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BOOKS

THE NETWORK SAGA*

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Barabási, Albert-László: *Linked. The New Science of Networks.* Cambridge MA: Perseus Publishing, 2002.

A Hungarian sociologist has two good reasons to be proud nowadays.

First, as a Hungarian, since on the other side of the ocean a Hungarian book has become a real hit. Considered a scientific bestseller "Linked" can be thought of as a hundred per cent Hungarian, not only due to the author's Hungarian origin, but also, because the book offers a wide spectrum of Hungarian-related information.

On the other hand, for a sociologist it is of no little consequence that finally – after a century during which it was predominantly the area of natural sciences that served as a source of inspiration for social sciences – a reverse process has been witnessed. The theoretical and methodological results of *social network analysis* – basically a discipline of sociology/anthropology – are now the focus of natural sciences. Barabási's book deals with familiar questions in the fields of economy and sociology, but beyond that it examines a number of examples from the areas of physics, information sciences and cell biology where network analysis is the key to making further progress.

Obviously, it is not the Hungarian connections, nor the implications in the area of social sciences to which *Linked* owes its international success. Rather, the fact is that the book was capable of presenting the recent and significant challenges of modern science in an intriguing, non-technical language, in the manner of a real page-turner. This book is a popular scientific summary of the author's earlier publications – and it is also the first book about network analysis to warrant widespread public attention.

The present review aims at not only expounding on the book, but to showing its international reception, partly based on an interview with the author.

* This review has been translated by Kata Erdődi.

SCALE-FREE NETWORK

The slogan-like subtitle on the cover of the book invites us to read and learn “how everything is connected to everything else and what it means for science, business and everyday life”. A review published in *New Scientist* (Cohen 2002) claims that *a single law has been discovered that simultaneously applies to our sexual life, the functioning of proteins and the world of movie stars.* This “omnipotent” law *is the scale-free model.*

The concept of the scale-free network was previously published by Albert-László Barabási and his research group (Réka Albert and Hawoong Jeong) in a number of papers. The article that appeared in *Science* in 1999 became the most cited paper in the area of physics in the United States in the year 2002. The paper dealing with the authors’ insights on the *attack* and *error tolerance* of Internet and modern economy was published in 2000, making it a Nature cover story. Success encouraged Barabási to write further papers and finally a book that was meant to convey the message to all: think network.

The message of the book can be summed up briefly. Earlier, following in the wake of Paul Erdős and Alfred Rényi, graph theory dealt with the examination of *random* connections where the number of links belonging to each node follow a Poisson distribution. Barabási points out that in systems that evolve without regulation, in a natural way the connections are not random. On the contrary, the new arrivals are prone to link themselves to previously formed, highly connected hubs (cf. “network dependent path dependence” Sik 2003). For this reason most of the networks found in nature and in society are characterized by a power law, rather than a Poisson distribution. In order to demonstrate the difference between networks with Poisson and power law degree distributions, Barabási uses a number of ingenious examples. Of these I will present the comparison of the highway map and the air traffic system in the United States. *“On the roadmap cities are the nodes and the highways connecting them the links. This is a fairly uniform network: Each major city has at least one link to the highway system, and there are no cities served by hundreds of highways. Thus most nodes are fairly similar, with roughly the same number of links. (…) Such uniformity is an inherent property of random networks with a peaked degree of distribution.*

The airline routing map differs drastically from the roadmap. The nodes of this network are airports connected by direct flights between them. Inspecting the maps displayed in the glossy flight magazines placed on the back of each airplane seat, we cannot fail to notice a few hubs, such as Chicago, Dallas, Denver, Atlanta, New York... (…) The vast majority of airports are tiny, appearing as nodes with at most a few links connecting them to one or several hubs. Thus, in contrast to the highway map, where most nodes are equivalent, on the airline map a few hubs connect hundreds of small airports” (Barabási 2002: 6th link/2).

Consequently, based on the argument above, the scale-free model can be defined: *“Power laws mathematically formulate the fact that in most real networks the majority of nodes have only a few links and that these numerous tiny nodes coexist with a few big hubs, nodes with an anomalously high number of links.*

In a random network the peak of the distribution implies that the vast majority of nodes have the same number of links and that nodes deviating from the average are extremely rare. Therefore, a random network has a characteristic scale in its node connectivity, embodied by the average node and fixed by the peak of the degree distribution. In contrast, the absence of a peak in a power-law degree distribution implies that in a real network there is no such thing as a characteristic node. We see a continuous hierarchy of nodes, spanning from rare hubs to the numerous tiny nodes. The largest hub is closely followed by two or three somewhat smaller hubs, followed by dozens that are even smaller, and so on, eventually arriving at the numerous small nodes.

The power law distribution thus forces us to abandon the idea of a scale, or a characteristic node. (...) There is no intrinsic scale in these networks. This is the reason my research group started to describe networks with power-law degree distributions as ***scale-free****"* (Barabási 2002: 6th link/2).

Barabási first discovered the existence of scale-free networks when investigating how the World Wide Web functions. While examining how websites are connected to one another by *links,* he realized that the World Wide Web is composed of very few central and a vast number of peripheral websites. Such a construct could evolve, because the World Wide Web is a system where growth is not regulated and where most of the new websites are linked to already existing, in fact, already well-known and therefore important websites.

The author's extraordinary achievement is that he could "think outside the box" and cross the frontiers of information sciences – his research field in the strict sense – to collaborate with physicists, biologists and many others. In the book one may find several examples that show how all of a sudden the scale-free model provides a solution to many unsolved mysteries of modern science. While the cell biologists' main concern was trying to determine the components and the functions of proteins, Barabási and Zoltán Oltvai tried to shed light on the functioning of proteins by examining how these components are connected. They stated that *"each cell looked like a tiny web, extremely uneven, with a few molecules involved in the majority of reactions – the hubs of the metabolism – while most molecules participated in only one or two"* (Barabási 2002: 13th link/3). The cell's scale-free structure may be the consequence of its non-regulated evolution: *"to be sure, the original assembly of the first protocells from a primordial soup of organic molecules might have resembled a growing network".*

Based on the results of research conducted in several countries, Barabási points out that the *network of sexual relationships* is also scale-free: contemporary society is made up of a great number of people who had had very few sexual relationships and a few who had had extremely many. Consequently, with regard to the AIDS epidemic and other sexually transmitted diseases the author makes a simple, but no doubt shocking suggestion: *"...Hubs play a key role in these processes. Their unique role suggests a bold but cruel solution: As long as resources are finite we should treat only the hubs. That is, when a treatment exists but there is not enough money to offer it to everybody who needs it, we should primarily give it to the hubs. This was the conclusion reached in two recent studies, one by Pastor-Satorras and Vespignani, the* *other by Zoltán Dezső, a graduate student in my research group. (…) Any selective policy raises important ethical questions. Indeed, our results indicate that, faced with limited resources, we would end up rewarding promiscuity. (…) Are we ready to offer drugs to the more connected poor prostitutes than to the wealthier but sexually less connected middle class?"* (Barabási 2002: 10th link/10)

Further examples range from the world of the movies to business and microelectronics and apparently support what Barabási himself wrote about the reception of their insights: *"With the realization that most complex networks in nature have a power-law degree distribution, the term* ***scale-free networks*** *rapidly infiltrated most disciplines faced with complex webs"* (Barabási 2002: 6th link/2).

In addition to discovering the significance of scale-free networks, Barabási and his research group were also interested in mapping the characteristics of scale-free systems. Their most important findings concern the *robustness* of the system. *"Node failures can easily break a network into isolated, noncommunicating fragments. (…) A significant fraction of nodes can be randomly removed from* ***any scale-free network*** *without its breaking apart. The unsuspected robustness against failures is that scale-free networks display a property not shared by random networks. As the Internet, the World Wide Web, the cell, and social networks are known to be scale-free, the results indicate that their well-known resilience to errors is an inherent property of their topology"* (Barabási 2002: 9th link/2). Basically robustness means that the system is able to function with a few highly connected centers, even if the greater part of its elements experience random failure. On the contrary, however these systems are vulnerable to *deliberate attacks,* the elimination of a few of these centres will cause immediate breakdown and the system will fall to pieces. Barabási had shown that among others society and the human body are also scale-free networks and he now debates whether this is *"good news for the people who depend on them."*

David Cohen (2002) claims that the discovery of the scale-free model, moreover the understanding of the characteristics of the scale-free system will transform the way we look at the world. As for myself, I am unable to judge whether these findings are revolutionary.

All I know is that the book makes me believe they are.

THE ARRIVAL OF FURTHER MARTIANS

The American reader who after finishing György Marx's book, *The arrival of the Martians,* had indulged in the slightest hope that perhaps Hungarians were (are) not the pioneers of network analysis, surely admits defeat after reading *Linked*. In the book it is made clear that the ideas of "small world" and "six degrees of separation", two basic concepts of network theory first appeared in a short story by Karinthy, decades before being published in American scientific journals. Barabási speculates that perhaps Stanley Milgram, the American scientist to whose name six degrees of separation is linked – *"a child of a Hungarian father and a Romanian mother"* – might have incidentally heard about Karinthy's short story and its five degrees thanks to the Hungarian connections. It is almost impossible to count how many Hungarians are mentioned in the book, ranging from Erdős and Rényi, the fathers of graph theory to the author himself and his co-authors who discovered the importance of scale-free distribution.

The thought that everybody and everything is Hungarian, seems at times to lead the author astray. Without doubt it is touching to read in an American scientific work that in the Kamra Theatre on Ferenciek Square there are good plays applauded by the audience. But I find that when writing about synchronized clapping it is not necessary to debate whether it is unique to Budapest or Eastern Europe. Fortunately, later on the American examples serve to compensate such excesses (Barabási 2002: 4th link/1).

On the other hand, it is lamentable that in the case of certain innovations of genuine importance there is no mention of Hungarian pioneers. To my best knowledge, most technology historians, along with György Marx attribute the discovery of electronic mail, that is e-mail, to János Kemény who had used it to communicate with his wife in the beginning of the sixties. Instead Barabási claims that *"For example, e-mail was born when an adventurous hacker, Rag Tomlinson, working at BBN, a small consulting firm in Cambridge, Massachusetts, figured out how to modify file transfer protocols to carry mail messages. For a long time Tomlinson kept quiet about his breakthrough. When he first showed it to one of his colleagues, he warned him, "Don't tell anyone! This isn't what we're supposed to be working on." E-mail leaked out, however, and became one of the dominant applications of the early Internet."* (Barabási 2002: 11th link/3)

When dealing with the virtual networks of Internet users, the ICQ and the SETI programs are mentioned among others, while the WIW (Who is Who) project developed by Hungarians is not acknowledged. Although it has fewer users, it is no doubt the first in the world to draw the graphical map of e-mail networks upon request.

Finally, one cannot help, but notice that there is no mention of the results of Hungarian and Central-Eastern European network analysis. To name only one of such findings: in my opinion, the concept of "*connection/relation*-sensitive path dependency" may prove useful regarding the evolution of scale-free networks. This concept is linked to Endre Sik (2003) in the international scientific literature. In the area of network analysis, Hungary and Slovenia are the countries of the region where serious research is done: in the latter the development of the popular Pajek network analysis program deserves mentioning.

MISSING SOCIOLOGISTS

In the introduction of the present review I stated that *social network analysis* – considered a discipline of sociology/anthropology until recently – is now the focus of natural sciences. This is probably true, but it is also part of the whole truth that Barabási's book sheds little light on this process. In this aspect I share the views of Fernard Amblard who notes, with regard to *Linked* and two other books that *"the fact that the authors don't mention the contribution of sociology to the "science networks" is disappointing. Many empirical studies (in Social Networks or JOSS for instance), measures (Wasserrmann and Faust 1994) and rationales (Coleman 1990) have been* *developed in network research and social capital theory but these are totally absent from the books reviewed."* About Barabási's book Amblard also remarks *"a tendency to present it in a partial way, i.e. as a physicist interested through his work in many diverse areas but forgetting most of the time what professionals in these domains may have to say about networks or his findings."*

Let's state the facts: Barabási writes about four studies in the field of sociology. Stanley Milgram's "small world" theory, Mark Granovetter's thesis on the strength of weak ties, and with regard to tetracycline and hybrid corn, the work of Bryce Ryan, Neal C. Cross, Elihu Katz, James Coleman and Herbert Menzel is presented in the book, in an extremely entertaining way. The author cannot be blamed for not giving the reader a general overview of the development of social network analysis, because this was not his point. But in addition to the ones listed above, it would have been essential to mention those social scientists who have dealt with methodological problems very similar to the ones Barabási faces and have important findings in this area. To name only a few: Franz Stokman whose research interest is network dynamics, Philip Bonacich who worked out the indicators of network centrality, Ronald Burt who investigated structural holes and Linton C. Freeman who worked on the visualization of networks.

Let's see an example! Regarding network density and centrality (Barabási does not use these concepts), the book cites a physics-related paper published in 1998: *"Watts and Strogatz introduced a quantity called the* ***clustering coefficient.*** *Let's assume that you have four good friends. If they are all friends with* ***each other*** *as well, you can connect each of them with a link, obtaining altogether six friendship links. Chances are, however, that some of your friends are not friends with each other. Then the real count will give fewer than six links –let's say, four. In this case the clustering coefficient for your circle of friends is 0.66, obtained by dividing the number of actual links between your friends (four) by the number of links that they could have if they were all friends with each other (six). The clustering coefficient tells you how closely knit your circle of friends is. A number close to 1.0 means that all your friends are good friends with each other. On the other hand, if the clustering coefficient is zero, then you are the only person who holds your friends together, as they do not seem to enjoy each other's company."* (Barabás 2002: 4^{th} link/1)

In fact, the concepts and coefficients of clustering (and network density) date further back, so that when speaking of their introduction, it applies only to the area of physics. The methodological paper of Philip Bonacich published in 1987, already deals with the phenomenon of clustering as that of common knowledge and writes about the different methods of its measurement in far more detail than the above cited paper.

If there is little mention in Barabási's work of the implications of network theory in the field of sociology, there's absolutely no mention of its implications in the field of anthropology. This is surprising, because it is generally known that Radcliffe-Brown was the first one to suggest that social scientists investigate social relations at his inauguration as the head of the Royal Anthropological Society. Several studies link the evolution of social network analysis to social anthropology, the "Manchester School" (cf. Molina 2001). The classic work of Larissa Adler Lomnitz published in 1971, about the role of social relations in the Chilean middle class is also absent from the book. The article is as well known in the community of anthropologists as Granovetter's paper on weak ties in the community of sociologists. It was translated into several languages and has also been published in Hungarian (Lomnitz 1998). The *Anthropack* software developed in the beginning of the nineties for anthropologists was one of the first programs also capable of network analysis. One of the creators, the anthropologist Steve P. Borgatti collaborated in the development of the UCINET program later on. This is the program that most researchers doing network analysis use nowadays.

When we met in person, I asked the author why he had disregarded the pioneers of network theory, that is the social scientists. His answer was frank and sincere: his knowledge of this literature had not been adequate. He also claimed that he intended to further his knowledge in this field, especially since he now wished to focus on the quality of relations. He wants to investigate beyond the limits of theories that assume that each relation is of equal importance and hopes that social theories will be of help.

And finally some good news: Albert-László Barabási and Duncan Watts are currently working on the edition of an anthology where network theory's social scientist pioneers and its contemporary natural scientist contributors will be equally represented. The first piece – and also the motto - of the anthology will not be a scientific work, but a short story by Frigyes Karinthy written in 1929, the *Chains*.

SCALE-FREE LITERATURE

In the past years three books have been published more or less simultaneously that approach network analysis from the perspective of physics (Barabási and Zoltán 2002, Watts and Strogatz 1998 and Buchanan 2002). The scientific community received all three books, especially Barabási's, with great interest. It cannot be wondered that the discourse they generated continues growing according to power function, since an ever-growing network keeps adding to the relevant literature – very much in the manner of a scale-free system.

Apart from the reviews of the publishers, there are four critiques of high standard that I know of: Amblard 2003, Cohen 2002, Eakin 2003 and Schrage 2002. Of these the most well known is no doubt the review published in New York Times. All of them are criticisms of high recognition that emphasize the author's efforts to make his results known, not only in countless publications, but by the means of media, such as BBC, NPR, CBS, NBC, ABC and CNN.

Researchers doing network analysis received the results with more scepticism. Understanding why network analysis, during the many decades of its evolution, never received much attention from the press and now, all of a sudden, recent discoveries originating from the area of physics are causing such havoc, is proving truly difficult. On the mail lists of network analysts, such as SOCNET (English), REDES (Spanish), HUNNET (Hungarian), it was emphasized by all that the phenomenon Barabási calls scale-free model is by no means unknown to them. It has been recognized a while ago, but at the same time no one had considered it a general principle the way Barabási had. Many scientists (such as Ivan Blanco, Valdis Krebs, Mark Handcock, Martina Morris) stressed that networks may follow other types of distributions, not only the two (Poisson and power law) mentioned in the book.

ABEL ON THE WEB

Abel is the legendary main character of a series of novels *(Abel in the Wilderness)* written by Áron Tamási, a well-known Transylvanian writer.

After finishing an exciting book, it is not surprising to become curious about the author. I made good use of the Internet and the search engine produced Albert-László Barabási's home page in no time. The home page told the story of a versatile, interesting person. Barabási is originally from Csíkszereda and studied physics at the university in Budapest, then got a Ph.D. in the U. S. and finally, after spending a few years earning money, returned to the university to do research on the Internet. Although far from home, the research group he "recruited" is mainly Hungarian. He is a modern Stakhanovist of science: in 2002 he added 18 papers – that were either published and/or approved – to the palette of scientific literature, not counting the book in question. On his home page three links can be considered *personal:* my country (Transylvania), my city (Csíkszereda) and my people (the *Székely*s). The original English version of Linked is dedicated to his parents in Hungarian: "Szüleimnek".

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RECOMMENDED WEBSITES

The home page of Albert-László Barabási *http://www.nd.edu/~alb/*
Magyar Könyvklub *http://www.mkk.hu/leiras.jsp?bookID=178865*
Social Network Department of Hungarian Sociological Association: *www.socialnetwork.hu*
HUNNET mail list: *http://groups.yahoo.com/group/hunnet/*
Journal of Connections *http://www.sfu.ca/˜insna/indexConnect.html*
http://www.heinz.cmu.edu/project/INSNA/joss/index1.html
Journal of Social Structure *http://www.heinz.cmu.edu/project/INSNA/joss/index1.html*
Journal of Redes *http://seneca.uab.es/antropologia/jlm/*
http://usuarios.tripod.es/revistaredes/
UCINET, Anthropack software: *http://www.analytictech.com/*
Erdős number: *http://www.acs.oakland.edu/˜grossman/erdoshp.html*
The Network Analysis Manual of Robert Hanneman
http://faculty.ucr.edu/˜hanneman/SOC157/NETTEXT.PDF