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Connect, They Say, Only Connect

By EMILY EAKIN

The whiteboard in Duncan J. Watts's office at Columbia University was a thicket of squiggly blue lines, circles and calculus equations. Mr. Watts, an associate professor of sociology, had just begun a passionate disquisition on the virtues and liabilities of scale-free networks when the telephone rang. It was Alfred Berkeley, the vice chairman of Nasdaq, hoping to chat about the exchange's design.

Mr. Watts, 31, is a network theorist. And these days that means fielding frequent calls from powerful admirers like Mr. Berkeley — Wall Street moguls and government officials eager to tap into a nascent academic science that few understand but that many think may hold the key to everything from predicting fashion trends to preventing terrorism, stock market meltdowns and the spread of HIV.

Never mind that Mr. Watts's new book on the subject, "Six Degrees: The Science of a Connected Age," which will be published by W. W. Norton next month, is littered with the arcana of theoretical physics as well as charts and graphs that appear to require an advanced degree in math in order to decipher. Network theory is hot. Two other recent books on networks, "Linked: The New Science of Networks" (Perseus, 2002) by Albert-Laszlo Barabasi and "Nexus: Small Worlds and the Groundbreaking Science of Networks" (W. W. Norton) by Mark Buchanan, have already sold tens of thousands of copies.

And that's not counting sales in the burgeoning genre of consumer studies, where network science terms and concepts are invoked with near religious fervor. From Malcolm Gladwell's three-year-old best seller, "The Tipping Point," to just-published analyses like "The Influentials" and "Branded: The Buying and Selling of Teenagers," the shelves at Barnes & Noble are laden with books alternately applauding and deploring the importance of things like hubs, connectors, mavens and influencer teens for creating fads, cementing brand loyalty and swelling profits.

"Network theory has become a bit of a fad," Mr. Watts conceded after hanging up the phone. "I spend half my time telling people I think it's relevant to a lot of problems people care about and half my time trying to tone down the hype."

Network scientists study networks: collections of people or objects connected to each other in some way. Think of the 1.5 million Manhattan residents or the 30,000 genes inside a human cell. Such networks, scientists argue, behave in ways that can't be understood solely in terms of their component parts. Without knowing what every single person or object within the network is doing, they say, it's nevertheless possible to know something about how the network as a whole behaves.

Stated that way it sounds simple. But as an intellectual approach, network theory is the latest symptom of a fundamental shift in scientific thinking, away from a focus on individual components — particles and subparticles — and toward a novel conception of the group. As Mr. Barabasi, a professor of physics at the University of Notre Dame, put it: "In biology, we've had great success stories — the human genome, the mouse genome. But what is not talked about is that we have the pieces but don't have a clue as to how the system works. Increasingly, we think the answer is in networks."

Not that network theory is an entirely contemporary creation. Its roots stretch back nearly 300 years, to Leonhard Euler, a brilliant 18th-century Swiss mathematician who dabbled in nearly every branch of modern science, from algebra to astrophysics. In 1736, Euler took up a brain teaser that had preoccupied the residents of Königsberg, a Prussian town on the Pregel River not far from where he lived: how to cross all seven bridges in town without crossing the same bridge twice. No one had been able to pull off the feat, but Euler provided the mathematical proof that it could not be done. To do so, he turned the problem into a network, depicting the bridges as lines and the landmasses they connected as nodes.

After Euler, mathematicians continued to analyze networks, then called graphs, enumerating the properties of orderly and static structures like ice crystals and beehives. No one thought to tackle networks of people or objects that were, as Mr. Watts puts it in his book, "actually doing something — generating power, sending data or even making decisions." Such complex real-world networks were assumed to be random: nodes and links connected in an arbitrary, disorderly fashion.

But clearly this is not always the case. "Imagine that you really did pick your friends at random from the global population of over six billion," Mr. Watts writes. "You would be much more likely to be friends with someone on another continent than someone from your hometown, workplace or school. Even in a world of global travel and electronic communications, this is an absurd notion."

Of course, studying a network of six billion people is an unfathomable proposition. It wasn't until the mid-1990's and the advent of powerful computers that network scientists were able to analyze real-life networks of significant size and complexity. And in doing so, Mr. Watts and his colleagues made some tantalizing discoveries. By 1998, they had found that networks as diverse as actors, power grids, the World Wide Web, the proteins in a human cell and the neurons of a wormlike organism called C. elegans aren't random at all but obey the same simple, powerful rules.

For example, whether the network has nearly a billion nodes (the estimated number of Web pages) or just half a million (roughly the number of actors in the Internet Movie Database), the paths between any two nodes tend to be extremely short — such that, for example, any two movie actors can be connected by an average of less than four links.

That may not seem like news to anyone who has played the Kevin Bacon Game — in which film actors invariably turn out to have starred in a movie with Mr. Bacon or else with another actor who has — or seen John Guare's play "Six Degrees of Separation." (The play was inspired by the famous 1967 experiment in which the Harvard social psychologist Stanley Milgram tried to prove that anyone in America could reach anyone else through a chain of fewer than six people.) But it was not entirely clear why these should all be "small-world" networks. As Mr. Watts points out, "There is nothing similar at all about the detailed way in which movie actors choose projects and engineers build transmission lines."

Eerier still, in 1999, Mr. Barabasi and a student at Notre Dame found that many of these small-world networks are also what scientists call scale-free. Many natural phenomena, including traits like height and I.Q., tend to cluster around an average (producing the familiar bell curve distribution). By contrast, scale-free networks go in for extremes: a few hubs — nodes with lots of links — and many more nodes with hardly any links at all. (Think of Google, the search engine, as a hub, and your personal homepage — which probably has just a few links — as an ordinary node.)

Mr. Barabasi's discovery startled scientists. "People always knew there were networks but thought they were random," he said. "To know they were nodes linked by hubs was very unexpected."

It also provoked a frenzy of research. For as Mr. Barabasi and his collaborator were able to show, the structure of scale-free networks has important practical implications. If you remove a few nodes at random, the network can still function normally. But if you remove one of the hubs, the results can be catastrophic.

Inspired by this insight, cancer researchers are now homing in on the cell's hub proteins in order to learn how to defend them from devastating attacks. Epidemiologists studying sexually transmitted diseases are arguing that it makes more sense to identify and treat the hubs in the transmission network than to give drugs to everyone. "The Bush administration's policy to give drugs to mothers with children is completely irrelevant to stopping AIDS in Africa," Mr. Barabasi said. "It's much better to go and target the hubs."

Even the United States military has begun recruiting network theorists to conduct counterterrorism research, with the goal of learning how to protect information and economic networks at home and destabilize terrorist networks abroad.

Yet just which network model describes human society remains a subject of fierce debate. Mr. Barabasi believes the human social network is scale-free with the expected smattering of richly connected hubs. Mr. Watts disagrees. "If you asked people to list the number of people they recognize, that could be scale-free, everyone recognizes Michael Jordan," he said. "But if you said, `Who would you trust to look after your kids?' That's not scale-free. As you start to ratchet up the requirements for what it means to know someone, connections diminish."

Is society a small-world network of the sort Milgram was interested in? Mr. Watts spent the past year trying to test that idea, using the Internet as a proxy for the world population. Whatever the results, he says, it's clear that human psychology has not yet adapted to the implications of a connected world.

"We like to think of our world as full of atomized individuals," he said. "But decisions people make and the actions they take are so hopelessly entwined with the behaviors of everyone else that it's difficult to draw the boundaries around the individual." When it comes to choosing a CD or explaining the success of Harry Potter, your preference may matter less than the network's.

But some scholars dismiss the network hypothesis altogether. Judith S. Kleinfeld, a psychologist at the University of Alaska at Fairbanks, prompted a flurry of media attention last year when she published an article questioning the validity of Milgram's small-world findings. Given the prevalence of networks — from power grids to airports to the Internet — it's tempting to assume that human society is a network as well, she says. But ultimately, that is impossible to prove.

"Duncan assumes the world is a matrix," Ms. Kleinfeld said in a telephone interview. "He wants to know how you get from one point on it to another. But what if the world isn't a matrix? What if people aren't all connected? What if they're islands in space?"

Mr. Watts admits that he faces daunting empirical challenges — and that overzealous scientists are a concern. "You can turn almost anything into a network," he said, holding up two papers he had received on the "small world of human language" and shaking his head. "So what?"

"When I'm brutally honest with myself, I think that if we can figure this out, we can answer some important questions. Other times, I think it's just too hard."