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The death of space and time

How we discovered that light is the rock on which the universe is founded and

time

and space are shifting sand

When a man sits with pretty girl for an hour, it seems like a minute.

But let him sit on a hot stove for a minute - it's longer than an hour.

That's relativity!

Albert Einstein

The faster you go, the slimmer you are.

Albert Einstein

It's the most peculiar 100 metres anyone has ever seen. As the sprinters explode out of their starting blocks and get into their stride, it seems to the spectators in the grandstand that the runners get ever slimmer. Now, as they motor past the cheering crowd, they appear as flat as pancakes. But this isn't the most peculiar thing - not by a long way. The arms and legs of the athletes are pumping in ultra-slow motion, as if they are running not through air but molasses. Already, the crowd is beginning to slow-hand-clap. Some people are even ripping up their tickets and angrily tossing them into the air. At this pathetic rate of progress, it could take an hour for the sprinters to reach the finishing tape. Disgusted and disappointed, the spectators, get up from their seats and, one by one, traipse out of the stadium.

The scene seems a totally ridiculous. But, actually, it is wrong in only one detail - the speed of the sprinters. If they could run 10 million times faster, this is exactly what everyone would see. When objects fly past at ultra-high-speed, space shrinks while time slows down. It's an inevitable consequence of one thing – the impossibilty of ever catching up a light beam.

Naively, you might think that the only thing that is not catch-up-able is something travelling at infinite speed. Infinity, after all, is defined as the biggest number imaginable. Whatever number you think of, infinity is bigger. So, if there were something that could travel infinitely fast, it is clear you could never get abreast of it. It would represent the ultimate cosmic speed limit.

Light travels tremendously fast - 300,000 kilometres in empty space – but this is far short of infinite speed. Nevertheless, you can never catch up a light beam, no matter how fast you travel. In our universe, for reasons nobody completely understands, the speed of light plays the role of infinite speed. It represents the ultimate cosmic speed limit.

The first person to recognise this peculiar fact was Albert Einstein. Reputedly aged only 16, he asked himself: what would a beam of light look like if you could catch it up?

The reason Einstein could ask such a question and hope to answer it was because of a discovery made by the Scottish physicist James Clerk Maxwell. In 1868, Maxwell summarised all known electrical and magnetic phenomena - from the operation of electric motors to the behaviour of magnets - with a handful of elegant mathematical equations. The unexpected bonus of "Maxwell's equations" was that they predicted the existence of a hitherto unsuspected "wave" - a wave of electricity and magnetism.

Maxwell's wave, which propagated through space like a ripple spreading on a pond, had a very striking feature. It travelled at 300,000 kilometres per second - the same as the speed of light in empty space. It was too much of a coincidence. Maxwell guessed - correctly - that the wave of electricity and magnetism was none other than a wave of light.

Nobody - apart perhaps from the electrical pioneer Michael Faraday - had the slightest inkling that light was connected with electricity and magnetism. But, there it was, written indelibly in Maxwell's equations: light was an "electromagnetic wave".

Magnetism is an invisible "force field" which reaches out into the space surrounding a magnet. The "magnetic field" of a bar magnet, for instance, attracts nearby metal objects such as paperclips. Nature also boasts an "electric field", an invisible force field which extends into the space around a body which is electrically charged. The electric field of a plastic comb rubbed against a nylon sweater, for instance, can pick up small scraps of paper.

Light, according to Maxwell's equations, is a wave rippling through these invisible force fields much like a wave rippling through water. In the case of a water wave, the thing that changes as the wave passes by is the level of the water, which goes up and down, up and down. In the case of light, it is the strength of the magnetic and electric force fields, which grow and die, grow and die (Actually, one field grows while the other dies, and vice versa, but that’s not important here).

Why go into such gory detail about what an electromagnetic wave is? The answer is because it is necessary in order to understand Einstein's question: what would a light beam look like if you could catch it up?

Say you are driving a car on a motorway and you catch up another car travelling at 100 kilometres per hour. What does the other car look like as you come abreast of it? Obviously, it appears stationary. If you wind down your window, you may even be able to shout to the other driver above the noise of the engine. In exactly the same way, if you could catch up a light beam, it ought to appear stationary, like a series of ripples frozen on a pond.

However - and this the key thing noticed by the 16-year-old Einstein - Maxwell's equations have something important to say about a frozen electromagnetic wave, one in which the electric and magnetic fields never grow or fade but remain motionless forever. No such thing exists! A stationary electromagnetic wave is an impossibility.

Einstein, with his precocious question, had put his finger on a paradox, or inconsistency, in the laws of physics. If you were able to catch up a beam of light, you would see a stationary electromagnetic wave, which is impossible. Since seeing impossible things is - well - impossible, you can never catch up a light beam! In other words, the thing that is uncatchable - the thing that plays the role of infinite speed in our Universe - is the speed of light.

Foundation stones of relativity

The uncatchability of light can be put another way. Imagine that the cosmic speed limit really is infinity (though, of course, we now know it isn't). And say, for instance, there is a missile that can fly at infinite speed which is fired from a fighter plane. Is the speed of the missile relative to someone standing on the ground infinity plus the speed of the plane? If it is, the missile's speed relative to the ground is greater than infinity. But this is impossible since infinity is the biggest number imaginable. The only thing that makes sense is that the speed of the missile is still infinitely fast. In other words, its speed does not depend on the speed of its source - the speed of the fighter plane.

It follows that, in the real Universe, where the role of infinite speed is played by the speed of light, the speed of light does not depend on the motion of its source either. It's the same - 300,000 kilometres per second - no matter how fast the source of light is travelling.

The speed of light's lack of dependence on the motion of its source is one of the two pillars on which Einstein, in his "miraculous year" of 1905, proceeded to build a new and revolutionary picture of space and time - his "special theory of relativity". The other one - equally important - is the "principle of relativity".

In the 17th century, the great Italian physicist Galileo noticed that the laws of physics are unaffected by relative motion - in other words, they appear the same, no matter how fast you are moving relative to someone else. Think of standing in a field and throwing a ball to a friend 10 metres away. Now imagine you are on a moving train instead and throwing the ball to your friend, who is standing 10 metres along the aisle. The ball in both cases loops between you on a similar trajectory. In other words, the path the ball takes takes no account of the fact that you are in a field or on a train barrelling along at, say, 120 kilometres per hour.

In fact, if the windows of the train are blacked out, and the train has such brilliant suspension that it is vibration free, you will be unable to tell from the motion of the ball - or any other object inside the train for that matter - whether or not the train is moving. For reasons nobody knows, the laws of physics are the same no matter what speed you are travelling, as long as that speed remains constant.

When Galileo made this observation, the "laws" he had in mind were the laws of motion which govern such things as the trajectory of cannon balls flying through the air. Einstein's audacious leap was to extend the idea to all laws of physics, including the laws of optics which govern the behaviour of light. According to his "principle of relativity", all laws appear the same for "observers" moving with constant speed relative to each other. In a blacked out train, in other words, you could not tell even from the way light was reflected back and forth whether or not the train was moving.

By combining the principle of relativity with the fact the speed of light is the same, irrespective of the motion of its source, it is possible to deduce another remarkable property of light. Say, you are travelling towards a source of light at high speed. At what speed does the light coming towards you strike you? Well, remember there is no experiment you can do to determine whether it is you or the light source that is moving (Recall the blacked-out train again). So, an equally valid point of view is to assume that you are stationary and the light source is moving towards you. But, remember, the speed of light does not depend on the speed of its source - it always leaves the source at precisely 300,000 kilometres per second. Since you are stationary, therefore, the light must arrive at you at precisely 300,000 kilometres per second.

Consequently, not only is the speed of light independent of the motion of its source, it is independent of the motion of anyone observing the light as well. In other words, everyone in the Universe, no matter how fast they are moving, always measures exactly the same speed of light - 300,000 kilometres per second.

What Einstein set out to answer in his "special theory of relativity" was how, in practise, everyone can end up measuring precisely the same speed for light? It turns out that there is only one way: if space and time are totally different from what everyone thinks they are!

Shrinking space, stretchy time

Why do space and time come into things? Well, the speed of anything - light included - is the distance in space the thing travels in a given interval of time. Rulers are commonly used to measure distance and clocks to measure time. Consequently, the question - how can everyone, no matter what their state of motion, measure same speed of light? - can be put another way. What must happen to everyone's rulers and clocks so that, when they measure the distance light travels in a given time, they always get a speed of exactly 300,000 kilometres per second?

This, in a nutshell, is special relativity is - a "recipe" for what must happen to space and time so that everyone in the Universe agrees on the speed of light.

Think of a spaceship firing a laser beam at a piece of space debris which happens to be flying towards it at 0.75 times the speed of light. The laser beam cannot hit the debris at 1.75 times the speed of light because that is impossible; it must hit it at exactly the speed of light. The only way this can happen is if someone observing the events and estimating the distance that the arriving light travels in a given time either underestimates the distance or overestimates the time.

In fact, as Einstein discovered, they do both. To someone watching the spaceship from outside, moving rulers shrink and moving clocks slow down. Space "contracts" and time "dilates", and they contract and dilate in exactly the manner necessary for the speed of light to come to out as 300,000 kilometres per second for everyone in the Universe. It's like some huge cosmic conspiracy. The constant thing in our Universe isn't space or the flow of time but the speed of light. And everything else in the Universe has no choice but to adjust itself to maintain light in its pre-eminent position.

Space and time are both relative. Lengths and time intervals become significantly warped at speeds approaching the speed of light. One person's interval of space is not the same as another person's interval of space. One person's interval of time is not the same as another person's interval of time.

"When a man sits with pretty girl for an hour, it seems like a minute," said Einstein to illustrate the point. "But let him sit on a hot stove for a minute--it's longer than an hour. That's relativity!"

Time, it turns out, runs at different rates for different observers, depending on how fast they are moving relative to each other. And the discrepancy between the ticking of their clocks gets greater the speedier the motion. The faster you go, the slower you age![1] It's a truth which has been hidden from us for most of human history for the simple reason that the slowing down of time is apparent only at speeds approaching that of light, and the speed of light is so enormous that Concorde, by comparison, flies at a snail's pace across the sky. If the speed of light had instead been only 30 kilometres per hour, it would not have taken a genius like Einstein to discover the truth. The effects of special relativity such as time dilation and length contraction would have be glaringly obvious to the average 5-year-old.

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[1] To be precise, a stationary observer sees time slow down for a moving observer by a factor gamma, where gamma = 1/(1 - sqrt(v^2/c^2)) and v and c are the speed of the moving observer and the speed of light, respectively. At speeds close to c, gamma becomes enormous and time for a moving observer slows almost to a standstill!

As with time, so with space. The spatial distance between any two bodies is different for different observers, depending on how fast they are moving relative to each other. And the discrepancy between their rulers gets greater the faster the motion. "The faster you go, the slimmer you are," said Einstein[2]. Once again, this would be self-evident if we lived our lives travelling close to the speed of light. But, living as we do in nature's slow lane, we cannot see the truth - that space and time are shifting sand, the unvarying speed of light the bedrock on which the Universe is built.

If you think relativity is hard, take heart from the words of Einstein who said: "The hardest thing in the world to understand is income tax!" Ignore, however, the words of Israel's first president, Chaim Weizmann who, after a sea voyage with the great scientist in 1921, said: "Einstein explained his theory to me every day and, on my arrival, I was fully convinced that he understood it!"

Can anything travel faster than light? Well, nothing can catch up a beam of light. But the possibility exists that there are "subatomic" particles which live their lives permanently travelling faster than light. Physicists call such hypothetical particles "tachyons". If tachyons exist, perhaps in the far future, we could find a way to change the atoms of our bodies into tachyons and then back again. Then we too could travel faster than light.

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[2] To be precise, a stationary observer sees the length of a moving body shrink by a factor gamma, where gamma = 1/(1 - sqrt(v^2/c^2)) and v and c are the speed of the moving observer and the speed of light, respectively. At speeds close to c, gamma becomes enormous and a body becomes as flat as a pancake in the direction of its motion!

One of the problems with tachyons, however, is that from the point of view of certain moving observers, a body travelling faster than light could appear to be travelling back in time! In the words of the limerick...

A rocket explorer named Wright,
Once travelled much faster than light.
He set out one day, in a relative way,
And returned on the previous night!

Anonymous

Time travel scares the living daylights out of physicists because it raises the possibility of "paradoxes", events which lead to logical contradictions like you going back in time and killing your grandfather. If you killed your grandfather, goes the argument, how could you have been born to go back in time to kill your grandfather? Some physicists, however, think that some, as yet undiscovered law of physics intervenes to prevent any paradoxical things from happening and so time travel may be possible.

The meaning of relativity

But what does relativity mean in a nuts-and-bolts sense? Well, say, it were possible for you to travel to the nearest star and back at 99.5 per cent of the speed of light. To an observer back on Earth, everything on your spaceship would appear to happen 10 times slower than normal. Although the round-trip to Alpha Centauri would take about 9 years for you and your fellow crew members - assuming a very brief stop-over! - for those back on Earth it would appear to take 86 years. Say, you departed on your journey as a very youthful 14-year-old, waved off from the spaceport by your identical twin brother. When you arrived back home, now 9 years older at 23, your twin - provided of course he had not died of old age - would be 100![3]

Of course, the more rapidly you travelled to Alpha Centauri and back, the greater the discrepancy between the ages of you and your twin. Travel fast enough and you will return to find that your twin is long dead and buried. Even faster and you will find that the Earth itself has dried up and died. In fact, if you travelled within a whisker of the speed of light, time would go so slowly for you that you could watch the entire future history of the Universe flash past you like a movie in fast-forward! "The possibility of visiting the future is quite awesome to anyone who learns about it for the first time," says the Russian physicist Igor Novikov.

As yet, we do not yet have the ability to travel to the nearest star and back at close to the light speed (or even 0.01 per cent of the speed of light!). Nevertheless, time dilation is detectable - just - in the everyday world. Experiments have been carried out in which super-accurate "atomic clocks" are synchronised then separated, one being flown round the world on an airliner while the other stays at home. When the clocks are re-united, the experimenters find that the round-the-world clock has registered the passage

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[3] Actually, there is a subtle flaw in this argument. Since motion is relative, it is perfectly justifiable for your Earthbound to assume that it is the Earth that receded from your spacecraft at 99.5 per cent of the speed of light. However, this viewpoint leads to the opposite conclusion to before - that time slows for your twin relative to you. Clearly, time cannot run slowly for each of you, with respect to the other. The resolution of this "twin paradox", as it is known, is to realise that your spaceship actually has to slow down and reverse its motion at Alpha Centauri. Because of this "deceleration", the two points of view - your spaceship moving or the Earth moving - are not really equivalent and interchangeable.

of marginally less time than its stay- at-home counterpart. The shorter time measured by the moving clock is precisely what is predicted by Einstein.

The slowing of time affects astronauts too. As Novikov points out in his excellent book, *The River of Time*: "When the crew of the Soviet Salyut space station returned to Earth in 1988 after orbiting for a year at 8 kilometres a second, they stepped into the future by one hundredth of a second."

The time dilation effect is minuscule because airliners and spacecraft travel at only a tiny fraction of the speed of light. However, it is far greater for cosmic ray "muons", "subatomic" particles created when cosmic rays - super-fast atomic nuclei from space - slam into air molecules at the top of the Earth's atmosphere.

The key thing to know about muons is that they have tragically short lives and, on average, disintegrate, or "decay" after a mere 1.5 millionths of a second. Since they streak down through the atmosphere at more than 99.92 per cent of the speed of light, this means that they should travel barely 0.5 kilometres before self-destructing. This is not far at all when it is realised that cosmic ray muons are created about 12.5 kilometres up in the air. Essentially none should, therefore, reach the ground.

Contrary all to expectations, however, every square metre of the Earth's surface is struck by several hundred cosmic ray muons every second. Somehow, these tiny particles manage to travel 25 times farther than they have any right to. And it is all down to relativity.

The time experienced by a speeding muon is not the same as the time experienced by someone on the Earth's surface. Think of a muon as having an internal alarm clock which tells it when to decay. At 99.92 per cent of the speed of light, the clock slows down by a factor of about 25, at least to an observer on the ground. Consequently, cosmic ray muons live 25 times longer than they would if stationary - time enough to travel all the way to the ground before they disintegrate. Cosmic ray muons on the ground owe their very existence to time dilation.

What does the world look like from a muon's point of view? Or, come to think of it, from the point of view of the space- faring twin or the atomic clock flown round the world? Well, from the point of view of all of these, time flows perfectly normally - each, after all, is stationary with respect to itself! Take the muon. It still decays after 1.5 millionths. From its point of view, however, it is standing still and it's the Earth's surface that is approaching at 99.92 per cent of the speed of light. It therefore sees the distance it has to travel shrink by a factor of 25, enabling it to reach the ground even in its ultra-short lifetime.

The great cosmic conspiracy between time and space works whatever way you look at it!

Why relativity had to be

The behaviour of space and time at speeds approaching that of light is indeed bizarre. However, it need not have been a surprise to anyone. Although our everyday experience in nature's slow lane has taught us that one person's interval of time is another person's interval of time and that one person's interval of space is another person's interval of space, our belief in both of these things is in fact based on a very rickety assumption.

Take time. You can spend a lifetime trying futilely to define it. Einstein, however, realised that the only useful definition is a practical one. We measure the passage of time with watches and clocks. Einstein therefore said: "Time is what a clock measures" (It takes a genius to state the obvious!).

If everyone is going to measure the same interval of time between two events, this is equivalent to saying that their clocks run at the same rate. But as everyone knows this never quite happens. Your alarm clock may run a little slow, your watch a little fast. We overcome these problems by, now and then, "synchronising" them. For instance, we ask someone the right time and, when they tell us, we correct our watch accordingly. Or we listen out for the time signal "pips" on the BBC.

But, in using the pips, we make a hidden assumption. The assumption is that it takes no time at all for the radio announcement to travel to our radio. Consequently, when we hear the BBC announcer say it is 6am, it is 6am.

A signal that takes no time at all travels infinitely fast - the two statements are entirely equivalent. But, as we know, there is nothing in our Universe that can travel with infinite speed.

On the other hand, the speed of radio waves - a form of light invisible to the naked eye - is so huge compared to all human distances that we notice no delay in their travel to us from the transmitter. Our assumption that the radio waves travel infinitely fast, although false, is not a bad one in the circumstances. But what happens if the distance from the transmitter is very large indeed? Say, the transmitter is on Mars, which might be possible one day if humans go to the Red Planet.

When Mars is at its closest, the signal takes 5 minutes to fly across space to the Earth. If, when we hear the announcer on Mars say it is 6am, we set our clock to 6am, we will be setting it to the wrong time. The way around this is obviously to take into account the 5-minute time delay and, when we hear 6am, set our clock to 6.05am.

Everything, of course, hinges on knowing the time it takes the signal to travel from the Earth to Mars. In practice this can be done by bouncing a radio signal from Earth off Mars and picking up the return signal. If it takes 10 minutes for the round-trip, then it must take 5 minutes to travel from the spaceship to the Earth.

The lack of an infinitely fast means of sending signals is not, therefore, a problem in itself for synchronising everyone's clocks. It can still be done by bouncing light signals back and forth and taking into account the time delays. The trouble is that this only works perfectly if everyone is stationary with respect to everyone else!

In reality, everyone in the Universe is moving with respect to everyone else. And, the minute you start bouncing light signals between observers who are moving, the peculiar constancy of the speed of light starts to wreak havoc with common sense.

Say there is a spaceship travelling between Earth and Mars and say it is moving so fast that, by comparison, Earth and Mars appear stationary. Imagine that, as before, you send a radio signal to Mars, which bounces off the planet and which you then pick up back on Earth. The round-trip takes 10 minutes so, as before, you deduce that the signal arrived at Mars after only 5 minutes. Once again, if you pick up a time signal from Mars, saying it is 6am, you will deduce from the time delay that it is really 6.05am

Now consider the spaceship. Assume that at the instant you send your radio signal to Mars, it sets off at its full speed to Mars. At what time does an observer on the spaceship see the radio signal arrive at Mars?

Well, from their point of view, Mars is approaching, so the radio signal has a shorter distance to travel. But the speed of the signal is the same for you and for the observer on the spaceship. After all, that's the central peculiarity of light - it has exactly the same speed for everyone.

Speed, remember, is simply the distance something travels in a given time. So if the observer on the spaceship sees the radio signal travel a shorter distance and still measures the same speed, they must measure a shorter time too. In other words, they deduce that the radio signal arrives at Mars earlier than you do. To them, clocks on Mars tick more slowly. If they pick up a time signal from Mars, saying it is 6am, they will correct it using a shorter time delay and conclude it is, say, 6.03am, not the 6.05 am you conclude.

The upshot is that two observers who are moving relative to each other never assign the same time to a distant event. Their clocks always run at different speeds. And what is more, this difference is absolutely fundamental - no amount of ingenuity in synchronising clocks can ever get around it.

Shadows of space-time

The slowing of time and the shrinking of space is the price that must be paid so that everyone in the Universe, no matter what their state of motion, measures the same speed of light. But this only the beginning!

Say, there are two stars and a space-suited figure is floating in the blackness midway between them. Imagine that the two stars explode and the floating figure sees them detonate simultaneously - two blinding flashes of light on either side of him. Now picture a spaceship travelling at enormous speed along the line joining the two stars. The spaceship passes by the space-suited figure just as he sees the two stars explode. What does the pilot of the spaceship see?

Well, since the ship is moving towards one star and away from the other, the light from the star it is approaching will arrive before the light from the star it is receding from. The two explosions will therefore not appear simultaneous.

Consequently, even the concept of "simultaneity" is a casualty of the constancy of the speed of light. Events that one observer sees as simultaneous are not simultaneous to another observer moving with respect to the first.

The key thing here is that the exploding stars are separated by an interval of space. Events that one person sees separated by only space, another person sees separated by space and time. And vice versa. Events one person sees separated only by time, another person sees separated by time and space.

The price of everyone measuring the same speed of light is therefore not only that the time of someone moving past you at high speed slows down while their space shrinks but that some of their space appears to you as time and some of their time appears to you as space! One person's interval of space is another person's interval of space and time. And one person's interval of time is another person's interval of time and space.

The fact that space and time are interchangeable in this way tells us something remarkable and unexpected about space and time. Fundamentally, they are same thing - or at least different sides of the same coin!

The person who first saw this - more clearly even than Einstein himself - was Einstein's former mathematics professor Hermann Minkowski, a man famous for calling his student a "lazy dog" who would never amount to anything (To his eternal credit, he later ate his words). "From now on", said Minkowski, "space of itself and time of itself will sink into mere shadows and only a kind of union between them will survive."

Minkowski christened this peculiar union of space and time "space-time". Its existence would be blatantly obvious to us if we lived our lives travelling at close to the speed of light. Living as we do in nature's ultra-slow lane, however, we never experience the seamless entity. All we glimpse instead are its "space" and "time" facets.

As Minkowski put it, space and time are like "shadows" of space-time. Think of a stick suspended from the ceiling of a room so that it can spin round its middle and point in any direction like a compass needle. A bright light casts a shadow of the stick on one wall while a second bright light casts a shadow of the object on an adjacent wall. We could, if we wanted, call the size of stick's shadow on one wall its "length" and the size of its shadow on the other wall its "width". What then happens as the stick swings around?

Clearly, the size of the shadow on each wall changes. As the "length" gets smaller, the "width" gets bigger, and vice versa. In fact, the "length" appears to change into the "width" and the "width" into the "length" - just as if they are aspects of the same thing.

Of course, they are aspects of the same thing. The "length" and "width" are not fundamental at all. They are simply artefacts of the direction from which we choose to observe the stick. The fundamental thing is the stick itself, which we can see simply by ignoring the shadows on the wall and walking to the centre of the room.

Well, "space" and "time" are much like the "length" and "width" of the stick. They are not fundamental at all but artefacts of our viewpoint - specifically, how fast we are travelling. But though the fundamental thing is "space-time", this is apparent only from a viewpoint travelling close to the speed of light, which is of course why it is not obvious to any of us in our daily lives.

Of course, the stick-and-shadow analogy, like all analogies, is helpful only up to a point. Whereas the "length" and "width" of the stick are entirely equivalent, this is not quite true of the space facet and the time facet of space-time. Though you can move any direction you like in space, as everyone knows you can only move one direction in time.

The fact that space-time is solid reality and space and time the mere shadows raises a general point. To make sense of the world, we search desperately for things that are unchanging, like shipwrecked mariners clinging to rocks in a wild sea. We identify things like "distance" and "time" and "mass". But later, we discover that the things we identified as unchanging are unchanging only from our limited viewpoint. When we widen out our perspective on the world we discover that other things we never suspected are the invariant things. So it is with space and time. When we see the world from a high-speed vantage point, we see neither space nor time but the seamless entity of space-time.

Actually, we should long ago have guessed that space and time are inextriccably entwined. Think of the Moon. What is it like now, at this instant? The answer is that we can never know. All we can ever know is what it was like 1 1/4 seconds ago, which is the time it takes light from the Moon to fly across the 400,000 kilometres to the Earth. Now think of the Sun. We cannot know what it is like either, only what it was like 8 1/2 minutes ago. And for the nearest star system, Alpha Centauri, it is even worse. We have to make do with a picture which by the time we see it is already 4.3 years out of date.

The point is that, although we think of the Universe we see through our telescopes as existing "now", this is a mistaken view. We can never know what the Universe is like at this instant. The farther across space we look, the farther back in time we see. If we look far enough across space we can actually see close to the big bang itself, 13.7 billion years back in time. Space and time are inextriccably bound together. The Universe we see "out there" is not a thing that extends in space but a thing that extends in space-time.

The reason we have been hoodwinked into thinking of space and time as separate things is because light takes so little time to travel human distances. We rarely notice the delay. When you are talking with someone, you see them as they were a billionth of a second earlier. But this interval is unnoticeable because it is 10 million times shorter than any event that can be perceived by the human brain. It is no wonder that we have come to believe that everything we perceive around exists "now". But "now" is a fictitious concept, which becomes obvious as soon as we contemplate the wider universe, where distances are so great that it takes light billions of years to span them.

The space-time of the Universe can be thought of as a vast "map". All events - from the creation of the universe in the big bang to your birth at a particular time and place on Earth - are laid out on it, each with its unique space-time location. The "map" picture is appropriate because time, as the flip-side of space, can be thought of as an additional spatial dimension. But the "map" picture poses a problem. If everything is "laid out" - pre-ordained almost - there is no room for the concepts of past, present and future. As Einstein remarked: "For us physicists, the distinction between past, present, and future is only an illusion."

It's a pretty compelling illusion, mind! Nevertheless, the fact remains that the concepts of past, present and future do not figure at all in special relativity, one of our most fundamental descriptions of reality. Nature appears not to need them. Why we do is one of the great unexplained mysteries.

$E = mc^2$ and all that

The special theory of relativity does more than profoundly change our ideas of space and time. It changes our ideas about a host of other things too. The reason is that all the basic quantities of physics are ultimately built out of space and time. A body's velocity, for instance, is the interval of space it covers in a certain interval of time. If, as relativity tells us, space and time are malleable, blurring one into the other as the speed of light is approached, then so too are the other entities of physics. Like space and time which merge into space-time, they too are tied together in the interests of keeping the speed of light constant.

Take electricity and magnetism. It turns out that, just as one person's space is another person's time, one person's magnetic field is another person's electric field. Electric and magnetic fields are crucial to both generators which make electrical currents and motors which turn electric currents into motion. "The rotating armatures of every generator and every motor in this age of electricity are steadily proclaiming the truth of the relativity theory to all who have ears to hear," wrote the physicist Leigh Page in the 1940s.

Because we live in a slow-motion world, we are hoodwinked into believing that electric and magnetic field have a separate existence. But just like space and time they are merely different faces of the same coin. In reality, there is only seamless entity: the electromagnetic field.

Two other quantities that turn out to be different faces of the same coin are energy and momentum[4]. And, in this unlikely connection, is hidden perhaps the greatest surprise of relativity - that mass is a form of energy. The discovery is encapsulated in the most famous, and least understood, formula in all of science: $E=mc^2$.

[4] The momentum of a body is a measure of how much force is required to stop it. For instance, an oil tanker, even though it may be going at only a few kilometres an hour, has far more momentum than a Formula 1 racing car going at 200 kilometres per hour.