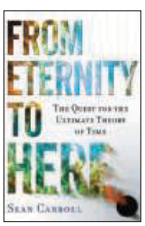
Time ain't what it used to be

Why does time only move forward? **Craig Callender** wonders how far we should go to find out

From Eternity to Here: The quest for the ultimate theory of time by Sean Carroll, Dutton, $26.95



IN 1516, Mark Anthony Zimara hit upon the ultimate idea in renewable energy. Instead of merely using windmills to generate energy, he suggested employing them to power bellows to blow air… back at the windmills! The self-blowing windmill, he thought, would run forever.

Zimara's machine failed, of course. The laws of thermodynamics put the kibosh on perpetual motion machines. No matter how cleverly designed, they will eventually grind to a halt without ever producing the desired free work.

This is due to an all-pervasive macroscopic temporal asymmetry: entropy, a measure inversely related to the energy available for work, increases with time. That is why ice melts and gases expand, and never the reverse. Arguably it is also the reason why you can know yesterday's stock market results but not tomorrow's.

Where does this arrow of time come from? After all, macroscopic objects are composed of microscopic particles, and the laws governing these are allegedly time symmetric. The particles can execute anti-thermodynamic behaviour just as easily as thermodynamic behaviour, so how do those comprising air, windmills and the rest "know" to execute a trajectory of increasing entropy? It seems downright conspiratorial.

Sean Carroll's goal in *From Eternity to Here* is to explain this puzzle. While it covers much of the same ground as Brian Greene's *The Fabric of the Cosmos* (curved space-time, black holes) and is aimed at the same audience, Carroll's book is distinctive in two ways: it devotes more attention to the mystery of the direction of time and it offers a speculative solution. The middle of the book is perhaps the best

"The mystery is not why entropy increases with time, but why it was lower in the early universe"

and most comprehensive discussion of time's arrow that is widely accessible. Carroll explains time's fascinating subtleties in a lucid and entertaining manner.

The standard explanation for why entropy increases is that high entropy microscopic configurations are far more likely than low entropy ones. There are vastly more ways for gas molecules to be spread out in a room than to be condensed in the corner, for example, just as there are many more poker hands with only one pair than two pairs.

The trouble is this explanation works in both directions of time: entropy is highly likely to increase towards the future and the past – the latter contrary to thermodynamics. The mystery, then, is not why entropy increases with time, but why it was lower in the past. The accepted solution is to simply say that the universe just happened to begin in a state of very low entropy. It seems innocuous enough: the low entropy posit accords with cosmological observations and is a simple add-on to the laws of physics.

Carroll, however, is unsatisfied. He finds the low entropy posit

Sean Carroll answers readers' questions about time

Is time a real phenomenon or a human perception?
cathal76
Time is real! That's my position, anyway.

More specifically, time isn't real in the same way that a basketball is "real" – it's not something you can poke at or hold in your hands. Instead, we should say that time – like space and quarks – is "real" if it is a useful concept in our best understanding of how the universe works. And that's certainly true. In every theory that we have – Newtonian mechanics, relativity and quantum mechanics – time plays a central role. That's not to say a better theory won't come along where time isn't fundamental, but even then, that theory will have to show how time emerges to play such an important role in how we perceive the world.

Is time digital or analogue?
Kingsley
The short answer is we're not sure. The slightly longer answer would add "… but it's probably analogue".

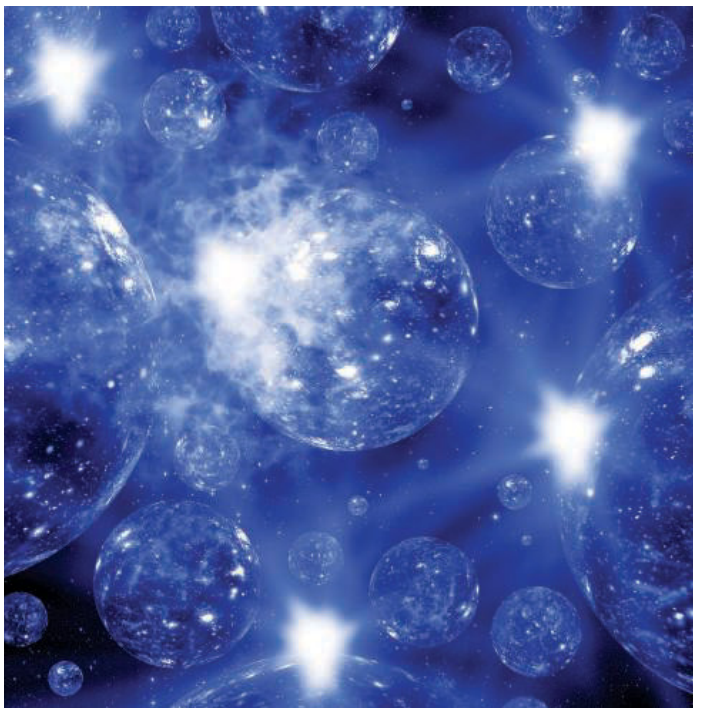
Time is certainly analogue (continuous and smooth) according to the measurements we can do with present-day technology. Quantum mechanics and general relativity both feature a perfectly continuous notion of time. However, it's possible that an eventual reconciliation of the two will result in time becoming digital.

If we started to fall into a black hole, would we notice that time was moving more slowly?
Mark B
The issue here is one of human perception, not of physics. We perceive time to move because we come equipped with clocks in our bodies – our heartbeat, breathing and pulses in the central nervous system. We would only ever perceive time to slow down or speed up if those biological clocks became out of sync with mechanical clocks. But a physical phenomenon like falling into a black hole affects all types of clocks in the same way. So rather than thinking of time as speeding up or slowing down, it's better to compare the amount of time elapsed on different clocks that travel through different paths in space-time.

Does time exist in an empty universe?
Richard Kenno
The simple answer is yes, time would exist, just as space does. It would be governed by relativity.

However, the arrow of time – the flow of entropy that determines which direction is the past and which is the future – would not exist in a truly empty universe.

For more of Sean Carroll's answers to readers' questions, visit: newscientist.com/blogs/culturelab



MEHAU KULYK/SPL

In an infinite multiverse, individual arrows of time are bound to arise

"unnatural" – after all, low entropy states are highly unlikely – and heads off in search of an explanation. Daring to speculate in the absence of well-confirmed theory, Carroll jumps from clue to clue, from black hole physics to string theory to the holographic principle, until he arrives at his destination: an eternal "mother space-time" from which a multiverse of baby universes are continually bubbling up and pinching off. The mother space-time is a high entropy vacuum that gives birth to universes like our own, some of which we can expect to begin with low entropy. Problem solved, says Carroll, because that is natural.

Carroll seems slightly embarrassed by the many leaps of faith he asks of his reader in proposing this solution, and the prose of Part IV sometimes reads like the pitch of an honest used-car salesman: "This car is a dream! True, the tyres are bald, brakes unsound and transmission sticky, but you'll love it!"

Carroll and other peddlers of multiverses make us an offer: we will explain the unexplained if you add vast unconfirmable matters of fact into your ontology. In this case that includes a host of disconnected baby universes, an eternal mother universe entirely unlike ours, and half a dozen unknown mechanisms to get all this working. Assuming this explains the low entropy past – and with so much unknown it is hard to be sure another conspiracy isn't lurking within – is this a good deal?

In most cases I don't think so. Why is Manchester United perennially a good soccer team? Surely most solutions of the laws of physics don't have them winning so much. How unnatural (and unfair) those initial conditions are! Nonetheless, a frothy sea of baby universes tempts no one. We shrug and say, that's just the way it is. Sometimes it is best not to scratch explanatory itches. ■

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Scary thoughts

Extreme Fear: The science of your mind in danger by Jeff Wise, Palgrave Macmillan, £16.99/$27

Reviewed by Alison Motluk

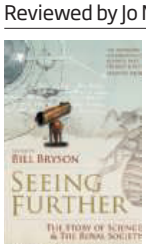
CAN understanding how fear works make it easier to manage? Jeff Wise, an outdoor adventurer and science writer, believes it can. He uses stories of real people – like Sue Yellowtail, who found herself alone with a hungry mountain lion, and Ian Thomas, who defended his house against a raging forest fire – to explore how we react to terrifying situations. Juxtaposed with these tales are explanations of what is going on in our brains and bodies when we are afraid.

Wise is a good writer and his anecdotes are arresting, if a bit cursory. His blurring of the line between "fear" and "stress" is unfortunate, but overall his message is hopeful: fear can be tamed, whether by skill or habituation. It doesn't always work that way, though. Wannabe scuba divers who are naturally anxious should accept that reality and keep their heads above water.

The smart set

Seeing Further: The story of science and the Royal Society edited by Bill Bryson, HarperPress, £25

Reviewed by Jo Marchant



ONE wet evening in November 1660, a small group of scholarly gentlemen founded a society "to assist and promote the accumulation of useful knowledge". This lavish volume reflects on the 350 years of intellectual adventures that ensued, from the problems that concerned the Royal Society's early members, such as lightning rods and ballooning, to those that exercise its fellows today.

As well as big-name writers there are unexpected gems, notably Margaret Wertheim's discussion of how cosmology leaves no room for a concept of self, and Oliver Morton's plea for us to stop seeing Earth as a fragile blue drop and instead view it as a dynamic system of cycles and flows. In his colourful introduction, Bill Bryson says what impresses him about the society is the "boundlessness of its range". This book fully lives up to that description.

Intrigue in Paris

The Coral Thief by Rebecca Stott, Weidenfeld & Nicolson, £14.99/$25

Reviewed by Andrew Robinson

WHEN Charles Darwin studied at the University of Edinburgh in the 1820s, one of his professors, Robert Jameson, firmly believed in the fixity of species, while another was a closet follower of transmutation, Lamarck's revolutionary theory of how one species can change into another.

This intellectual debate drives the new novel by science historian Rebecca Stott. Set in the turbulent Paris of 1815 after the fall of Napoleon – whose deportation punctuates the narrative – the protagonist is a student of Jameson's who is dispatched to the city to study with the great Georges Cuvier, a fierce critic of transmutation. En route, his papers and specimens, including fossil corals, are stolen by a mysterious female transmutationist, who eventually embroils him in underworld dealings, ending in a shoot-out in the quarries beneath Paris. An enjoyable, atmospheric and carefully researched yarn.