

New York City is in some respects a scaled-up version of smaller settlements.

COMPLEXITY

Decoding deep similarities

Philip Ball applauds Geoffrey West's opus on the laws that lurk in organisms, cities and companies.

Plato and Aristotle stand proxy for two types of scientist: those who see similarities, patterns and universals, and those who see differences, variation and specifics. Both viewpoints are needed, but they are hostage to disciplinary and cultural fashions. It's probably safe to say that physics stresses the former, biology the latter.

Geoffrey West — a theoretical physicist and erstwhile head of that mecca of multi-disciplinary complexity studies, the Santa Fe Institute in New Mexico — takes a Platonic view. In *Scale*, he explains mathematical relationships between the size and properties of many complex systems, natural and human, that are more often subjected to an Aristotelian scrutiny of particulars — living organisms, cities, companies, economies. Each has properties predictable from their

scale: an elephant is a scaled-up mouse; New York City, a scaled-up Santa Fe; Walmart, a scaled-up version of your local grocery.

Scaled up how? Elephants don't have fur and whiskers; New York has (to my knowledge) no skyscrapers made from adobe. Instead, these relationships are apparent in measures of what one might call performance or metabolism — rates of wealth creation, say, and of energy consumption. Crucially, the link isn't linear. Owing to economies of scale (efficiencies that arise from increased size), New York has half the per-capita carbon footprint of Santa Fe, even though the former feels grimy and gridlocked and the latter eco-friendly. As a result, such scaling relationships tend to obey power laws: a parameter will increase in proportion to size raised to some exponent. The canonical example is that

metabolic rate scales as (body mass)^{3/4}.

So, for cities, size determines (among other things) the pace of life. Anyone can get a sense of that by trotting along New York's mammoth thoroughfare Fifth Avenue or strolling the pueblo-

style streets of Santa Fe. And it is quantitatively revealed in the statistics. As West says, in big cities "diseases spread faster, businesses are born and die more often, commerce is transacted more rapidly, and people even walk faster". The average walking speed in cities with more than one million inhabitants is nearly double that in towns of a few thousand.

For living things, it's the reverse: if an animal is small, then, with very rare exceptions, it lives fast and dies young. Those two factors, as measured by heart rate and lifespan, balance out so precisely that all creatures, from pygmy shrews to whales, have equal lifespans when accounted in number of heartbeats: about one billion of them. West also discusses the inevitable laws of growth, ageing and death, both in living and human-made systems — why, say, companies have life cycles but cities persist.

If you find such regularities astonishing, you're a Platonist at heart. If you shrug, feeling that they reveal little about pygmy shrews or what makes Shanghai so captivating, you're an Aristotelian. There is a suspicion, often heatedly voiced, that the universality of the laws West and others have uncovered can't tell us anything very interesting about any one system.

That criticism has long been levelled at those who posit that mathematical laws govern aspects of life, arguably starting with biologist D'Arcy Wentworth Thompson and his magisterial book *On Growth and Form*, published 100 years ago (see P. Ball *Nature* **494**, 32–33; 2013). But a recognition of mathematical principles in biology and social science — in particular, an acknowledgement that simple laws underpin complex growth, form and dynamics — has been growing over the past several decades. Computer algorithms have helped tremendously in that process. Since the 1980s, the Santa Fe Institute has been hugely influential, inspiring similar complexity hubs from Singapore to Arizona, Amsterdam and Vienna.

Yet this broader view of complex human systems has been slow to enter the mainstream, and its absence has had some troubling consequences. The narrow focus on growth, turnover and gross domestic product as indicators of economic well-being, for example, has led to unsustainable growth coupled to environmental despoliation and climate change. That point has been

Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life, in Organisms, Cities, Economies, and Companies
GEOFFREY WEST
Penguin: 2017.

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made before, but West brings it home with particular clarity.

He notes that although thermodynamic flows — rates of fossil-fuel consumption, say, and consequent entropy production — are central to socio-economic progress, discussion of that hardly figures in economics textbooks: “Remarkably, concepts like energy and entropy, metabolism and carrying capacity have not found their way into mainstream economics.” If these are acknowledged at all, it tends to be by economists such as Julian Simon and Paul Romer, who have argued that human ingenuity will solve any problems. Ideas, however, are themselves the product of complex social systems — vitally dependent on institutions, opportunities, equality, liberty and the spiritual health of societies.

This blind belief in innovation as a panacea is, as West points out, often coupled to misapprehension or even denial of the costs of open-ended growth, such as climate change. At best, such issues are swept under the carpet as “externalities”, market failures that pose a nuisance for economic accounting. An economics afflicted by such attitudes is not even a dismal science; it’s a pseudoscience.

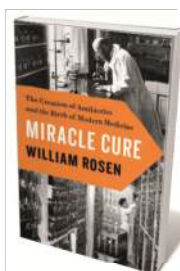
Likewise, cities have often been regarded as if they are mechanical entities that can be arbitrarily redesigned, rather than, as urban theorist Lewis Mumford argued, being more like living organisms, constantly adapting and evolving. West particularly highlights the pioneering ideas of another urban theorist, Jane Jacobs. Her advocacy of the organic approach to urbanism in the 1950s and 1960s invoked the idea of self-organization, now so central to the science of complex systems, before that language even existed (see A. Williams *Nature* 537, 614–615; 2016).

West is too canny to imagine that universal laws of size and growth say all that needs saying about such systems. But *Scale*, a grand synthesis of topics he has studied for several decades, makes an important and eloquent case for their significance in an ecology of the natural and human world — and in understanding whether the two can fit together. He calls this “a grand unified theory of sustainability”, allowing “quantitative, predictive, mechanistic” parsing of that relationship. West has no prescription for what such a theory might look like. It surely won’t be built bottom-up from an Aristotelian assemblage of details; neither will it reduce simply to a series of scaling laws.

Much of what *Scale* contains has been popularized before, but West manages to reveal the deeper principles on which these regularities rest. These are inevitable aspects of complex systems. You can ignore them, but you can’t escape them. ■

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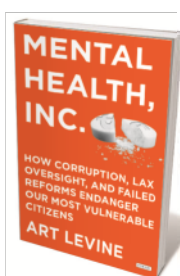
Books in brief



Miracle Cure

William Rosen VIKING (2017)

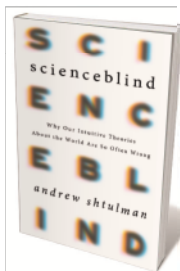
In this assured chronicle of the twentieth-century antibiotics revolution, William Rosen delivers reams of science at a thrilleresque pace. The experimentalists — Gerhard Domagk and Howard Florey among them — are vividly portrayed, as are the patients cured, the pharmaceutical corporations created and the moment in 1943 when bacteriologist Mary Hunt found the ancestor of all penicillin used today, on a mouldy melon. Antibiotic resistance and putative solutions are given their due, including Michael Fischbach’s work on microbial-gene clusters in the human microbiome.



Mental Health, Inc.

Art Levine OVERLOOK (2017)

Some 18% of US citizens grapple with mental illnesses, but the country’s mental-health-care system is struggling too. In this trenchant exposé, investigative journalist Art Levine examines challenges such as US\$4-billion cuts to state mental-health budgets, as well as case studies of casualties, from prison inmates to teenagers in residential ‘boot camps’. While lauding judicious medication, Levine takes aim at endemic “drug-and-sedate” practices. He sees hope in institutional reform, peer-to-peer counselling and innovations in de-stigmatizing therapies for post-traumatic stress disorder.



Scienceblind

Andrew Shtulman BASIC (2017)

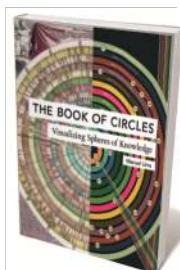
Many people misconstrue basic physical or biological phenomena, from the nature of gravity to the transmission of disease. At a time of widespread science denialism and potential pandemics, intuitive theories can have a pernicious impact, argues Andrew Shtulman. In his lucid and methodical corrective, the psychologist reveals how such stabs in the dark arise, drawing on developmental research and snippets of history, such as chemist Joseph Black’s discovery in 1761 that heat and temperature are distinct. A reminder that scientific literacy is the backbone of functional, democratic societies.



Imagining the Arctic: Heroism, Spectacle and Polar Exploration

Huw Lewis-Jones I. B. TAURIS (2017)

To Victorian Britain, Earth’s poles were an icy terra incognita, ostensibly ripe for exploration. Yet as historian and polar guide Huw Lewis-Jones reveals in this monumental cultural and political chronicle, the public was much less obsessed with that heroic narrative than many histories claim, despite relentless boosterism by the likes of geographer Clements Markham. Lewis-Jones shows how exploration was itself explored in art, literature and the media — an Arctic of the imagination in which the triumphalism of John Ross and broken dreams of Robert Falcon Scott commingled.



The Book of Circles: Visualizing Spheres of Knowledge

Manuel Lima PRINCETON ARCHITECTURAL PRESS (2017)

The human iris, a full Moon, volcanic calderas: natural circles have inspired culture for millennia. Information visualizer Manuel Lima gathered centuries’ worth of circular charts, graphics and illustrations for this volume, organized in a ‘taxonomy’ spanning everything from spirals to pies. It’s a ravishing tour, from the spangled glory of globular star cluster M13, imaged by the Hubble Space Telescope, to Martin Krzywinski’s bold 2007 radial genomics diagram *Human–Dog Homology*. Puts circular thinking in a whole new light. **Barbara Kiser**