

lent, modestly priced, and generally accessible book. Davies is well qualified to do this. He is a member of a group of scientists at the Australian National University who developed much of the modern synthesis of the underlying dynamics and geochemistry associated with global tectonics. His contributions include the relationship of convection within Earth to gravity anomalies and topography at the surface and the underlying processes beneath such hotspots as Hawaii and Iceland.

Davies begins with the history of his science, which is essential for understanding the development of current dynamic theory and the confusing nature of its terminology. Forty years ago, Earth sciences was mainly descriptive. Geologists since the late 1700s had developed a relative geological time scale, locally from positional relationships of rocks and globally from fossils. Beginning at the start of the 20th century, they forged an absolute scale.

It was commonly known that Earth had an eventful history, with mountains and their subsequent erosion being the most eye-catching feature. No one knew much about the underlying processes. Geophysicists had developed effective methods for remotely sensing the shallow subsurface and, on a global basis, had considered topics such as Earth tides and hydrostatic ellipticity, and they had determined the deep structure of Earth from seismic studies. Seismologists routinely detected and catalogued earthquakes, but they could not explain why more earthquakes occurred in some places than in others.

By 1970, plate tectonics had unified the concept of continental drift with the more recent concepts of seafloor spreading and subduction. The initial evidence for the hypothesis was largely kinematic, including magnetic stripes on the seafloor and the directions of fault-slip inferred from earthquake studies. The initial investigators learned much by just considering the geometry of the surface plates and their physics down to about 100 km.

In the modern synthesis, plate tectonics is a form of thermal convection. In fluid-dynamics terms, the oceanic plates are the upper thermal boundary layer, which founders into the mantle as slabs. The negative buoyancy of slabs and lateral temperature contrasts that exist at midoceanic ridges drive flow. The mantle cools slowly with time, and radioactivity heats it from within. Earth's core

heats the mantle from below, giving rise to another feature of the modern synthesis: mantle plumes, which supply some 10% of the heat reaching the surface. Plumes are thin conduits formed by and carrying hot, low-viscosity material up from great depths. This hot mantle material impinges on the base of the plates, giving rise to hotspots. In the case of Hawaii, the plate moves relative to the top of the conduit, producing a series of volcanic islands. The process is analogous to a series of burns caused by moving one's hand slowly over a candle.

This is a general interest book on global Earth processes for the educated public, including K-12 teachers. Most of it is accessible to anyone having knowledge of high-school science. Davies clearly explains the way scientists dimensionally obtain the magnitude of physical quantities without having fully to solve complex problems. He provides concise vector calculus overviews of heat and mass transfer for the mathematically inclined. The book is quite usable as a gateway to the geodynamics literature or as an overview for other types of Earth scientists. Specialists will find valuable Davies's insights on geochemistry, plumes, and the effect of phase changes on convection.

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Small Worlds: The Dynamics of Networks between Order and Randomness

 Duncan J. Watts
Princeton U. P., Princeton, N.J.,
1999. 262 pp. \$39.50 hc
ISBN 0-691-00541-9

The term "small worlds" in Duncan J. Watts's book title refers to the observation that everybody is connected with everybody else through a short chain of acquaintances. A character, Ouisa, in John Guare's play *Six Degrees of Separation* makes the claim that we are all, presidents, gondoliers, and Eskimos alike, separated by only six other people. So the phenomenon is sometimes referred to as "six degrees of separation."

Computer scientist Brett Tjaden applied the same small-worlds idea to the links among actors who have performed in movies together. If you have been in a movie with Kevin Bacon, for example, then you have a "Bacon number" of one. If you have never been in a

film with Kevin Bacon, but have been in a film with someone who has been in a film with Kevin Bacon, you have a Bacon number of two, and so on.

The first person to have his name associated with this small-worlds phenomenon is the great 20th-century mathematician and cofounder of probabilistic graph theory, Paul Erdős. People's "Erdős numbers" are a measure of how close they are to Erdős, via their coauthors; four hundred seventy-two people can boast an Erdős number of 1, since they have coauthored a paper with this prolific scientist. Of course, most people do not have Erdős numbers, since they are not scientists or mathematicians, so there is a limit to the applicability of the idea.

It is quite easy to understand the small-world idea: If each person knows, say 100 random others, each of whom know some 100 other random persons, then, obviously, in only 6 links each, each person connects with $100^6 = 10^{12}$ persons, which means that (almost) everybody in the world is connected by not only one but by very many paths of length 6 to one another.

This goes for random networks, or random graphs. However, we know that a lot of local clustering occurs. The caveman knew only his nearest neighbors, who also knew only their nearest neighbors. It is very likely that a lot of our closest friends are also our friends' closest friends. This makes the world "larger": More links are needed in order to reach everybody.

The extreme "large" world emerges if we consider people located on a simple d -dimensional regular lattice of a given large size, as for instance a one-dimensional ring of size N , on which everybody knows only his or her nearest neighbors. The maximum number of links between any two persons on the ring is $N/2$, which could be a very large number.

Most real networks are somewhere between the two extremes of randomness and order. We have some local connections, as in the ring model, but also some distant acquaintances. Duncan Watts's claim to fame is the introduction of a small number of random shortcuts into the ring model, which he described in a recent *Nature* paper he coauthored with Steve Strogatz of Cornell University. By tuning this number, one produces a phase transition, or rather a smooth crossover, between the small world represented by the random network and the large world represented by the lattice. Watts and Strogatz argued that three disparate systems—the neural

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network of the worm *Caenorhabditis elegans*, the power grid of the western US, and the collaboration graph of film actors—can all be described in this way.

This is, roughly, the content of Watt's book. The ideas are applied to many phenomena, and the (rather simple) mathematics is presented in every detail. A rather unrelated and quite uninspired chapter on cellular automata and coevolutionary games is tagged on.

Watt's interest in networks came from a study of synchronization of biological oscillators—crickets, to be precise. Each cricket listens to the chirps of other crickets and adjusts its chirp in response, and the whole population winds up oscillating as one. But who is listening to whom? How are the crickets linked? Clearly, long-distance shortcuts increase the tendency towards synchronization. Also, random shortcuts facilitate signal propagation in communication networks as well as computational power in computer networks. In our modern internet world, everybody is directly connected with everybody, so our "internet number" is unity—the extreme small-world case.

Watts addresses an extremely interesting subject, but in a weak and superficial way. The formation and the dynamics of networks are at the core of the entire field of complexity. Scientists like biological physicist Stuart Kauffman have spent lifetimes trying to understand the structure of genetic regulatory networks, and the entire field of ecology deals with the dynamics of networks of interacting species. Why does a given network have a given structure? What is the function of the network related to its structure—is something being optimized? The optimizing of networks is another subject of great interest, and has been applied by Andrea Rinaldo and coworkers at the University of Padova, Italy, to such problems as the formation of river networks. How about the network of economics agents, and of neurons in the brain? Why does the network of *C. elegans* have the geometry that it has? And there is much more.

The connectivity in all of these systems is certainly more involved than Watt's simple *ad hoc* structure; presumably there is often a whole range of interactions covering everything from the local neighborhood to far-away strangers. A visual inspection of the map of the western-states power grid depicted in the book indicates that this is indeed so. And what is

more important, despite the subtitle of the book, there is nothing here about the dynamics of networks; only the geometry of static, predefined structures is discussed. Watts seems to be strangely unaware of the scope of the exciting field that he seeks to cover. The reader who gets his information on networks only from Watts will be left in the dark with respect to an extremely exciting and active field of research.

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Principles of Seismology

▶ Agustín Udías
Cambridge U. P., New York, 1999.
475 pp. \$90.00 hc (\$39.95 pb)
ISBN 0-521-62434-7 hc
(0-521-62478-9 pb)

Introduction to Seismology

▶ Peter M. Shearer
Cambridge U. P., New York, 1999.
260 pp. \$74.95 hc (\$29.95 pb)
ISBN 0-521-66023-8 hc
(0-521-66953-7 pb)

As I read through the new textbook, *Principles of Seismology*, by the Spanish geophysicist, Agustín Udías, I was reminded of some of the scenes at the University of Tokyo, where I started my graduate study: dark hallways, high humidity, the particular smell of the building in which the department of geophysics was housed at that time. All of these came back to me as vivid memories. This is probably because Udías's new book somehow made me recall the first seismology textbook I read in that building, K. E. Bullen's *An Introduction to the Theory of Seismology* (Cambridge U. P., 1963).

This is not to say that Udías's book is a copy of Bullen's; it is definitely not. But it is probably based on the same tradition, perhaps a European tradition. It covers a wide range of topics, such as the brief history of seismology, basic physics of wave propagation, and various topics on the generation, propagation, and recording of elastic waves in Earth. It contains everything I would want my graduate students to have as their initial core knowledge of seismology as they delve into their research. All concepts, both theoretical and observational, are concisely explained within a few pages, and descriptions are crisp and

clear. Overall, the whole book is built on the accumulation of such concise, well-written short segments.

Udías's book is an intermediate-level textbook and assumes a good mathematics and physics background. Upper-level undergraduate students in physics may be able to handle it, but in general it seems most appropriate for first-year graduate students. It is easier to read than the now classic seismology textbook by Keiiti Aki and Paul G. Richards (*Quantitative Seismology*, Freeman, 1980), which I struggled through as a graduate student. And yet this book covers almost the same range of material as volume 1 of Aki and Richards; any student who can digest it will be well equipped to attack any seismological research topic. Explanations are comprehensive, in that they do not skip essential derivation processes, but they are more mathematical than physical, which is not necessarily to my personal taste. For example, Udías spends a page deriving the Eikonal equation in ray theory. In my opinion, this could have been shortened greatly by invoking a simple physical argument. On the other hand, there may be nothing wrong in requiring serious students of seismology to go through such algebraic details.

Udías's book aims at the same audience as *Modern Global Seismology* by Thorne Lay and Terry C. Wallace (Academic, 1995); the Lay and Wallace book has more real examples from current research topics and is thus superior in providing exposure to current data. But Udías presents theoretical concepts in a crisp and complete manner; his work seems superior in that regard.

Peter M. Shearer's *Introduction to Seismology*, on the other hand, is a practical, typically American textbook. Although it is not clear how much time we would need to go through Udías's book (less than some Russian novels), Shearer's book clearly aims to be the best textbook for a one-quarter course. There seems to be a relationship: Quarterly instruction consists of ten weeks; this book has 11 chapters, with the last chapter being called "Miscellanea."

The targeted level for Shearer's book is slightly lower than that for Udías's. The material in general is easier to follow, perhaps because explanations are more physical and intuitive than those Udías uses. Shearer's book is certainly limited in scope by the selection of topics appropriate to a one-quarter course, but it touches on essential aspects of seis-