Open book Test 1 Reminder

Test 1: Wednesday Lecture slot : 10:00 am (one Hour test)

3rd March 2021 (7th week) : after one week-term break

Instructions : need you to position your "PC or handphone" cameras on yourselves for the Zoom.

MCQ & short Questions : If you have participated in all the (Zero to where we stop next week) lectures & Tutorials, LumiNUS Forum and read the uploaded Relativity related essays/articles, it should be straightforward. (the pdf readings in LumiNUS should consolidate your learning)

Lecture 6

"The views of space and time … henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

H. Minkowski, 1908

A Recollection
Special and General Relativity
Interesting Space-Time Diagrams

"The views of space and time … henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality."

H. Minkowski, 1908

Socrates, 469 -399 BC

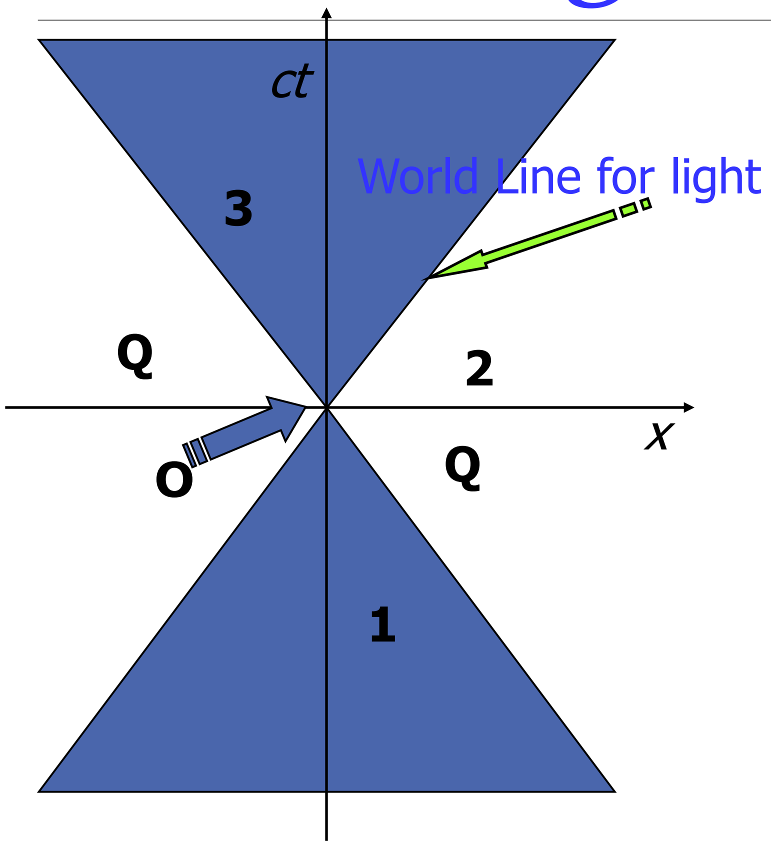
Pioneered the Socratic Method : Plato

a) Raise the Questions first !

b) Repeating … rely on innate ability to think first !

c) … stay happy …

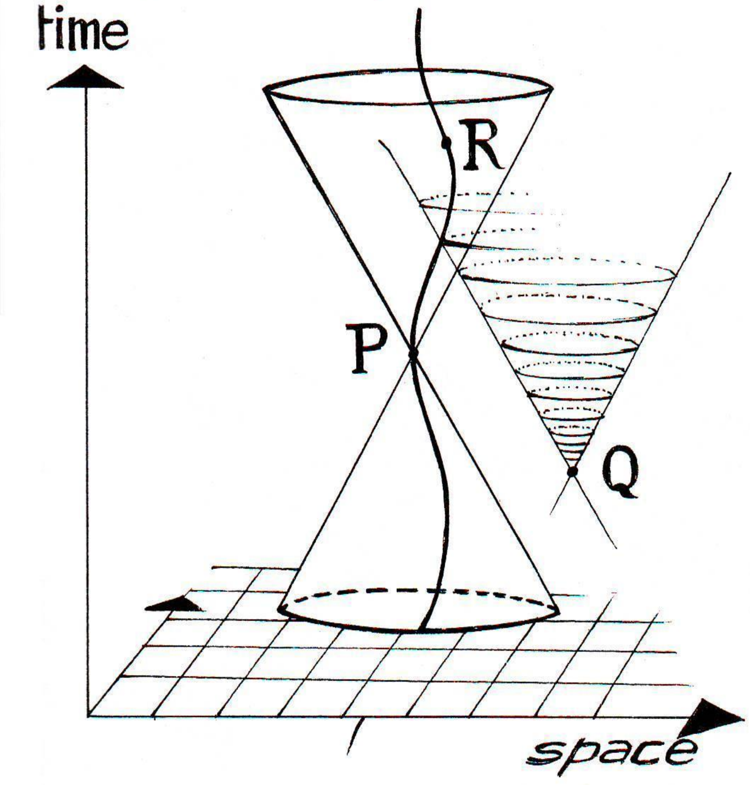
Interesting Feynman comment !



What we mean by "Right now" is a *mysterious thing* which we cannot define and we cannot affect, but it can affect us later, or we could have affected it if we had done something far enough in the past.

Note: People who tell us they can know the future … but actually there is no one who can even tell us the present.

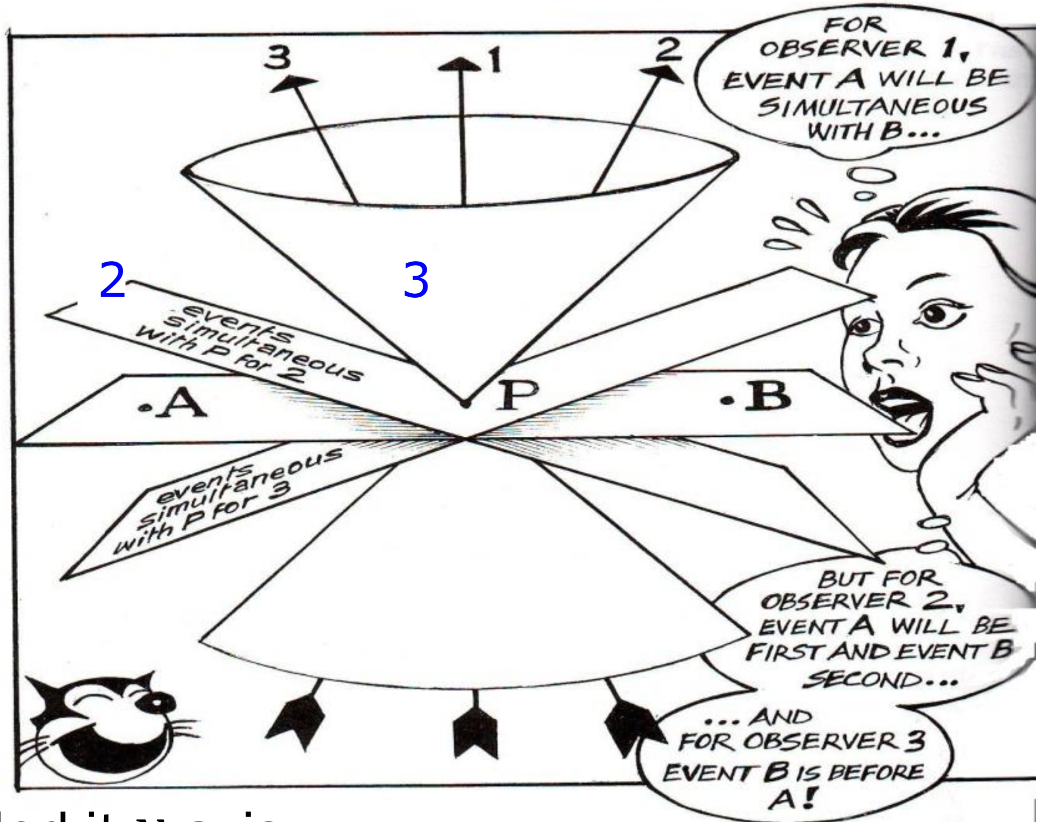
Space Time Diagrams



Time and Observer Dependency

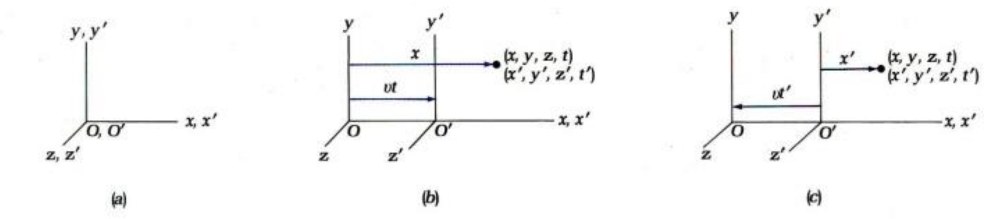
One important fact about lightcones is that they represent the limits of which events can affect one another. Nothing goes faster than light, so anything that will influence you must be travelling either on the lightcone itself (if it's light) or within the lightcone (if it's going slower than light). The same goes for anywhere you hope to go or influence.

Now, we've drawn our picture with one time, but that was merely for the sake of simplicity. The march of time is observer-dependent, to a certain extent. Within one particular observer's lightcone, the order of events is definite. But another observer, moving relative to our first observer, will disagree with the first as to what events are simultaneous with event P.



x, y, z absorbed in this space axis … just called it x axis.

3 + 1 dimensions



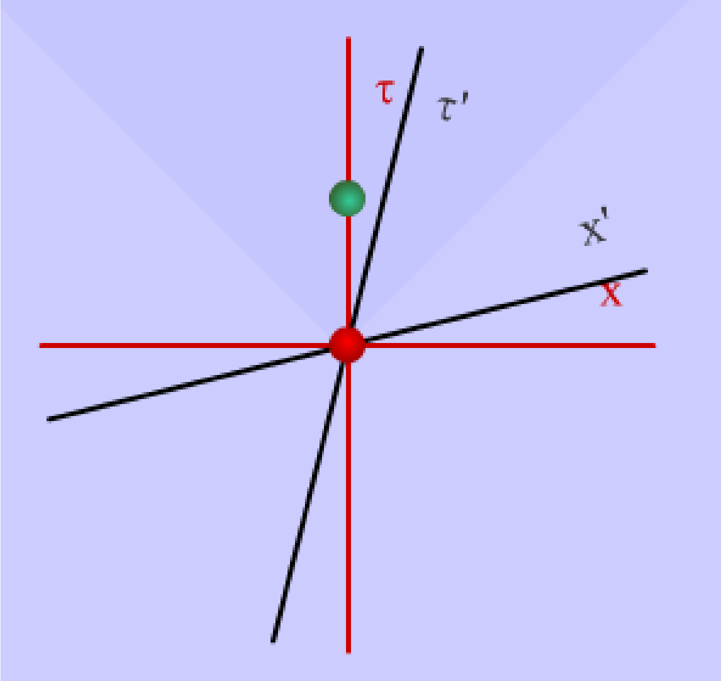
The *x*-*t* axes look normal but the *x'*-*t'* axes are somewhat skewed. $\tau = ct$

The angle of tilt depends on the velocity *v*.

This means that the Lorentz transformations are "not orthogonal" from this point of view.

Recall $\gamma = \dfrac{1}{\sqrt{1-\beta^2}}$ $\qquad \beta^2 = \dfrac{v^2}{c^2}$

TimeLikeboost1.swf



3 + 1 dimensions

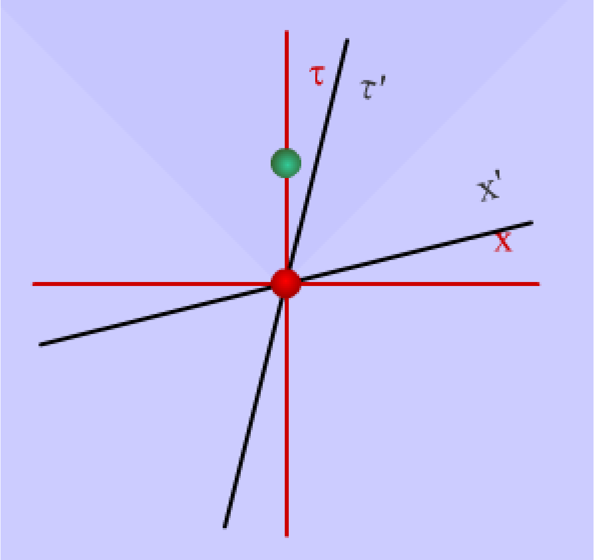
$$\frac{SPACE}{TIME} = \frac{SPACE}{TIME} = c$$

The x-t axes look normal but the x'-t' axes are somewhat skewed.

TimeLikeboost1.swf

Why is this so ?

$$\frac{\Delta x}{\Delta t} = \frac{\Delta x'}{\Delta t'} = c$$

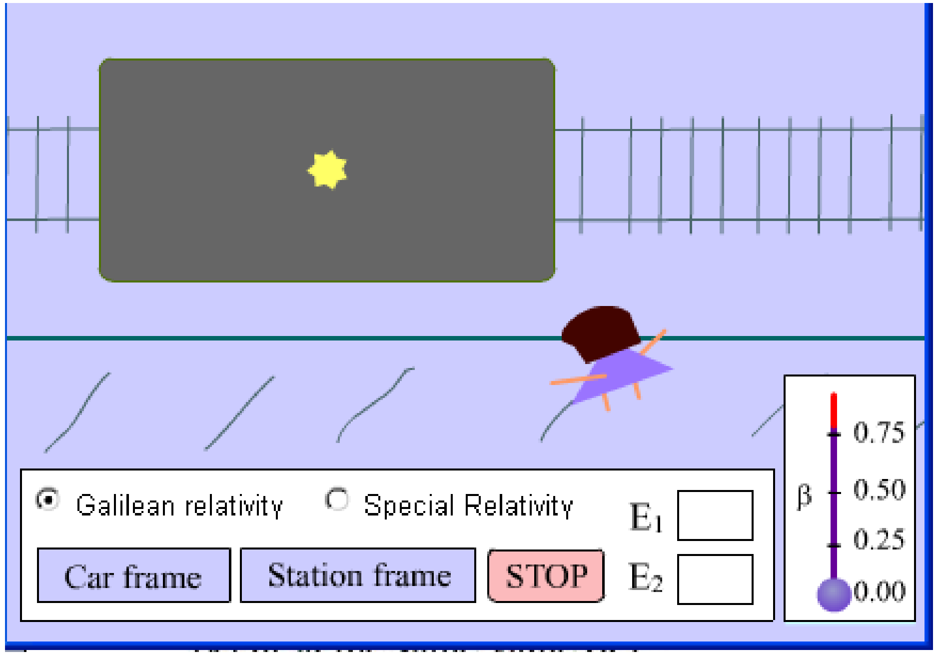


Speed of light is c in all frames of reference or co-ordinates.

What good is this Space-time diagram ?

Applications of Space-Time diagrams

Simultaneity Revisited



Simult.swf

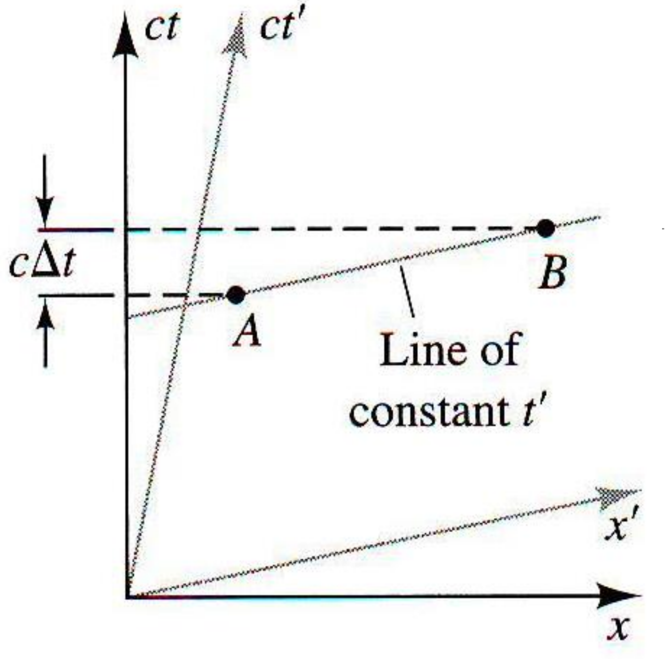


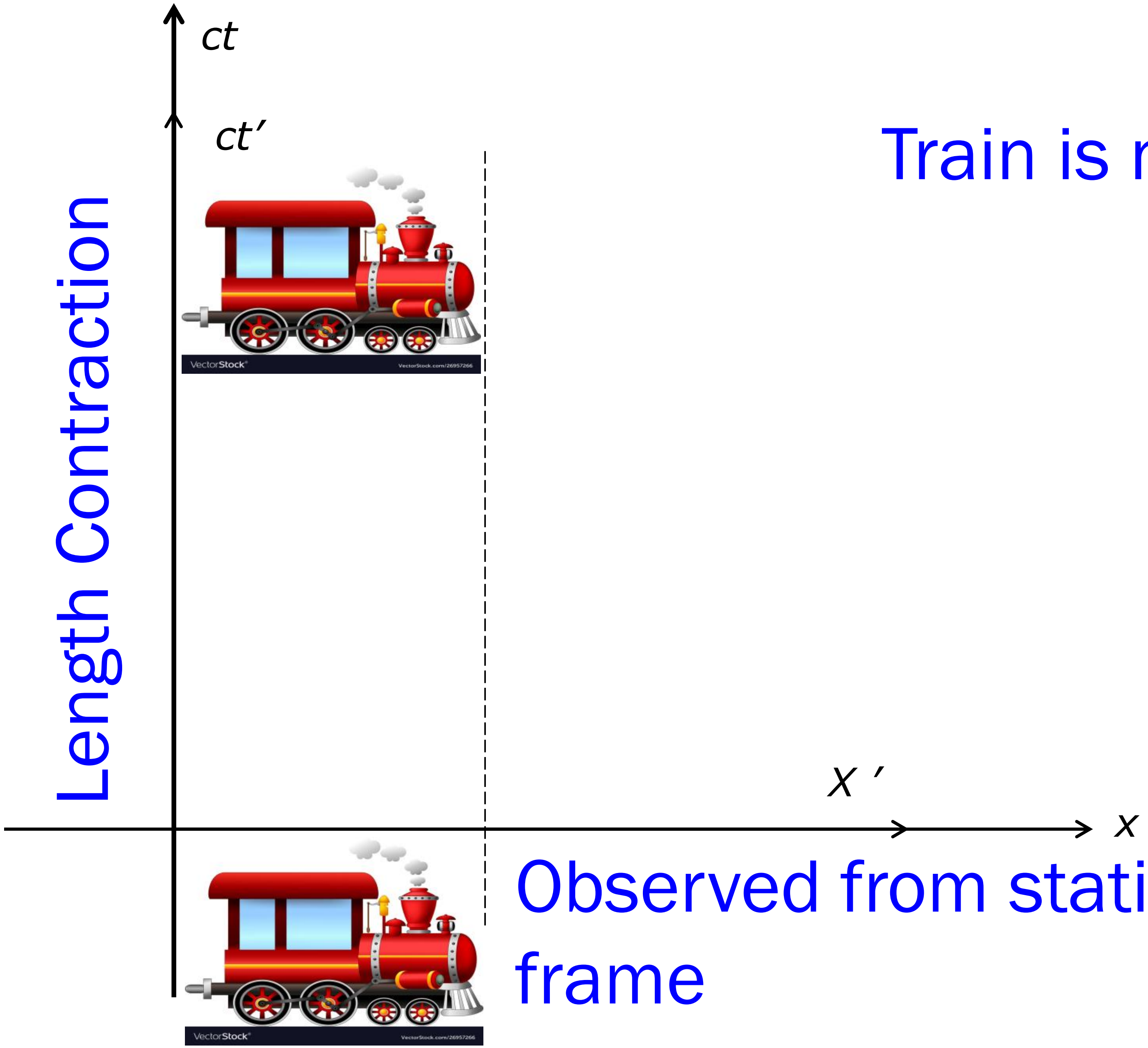
FIGURE Events A and B are simultaneous in the (ct', x') frame because they occur at the same value of t'. They are not simultaneous in the (ct, x) frame, where A occurs before B.

A note on measuring lengths …

measuring the ends are Simultaneous events

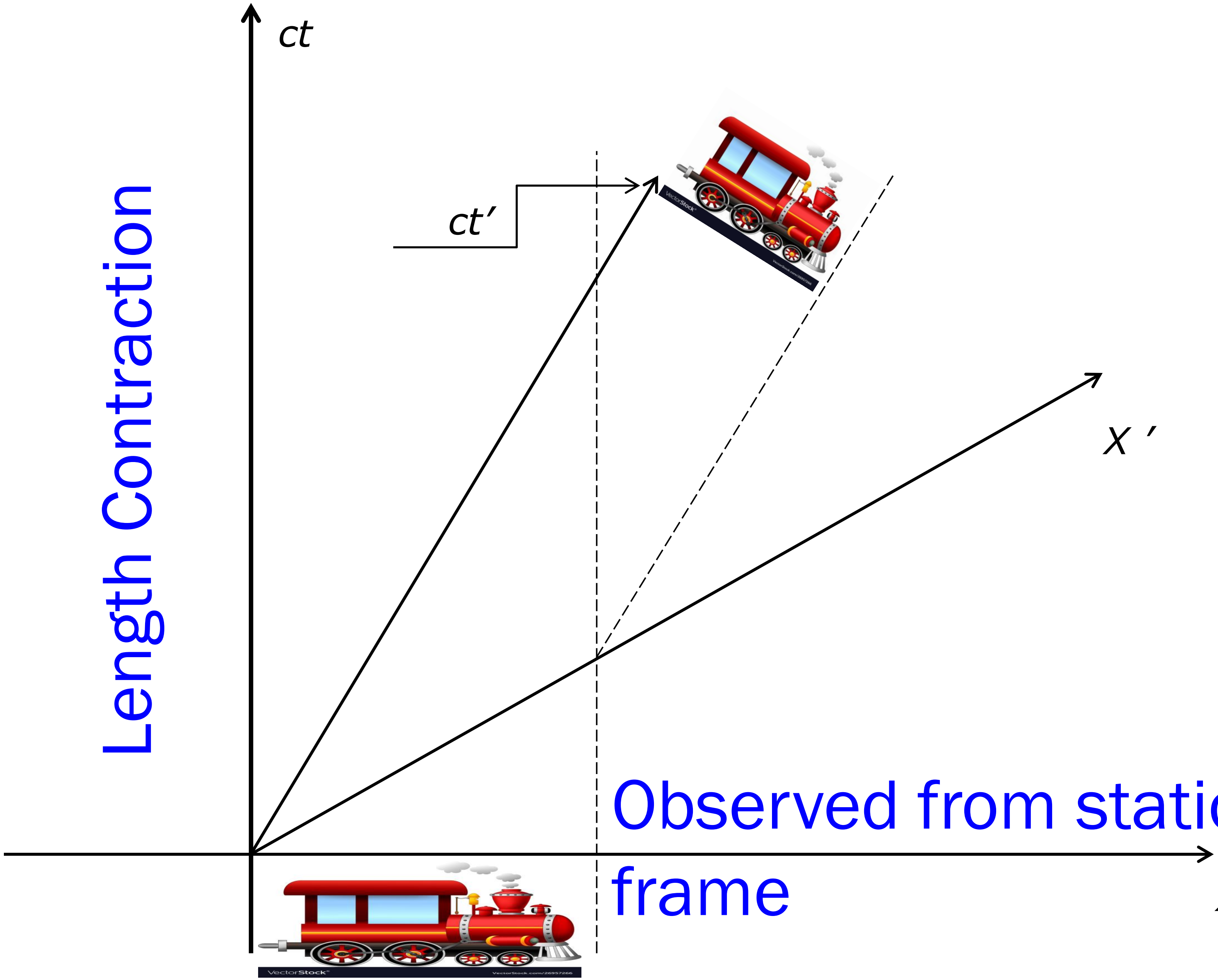
Length Contraction

Train is not moving



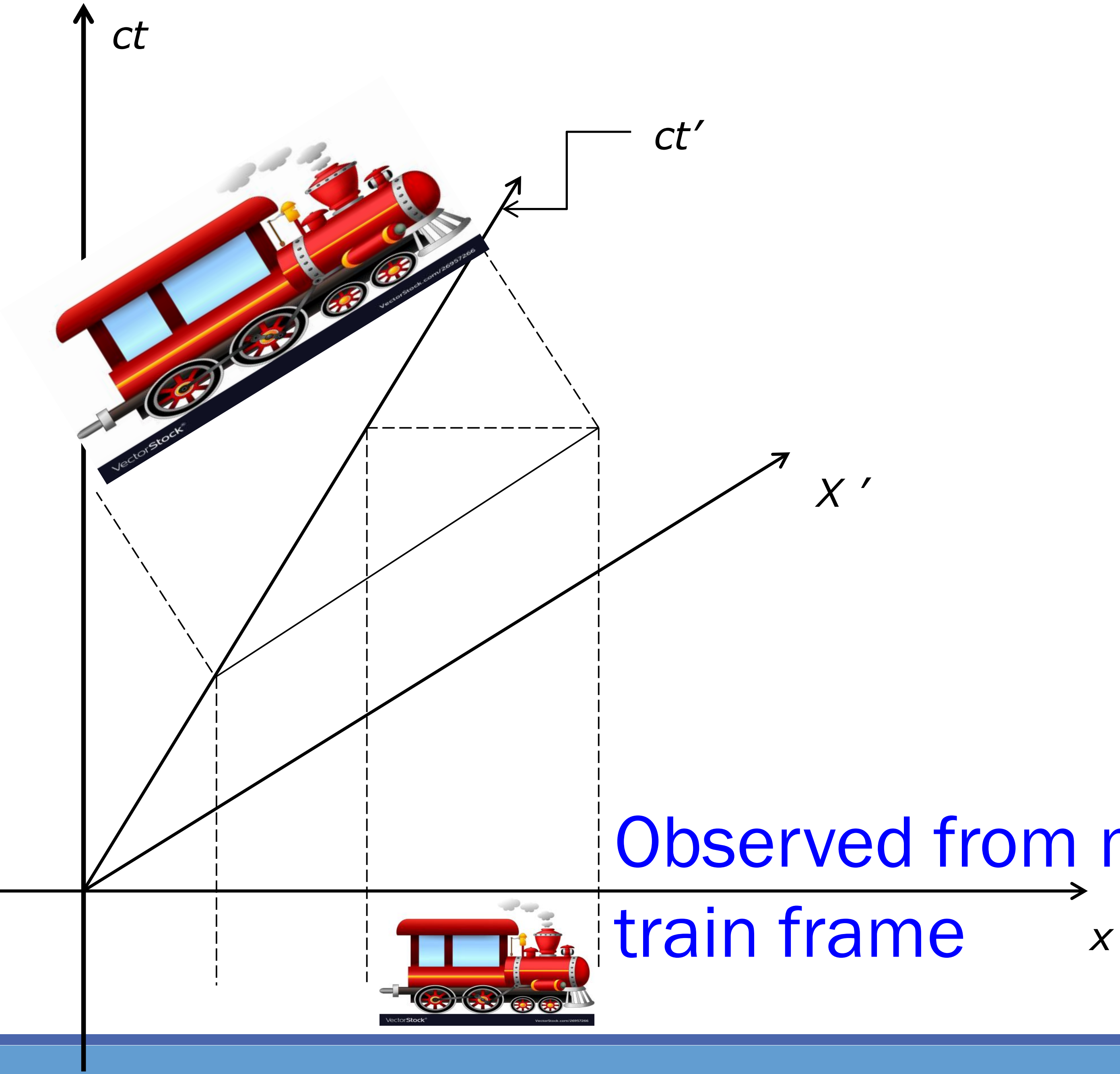
Observed from stationary frame

Length Contraction



Observed from stationary frame

Length Contraction



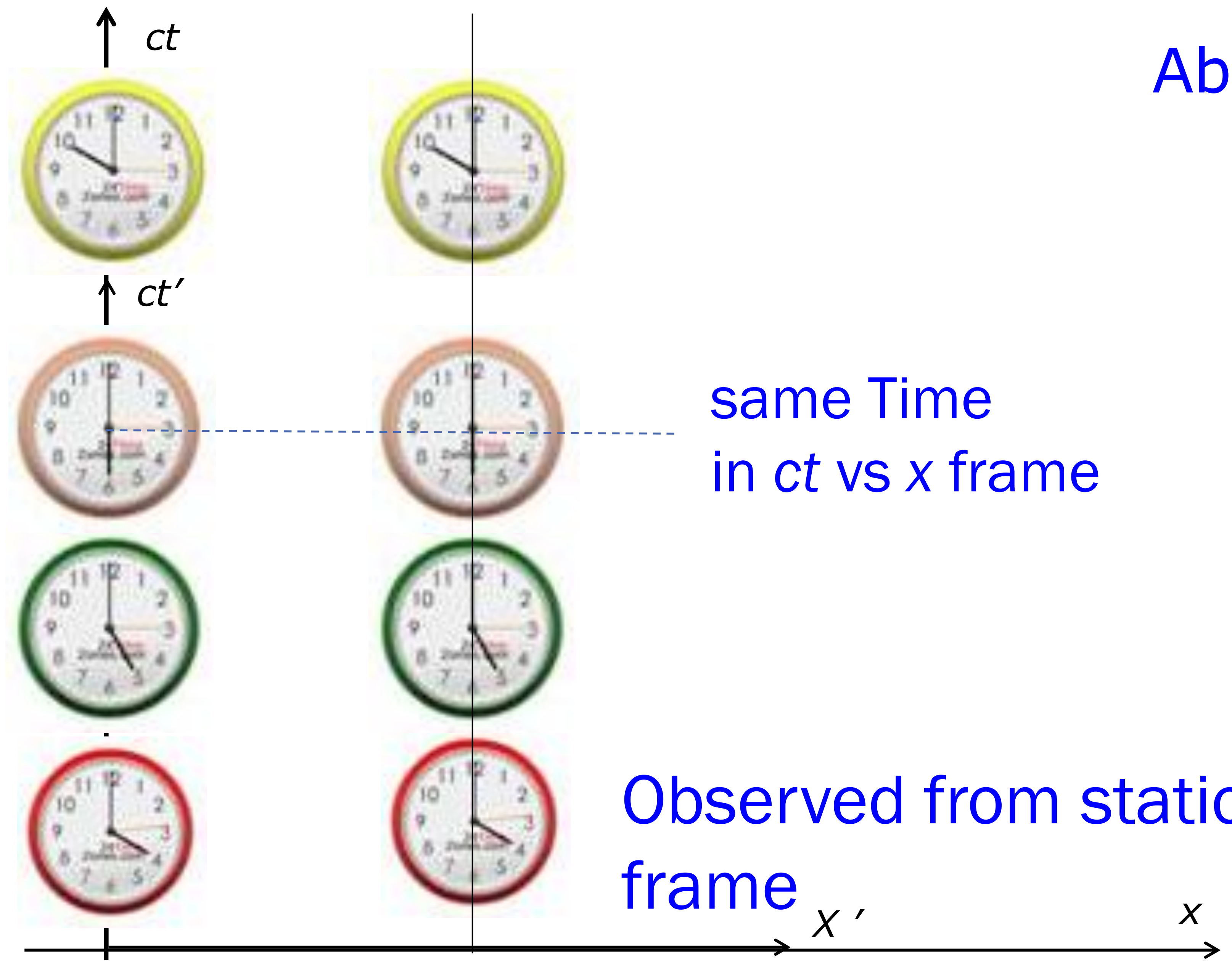
Observed from moving train frame

It is about time !

… Dilation

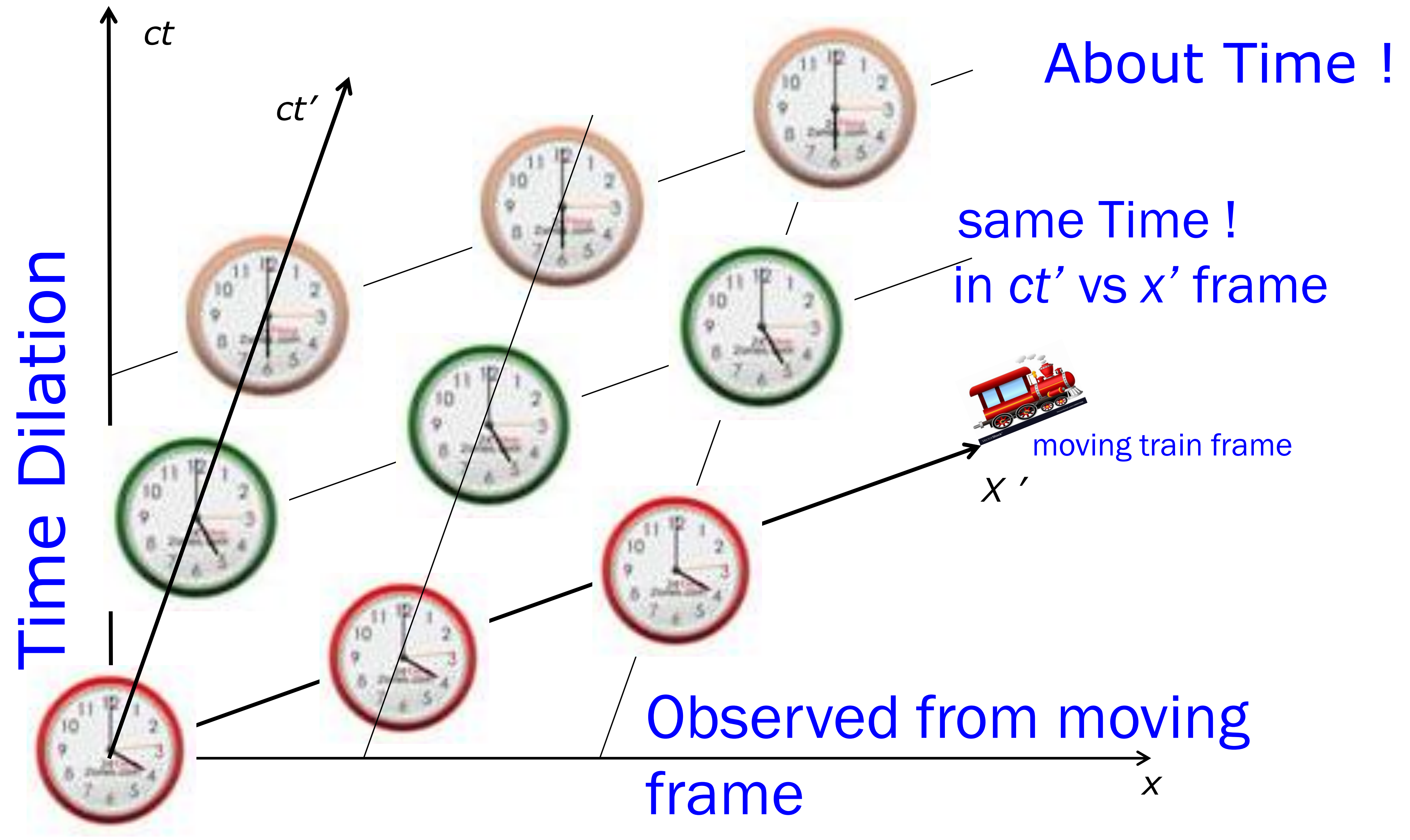
About Time !

Time Dilation



same Time
in *ct* vs *x* frame

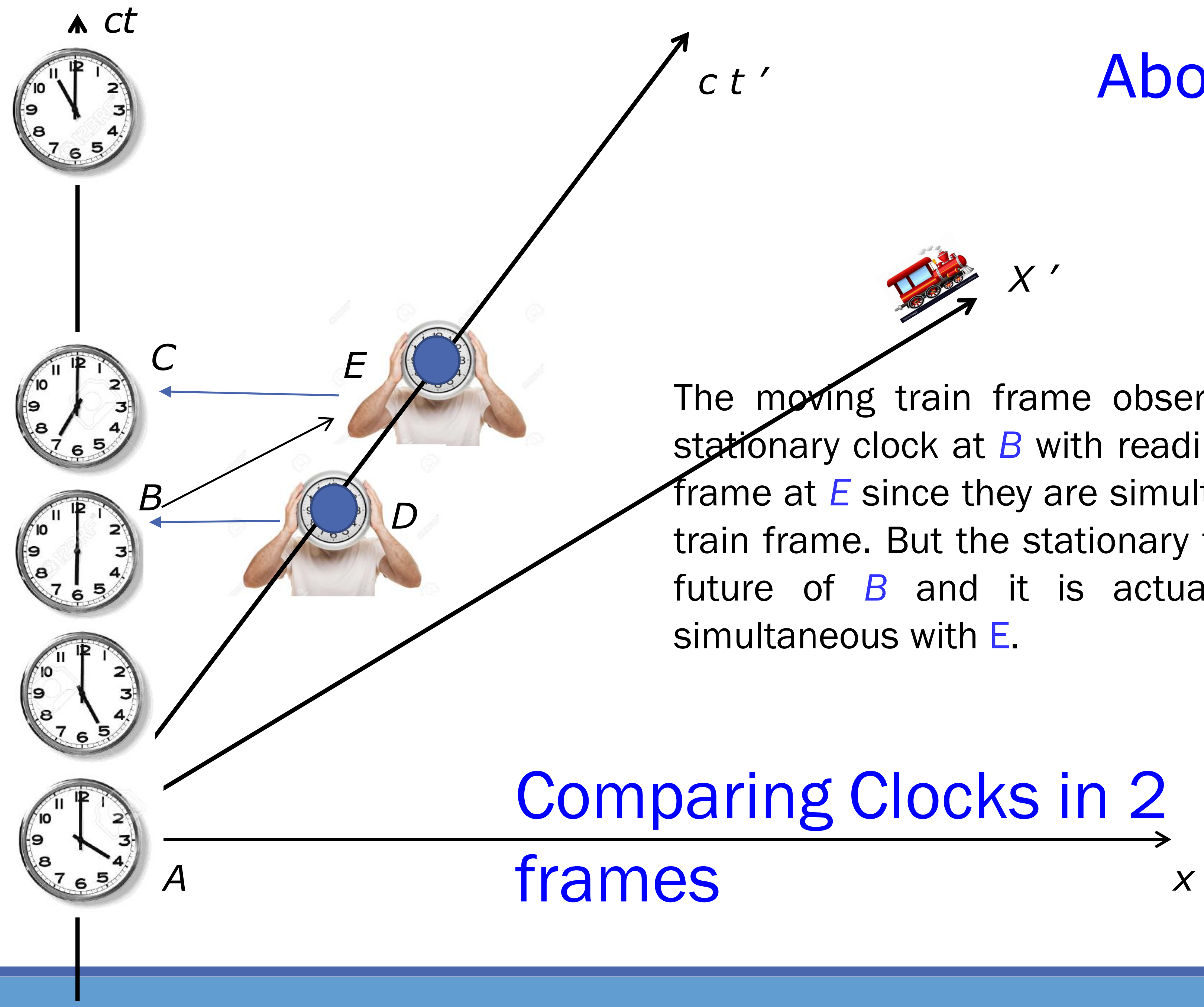
Observed from stationary frame



ct
ct'
About Time !
same Time !
in ct' vs x' frame
moving train frame
X '
Time Dilation
Observed from moving frame
x

About Time !

Time Dilation

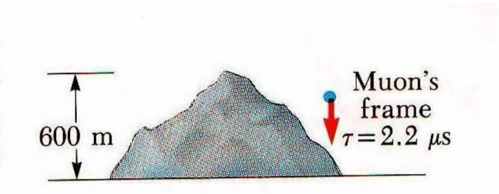


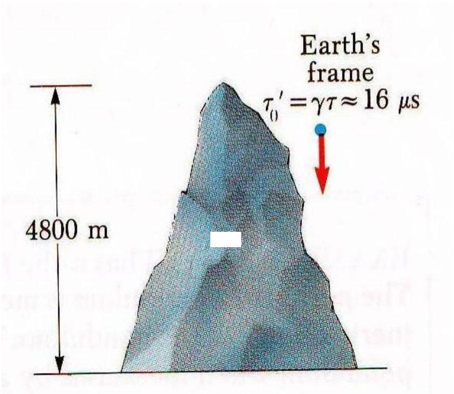
The moving train frame observer compares stationary clock at *B* with reading of the train frame at *E* since they are simultaneous in the train frame. But the stationary frame *E* is the future of *B* and it is actually *C* that is simultaneous with E.

Comparing Clocks in 2 frames

Time dilation is always accompanied by length contraction

Reminder : Muon Again !





In the example above, an observer in the muon's frame would measure the t_0 = 2.2 μs lifetime, while an earth-based observer measures the L_0 = 4800m height of the mountain.

Likewise, on the earth observer's frame; observes that there is time dilation on the muon, but the distance of travel is measured to be actual height, L_0 of the mountain.

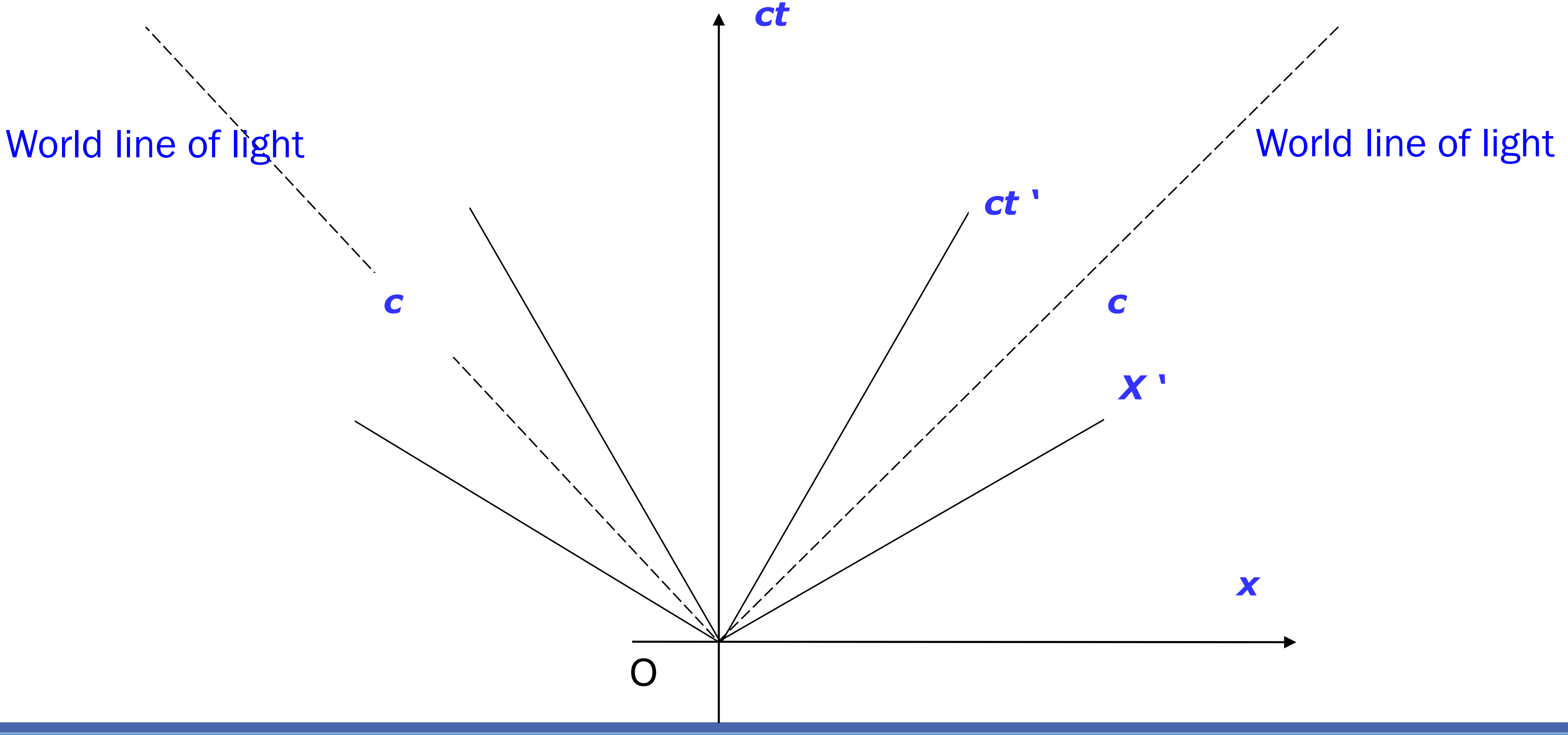
In the muon's frame, there is no time dilation, but the distance of travel, L is observed to be shorter when measured in this frame.

There is a kind of "offsetting" effect but **the outcome should be the same !**

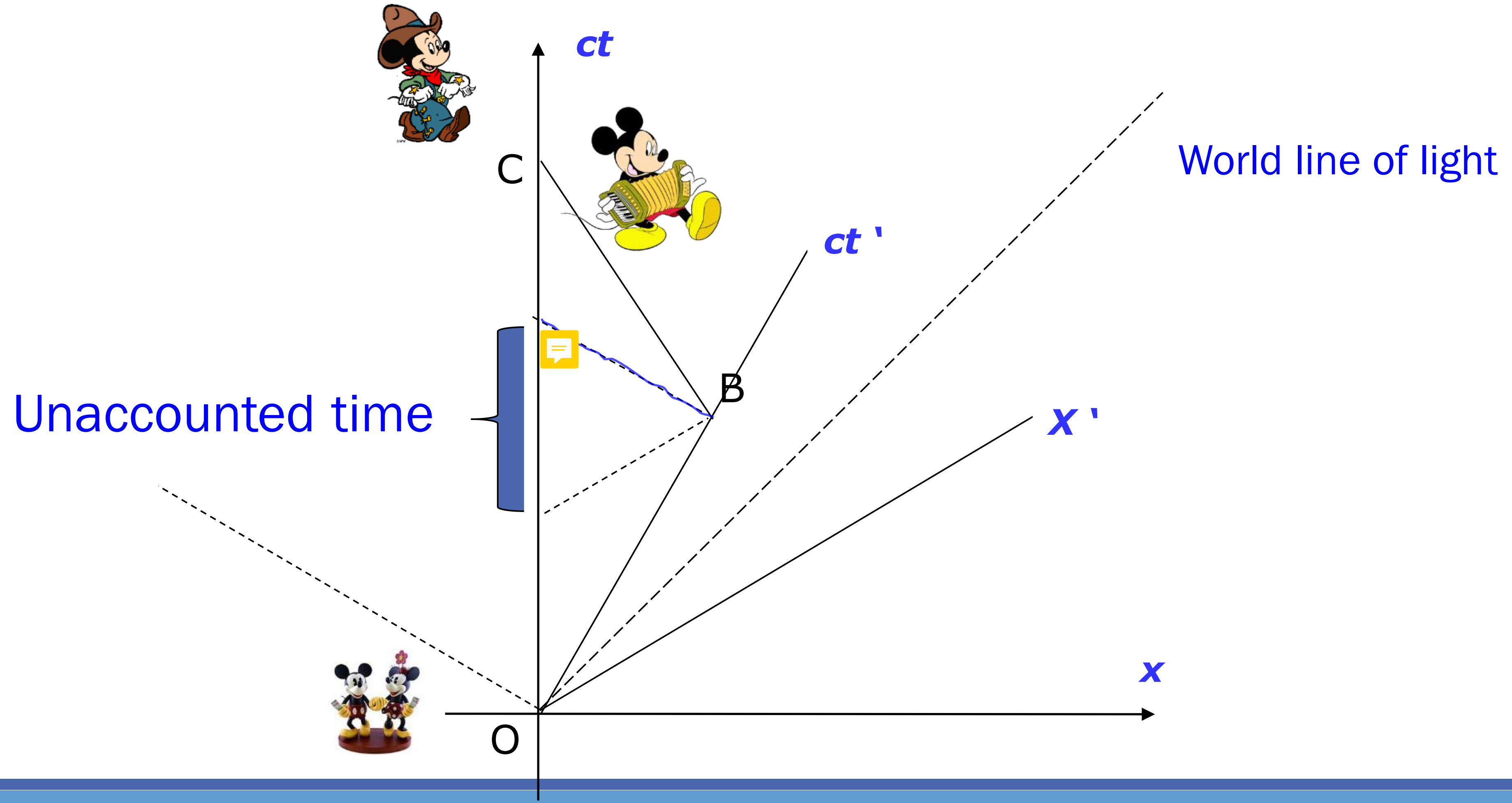
About the other direction …

… this relativity … … twin Paradox

Space Time (the other direction)



Twin Paradox Revisited



Twin Paradox Revisited

Note: The twins' paths are not symmetrical … hence the returning twin (OBC) will be younger and the twin (OC) that stayed on earth will be older.

The twin (OBC) who left earth can claim that she felt weight because her engines counteracted a gravitational field (acceleration) … we know that time runs slowly in gravitational fields (acceleration) … Equivalence Principle …

A further Illustration on Space time Diagrams

add a 3rd constant moving Reference Frame

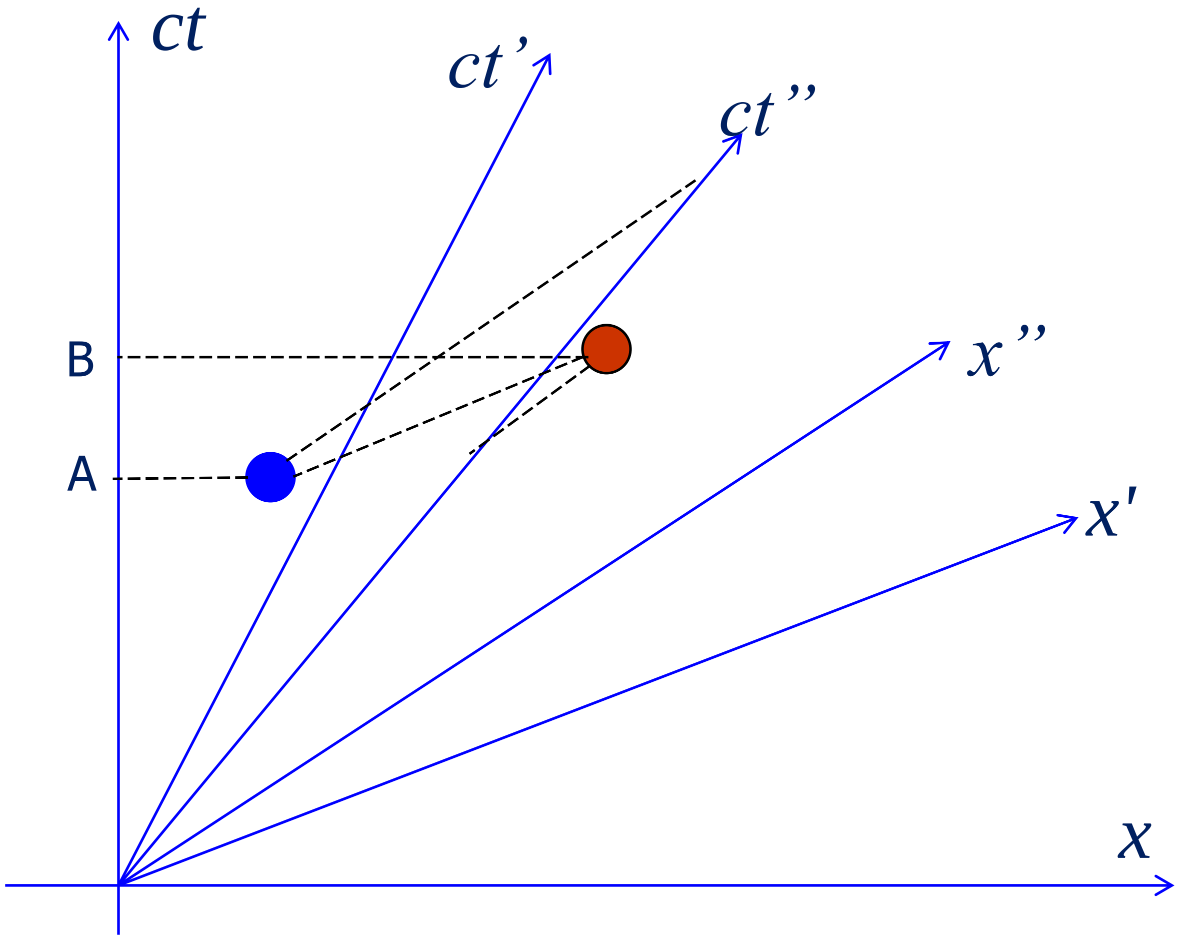
A Space-time diagram Illustration

In reference frame ct' vs x' events A and B happened at the same time.

In reference frame ct vs x events A happened before event B.

What about in reference frame ct'' vs x''? Anything peculiar ?

A (**cause-effect**) Question ?



Applications of Space-Time diagrams

… Pythagorean expression

Reminder: Same Space-Time Intervals

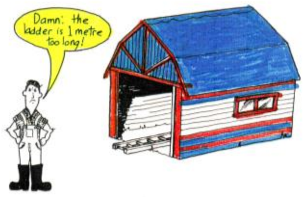
Consider the Farmer and Son at the barn.

They both disagreed on both the space and time separation between these 2 events … the ladder and doors.

Is there a quantity such that 2 observers can agreed ?

Yes, they would find the same interval of space-time separation between these 2 events.

$$ds^2 = -d(ct)^2 + dx^2 + dy^2 + dz^2$$
$$ds^2 = -d(ct')^2 + dx'^2 + dy'^2 + dz'^2$$



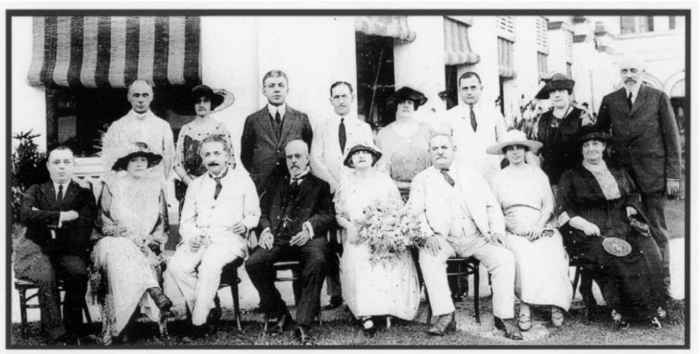
Velocity Addition

$$\boxed{u = u' + v}$$

$$\boxed{u = \frac{u' + v}{1 + \frac{u'v}{c^2}}}$$

$$\begin{aligned} x &= (x' + vt') \\ y &= y' \\ z &= z' \\ t &= t' \end{aligned}$$

Inverse Galilean Transformation



Albert Einstein with prominent members of Singapore's Jewish community.

Photo includes, seated from left to right: the Einsteins' hosts, Alfred Montor and his wife; Albert Einstein; Sir Menasseh Meyer, whom Einstein refers to as 'Croesus'; and Einstein's wife Elsa. Meyer's daughter Moselle stands behind Einstein.

photo courtesy of Alan Frankel

Divide by *time* and recall

$$\gamma^2 = \frac{1}{1 - \left(\frac{v}{c}\right)^2} \qquad \gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

$$\begin{aligned} x &= (x' + vt')\gamma \\ y &= y' \\ z &= z' \\ t &= \left(t' + \tfrac{vx'}{c^2}\right)\gamma \end{aligned}$$

Inverse Lorentz Transform

$$E_T = K$$

$$E_T = K + m_o c^2$$

Length Contraction Revisited

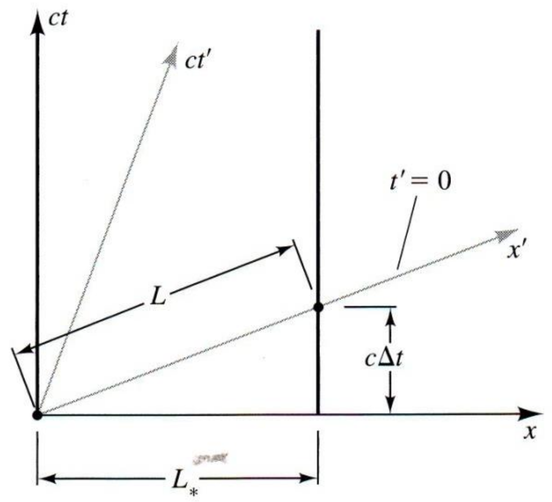


FIGURE 4.16 Lorentz contraction of length. The figure shows the world lines of the ends of a rod oriented along the x-axis in its own rest frame spanned by coordinates (ct, x). The distance L_* between the world lines is the rest length of the rod. Also shown on the same plot are the axes (ct', x') of an inertial frame moving with speed V with respect to the rest frame. In this frame the rod is moving with velocity $-V$ along the x'-axis. The length of the rod L in this frame is the distance between its ends at a single moment of time, t'. The events at the ends at time $t' = 0$ are indicated by •'s in the figure. Although the length L looks longer than L_* in the figure, it is actually shorter because of the non-Euclidean geometry of spacetime.

James Hartle, Gravity, Addison Wesley Pub.

$$L = L_* \sqrt{1 - \frac{v^2}{c^2}}$$

or

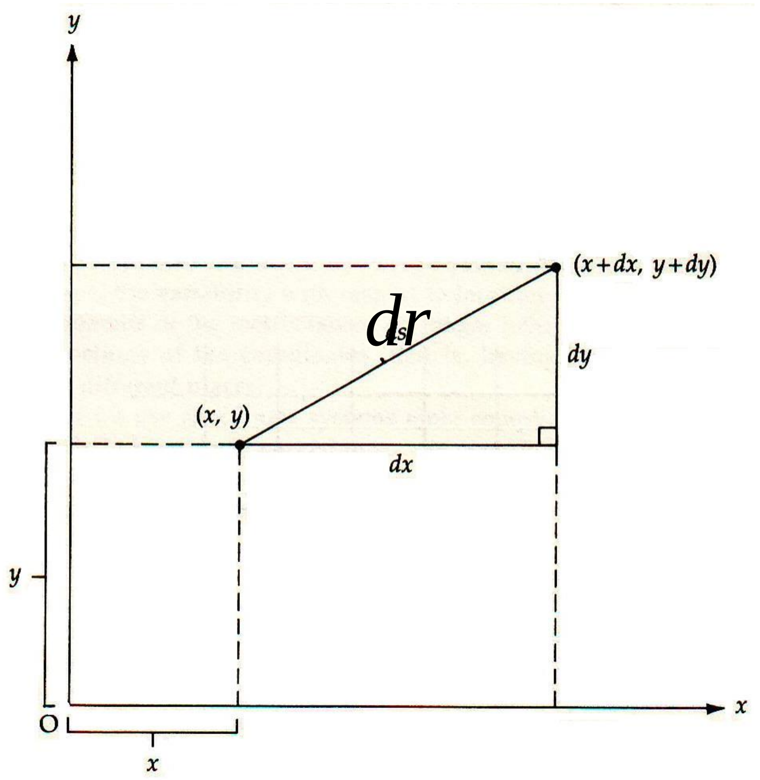
$$L = \frac{L_*}{\gamma}$$

Something strange isn't it ?

Wait a minute … what da ?

Sec. Sch. Pythagoras Theorem

2 Dimensional Euclidean Geometry (flat like your paper)



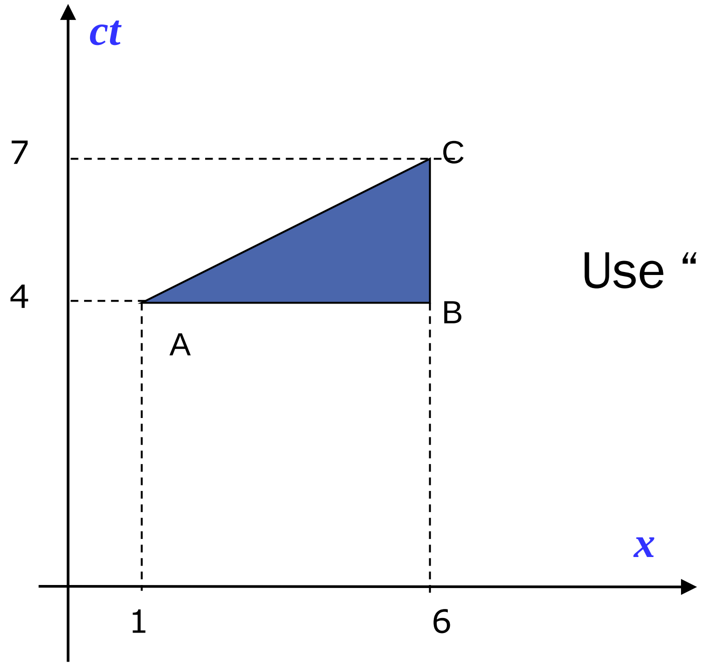
Reminder : Lazy to write this

$$(dr)^2 = (dx)^2 + (dy)^2$$

We rewrite, so we have

$$dr^2 = dx^2 + dy^2$$

A peculiar note on Space Time Diagrams



Use “Pythagoras Theorem” !

Which is the longest side ?

Find the length of side AC ?

Answer : 4 units **Shocking ! !**

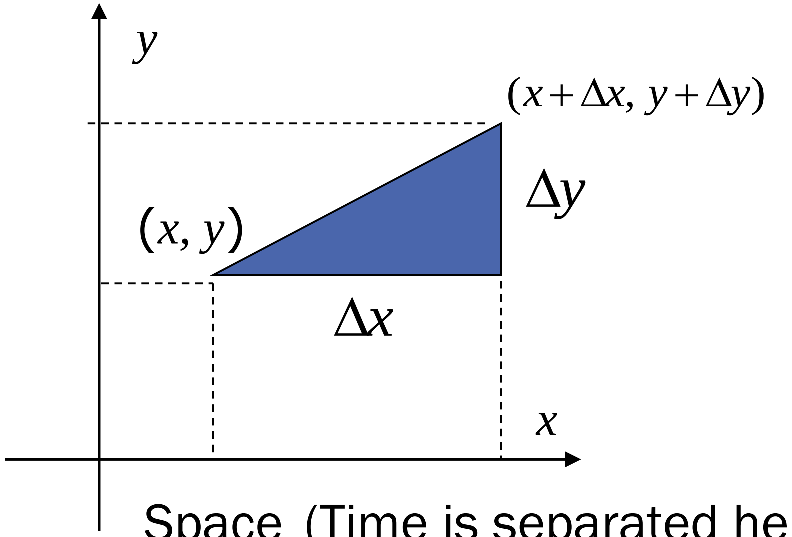
but why ?

$$ds^2 = -d(ct)^2 + dx^2$$

Non-Euclidean Geometry

Note : Some books put $ds^2 = +d(ct)^2 - dx^2$

Epistemic Summary

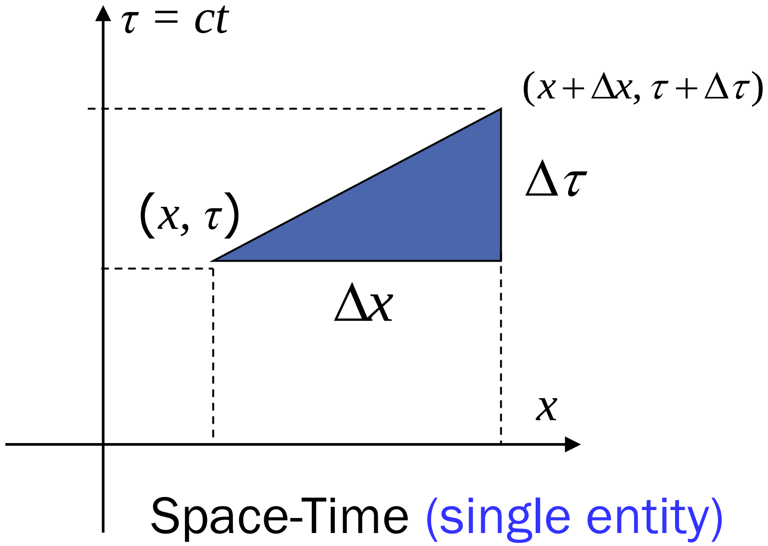


Space (Time is separated here)

Hypotenuse is

$$\sqrt{\Delta y^2 + \Delta x^2}$$

is the longest side (Secondary School)



Space-Time (single entity)

Hypotenuse is

$$\sqrt{-\Delta \tau^2 + \Delta x^2}$$

is not the longest side (University)

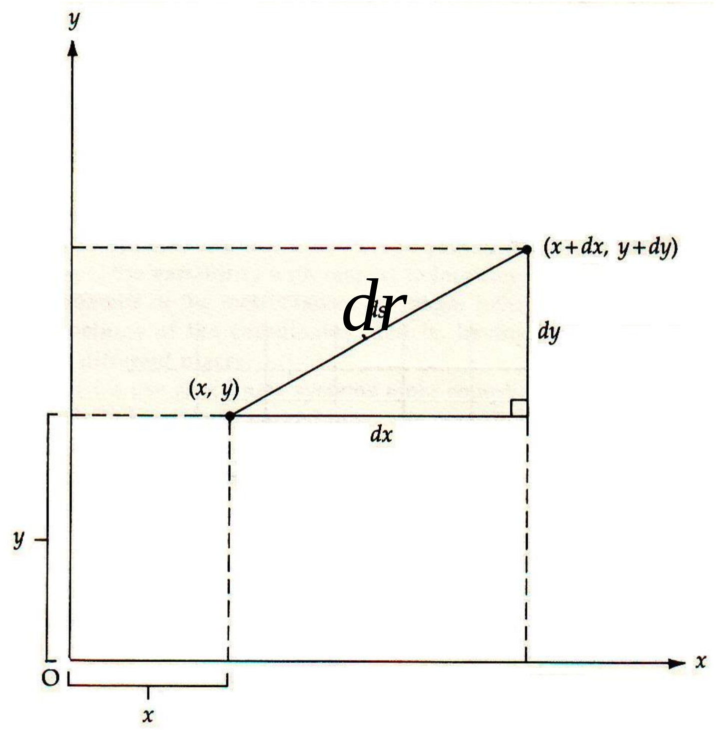
(Reminder : sometimes c is set to one)

Applications of Space-Time diagrams

… Geometry

"Pythagoras Theorem" in GR

Euclidean Geometry



$$(dr)^2 = (dx)^2 + (dy)^2$$

or

$$dr^2 = dx^2 + dy^2$$

Actually there are other terms …

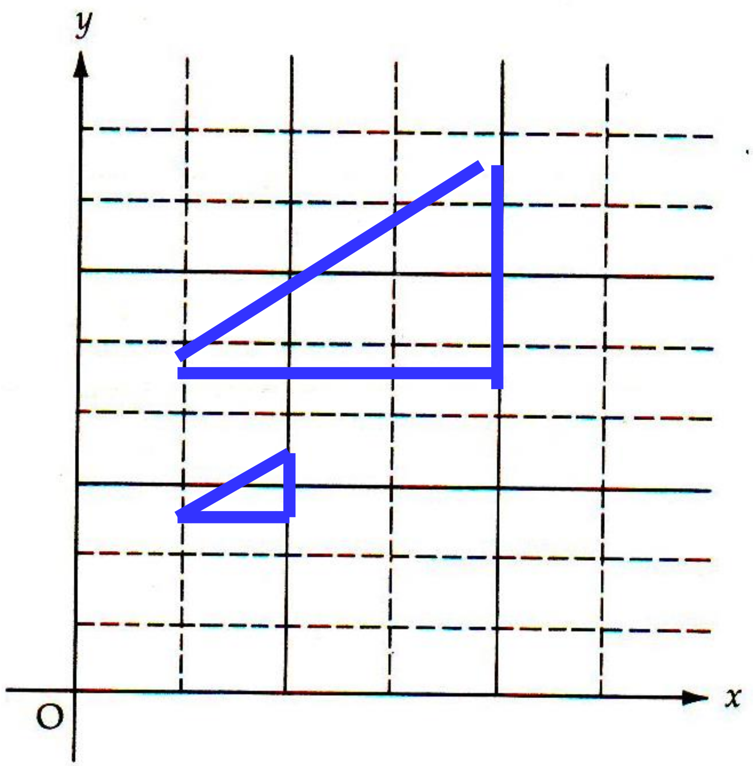
In general it is :

$$dr^2 = 1dx^2 + 0dxdy + 0dydx + 1dy^2$$

Why ? Why ? What are these cross-terms ?

What happens if the scale changes ?

Still Euclidean Geometry



Let's say: the *x*-axis and *y*-axis shrinks to 1/3 each.

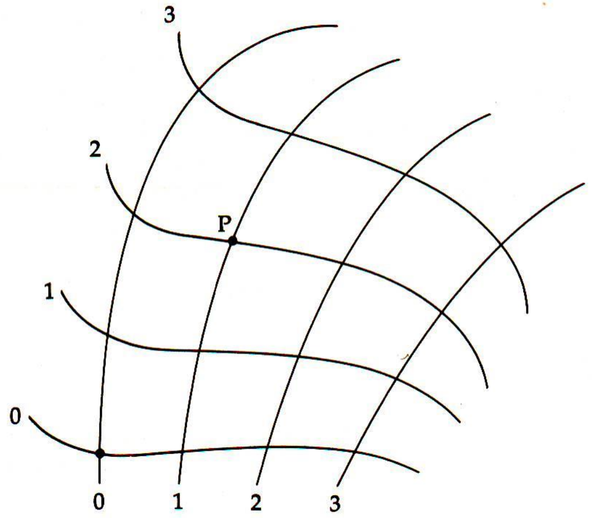
What will happen to the Pythagoras Theorem that we know ?

$$dr^2 = \left(\tfrac{1}{3}\right)^2 dx^2 + \left(\tfrac{1}{3}\right)^2 dy^2$$

Notice Coefficients are no more one !

"Pythagoras Theorem" for GR (An analogy)

When axes are no more linear (are distorted).



Do you know why there are extra terms in this generalized Pythagoras theorem by now ?

$$dr^2 = \alpha dx^2 + \beta dxdy + \gamma dydx + \delta dy^2$$

Reminder : Sometimes called The Metric

Notice: β and γ will no longer be zero, α and δ may not be **+/- unity**.

Recall what Einstein did: $$dr^2 = g_{11}dx^2 + g_{12}dxdy + g_{21}dydx + g_{22}dy^2$$

In fact, Einstein thinks that coefficients may be **functions**, g_{uv}

How do we get the g (or V) terms in the 1st place ?

For Pundits and Amateurs alike !

Say :

$$x = x(x^1, x^2, x^3); \quad y = y(x^1, x^2, x^3); \quad z = z(x^1, x^2, x^3)$$

Let you experience it !
Enjoy it ! this 3 dimensional case !

$$dx = \frac{\partial x}{\partial x^1} dx^1 + \frac{\partial x}{\partial x^2} dx^2 + \frac{\partial x}{\partial x^3} dx^3$$

Must have done these before in error analysis in engineering and thermodynamics.

Recall **chain rule** $\frac{dy}{dx} = \frac{dy}{du} \times \frac{du}{dx}$

For those who cannot wait !

Notice only derivatives !

$$dr^2 = dx^2 + dy^2 + dz^2$$

Notational Reminder $dx^2 = (dx)^2$

$$dr^2 = \left[\left(\frac{\partial x}{\partial x^1}\right)^2 + \left(\frac{\partial y}{\partial x^1}\right)^2 + \left(\frac{\partial z}{\partial x^1}\right)^2\right](dx^1)^2$$

$$+2\left[\frac{\partial x}{\partial x^1}\frac{\partial x}{\partial x^2} + \frac{\partial y}{\partial x^1}\frac{\partial y}{\partial x^2} + \frac{\partial z}{\partial x^1}\frac{\partial z}{\partial x^2}\right]dx^1 dx^2 \quad + \ldots$$

$$dr^2 = \sum_{\mu=1}^{3}\sum_{\nu=1}^{3} g_{\mu\nu}dx^\mu dx^\nu$$ Cartesian (Pythagorean)

$$ds^2 = \sum_{\mu=0}^{3}\sum_{\nu=0}^{3} g_{\mu\nu}dx^\mu dx^\nu$$ Minkowski Metric

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

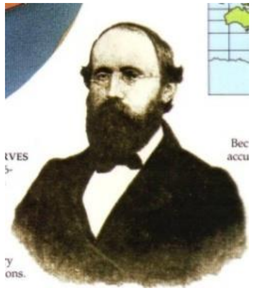
Einstein's Field Equations

The Price to pay … for new ideas

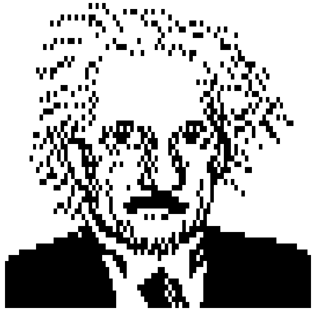
It is not until we attempt to bring the theoretical part of our training into contact with the practical that we begin to experience the full effect of what Faraday has called “mental inertia” … not only the difficulty of recognizing among the objects before us, the abstract relations which we have learned from books, but ***the distracting pain of wrenching the mind away from the symbols to the objects, and from the objects back to symbols.*** This, however, is the price we have to pay for new ideas.

J.C. Maxwell, Intro lecture at Cavendish Lab. 1871

About Mathematics !



Do not worry about your difficulties in Mathematics, I assure you mine are still greater …



When I examine myself and my methods of thought, I come to the conclusion that the gift of fantasy has meant more to me than my talent of absorbing positive knowledge.

A. Einstein

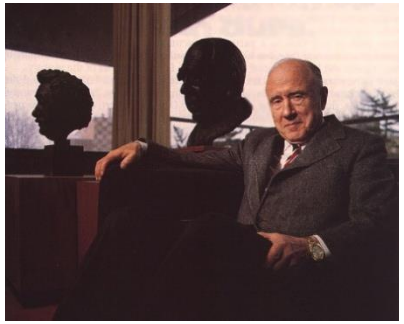
No force Concept in General Relativity Theory
A paradigm shift …in *Time*

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

Many not close to his work of Einstein as a man who could only make headway by dint of pages of complicated mathematics. The truth is the direct opposite. As the great mathematician of the time, D. Hilbert, put it, "Every school boy in the streets of Gottingen understands more about 4 dimensional geometry than Einstein".

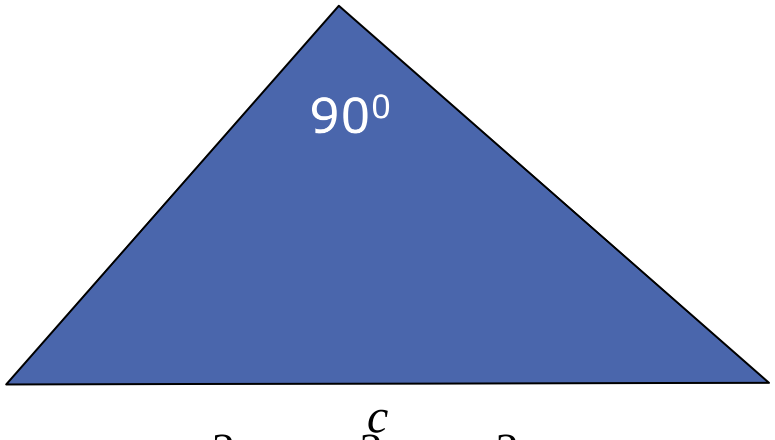
Yet … Einstein did the work and not the mathematicians" the amateur grasped the simple central point that had eluded the expert …

J. A. Wheeler

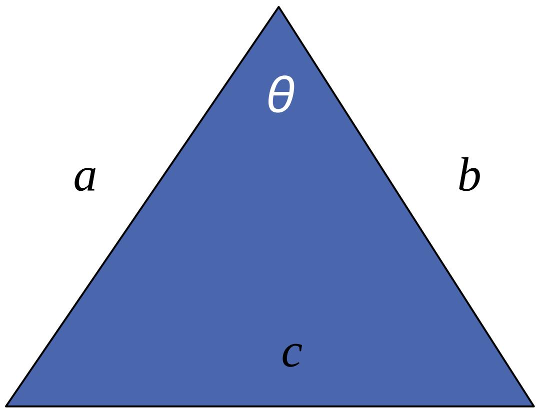


From Secondary School !

Not so surprising !



$$c^2 = a^2 + b^2$$



$$c^2 = a^2 + b^2 - 2ab\cos\theta$$

$$c^2 = a^2 + b^2 - (2\cos\theta)ab$$

The cross term !

Einstein said in 1934 …

In the light of knowledge attained, the happy achievement seems almost a matter of course, and any intelligent student can grasp it without too much trouble.

But the years of anxious searching in the dark with their intense longing, their alternations of confidence and exhaustion and the final emergence into light – only those who have *experienced* *it* can understand that.

Epistemic Summary

Newtonian vs Einsteinian Gravity

Newtonian

Only one gravitational Potential Term

$$V(r) = -G\frac{Mm}{r}$$

or

$$V_{tt} = 1 + \frac{2V(r)}{c^2}$$

Einstein

16 Gravitational Potential terms

$$\begin{pmatrix} V_{tt} & V_{tx} & V_{ty} & V_{tz} \\ V_{xt} & V_{xx} & V_{xy} & V_{xz} \\ V_{yt} & V_{yx} & V_{yy} & V_{yz} \\ V_{zt} & V_{zx} & V_{zy} & V_{zz} \end{pmatrix}$$

Einstein assigned the metric tensor $g_{uv} = V_{uv}$ a dual role, one geometrical and the other gravitational. **Note a tensor is a matrix.**

In short, gravitation turns out to be not a force but something geometrical.

Newtonian vs Einsteinian Gravity

Newtonian

Only one gravitational Potential Term

$$g_{tt} = 1 + \frac{2V(r)}{c^2}$$

$$V(r) = -G\frac{Mm}{r}$$

Space (x, y, z) and time, t are separated

$$dr^2 = dx^2 + dy^2 + dz^2$$

Gravity is a force $\quad F = G\frac{Mm}{r^2}$

Force ~ mass

Einstein

16 Gravitational Potential terms

$$\begin{pmatrix} g_{tt} & g_{tx} & g_{ty} & g_{tz} \\ g_{xt} & g_{xx} & g_{xy} & g_{xz} \\ g_{yt} & g_{yx} & g_{yy} & g_{yz} \\ g_{zt} & g_{zx} & g_{zy} & g_{zz} \end{pmatrix}$$

Space (x, y, z) and time, t are treated the same

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu \qquad (t, x, y, z) \to (x^0, x^1, x^2, x^3)$$

Gravity is Geometry $\quad R_{\mu\nu} - \cancel{\frac{1}{2}R}g_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$

There is no force concept here.

Geometry ~ (mass ~ energy)

Special vs General Relativity

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \cancel{\Lambda g_{\mu\nu}} = \kappa T_{\mu\nu}$$

Special Relativity | **Covariance**

Rest / Uniform Moving Frame

No acceleration

No Gravity mentioned

Space-time is interrelated in Flat geometry

$E=mc^2$ (Energy ~ mass)

General Relativity

Accelerated (Non-uniform)

Principle of Equivalence

Gravitation is present

Space-time is intermeshed in Curved geometry

$R_{ik} = 0$? (Geometry ~ mass)

It happens that the metric tensor, $g_{\mu\nu}$ or g^{uv}, contains all the data needed to calculate the intrinsic curvature of Space-time. Since Einstein was representing gravitation by means of the metric tensor, it is not surprising that in his theory, gravitation should turn out to be a curvature of Spacetime.

Actually …

how did Einstein do it ?

Actually, how did Einstein do it ?

Principle of Covariance

Principle of Equivalence

Principle of Minimal Gravitational Coupling:

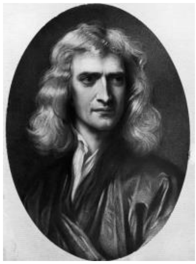
Correspondence Principle

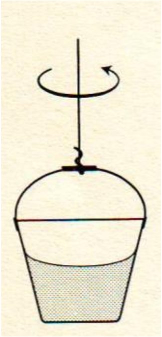
Simplicity principle or Occam's Razor

http://en.wikipedia.org/wiki/Mach's_principle

Ray D'Inverno, *Introducing Einstein's Relativity,* Oxford Clarendon Press, 1993

Newton's Bucket



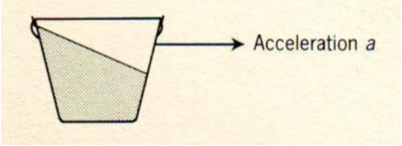


At first, the bucket rotates, but the water does not, its surface remaining flat.

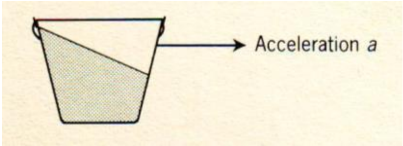
The frictional effects between the bucket and the water eventually communicate the rotation to the water. The centrifugal forces cause the water to pile up round the edges of the bucket and the surface becomes concave. The faster the water rotates, the more concave the surface becomes.

Eventually the bucket will slow down and stop, but the water will continue rotating for a while, its surface remaining concave

Finally, the water will return to rest with a flat surface.



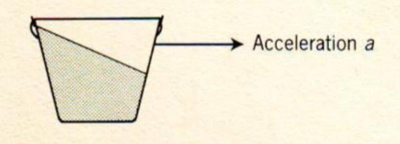
Reading Assignment



Isaac Newton conducted an experiment with a bucket containing water which he described in 1689. The experiment is quite simple and any reader of this article can try the experiment for themselves. All one needs to do is to half fill a bucket with water and suspend it from a fixed point with a rope. Rotate the bucket, twisting the rope more and more. When the rope has taken all the twisting that it can take, hold the bucket steady and let the water settle, then let go. What happens? The bucket starts to rotate because of the twisted rope. At first the water in the bucket does not rotate with the bucket but remains fairly stationary. Its surface remains flat. Slowly, however, the water begins to rotate with the bucket and as it does so the surface of the water becomes concave. Here is Newton's own description:- ... the surface of the water will at first be flat, as before the bucket began to move; but after that, the bucket by gradually communicating its motion to the water, will make it begin to revolve, and recede little by little from the centre, and ascend up the sides of the bucket, forming itself into a concave figure (as I have experienced), and the swifter the motion becomes, the higher will the water rise, till at last, performing its revolutions in the same time with the vessel, it becomes relatively at rest in it. Soon the spin of the bucket slows as the rope begins to twist in the opposite direction. The water is now spinning faster than the bucket and its surface remains concave.

https://mathshistory.st-andrews.ac.uk/HistTopics/Newton_bucket/

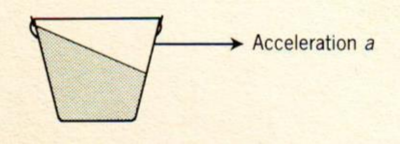
Reading Assignment



What is the problem? Is this not precisely what we would expect to happen? Newton asked the simple question: why does the surface of the water become concave? One is inclined to reply to Newton: that is an easy question - the surface becomes concave since the water is spinning. But after a moment's thought one has to ask what spinning means. It certainly does not mean spinning relative to the bucket as is easily seen. After the bucket is released and starts spinning then the water is spinning relative to the bucket yet its surface is flat. When friction between the water and the sides of the bucket has the two spinning together with no relative motion between them then the water is concave. After the bucket stops and the water goes on spinning relative to the bucket then the surface of the water is concave. Certainly the shape of the surface of the water is not determined by the spin of the water relative to the bucket.

Newton then went a step further with a thought experiment. Try the bucket experiment in empty space. He suggested a slightly different version for this thought experiment. Tie two rocks together with a rope, he suggested, and go into deep space far from the gravitation of the Earth or the sun. One certainly cannot physically try this today any more than one could in 1689. Rotate the rope about its centre and it will become taut as the rocks pull outwards. The rocks will create an outward force pulling the rope tight. If one does this in an empty universe then what can it mean for the system to be rotating. There is nothing to measure rotation with respect to. Newton deduced from this thought experiment that there had to be something to measure rotation with respect to, and that something had to be space itself. It was his strongest argument for the idea of absolute space.

Reading Assignment



Now Newton returned to his bucket experiment. What one means by spin, he claimed, was spin with respect to absolute space. When the water is not rotating with respect to absolute space then its surface is flat but when it spins with respect to absolute space its surface is concave. However he wrote in the *Principia*:- I do not define time, space, place, and motion, as they are well known to all. Absolute space by its own nature, without reference to anything external, always remains similar and unmovable. He was not too happy with this as perhaps one can see from other things he wrote:-

“It is indeed a matter of great difficulty to discover and effectually to distinguish the true motions of particular bodies from the apparent, because the parts of that immovable space in which these motions are performed do by no means come under the observations of our senses.”

Mach Principle :

The idea is that the local notion of rotating reference frame is determined by the large scale distribution of matter, as exemplified by this anecdote:

You are standing in a field looking at the stars. Your arms are resting freely at your side, and you see that the distant stars are not moving.

Now start spinning.
The stars are whirling around you and your arms are pulled away from your body. Why should your arms be pulled away when the stars are whirling? Why should they be dangling freely when the stars don't move?

Mach Principle :

Mach's principle says that this is not a coincidence—that there is a physical law that relates the motion of the distant stars to the local inertial frame. If you see all the stars were whirling around you, Mach suggests that there is some physical law which would make it so you would feel a centrifugal force.

The principle is often stated in vague ways, like "mass out there influences inertia here".

A very general statement of Mach's principle is "*Local physical laws are determined by the large-scale structure of the universe.*"

SUBTLE is the LORD ! Abraham Pais

After Einstein, the Mach principle faded but never died. ... I am told that the *Zeitschrift fur Physik* no longer accepts papers on general relativity on the grounds that articles on Mach's principle provoke too many ptolemical replies. ... It must be said that, as far as I can see, to this day Mach's principle has not brought physics decisively farther.

It must also be said that the origin of inertia is and remains the most obscure subject in the theory of particles and fields. Mach's principle may therefore have a future ... but not without quantum theory.

General Relativity seems very successful

… there is a major problem ?

A General Relativity Failure ?: Black Hole Singularity:

However it was discovered after long study that this singularity in the metric is due to the choice of co-ordinates and is not real. On the other hand, the singularity at r = 0, appears to be real. … Any way, nature has hidden away the singularity inside $r = 2M$, so we cannot find out while remaining outside … all real singularities are “clothed”.

That is, anything falling to the center of a black Hole is crushed to zero volume … to a single point … quantum theory predicts that nothing … not even a single electron … can be confined to a point.

What is the truth ? Nobody knows … need a quantum gravity theory that combines quantum mechanics and general relativity. Taylor and Wheeler

General Relativity brings about its own downfall by predicting singularities. S. Hawking

This is a GEM module !

Education is not the filling of a pail, but the lighting of a fire.
William Butler Yeats 20th century poet & writer

"For everything that's lovely is/But a brief, dreamy, kind delight." - 'Never Give All the Heart', W. B. Yeats

An educated mind is never certain. K. P. Mohanan, NUS

Education's purpose is to replace an empty mind with an open one.
Charles Sturt University

We (Tutor and myself) really hope to have opened your minds and rubbed onto you all some of the strong passions we feel about all these weird but wonderful things that nature offers.

The Universe in a Nutshell ! S. Hawking

Any sound scientific theory, whether of time or of any other concept, should in my opinion be based on the most workable philosophy of science, the positive approach put forward by Karl Popper.

According to this way of thinking, a scientific theory is a mathematical model that describes and codifies the observations we make. A good theory will describe a large range of phenomena on the basis of a few simple postulates and will make definite predictions that can be treated.

The Universe in a Nutshell ! S. Hawking

If predictions agreed with the observations, the theory survives that test, though it *can never be proved* to be correct.

On the other hand, if the observations disagree with the predictions, one has to discard or modify the theory.

It is about Time ! Why Relativity is 3+1 Theory ?

If one takes the positive position, as I do, *one cannot say what time actually is* ?

All one can do is describe what has been found to be a very good mathematical model for time and say what predictions it makes.

Let us do Mathematics :
Kurt Godel's Incompleteness Theorem (1931) …

The Theorem states that within any formal system of axioms, such as present-day mathematics, questions always persist that can neither be proved nor disproved on the basis of the axioms that define the system.

In other words, there are problems that cannot be solved by any set of rules or procedures.

Godel's theorem set fundamental limits on mathematics. It came as a great shock to the scientific community, since … widespread belief that mathematics was a coherent and complete system based on a single logical foundation.

Gödel's first **incompleteness theorem** says that if you have a consistent logical system (i.e., a set of axioms with no contradictions) in which you can do a certain amount of arithmetic [4], then there are statements in that system which are unprovable using just that system's axioms

Recall Intro. Lecture : Relativity

When told that only 3 persons in the world understood relativity,

A. Eddington asked “I wonder who is the 3rd ?”