Time on trial

If you want to understand the universe be prepared to get your moments in a muddle, advises **Michael Brooks**

LEE SMOLIN wants to save your time. He is not a lifestyle guru offering handy tips on managing a diary, though: he is a physicist who works at the Perimeter Institute for Theoretical Physics in Ontario, Canada. Many of his colleagues, he says, are planning to rid the universe of the common-sense notion that time passes. Smolin is having none of it.

Physicists have become increasingly argumentative about what exactly time is. because this is now being recognised as perhaps the most fundamental question of all. For decades they have been attempting to wed quantum mechanics, our theory of how very small things behave, to relativity, our theory of how space, time and matter interact. This would give us the long-sought-after theory of quantum gravity that describes the entire universe.

Constructing this theory has been an uphill struggle, though, because it is unclear how time fits within it. "There are very different notions of time in general relativity and quantum theory," Smolin says. "It's pretty clear that the nature of time is the key issue."

Last month, Smolin and other theorists, along with mathematicians and philosophers, got together at the Perimeter Institute to thrash out time's problems. So complex is the issue that everyone involved seems to have a different idea. It turns out that if you want to understand time, you might need to grab some measurements from the future, watch a big bang explode at the edge of the universe, or delve into the anomalies presented by the most unruly of the subatomic particles. For some, the only solution is to scrap the notion of time altogether.

Scientists have long worried about the nature of time. At the beginning of the 18th century, Isaac Newton and Gottfried Leibniz argued over whether time was truly fundamental to the universe. Then Einstein came along and created more problems: his general theory of relativity is responsible for our most counter-intuitive notions of time.

General relativity knits together space, time and gravity. Confounding all common sense, how time passes in Einstein's universe depends on what you are doing and where you are. Clocks run faster when the pull of gravity is weaker, so if you live up a skyscraper you age ever so slightly faster than you would if you lived on the ground floor, where Earth's gravitational tug is stronger. "General relativity completely changed our understanding of time," says Carlo Rovelli, a theoretical physicist at the University of the Mediterranean in Marseille, France.

> "Some physicists believe we should think the unthinkable and abolish time altogether"

At the other extreme there is the quantum world, where time seems to be almost irrelevant. "Quantum theory doesn't really allow for measurements of time," says Aephraim Steinberg of the University of Toronto in Canada. "Asking how long a particle is in a certain region of space turns out to be something that, in quantum theory, may have hundreds – or an infinite number – of different answers."

This contradiction in general relativity's and quantum theory's description of time is the fundamental sticking point for a single theory that describes the entire universe. How to reconcile the two descriptions of time continues to stump the world's best minds. There is no shortage of ideas, though, with some believing we could make better progress towards a quantum theory of gravity if we think the unthinkable and abolish time altogether. "The solution of the present difficulties about time is just to forget about it," says Rovelli.

His approach at least has the merit of simplicity. Instead of describing how things evolve in time, we should describe only how physical things relate to one another, Rovelli says. So rather than thinking that a pendulum oscillates with time and the hand of a clock moves in time, we would do better to consider the relationship between the position of the pendulum and the position of the hand.

In Rovelli's scheme, a clock's hands do not point upright because the universe says it is 12 o'clock; they point upright because of the location of the pendulum. Therefore the notion of time is meaningful only in a small range of physical situations in the universe, such as human experience. In most cases, however, time is meaningless. "In general, there is no time at all," Rovelli says.

Though this approach might seem radical, many researchers share Rovelli's sentiments. For example, Harvey Brown, an expert on scientific interpretations of reality from ▶

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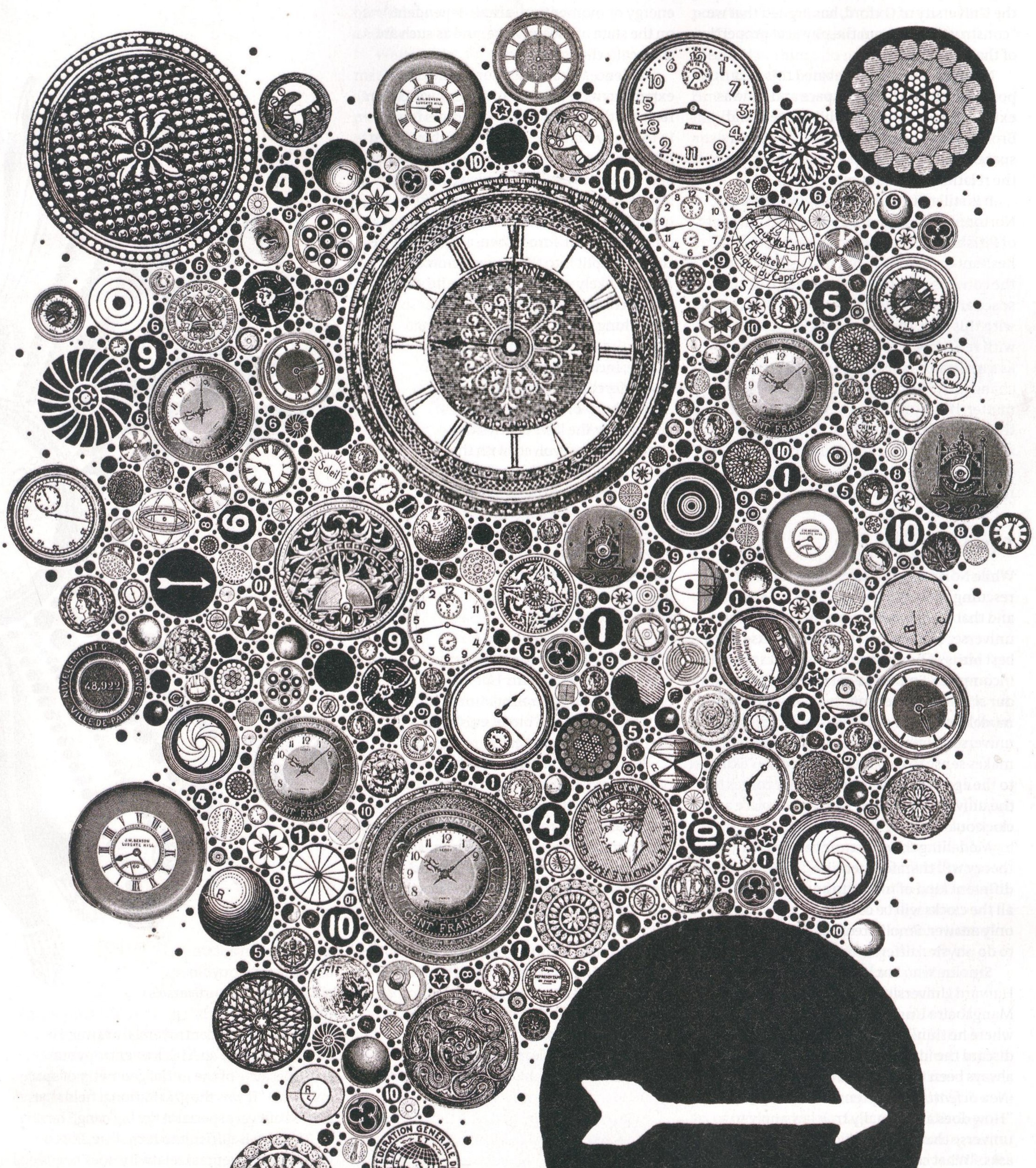


the University of Oxford, has argued that we "construct" time from the physical properties of the things around us.

Newton and Leibniz debated this very point. Newton portrayed space and time as existing independently, while Rovelli and Brown share Leibniz's view that time and space exist only as properties of things and the relationships between them.

It is still not clear who is right, says John Norton, a philosopher based at the University of Pittsburgh, Pennsylvania. Norton is hesitant to express it, but his instinct – and the consensus in physics – seems to be that space and time exist on their own. The trouble with this idea, though, is that it doesn't sit well with relativity, which describes space-time as a malleable fabric whose geometry can be changed by the gravity of stars, planets and matter. If the central property of space-time is the result of the existence of matter, how can we be sure that space and time exist on their own and are not convenient illusions? "Hence my hesitation," Norton says.

Time keepers

While Norton hesitates, Smolin is intent on rescuing time. He believes time has to be real and that it is a fundamental property of the universe. The confusion arises because our best ideas of how the universe works are still incomplete, Smolin says. He points out that our scientific experiments and mathematical models only ever deal with a subsection of the universe. Timing a boiled egg, for example, makes sense to us because the clock is external to the egg-boiling system. When it comes to the universe, however, you cannot place a clock outside it.

Modelling the entire universe in a single theory will therefore require a fundamentally different kind of model to any other because all the clocks will be contained within it. The only answer, Smolin reckons, is that we have to do physics differently.

Smolin, who has been working with Harvard University philosopher Roberto Mangabeira Unger on this topic, has a feel for where he thinks we should go. He wants to discard the idea that the laws of physics have always been true and will remain true forever (*New Scientist*, 23 September 2006, p 30). "How does an eternally true law apply to a universe that began only a short time ago?" he asks. "What could it possibly mean to say that the laws of physics are eternally true if the universe they apply to is less than 14 billion years old?"

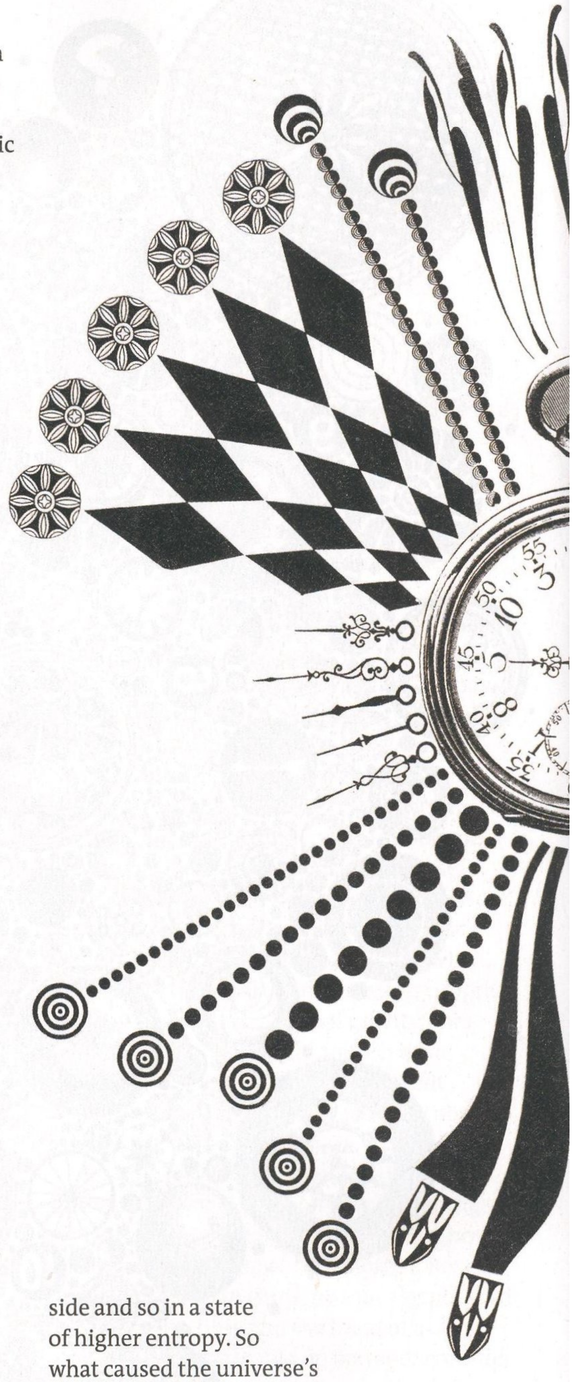
Instead, space and the laws of physics must emerge as the universe unfolds, he says. The properties of fundamental particles and forces, even the idea of the conservation of energy or momentum, are all dependent on the state of the universe, and as such are subject to change.

Evidence to back this view comes from experiments at particle smashers, which can recreate the energy per unit volume found in the early universe. These have shown that interactions governed by the electromagnetic and so-called "weak" forces have not always been the same. In the universe's early moments, the two forces were rolled into one electroweak force. Then, as the universe cooled, it split into the two we know today. And it is likely – if attempts to unite all the forces of nature into a theory of everything are on the right lines – that this is also true of the other forces in nature, including gravity and the strong force inside atomic nuclei.

In other words, there is no reason why the laws of physics could not have evolved, with the only fundamental element being time. "Space could be emergent, matter could be emergent, particles and fields can be emergent, but I don't believe there's a fundamental description of nature without time," Smolin says.

Roger Penrose, a mathematician at the University of Oxford, is not so sure. He occupies a middle ground: time, he says, pops in and out of existence as the universe matures.

Penrose's suggestion arises from one of the most persuasive observations on time, made by the Austrian physicist Ludwig Boltzmann. Boltzmann identified that the reason time has an "arrow" pointing from the past to the future lies in the second law of thermodynamics, which states that the entropy, or disorder, of the universe is always increasing.



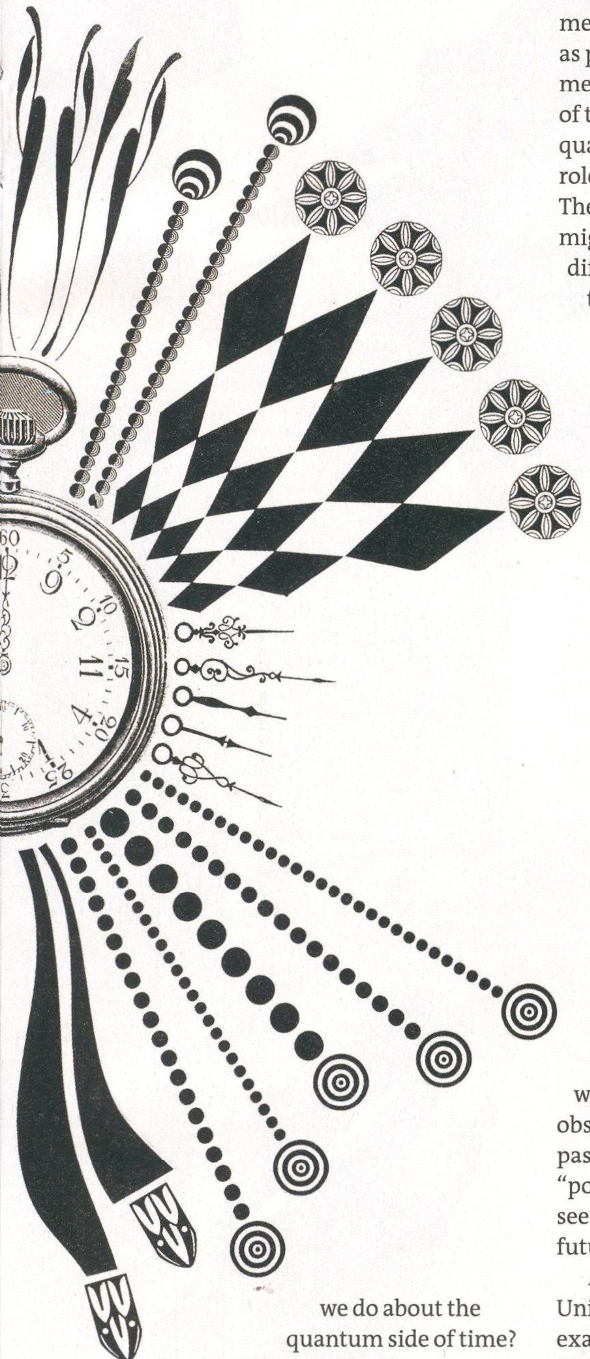
Boltzmann's arrow of time presents a conundrum because it means that the universe must have started out in its most orderly state and has been getting messier ever since. Such low-entropy states are very special: for example a pencil balanced on its point will inevitably end up lying on its side and so in a state of higher entropy. So what caused the universe's initial specialness?

> "How can we be sure that time and space exist on their own and are not convenient illusions?"

Penrose has a controversial answer. He believes that the special, low-entropy state arose because of the initial geometry of space and time. "It was the gravitational field that started out very special at the big bang," he says.

The idea is difficult to formalise, Penrose says, because general relativity does not provide a clear measure of the entropy of a gravitational field. But he believes there are good reasons to see the suggestion as plausible, including the way that black holes and the geometry of the universe evolve.

If time does indeed exist, then it brings us back to the other part of the problem. What do



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we do about the quantum side of time? This question also has a strong pedigree. In the 1930s, the mathematical genius John von Neumann tried to use Boltzmann's ideas to construct a quantum arrow of time. He failed – as has everyone who has tried it since.

That doesn't surprise Steinberg, whose work with quantum systems has left him convinced that we are missing a fundamental idea of what time is. To illustrate the point, Steinberg considers a quantum-mechanical process called tunnelling, which allows particles such as photons to burrow through barriers they don't have enough energy to get over. Steinberg asks a simple question: how long does the particle take to cross the barrier? It was first asked in the 1930s, and the answer remains elusive.

While quantum experiments happily measure certain properties of particles, such as position, momentum or spin, they do not measure how the particles mark the passage of time. "In the standard formulation of quantum mechanics, time doesn't play the role of an 'observable' at all," Steinberg says. There are a variety of subtle experiments that might elicit an answer, but so far they all give different results – sometimes hundreds of them, Steinberg says.

Another problem with quantum ideas of time is that particles such as electrons and photons are not bound by the same arrow of time that we are. Instead, the quantum state that describes them evolves both forwards and backwards in time. It is an issue that Lev Vaidman of Tel Aviv University in Israel thinks we have to resolve before we can build a theory of quantum gravity. Our descriptions of the universe, he says, are incomplete if we do not have information from the future. "The past does not describe completely the present state of the world," Vaidman says. "Results of future measurements add new information about the present."

It might sound ridiculous that information from future measurements affects the present. However, quantum researchers are learning to perform experiments with photons and electrons where the observations made affect the nature of their past. Physicists call this strange phenomenon "post-selection", and it shows how we can see the information that leaks back from the future (*New Scientist*, 30 June 2007, p 30).

According to Joan Vaccaro of Griffith University in Queensland, Australia, it is exactly this kind of consideration that might finally give us the answer to one of the most fundamental human questions: why, when quantum particles have it both ways, do we perceive time as running only forwards?

Vaccaro reckons the key to understanding time might lie in a 40-year-old anomaly that centres on the time-travelling properties of particles called neutral kaons. These long-lived particles are peculiar because two of their properties, known as charge and parity, violate an otherwise well-respected conservation law. Known as CP invariance, it says that particles will look the same if you reverse their charge and exchange left for right, up for down. Yet physicists have found that neutral kaons decay in ways that are only possible if they flout CP invariance.

CP violation has a wider implication. It means that things do not run the same for neutral kaons if you reverse the direction of time, whereas nearly all other particles are indifferent to the direction of time. In her analysis of this scenario, Vaccaro has found that a "present" quantum state of a neutral kaon is a billion times more similar to its future quantum state than its past quantum state. This means the present state is more likely to evolve into the future than the past.

> **"Experiments show how we can see information that leaks back from the future"**

"The overall effect is like a random walk with a strong bias in one direction," Vaccaro says. "We may sometimes step backwards, but on average we are moving forwards in time."

Such a violation could yield significant effects, Vaccaro reckons – effects like a universe that moves in only one direction in time. "The universe as a whole violates CP invariance because the neutral kaons it contains do," she says. "If the universe is more likely to be in the future state, then so are we, because we are part of it."

It is just an idea, and it is hard to see how you would test it in an experiment. But, like all the cutting-edge ideas on time, it shows we are learning how to approach this most baffling of tasks. Perhaps, if we knew which direction to reach in, we would find the ultimate theory of time is only just beyond our fingertips.

Surprisingly, there is one option that no one seems to be considering. We have long known that relativity allows travel through time: astronauts travelling fast enough, for example, would actually move into Earth's future. So perhaps the easiest way to find the secrets of time would be to build a fast enough rocket and blast off to see how future generations of physicists did it. Maybe, in an act of temporal espionage, we could bring the answers back for Smolin and his colleagues to examine. Now that really would save time. ●

Michael Brooks is author of *13 Things That Don't Make Sense* (Profile/Doubleday)