The Theory of Time Travel
By
Michael McCollum

There are a few universal human desires. One of these is the wish that we could fly like a bird and soar among the clouds without the encumbrance of airplane or engine. Another is to attain godlike control over our fellow man, forcing everyone to live in accordance with your whims and wishes. A third is the desire to change things in the past, whether to make some crucial decision in our lives differently, or possibly to prevent a tragedy to our loved ones. Who among us has not wished at one time or another for a time machine?

If you have ever uttered that most universal of prayers, "Dear God, please make it didn't happen!" I have news for you. Time travel *is* possible ... at least, in theory. Whether it is possible in fact is a question we cannot yet answer.

Whether or not time travel is actually possible, the time travel story is one of the most enduring in all of science fiction. When done properly, tales of travelers in time generate a "Sense of Wonder" that few other stories can match. Before we get down to the mechanics of how to write a time travel story, however, let's look at the scientific theories of time. Warning!!! The science is about to get a little deeper than many people feel comfortable with. However, stick with me. I think you'll enjoy the ride!

One of the great questions philosophers have asked down through the ages has been "What is the nature of time?" You can understand their curiosity. The passage of time sees us move from infancy, through childhood, to mature adult, to old age, and finally, to death. It is that last step which spurs people to think about time and how its effects might be reversed.

Inherently, aging feels like a journey. The usual analogy is to view time as a great river in which we are all submerged, to be carried inexorably downstream with the swiftly flowing current. Personally, I prefer to think of time as a road. We all seem to be barreling down the highway at breakneck speed in our Volkswagen beetles, unable to either stop or reverse course. We must continue with our right foot planted heavily on the accelerator until that inevitable day when we slam into the concrete abutment with the graffiti, "Th ... th ... that's all, Folks!" spray painted across its face. What sort of highway is it that you can't turn around on, even if you are willing to risk a ticket for driving the wrong way on a one way street?

Cosmology is the study of the origins and possible outcomes of the universe. Its subject matter isn't limited to such things as planets, stars, and galaxies. Cosmologists take a wider view — 30 billion light years wider, to be precise. The nature of time is a study that naturally comes under the cosmologists' purview.

When cosmologists speak of time, they almost never speak of it in isolation. Time is merely one component of the space-time continuum, so named because space and time appear to be inextricably linked. In fact, they *are* the universe, or rather, the universe is them.

Once again we find ourselves faced with an obscure concept from which deeper truths flow, so let me make myself clear on this point. Usually when people speak of *The Universe*, what they are referring to is the present day universe, which is probably a spherical object some 30 billion light years in diameter filled with near vacuum and untold trillions of stars. The only problem with speaking of the "present day universe" is that Einstein proved that there is no such thing as "present day" in a universe where the speed of light is a finite number. Still, for purposes of discussion we won't fall into that trap. The Universe (by definition) is that region of space encompassing every atom, molecule, and photon that was initially present in the Big Bang, or which has been created since.

The space-time continuum is a larger concept than the universe. For the space-time continuum encompasses not only the present day universe, but also the universe clear back to the Big Bang and forward to whatever ultimate fate awaits it.

Think of the space-time continuum as a long, black, snakelike object where the measurement of the snake's length is in years. This black snake began as a pinpoint some 15 billion years ago, and has grown to its present size through the continuous expansion that is the natural result of the universe's birth in a really big explosion. What it will do in the future is the subject of hot argument among cosmologists. Some believe that the universe (the physical part of the space-time continuum) will expand forever, growing cooler and cooler until it suffers heat death. (See the section on entropy below.) Others think that it will eventually halt its current expansion and then begin to fall in upon itself. If that is the case, the space-time snake will look like it has swallowed a donkey — thin at both ends and fat in the middle.

Yet, if time is one of the dimensions of the four dimensional space-time continuum, that implies that those past universes still exist ... somewhere. In fact, the implication is that every moment of our lives is still out there in this long, snakelike thing we inhabit, and that all we have to do to visit ourselves as children is to learn to swim against the stream rushing from the snake's head to its tail. (That analogy may be unfortunate, since it implies that we aren't caught in the river of time, but rather in the alimentary canal of time. Still, that would explain a great deal, wouldn't it?)

If you are totally mystified as to what it is that I have been talking about, consider this: time is a dimension. It is a dimension exactly like length, depth, and width. As all the old science fiction movies tell us, time is the fourth dimension, the one in which we lack freedom of independent movement. Tomorrow you will be two days older than you were yesterday, and no amount of wishing will make it different.

Actually, current theory suggests that the universe has ten dimensions. We've identified four of them, the three space dimensions plus time. That leaves the interesting question as to exactly where the other six dimensions have gotten to.

When physicists first began wondering about the nature of time, they discovered something interesting. If you look at all the equations of science, many contain the letter t, denoting elapsed time. Velocity equals Acceleration multiplied by Time ($v=at$), Distance equals Velocity multiplied by Time (*d=vt*), Distance equals one-half the Acceleration multiplied by Time Squared ($d=0.5at^2$). Yet, none of these equations is in a form that suggests that time (*t*) must be input as a positive value. The equations work just as well if you insert a negative value for elapsed time. In other words, the equations work equally well whether time is flowing forward or backward.

If this seems difficult to swallow, think about the last time you saw a movie projected backwards, or put your VCR on fast rewind. The characters look funny running in reverse at high speed, and watching spilled milk jump back into the glass seems counter-intuitive. But mathematically speaking, there is no more reason why the milk shouldn't jump from the carpet to the glass than vice versa.

Well, perhaps there is *one* reason. And for that we will have to introduce one of the subtlest concepts in science, entropy.

Entropy

Entropy is a difficult thing to explain, although we all have an intuitive understanding of the concept because we deal with entropy in our daily lives. We just don't call it that. Entropy is a measure of the degree of order in the universe, or if you prefer, a measure of the universe's randomness.

Consider a teenager's bedroom. On Day One, the bed is made, the clothes are folded and arranged properly in bureau drawers, other clothes are hung neatly in the closet, and all shoes are in their places on the shoetree. Day One is the neatest that room will ever look again. By Day Two, the bed is unmade, various pieces of clothing are strewn around the floor, books are left open on chairs and a fine patina of dust has descended everywhere. By Day Seven, there is so much clutter on the floor that you can no longer see the carpet. The closet door is open (or off its tracks) and an odd number of shoes are piled in a jumble at the foot of the bed.

On Day One the bedroom was in what physicists refer to as a low state of entropy. It was ordered and neat, with everything in its place. Then, as the natural process of teenage living occurred, the level of entropy increased. Things became progressively more disorganized. Where the clothes were originally in their proper position, as days go by, more and more of them end up in a jumble on the floor. By Day Seven, the jumble is nearly complete. It is impossible to predict precisely where any particular piece of clothing is lying. In other words, if you look at one particular place on the carpet (say at the grape juice stain just inside the door), then the probability of finding a given piece of clothing at that spot is exactly the same as for finding any other piece of clothing there. Clothing distribution has become completely random.

If you think about it, virtually every physical process in our lives involves a highly ordered system becoming a highly disordered system over time. Things tend to run down. Newly painted buildings weather and become dilapidated. Newly picked fruit spoils and eventually rots. Places that are significantly hotter than their surroundings cool off until they are at the same temperature. Places that are cooler warm up until they reach equilibrium.

This is not an accident. One of the most basic laws of the universe is that in a closed system (which the universe is), the degree of randomness will always increase with time. In other words, entropy increases as we move from past to future. For that reason, physicists often call entropy “Time's Arrow.” It is the only measure in the universe that we know of which isn't the same whether time flows forward or back. It is the increase in universal entropy that acts as the ONE WAY ONLY sign on our highway of time.

But does entropy always have to increase? The answer to that is a bit complicated. In the case of the universe, the answer is an unequivocal yes. Stars radiate their energy to the great blackness. They eventually grow old and die. Some day all of the energy in the universe will have been radiated away into space, and all that will be left will be a uniform background radiation. Scientists refer to this state as the "heat death" of the universe because there are no temperature differentials anywhere.

The fact that entropy must always increase in the universe as a whole does not mean that entropy must always increase everywhere. The entropy of the teenager's bedroom is reduced when his or her mother gets sick of the mess and goes in to clean it up. The mother restores the room to its low entropy state and the cycle begins again. In some households, this cycle operates from weekend to weekend. In my house the cycle is more seasonal. But to restore the bedroom to its state of low entropy requires the expenditure of energy; i.e., the mother's exertions in picking up, vacuuming, and making beds.

This same principle works for processes unrelated to housekeeping. We routinely decrease the entropy of our dwellings using a machine called an air conditioner. Air conditioners take highly randomized air masses (hot air) and turn them into relatively lower entropy air masses (cool air). They do this at a cost, however (as anyone who operates an air conditioner in Arizona in the summer knows all too well!). They pump the heat from your house, dumping that heat to the outside air. They also dump the energy required to run the compressor. Thus, while the entropy of your dwelling has been reduced, the overall entropy of the universe has risen.

Life is also an anti-entropy process. The egg is fertilized, grows to be a baby, is born, then grows to adulthood, all the while becoming more and more ordered (that is, reducing its level of entropy). But like the air conditioner, living things must expend energy to operate. If you don't believe me, just stop eating.

Entropy can be reduced so long as the system in which the reduction occurs is not a closed one. In effect, air conditioners and living cells act as "entropy pumps," extracting entropy and then dumping it outside the system boundaries. And since our machines are not 100% efficient, the increase in entropy outside the system exceeds the reduction of entropy within.

What does this lecture on thermodynamics have to do with time travel? More than you may think. For if we are ever to invent time machines, we have to be able to perform the same trick that the air conditioner does. We must move some quantity of the universe's mass from a region of high entropy (the present) to a region of lower entropy (the past). Presumably, that will require us to expend energy, which in turn will increase the entropy of the present by more than we reduced it in our time travelers. Don't forget. Machines that operate at 100% efficiency aren't even believable in science fiction.

But that's impossible, right? Maybe it is and maybe it isn't. However, current physics can visualize one special situation where time travel is, indeed, possible. Let's look at it for a moment.

Rotation of Space-Time Coordinate Systems

A few years ago I worked with Stanford University to provide them components for their Gravity Probe B Project. Gravity Probe B is the culmination of a 30-year effort to prove out one of the more esoteric predictions made by Albert Einstein in his General Theory of Relativity. In 1916, Einstein postulated that gravity is not a force. Rather, it is a curvature of the space-time continuum (there are those words again).

The reason that we know this is that gravity bends light, even though photons have no mass. Using Newton's second law ($F=MA$), we can see that a massless particle subjected to a force would experience infinite acceleration. This is clearly impossible and the logical conclusion is that a massless particle cannot be acted upon by any force. Yet, gravity bends light! How can this be?

The answer to that question revolutionized physics, transforming Newtonian Physics into Einsteinian Physics in the process. It isn't that Newton was wrong, just too limited in his outlook. But I digress...

When gravity curves light beams, it isn't because a "force" is acting on the individual photons that make up the beam. Rather, gravity "curves" space and the beam is merely following the bent path that results from that curvature. Just as a hiker follows the contour of a hill, light follows the contour of space, and since space is no longer "flat," the light beam is no longer a straight line.

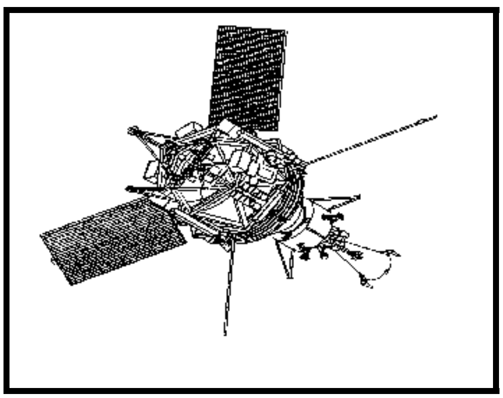

Figure 1: Stanford University Gravity Probe B

The usual example used to explain this very advanced concept is to imagine that the Earth and Sun are steel balls sitting on a taut sheet of rubber. Because both have mass, they sink into the rubber, with the Sun sinking in farther because it has the greater mass. These dimples in the rubber are known as a gravity wells, and they are the reason why it takes energy for a human being to climb stairs, or to launch a rocket into orbit.

The Earth circles the Sun because it is trapped midway down the parabolic-curved sides of the sun's gravity well. All gravity wells can be thought of as being parabolic in shape. That is because the "force" of gravity falls off with the square of the distance. Actually, it is the slope of the gravity well that falls off with the square of the distance. Remember that gravity is not a force!

Venus and Mercury are trapped just as Earth is; but since they orbit closer to the sun, they are deeper in the sun's gravity well. Mars, Jupiter and all the rest of the planets are higher in the well. Since the edges of the well extend to infinity, it isn't possible to escape the sun's pull entirely, but as one gets farther away, the local curvature becomes so slight that the difference between the sun's gravity well and flat space becomes imperceptible.

We, too, are trapped in a gravity well. However, ours is the Earth's gravity well, which both holds us captive and nurtures us. We sit precariously on the slippery sides of the well, prevented from sliding further into the depths by the solid ground under our feet. Lose your footing for even an instant, however, and your body is pulled deeper into the well at the rate of 9.8 meters per second squared. We have a common name for the act of being pulled into the gravity well. We call it "falling."

Note that I said we sit on the *side* of the well, not at the bottom. The phenomenon we perceive as gravity is determined not by our depth down the gravity well, but rather by the degree to which space is curved in our vicinity. If space is lightly curved, then the pull of the gravitational “force” is low. If space is sharply curved, then the pull of gravity is strong. This is why you weigh one-sixth as much on the Moon as you do on Earth. The sides of the Moon's gravity well are curved only one-sixth as steeply as are the sides of Earth's well.

According to Einstein, the presence of mass in space does more than merely “curve” space, however. If a mass is also rotating, then space is also “twisted” slightly in the direction of rotation. The rotating Earth not only sinks down into the stretched rubber sheet, it also “twists” the rubber in the direction of rotation. Think of a partially inflated, long balloon that has been twisted and you will have a good mental image of what Einstein is talking about.

The Theory of Relativity predicts that the Earth drags the space-time continuum around with it as it rotates. This phenomenon, known as the Lense-Thirring or Einstein-Schiff “frame dragging” effect, has yet to be verified experimentally. The reason is simple. The effect is a very tiny one, and until recently, we have not had instruments sufficiently sensitive to test the theory.

That is where Stanford University comes into the picture. The Gravity Probe B Project will launch a satellite that will confirm or disprove the theory of frame dragging. The satellite will be launched into a perfectly inclined north-south orbit. Aboard the satellite is a large Dewar of liquid helium and four perfectly round crystal spheres. The spheres are cooled to cryogenic temperatures by the liquid helium and then “spun up” (using various components my company builds). Once the spheres are rotating, sensitive electronics measure the direction of their various axes of rotation.

Like any gyroscope, the spheres will “wobble” slightly as they spin, causing their axes of rotation to trace out a small circle. This gradual shift in the axis of rotation is called precession, and it is inherent in any gyroscopic system. Remember how a spinning top wobbles slowly as it rotates? That is precession.

Because the degree to which the Earth drags the space-time continuum around is very small, the quartz spheres used for gyroscopes in the Gravity Probe B satellite are the most perfectly round objects ever produced by human beings. The spheres, which are 38-millimeters in diameter, are so precise that if the Earth were equally round, Mount Everest would only be six inches tall!

Assuming that Einstein's prediction is correct, the gyroscopes will precess 42 milliarc-seconds more in a year in the direction of Earth’s rotation than at right angles to the Earth’s rotation. (A milliarc-second is 1/1000 of an arc-second, which is 1/3600 of a degree, and we are talking about a movement of only 42 of these tiny measurements over the course of a whole year! No wonder no one has tried this before now.)

What has this to do with time travel? Simply this. When the Earth drags the space-time continuum around with it, it causes the various axes to rotate toward the other axes. Length rotates toward height, height rotates toward width, and *width rotates toward time!*

HUH???

You heard me. Since time is a dimension in the space-time continuum just like length, height, and width, when the planet's rotation drags the space dimensions around, it also drags the time dimension. One of the space dimensions rotates toward time and the time dimension to rotates toward space. The effect is miniscule when you have a mass as small as the Earth, but what if you had something a bit larger to work with? Say a rotating black hole with a mass equal to 100 million suns?

Black holes have the same angular momentum as the stars that were sucked into them. This means that they rotate very, *very* quickly — hundreds of thousands of times per second. They also are massive; both conditions that promote frame dragging. If you passed sufficiently near such an object (ignoring the potentially lethal conditions that exist in the vicinity of black holes), you would encounter a region of space where the time axis is rotated through the fourth dimensional equivalent of 90 degrees. Under such conditions time travel would not only be theoretically possible, it would become practical.

How would such a thing work?

You are the captain of Starship *Tempus Fugit*, en route to ancient Rome. First you fly to the center of the galaxy, where a multimillion-solar-mass black hole rotates at extremely high speed. As you approach the hole, the space-time axes begin to rotate about you. You dive deep, skimming close to the black hole's event horizon. Use caution here! If you accidentally cross the event horizon, you will be sucked into the hole and no one will ever see you again.

Since you are traveling at a high percentage of the speed of light, you fly a million miles in a few seconds before pulling up and away from the hole. After you climb out of the hole's vicinity, you take sightings on some familiar stars. You discover that it is now the year 5 AD. *Voila!!!* Time travel. It’s just that simple.

But do we really need a rotating black hole to drag the time coordinate around to replace one of the space coordinates? Perhaps not. Remember, it is one of humanity's dreams to sail effortlessly through the clouds without the aid of an airplane. To do that requires some sort of antigravity belt. Since gravity is caused by local curvature of the space-time continuum, inventing anti-gravity may give us the means for artificially rotating the space-time continuum’s four axes at will. In that event, we would be getting two marvels: practical antigravity and a time machine, all wrapped up in one neat package.

Some of you are undoubtedly feeling a bit bewildered by this lightning trip through space and time. Let me assure you that everything I have said in this chapter is absolutely orthodox modern physics, at least to the degree that I understand the subject.

Einstein predicted that a rotating mass will drag the coordinates of the space-time continuum around with it and Stanford University is working on proving it. The Gravity Probe B experiment is currently scheduled to be launched into a 660 kilometer (400 mile) high orbit in October, 2000, where it will orbit for 1.6 years while measuring both the curvature of local space and the degree to which the Earth drags the space-time continuum about with it. If Gravity Probe B confirms the frame dragging prediction of the General Theory of Relativity, then time travel is possible. If it proves that there is no such thing, then we will have to scrap the entire structure of modern physics and start over.

Either way, exciting times lay ahead.

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The End

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3. Antares Dawn - US$4.50

When the super giant star Antares exploded in 2512, the human colony on Alta found their pathway to the stars gone, isolating them from the rest of human space for more than a century. Then one day, a powerful warship materialized in the system without warning. Alarmed by the sudden appearance of such a behemoth, the commanders of the Altan Space Navy dispatched one of their most powerful ships to investigate. What ASNS Discovery finds when they finally catch the intruder is a battered hulk manned by a dead crew.

That is disturbing news for the Altans. For the dead battleship could easily have defeated the whole of the Altan navy. If it could find Alta, then so could whomever it was that beat it. Something must be done…

4. Antares Passage - US$4.50

After more than a century of isolation, the paths between stars are again open and the people of Alta in contact with their sister colony on Sandar. The opening of the foldlines has not been the unmixed blessing the Altans had supposed, however.

For the reestablishment of interstellar travel has brought with it news of the Ryall, an alien race whose goal is the extermination of humanity. If they are to avoid defeat at the hands of the aliens, Alta must seek out the military might of Earth. However, to reach Earth requires them to dive into the heart of a supernova.

5. Antares Victory – First Time in Print – US$7.00

After a century of warfare, humanity finally discovered the Achilles heel of the Ryall, their xenophobic reptilian foe. Spica – Alpha Virginis – is the key star system in enemy space. It is the hub through which all Ryall starships must pass, and if humanity can only capture and hold it, they will strangle the Ryall war machine and end their threat to humankind forever.

It all seemed so simple in the computer simulations: Advance by stealth, attack without warning, strike swiftly with overwhelming power. Unfortunately, conquering the Ryall proves the easy part. With the key to victory in hand, Richard and Bethany Drake discover that they must also conquer human nature if they are to bring down the alien foe …

6. Thunderstrike! - US$6.00

The new comet found near Jupiter was an incredible treasure trove of water ice and rock. Immediately, the water-starved Luna Republic and the Sierra Corporation, a leader in asteroid mining, were squabbling over rights to the new resource. However, all thoughts of profit and fame were abandoned when a scientific expedition discovered that the comet's trajectory placed it on a collision course with Earth!

As scientists struggled to find a way to alter the comet's course, world leaders tried desperately to restrain mass panic, and two lovers quarreled over the direction the comet was to take, all Earth waited to see if humanity had any future at all…

7. The Clouds of Saturn - US$4.50

When the sun flared out of control and boiled Earth's oceans, humanity took refuge in a place that few would have predicted. In the greatest migration in history, the entire human race took up residence among the towering clouds and deep clear-air canyons of Saturn's upper atmosphere. Having survived the traitor star, they returned to the all-too-human tradition of internecine strife. The new city-states of Saturn began to resemble those of ancient Greece, with one group of cities taking on the role of militaristic Sparta...

8. The Sails of Tau Ceti – US$4.50

Starhopper was humanity's first interstellar probe. It was designed to search for intelligent life beyond the solar system. Before it could be launched, however, intelligent life found Earth. The discovery of an alien light sail inbound at the edge of the solar system generated considerable excitement in scientific circles. With the interstellar probe nearing completion, it gave scientists the opportunity to launch an expedition to meet the aliens while they were still in space. The second surprise came when *Starhopper's* crew boarded the alien craft. They found beings that, despite their alien physiques, were surprisingly compatible with humans. That two species so similar could have evolved a mere twelve light years from one another seemed too coincidental to be true.

One human being soon discovered that coincidence had nothing to do with it...

9. Gibraltar Earth – First Time in Print — $6.00

It is the 24th Century and humanity is just gaining a toehold out among the stars. Stellar Survey Starship *Magellan* is exploring the New Eden system when they encounter two alien spacecraft. When the encounter is over, the score is one human scout ship and one alien aggressor destroyed. In exploring the wreck of the second alien ship, spacers discover a survivor with a fantastic story.

The alien comes from a million-star Galactic Empire ruled over by a mysterious race known as the Broa. These overlords are the masters of this region of the galaxy and they allow no competitors. This news presents Earth's rulers with a problem. As yet, the Broa are ignorant of humanity's existence. Does the human race retreat to its one small world, quaking in fear that the Broa will eventually discover Earth? Or do they take a more aggressive approach?

Whatever they do, they must do it quickly! Time is running out for the human race…

10. Gibraltar Sun – First Time in Print — $7.00

The expedition to the Crab Nebula has returned to Earth and the news is not good. Out among the stars, a million systems have fallen under Broan domination, the fate awaiting Earth should the Broa ever learn of its existence. The problem would seem to allow but three responses: submit meekly to slavery, fight and risk extermination, or hide and pray the Broa remain ignorant of humankind for at least a few more generations. Are the hairless apes of Sol III finally faced with a problem for which there is no acceptable solution?

While politicians argue, Mark Rykand and Lisa Arden risk everything to spy on the all-powerful enemy that is beginning to wonder at the appearance of mysterious bipeds in their midst…

11. Gridlock and Other Stories - US$4.50

Where would you visit if you invented a time machine, but could not steer it? What if you went out for a six-pack of beer and never came back? If you think nuclear power is dangerous, you should try black holes as an energy source — or even scarier, solar energy! Visit the many worlds of Michael McCollum. I guarantee that you will be surprised!

Non-Fiction Books

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16. The Astrogator's Handbook – Expanded Edition and Deluxe Editions

The Astrogator's Handbook has been very popular on Sci Fi – Arizona. The handbook has star maps that show science fiction writers where the stars are located in space rather than where they are located in Earth's sky. Because of the popularity, we are expanding the handbook to show nine times as much space and more than ten times as many stars. The expanded handbook includes the positions of 3500 stars as viewed from Polaris on 63 maps. This handbook is a useful resource for every science fiction writer and will appeal to anyone with an interest in astronomy.

