

in molecules can typically be arranged in many stable ways, and each configuration has an associated energy; this is how Schrödinger envisages different gene alleles. But “quantum jumps” between them are generally inhibited by high energy barriers.

He goes on to propose that such gene-encoding molecules (he was among those who suspected that they were large proteins) have enough potential variety in their configurations to encode huge amounts of information, and that this variety can furnish a cell’s “code-script”. The position of each atom matters, but the pattern does not repeat — hence his description of the

**“What Is Life? dropped into a tumultuous time for science as well as for sociopolitics.”**

molecules as being like an aperiodic (irregular) solid. It wasn’t an entirely new idea; Delbrück had suggested something of the kind in 1935.

And biologists Hermann Muller and J. B. S. Haldane had independently proposed that chromosomes might act as templates for their own replication, in the same way that new crystal layers build up on pre-existing ones.

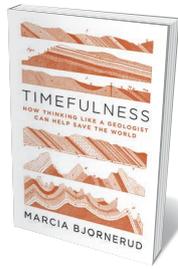
None of this, Schrödinger admits, answers the deeper question of “how the hereditary substance works” — that is, how it is used in development and metabolism, enabling an organism to build and sustain itself from moment to moment in what Schrödinger calls its “four-dimensional pattern” in space and time. But he makes a start on that issue by posing the question in thermodynamic terms.

This isn’t a matter of energy (organisms’ energy intake and output must be balanced, or they’d burn up), but of entropy, the measure of atomic disorder. The second law of thermodynamics states that entropy must increase in all processes of change. But organisms somehow stave off entropic dissolution. As Schrödinger put it, they feed on “negative entropy”, using it to sustain the organization apparent in the structures and functions of cells, while paying their thermodynamic dues by heating the environment.

How they mine negative entropy, he could not say. He was forced to suggest that, in living systems, “we must be prepared to find a new type of physical law”. Today, no such drastic solution seems to be needed.

The concept missing from his analysis is information. The information theory of Claude Shannon and the cybernetics of Norbert Wiener in the 1940s and 1950s began to fill that lacuna, although only more recently have researchers begun to understand how information truly features in biology. As Schrödinger’s talk of negative entropy hinted, life is a pocket of out-of-equilibrium order in an open system, and the DNA code is just part of what sustains it. It’s a shame that Schrödinger didn’t touch on ▶

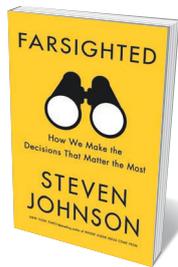
## Books in brief



### Timefulness

Marcia Bjornerud PRINCETON UNIVERSITY PRESS (2018)

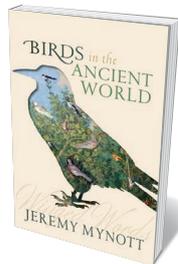
As a geologist, Marcia Bjornerud works in many time frames: the 4.5-billion-year history of Earth, the academic year, the daily grind. That layered perspective has made her aware of the short-term thinking common in a society wedded to political terms of office and the news cycle — all of which has, she argues, contributed to our inadequate, sometimes wrongheaded response to climate change. In this trenchant study, Bjornerud calls for a new geological literacy to instil deeper knowledge of planetary rhythms and processes — “thinking like a mountain”, as ecologist Aldo Leopold put it.



### Farsighted

Steven Johnson RIVERHEAD (2018)

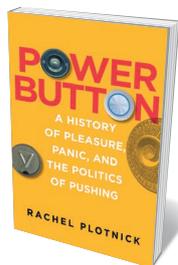
Many researchers (notably psychologist Daniel Kahneman) have wrestled with the subtle mechanics of decision-making. Now, science writer Steven Johnson has his decisive moment, looking at the deep deliberations — mapping of variables, predictions of outcomes and balancing of aims and possibilities — that underpin life-changing choices. He draws on research and compelling examples, from George Eliot’s 1871 novel *Middlemarch* (which examines the “threadlike pressure” on the deciding mind) to the supercomputer-based climate models now influencing climate-relevant decisions across the globe.



### Birds in the Ancient World

Jeremy Mynott OXFORD UNIVERSITY PRESS (2018)

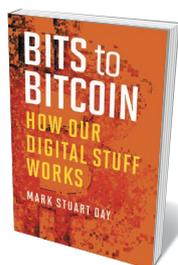
From nightingales trilling in ancient Rome’s suburbs to the migrating cranes minutely observed by Aristotle in his fourth-century-BC *History of Animals*, birds pervaded early Mediterranean civilizations. Jeremy Mynott’s masterful cultural and scientific history tours their roles as timepieces, soundscapes, pets, messaging services — even intermediaries with the supernatural. The vivid artworks and literary passages give this wings: here is the Greek poet Aratus on finches “chirruping shrilly at dawn” before a storm; there, a surreal Roman recipe for flamingo stewed with coriander.



### Power Button

Rachel Plotnick MIT PRESS (2018)

Push buttons pop up on everything from blenders to aeroplanes. Yet, as Rachel Plotnick reveals in this unusual technological history, the mechanism had an explosive impact on culture from its debut in the 1880s to the 1920s and beyond. The idea that huge machines or even bombs could be activated by a finger became a metaphor for human hegemony, and a source of fear and wonder. And, as Plotnick notes, some ‘buttonized’ inventions (such as the electrified tie pin) may be defunct, but in an era of nuclear weaponry and disruptive leadership, one-touch technology still has the power to shock.



### Bits to Bitcoin

Mark Stuart Day MIT PRESS (2018)

In this methodical primer, technologist Mark Day examines the computational infrastructure — the elements that underlie the workings of digital devices and networks. He unpicks operating systems, examines processes, explains esoteric defensive techniques such as cryptography and reveals Bitcoin to be an “intriguing combination of self-interest and mathematics”. If you want to know why data streams turn lumpy when compressed, or yearn to get inside the cloud, a handy reference awaits. [Barbara Kiser](#)