Book Review

A review of *Linked: How Everything is Connected to Everything Else and What It Means for Business, Science and Everyday Life*, by Albert-László Barabási, 2003. New York: Plume Books, 294pp. ISBN 0452284392. $15.00 USD.

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Barabási is a physicist at the University of Notre Dame and a very gifted writer. He wrote *Linked*, as the title suggests, to spread the word about "how everything is connected to everything else and what it means for business, science, and everyday life." The power in Barabási's writing lies primarily with the reader's recognition that Barabási is recounting his own efforts to understand how networks evolve and what the implications are for everything and everyone that is part of a network—which is, of course, literally "everything" and "everyone."

Barabási begins his book with the notion that networking, or "spreading the word" is not a recent phenomena. He recounts the story of MafiaBoy, the Canadian teen who attacked and paralyzed the Internet search engine Yahoo.com in 2000, and makes MafiaBoy's story analogous to that of St. Paul, another troublemaker who attacked a different giant and won. St. Paul is credited with spreading the word about Christianity on his 12-year walking journey of some 10,000 miles. The link? Both of these men understood systems. MafiaBoy recognized that he could cripple a significant portion of the Internet by disabling a main connector, such as Yahoo, on the World Wide Web. St. Paul's efforts were also not a random coincidence. He did not simply talk to whomever he chanced to meet in his travels. Instead he travelled from one major population centre to the next, recognizing that these

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locations were main connectors in his world, places from which others would help him to spread his gospel.

The recounting of the journey taken by Barabási and his team of graduate students and post-doctoral researchers continues with an examination of Leonhard Euler's development of graph theory. Euler's work served to demonstrate visually the structure of networks. Working with Euler's theories, Barabási's team could recognize formed networks. However, they were no further ahead in understanding their formation. To further their research, Barabási's team turned their attention to mathematicians Erdös and Rényi's proposition of random connection in networks. Random connections demonstrate that all nodes in a network share a roughly even number of links to other nodes and that graphing these nodes reveals a Poisson distribution, more commonly known as a bell or normal curve. However, Barabási asserts that Erdös and Rényi were not as interested in the study of network formations as they were in generating elegant mathematical theories. Thus, they could not be faulted when their theory of random connections in networks did not bear itself out in real world networks. Barabási's team found that in real world networks there exist connector nodes, which somehow gather many more links than other nodes, and their link gathering is by no means random. They called these heavily connected nodes "hubs."

"Sprinkled among every walk of life … are a handful of people with a truly extraordinary knack of making friends and acquaintances. They are connectors" (p. 55). Barabási uses this social analogy to describe hubs as the points in a network that link many nodes together, creating very short paths between nodes. He continues demonstrating the social examples of hubs using the "Bacon Factor" and Erdös numbers. The Bacon Factor is a popular bit of entertainment trivia, which demonstrates how any Hollywood star can be linked to actor Kevin Bacon within six "moves" between people. Erdös numbers are used by academics worldwide to describe their particular connectedness to the prolific mathematician. Erdös himself has the number "0," while those who have published with him have the number "1," and those who have published with the 1s have the Erdös number "2," and so on. It turns out the Bacon Factor is a bit of media-hyped hyperbole because research has shown that most Hollywood personalities are separated by no more than three "jumps," if the jumper knows which connections to make. Interestingly, it turns out that Bacon and Erdös are also very closely linked, so Bacon has his own, low Erdös number. Barabási shows though, that by removing Hollywood hubs like Robert Wagner (who is a much more critical hub than Kevin Bacon) or any quantity of Erdös number 2s, we end up with dramatically longer paths between nodes in those networks.

A graphic representation of networks demonstrates how nodes and hubs obey power laws and not normal distribution rules, as would be the case in

randomly connected networks. Where normal distributions, depicted by bell curves, show a scale that represents statistically common events, graphs depicting power laws show many small events co-existing with a few large ones. This phenomenon is known as a scale-free network, wherein there are no typical events. The discovery of scale-free networks was Barabási's group's first real indication that there might be some rules underlying the formation of networks. Using the aphorism "the rich get richer" as a metaphor, Barabási shows how growth, preferential attachment, and fitness are critical features of scale-free networks, and how this triad explains the development of hubs. In short, growth is the notion that networks are dynamic, growing one node at a time. Preferential attachment is demonstrated by the tendency of new nodes to link to existing nodes (hubs) that already have more links than other nodes. Fitness is the hub's demonstrated ability to attract new links. The scale-free feature of networks is the central theme in *Linked* and informs each of the book's subsequent sections.

The nodes and hubs of scale-free networks represent the network's greatest strength and its largest vulnerability. Because of a network's diverse and decentralized interconnectedness, it can easily respond to changes in its environment. Networks display a high tolerance for change and internal errors. Therefore, even if a hub is damaged or removed, there are likely enough other hubs and nodes to keep the network viable. However, as much as the removal of many individual nodes or a small number of hubs may not have lasting effects on a network, damage to several hubs, or to one super-connected hub is likely to cripple any network. Here we recall MafiaBoy's attack on Yahoo. The vulnerability to which networks are subject due to direct attacks on key hubs is at once a blessing and curse. Barabási explains that in terms of fighting epidemics such as HIV/AIDS, the ability to find and destroy hubs gives epidemiologists real hope, but in terms of world markets, the cascading failures in the Asian economic crisis of 1997 demonstrates the vulnerability that interconnectedness brings.

Much of Barabási's emerging understanding of networks is due to his group's efforts to map the World Wide Web. He relates that it was not an easy task to chart what little of the web they could, but their findings do have implications for other network research projects, including those on cells. Barabási identifies his web research as analogous to the Human Genome Project. While he asserts that the Project's results are extremely impressive and vital, they are not inherently sufficient to understand life itself. He writes that having the genome map is like having thousands of car parts in your backyard, but lacking the blueprint to put it all together to go for a drive. Interestingly, whereas in the book *Emergence*, Steven Johnson asks if the Internet is a self-learning system that may be able to become self-aware, Barabási asks not *if* the Internet's self-awareness will emerge, but *when*.

At the mention of MafiaBoy in the book's introduction and Barabási's related question about how vulnerable we all might be to organized attacks on our very ways of life, I was immediately put off and was preparing for three hundred pages of fear-mongering. However, when one considers that Barabási, living in the United States, was researching this book prior to the September 11th attacks, and wrote it shortly afterward, his evocations of terrorism and terrorist links are mercifully rare. He does address terrorist groups as self-organizing cells and makes a plea to the world's citizens to deal with the political, economic, and social problems that fuel the passions of terrorists. "We must help eliminate the need and desire of the nodes to form links to terrorist organizations by offering them a chance to belong to more constructive and meaningful webs." In this way, Barabási evokes notions of ethical responsibility, a central theme in complexivist thought (see, for example, Bai, 2003; Biesta & Egéa-Kuehne, 200l; Prigogine, 1997), and thus, his invocation of current events within his writing provides an illuminating reading strategy.

Linked not only offers insight into the process of network formation, but also provides insights into the recognition of existing networks, of which we are all nodes and hubs. In doing so, the book offers inspiration and challenges for educators and for educational research. For example, Barabási's research directs us to the need for an integrated curriculum, one that can help students recognize links between disciplines as well as the possible links between these disciplines and their futures. Teachers are complicit in helping to shape students' ever-emerging experience, and to become fully participatory citizens, students need the ability to make connections and to perceive connections already made. However, educators need to be mindful to make these links more explicit as students may not be naturally adept at transferring experience between domains. Teachers can help students develop the habit of making and recognizing links, confirming the students' own complicity in the life of the global community.

Barabási's book is thoroughly engaging and skillfully presented, so much so, that until I re-read his acknowledgements, I had entirely forgotten that English is not this Transylvanian's first language. He is unnervingly adept at employing diverse analogies and references to explain his ideas, which range from pop culture and mythology to history and current research in diverse natural and social sciences. This book plays out like a fine horror movie, manipulating tension and release as he appears poised to leave the general reader behind in a cloud of scientific dust, but then offers an easily recognizable example or story that reassures all readers that he has not abandoned them. As much as this book is written for a general audience, Barabási's extensive concluding notes section also offers the seasoned complexivist tantalizing perspectives to ponder.

References

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