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PHYSICS

The time lord and fellow travellers

As television's time-bending *Doctor Who* turns 50, **Andrew Jaffe** explores time travel in fiction and science.

In 1963, an extraterrestrial burst from his time machine and onto British television screens to the strains of a deliciously eerie electronic theme tune, courtesy of the BBC's pioneering Radiophonic Workshop. *Doctor Who* was born. The series' doughty and eccentric time lord has been zipping from past to future ever since in his TARDIS (Time and Relative Dimension in Space). Regenerated 11 times by new actors — including the latest, Peter Capaldi — the Doctor is going stronger than ever since the show's 2005 reboot.

Generations of fans in numerous countries have fallen for his world-saving, time-hopping antics. But in much science fiction the possibilities of time travel are taken more seriously: its creators try to build a coherent set of rules. Because once you allow the capacity to change past or future, in the real world or in fiction, anything seems possible. For more than a century, time travel has been a rich vein for science-fiction writers and even some scientists — especially those willing to travel farthest from the known laws of physics.

Robert Heinlein's short story "—All You Zombies—" is noted for its rigorous internal logic: all the main characters are the same individual at different times in his/her subjective life. The character travels back and forth through time, changing sex and becoming both of his own parents. In a sense, the story is completely self-consistent: cause and effect seem to be preserved, from the protagonist's point of view; life progresses, albeit with science-fictional sex changes and time travel. But something — that is, someone — has been created from nothing, seemingly violating the local laws of physics (and biology).

Amazingly, this kind of time travel is not obviously forbidden by the laws of physics on a global scale. Einstein's general theory of relativity allows 'closed timelike curves' in which a particle can travel back to the same space-time event at which it began. Travelling along such a curve, everything seems fine. But to other observers, something or someone seems just to pop into and out of existence.

This makes physicists very uncomfortable, so theoretical physicist Igor Novikov and collaborators proposed a 'self-consistency principle' in which time travel is possible. Such a trip must be free of paradoxes, and have a single, coherent four-dimensional view of space and time: travel into the past can happen only if it occurred in the Universe's past! Mathematically, we would lose the ability to make predictions in such a Universe, or parts of it: we don't have enough information about the future to know whether a time traveller will emerge in the present. (This also makes physicists very uncomfortable.)

The US television series *Lost* codified the self-consistency

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For Graham Farmelo on Albert Einstein, see:
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principle as 'Whatever Happened, Happened': even an atomic bomb exploded by the castaways cannot change the past and bring them home. The 1995 film *12 Monkeys* (or its 1962 progenitor *La Jetée*) similarly plays with the chronology of a single event: a character sees himself release an apocalyptic virus and usher in the very future he was sent back in time to prevent.

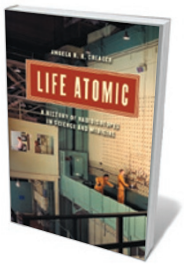
But maybe time travel can occur in other ways; perhaps it is possible to change the past after all. The *Star Trek* episode 'City on the Edge of Forever' has Dr McCoy travelling back in time to Depression-era America. There he saves the life of a woman, thus changing the future so that the *Enterprise* is never built. So Kirk and Spock travel back in time and change the past, to save the present, at the price of annihilating the woman with whom Kirk has fallen in love.

In Charles Stross's 2009 sci-fi novella *Palimpsests* (much influenced by Isaac Asimov's *The End of Eternity* and 1930s sci-fi pioneer Olaf Stapledon's grander cosmic visions), each intervention in the past revises present and future. In this scenario, when you kill your ancestor, the Universe becomes one in which you were never born. So you never went back in time, so you didn't kill your ancestor, so you were born, so you were able to travel through time, so you did kill your ancestor, so … . Stross makes a virtue of this: the initiation into his Stasis, a sort of universal time-police, is to go back and kill your own grandfather.

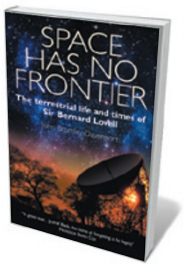
The other change-the-past trope is to make today's world a better place by getting rid of some of its more evil past denizens — Desmond Warzel's short story *Wikihistory* (go.nature.com/txib8y) is the funniest version of this I've seen: newbie time travellers keep killing Hitler, so the gurus have to go back and fix the past each time. Or perhaps each intervention cleaves off a new Universe, as in the so-called many-worlds interpretation of quantum mechanics (itself a rich source of scientific and science-fictional ideas, as discussed previously in these pages; go.nature.com/f3oz9w). Indeed, it seems that understanding the possible (or impossible) physics of time travel will require a full understanding of the 'theory of everything', marrying general relativity and quantum mechanics.

In any scenario, it seems impossible to have time travel without paradoxes or violations of physical laws. So some physicists have theorized that a corollary to the fundamental laws may be that time travel is effectively impossible. In some varieties of the principle, any time machine is censored, hidden inside a black hole formed as a side effect to its creation, walled off from the rest of the Universe by an event horizon. Stephen Hawking has come up with a stronger version, the 'chronology protection conjecture': the laws of physics, relativistic and quantum-mechanical,

Books in brief

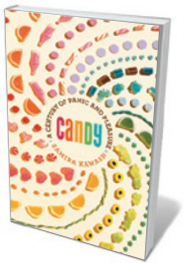


Life Atomic: A History of Radioisotopes in Science and Medicine
Angela N. H. Creager UNIVERSITY OF CHICAGO PRESS *(2013)*
The Manhattan Project's impact reverberated beyond the atomic bomb, reveals Angela Creager in this lucid scientific history. It paved the way for the Oak Ridge National Laboratory in Tennessee to mass-produce radioisotopes — elemental variants that emit radiation — for peacetime use. These newly abundant products of the "physicists' war" transformed biology, particularly as molecular tracers in processes such as protein synthesis. Creager deploys radioisotopes as "historical tracers" to explore shifts in medicine, perceptions of cancer risk and the porous "civilian-military divide".

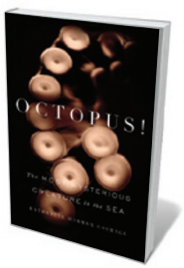


Space Has No Frontier: The Terrestrial Life and Times of Sir Bernard Lovell
John Bromley-Davenport BENE FACTUM *(2013)*
He made waves in radio astronomy, founded the UK-based Jodrell Bank Observatory and was an 'incidental' cold-war spy. Bernard Lovell, who died aged 98 in 2012, emerges as complex and brilliant in John Bromley-Davenport's biography. There is much to savour, from Jodrell Bank's use both in anti-Soviet defence and in tracking the Soviet satellite Sputnik; Lovell's risky, newly revealed 1963 visit to the Soviet Deep Space Network; and the observatory's latest role as control centre for the Square Kilometre Array radio telescopes.

The Long and the Short of It: The Science of Life Span and Aging
Jonathan Silvertown UNIVERSITY OF CHICAGO PRESS *(2013)*
Ecologist Jonathan Silvertown revivifies an old story in this primer on the science of ageing. His look at lifespan centres on a "Methuselah's menagerie" of bats, naked mole rats, ocean quahogs and humans — in whom cancer is often the price of longevity. He skips from heredity to semelparity ("once-only" reproduction followed by death), drawing on studies of everything from the Japanese hump earwig to human twins. The result is packed with cultural allusions and useful scientific shorthand: if whales lived at the metabolic rate of shrews, for instance, they "would boil the ocean around them".



Candy: A Century of Panic and Pleasure
Samira Kawash FABER & FABER *(2013)*
That Halloween haul is a tricky treat. Once reviled as an intoxicant and trigger for lust, candy is now attacked as biochemically dangerous. It is also, as Samira Kawash reveals, a fascinating strand of US cultural history. Sweets evolved from a luxury into the first junk food as, from the 1850s onwards, mass-production technology and sugar chemistry transformed the confectionery industry and built empires such as Mars. Now, argues Kawash, the hidden 'candification' of processed foods with corn syrup presents a bigger health hazard than the lollipop — so blatantly sugary that it is easy to avoid.



Octopus! The Most Mysterious Creature in the Sea
Katherine Harmon Courage CURRENT *(2013)*
Three hearts, eight arms and blue blood — the bizarre appeal of the octopus holds us in a sucker-like grip. They can change colour in three-tenths of a second, thanks to skin sacs called chromatophores. Their arms hold two-thirds of their brain capacity. They can play, use tools, solve mazes and open child-proof bottles. Katherine Harmon Courage's reportage on what the mollusc is teaching us about robotics, invertebrate intelligence and camouflage is excellent, but sits oddly with the interspersed octopus recipes. **Barbara Kiser**

conspire to prevent time machines' construction (or natural occurrence) in the first place.

Some take a more nuanced, if less physically plausible, approach. Stephen King's book *11/22/63* is premised on attempts to change the history of the day on which President John F. Kennedy was shot. "There's a kind of a rule that you'd express as a ratio," King told *Wired* magazine. "The more potential a given event has to change the future, the more difficult that event would be to change." But not all fictional time travel needs to involve material bodies and the problem of causality. In Kurt Vonnegut's *Slaughterhouse-Five*, it is Billy Pilgrim's consciousness that has "come unstuck in time" and travels between upstate New York, the planet Tralfamadore and the firebombed city of Dresden.

More than a century ago, writers were already using time travel for dramatic ends. Mark Twain's *A Connecticut Yankee in King Arthur's Court* skewers the American technophiles of the 1880s as much as the early-medieval Brits whose world he enters. And H. G. Wells's *The Time Machine* is a polemic on the social stratification of late-Victorian Britain, couched in the language of extra dimensions that would inform Einstein's relativistic merger of space and time in the following decades.

In 1899, the playwright Alfred Jarry leapt off from Wells's ideas to make time travel part of his knowingly absurd 'pataphysics', in his pamphlet *Commentary and Instructions for the Practical Construction of the Time Machine*. As part of the Beyond Entropy project with the Architectural Association in London, architect Shin Egashira and I tried to realize some of Jarry's machine. Alas, our success, if any, was aesthetic rather than technological.

And then, of course, there is the time lord himself. Paradoxes rarely trouble the Doctor. Time travel serves mostly as a plot device allowing him to visit humans (much easier on the special-effects budget than aliens) in different circumstances, from the recognizable past to the distant future, defeating his enemies again and again. More recently, however, the show has attempted some sort of cross-temporal continuity, even when this means retroactively changing the past and future to bring his nemeses, the Daleks, back from the dead.

The creators of Doctor Who have tended to favour thrills and chills over scientific (or pseudoscientific) precision. But they have also inspired millions to ponder profound questions about the nature of space and time and our movements through them. Here's to the next 50 years. ■

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PSYCHOLOGY

The appetite for right

John Whitfield explores two studies that take us from infant ethics to moral choices faced by adults in society.

Just Babies: The Origins of Good and Evil
PAUL BLOOM
Crown: 2013.

Moral Tribes: Emotion, Reason, and the Gap Between Us and Them
JOSHUA GREENE
Penguin: 2013.

It would be nice to think that ideas of right and wrong were founded on a blend of insight, experience and instruction. But mostly, instinct is in charge. Morality is an appetite for certain types of behaviour in oneself and others. Like tastes in food and sex, it is rooted in biology, shaped by culture and imperfectly controlled by reason.

As with those other appetites, we develop moral urges because our ancestors prospered by heeding them. Morality underpins social life by guarding against the selfishness that threatens cohesion, and turning that togetherness into a weapon against outsiders. But ethical instincts that put 'us' before 'them' are poorly suited to a globalized world in which different moral systems are in constant contact and problems such as climate change demand cooperation on an unprecedented scale.

Psychologists Paul Bloom and Joshua Greene share this view of the evolutionary roots, social function and limitations of morality. They diverge, however, on the aspects of it that they tackle.

IMAGE SOURCE/GETTY

In *Just Babies*, Bloom looks at how moral psychology develops in childhood. Using puppet shows or animations that depict helpful or antisocial behaviour, researchers are probing how the ability to judge others develops in infants. These studies, many of which are the work of Bloom and his colleagues, show that ideas of right and wrong begin to emerge so early in life that they must be innate: three-month-olds show that they recognize and prefer good deeds by, for example, looking longer at a kind character than a mean one.

Bloom, ever brisk and authoritative, generally focuses on how things are rather than on how developmental psychology might inform philosophy. His discussion of disgust is particularly good. This is partly because the experiments he describes are nifty. Moral purity, for example, is a value associated with conservative philosophies, and students' political views have been shown to move rightwards when they are standing next to a hand-sanitizer dispenser. And it is partly because he pursues the implications further, arguing that disgust is a poor guide to right and wrong and is liable to make people prejudiced and abusive.

In two senses, Greene picks up where Bloom leaves off. *Moral Tribes* looks at how adults resolve ethical dilemmas, and makes a detailed case for how they should do this. Greene argues that we have two moral systems that engage different parts of the brain. A fast, automatic, 'tribal' one operates through the emotions and is well suited for solving problems within groups; a slower, deliberative one allows a more impartial perspective. This echoes ideas in Daniel Kahneman's *Thinking, Fast and Slow* (Farrar, Straus and Giroux, 2011); the relevant bit of Greene's book is even called 'Morality Fast and Slow'. Greene's research has focused on conflicts between the