TIME

A stubborn illusion ?

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Introduction

Birds flying, water flowing, rising and setting of sun and moon and so on. In our daily life, we observe many phenomena around us. We have a sense that these things are happening because of the continuous and uninterrupted flow of time. But, why and where is it flowing? Is there some sort of river of time present?

Just imagine that we are in a state where no information can reach us, then, will we be able to perceive the notion of time?

Is time nothing more than the notion of “possibility of something to change”?
Is time itself the change? Or does time arise as a byproduct of the comparison that we humans do ? Has time existed before the existence of the universe itself ? And will it continue to exist even after the universe ends?

There are a lot of questions that arise in our human mind, whenever we talk about these deep conceptual and philosophical topics. So, In this article we will explore different ideas, theories and paradoxes that paved a path for our current understanding of time.

What is Time?

So, time is an age-old debate between thinkers and philosophers, physicists and mathematicians.
Ancient philosophers got divided into two groups, one that rejected the concept of time itself and other that thought time was something fluid. These debates and thought differences led to the formation of numerous paradoxes.

Aristotle wandered on a very interesting nature of time, which turned into a paradox later, he stated :-

“The past doesn’t exist, the future is coming."
So only the present exists, but if time is composed of things
which doesn’t exist, how can time exist at all.”

Zeno of Elea gave some of the most famous paradoxes in the 5th century BCE. One of them was the Dichotomy paradox, he states :-

“To reach any destination one must first travel halfway, But before that half of that half and before that half of that half,
And so on …and one will never reach the other end.”

But, we know that in reality, if we want to travel from some point A to a point B, we can do that in a certain interval. Hence, his statement fails miserably in the real world. But still isn’t it paradoxical? Even if we know that *Zeno's* statement is not true, there can still exist an infinite division for a finite motion.

He was trying to prove the ideology of his master ***Parmenides*** (he believed in monism), who said that :-

“Change is impossible and time
Is nothing more than an illusion of mind”

This idea of monism was opposed by an ancient Greek philosopher, ***Heraclitus,*** he stated :-

“*Time is the measure of change,everything flows,*
and time is the essence of being”

The idea of bounded infinity

I can’t resist talking about this idea here, The *zeno’s dichotomy paradox* gives rise to an interesting concept of bounded infinity.
Let’s see how :-

1 can be written as :-

$$1 = \frac{1}{2} + \frac{1}{2}$$

Further, $\frac{1}{2}$ can be written as,

$$\frac{1}{2} = \frac{1}{4} + \frac{1}{4}$$

And then, $\frac{1}{4}$ can be written as,

$$\frac{1}{4} = \frac{1}{8} + \frac{1}{8}$$

Then, $\frac{1}{8}$ can be written as,

$$\frac{1}{8} = \frac{1}{16} + \frac{1}{16}$$

And so on, hence 1 can be written as,

$$1 = \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} + \frac{1}{32} + ...\infty$$

So, as we can see that this pattern can be continued till infinity, but it will still always be equal to one, no matter how many terms we add in it.
Isn't it fascinating? that a finite number can contain an infinite series inside it.

Coming back to the debates, ideologies and paradoxes, those were the precursor of thinking about time itself. Many of them got discarded, but some of the interesting and logical ones got much broadened over time.

Evolving physics of time

Earlier attempts

In ancient India and Greece, time was measured using sundials and water clocks.
Babylonians introduced the sexagesimal system for the division of time as a base of 60 which is used till today.

Egyptians divided the day into a 24-hour cycle.
To keep a check on time different civilisations created their own solar and lunar based calendars.

Earlier Indian astronomers, like *Aryabhata* and *Varahamihira* studied the motion of celestial objects like the motion of sun, moon and stars to refine the notion of time. *Aryabhata* also gave different equations to calculate time. One of them is :-

$$day = \frac{\pi \times r}{360}$$

He also concluded that the earth orbits the sun in an elliptical path, causing the seasons to change. The concept of time in Indian cosmology is cyclic.

Newton's notion of time (classical physics)

According to *Issac Newton*, time is absolute and can't change, like a stage on which an act takes place, but the stage itself remains unchanged.
More like a cosmic clock, which is ticking at a constant rate everywhere and for everyone, unaffected by anything that is happening in the universe.

This notion most often seems to be true in our daily life, but is it so?

Newton's laws of motion and universal gravitation requires an absolute time to work, if time flowed differently in different frames of reference, these laws would lose all their validity.

This concept of absolute time worked for approximately 200 years, until light was established as an electromagnetic wave by the theory electromagnetism given by James Clerk Maxwell, whose speed remains constant in vacuum i.e. 3×10^8, and doesn't change by changing frames of reference.

Newton's theory failed at certain aspects such as:-

- Very high speeds,
- Very strong gravitational fields or
- When dealing with microscopic particles.

Einstein’s approach (Relativistic physics)

Special relativity

On 26 September 1905, Albert Einstein's paper titled “On the electrodynamics of moving bodies” was published which shattered the belief of the absoluteness of time that was prevalent, since the last 200 years.

His work was based on two main postulates:-

1. The principle of relativity.
2. The principle of invariant light speed.

A. Relativistic Simultaneity

It states that for two observers at different frames of reference, two events can happen at same time for one and at different times for another one.

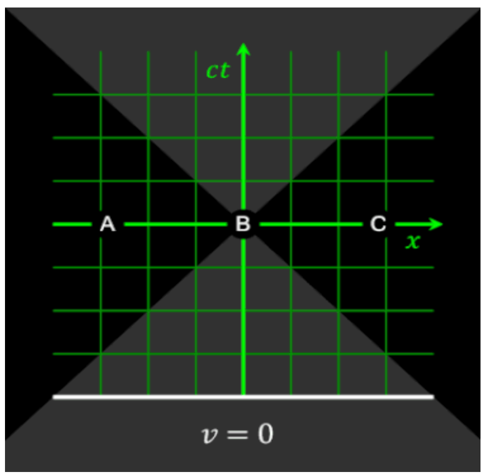

Fig:- (reference:- wikipedia)The three events (A, B, C) are simultaneous in the reference frame of some observer **O**. In a reference frame moving at *v* = 0.3*c*, as measured by **O**, the events occur in the order C, B, A. In a reference frame moving at *v* = −0.5*c* with respect to **O**, the events occur in the order A, B, C. The white lines, the *lines of simultaneity*, move from the past to the future in the respective frames (green coordinate axes), highlighting events residing on them. They are the locus of all events occurring at the same time in the respective frame. The gray area is the light cone with respect to the origin of all considered frames.

For example, The famous Einstein's thought experiment, about lightning strikes and a very fast moving train, in which for a person standing on a mountain, at a distance from the railway track, observes two lightning strikes occurring exactly together, but, for a person in that train the strike in the direction of the motion of the train occurs first and the strike in the opposite direction occurs later.

So, from this we can see that, the present for the same event can be different for different observers.
Then, the same old philosophical question asked by *Aristotle* arises in a more scientific form that, what really is present?

As we know, the speed of light remains constant in every reference frame, no matter what, so, space and time should adjust itself to maintain this constant speed. Which results in time dilation and length contraction.

B. Kinematic Time Dilation

Time dilation is basically the slowing of time for a frame of reference moving at or close to the speed of light compared to a frame relatively at rest.
It is given by the formula :-

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Where:

- t' is the time interval observed in the moving frame,
- t is the time interval observed in the stationary frame,
- v is the velocity of the moving frame relative to the stationary frame, and
- c is the speed of light in vacuum.

C. Length Contraction

An object moving nearly or at the speed of light, appears shorter in length, when observed from a frame relatively at rest.
Here's the formula used to find it :-

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

where:

- L' is the contracted length as observed in the stationary frame,

- *L* is the proper length (the length of the object in its rest frame),
- *v* is the velocity at which the object is moving relative to the observer,
- *c* is the speed of light in vacuum.

Spacetime

Time and space which were seen as separate entities were now viewed as one, and together they are called Spacetime.

In 1908, *Einstein's* former mathematics professor, *Hermann Minkowski* proposed a mathematical model for the spacetime or the space-time continuum, by using Lorentz transformations and special theory of relativity.

His geometric interpretation fused the 3 dimensions of space and 1 dimension of time into a single 4-dimensional continuum.

Since there are also other types of spacetime, the spacetime that is related to special relativity is known as Minkowski spacetime.

Minkowski, while presenting his talk, space and time, to the German society of scientists and physicians, Stated that :-

“Henceforth, space for itself, and time for itself, shall
Completely reduce to a mere shadow, and only some sort of
Union of the two shall preserve independence.”

In an ordinary 3-D space, distance is invariant, the distance (Δd), between two points can be defined using the pythagorean theorem :

$$(\Delta d^2) = (\Delta x^2) + (\Delta y^2) + (\Delta z^2)$$

But, things get tricky in the case of special relativity and 4 dimensional *Minkowski* spacetime. The distance between two points no longer remains the same if measured by 2 different frames of reference.

So, in spacetime, separation is described by the interval, which is invariant in nature, and is known as spacetime interval (S^2) :-

$$S^2 = (c^2 \times t^2) - x^2 - y^2 - z^2$$

If :-

- ★ $S^2 > 0 \rightarrow$ events may be connected to each other and may influence each other directly.
- ★ $S^2 = 0 \rightarrow$ two events are separated by each other, by light speed interval.
- ★ $S^2 < 0 \rightarrow$ events can't influence each other at any cost.

This formula solidifies the interdependency of space and time.

A noticeable thing is that the spacetime interval also gives rise to the concept of causation and correlation.

General relativity

It is also known as the *general theory of relativity* or as *Einstein's theory of gravity.*

Published in the year 1915, by Albert Einstein, this theory generalised *Newton's* law of universal gravitation, for the curving spacetime, before which it was just applicable for almost flat spacetime geometry.
According to Newton, gravity is a force that acts between two or more objects almost instantly and requires no medium. But, Einstein reimagined gravity in a whole new way, as a curve in the fabric of spacetime, caused by mass and energy.
So instead of being pulled, objects follow the natural geodesics of spacetime.

This curvature can be described using Einstein's field equation:-

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

And, the rate of flow of time around matter can be determined using the equation:-

$$\frac{d\tau}{dt} = \sqrt{1 - \frac{2GM}{rc^2}}$$

In one line we can say that matter dictates the curve of spacetime, and spacetime dictates matter how to move.

Gravitational Time Dilation

It was first described by Albert Einstein in the year 1907, and was confirmed in the year 1959 by the Pound-Rebka experiment.

Suppose a person is on a planet that is very close to a super massive blackhole, so, he is exposed to a very large amount of gravitational field, and for him time will run at a very slower rate, compared to the person who is present on earth.

And hence, there clearly will be a measurable amount of difference in time elapsed, between the two events, depending on the amount of gravitational field they are facing. And this difference is called gravitational time dilation.

Mathematically it can be shown as :-

$$\Delta t' = \Delta t\sqrt{1 - \frac{2GM}{rc^2}}$$

Where:-

- $\Delta t' \rightarrow$ The amount of time measured by an observer in a gravitational field.
- $\Delta t \rightarrow$ The amount of time measured by an observer far away from the gravitational field.
- $G \rightarrow$ Universal gravitational constant.
- $M \rightarrow$ Mass of the object creating the gravitational field.
- $r \rightarrow$ Distance from center of mass to observer.

Shapiro time delay

Irwin I. Shapiro proposed the Shapiro time delay, also known as gravitational time delay first in 1964, it's also the 4th test of general relativity.

When a radar signal or light beam passes close to a massive object like the sun, its path gets bent, and a time dilation can be seen due to the curvature of spacetime. The extra time delay which otherwise wouldn't have been, if spacetime fabric remained flat.

The delay can easily be calculated using this mathematical equation :-

$$\Delta t = \frac{2GM}{c^3} \times ln(\frac{4r_E r_P}{b^2})$$

Where :-

- M $\rightarrow$ mass of the central body.
- r_E $\rightarrow$distance from the massive body to earth.
- r_P $\rightarrow$distance from the massive body to the planet (reflector).
- b $\rightarrow$impact parameter (closest distance between the signal path and the mass).

In 1966, Shapiro himself confirmed it first. He observed a time delay of about 200 microseconds, when radar signals bounced off Venus and Mercury and passed near the sun.

Problem of time

Quantum time

Time in quantum mechanics, takes a quite significant turn from its nature that was described in relativistic mechanics. It comes back to its absolute nature making it difficult and paradoxical to grasp its true nature.

There is no hamiltonian operator for time, and it does not behave like it did in space. The Hilbert spaces used in quantum theory relies on a complete set of observables, which only commute at a specific time.

Due to this behaviour of time, it is difficult to form a proper theory on quantum gravity.

Modern theories do try to give solutions for this problem of time. Many theories such as the Page-Wooters mechanism, Loop quantum gravity, Casual set theory, etc. suggest that time emerges from correlation between many small quantum systems present in the universe.

John Wheeler and Bryce dewitt tried to write a quantum version of Einstein's equation, which is very important in quantum gravity. The equation is :-

$$\hat{H}(x)|\psi\rangle = 0$$

According to this equation, there is no involvement of time, and hence the hamiltonian doesn't determine the evolution of the system. We can say that time is frozen as a whole.

Thermal time hypothesis

Proposed by Carlo Rovelli and Alain Connes in the 1990s. It is a possible solution to the problem of time.

According to this theory, time might be state dependent and even in a global timeless state it can emerge thermodynamically.for any physical system in a quantum state, there exists a natural flow defined by that state, this flow is what we call time.
The flow is generated by the modular hamiltonian :-

$$K = -ln(\rho)$$

Where, ρ is the density matrix.

The modular flow of a state A is given by :-

$$A(t) = e^{\frac{iKt}{\hbar}} A e^{\frac{-iKt}{\hbar}}$$

As we can see, that time here is not an external parameter but an internal property defined by the state itself.

So, when spacetime is flat like in special relativity where spacetime is flat (Minkowskian)
The modular flow coincides with the usual time evolution.

But, when spacetime is curved , the notion of global time fades away, but modular flows for local regions can still be defined, possessing their own local thermal time.

There are much more future developments and refinings yet to be made to this theory.

The arrow of time concept, that why time seems to flow in a particular direction is also related to thermodynamics, mathematically every event can occur in the opposite direction also, with the same probability, but physically it never happens, like the breaking of glass takes place but reassembling doesn’t.

The explanation of this preference of nature can be explained mainly using the second law of thermodynamics which talks about the entropy of a system, weirdly time flows in the direction of increasing entropy and not vice versa. This might be because of the initial low entropy state of the early universe. But, still this is one of the greatest puzzles to be solved.

Conclusion

Some recent speculations and theories do suggest time as the stage with multiple dimensions and space as an actor or a secondary effect. But these theories still need more solid proof and evidence to be true.

From early philosophies, paradoxes to modern scientific theories and mathematical approaches, every new idea contributed something to our knowledge about time and its nature. Those ancient theories and paradoxes resurfaced several times while we tried to know about time more scientifically and mathematically. Apparently, those questions about past, present and future are still unanswered. We still need a more refined and tested edition of the existing theories or maybe a new one. Who knows?

I will leave it to the readers to answer, if time is just a stubborn illusion? Or more than that.

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