lecture 4

Simultaneity and relativity of time and length

Announcements:

- lecture 3 is posted
- homework 2 *(due Monday, Jan 25 in class)* is posted
- homework 1 solutions are posted
- reading for this week is:
    - finish Ch 1, start Ch 2 in TZD

Last Time

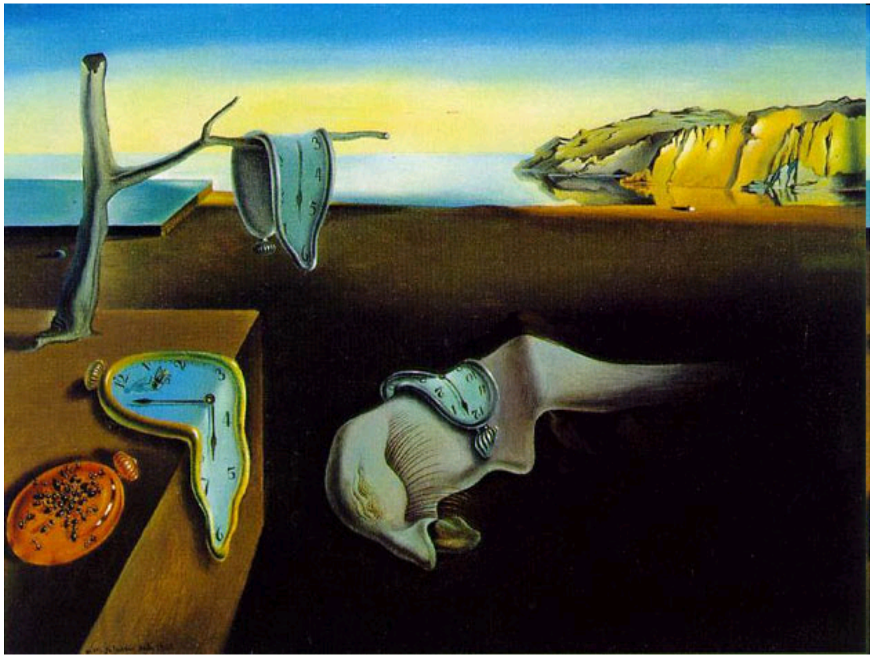
recall lecture 3:

- electromagnetic waves
- Michelson-Morley experiment
  - c is indeed frame-independent, i.e., there is no ether
- postulates of Einstein's special theory of relativity
  - laws of nature are frame-independent
  - speed of light, c is constant, i.e., same in all frames

Today

Time to talk about time:

- space-time event
- synchronization of clocks
- simultaneity is frame dependent
- relativity of time



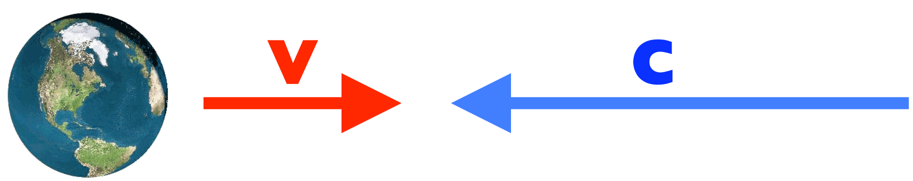
clicker question

Speed of light in a moving frame

Q: *Suppose earth is moving through space with speed v in a direction opposite to light, that moves with speed $c=3x10^8$ m/s with respect to far away stars.*

According to Einstein's relativity *what is speed of light as viewed from the earth?*

* Assume the earth is not accelerating



$\boxed{\text{a) c,}}$ b) c+v, c) c-v, d) none of the above

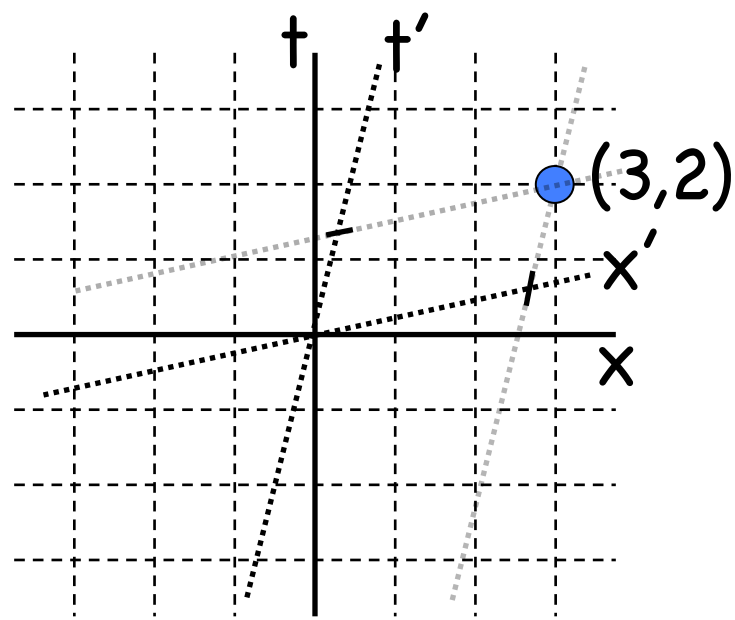
A: *There is no ether and light moves with the same speed, c in all inertial reference frames*

Space-time event

location and time of events

- "old" (non-relativistic) thinking:
  - 3D spatial coordinate (x,y,z) and time t
- new (relativistic) thinking:
- 4D space-time (x,y,z,t) labeling space-time events
- same event has different coordinates in different frames:

  $(x,y,z,t) \xrightarrow{v} (x',y',z',t')$



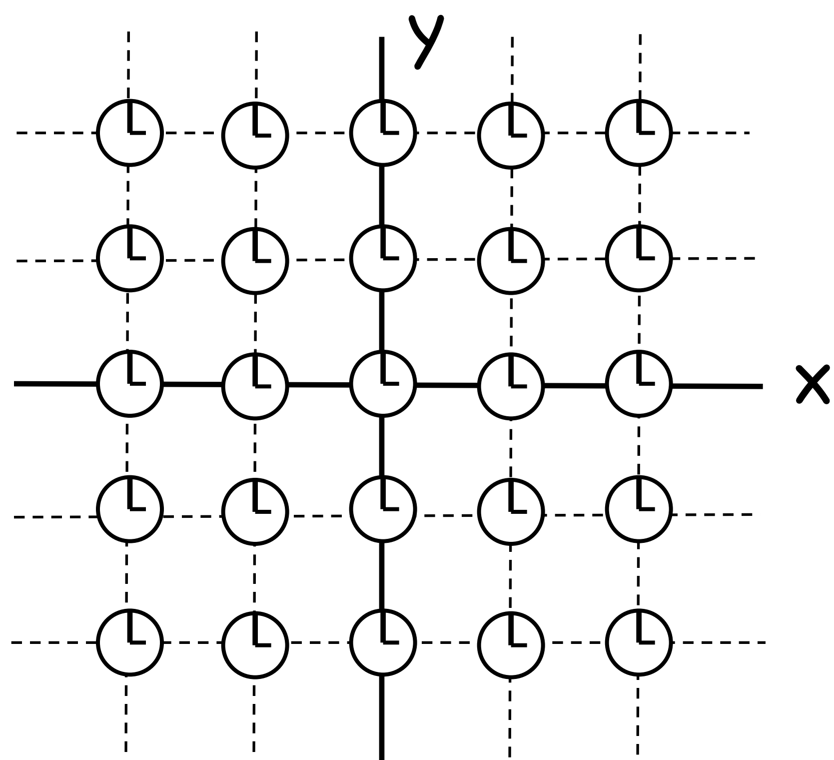
- space-like and time-like events

Synchronization of clocks

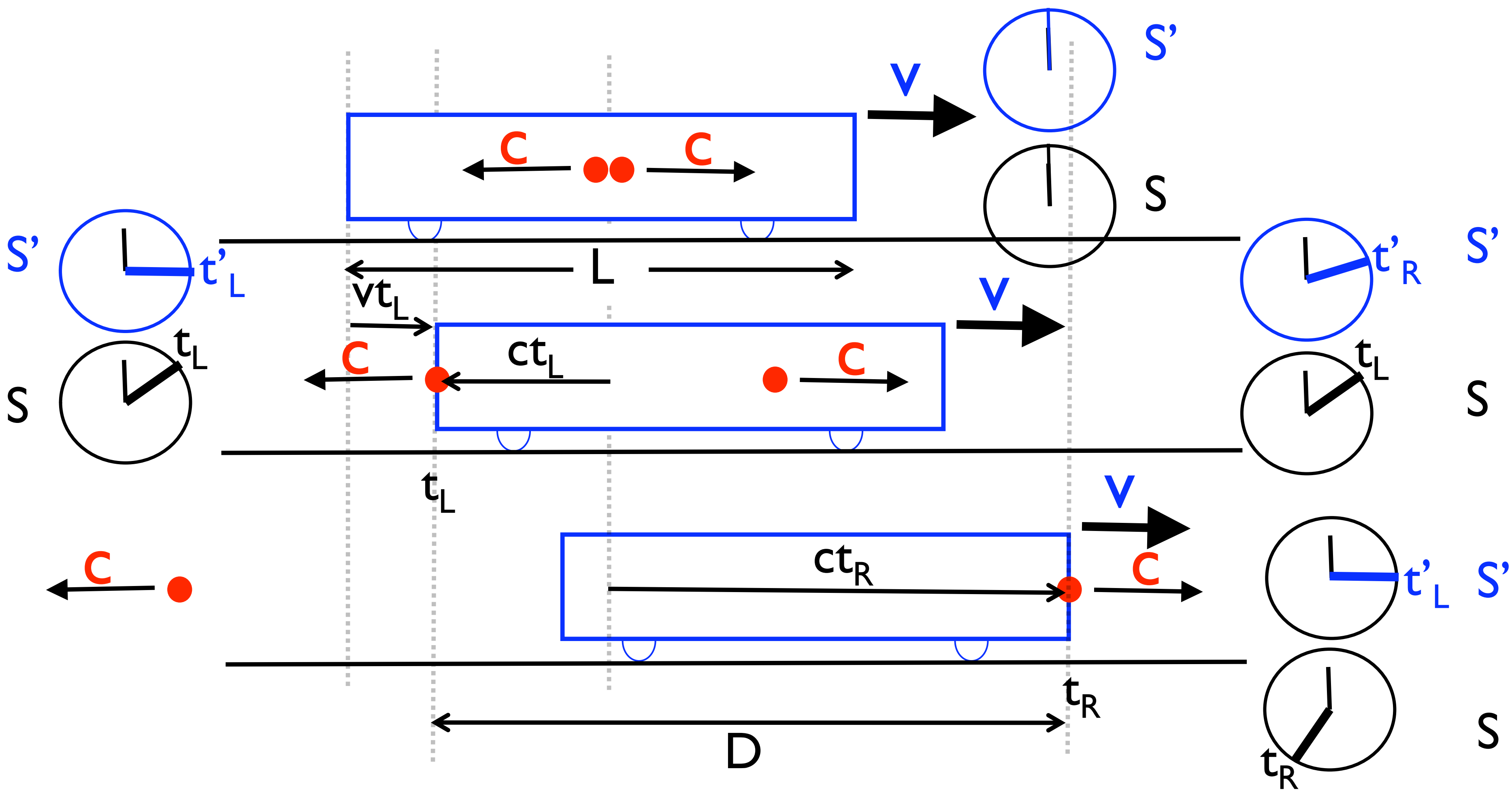
- need synchronized perfect clocks at different locations
- quite nontrivial at different x_1 and x_2, but doable:

  synchronize at same point x_1=x_2, then move slowly apart; if arbitrarily slowly do not screw up synchronization

- positions via $x = c\ t$ → create space-time grid



Simultaneity is a relative concept



- S′: photons arrive *simultaneously* (at left/right ends) at $t'_L = t'_R = L'/2c$
- S: photons arrive at right *after* left ends: $t_L = \dfrac{L/2}{c+v} < t_R = \dfrac{L/2}{c-v}$

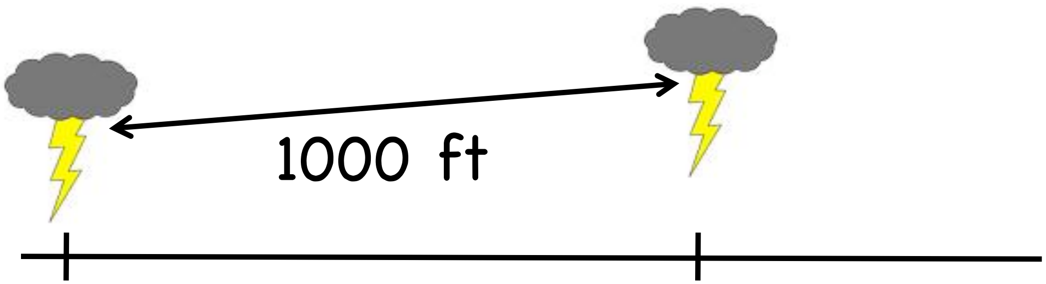
not simultaneous in S !

$$t_R - t_L = \frac{Lv}{c^2 - v^2} = D\frac{v}{c^2} > 0$$

front (right) clock on moving train lags behind back (left) one

Relativity of simultaneity and coincidence

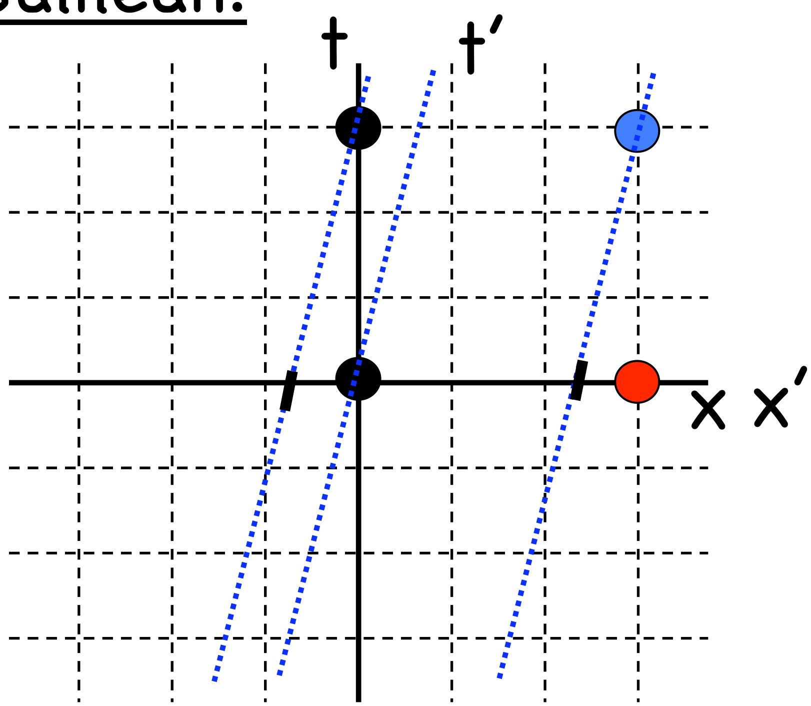
- magnitude of non-simultaneity: $\Delta t = v\,\Delta x$ ($c \approx 1$ ft/nsec)



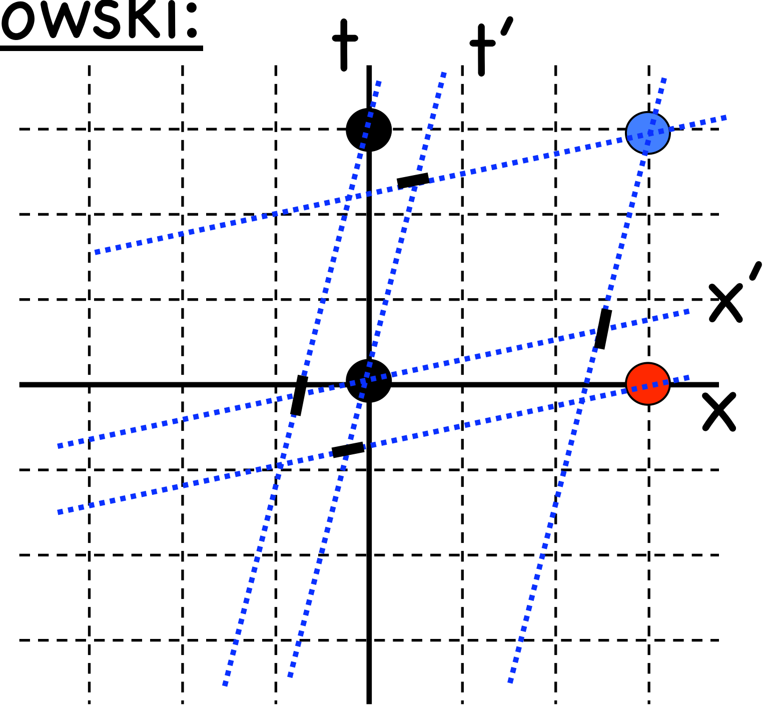
$$\Delta t \approx 10^{-9}\ \text{s/nsec} \times 1000\text{ft/s} \times 1000\ \text{ft}$$
$$\approx 10^{-3}\ \text{nsec} = 10^{-12}\ \text{sec}$$

- space-time symmetry (non-coincidence): $\Delta x = v\,\Delta t$

Galilean:



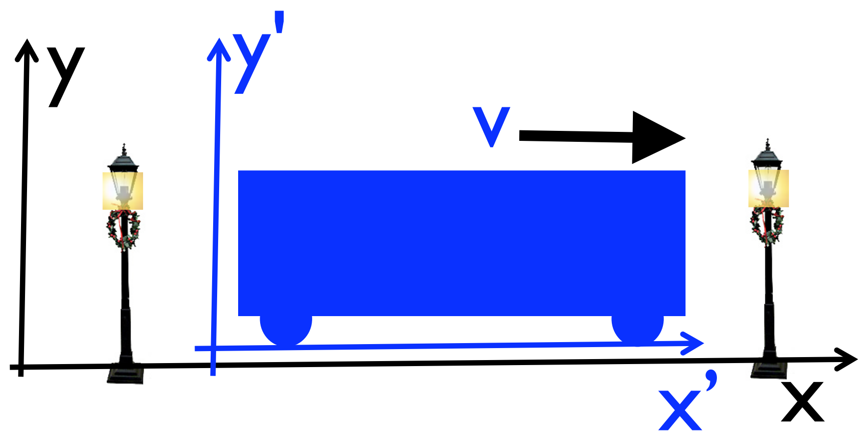
Minkowski:



clicker question

Simultaneity is a relative idea

Q: *Two lights (some distance apart on a sidewalk) are turned on simultaneously as observed from the ground, based on two local clocks synchronized on the ground.*
From the point of view of the train moving with velocity v to the right, which (if either) of the two lights turns on first?



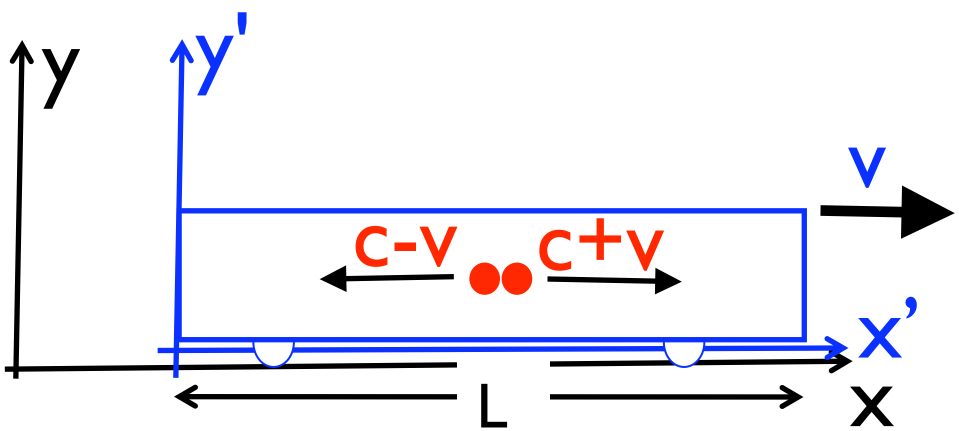
a) left, $\boxed{\text{b) right,}}$ c) simultaneously, d) neither

b) From the point of view of the train, the lamp posts are moving to the left with the left one in the front and therefore from previous analysis is behind in time. Thus, from the train the left light turns on later by Dv/c^2 .

clicker question

Simultaneity in Galilean relativity

Q: *A light in the middle of a train is turned on, sending out two pulses of light toward two ends of a moving train. According to (incorrect) Galilean relativity, from the point of view of the frame of the tracks (ground) which pulse will reach the end of the train first? Why?*



$t_R = (L/2 + v t_R)/(c+v)$
$= L/2c$
$t_L = (L/2 - v t_L)/(c-v)$
$= L/2c$

a) left, b) right, $\boxed{\text{c) simultaneously,}}$ d) neither

From the point of view of the track, the speed of right (left) moving light is c+v (c-v) and so even though longer (shorter) distance is travelled, it is travelled at different speeds and keeping the time of arrival the same in both frames.