SIMPLE RELATIVITY

ANIMATION DESIGN PROJECT III
AN III - 66

BY
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GUIDE:
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INDUSTRIAL DESIGN CENTER
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY
2014

Project III

Simple Relativity

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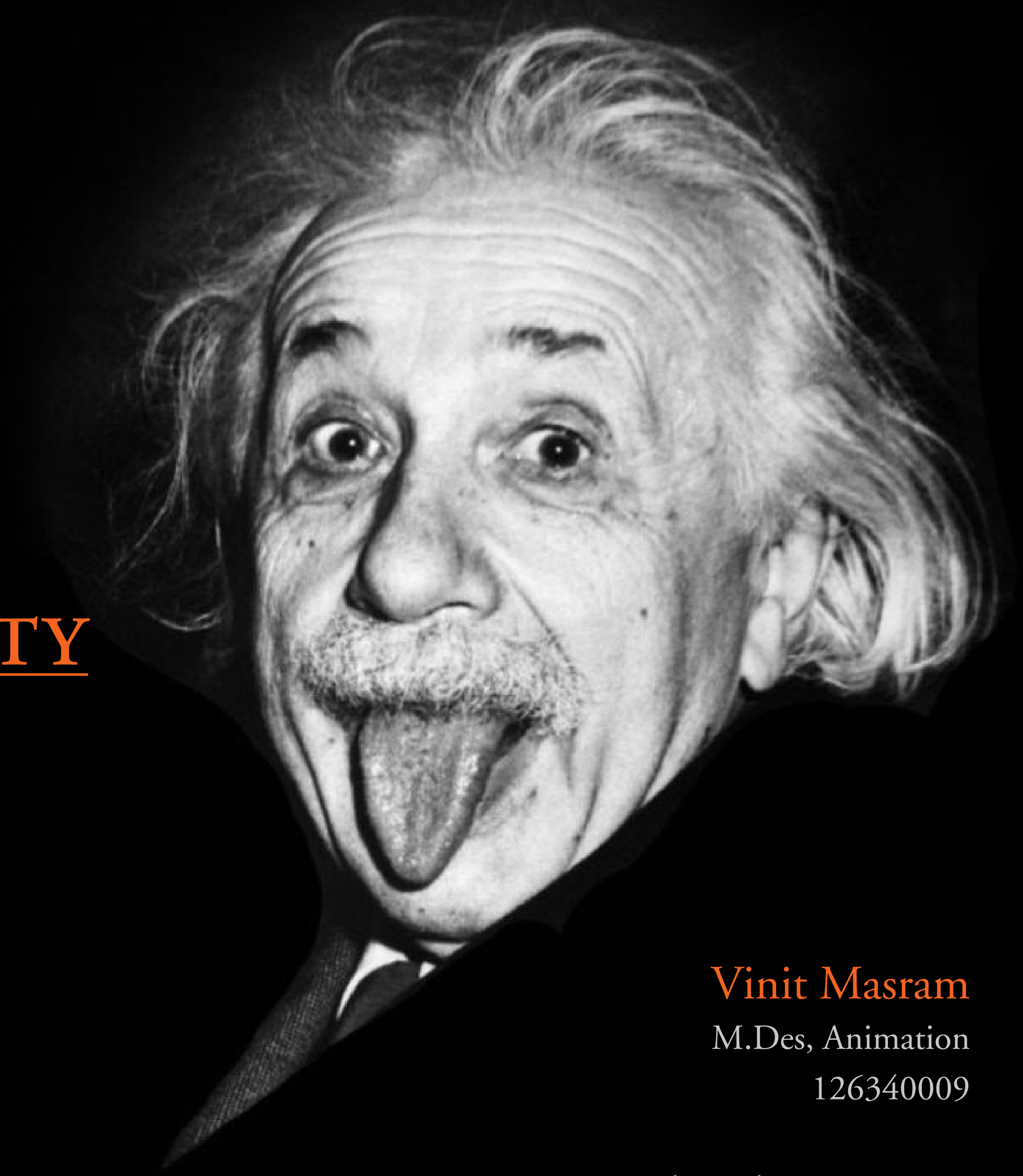

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Approval Sheet

The project titled 'Simple Relativity' by Vinit Masram, is approved for the partial fulfillment of the requirement for the degree of 'Master of Design' in Animation Design.

Guide

Chairperson

Internal Examiner

External Examiner

Date 13-06-14

Declaration

I declare that this written submission contains my interpretation of the work done by great scientists from 19th and 20th century. However, it also contains material that represents my ideas in my own words and where other ideas and work have been included; I have adequately cited and referenced the original sources.

I also declare that I have adhered to all principles of academic honesty and integrity and have not fabricated, misrepresented or falsified any idea/data/fact/source in my submission.

I understand that any violation of the above will cause for disciplinary action by the institute and can evoke penal action from the sources which have thus not been properly cited or from whom permission has not been taken when needed.

Signature:

Name: Vinit Masram

Roll No. 126340009

Date: 12-06-2014

Acknowledgement

I would like to thank my project guide Prof. Sumant Rao for his constant support and expert guidance in my work leading up to the finished stage of the film. His inputs have helped me shape my initial ideas into a concrete form and turn into a deliverable animation short.

I would also like to express my gratitude to Prof. Girish Dalvi for his valuable inputs and suggestions during the course of the data collection for this project. They helped me address the issues from different dimen¬sions I wasn't considering at first.

I would also thank Ashwin Vasudevan, Paulanthony George and Ravi Rao for listening to my ideas patiently and providing valuable insights. Lastly, I would like to thank Avinash and Divya for taking time out from their busy schedules to become the voice of the film.

Vinit Masram

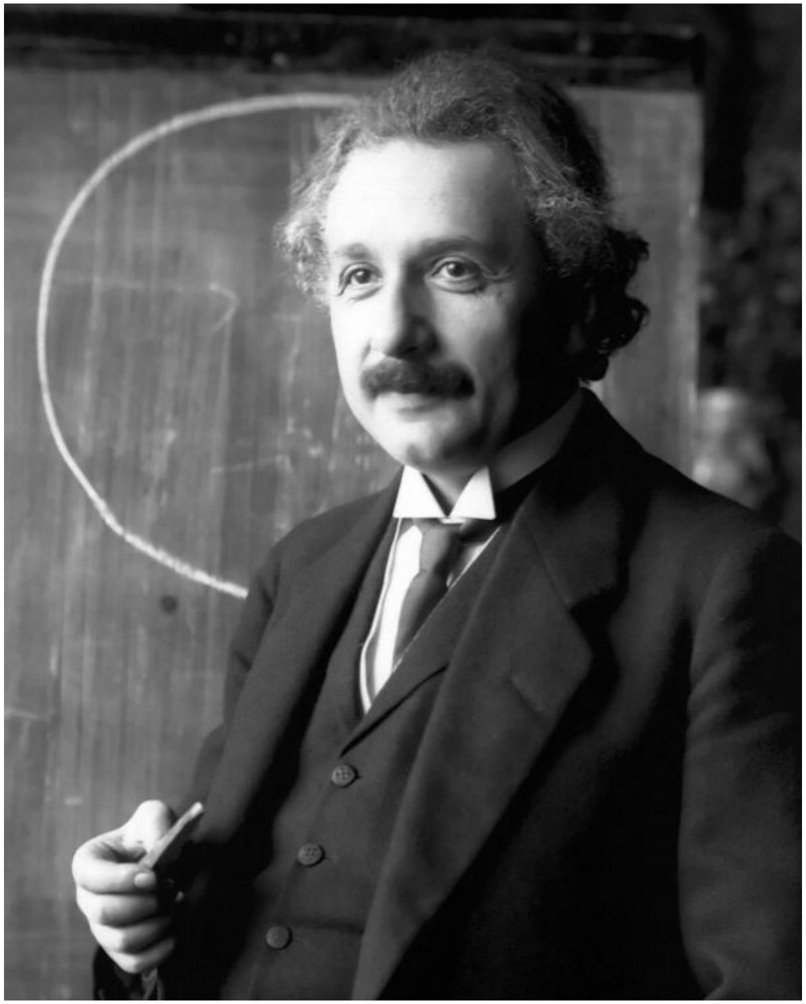
June 2014

Abstract

The project being developed named “Simple Relativity” is a 2D short educational animation film. The film is an attempt to explain Albert Einstein’s Special Theory of Relativity with a simpler visual representation and exciting animation.

In a time when our day-to-day life is surrounded by technology, most people find it daunting to understand the science and its application. Simple Relativity is an attempt to excite the viewer about this complex phenomenon of Relativity so that they can approach this, and science in general, with a lot more curiosity rather than inhibition.

Content



Introduction

> *"Learn from yesterday, live for today, hope for tomorrow.*
> *The important thing is not to stop questioning."*
> -Albert Einstein

Albert Einstein (1879–1955) is the most prominent physicist of the twentieth century and one of the greatest scientists ever. Born on 14 March 1879 in Ulm Germany, Einstein passed his Swiss Matura, equivalent of a high school exam in India, in September 1896 and finished his Zürich Polytechnic teaching diploma in 1900. After graduation Feinstein secured a job as a patent clerk in the patent office in Bern after two years looking for a teaching job. In 1905 Einstein published The Annus Mirabilis papers which focused four areas named, Photoelectric Effect, Brownian Motion, Special Relativity and Matter-Energy Equivalent. This propelled him in science world as one of most famous Physicists and earned him the Nobel Prize in 1921 for his discovery of law of photoelectric effect. His greatest achievements are known by many people but understood by a few.

Albert Einstein's theories are one of the most interesting groundbreaking theories in science. The greatest and most popular of all is his Theory of Relativity. It is the most amazing work of science anyone can come up with. But there's a little problem with it. It is hard to understand. There's a great deal of difficulty amongst people not only to understand it for themselves but to make people understand as well. This inhibits one of the primary goals of science, goal of enlightening people about the working of universe and how it affects our lives. But the answers within themselves are so extravagant and overwhelming; it makes science a daunting field to walk on. Many people who has curiosity of understanding the working of science get caught into its complexity and intricacy resulting in a inhibited mind discouraged to learn more and question its validity that'll help fuel its further development.

This became the primary reason to create a project that can help people understand theory of relativity in a simple and exciting way so that it becomes more approachable. There's a great quote by Einstein himself saying, "If you can't explain it simply, you don't understand it well enough". And animation film is an exciting medium to handle this complex piece of work in a simple manner.

Why Relativity?

The path of the evolution of science can be traced as far back as the start of the evolution of human species itself. Although the day to day inventions and innovations for survival earned the term "science" much later, however, the humans and science has always been glued together. Torricelli's barometer, Babbage's Computer, Newton's Gravity are just a few example of scientists and their discoveries and/or inventions that have affected the human life forever. Then why choose relativity? Why is it important for any non-science person to understand?

There is a great existentialist question everyone comes across at least once in their life. That question is, 'Why are we here?' And almost every philosopher has his own version of answer to this question. Einstein's Theory of Relativity does not answer this question but answers as important a question as the existentialist one. And that question is, “How did we get here?” Relativity has helped us understand the origin of universe with its theory of Big Bang. It has solved many mysteries about the intricate workings of the universe. Working that affect us human being and our habitat every single moment. There would be no space missions without relativity. There would be no quantum physics without relativity. There would be no GPS navigation without relativity. Millions of people benefits from its application without knowing how it actually works.

Relativity has been a fascinating and an exciting subject in the movies. Some of the most successful Hollywood movies are based on relativity. The Terminator, Back to the Future, Prisoner of Azkaban derives their central plot from relativity and most of the audience is oblivious to it. But it’s not easy to understand how relativity works. There’s a great quote for relativity which goes like, ‘Theory of Relativity is so simple that it’s complex.’ Hence, relativity seems a good candidate for an educational animation film to make it simple for the non-science audience to understand.

Scope and Limitations

Theory of Relativity was proposed in 1905 giving rise to a completely new way of looking at and understanding science. Einstein's work on photoelectric effect gave birth to a new field of science called quantum physics. The science so complicated that it is not taught in schools. But the science that precedes relativity is part of the general academic structure almost throughout the world. And knowledge of that science is very important for anyone to even begin to understand relativity. Hence it's a limitation but a good limitation that one at least has to have knowledge of Newtonian Physics to absorb Einstein's theories.

Pre-Production

Understanding the Theory

Let's first take a brief detour into the Theory of Relativity.

There are two theories of relativity, Special and General. Special Relativity is about the relationship between space and time explaining what happens to the moving objects nearing speed of light. As of today, special relativity is the most accurate scientific model to explain and measure the speeding bodies. The General relativity, proposed eleven years after Special, in literal terms, generalized the Special relativity and Newton's law of Universal Gravitation. That means it unified the space and time into 'spacetime' with gravity being its geometric property. Let us take a closer look at special relativity.

Special Relativity

The special relativity incorporates some of the most fundamental physical quantities, i.e. space, time, matter, motion, mass, gravity, energy and light. These fundamental quantities act in a completely different way in special relativistic circumstances. There are two postulates to this theory,

1. The laws of physics are invariant (i.e., identical) in all inertial systems (non-accelerating frames of reference).

and

2. The speed of light in a vacuum is the same for all observers, regardless of the motion of the light source.[1]

Special Relativity is a study of relative motion in a special condition and hence named 'Special Relativity' and the special condition is 'Frame of Reference'. The best way to understand Special Relativity is by understanding what effect it has on the basic fundamental quantities from different frames of references.

Frame of Reference

A frame of reference, simply put, is the position in the universe at which an observer observes the unfolding events. For example, let's say you are reading this text sitting in a chair. From your frame of reference, you are in a stationary position. But for an astronaut sitting in the space station he observes you moving in the same speed of Earth's rotational speed. It is also worth noting that there is no absolute frame of reference as everything in the universe is in motion relative to one another.

The First Postulate

Out of the two postulates of special relativity, the first one is quite easy to understand. It states that the laws of physics holds true for all the frames of references. We observe this in our everyday life. If it wasn't true, we wouldn't be able to play cricket or drive our vehicles or even cross the road. If we measure the length of a wooden block on ground or on a moving bus, it comes out to be the same. Measure the time it takes for the pendulum to complete 10 swings on ground or on a moving bus, it's the same. In the relativity's words, laws of physics holds true for all the frames of references.

The Second Postulate

This is where relativity gets a little complicated. It says that the speed of light is same for all the observers regardless of the frame of reference. So what does this imply? Consider you are travelling in your car at 100km/hr. on a highway. A car travelling at the speed of 200km/hr. in the same direction overtakes you. As the car goes past your car, you observe it travelling at a slower speed, which is 100km/hr. The speed is subtracted. Now consider the opposite scenario where the car travels towards you at 200km/hr. Now when it goes past your car, you observe the speed to be 300km/hr. Here, the speed is added. However, according to the second postulate of special relativity, it is not the same case with light.

Consider you are in a small space ship and travels away from a light source with 75% the speed of light. Now the light source is switched on and a beam of light speeds past you. Now ideally, you should observe the speed of light at its 25% speed. However, you will not. You'll observe the light beam speed past you at its original speed i.e. 299792.458 km/s. Similarly, if you travel towards the beam of light at 75% of its speed, you won't observe the light at 175% of its original speed. Instead, it would be same, 299792.458 km/hr. The speed of light is same for all the observers in all frames of references. This turns out to be true. There were several experiments done in late 1800s and early 1900s to calculate the speed of light in vacuum and a medium. The most significant one is known by Michelson–Morley experiment, which tries to detect the relative motion of the matter through a luminiferous aether. This experiment became the primary research topic in the development of special relativity. The speed of light 'c', from then on, stands as a speeding limit for cosmos, a constant.

So what if speed of light is constant? We all know that speed is a distance travelled in unit time.

S=distance/time.

In order for the speed of light to remain constant, either distance or time has to be skewed even if the light source is in motion. As it turns out, both, distance i.e. space and time skews.

Length Contraction

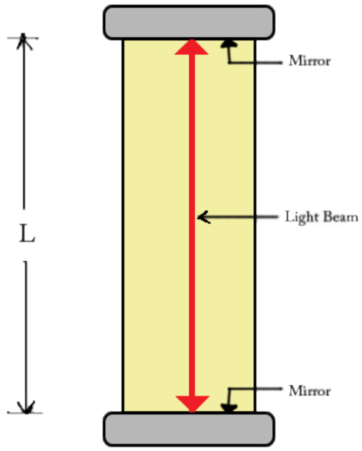
Stationary Car

Moving Car

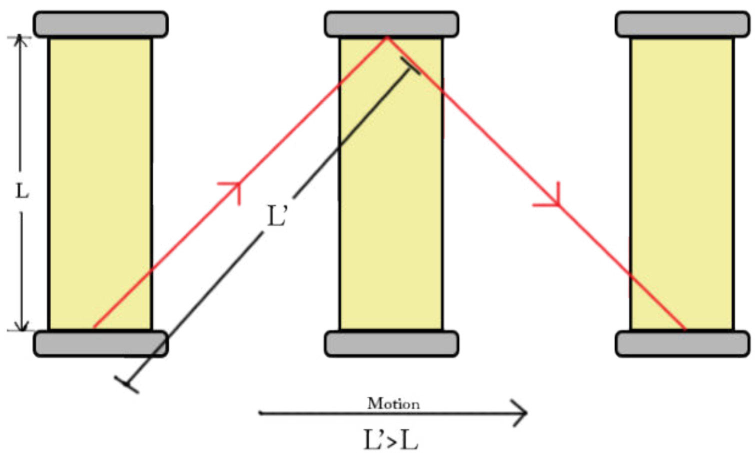
Length Contraction is actually a consequence of special relativity. A hard concept to grasp and equally difficult to digest but it is true. When an object (with mass) is in motion, its measured length shrinks in the direction of its motion. If the object reaches the speed of light, its measured length shrinks to nothing. Only a person that is in a different frame of reference from the object would be able to detect the shrinking - as far as the object is concerned, in its frame of reference, its size remains the same. This phenomenon is referred to as "length contraction".[2] It means, for example, if your car approaches the speed of light, the length of the car measured by a stationary observer would be smaller than if the car was measured as it stood still.

In the adjacent figure, the one car is stationary and the same car is moving past you in next frame. You will notice that the moving car in the second frame measures shorter than the stationary car. Note that the car would only be measured shorter in the direction it is traveling, whereas its height and width are not affected. Length contraction only affects the length in the direction the object is traveling

Time Dilation



Stationary Clock



Moving Clock

Like length contraction, time dilation is also a consequence of special relativity and it has the same effect on time as it has on the length. It says that time, for an object approaching the speed of light, slows down. This slowing down of time can only be observed at the speed closer to the speed of light and as one travels at the speed of light, time slows down to zero. This phenomenon is known as time dilation.

To explain time dilation, consider a light clock with a photon bouncing off two mirrors. One cycle is one unit. When the clock is stationary in fig.1, it calculates the time at a steady rate as the speed of light i.e. the photon is constant. Now if this clock travels at a certain speed, the photon in the clock needs to cover more distance in order to complete a cycle and calculate the unit time. As we know that the speed of light is constant, and at uniform speed the distant that photon has to travel is also the same. Then something has to change in order to keep the light speed constant. That something is time. Remember, speed equals distance divided by time. In order to keep the time constant, time slows down.

Only the observer not traveling will be able to observe this lag in time whereas if you travel with the clock, you'll observe the time passing in same rate as it passes for the stationary clock. The conclusion drawn from this thought experiment was, 'moving clocks slow down'.

$$E=mc^2$$

Unification of Mass and Energy

We all are familiar with Einstein's and probably world's most famous equation, E=mc2. Energy equals mass, times square of speed of light. After looking at it one should readily understand how tremendous amount of energy a matter with little mass hold in it. In nuclear fission, an atom splits to form two more atoms. In this process, a neutron is released. If the masses of the new atoms and the mass of the neutron are added up, the sum turns out to be less than the mass of the original atom before fission. Where did the missing mass go? It turns out that the mass was released in the form of heat i.e. kinetic energy. This energy is exactly what Einstein's $E=mc^2$ predicts.

The biggest misinterpretation of the energy-mass unification is that as a matter approaches speed of light, its mass also increases to infinity. This is not correct. Let's consider a rocket travelling in the space. Energy must be added to the rocket to increase its speed. More of the added energy goes towards increasing rocket's resistance to acceleration and a little into increasing the speed. In the end, the amount of energy needed to reach the speed of light would become infinite.

The rocket's resistance to acceleration is a measurement of its energy and momentum. Notice that in the whole description of the energy, there is no reference to mass.

These three consequences, as it turns out, are the best way to understand special relativity. Moreover, among these, the time dilation is the simplest and best way.

Relativity in Academic World

A student is introduced to the Theory of Relativity, in academic structure, in high school [?] or senior high school.[?] The rigidity of the way this theory is introduced comes into play when you consider the complexity of the theory. Here's an excerpt from a text book approved by Maharashtra Board as a reference book for Higher Secondary School Certificate Exam.

"7.6.2 Time dilation

Consider two frames S and S'. Let S' be moving with a velocity v with respect to S in the positive X–direction. Suppose a clock situated in the frame S' at a position gives out signals at an interval to.

If this interval is observed by an observer in frame S, then the interval t recorded by him is

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

i.e. **t > to**

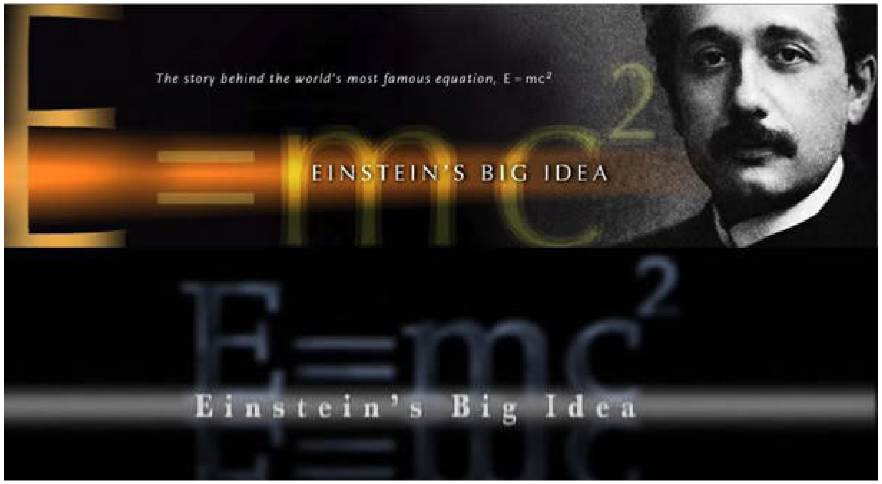
To a stationary observer in S, time interval appears to be lengthened by a factor sqrt[1-(v2/c2)]. In other words, a moving clock appears to be slowed down to a stationary observer. This is known as time dilation.

Example : The clock in the moving space ships will appear to go slower than the clocks on the earth."

In academic world, this is the simplest description and presentation of relativity.

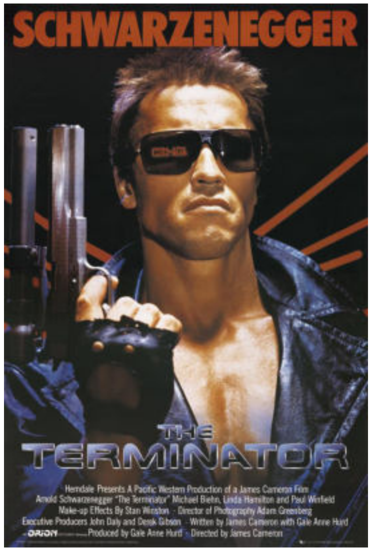
For non-academic books, there is an enormous pile of written material on relativity. From books to journals to paper presentations, people are trying to serve the non-academic people or one who bid the farewell to science study with their school with simplified material. Even Einstein wrote simple material. One such example from the book named "Relativity for Dummies" explains relativity using multiple real life examples like the one used so far in this text. However, the one example that is repeated more often is that of time dilation. Be it non-academic reference books or science and technology websites and blogs, time dilation experiment seems to be the way for the world to understand relativity. In addition, it's fitting that the thought experiment conceived by Einstein that resolved the mystery for him is, arguably, the best example to explain how relativity works.

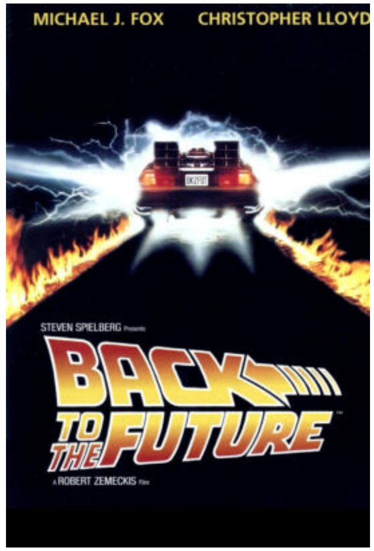
Relativity in Visual Medium



Einstein and the theory of relativity has been a regular subject for the science documentaries. Since the launch of Discovery Channel and National Geographic Channel, theory of relativity has always been a subject of interest among documentary filmmakers, short or feature length. The 2005 BBC documentary film, Einstein's Big Idea, explains the unification of mass and energy i.e. E=mc2 and the stories behind the origin of each of its variable. On top of it, it also talk about the formula's destructive nature and how E=mc2 helped galvanize a new science. The science we now know as quantum physic. [3]

Similarly, History Channel's biographical documentary named 'Einstein' dedicates some of its part in explaining Theory of Relativity, both Special and General.[4] The medium of 3D animation gives it a more futuristic and simpler but exciting way so that the complex math feels more approachable. Along with these, Einstein based documentaries; there are numerous science documentaries trying their hand in solving the mysteries of Relativity. BBC documentaries such as 'Time Machine' and 'What on Earth is wrong with the Gravity', tackles the intricacies of the consequences of special and general relativity along with their effects in day-to-day life. Another science documentary series called 'Through the Wormhole' has couple of episodes *Is Time Travel Possible* and *Can We Travel Faster Than Light?* , dedicated to the effects, possibilities and limitations of Relativity.





Relativity in Cinema

There is no science fiction movie ever made just to explain the relativity or its effects. However, relativity has been a central driving plot to some of the very successful movies.

The 1984 movie Terminator has its protagonist and antagonist travel from future to the present in order to kill a character named Sarah Conner so that the future doesn't exist at all.[5] This actually is against the predictions of relativity whose math only allows travelling in the future. The 1985 science fiction movie 'Back to the Future' uses time travel and the infamous The Grandfather Paradox as its driving device for the central plot.[6] In the 2004 fantasy film 'Harry Potter and The Prisoner of Azkaban' also involves travelling back in time in one sequence which still bamboozles its audience. [7] In 2006 science fiction thriller 'Deja Vu', the concept of wormhole is used as driving plot device for the characters to look back in time.[8]

The YouTube!

One must believe that the free video hosting websites like YouTube and Vimeo would be choke full of videos explaining relativity. And the answer is yes, but they vary in their category a great deal. Some are pure classroom lectures; some are storyboard or still drawing videos with a voiceover explaining the drawings. The most exciting one are a couple of animation videos trying to simulate the relativistic situations to explain relativity. Yet, one believes there are possibilities of explaining it a little differently using animation.

Initial Concept

Based on the study of Special Relativity and the research of where and how the relativity has been explained so far, initial concepts were developed. The final format of the video was narrowed down to a narrative voiceover explaining audience relativity with the scenarios depicted using a combination of animation, still images and drawings/diagrams.

Version 1

The Narrative Voiceover:

Have you ever wondered how your clock actually works? The reason being the electrical energy of the batteries converted into mechanical energy. Mechanical energy moves the gears. And gears move the hands to show the time. Ever wondered how much energy a one-gram coin contains in it? You will be surprised to know it is enough to blow the south Bombay on its own.

And have you ever wondered what will happen when you ride on the front of a beam of light holding a mirror? Will you be able to see your face in the mirror?

These are some of the questions occurred to a kid from Ulm, Germany, who'd go on to become one of the greatest and certainly the most famous scientist in the history (Einstein wearing a t-shirt saying God of Nerds). And what was the answer to all of these questions?

Einstein's Special Theory of Relativity.

Special Theory of Relativity or simply Relativity is a physical theory regarding the relationship between space and time. This theory is based on two postulates.

1. The laws of physics hold true for all frames of reference.
Measure the length of a wooden block on ground or on a moving bus, it's the same. Measure the time it takes for the pendulum to complete 10 swings on ground or on a moving bus, it's the same.

The laws of physics hold true for all frames of reference. Duh!

2.The second postulate states…The speed of light is measured as constant in all frames of reference.

This is where it gets interesting!
James Clark Maxwell in 1905 predicted that light travels with same speed no matter what. It was a pretty odd prediction to make. Consider you are in a car traveling with a speed of 100km/hr. Another car, traveling at a speed of 150km/hr. in the same direction overtakes you. You'll observe the speed of overtaking car to be 50km/hr. instead of 150 since both of you are traveling in same direction. The speed is subtracted. Now if you travel in opposite directions, you'll see the other car travelling past you with a speed of 250km/hr. Speed, this time around, adds up. But it's not the same case with light.

Now consider you are traveling in your car with half the speed of light. And the other car, Car B is traveling in opposite direction switches its headlights on. You'll observe the light beams speeding past you at a speed of 299, 792,458 m/s. Exactly at the speed of light, not with one and half the speed of light. Or, if you are speeding away from the Car B with half the speed of light and then Car B switches its light beam on, you won't see light beams overtaking you with half of its speed. The light beams will still race past you at a speed of 299, 792, 458 m/s.

The speed of Light is constant for all the frame of references.

This assumption became the heart of relativity.

Although everyone in the world of science found the prediction hard to digest, Einstein took it genuinely seriously. So what does it imply?

Einstein came up with a beautiful thought experiment. Imagine a light clock with two mirrors in the opposite directions and the light bouncing between them is the pendulum. If we consider the one cycle of the light from one mirror to the other back to first as one second, it works as an accurate clock as the light speed is always constant.

Let's make one clock stay on ground with you and mount the other on a space car with Albert. When both the clocks are at rest, they'll show the same time. Now, Albert starts the engine and travels in space at a certain speed. As the light speed is constant, and clock is moving forward with the space car, it has to travel more distance to complete a cycle. That means, Albert's clock SLOWS DOWN.

That means, moving clock slows down.

Faster the Albert travels, slower the time will move for him. Hence, what could be an hour for Max on ground; could well be 100s of years for Albert in space depending on how fast he's moving. So when Albert comes back on ground, he'd be landing 100s of years in future.

This is relativity!

So why is this important? We see the relativity being used every day now. The simplest example would be GPS! The GPS satellites, orbiting with great speed around the planets in space where gravity is weak, uses relativity to measure the time difference between the clocks on the navigation satellite and the clocks on the ground. Turns out that time passes at different rate. By how much? Einstein predicted it, 100 years ago, that it would shift by 36000 nanoseconds per day. If satellite navigation system doesn't take this time difference into account, GPS system will drift by around 11Kms per day leading you somewhere else.

It is funny how beautiful bit of physics predicted in 1905 has found its application 100 years later in the form of GPS and Hydron Collider and astronomy to name a few. And who knows, with the help of relativity and new rapidly developing technology, we might just make time travel an everyday event. Just a wishful thought.

Version 2

The first version of the film narration and animatic stood for 4 min 53 sec. But as you can see there's a lot of material not required for its simplicity. Hence, a second version was developed and rewritten that stands for 3 min 16 sec without titles and end credits.

The Narration:

Time... you can't see it, you can't hear it, you can't weigh it. But we experience it every moment. The whole piece of time is a landscape and we move through it... slice by slice.

But do we really understand Time? Is time same for everyone?

To understand time, let's go back in time and make a small journey with a certain young patent clerk, Albert Einstein.

Imagine you are travelling with Einstein in a train moving at certain uniform speed. The train, relative to the outside environment is in motion. You two sitting inside, on the other hand, observe each other as stationary, as both of you and the train are moving at the same speed. Hence, relative to train, you are stationary, and the laws of physics stay same inside the train as they would on the ground when you are standing still.

Now let's consider, you get down the train and observe it moving across you. Now, you are stationary and relative to you Einstein is moving in the same speed as the train.

We observe this phenomenon of relative motion every day.

Does everything in the universe observe this relative motion the same way? Yes, everything except Light. Why? Because of it's speed. The great speed records we've observed when compared to the speed of light fall way short to challenge it. See!

There were multiple experiments done in 19th century to calculate this speed of light. And a Scottish physicist James Clerk Maxwell predicted that this speed of light is constant and light travel with this same speed no matter what.

Although everyone in the world of science found the prediction hard to digest, Einstein took it genuinely seriously. So what does it imply?

Imagine you and Einstein possess a light clock with two mirrors in the opposite directions and the light bouncing between them is the pendulum. If we consider the one cycle of the light from one mirror to the other back to first as one tick, it works as an accurate clock as the light speed is always constant. Now let's make one clock stay on ground with you and mount the other on a space car with Albert. When both the clocks are at rest, they'll show the same time. Now, Albert starts the engine and travels in space at a certain speed. For Albert, the light clock with the reference to the space car is at rest. But from your frame of reference, you see something like this. As the light speed is constant, and clock is moving forward with the space car, it has to travel more distance to complete a cycle.

This implies that moving clock slows down as you travel faster and faster towards the speed of light. The faster Albert travels, slower the time will move for him. Hence, what could be an hour for Albert in space car; could well be 100s of years for you on ground.

This became the fundamental conclusion of the Theory of Relativity. A theory proposed by Albert Einstein in 1905 broke the traditional understanding of time as a constant entity and proved that time in fact is different for different observers. The Theory of Relativity led to multiple consequences. The most important being the unification of mass-energy which is represented by the famous equation, E=mc2. And then Einstein came up with another profound theory, The General Theory of Relativity, which challenged the father of Gravity, Isaac Newton himself. But more on that, later!

Final Version:

Time... you can't see it, you can't hear it, you can't weigh it. But we experience it every moment. The whole piece of time is a landscape and we move through it... slice by slice.

But do we really understand Time? Is time same for everyone?

To understand time, let's go back in time and make a small journey with a certain young patent clerk, Albert Einstein.

Imagine you are travelling with Einstein in a train moving at certain uniform speed. The train, relative to the outside environment is in motion. You two sitting inside, on the other hand, observe each other as stationary, as both of you and the train are moving at the same speed. Hence, relative to train, you are stationary, and the laws of physics stay same inside the train as they would on the ground when you are standing still.

Now let's consider, you get down the train and observe it moving across you. Now, you are stationary and relative to you Einstein is moving with the same speed as the train.

We observe this phenomenon of relative motion every day.

Does everything in the universe observe this relative motion the same way? Yes, everything except Light. Light behaves in a different way.

Imagine you have a light clock with you. This light clock has two mirrors in the opposite directions and a light bouncing between them. Let's say, the distance between the two mirrors is 'd1' and the time it takes for the light to cover that distance is 't unit'. For the sake simplicity, let's say it's 1sec. So when this clock is with you at rest position, the light bounces between the mirrors covering distance d1 in 1sec giving us the speed of light s1. Remember, speed = distance per unit time?

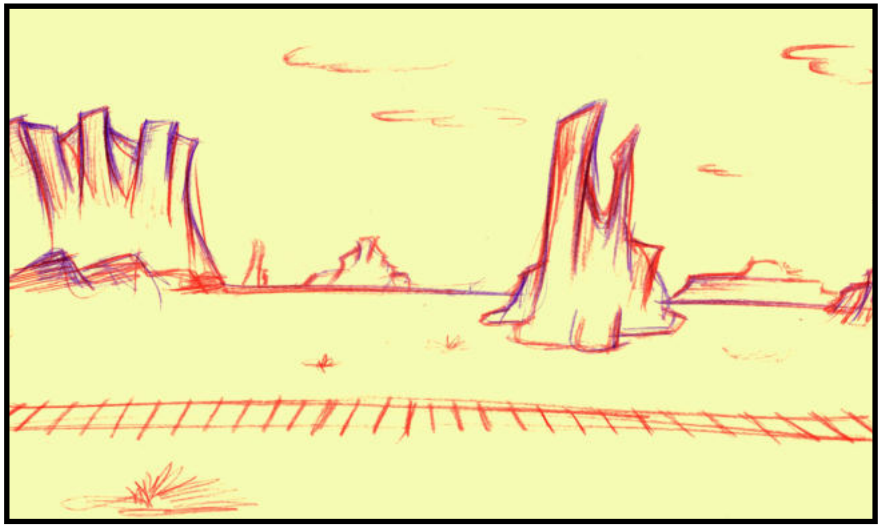
Now consider Einstein also possess the same light clock with him. Only this time, he's traveling in a space ship along with the clock. When Einstein travels in a certain speed, the clock travels with the same speed of space ship in the same direction. Here, light have to travel some extra distance in one 1sec. Let's consider this distance to be 'd2'. The speed of light here is s2. Which has to be greater than s1.

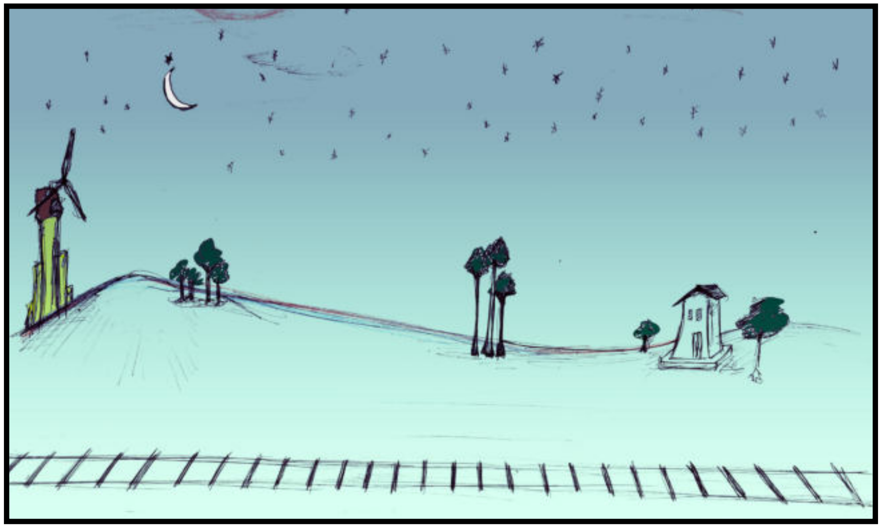
But here's something profoundly wrong. Because in late 1800s, an experiment named Michelson–Morley experiment, which tried to detect the relative motion of the matter through an aether, concluded that the speed of light is constant. This cosmic speed limit is known as c.

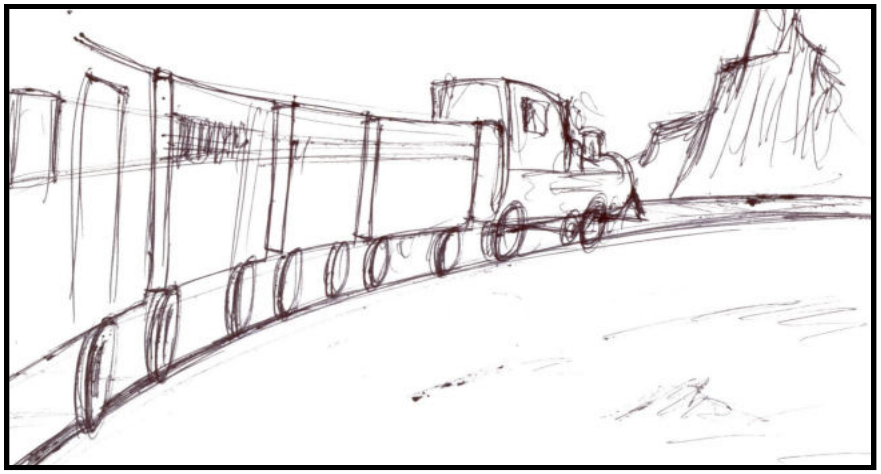
So in our little scenario, s1=s2=c. So, for the speed of light for both you and Einstein to remain constant, something has to give. That something is "Time". It turns out, time slows down when you travel faster and faster nearing the speed of light. Faster the Einstein travels, slower the time passes for him. Hence what could be a day for Einstein in space, could be 50 years for you on the ground.

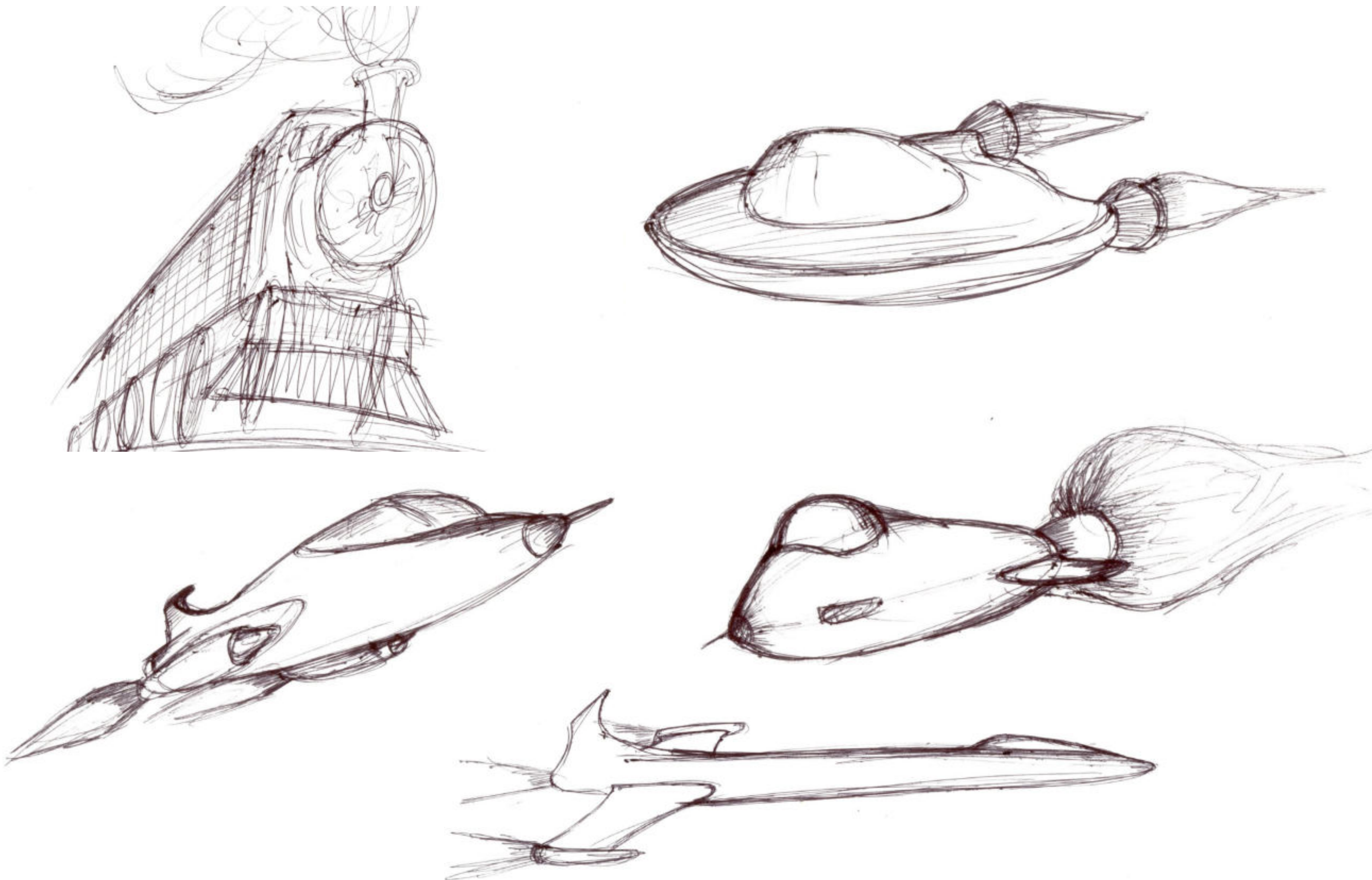
This became the fundamental conclusion of the Theory of Relativity. A theory proposed by Albert Einstein in 1905 broke the traditional understanding of time as a constant entity and proved that time in fact is different for different observers. The Theory of Relativity led to multiple consequences. The most important being the unification of mass-energy which is represented by the most famous equation in the whole wide world, E=mc2.

Visual Exploration





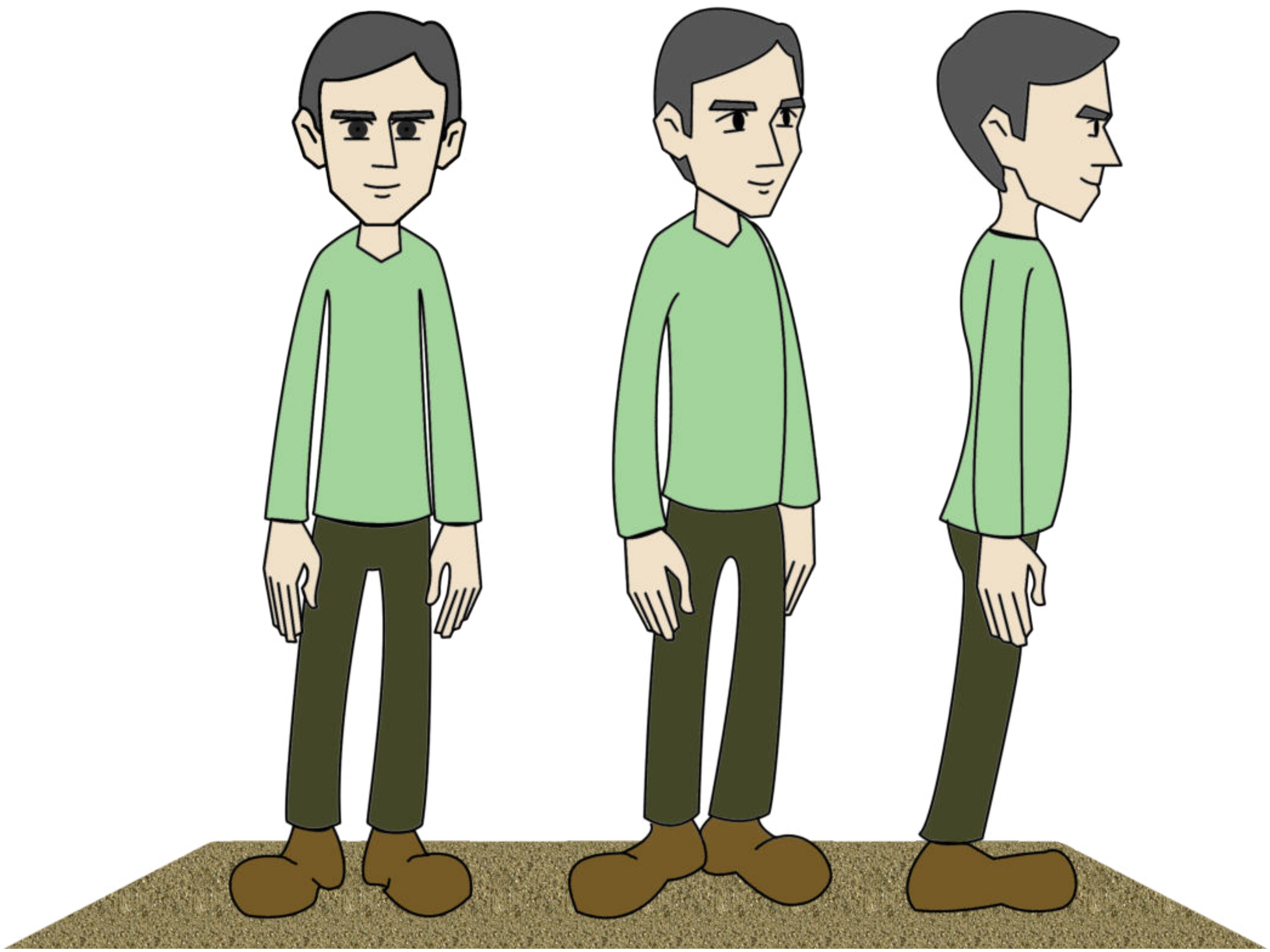




Character Exploration and Design

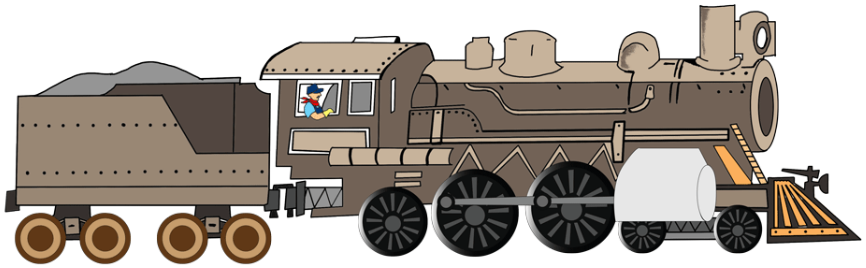
Final Character

Albert Einstein

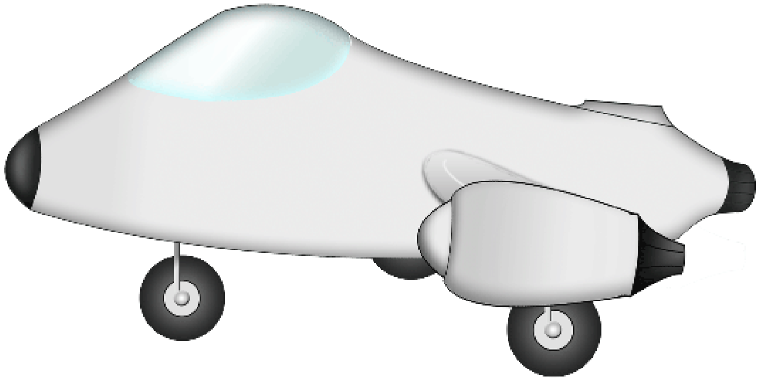


The Observer

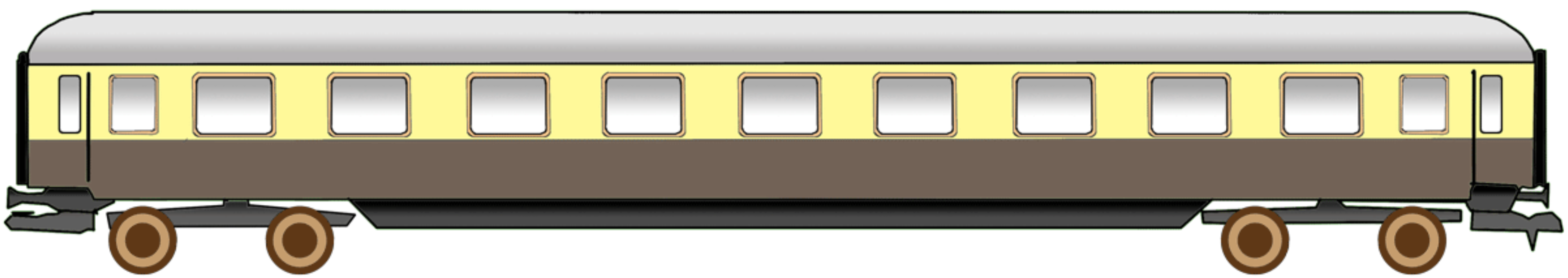
The Vehicles



The Engine



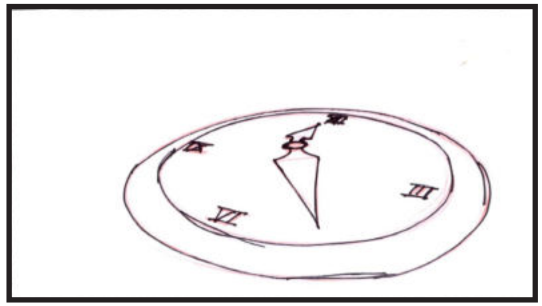
The Spacecraft



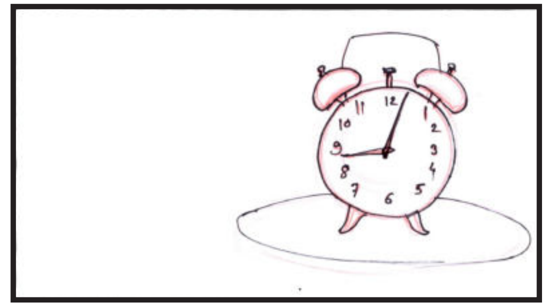
The Carriage

The Storyboard

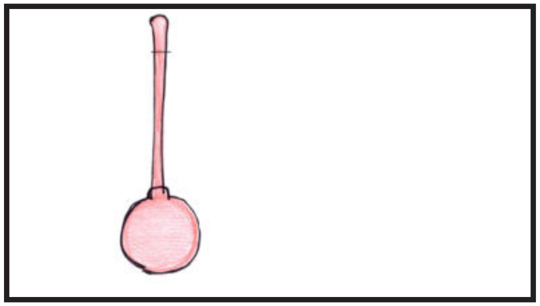
Time...



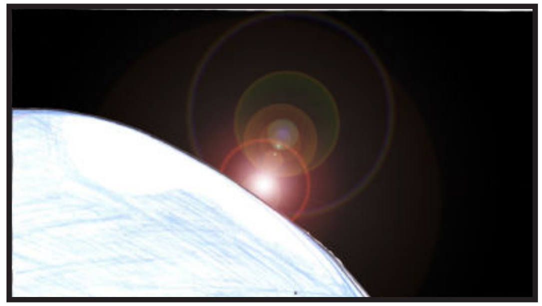
...you can't see it, you can’t hear it...



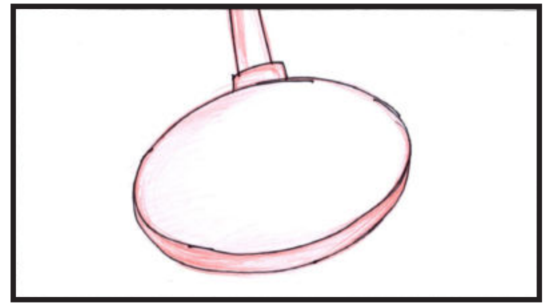
...you can’t weigh it.



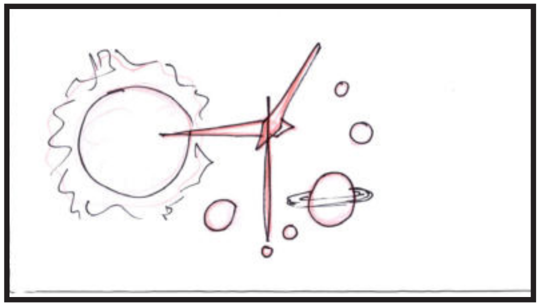
But we experience it every moment.



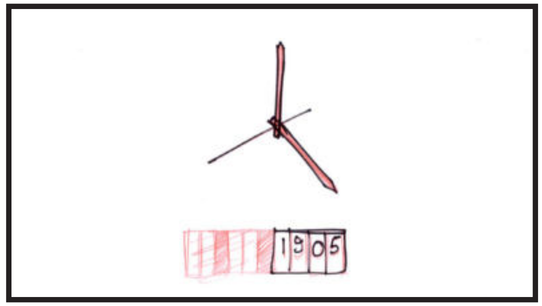
The whole piece of time is a landscape and we move through it...



...Slice by Slice.

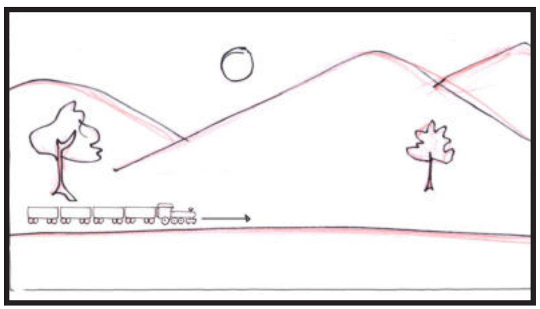


But do we really understand Time? Is time same for everyone?



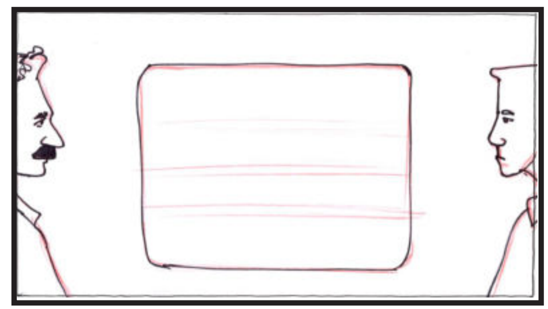
To understand time, let's go back in time and make a small journey...

... with a certain young patent clerk, Albert Einstein.



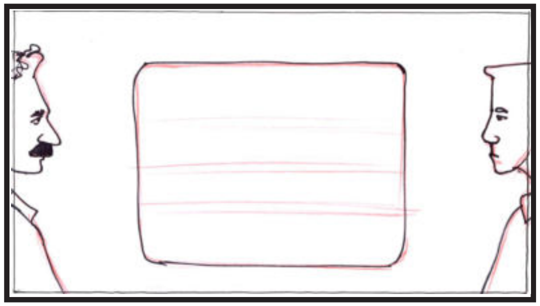
Imagine you are travelling with Einstein in a train moving at certain uniform speed.

The train, relative to the outside environment is in motion. You two sitting inside, on the other hand, observe each other as stationary...

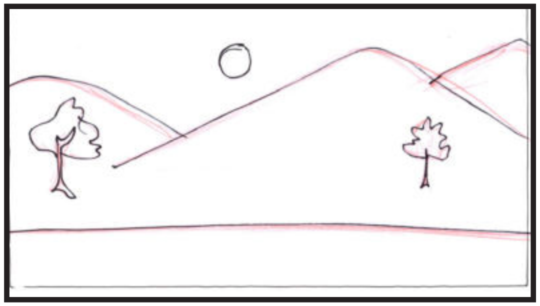


... as both of you..

and the train are moving at the same speed. Hence...

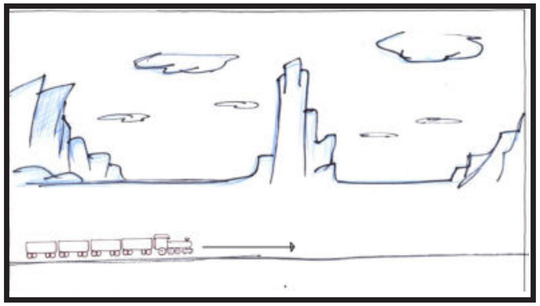


...relative to train, you are stationary, and the laws of physics stay same inside the train as they would...

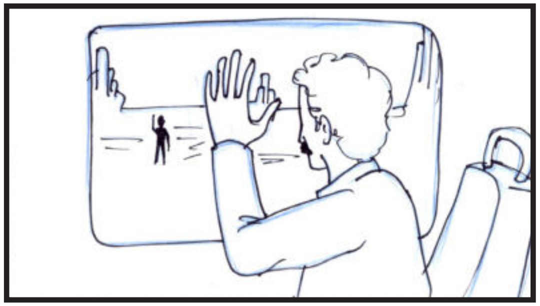


...on the ground when you are standing still. Now let's consider...

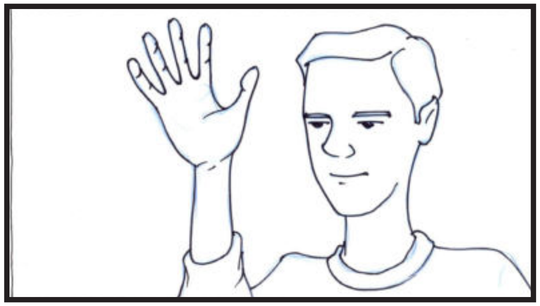
you get down the train and observe it moving across you.



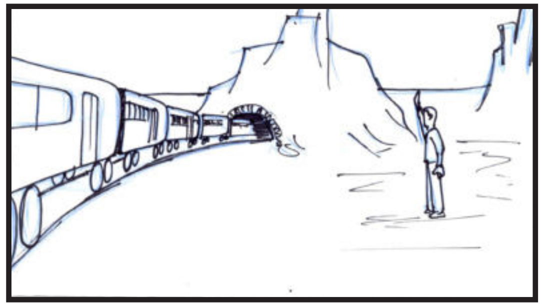
Now, you are stationary and relative to you...



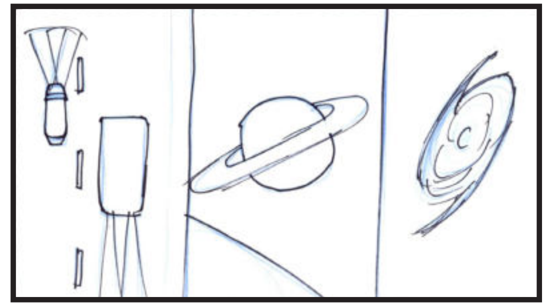
... Einstein is moving with the same speed as the train.



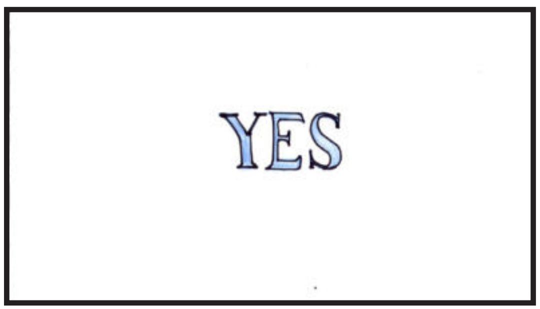
We observe this...



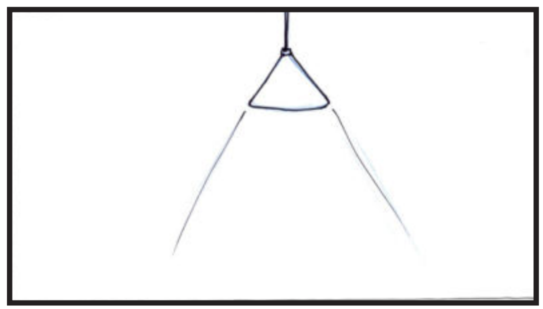
...phenomenon of relative motion every day.



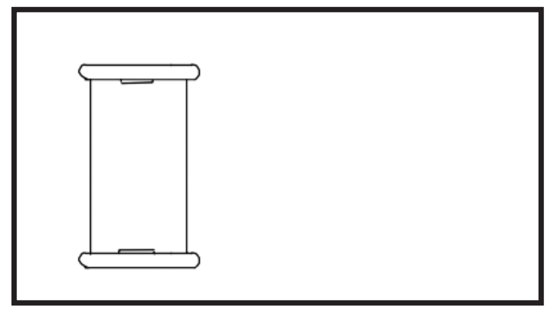
Does everything in the universe observe this relative motion the same way?



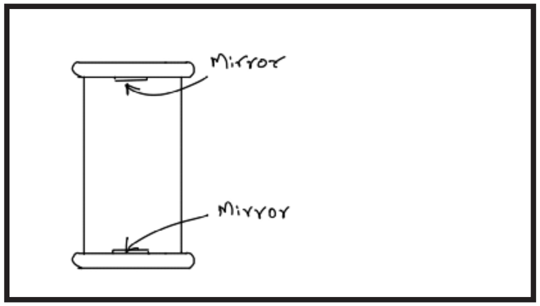
Yes, everything except...



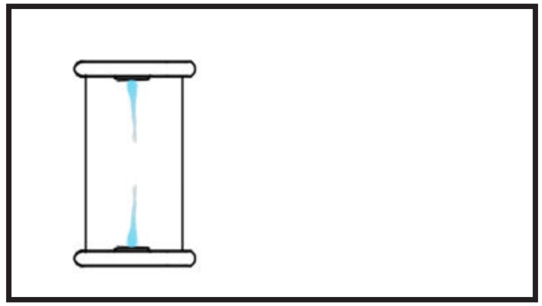
...Light. Light behaves in a different way.



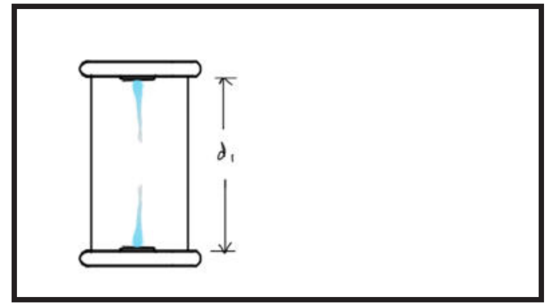
Imagine you have a light clock with you.



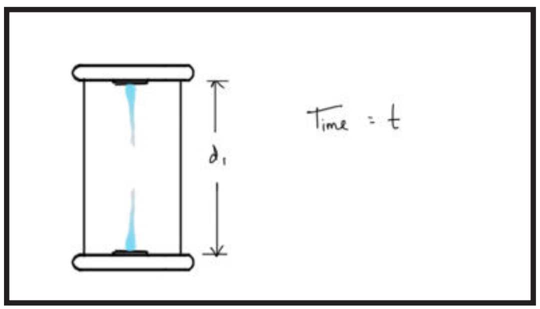
This light clock has two mirrors in the opposite directions...



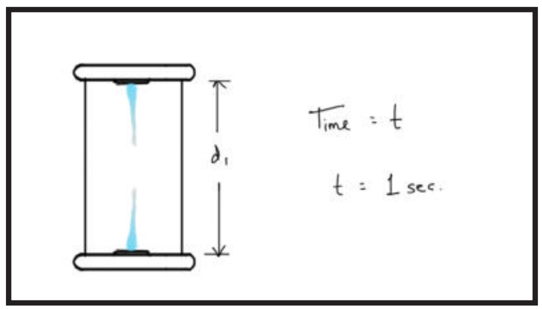
...and a light bouncing between them.



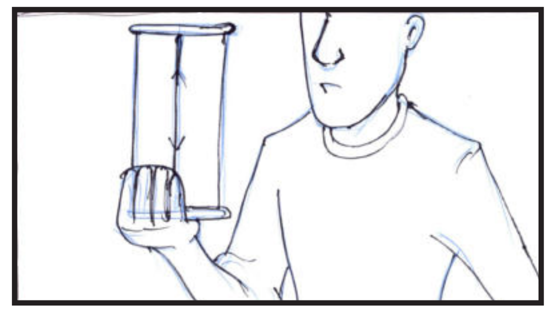
Let's say, the distance between the two mirrors is 'd1'...



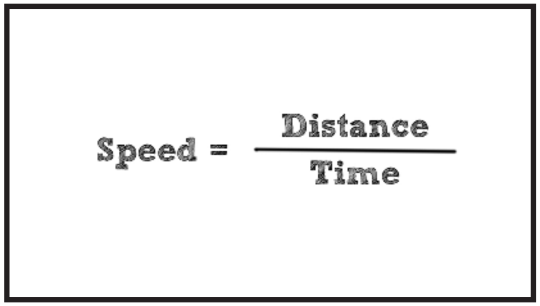
...and the time it takes for the light to cover that distance is 't unit'.



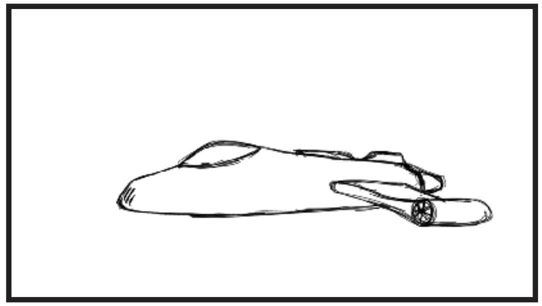
For the sake simplicity, let's say it's 1sec.

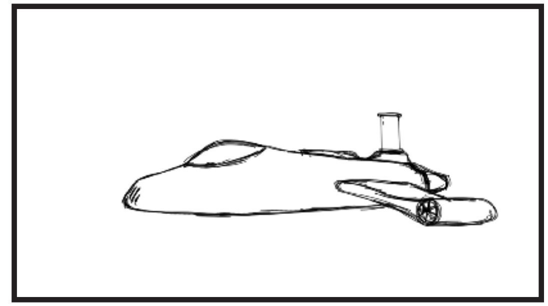


So when this clock is with you at rest position, the light bounces between the mirrors covering distance d1 in 1sec giving us the speed of light s1.

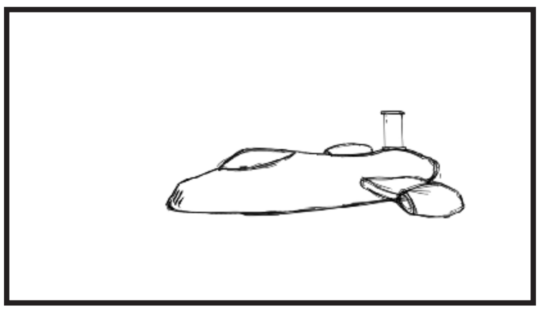


Remember, speed = distance per unit time?

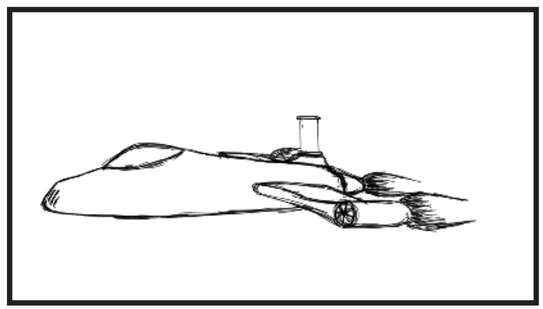


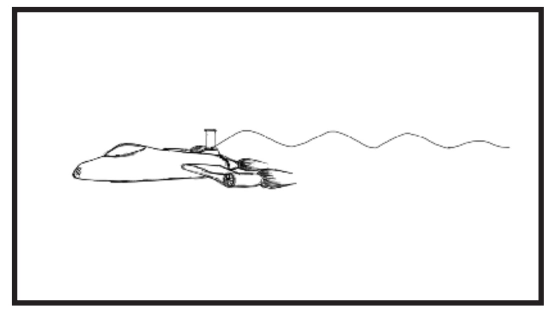


Now consider Einstein also possess the same light clock with him.

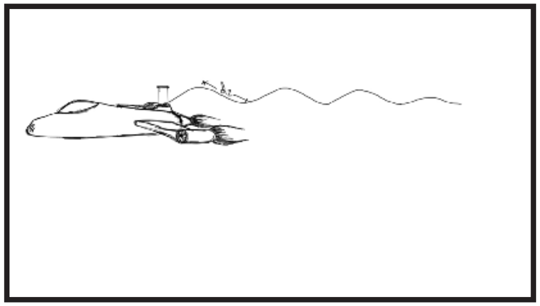


Only this time, he's traveling in a space ship along with the clock.

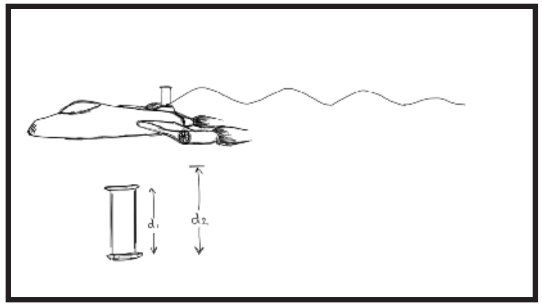




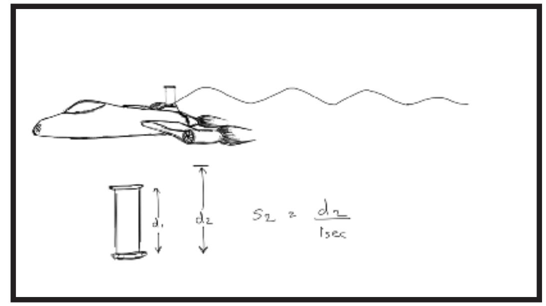
When Einstein travels in a certain speed, the clock travels with the same speed of space ship in the same direction.



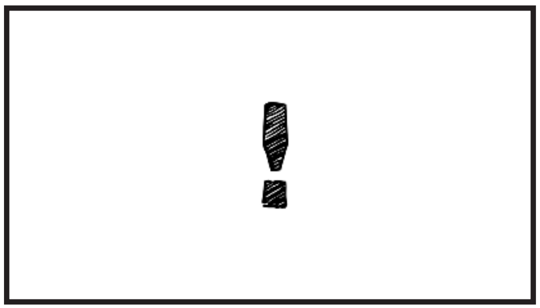
A Here, light have to travel some extra distance in one second.



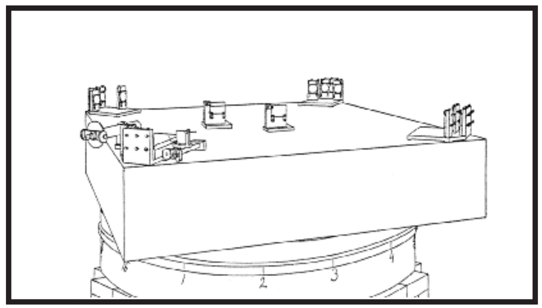
Let's consider this distance to be 'd2'.



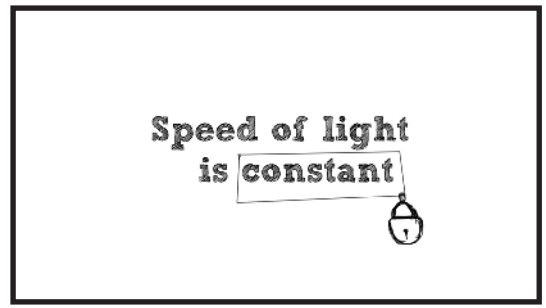
The speed of light here is s2. Which has to be greater than s1.



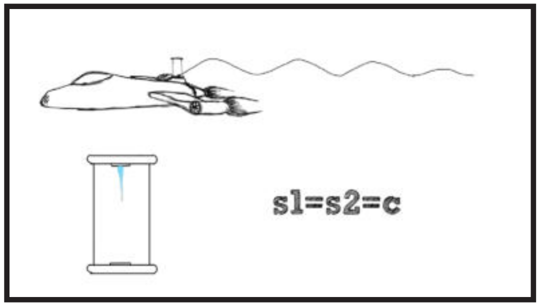
But here's something profoundly wrong.



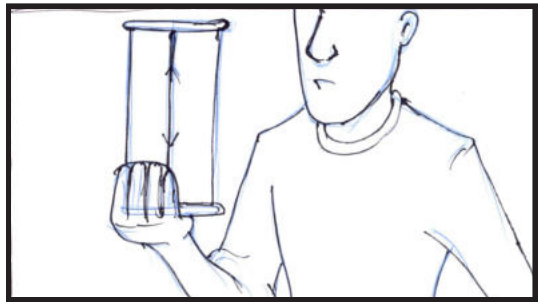
Because in late 1800s, an experiment named Michelson–Morley experiment, which tried to detect the relative motion of the matter through an aether, concluded that...



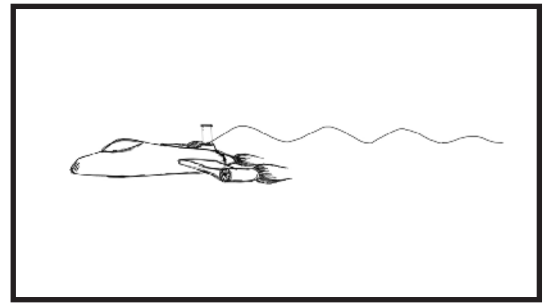
...the speed of light is constant. This cosmic speed limit is known as c.



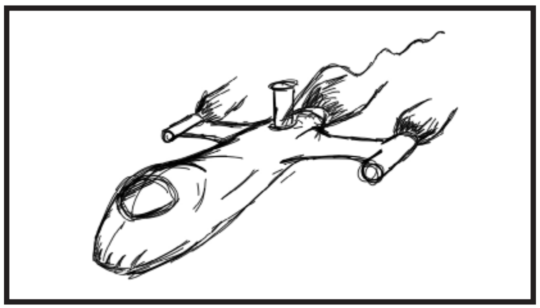
So in our little scenario, the speed of light same in both cases.



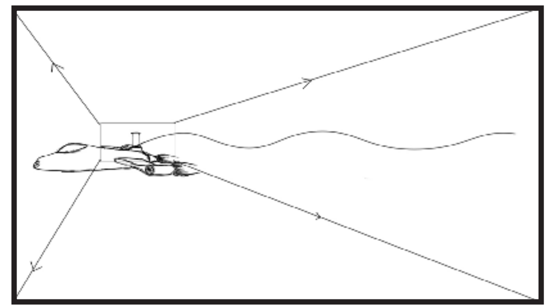
So, for the speed of light for both you...



... and Einstein to remain constant, something has to give. That something is “Time”.

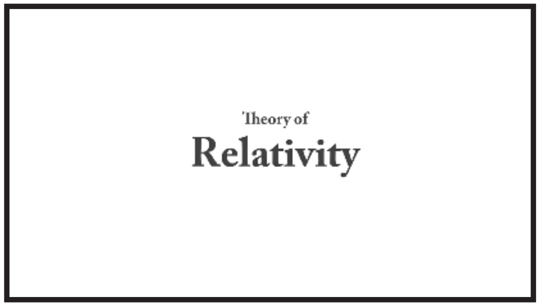


It turns out, time slows down when you travel faster and faster nearing the speed of light.

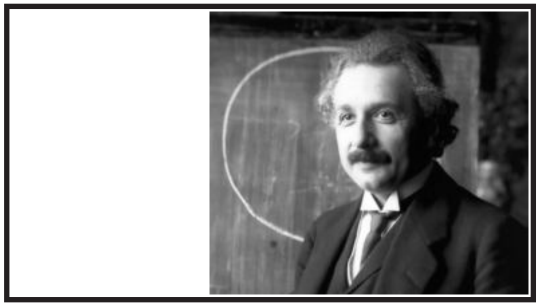


Faster the Einstein travels, slower the time passes for him.

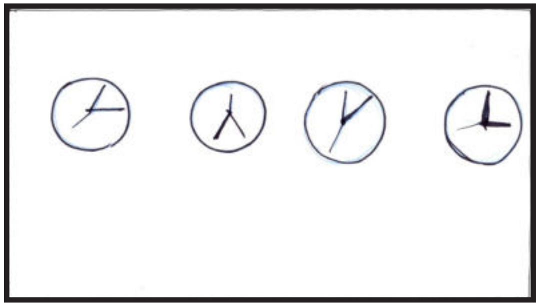
Hence what could be a day for Einstein in space, could be 50 years for you on the ground.



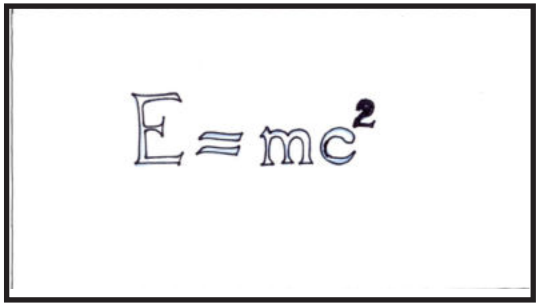
This became the fundamental conclusion of the Theory of Relativity.



A theory proposed by Albert Einstein in 1905...

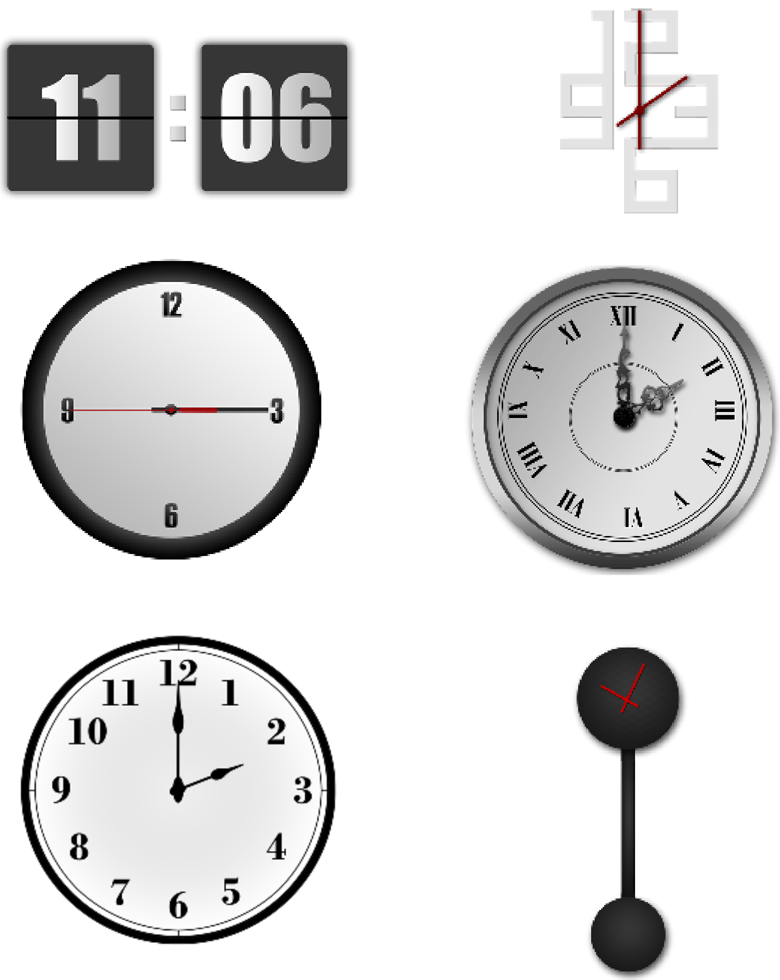


...broke the traditional understanding of time as a constant entity and proved that time in fact is different for different observers.



The Theory of Relativity led to multiple consequences. The most important being the unification of mass-energy which is represented by the most famous equation in the whole wide world, E=mc2.

But more on that, later!



Library of Clocks for the Opening Sequence

Production

For this project, digital style animation was chosen with different elements and layers composed together once animated. This style not only gives a freedom of improvisation as shot are animated further and further to shape the film out, but also provides a speed with which animation can be finished quickly to get an instant feedback provided all the elements are in place. To achieve the maximum efficiency and desired result, a thorough library was created which would later be added in the composition as a character or a prop or as a set decoration.

To give an example, the film opens with the narrator questioning our understanding of time and how we perceive time as a constant entity. Visually, this sequence is depicted with montage of various kinds of clocks measuring varied time. A library of clocks was created in order to create a syntactical seamlessness of clocks and the notion of time supported by the narration.

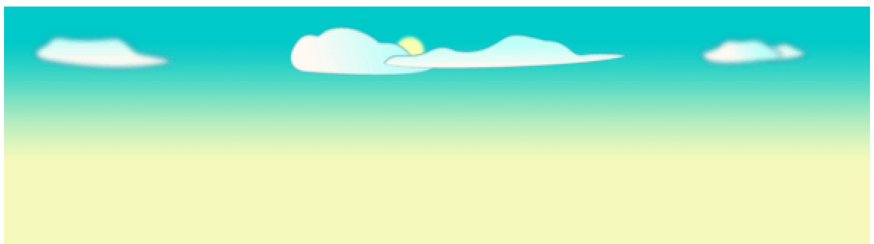
The entire animation is carried out in animation and compositing software, Adobe After Effects. One of the biggest challenges while animating in After Effects was to maintain a certain discipline in arranging and managing the library. The animation is first set using keyframes while graph editor helped achieve seamless animation that follows the principles of animation to best effects.

Post Production

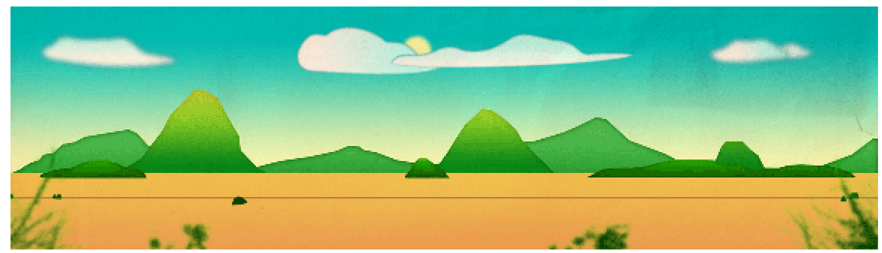
Composition

Once the animation is done, the animated components along with the props and set decorations and background layout are composed using the same software, Adobe After Effects. Here are the composition layers from the point of view shot of the character observing the train passing by at a distance.

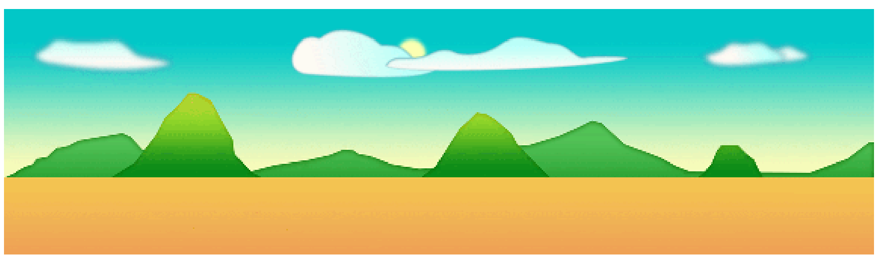
1.Sky



2. Adding Clouds and Sun



4. Adding the Foreground Bushes and Texture



3. Adding Mountains

5. Finally, Adding the Train moving from Left to Right

Editing

A special care was taken while designing the shots and cuts. The narration most of the time hold the spine of the visual trajectory of the images and the cuts are made to provide a first person point of view towards the visuals. For example, in the opening sequence, different shots of ticking clocks are for a montage. These shots are designed to provide a first person point of view like the dolly moving in and travelling through the gears of clocks.

In another shot, when the concept of frame of reference is introduced, the shots are cut to provide the point of view of both the Einstein and the regular observer. Plus the first person point of view shot of the train passing across the desert brings the audience in the shoes of the observer himself. This is important so as to establish the concrete understanding of the frame of reference.

Sound Design and Sound Editing

The sound design process required producing, reproducing and/or using the existing sound library for each and every element in the film. For example, the sound of the train was used from an existing sound library as the train is an old one. Whereas the sounds for the clocks from the opening sequence were recorded from table and wall clocks. The sound of photon clock is the sound of the contact of table tennis ball hitting the table. The sound was recorded using Zoom H2N Sound Recorder and editing is done using Adobe Audition and Apple ProTools.

Conclusion & Further Scope

As the project went further in the development, one of the deciding factors while taking decisions was the simplicity. For science so complicated such as this needed to be presented with the simplicity so that the target audience understands the topic with ease. But as it turns out, one size doesn't fit all. If one example works for one group of people doesn't necessarily mean it'll work for all. This is still the biggest challenge when it comes to explaining relativity. Not one example works for everyone and it is the same case with this film as well. But more refinement and concentration on creating a coherent relevance over various subtopics can lead to a well crafter representation of the Relativity.

Special Theory of Relativity, as already mentioned, gives rise to multiple consequences and its further development lead to the proposition of General Theory of Relativity, which are equally if not more complex that Special Relativity but at the same time, interesting to study. The further development of this project can incorporate topics such as 'Time Travel' and related effects like the infamous 'Grandfather Effect', along with the explanation of how $E=mc^2$ works and how it helped build the atomic bomb and last but not the least, how General Theory of Relativity challenged our notion of Newtonian Gravity, giving rise to a completely new understanding of Gravitational Force. Together, there will be a complete series of Einstein's Relativity explained in the form of animation films.

Reference

1. *"Relativity: The Special and General Theory", by Albert Einstein. Published in 1916.*

2. *www.howstuffworks.com. How Special Relativity Works.*
http://science.howstuffworks.com/science-vs-myth/everyday-myths/relativity8.htm

3. *"Einstein's Big Idea", a documentary.*
https://www.youtube.com/watch?v=YgpD4XZP0uM

4. *"Einstein", a History channel documentary.*
https://www.youtube.com/watch?v=KcXxHZssCh4

5. *The Terminator (1984) Dir. James Cameron*
http://www.imdb.com/title/tt0088247/?ref_=nv_sr_1

6. *Back to the Future(1985) Dir. Robert Zemeckis*
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