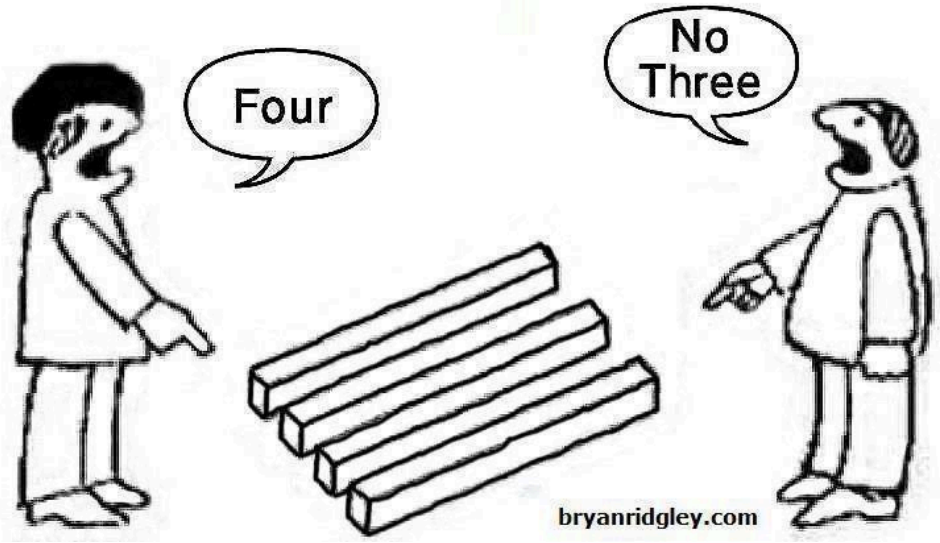
# The problem of perspective

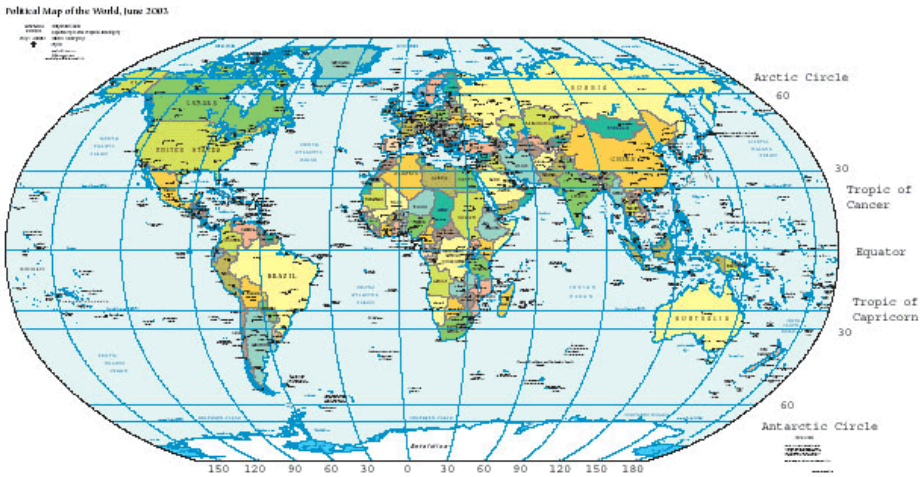
**Reality can be so complex that equally valid observations from differing perspectives can appear to be contradictory.**



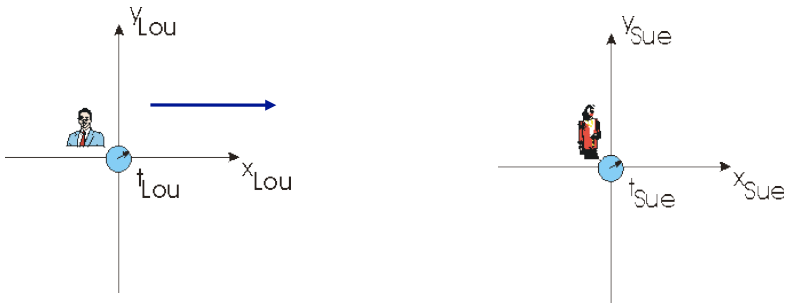



# Preamble: there is no “here”

## A coordinate system (“reference frame”)

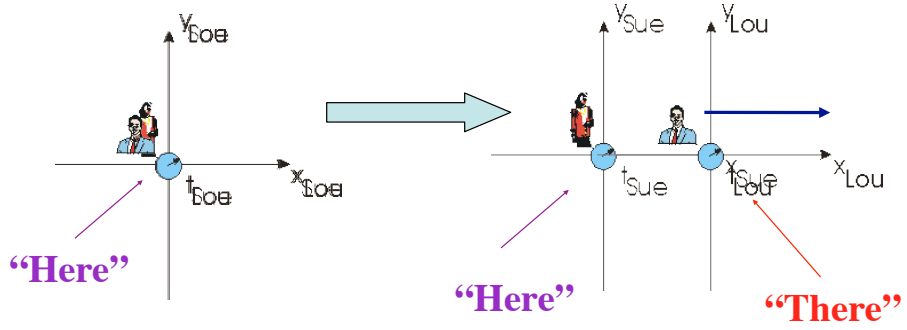


# Sue & Lou



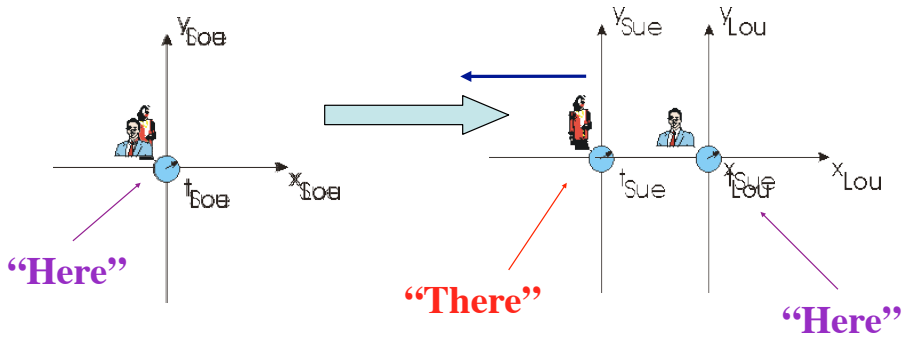



# Sue's perspective




**Sue: Lou isn't here any more.**

# Lou's perspective

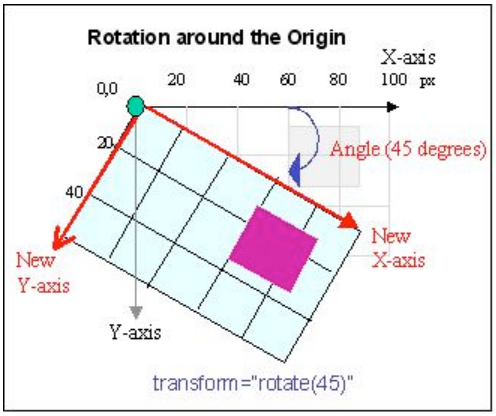



**Sue: Lou isn't here any more.**

**Lou: Of course I'm here. *Sue* is the one who isn't here any more.**

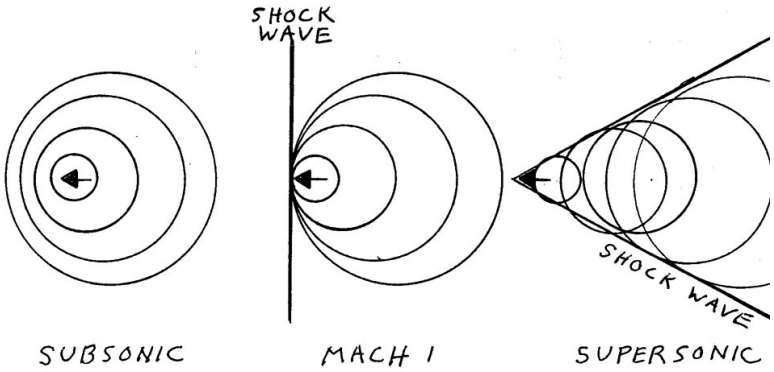


# More complicated "reference frames"



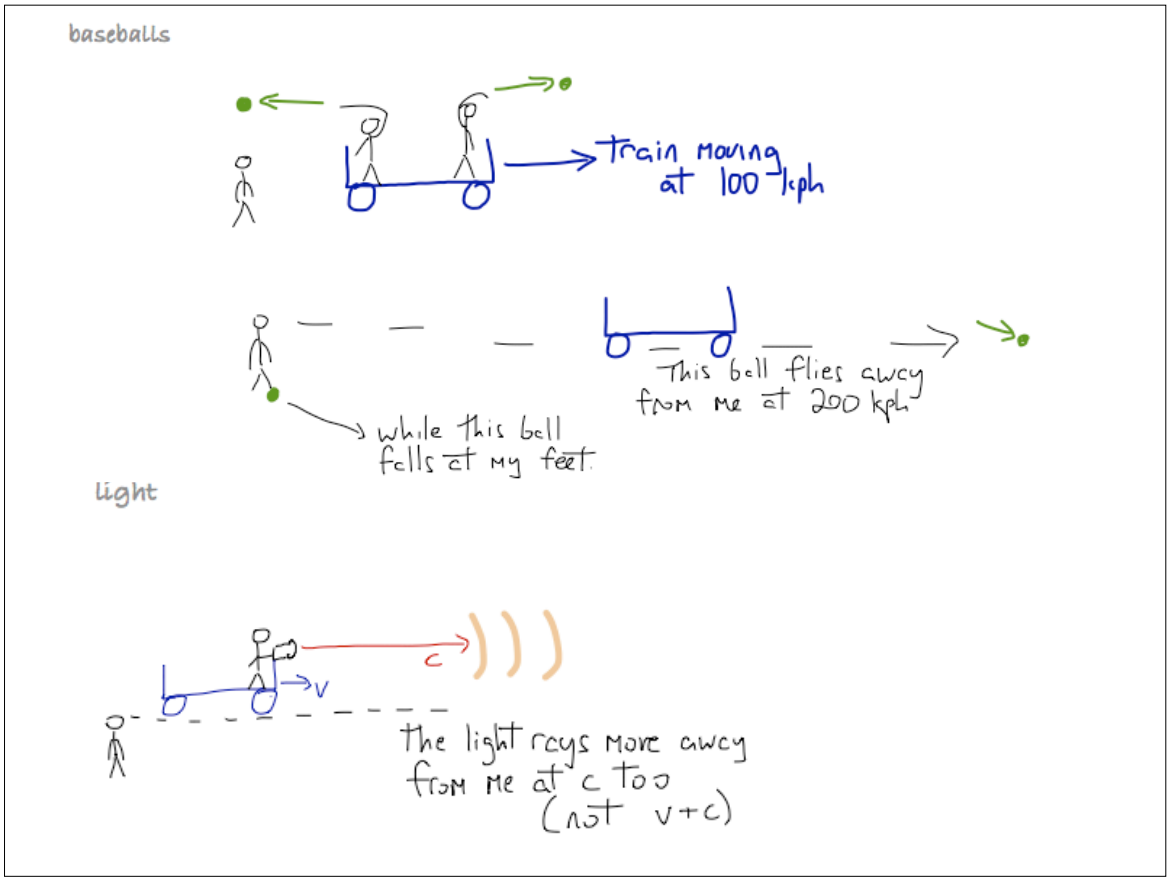

**Note: distances are *invariant*.**
**I could say "walk 5 blocks East"**
**or you might say "walk 4 blocks ESE and then 3 blocks NNE",**
**but we're talking about the same place, and it's the same distance away.**

# Sound waves move at a given speed
## *relative to the air*






# A sonic boom






# Solving this apparent contradiction required revising the formulas we use to add velocities when we change reference frames...

**What Einstein realized is this actually meant revisiting our definitions of time & space...**

# There IS no “now”!

What then is time? If no one asks me, I know what it is. If I wish to explain it to him who asks, I do not know.

Saint Augustine

**Epicurus argued that time cannot be understood as a "thing in itself", but as a property of other things (Ref: Letter to Herodotus).**
**It is signified by analogy with other events that take place, e.g. the alternation of day and night, the changing seasons, etc.**



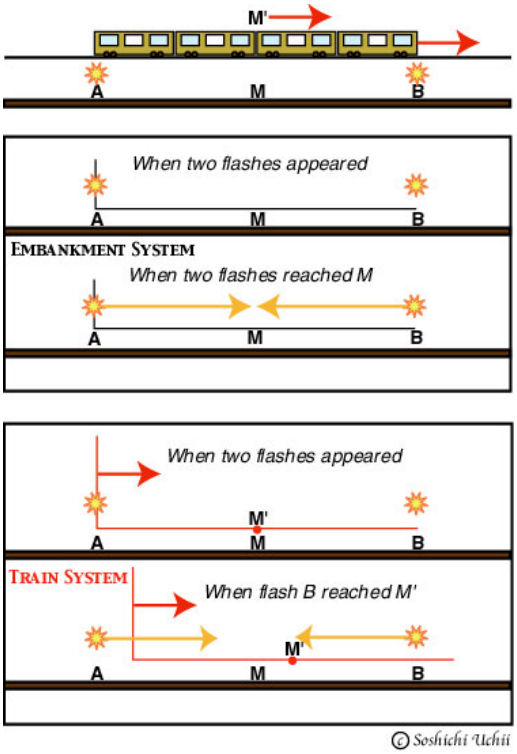
# If I see two things at the same time, do I know they occur at the same time?

**No: light travels at finite speed, so I know I’m *seeing* them some time after they actually occurred...**

**But: the speed of light is constant, so I will define two things to be simultaneous *if they are both the same distance away from me* and I see them (“receive light signals from them”) at the same time.**

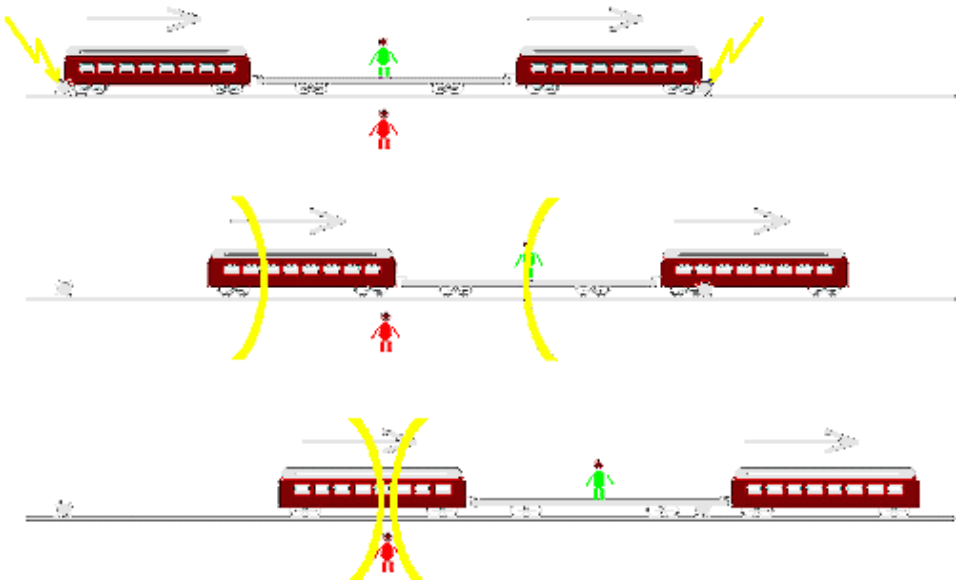
[If they’re not the same distance from me, then it’s more complicated – I may need some help to determine when they occurred...]

# Two simultaneous flashes?






# Which happened first according to green Gus, or red Roger?



# Question

**How would Gus (perhaps with the aid of some helpers) be sure they occurred the same distance away from him?**

**How would Roger?**



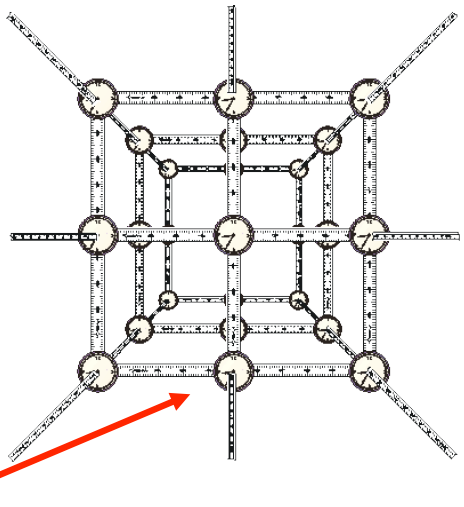
# What does relativity of simultaneity mean?

**The same problem exists for time as for space.**

**"Now" is observer-dependent in the same way that "here" is.**

**To ask "are NY and SF on the same line of latitude," we needed to agree how to draw lines of (constant) latitude.**

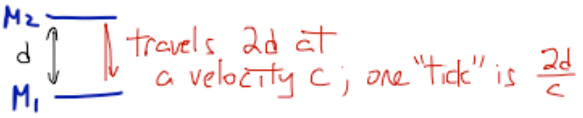
**To ask "does your plane take off at the same time as mine," we need to *agree* how to define "lines of constant time" -- we must synchronize our clocks.**

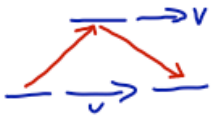


**Otherwise, you might say "yes" and I might say "no," but we could both be right!**

# Clocks should be based on physics.

**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.**




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

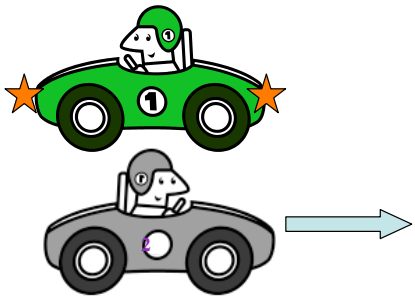
**MOVING CLOCKS GO MORE SLOWLY!**
**(Hey -- what about the folks *with* the moving clock?)**



# Question 1:

**Cars 1 and 2 are approaching a pair of lights from opposite sides.**
**Car 1 sees the two lights change at the same instant.**
**Which light changes first from car 2's perspective?**
**(Think of the lights as being at exactly the same position.)**

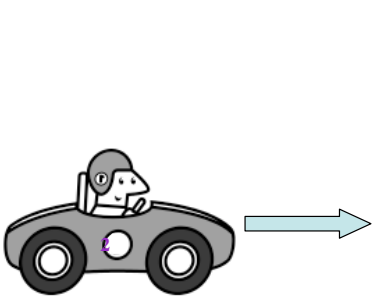
# Question 2:



**Car 1 is sitting still as car 2 passes him.**
**Just as car 2 passes, car 1 turns on his front & rear lights (simultaneously, from his own perspective).**
**Which light does car 2 consider to have turned on first?**

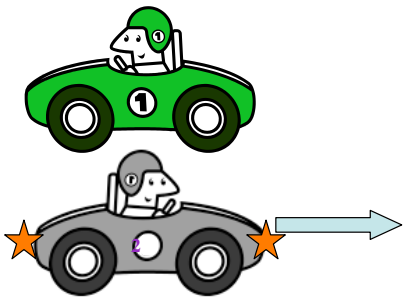


# Note to question 2:



**Simultaneity depends on how *fast* you are moving, but not on *where* you are.**
**In this picture, car 2 will see car 1's headlight before the tail-light.**
**Nevertheless, he *knows* this is because the headlight had less distance to travel; when he figures out when the lights "*really*" turned on, he'll still conclude it was the tail-light which went on first.**
**(He imagines his latticework of clocks and rulers, and what the clocks next to car 1's lights must have read.)**

# Question 3:

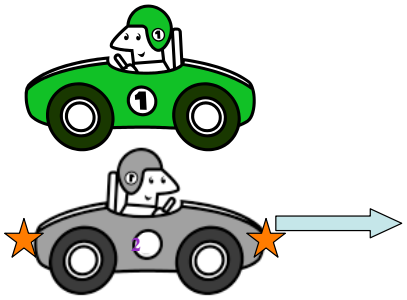


**What if the *moving* car turns on his lights simultaneously?**
**Which light does car 1 consider to have turned on first?**

**The meaning of relativity:**
**it makes no sense to ask "which is the moving car?"**
**Each car thinks the other is moving.**
**Whatever 1 thinks about 2, 2 thinks exactly the same about 1.**
**And they are both right, within their own "reference frame."**



# Question 3:



**What if the *moving* car turns on his lights simultaneously?**
**Which light does car 1 consider to have turned on first?**

**Subtlety: when I say "turns on his lights simultaneously,"**
**I suppose I mean *from his perspective* (I mean that he *sees* both lights at the same time)...**
**but if I fail to specify this, it's ambiguous: "simultaneously" doesn't *mean anything* independent of a reference frame.**

# Invariance of a theory (a set of equations)

If you *rewrite* the equations of physics, and everywhere you had an $x_{Sue}$ you plug in the right formula for $x_{Lou}$ and everywhere you had $t_{Sue}$ you plug in the right formula for $t_{Lou}$, et cetera, you get formulas which tell you how to predict $x_{Lou}$ at all times instead of predicting $x_{Sue}$ at all times.

Invariance: the equations look exactly the same. (The laws of physics are the same for Lou as for Sue.)

Galilean invariance: Newton says acceleration (the change in v) depends on F, and F depends on distances.
Sue & Lou may disagree about positions, but they agree about velocities, and they agree about distances -- so the laws are ok.



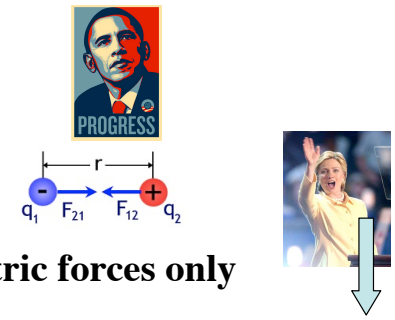
# Electromagnetism is *not*

Electric fields depend on the distance from a charged particle (the same way the gravitational field depends on distance from Earth)

But *magnetic* fields

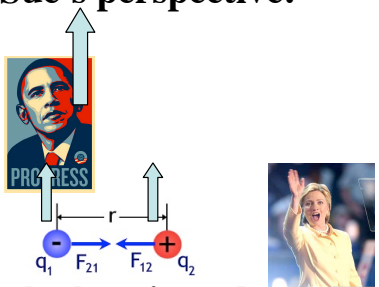
- only appear for moving charges (current in electromagnet; spinning electrons in iron atoms)
- only *act on other moving charges*.

**Lou's perspective.**




**electric forces only**

**Sue's perspective.**




**both electric and magnetic forces...**

# Electromagnetism is *not*

**We already knew this -- EM predicted light travels at 300 000 km/s; according to Galileo, if I'm already travelling 100 000 km/s, then this would look like only 200 000 km/s. The theory isn't invariant.**

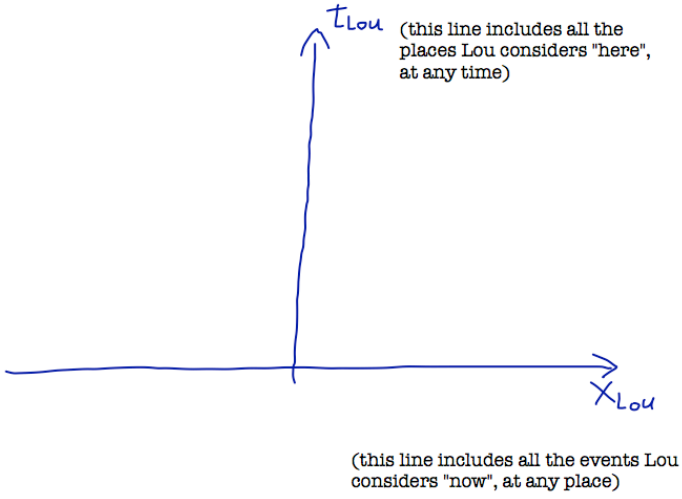
**Three possibilities:**

- **The theory is wrong**
- **The laws of physics *don't* look the same at all velocities**
- **The Galilean transformation is wrong**

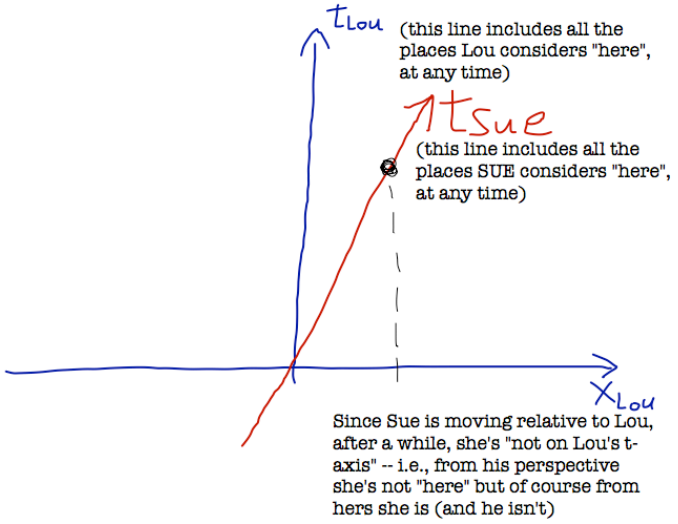
**There is a *different* set of equations for figuring out $x_{Sue}$ and $t_{Sue}$ from $x_{Lou}$ and $t_{Lou}$, which would leave the laws of E&M intact. These were worked out between 1887 and 1905 by various people– but until Einstein in 1905, no one realized what they *meant*.**



# Lou & Sue really have different ideas of both time *and* space,

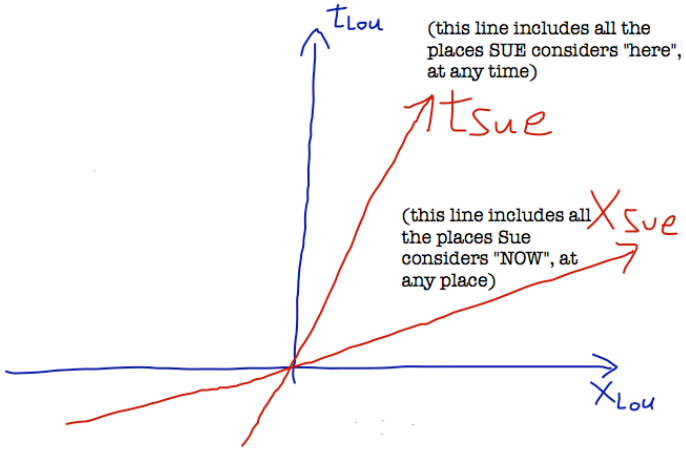


# Sue's idea of "here" is different (Galileo)

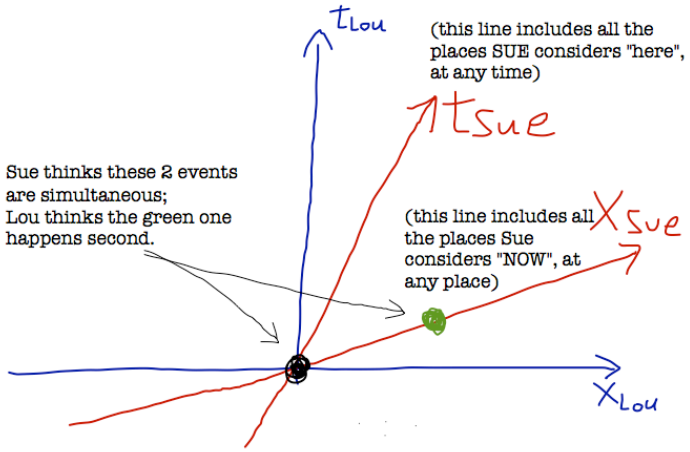





# "Spacetime" -- we used to think "now" (and time in general) was an absolute concept, not like "here"; Einstein realized that this is not the case.

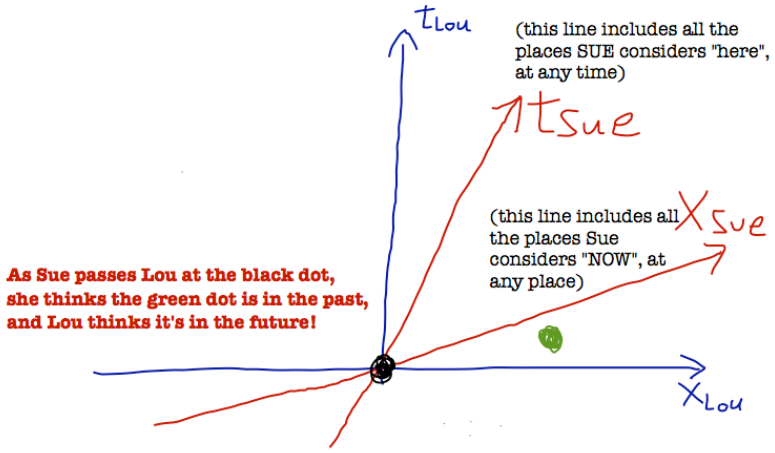


# Simultaneous or not?






# Past or future?




**Puzzle which will remain with us:**

**how can we have a theory with causes & effects if we don't even agree on which event happened first??**