other individuals with the same gene to reproduce. So, a gene that promotes an action that is costly to the individual might be able to survive if it provides a benefit for a relative. And because close relatives share more of the same genes than distant ones, interactions between kin increase the likelihood of maintaining such acts of altruism.

Wilson argues that Hamilton's model is based on overly simplistic assumptions about population structure. It does not take into account indirect fitness advantages (all the people who are helped by the people we help, for example). Inclusive fitness is a special case of Wilson's model, but he asks: "Why not simply use the general theory everywhere?"

Many of Wilson's ideas in this book will stand the test of time. However, he is perhaps a bit too assertive in the way he frames his theory. He is excessively critical of inclusive fitness theory, repeatedly claiming that it is "incorrect", and saying that the literature on it has produced "meager" results. Yet inclusive fitness theory has prompted much empirical and theoretical investigation, with more than 1,000 articles published in the past 40 years. Albert Einstein, after all, didn't disparage the numerous physics experiments showing that Isaac Newton's simple formulae work remarkably well under specific conditions.

Wilson would, I am sure, object to this characterization on the grounds that inclusive fitness theory accounts for a much smaller subset of his own theory than Newton's work does for Einstein's. In fact, Wilson continually claims that inclusive fitness theory works only "under stringently narrow conditions". But there is no empirical evidence for this.

One of Wilson's laments is that we have few examples of attempts to specifically measure fitness and interaction networks to test inclusive fitness theory — but the same is true for his own theory. So whether the special case of inclusive fitness is a reasonable simplification remains an open question.

Fortunately, Wilson's provocative and important book gives us a new way to test this theory coherently. ■

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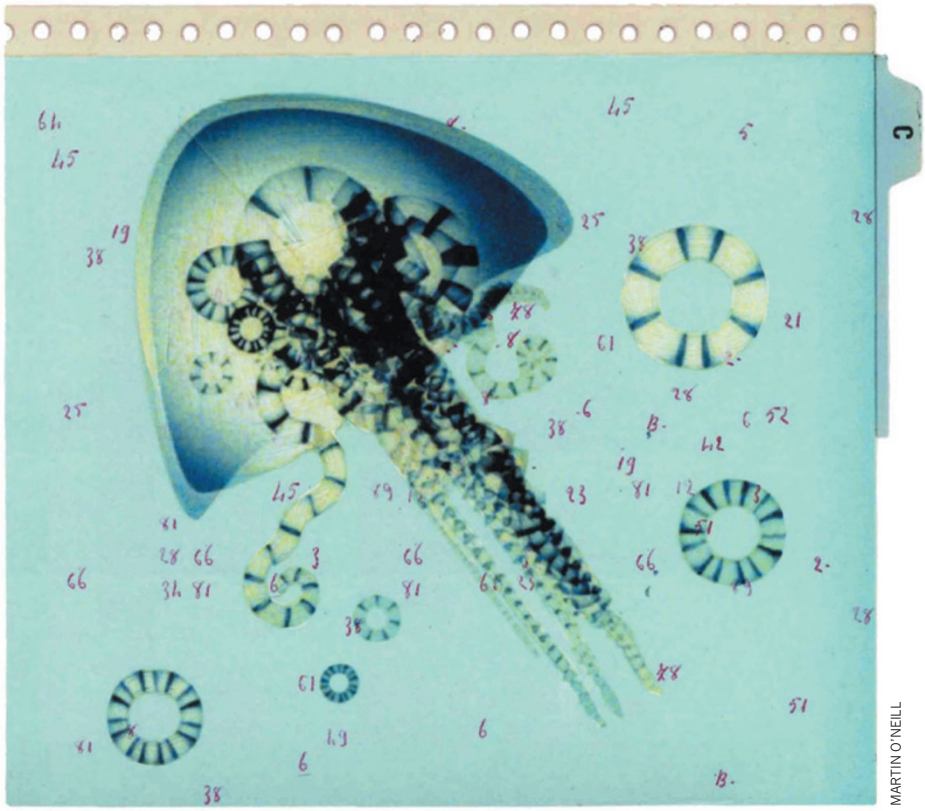


MARTIN O'NEILL

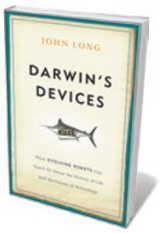
ROBOTICS

Enter the evolvabot

Noel Sharkey is engaged by a take on the intriguing overlap between biology and robotics.

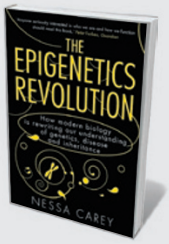
A book on robotics by a marine biologist sounds a bit fishy, but *Darwin's Devices* is anything but. John Long takes us on a journey through the wonderful, oceanic world of research on the evolution of the vertebrae of extinct species.

Long's work is innovative because of his use — and strong defence — of modelling with physically embodied robots, rather than the usual software simulations of computational biology. He is also unusual, as a biologist, for the way that he exploits artificial evolutionary methods called genetic algorithms to test evolutionary hypotheses.



Darwin's Devices: What Evolving Robots Can Teach Us About the History of Life and the Future of Technology
JOHN LONG
Basic Books: 2012. 288 pp. $26.99, £17.99

Long's accounts of justifying his research to sceptical fellow biologists contain both triumphs and difficulties. He relates how, when a colleague asked what robots have to do with biology, he replied that they are



The Epigenetics Revolution
Nessa Carey (Icon Books, 2012; £9.99)
Epigeneticist Nessa Carey brings the emergent and controversial field of epigenetics to a wide audience. Carey's lively vision of how DNA works resembles a film script, with "plenty of room for interpretation and retakes", noted reviewer Jonathan Weitzman (*Nature* **477,** 534–535; 2011).

The Big Thirst: The Secret Life and Turbulent Future of Water
Charles Fishman (Free Press, 2012; $16)
In what reviewer Margaret Catley-Carson called a "torrential flow of a book", journalist Charles Fishman argues that we must value water. He shames overusers, praises heroes and sets out policy challenges (*Nature* **473,** 27–28; 2011).

used to model extinct species — and how he realized, "with dread", that the question would haunt his research. This book is his answer.

The opening chapters lay a solid foundation for the use of robots to model biological theories, underlining why testing models in the physical rather than the simulated world is important. In the rest of the book, Long describes a series of his experiments with the robots he dubs evolvabots. Each leads on to the next, adding only what is necessary to get to the next level: a virtue in any scientific model.

Long's chatty style made me laugh out loud at times. But beneath the levity lie robust and sometimes powerful arguments about biomimetics. He moves from his childhood love of fish to his graduate work on the biomechanics of marlin vertebral columns. He gives us an accessible run-through of evolution, then moves on to the design issues of engineering his evolvabots, including key decisions about which features of the animal to include. His guiding principle follows Albert Einstein's famous dictum to be as simple as possible, but no simpler.

The brain alone, Long shows, is not sufficient to explain behaviour. As he asks, "Who needs a brain when you have a smart body?" He argues that brainless robot bodies moving through the real world can exhibit seemingly complex cognitive behaviour with little computation. Few have demonstrated this point better than biological cyberneticist Valentino Braitenberg, in his book *Vehicles: Experiments in Synthetic Psychology* (MIT Press, 1984), and Long makes ample use of Braitenberg's core ideas. Robotics researchers such as Rolf Pfeifer, with his morphological computation, have carved out this territory, but Long offers new twists — such as questioning where the brain begins and ends.

By chapter six, sleeves rolled up, we are at the nub of the science. It is time for the test results of Long's key evolutionary hypothesis: "selection for enhanced feeding performance and predator avoidance would increase the number of vertebrae" for robot models of extinct fish. Long is in his stride here and gets down to the technicalities, telling us much about the real evolution of sea creatures.

I was intrigued to see how a biologist might use genetic algorithms to test specific hypotheses about bodily evolution and its impact on behaviour. Such algorithms have been used widely in biologically inspired robotics to create artificial gene strings that determine how robots behave; they allow researchers to run through thousands of machine generations in hours. For each generation, the best robots are selected using a mathematical fitness function rather than natural selection, and their genes are incorporated to make the next generation and simulate breeding.

MARTIN O'NEILL

WHO NEEDS A BRAIN WHEN YOU HAVE A SMART BODY?

But in Long's experiments, the evolving artificial genes do not directly change the behaviour of the robot fish. Instead, they add vertebrae to the robot bodies, indirectly altering the behaviour of the robots to make them better at feeding and avoiding predators. This drives home Long's point that behaviour is created in the interaction between the physically embodied robot and the world.

There are minor problems with Long's discussion of genetic algorithms. He seems to think that they tell him more about evolution than may be the case. At one point, he writes: "I think Darwin, a keen observer, would have loved watching our robots evolve." But although Darwin would have been intrigued, I doubt he would have gained much scientifically from pure observation of these robots. Unlike natural selection, a genetic algorithm has an experimenter-designed fitness function, which demands a God-like decision about what features are important in choosing the fittest artificial gene strings.

Often, if a genetic-algorithm experiment does not work as hoped, we can make minor modifications to the fitness function and selection procedure until we get the desired results. So refuting a hypothesis is not always meaningful, because results can be dependent on the experimenter's design. A positive outcome, however, has different implications: if a genetic algorithm produces a simple model or mechanism that fits current data from a real creature, we have a scientific hit.

Aside from that, and a final chapter that tries to cram in too much — it includes 20 pages on the military uses of robotic fish, in which the arguments seem rushed and a little naive — this is a sound and hard-hitting work. It is also an insider's view of the scientific world: an honest account of the cut and thrust of academic ambition. Because Long questions his own methods and motivations throughout, his book lacks the pomposity of many texts that motivate through weak appeals to scientific method.

I read this book for the robotics, but I learned more about fish and the evolution of their bodies. *Darwin's Devices* represents a step forward in biomimetics. And, cleverly hidden among the discussions and the humour, gems of scientific philosophy shine. ■

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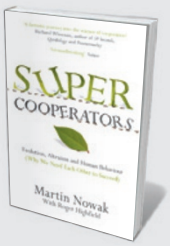
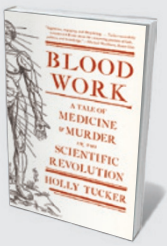


SuperCooperators
Martin Nowak with Roger Highfield
(Canongate, 2012; $15)
In a treatment that reviewer Manfred Milinski said was as pacy as a novel, biologist Martin Nowak sets out cooperation as the driving force of evolution, and defends his objections to kin-selection theory (*Nature* **471,** 294–295; 2011).



Blood Work: A Tale of Medicine and Murder in the Scientific Revolution
Holly Tucker (Norton, 2012; $15.95)
Medical historian Holly Tucker provides "page-turning insight" into the messy past of blood transfusions, focusing on Anglo-French rivalry during the scientific revolution, found reviewer W. F. Bynum (*Nature* **472,** 164–165; 2011).