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BOOK REVIEW

Linked: *How Everything Is Connected to Everything Else and What It Means for Business, Science, and Everyday Life* by Albert-László Barabási

Reviewed by Brian Grossmiller

From global economies to the Internet to cancer cells, networks are everywhere. Surprisingly, these networks often have very similar characteristics despite the very different circumstances in which they arise. In his book *Linked*, Albert-László Barabási, a nationally renowned expert on network theory, takes the reader on a journey through the development of science of networks.

The book explores both features common to many networks and theories as to how they develop and grow. Key terminology is also explained, such as how objects in a network are viewed as nodes and the connections between them as links.

One of the first network features explored is the "small world" phenomenon. This occurs when a network has a relatively small average distance between any two nodes compared to its size. For example, the idea in popular culture that there are six degrees of separation between you and any of the other six billion people on this planet is an example of a small world. The results of a study citied in *Linked* showed that of the 800 million documents on the World Wide Web in 1998 they were separated by an average of 19 links. Most networks have this property.

Another interesting network feature is the idea of a "hub" or "connector." These are nodes with an uncommonly large number of links. Internet search engines such as Yahoo! or Google are examples of hubs, which have far more than the average number of links pointing to them. The nation's air traffic system is another example; hubs such as New York or Chicago have connections to many more destinations than smaller airports.

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Hubs are often critical to navigating a network; in the example of airport travel one can reach much of the country in two flights by flying through a hub. The presence of hubs does have implications for the topology of networks. As explained in *Linked*, the distribution of links by nodes approximately follows a power law distribution in many networks. These are functions of the form $y=1/x^k$, the logistic function.

Networks will often have few hubs with a lot of connections and a much larger number of nodes with few connections. This type of structure provides resiliency against indiscriminate attacks on networks, as the bulk of the nodes targeted in such an attack have few connections, and the rest of the network can continue to function without them. Attacks targeted at hubs, however, can cripple a network by removing a small number of nodes from the network. This effect has been seen in denial-of-service attacks on websites.

Linked contains several examples of real-world networks and the potential risks that are inherent in them. The 1996 summer blackout, for instance, illustrates how a cascading failure can propagate throughout a network. A single power line failed and shifted its load to other nearby lines. These lines then failed and shifted their loads, which continued until 11 states and 2 Canadian provinces were without power. Other networks explored in the book include such disparate subjects as disease transmission and international financial arrangements.

The principal theory of network growth presented in the book is preferential attachment. Under a preferential attachment model, as new nodes are added to a network, they have a higher probability of connecting to existing nodes with a large number of links (the hubs). Intuitively this makes sense—as Barabási puts it, "the rich get richer." Models of networks generated under this theory are referred to as *scale-free networks*, as they follow a power law distribution and, if magnified, the tail of the distribution has the same shape as the overall distribution (see Figures 1 through 3).

Network theory can have some useful actuarial and business applications. Though not covered in *Linked*, some obvious examples include studying referral patterns among health care service providers and evaluating how failures at critical companies can propagate through the economy and potentially impact your firm's investment returns. Other applications might include the determination of non-obvious key personnel at your organization or attempting to target a marketing campaign preferentially at the social hubs of a community. Data collection for such efforts can be problematic, but in the absence of a formal evaluation a network approach can still be of use qualitatively.

I would highly recommend *Linked* to anyone interested in learning more about network theory. Though not a cookbook for business applications, it is an engaging read. Since reading *Linked* I have become much more aware of the networks around me. ▼

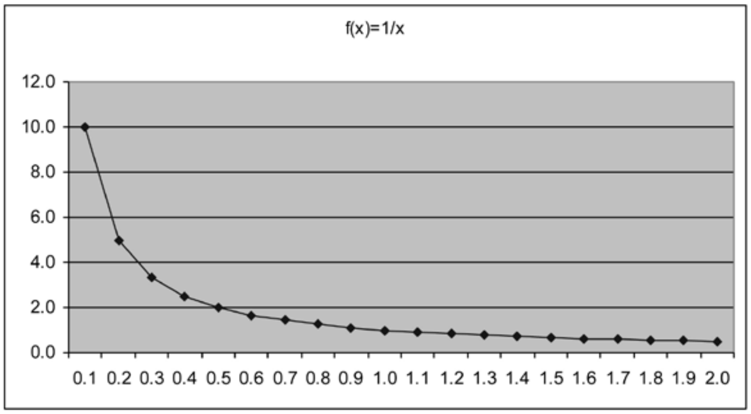

Figure 1: f(x)=1/x as x ranges from 0.1 to 2 with increments of 0.1.

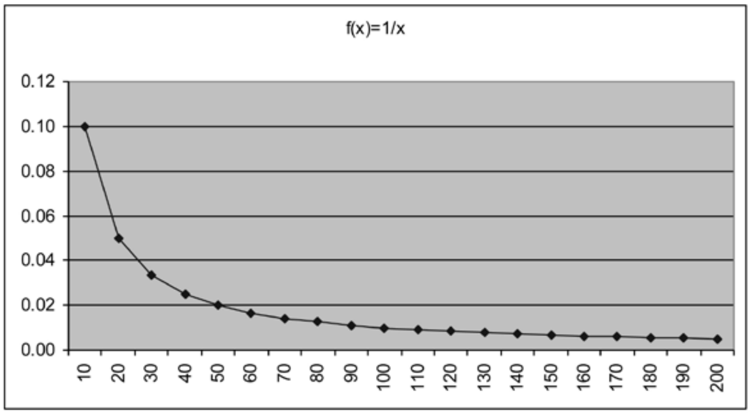

Figure 2: f(x)=1/x as x ranges from 10 to 200 with increments of 10.

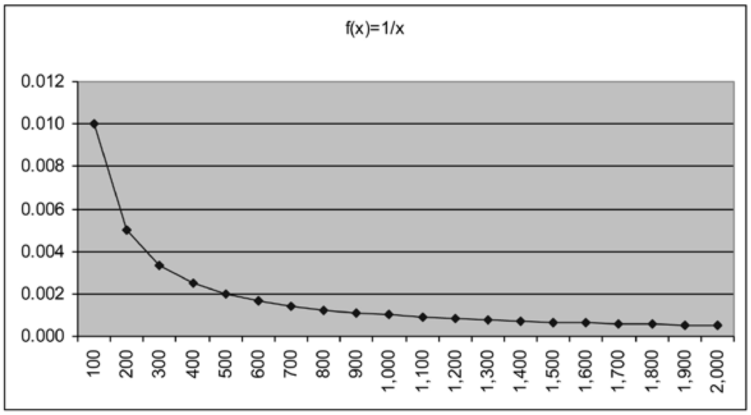

Figure 3: f(x)=1/x as x ranges from 100 to 2,000 with increments of 100.