MEGATECH

TECHNOLOGY IN 2050

edited by

DANIEL FRANKLIN

The Economist Books

Published under exclusive licence from The Economist by
Profile Books Ltd
3 Holford Yard
Bevin Way
London WC1X 9HD
www.profilebooks.com

Typeset in Milo by MacGuru Ltd

Printed and bound in Great Britain by CPI Group (UK) Ltd, Croydon CR0 4YY

A CIP catalogue record for this book is available from the British Library

ISBN 978 1 78125 972 6
eISBN 978 1 78283 166 2

Contents

Contributors

Ryan Avent is economics columnist at *The Economist*. He is the author of *The Wealth of Humans: Work and its Absence in the Twenty-First Century*.

Geoffrey Carr is *The Economist*'s science and technology editor.

Tim Cross is science correspondent at *The Economist*.

Robert Carlson is a scientist, entrepreneur and the author of *Biology is Technology: The Promise, Peril, and New Business of Engineering Life*. He is a managing director of Bioeconomy Capital, a biotech investment house, and a principal at Biodesic, a strategy, engineering and security consulting firm.

Kenneth Cukier is senior editor for digital products at *The Economist*. He is the co-author of *Big Data: A Revolution that Transforms How We Work, Live and Think*.

Gianrico Farrugia is chief executive of the Mayo Clinic at Jacksonville, Florida. A professor of medicine and physiology, he specialises in gastroenterology and is a pioneer of individualised medicine.

Luciano Floridi is professor of philosophy and ethics of information at the University of Oxford. His most recent book is *The Fourth Revolution: How the Infosphere is Reshaping Human Reality*.

Melinda Gates is co-founder and co-chair of the Bill & Melinda Gates Foundation.

Lynda Gratton is professor of management practice at London Business School. Her books on the impact of a changing world on work include *The Shift* and *The Key*. Her latest book, with co-author Andrew Scott, is *The 100-Year Life: Living and Working in an Age of Longevity*.

Nancy Kress is a multiple-award-winning American science-fiction writer, whose works include *After the Fall*, *Before the Fall*, *During the Fall* and *Yesterday's Kin*.

Paul Markillie is innovation editor at *The Economist*. He was previously editor of the newspaper's Technology Quarterly and author of a special report on the future of manufacturing, *The third industrial revolution*.

Leo Mirani is *The Economist*'s news editor. Previously he reported on technology for *Quartz*.

Oliver Morton is *The Economist*'s briefings editor and a seasoned science writer. His latest book is *The Planet Remade: How Geoengineering Could Change the World*.

Alastair Reynolds is a British science-fiction writer, whose works include the *Poseidon's Children* and *Revelation Space* series of novels.

Anne Schukat is a freelance journalist who has been a frequent contributor to *The Economist* on science and technology.

Tom Standage is deputy editor and head of digital strategy at *The Economist*. He is one of the paper's leading writers on technology. His books include *The Victorian Internet* and *Writing on the Wall: Social Media – The First 2,000 Years*.

Benjamin Sutherland is a regular contributor to *The Economist*. He is the author of *Modern Warfare, Intelligence and Deterrence: The Technologies that are Transforming Them*.

Frank Wilczek is Herman Feshbach professor of physics at the Massachusetts Institute of Technology. He was awarded the Nobel prize

in physics in 2004. His books include *A Beautiful Question: Finding Nature's Deep Design*.

Ann Winblad is a founding partner of Hummer Winblad Venture Partners, based in San Francisco, and for over 30 years has been a leading entrepreneur and investor in the software industry.

Adrian Wooldridge is *The Economist*'s management editor and Schumpeter columnist. His most recent book is *The Great Disruption: How Business is Coping with Turbulent Times*.

The editor

Daniel Franklin is executive editor of *The Economist* and editor of its annual publication on the year ahead, *The World in…* He co-edited *Megachange: The World in 2050*.

Introduction: meet megatech

Daniel Franklin

THIS BOOK IS BASED ON the idea that it can be useful to consider the long view. Setting our sights on 2050 is an invitation to identify the fundamental forces likely to shape the world between now and then. This volume's predecessor, *Megachange: The World in 2050*, published in 2012, provided an overview of such trends, from demography and religion to the economy and culture. Here the focus is narrower – on technology alone – but *Megatech* still ranges widely. For technology influences pretty much everything.

Clearly, it is impossible to know for sure what the technologies of 2050 will be, just as, 30 years ago, nobody could have envisaged today's world of Apple, Amazon, Facebook and Google. However, it is interesting and mind-stretching to make educated guesses. To do so, *Megatech* draws on the expertise of scientists, entrepreneurs, academics and sci-fi writers, as well as journalists from *The Economist*. The result is a rich variety of perspectives on how technology will evolve and affect us in the decades ahead.

Tools and platforms

We start with the basics. The first six chapters, in Part 1, address fundamental questions about the future of technology and what is likely to drive or constrain change. Where should we look for signs of what lies ahead? What will advances in science – physics and biology, in particular – make possible, and where might technology bump up against limits? How do investors spot emerging technologies and where are they putting their money now? Will change really be as fast and dramatic as is commonly supposed, or will it pale by comparison with the technology revolution of the last century?

To set about predicting the tech future, it helps to have a toolkit. Tom Standage provides one. He suggests that clues can be found in the patterns of the past, in the "edge cases" of the present and in the "imagined futures" of science fiction. He then tests these tools on four promising areas: virtual reality, self-driving cars, private spaceflight and gene editing. These examples suggest that a fertile period for discovery lies ahead (two science-fiction writers have dubbed the coming period of rapid change "the Accelerando"), which could echo the scientific revolution of the mid-17th century.

Advances in science make an Accelerando seem plausible. In his masterful overview of the state of fundamental physics (many readers will find themselves wishing the subject had been explained so clearly when they were at school), Frank Wilczek makes a striking claim:

> *We have, today, accurate, complete equations adequate to provide the foundation of nuclear physics, materials science, chemistry and all plausible forms of engineering.*

As a result, calculation can increasingly replace experimentation in developing technology, allowing far faster progress. This offers "brilliant opportunities for creativity in the service of human ends", and opens up "inspiring prospects for achieving new levels of material wealth and spiritual enrichment". Yet it also presents profound perils (or "failure modes"), the most worrying being nuclear war, ecological collapse and artificial-intelligence warfare.

If physics has reached a creative level of maturity, biology bubbles with youthful excitement. In the decades to 2050 we will learn how all the parts and systems underlying life fit together, predicts Robert Carlson. The sorts of things we can expect in the years to come include our brains being plugged into the internet and our used body parts being swapped out for new ones. All this will raise searching ethical questions. Meanwhile whole industries (from food to pharmaceuticals) will be transformed by bioengineering, as it becomes a platform to "build just about anything we see in nature", and much more besides.

Behind biotechnology's formidable potential lies the "hyper-exponential" increase in the productivity of DNA sequencing. A decade ago *The Economist* called this soaring efficiency "Carlson's curve", comparing it to a similar relentless improvement in microchips, known

as "Moore's law", which has driven digital development. But Moore's law is running out of steam. Does this mean that the massive demands for computing power – needed to do many of the wondrous things described elsewhere in this book – will bump up against physical limits in future? The short answer, according to Tim Cross, is: probably not. Other technologies will come to the rescue. Progress will be less regular and predictable without the "master metronome" of Moore's law, but a combination of 3D chips, quantum computers and having more of the processing work done in big data centres (hidden away in the "cloud") will enable the computing revolution to continue.

It will take the form of a succession of technology "waves", judging from the experience of recent decades. Half a dozen such waves have rolled in since the 1950s, from the early mainframes to today's smart machines and the "internet of things". In each wave a crowd of companies emerge, but only a few make it to the shore. And each successive wave is stronger than the last, boosted by the force of its predecessors. Silicon Valley investors are already riding the newest (seventh) wave, still in the early stages of formation: it carries artificial-intelligence (AI) companies. Early-stage venture capitalists began investing in AI around 2010, and billions of dollars are now pouring into firms developing AI software tools and applications. Ann Winblad reckons that "a rapid, virtuous and competitive cycle of innovation has picked up invisible momentum as the seventh wave builds". Its force will be felt in the decades ahead.

Yet how big will the impact of AI and other new technologies really be? An American economist, Robert Gordon, is among those who argue that the digital revolution, however impressive, has relatively limited transformative potential when compared with the great innovations of the second half of the 19th century. Electricity, cars, indoor plumbing and modern medicine powered a century of rapid productivity growth; today, despite the spread of the internet, smartphones, apps and bots, productivity and pay are rising at disappointingly slow rates. If anything, technology is contributing to inequality and fuelling frustration. As Ryan Avent explains, however, there is a strong case for greater optimism about the decades ahead. Learning to make the most of new technologies takes time; that was equally true of electrification (indeed, the pattern of labour-productivity growth in

the information-technology era is remarkably similar so far to that seen in the electrification age). As with previous tech-driven spurts in economic growth, tomorrow's advances will come in new ways that are hard to imagine now. That is not to say the rapid change ahead will be easy to cope with. On the contrary, it will be difficult and disruptive – something the later chapters of this book grapple with in more depth.

Industrial revolutions

First, though, we look in Part 2 at the transformation technology will bring about in a number of critical industries. Of these, none is more important than farming. How do you feed a planet of nearly 10 billion people by 2050? Comfortably, argues Geoffrey Carr, provided consumers accept the sorts of food-production techniques that will become possible in the not-so-distant future. Such techniques include the application to plants of precise gene-editing tools that could, for example, turbo-boost photosynthesis to make crops grow faster and dramatically improve yields. Urban fish farms could in effect bring the ocean inland and make fish the dominant source of animal protein. Unless, that is, it is outdone by mass production of animal products – steak, milk and eggs without shells should be on the menu – grown from cell culture, without any actual animals.

If there is no reason for the world to go hungry, there is every reason to expect it to be healthier. Health care has in the past been relatively slow to adopt new technology. Yet the pace of change is accelerating. Disruption will come from many areas, including AI, big data and ever-cheaper genome sequencing. The field will start to look very different. New apps and ever more sophisticated AI tools will do jobs once performed by doctors; "targeted therapies", aimed at specific molecules or cells, will dominate drug development; and whole new sub-industries will emerge, around regenerative medicine, for example, and data aggregation. But in one key respect, suggests Gianrico Farrugia, the result will look rather familiar: health care will more closely resemble other industries, with the patient seen as the customer.

The energy industry needs (for the planet's sake) to look less familiar in future, moving away from reliance on fuels that contribute to climate change. Anne Schukat expects to see a great shift away from fossil fuels

in the next decades, and a rapid rise of renewable sources of energy, especially solar and wind power, the costs of which are tumbling. Big improvements in battery technology will help: "distributed" storage of energy, in homes as well as businesses, will spread. The world used to worry about energy scarcity. But with the rise of renewables, and with "fracking" technology unlocking stores of oil and gas, the prospect instead is of energy abundance.

New materials will help to make manufacturing a lot more energy-efficient, too. As Paul Markillie points out, the way the BMW i3 electric car is "knitted" together using carbon fibre gives a glimpse of the future: production of the i3 uses 50% less energy and 70% less water than would be the case in a factory using traditional processes and materials. This is part of a materials revolution that includes, beyond carbon fibre, possibilities such as "smart" materials capable of remembering their shape and assembling themselves into components, and molecular-level manipulation to create bespoke substances and to change the way materials respond to light, electricity, water and heat. Clever new materials will also help the spread of "additive manufacturing", popularly known as 3D printing. As materials and processes become critical elements of firms' competitive advantage, a lot of the manufacturing that went offshore will come home, to be closer to customers.

New materials will also have military applications – giving soldiers lighter and more flexible armour, for example. And other technologies, including laser guns and military robots, will be on the march. The US still leads in the making of defence kit, but potential rivals are catching up. By mid-century, says Benjamin Sutherland, the West's monopoly on precision warfare may well be long gone. One hope for the West is that it can keep an edge thanks to a cultural advantage: the freedom of thought that may allow its soldiers to make more effective use of intelligence delivered via smart devices, such as "augmented reality" (AR) displays.

Yet such technologies will be spreading far and wide, anyway. They will, predicts Leo Mirani, change human behaviour even more than the advent of smartphones and the web has done. He describes a 2050 world in which AR glasses have replaced smartphones, conversations with people who speak other languages will be simultaneously translated,

and you need never forget a name as everything you know about a person will appear as you talk to them. He imagines technology moving ever closer to our bodies, and even inside them. As this happens, concerns about the amount of data collected about us, and what the companies that gather the information might do with it, will intensify.

Nigh society

By now it should be obvious that the social and policy implications of the technologies on the horizon are huge. This is the focus of the contributions in Part 3, starting with a mind-clearing look at an area that has drawn sombre warnings from the likes of Stephen Hawking and Elon Musk: artificial intelligence. Might ultra-intelligent machines pose an existential threat to the human race? Luciano Floridi argues that the machines won't be the problem, but the humans who create the environment for them could be.

Despite the pitfalls there is enormous scope for progress. In a data-driven world, Kenneth Cukier points out, things that are currently hard to do will become easier, things that are expensive will become cheaper and things that are scarce will become more abundant. So doctors will use big-data systems to help them make better decisions, teachers will use data to tailor the pace of instruction to individual students, lawyers will be able to find relevant evidence and precedents faster and more cheaply. These and other professions won't be swept away by technology – we may even want more doctors, teachers and lawyers, not fewer – but they will need to change their ways and learn new skills.

If the coming digital dynamics mean upheaval in developed economies, this is not the only way that technology can bring dramatic change. Just as significant, if not more so, is the spread to poorer countries of what is already common in rich ones. Melinda Gates imagines a world in which every woman has a smartphone. The effect – from health to farming and banking – would be transformational. And by 2050 it is surely possible.

This is one example of how technology could reduce inequality in the world. Adrian Wooldridge suggests others – making the case that, having been responsible for much of the rise in inequality in recent years, technology could in future help to reverse it. For instance, it

can help to detect and select talented youngsters regardless of social background, giving those who might otherwise languish a chance to shine. Whether in education and health, in tackling corruption or in making poorer neighbourhoods safer, it offers a powerful tool for policymakers.

With so much disruption on the horizon, worries are growing about what it will mean for the world of work. Will machines hollow out industries or create more employment? And will new jobs come fast enough to avoid mass misery for those displaced? Lynda Gratton identifies the questions that businesses and policymakers should be asking as they contemplate an uncertain future for work, and concludes that successful organisations will have adaptability at their core. This means creativity in designing career ladders, imagination in nurturing talent, flexibility in training and a fresh attitude to machines-as-partners: "what great feats can be accomplished by workers with their robotic co-workers?"

Imagination, remember, was (in the form of science fiction) part of Tom Standage's toolkit for looking at the tech future. So we include some "imagined futures" in these pages, inviting two sci-fi writers to contribute short stories set in 2050. Alastair Reynolds and Nancy Kress responded splendidly, bringing technological possibilities to life, along with the moral issues they raise. Their works of fiction feel remarkably real.

Risky bigness

Three strands run through *Megatech*, intertwining in intriguing ways from beginning to end. The first reflects the quality suggested by the title: a sense of bigness. The possibilities opened up by the technologies envisaged for 2050 are huge. It is hard not to feel excited about the extraordinary advances that will be within reach. Here is the tantalising prospect of a world where services are delivered faster, cheaper and better; where access to them is widened, reducing inequality; where food is abundant, energy cleaner and transport safer; where people are healthier and have more opportunities.

Yet a lot could go wrong, as Oliver Morton emphasises in his thought-provoking concluding chapter. There will be unintended

consequences, potentially dangerous disruption and misuse of technology's power. A wariness of the risks ahead is the second thread weaving its way through these chapters: megatech could become negatech. Frank Wilczek warns of "failure modes", others caution that policymakers will struggle to keep up with the questions posed by what technology makes possible, industry after industry faces upheaval – with all that implies for jobs and the lives of those that work in them. Luciano Floridi puts the pace of change pithily in perspective:

> *The agricultural revolution took millennia to exert its full impact on society, the industrial revolution took centuries, but the digital one only a few decades. No wonder we feel confused and wrong-footed.*

An Accelerando is hard as well as exciting.

Interlaced with the idea of bigness and risk, however, is a third theme: a recurrent notion that there is nothing inevitable about what lies ahead. The impact of technology is only partly a matter of the innovations of scientists, geeks and entrepreneurs. The outcome by 2050 will also be shaped by the decisions of governments, the strategies of companies and the choices of individuals. It is up to all of us to make the most of megatech.

PART 1

The fundamentals

1

A toolkit for predicting the future

Tom Standage

To see what lies ahead in technology, it helps to look in three places: the past, the present and the imagined futures of science fiction

A NEW NETWORKING TECHNOLOGY revolutionises long-distance communication, making it cheaper and more convenient than ever before. It is enthusiastically embraced by businesses, causing a speculative boom. The new technology is relentlessly hyped by its advocates and mocked by its detractors. It makes possible new business models and new forms of crime. Governments struggle to prevent the use of cryptography, demanding access to all messages. People make friends and fall in love online. Some say the new technology will lead to world peace, as communication erases borders and unites humanity. It sounds like the story of the internet in the 1990s. But this is in fact the story of the electric telegraph in the mid-19th century, which was known as the "great highway of thought".

The striking parallels between these two technologies, one modern, one 150 years old, are entertaining – but they can also be useful. The study of history is one of three tools that can be used to predict the future of technology, or at least make slightly more educated guesses about it.

History lessons

Historical analogies of this kind, across years, decades or even centuries, make it possible to foresee the social and cultural impact

of new inventions, put hype and scepticism into perspective, provide clues about how a technology might evolve in future, and provide a reminder that problems blamed on new technologies are often the result of human nature. There were, for example, instances of what we would now call "cybercrime" on the mechanical telegraph networks built in the age of Napoleon. "It is a well-known fact that no other section of the population avail themselves more readily and speedily of the latest triumphs of science than the criminal class," in the words of one law-enforcement official. Those words could have been spoken today, but were in fact spoken by a Chicago policeman in 1888.

Such analogies are never perfect, of course, and history never repeats itself exactly. But analogies do not have to be perfect to be informative. Look closely, and there are many repeating patterns in the history of technology, on both short and long timescales.

New inventions often provoke concerns that they will destroy privacy; the first Kodak camera caused a panic over surreptitious public photography in the 1880s, much as Google Glass did in 2013. They are accused of corrupting the morals of the young, a charge levelled at novels in the 1790s, motion pictures in 1910, comic books in the 1950s and video games in the 1990s. From 19th-century Luddites to modern prophets of robot-induced mass unemployment, the fear that new machines will deprive people of their jobs is centuries old. So too are concerns over new technologies that allow man to play god, from nuclear weapons to genetic modification to artificial intelligence; these are all modern-day versions of the myth of Prometheus, and the question of whether mankind could be trusted with the gift of fire. Whether such concerns are merited or not, an understanding of reactions to past technologies can give futurologists, entrepreneurs and inventors valuable clues about how new products might be received.

Tomorrow is another today

So much for history. The second place to look for glimpses of the future is the present. As William Gibson, a science-fiction writer, once memorably put it, "the future is already here – it's just not very evenly distributed". Technologies have surprisingly long gestation periods; they may seem to appear overnight, but they don't. As a result, if you

look in the right places, you can see tomorrow's technologies today. This approach is taken by journalists and corporate anthropologists who want to understand new trends. It involves seeking out "edge cases": examples of technologies and behaviours that are adopted by particular groups, or in particular countries, before going on to become widespread. A classic example of an edge case is that of Japan and smartphones at the turn of the century.

In 2001, mobile handsets with cameras and colour screens were commonplace in Japan. They could display maps with walking directions and allowed users to download e-books, games and other apps. Journalists and analysts flocked to Japan to see these phones in action. And whenever Japanese visitors to European and US technology conferences passed around their handsets, they were treated as though they were artefacts from the future that had fallen through a rift in the space-time continuum. Japan arrived in the future early because of the isolated, proprietary nature of its telecoms industry; its domestic market was large enough to allow its technology companies to experiment with new ideas without worrying about compatibility with other countries' systems. It was several years before consumers in Europe and the US could buy handsets with comparable features. For a while *Wired* magazine had a column called "Japanese Schoolgirl Watch", predicated on the idea that what Japanese schoolgirls (the most ardent users of early smartphones) do today, the rest of us might be doing tomorrow.

Edge cases can arise in the most surprising places. Kenya, for example, has long led the world in the adoption of mobile money, which allows funds to be transferred from one handset to another instantly, as easily as sending a text message. For many years you could pay your taxi driver using your phone in Nairobi, but not in New York. Mobile money took off in Kenya in part because the lack of banking infrastructure offered a clean slate; in a country where most people do not have bank accounts, there is little competition from incumbent payment systems. Political factors also played a role: use of mobile money took off during the post-election violence of 2007–08, when it was seen as a safer alternative to banks, which were entangled in ethnic disputes.

And sometimes it is people who share a particular interest,

rather than those in a particular place, who pioneer the use of a new technology. The most obvious example is the technology community: geeks are the earliest adopters of new innovations, from e-mail to Uber. But they can also pioneer wider trends. Techie types led the way in adopting fitness-tracking devices, for example; the "quantified self" movement, which involves obsessively monitoring your health and fitness activity, started as a technological cult but has since gained a wider following.

Chris Dixon, a venture capitalist at Andreessen Horowitz, says he often looks to see whether a new technology or behaviour has spawned a thread on Reddit, an online discussion board. If it has, this suggests that it is gaining traction. For example, a growing number of techies are now interested in novel food technologies, from nutritionally complete food shakes (no need to cook, just chug) to caffeine-laced sweets that provide an edible alternative to coffee, though it is too early to say whether this sort of thing will catch on more widely.

Indeed, just as historical analogies are not perfect, looking at edge cases can also be risky. Some technologies never take off – or, when they do, they take off in an unexpected or different way. In the West, for example, smartphones initially followed the Japanese trajectory, but then took a completely different turn with the advent of the iPhone and other touchscreen devices. But what is undeniable is that all technologies that do eventually catch on first go through an underground period where their use is restricted to a subpopulation; they don't appear from nowhere. Finding these edge cases and identifying emerging technologies and behaviours is more art than science; trendspotting is hard. But it is the stock-in-trade of countless consultants and futurologists, not to mention technology journalists, who are always looking for new ideas and trends to write about.

The vision thing

The third place to catch glimpses of what is coming next is in the imagined futures of science fiction, whether in the form of books, television shows or films. Sci-fi stories take interesting ideas and carry them to their logical conclusions. What if we could build general-purpose robots, or a space elevator? What would happen if

nanotechnology or biotechnology got out of control, or genetic self-modification became as commonplace as tattoos? Such futuristic tales provide visions of how the world might look with ubiquitous artificial intelligence, anti-ageing treatments that expand human lifespans, colonies on Mars and elsewhere in the solar system, or a fragmenting of humanity into post-human tribes. It can be a handy way to map out the space of potential long-term outcomes: what Elon Musk, a leading technology entrepreneur, calls the "branching probability streams" of the future.

Science fiction is not merely predictive, however. It also inspires technologists to invent things. Scratch a technologist and you'll find a sci-fi fan. The flip-open mobile phone of the 1990s, for example, seems to have been directly inspired by the portable communicators seen in *Star Trek* in the 1960s. More recently, the idea of being able to talk to computers, another idea from *Star Trek*, has inspired a new wave of computing devices, starting with the Amazon Echo, that use speech as their main interface, allowing always-on, hands-free use. Generations of computer scientists have grown up on Isaac Asimov's robot stories; today many entrepreneurs, including Musk, cite the Culture novels of Iain M. Banks as an inspiration. Like *Star Trek*, they depict a post-scarcity civilisation in which humans and artificial intelligences live and work together.

Yet although sci-fi is outwardly about the future in most cases, it is really about the present, and responds to contemporary ideas and concerns, such as an overdependence on machines or worries about environmental destruction. Reading a diverse selection of sci-fi can give you greater mental flexibility to envisage future scenarios, both technological and societal. But it can also unwittingly constrain, by shaping the way technological developments are perceived and discussed: robots, for example, look very different in the real world than they do in science fiction, and trying to imitate the fictional variety may steer roboticists in the wrong direction. So it is also worth reading classic sci-fi from the mid-20th century, to see what it gets wrong and why – and then ask yourself what mistaken assumptions are being made by today's tales.