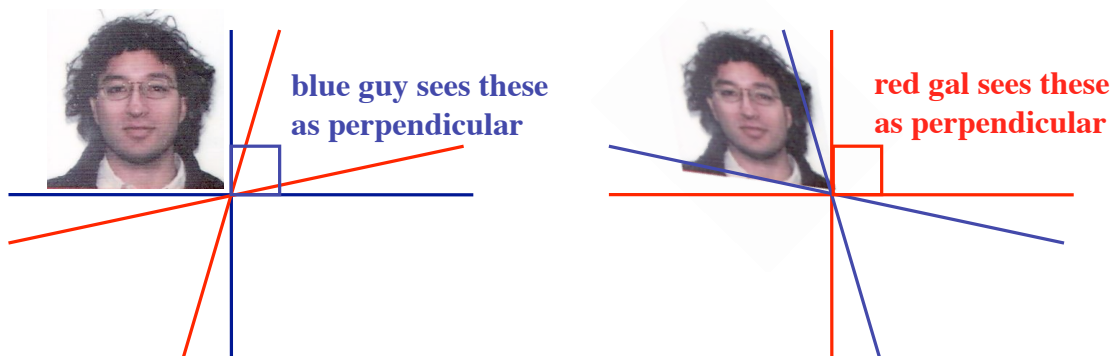
Conventionally, we *define* width by measuring *perpendicular* to something.

(This is like defining “the length of the pole”
as “the length of the pole *at some instant in time*”)

The problem with this “convention”

Rotating things in normal space, we all agree about “perpendicular”, so we can agree on this convention.

But in relativity, when we “rotate” things (i.e., when we look at them from a moving reference frame), they seem to distort. We can’t make a priori agreement about what “perpendicular” means.

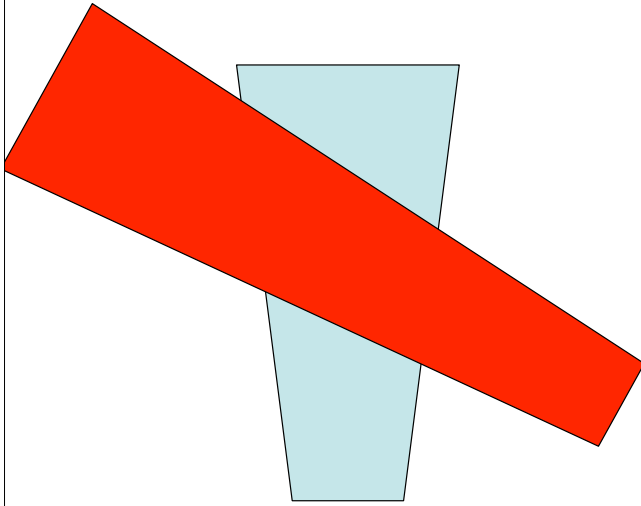


Even worse...

What if their widths aren't constant?

Which one is wider "here"?

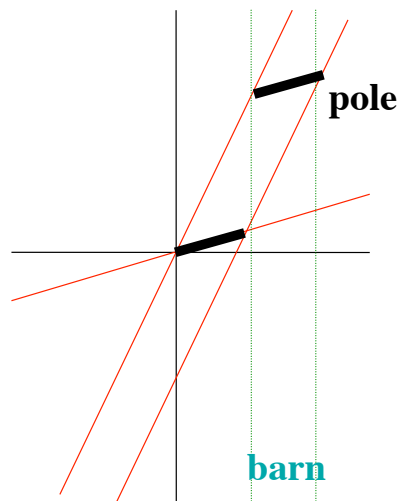
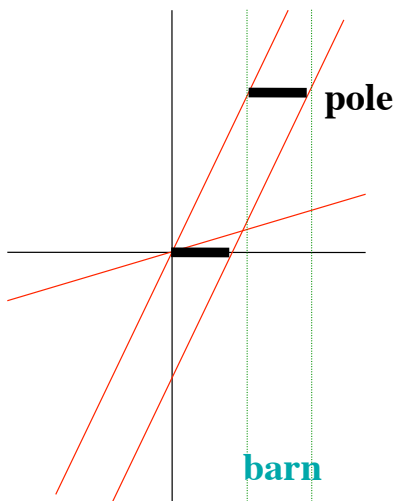
What does "here" mean?



The barn paradox & simultaneity

Barn's perspective

Moving pole's perspective

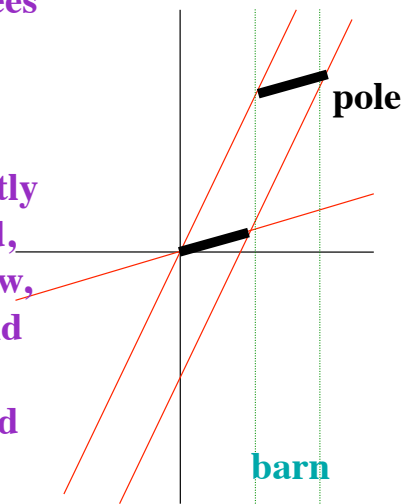


The barn paradox & causality

Moving pole's reference frame

At the instant the barn-owner sees the pole hit the far end of the barn, the other end has already entered...

But if the barn wall were perfectly solid and the pole perfectly rigid, then from the pole's point of view, it would have reached the far end before getting fully inside and gotten stopped; its left end would *never* make it into the barn.



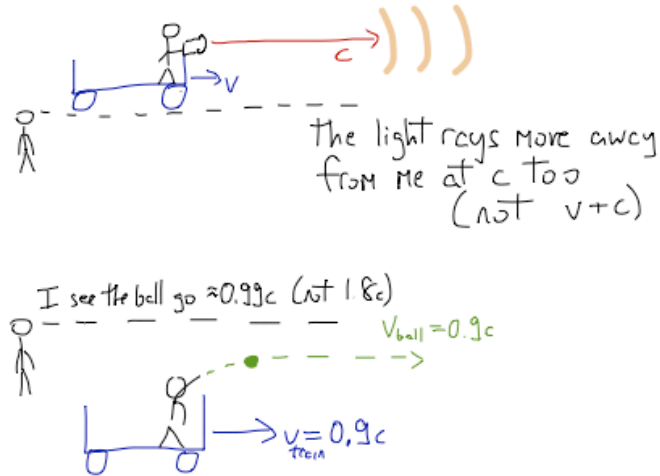
So did the left end ever get in at all?

The cosmic speed limit & causality

Nothing can travel faster than light -- *not even information.*

Thus the back of the pole "*doesn't know*" the front hit the wall, and is too stupid to stop. It really does make it into the barn, either because the pole compresses (since the back keeps moving after the front stops) or because the barn door breaks, or both.

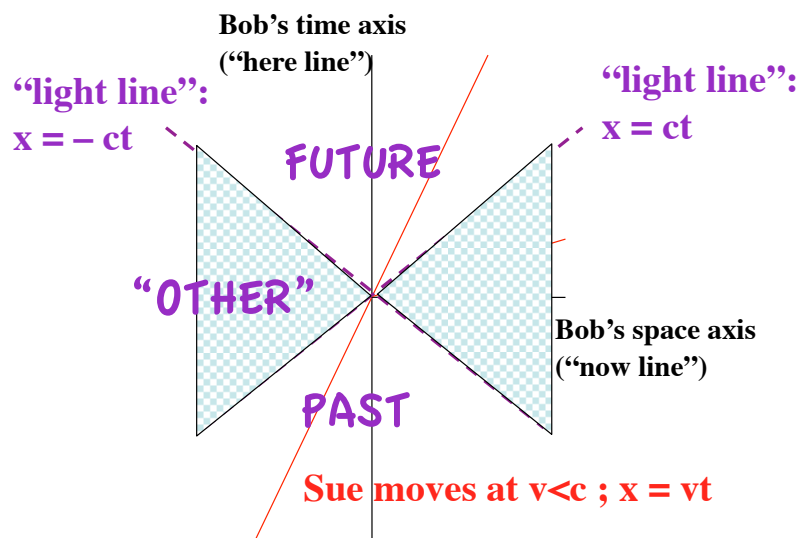
Why can't I make something go faster than light? (part 1)



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Why can't I make something go faster than light? (part 2)

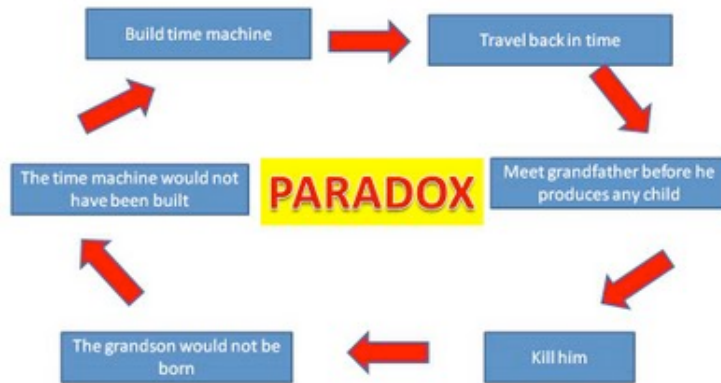


Any signal I sent faster than light could seem to some other observer to move backwards in time (the worry at CERN/Gran Sasso last yr)!
 Any signal I send *slower* than light goes forward in time in all frames.

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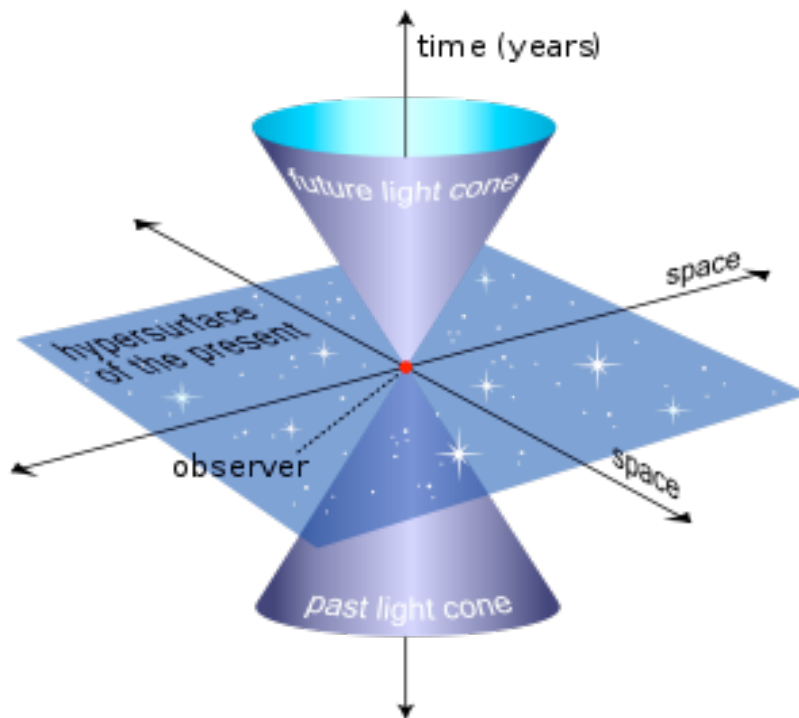
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The “grandfather paradox”



“Causality”: past events can influence future events, but never the other way around.

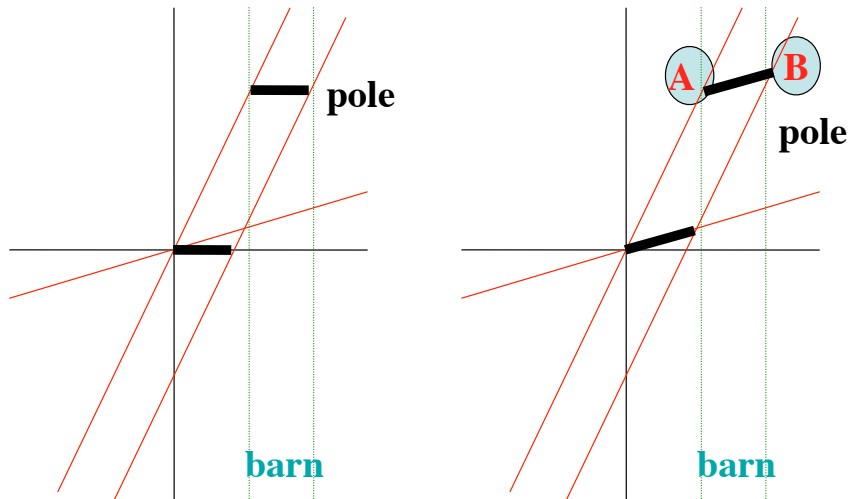
We live in 4 dimensions



The barn paradox & spacetime

Barn's reference frame

Moving pole's reference frame

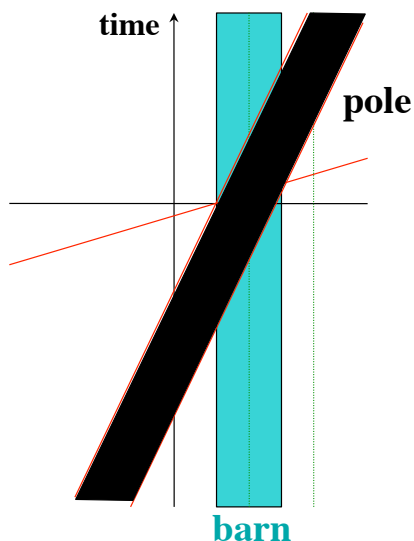


Even to someone in the barn's reference frame, the distance between A and B is larger than the length of the barn; only, he thinks A & B refer to the two ends *at different times*, while someone running with the pole thinks it's one time.

The barn paradox & spacetime

The pole and the barn both exist everywhere in time

Barn's reference frame

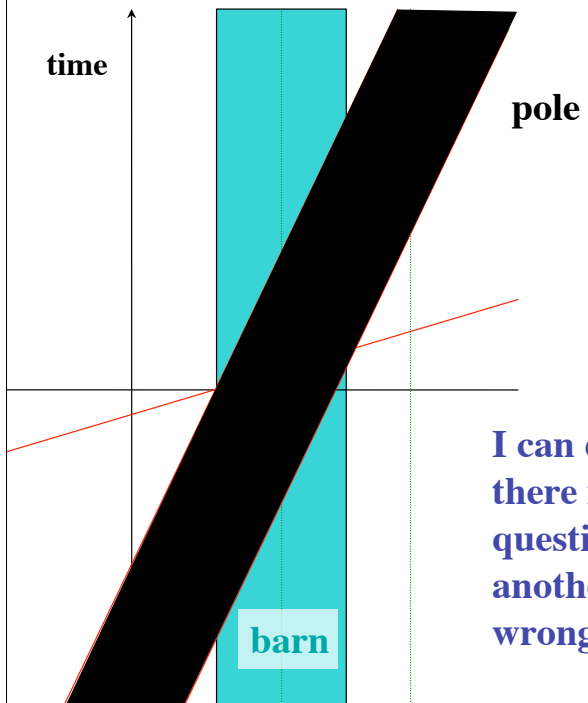


So, is the pole ever fully inside the barn?

What does that mean??

The barn paradox & spacetime

The pole and the barn both exist everywhere in time



So, is the pole ever fully inside the barn?

What does that mean??

I can draw whichever lines I want, but there is no objective meaning to the question. One “frame” says “yes”; another says “no.” Neither is right or wrong.

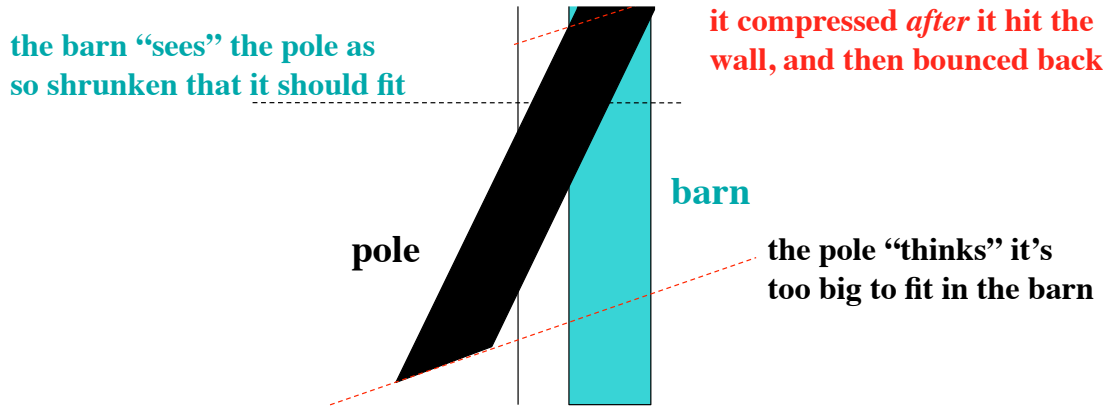
New-Age Digression

Does this mean that all times exist at once?

Or that everything happens at the same time?

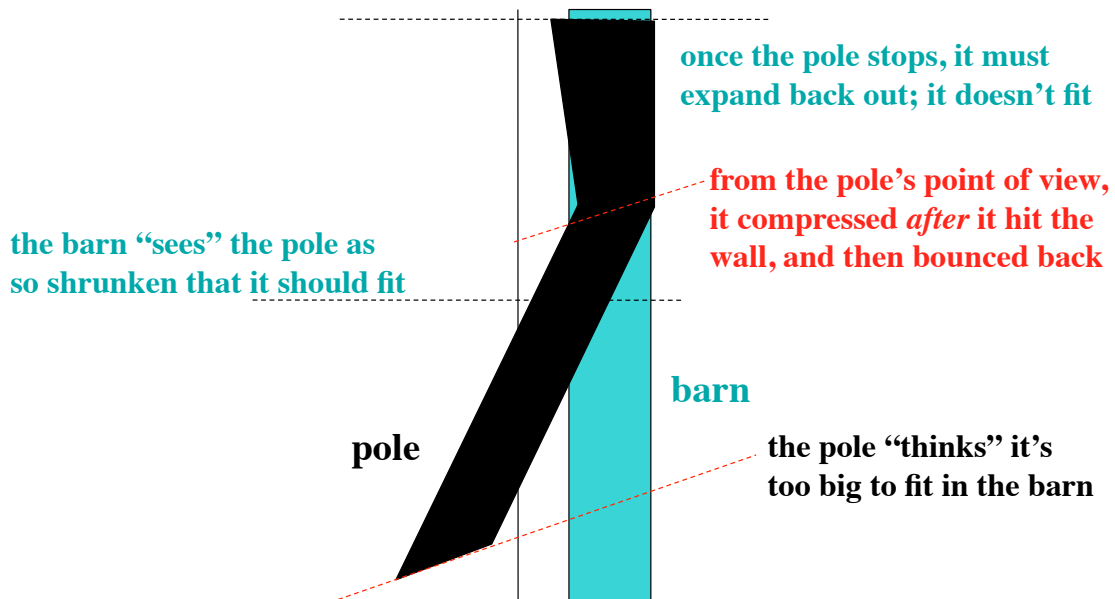
The barn paradox & spacetime

What would “*really*” happen even if we could assume the back wall of the barn was infinitely strong:



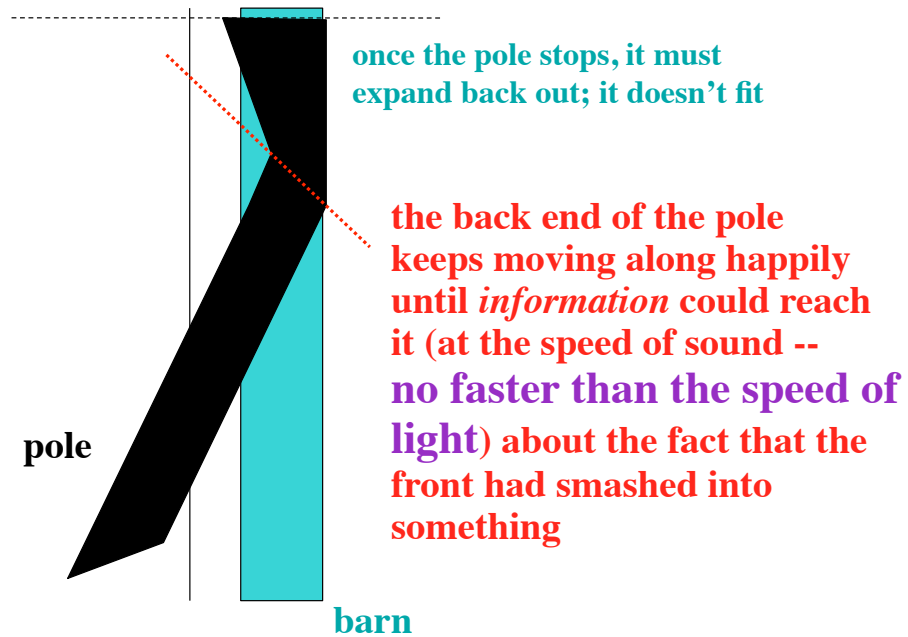
The barn paradox & spacetime

What would “*really*” happen even if we could assume the back wall of the barn was infinitely strong:



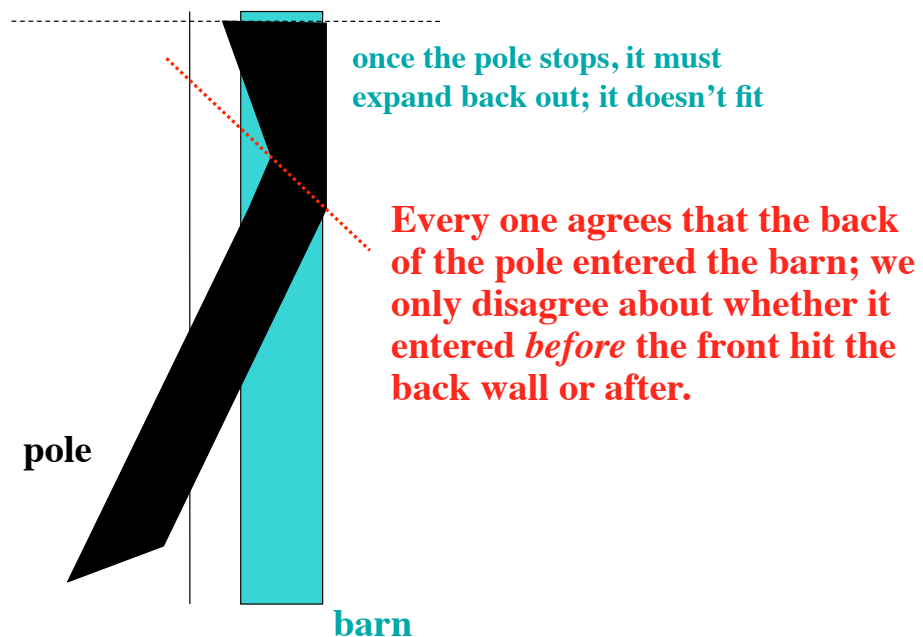
Actually, even the last was inaccurate

(Even in the barn's frame, the pole will keep contracting more):



Universal reality behind these different *perspectives*

The picture below is universal; only the axes are a matter of convention.



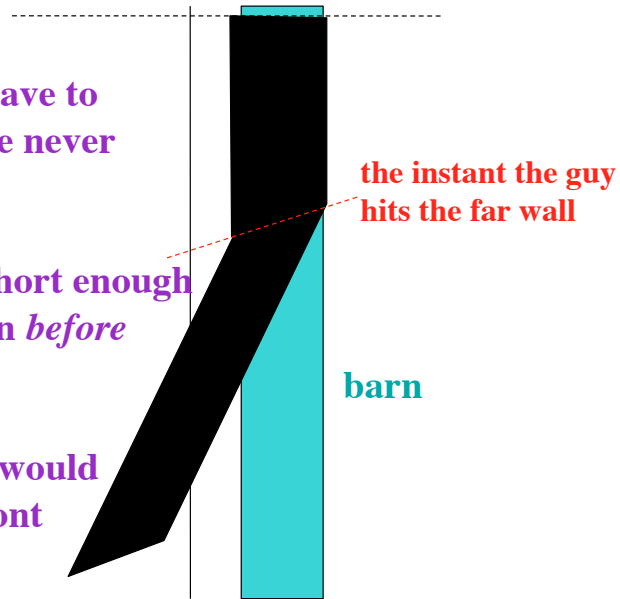
What if signals *did* travel faster than c ?

What would happen if the guy at the front of the pole could send a signal to the guy at the back of the pole saying “stop! I hit the wall!”

Even the barn-owner would have to admit that the back of the pole never made it into the barn.

But he thought the pole was short enough that the back end should get in *before* the front hit the wall.

From his viewpoint, the back would have had to stop *before* the front hit anything -- how did it get the signal?



What do things really look like?

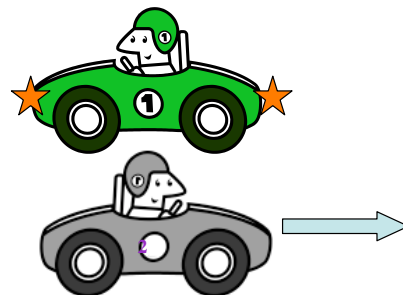
Remember that we don't *see* all simultaneous things at the same time; like the delay between lightning and thunder, we have to wait for the signal to reach us.

Relativity is *not* talking about this, but about when things “actually” happened (in a given frame...).

All observers agree that driver 2 sees car 1's tail-light go on first.

But driver 1 thinks this is because driver 2 moved closer to the tail-light before the flashes reached him; driver 2 thinks it's because the tail-light actually went on first.

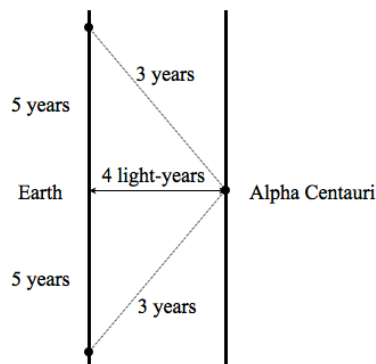
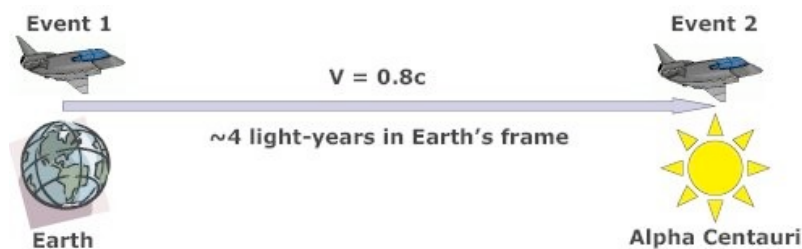
Different stories, but the same reality.





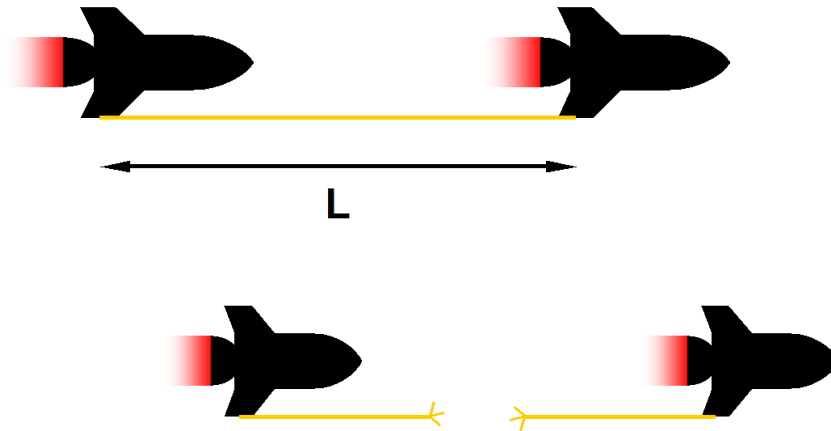
The Lorentz Centre in Leiden

So, is this all just about perspective, or does anything really happen?



We believe your aging (and all other physical processes) *really would slow down*, so that you could get to α -Centauri in 3 years of your time, even though light take 4 years of our time. Kind of weird; from *your* point of view, the distance to α -Centauri would just shrink while “it moves towards you”...

One more paradox...



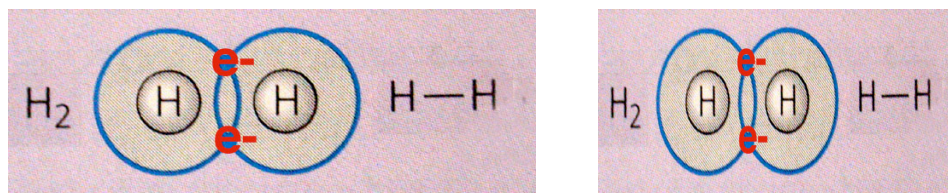
If the two ships start accelerating at the same time,
I always see them travelling at the same velocity,
and keeping a constant distance...
But I said the objects get shorter when they're moving;
is the rope now too short? **Does the rope break?**

The contraction is *real*

Remember that this started because the laws of electricity & magnetism didn't "look the same" at all speeds, according to Galileo.

Replacing Galileo's frames with Einstein (& Lorentz *et al's*), we find the laws *do* look the same -- and not just em laws, but *all laws of physics*.

This guarantees that something in those laws must actually make objects shrink.



new, magnetic force when the
atoms are moving, pulls them closer together

Must we even think about reference frames?

Not really -- if you understand the laws of physics from the earth's perspective,

you can figure out that moving objects really *do* “slow down” and contract;

since this includes the moving rulers & clocks, you know the moving observer won't see it this way.