that many aspects of high-level cognitive functions, such as decision-making, planning and creativity, are themselves hidden from consciousness: "You don't know your innermost thoughts." These thoughts are carried by "a little person, a homunculus, inside my head who perceives the world through the senses, who thinks, who plans and carries out voluntary actions" — another metaphor. This position implies that "you are aware only of the sensory representations associated with these mental activities."

This is reminiscent of a debate in the nineteenth century about the role of images in thought. In 1870, Hippolyte Taine compared the mind to "a polype of images", and recent ingenious experiments by Gordon Shepard and Stephen Kosslyn have confirmed the role of mental imagery as central to the substance of conscious thought. Yet it seems highly debatable that all the contents of consciousness are sensory. What about mathematical concepts and their creation? What about consciousness of our errors? It seems to me that many abstract non-sensory representations can also be conscious. But Koch's speculation does bring forward an important question: can we define the particular kind of conscious and non-conscious representations to which the prefrontal cortex contributes? I am convinced that these issues can now be investigated in neurobiological terms.

An important quality of *The Quest for Consciousness* is the book's attempt to compare the views of Koch and Crick to the work of others — in particular to Edelman's sophisticated framework, which is elegantly summarized in *Wider than the Sky*. Koch's competition between coalitions of neurons fits well with Edelman's clusters of neurons and group selection by a massive feedback signalling loop. However, Edelman's position contrasts in another respect with that of Crick and Koch (and Dehaene and myself, for that matter), who posit well-defined neural architectures for consciousness. These structures appeared in the course of evolution — possibly from what Derek Denton refers to as "primal emotions", such as thirst, hunger and sex — and relate in particular to the expansion of the prefrontal cortex and its inhibitory power. A further distinction between the view of Crick and Koch and that shared by Dehaene and myself is our emphasis on neural mechanisms of evaluation for actualized actions, but also self-evaluation for tacit plans. This crucial mobilization of reward systems in consciousness is missing from Koch's book.

In a field that is plagued by more philosophical than scientifically sound controversies, Koch's book is, on the whole, remarkably balanced. But it does not touch on one crucial issue: can a model of consciousness be formalized in mathematical terms? Is it realistic to conceive a computer model or a robot that implements the conscious versus non-conscious processing of sensory stimuli? My own answer would be a resounding 'yes'. I hope that the next generation of neuroscientists, inspired by reading *The Quest for Consciousness*, will soon start planning their experiments. ■

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Keep it simple

Deep Simplicity: Chaos, Complexity and the Emergence of Life
by John Gribbin
Allen Lane: 2004. 272 pp. £18.99

Mark Buchanan

The search for simplicity is perhaps the most basic theme of all science. As the late social and political scientist Herbert Simon put it, the purpose of science is "to find meaningful simplicity in the midst of disorderly complexity". In his new book *Deep Simplicity*, John Gribbin explores this theme in the context of two great movements of modern science — chaos and complexity — and argues that the discovery of simplicity hiding behind surface complexities will soon explain the origin of life itself.

Gribbin suggests quite plausibly that humans — and, by implication, our societies — are among the most complex things in the Universe. At the atomic level, individual particles follow relatively simple physical laws. It is out of the interactions of many particles, and then of objects made of them, that complexity arises, producing conductors and liquid crystals, biomolecules, living organisms, ecosystems and human culture. On a larger scale, the world again becomes relatively simple, for in the interior of a large planet, or a star, "gravity crushes any structure out of existence". Complexity occupies a middle world, which is also, probably for good reason, our world.

The aim of the book is to explore how simplicity arises on this level, and how it can be identified. But first Gribbin establishes why complexity, or at least the appearance of complexity, should be expected.

The classical newtonian view of the fully predictable Universe dominated science for two centuries. But as Gribbin points out, this world view actually rested on a vast leap of faith — on the supposition that if scientists were clever enough to solve Newton's equations for any system of interacting particles, their solutions would be just as regular as the periodic motion of two bodies, reflected in the elliptic orbits of the planets about the Sun. In 1890, the French mathematician Henri Poincaré proved otherwise: that the resulting motion can be irregular and unpredictable, even when only three bodies are involved. "It may happen," Poincaré wrote, "that small differences in the initial conditions produce very great ones in the final phenomena." This, in modern parlance, is chaos, and it implies — in the more general context of dynamical-systems theory — that scientific prediction over long periods of time is generally impossible.

Gribbin tells the story of the modern rediscovery in the 1960s and 1970s of Poincaré's insight. This is an exciting tale but has been told before, most notably in James Gleick's bestseller *Chaos* (Heinemann, 1988). On the positive side, the discovery of chaos reveals that many highly erratic phenomena, ranging from chemical reactions to fluctuations in biological populations, may actually arise from very simple underlying dynamics. This is one way that simplicity often lies behind complexity.

Gribbin then weaves the story of chaos together with more recent developments, and with a host of topics now gathered together under the term 'complexity science'. The book moves rapidly from spontaneous pattern formation to the mathematics of fractals and the idea of self-organized criticality, examining its relation to earthquakes, mass extinctions and a vast range of other prominently unpredictable phenomena. The book celebrates the contemporary emphasis, especially in physics, on seeking the explanation of complex phenomena through simple dynamical models of growth and evolution. The lesson is the same everywhere: what appears as surface complexity often has its origins in dynamical simplicity. Importantly, Gribbin points out that modern computers have played a central role in making the complexity sciences possible, altering not only the content of science but the way it is done.

Much of *Deep Simplicity* will be familiar to anyone who has read about chaos and complexity before, but Gribbin does his usually excellent job of making complicated ideas accessible to a broad readership, and the book would certainly make an excellent non-technical introduction to this way of thinking. One minor shortcoming is that the book could have been written in, say, 1998, and still contained virtually all the same material. This is a little disappointing, as the past five years have witnessed a flowering of the complexity sciences and their successful application to a broad range of scientific topics.

Gribbin is something of a phenomenon of science writing, judging from his prolific output over the past two decades. In *Deep Simplicity*, perhaps, he doesn't quite succeed in showing how chaos and complexity will soon "explain the origin of life itself". But he breathes life into the core ideas of complexity science, and argues convincingly that the basic laws, even in biology, will ultimately turn out to be simple. ■

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