The hypertime trap

*Why are physicists both thrilled by the idea of 2D time and fearful of its consequences? **Marcus Chown** investigates*

TIME ain't what it used to be. A hundred years or so ago, we thought that the seconds ticked away predictably. Tick followed tock, followed tick. And clocks ran... well, like clockwork. Then along came Einstein and everything changed.

His theories of relativity dealt a blow to our naive ideas about time. Hitch a ride on a rocket travelling close to the speed of light, and time slows to a virtual standstill. The same happens if you park near a black hole and feel its awesome gravity. Even worse, space-time becomes so warped inside a black hole that space and time actually switch places.

Now just as we're getting to grips with time's weirdness, one daring physicist has dropped another bombshell. "There isn't just one dimension of time," says Itzhak Bars of the University of Southern California in Los Angeles. "There are two. One whole dimension has until now gone entirely unnoticed by us."

Does this mean we can look forward to extra hours and seconds? Or will time's second dimension play havoc with our notions of the past, present and future? Or is Bars, in fact, a few quarks short of a proton? One thing Bars's extra time dimension does appear to reveal is the existence of deep and unexpected connections between disparate systems, such as atoms and the expanding universe. Such connections could point the way to a "theory of everything" that unites all the physical laws of the universe into one. Even better, Bars claims his theory has true predictive power and can be tested in upcoming particle physics experiments.

Physicists are no strangers to extra dimensions. For decades, theorists attempting to unify the forces of nature have been adding extra dimensions of space to their equations. As early as the 1920s, mathematicians found that moving up to four dimensions of space, instead of the three we experience, helped in their quest to reconcile electromagnetism and gravity. Later, in the 1980s, came various superstring theories, which describe the universe in terms of tiny one-dimensional strings vibrating against a backdrop of nine space dimensions, six of which are curled up so tightly we cannot see them. A decade or so on, theorists recognised the assorted string theories as different facets of a single idea called M-theory that adds yet another dimension, taking the total to 11: 10 of space and one of time.

Double time

Meddling with space, at least, is fair game. So how come so few have dared to tinker with time? There are two good reasons why adding extra time dimensions makes theorists queasy. For a start, when you insert time into your equations it tends to come with a negative rather than a positive sign. A second time dimension only makes this problem more severe and leads to events happening with a negative probability, a concept which is meaningless, says Bars.

Worse, it gives the green light to the idea of time travel. If time is one-dimensional, like a straight line, the route linking the past, present and future is clearly defined. Adding another dimension transforms time into a two-dimensional plane, like a flat sheet of paper. On such a plane, the path between the past and future would loop back on itself, allowing you to travel back and forwards in time (see Diagram, page 39). That would permit all kinds of absurd situations, such as the famous grandfather paradox. In this scenario, you could go back and kill your grandfather before your mother was a twinkle in his eye, thereby preventing your own birth.

Two-dimensional time gives every appearance of being a non-starter. Yet when Bars found hints of an extra time dimension in M-theory in 1995, he was determined to take a closer look. When he did, Bars found that a key mathematical structure common to all 11 dimensions remained intact when he added an extra dimension. "On one condition," says Bars. "The extra dimension had to be time-like."

Of course, Bars knew all about the horrors that emerge when you start to mess around with time. Undeterred, he wondered if negative probability and time travel would disappear if movement in the new space-time was severely constrained. But what kind of constraint? Bars guessed it had to be a hitherto unsuspected symmetry of nature.

Symmetry concerns the properties of objects that stay the same even when you do something to them – a cube looks the same no matter which face you view. And symmetry applies to the laws of physics too. So if you conduct an experiment it makes no difference to the results whether your laboratory is ▶

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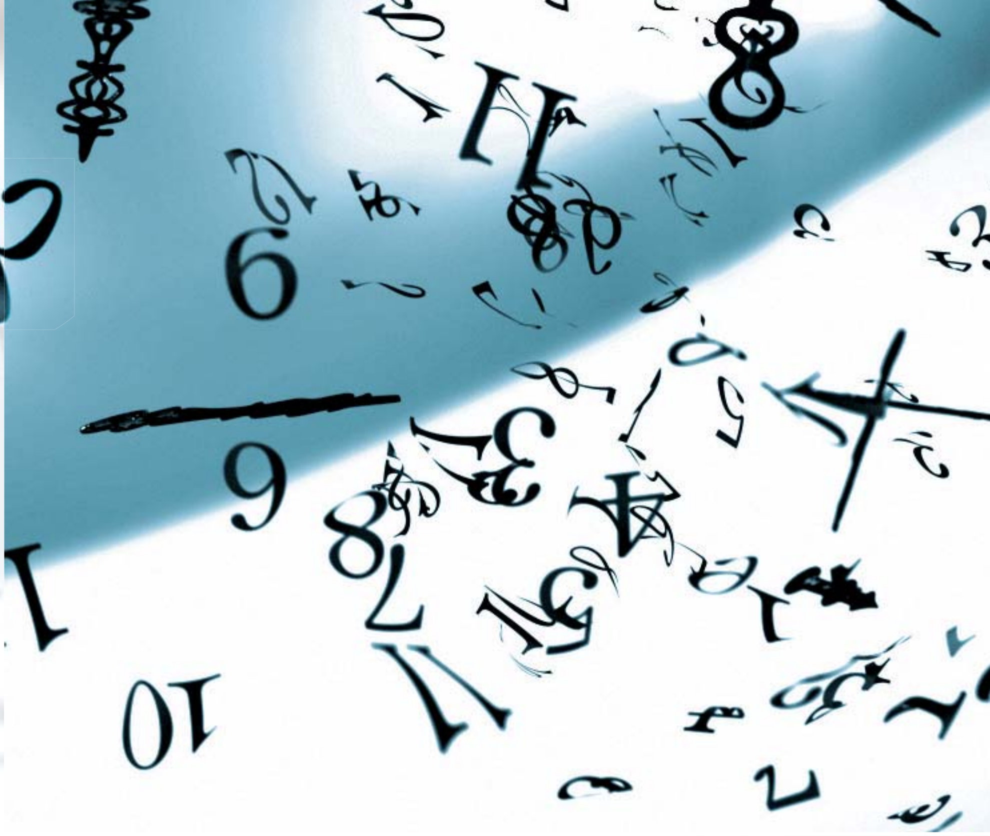


standing still, being carried along in the train or being whirled round on a fairground ride.

This connection between physics and symmetry was first recognised by the German mathematician Emmy Noether. In a remarkable paper published in 1918, she showed that many of the fundamental conservation laws of physics are nothing more than consequences of underlying symmetries. For instance, the law of conservation of energy – that energy cannot be created or destroyed, merely transformed from one form into another – is a consequence of "time translational symmetry", the fact that if you do an experiment today or tomorrow or next month, you will get the same result, all things being equal. Both general relativity and the standard model of particle physics are based on symmetries that hold independently at every point of space and time, so-called "gauge symmetries".

Noether's powerful insight was a powerful driving force behind modern fundamental physics, which is constantly looking for the deep and simple symmetries that spawn the complex phenomena we observe in the universe. Bars wondered whether an unsuspected gauge symmetry would make sense of an extra time dimension. And, in 1995, he began looking for one.

The clue came from quantum theory. Quantum uncertainty limits how well you can ever know certain properties of a physical system. Pin down the position of an atom and you can never measure its momentum, and vice versa. Bars wondered whether this result hints of a deeper relationship between position and momentum. Could there be an underlying symmetry between the two?

Living in a shadow

Two things happened when Bars tried to enforce such a gauge symmetry. First, he discovered that it didn't work unless there were two extra dimensions, one of space and one of time. According to his theory, then, we live in a world with six dimensions. (Or, if you extend M-theory, 13 dimensions.)

On the face of it, this does not solve the time-travel problem. However, Bars found that gauge symmetry is a very tight straitjacket indeed. "Phenomena in the six-dimensional world have very little room to manoeuvre," he says. This restriction on motion in six dimensions makes it impossible to climb into time's second dimension and travel through it back to the past. It also irons out those messy negative probabilities. "To all intents and purposes, the six-dimensional world behaves like a far more restricted world, one with only four dimensions," says Bars.

"Unrelated phenomena are shadows of the same six-dimensional reality"

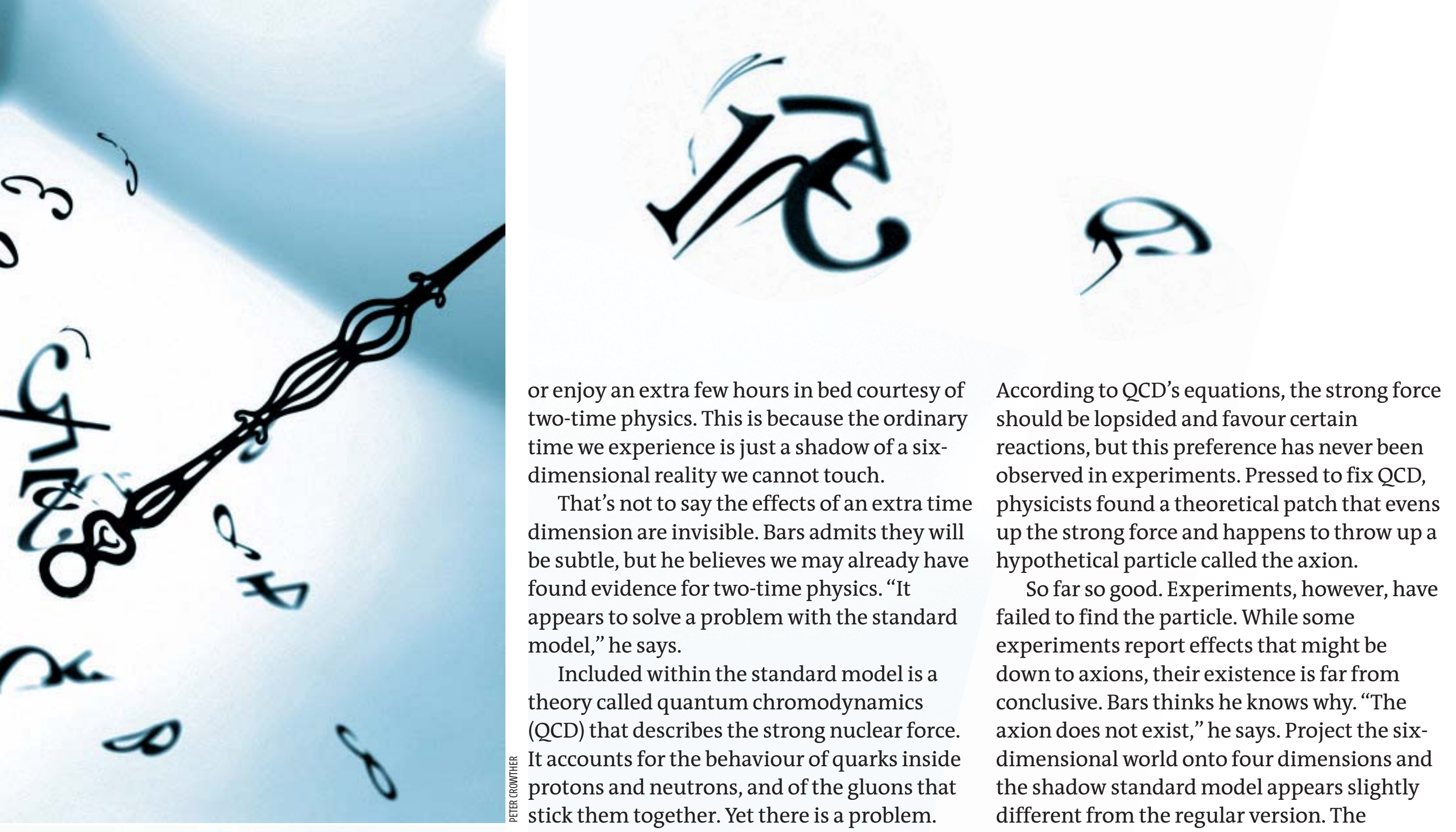
Except that it's not exactly like the four-dimensional world we inhabit, or there would be nothing new to write home about. It is here, Bars points out, that the big pay-off lies. "The severely restricted motions in higher-dimensional space-time reproduce the usual laws of motion in familiar space-time," says Bars, "but they also reveal new and unexpected relationships."

According to Bars, the world we see around us is merely a "shadow" of a six-dimensional world. Think of a 3D object like your hand and the 2D shadow it makes on a wall. Just as there are many different possible shadows of your hand depending on where the light source is located, there are many possible four-dimensional shadows of the six-dimensional world. "Each gives rise to a different set of phenomena in our world," he says.

Bars began exploring the simplest possible system in six dimensions, a particle moving in a straight line with no forces acting on it. Remarkably, he found that the system has at least two more complex shadows in four dimensions. One corresponds to an electron orbiting in an atom; the other is a particle in an expanding universe. "Although these phenomena seem unconnected, my picture unifies them," says Bars. "They are both shadows of the same six-dimensional reality."

Because "two-time" physics, as Bars likes to call it, unites seemingly unconnected phenomena, might it be able to reconcile the two mighty pillars of 20th-century physics, quantum mechanics and relativity?

Bars realised that his economical descriptions of hitherto unconnected phenomena are worth nothing unless they predict something new. Recently, he has been



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incorporating two-time physics into quantum field theory, which explains all the fundamental forces of nature within the framework of the standard model – except for that tricky beast gravity.

Last year, he published a paper in *Physical Review D* (vol 74, p 085019) showing that the standard model is in fact just one shadow of his six-dimensional theory. According to Bars, there are other shadows that include gravity, finally uniting it with the standard model.

So far, few physicists have pursued Bars's idea because previous attempts by others to introduce extra time dimensions have raised more questions than they have solved. Among them is the physical reality of the new dimension: is it on the same footing as time as we know it? Many physicists are comfortable with an extra time dimension as a mathematical concept but not as a real physical entity. "Stephen Hawking and others have used 'imaginary time' in calculations involving Einstein's general theory of relativity," says John Cramer of the University of Washington at Seattle. "I believe this is just a calculational device for sweeping certain things under the rug."

Bars insists his extra dimensions are more than mathematical sleight of hand. "Absolutely not," he says. "These extra dimensions are out there, as real as the three dimensions of space and one of time we experience directly."

Sadly, we will never experience a second time dimension in the way we experience ordinary time. For instance, we'll never be able to build a clock that records this second time, or enjoy an extra few hours in bed courtesy of two-time physics. This is because the ordinary time we experience is just a shadow of a six-dimensional reality we cannot touch.

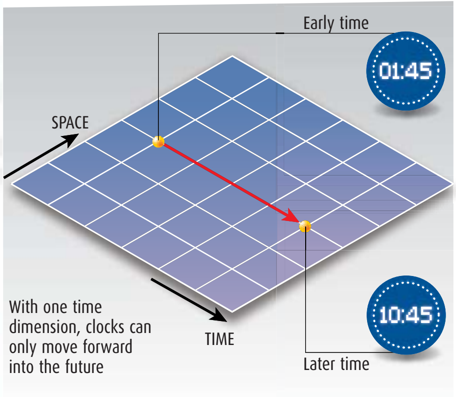
That's not to say the effects of an extra time dimension are invisible. Bars admits they will be subtle, but he believes we may already have found evidence for two-time physics. "It appears to solve a problem with the standard model," he says.

Included within the standard model is a theory called quantum chromodynamics (QCD) that describes the strong nuclear force. It accounts for the behaviour of quarks inside protons and neutrons, and of the gluons that stick them together. Yet there is a problem.

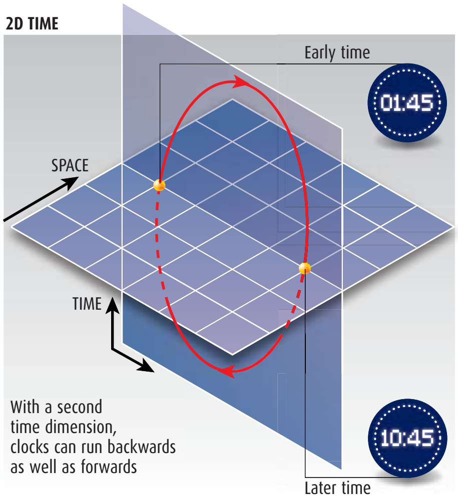
THE TROUBLE WITH 2D TIME

Attempts to add extra time dimensions usually run aground because they permit time travel

CONVENTIONAL SPACE-TIME



2D TIME



According to QCD's equations, the strong force should be lopsided and favour certain reactions, but this preference has never been observed in experiments. Pressed to fix QCD, physicists found a theoretical patch that evens up the strong force and happens to throw up a hypothetical particle called the axion.

So far so good. Experiments, however, have failed to find the particle. While some experiments report effects that might be down to axions, their existence is far from conclusive. Bars thinks he knows why. "The axion does not exist," he says. Project the six-dimensional world onto four dimensions and the shadow standard model appears slightly different from the regular version. The lopsidedness disappears and there simply is no need for the axion in two-time physics. Search as they might, experimentalists will never find it, he claims.

The axion's no-show is not enough to verify two-time physics. "The real test of such a theory is whether it makes experimentally testable predictions," says Cramer.

Bars's latest work does exactly this. He has applied two-time physics to supersymmetry, a model that says every particle in the standard model has a heavier, hitherto unseen "superpartner". Supersymmetric particles are expected to be produced in collisions at CERN's Large Hadron Collider near Geneva, Switzerland, which is due to start up next year. "Bars suggests his approach will place different constraints on the supersymmetric particles than will other theories," says Cramer.

Bars, however, is confident that now that he has embedded six-dimensional physics in quantum field theory he will find many other places where it differs in its predictions from four-dimensional physics. "This is only the beginning," he says. "I expect to get a lot more interest from other physicists soon."

It's a cliché, but time really will tell if he is right. ●

Further Reading: "The standard model of particles and forces in 2-T physics" by Itzhak Bars, *Physical Review Letters D*, vol 74, p 085019