BOOKS: GENERAL SCIENCE

Unexpected Consequences of Connections

Ian Foster

Linked
The New Science of Networks
by Albert-László Barabási

Perseus, Cambridge, MA, 2002. 288 pp. $26, C$39.50. ISBN 0-7382-0667-9.

Nexus
Small Worlds and the Groundbreaking Science of Networks
by Mark Buchanan

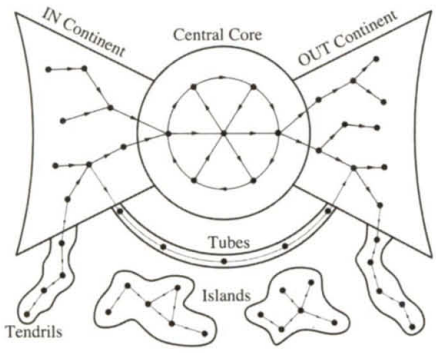
Norton, New York, 2002. 235 pp. $25.95, C$37.99. ISBN 0-393-04153-0.

Small World
Uncovering Nature's Hidden Networks

Weidenfeld and Nicholson, London, 2002. 235 pp. £18.99. ISBN 0-297-60742-1.

The Internet. Metabolic pathways within a cell. Data-sharing relationships in scientific collaborations. Food webs. Pathways of HIV infection. Corporate board memberships. What principles govern the structure of such systems? What statements can be made about their properties? Might these diverse systems have something in common, beyond the fact that they can all be thought of as networks—collections of nodes connected by links? Two recent books, Albert-László Barabási's *Linked* and Mark Buchanan's *Nexus*, tell the fascinating story of how these questions came to be posed and ultimately answered. Both also discuss the often-surprising implications for a broad range of issues ranging from the robustness of food webs and the Internet to strategies for combating AIDS.

The initial work on networks assumed simply that networks were random graphs, in which any pair of nodes has an equal probability of being connected. In the early 1960s, the inimitable Paul Erdős and his collaborator Alfréd Rényi derived elegant results concerning such things as the expected diameter (maximum distance, in links, between any pair of nodes) of a network as a function of the average number of links per node. Of course few real networks are randomly connected. For example, a network of acquaintances is likely to be clustered: if A is friends with B and C, then likely B and C also know each other. Intuitively, one might imagine that such clustered networks would have a large diameter. But in a famous 1967 experiment (*1*), sociologist Stanley Milgram had the bright idea of asking 160 people in Kansas and Nebraska to each direct a letter to a particular person in Massachusetts by sending it to an acquaintance whom they thought might be able to forward it to the target. To Milgram's surprise, 42 letters eventually arrived after an average of only 5.5 hops. Thus the famous "six degrees of separation." Apparently, a network could have both clustering and a small diameter.



Continental divisions. Networks with directed links, such as the Web, are fragmented.

This result remained a curiosity until the mid 1990s, when Duncan Watts and Steve Strogatz at Cornell used computer simulations to demonstrate that small-world networks could be created by adding a small number of remote links to a network otherwise characterized by purely local links (*2*). These few remote links reduce the diameter of the network dramatically.

The Internet offered the first opportunity to study really large-scale networks. For example, in 1999 Barabási and Réka Albert, a fellow physicist, studied links among Web pages within their home institution of Notre Dame. They discovered that the number of links per node was not distributed in a bell curve around a mean (as Erdős, Rényi, Watts, and Strogatz had assumed) but followed a power law, with the number of nodes having exactly k links given by $N(k) \sim k^{-\gamma}$ for some degree γ. This difference has two important implications for network properties. There is no characteristic number of links per node (as in a bell curve); instead, the network is "scale free." And the tail of a power law declines far less precipitously than that of a bell curve. This "fat tail" property allows for the occasional highly connected node, such as the CNN home page, Erdős himself in a co-authorship network, and adenosine triphosphate in a cell's metabolic pathway. Albert and Barabási also proposed a mechanism for the emergence of power-law structures. If networks are created via the incremental addition of nodes, and if each new node links preferentially to nodes that are more connected, then a scale-free network results. This preferential attraction rule has proven to be a powerful explanatory device.

Results such as these are exciting because they suggest new approaches to understanding the properties of a variety of systems. For example, early analytic studies based on random graph theory concluded that food webs become more fragile as they get larger. In contrast, studies that take into account the scale-free structure often found in real webs reach the opposite conclusion: larger scale-free webs are less susceptible to random damage. A less pleasant example: whereas in a random graph an infectious disease dies out once the probability of infection falls below a threshold, there is no such threshold in a power-law network. However hard it is to infect someone else, the highly connected nodes serve as reservoirs. This has a potentially disturbing implication for AIDS treatment: if the cost of retroviral drugs prohibits their prescription to everyone, then perhaps those drugs should be given preferentially to people with the most sexual partners.

Linked and *Nexus* both tell the story of networks well and in similar ways. Each traces the historical development of the key ideas and enlivens its presentation with anecdotes and observations on practical significance. Both books are well researched and well written. Although I must express a personal preference for Barabási's account, because of its semi-autobiographical nature and graceful and entertaining style, both are well worth reading. Despite being familiar with the technical details, I found both books wonderfully revealing and thought provoking in terms of the broad relevance of the ideas and their future implications.

The two books also reveal the state of the science of networks. In some respects, the field currently resembles the Wild West: The territory has been discovered and the first trails laid; but much remains unexplored, "boosters" overstate the value of virgin land, and many riches remain undiscovered. For example, in Buchanan's account small-world ideas are all-important and scale-free concepts are only a wrinkle; in Barabási's telling of the story, it is the discovery of scale-free properties that makes all the difference. In practice, both ideas are clearly important, but their relative significance in terms of the roles that they play in actual networks is still being determined. Similarly, the books approach the world as one newly armed with a hammer and seeing nails everywhere. Both authors are largely uncritical of the explanatory power of the theories they describe. Barabási, for in-

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stance, points out that one can map from a network fitness model to a Bose gas, and he then suggests that this mapping serves as an explanation of network fitness that allows one to make predictions about network structure: e.g., that "winner takes all" networks will arise, just as Bose-Einstein condensates form. But the relationship here is evocative, not explanatory. Though it may help guide the search for the mechanisms that determine the structure of a particular system, it does not describe those mechanisms.

Both *Linked* and *Nexus* observe correctly that these revolutionary ideas on network structure offer profound new insights into our world. Meanwhile, researchers continue both to validate these principles via increasingly careful studies of real networks and to extend and revise the ideas themselves. Such work continues to turn up surprises. For example, one recent study suggests that the scale-free interconnection structure of the Internet is not explained adequately by preferential attachment (*3*). So although Barabási and Buchanan succeed admirably in telling the story of how structure was first revealed within networks, the last word on this topic remains to be written.

References

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2. D. Watts, S. Strogatz, *Nature* **393**, 440 (1998).
3. W. Willinger, R. Govindan, S. Jamin, V. Paxson, S. Shenker. *Proc. Natl. Acad. Sci. U.S.A.*, **99** (Suppl. 1), 2573 (2002).

BOOKS: PSYCHIATRY

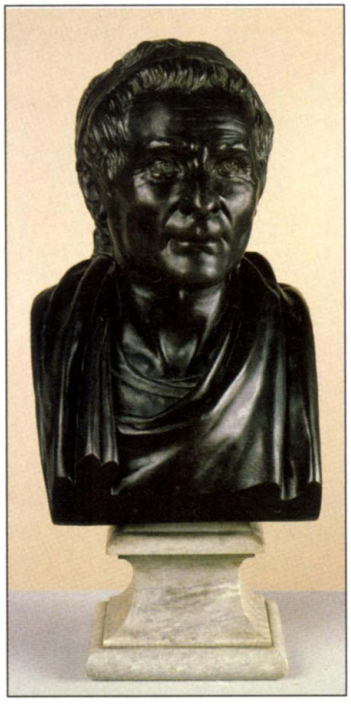
Marketing Drugs to Mend Minds

Herbert Y. Meltzer

In the last century, psychopharmacology produced the first effective drug treatments for schizophrenia and other mental illnesses and contributed greatly to the development of hypotheses about the biological basis of mood and anxiety disorders, schizophrenia, and other psychoses. David Healy, a distinguished but controversial psychiatrist and historian (*1*) at the University of Wales College of Medicine, describes these developments, especially those concerning antipsychotic drugs, in *The Creation of Psychopharmacology*. Furthermore, he prophesies that current research linking psychopharmacology to pharmacogenomics and brain imaging will lead to control of the major mental illnesses, so that psychopharmacology and psychiatry can and will turn their attention to the treatment of personality disorders and self-improvement in normal individuals. What many will find most provocative about this book and its predecessor, *The Antidepressant Era* (*2*), is the recommendation that powerful psychotropic drugs, including neuroleptics such as chlorpromazine, could or should be available without prescription.

The Creation of Psychopharmacology
by David Healy
Harvard University Press, Cambridge, MA, 2002. 479 pp. $39.95, £27.50, €39.95. ISBN 0-674-00619-4

The Creation of Psychopharmacology begins with an accurate and lively history of the treatment of psychosis and other deviant behaviors in the 18th and 19th centuries. After discussing the 1952 discovery of chlorpromazine (the first antipsychotic drug, which arguably launched the modern era of psychopharmacology), Healy offers a less detailed account of the remarkable advances which followed from its discovery and initial clinical trials. The author pays special homage to the 18th-century philosopher Jean-Jacques Rousseau, who was an exhibitionist in his youth and died in the throes of a psychotic disorder with paranoid features. He argued for the perfectibility of mankind, for trust in instinctual knowledge of what is in one's best interest, and against the corrupt and corrupting social order. His blend of Enlightenment and Romantic ideas exerts a powerful influence on Healy's conceptions and conclusions about psychopharmacology and on his prescription for the future. In the author's interpretation, "the antipsychotic story shows very clearly that the clash of a rationalist psychiatry with a romantic antipsychiatry [by which Healy refers to the writings of R. D. Laing, Thomas Szasz, and Michel Foucault, among others] did not lead to the triumph of either but rather led to the takeover of both by a psycho-pharmaceutical complex." Thus, a recurring theme in the book is Healy's blistering critique of the pharmaceutical industry. He believes the industry, aided and abetted by misguided public policy, has caused considerable iatrogenic illness and engaged in unconscionable profiteering. It has shaped our sense of self with drugs like the selective serotonin reuptake inhibitors, and, at the same time, it has limited access to drugs that could safely and effectively do so. Healy notes, "The possibility that marketing [of psychotropic drugs by the pharmaceutical industry] now determines culture is at the heart of this book."



An Enlightenment perspective. In his *Confessions*, Jean-Jacques Rousseau admitted to behaviors beyond his control and wondered about their origins. Healy hopes that any future Rousseau should be able to decide freely whether psychiatric interventions have anything to offer him.

The drug industry is not the only target of the book. Healy criticizes the U.S. legislation that regulates psychotropic drug approval and requires prescriptions from physicians to obtain these drugs. He faults members of the academic community who, he claims, have made gross errors in the conceptualization of—and, thus, the incidence of—depression, anxiety disorders, and catatonic schizophrenia, as well as in understanding the true nature of antidepressant and antipsychotic drugs (as "tonics" and "tension relievers"). He argues that, in some of their writings and lectures, these academics have been co-opted by the pharmaceutical industry to assist in the creation of a greater market for its wares. And he also criticizes research and clinical psychiatrists who have harmed schizophrenic and depressed patients by prescribing drugs in accord with misguided theories about their mechanism of action or with a lack of understanding that they may sometimes cause effects opposite to those intended (e.g., increase rather than decrease the risk of suicide).

The scientific literature, media, and government hearings document—and my personal experience agrees—that some, but not all, of these criticisms have merit. But hardly to the extent that Healy suggests, and rarely for the motives that he believes caused the problems. Some, though not all, of his criticisms are being addressed voluntarily by industry, academics,

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