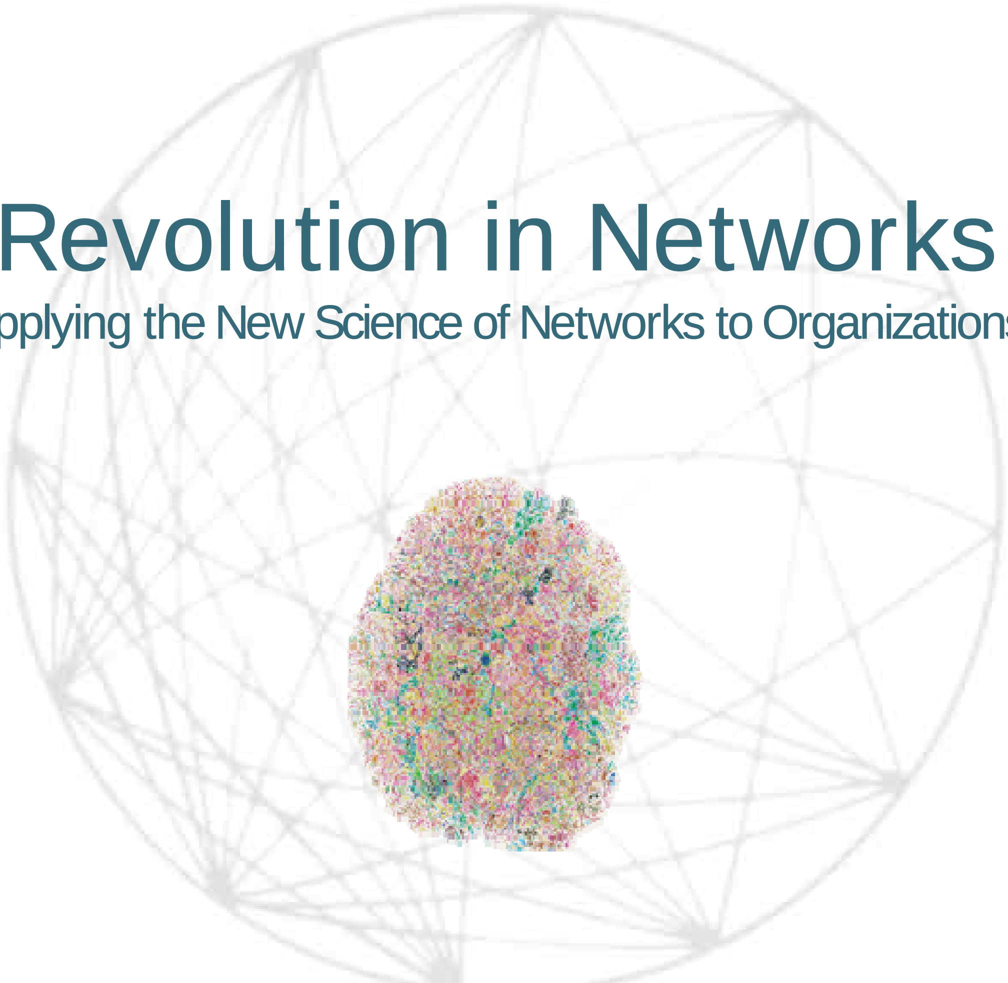
NetAge Working Papers

February, 2009

Revolution in Networks

Applying the New Science of Networks to Organizations



Jeffrey Stamps and Jessica Lipnack

www.netage.com

> *NetAge Working Papers* set out a new theory and practice for organizations. We feel compelled to publish these technical papers now as an urgent response to the collapse of traditional hierarchies and bureaucracies as evidenced by the current economic debacle. As the economic crisis deepens in 2009, we believe that now is the time for new ideas, new concepts, and new theory to come forward, approaches that will allow all kinds of organizations whether large or small to reorganize in smarter, better, and faster ways.

"Organization" network science is an application of a more general, and newly-advanced network science. This latest network science, which we present here, includes the concept of "scale-free networks" and their signature pattern of hubs developed by Albert-László Barabási and others. A second stream of contemporary network thinking, written about by Duncan Watts, reveals how a few "shortcuts" dramatically reduce path lengths to form "small-world networks." In this paper, we reframe generic network principles of growth and "preferential attachment" are reframed for use in understanding and managing organizations as networks.

In this series of working papers we have been presenting the practical theory of organizations as networks. In doing so, management science reaps the benefits of network knowledge learned in other areas. Thus, discoveries about hubs, shortcuts, and other network properties are immediately applicable to organizations.

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Revolution in Networks: Applying the New Science of Networks to Organizations

A Measure of Complexity: Organizations as Complex Adaptive Networks

A Systems Science of Networked Organizations

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Background on the Network Revolution

"Nothing is more practical than a good theory," says Duncan Watts, in "Connected: The Power of Six Degrees," a Discovery Channel show first aired February 15, 2009. The short description is: "Connected - The Real Matrix, is a thought provoking examination of an idea: that there is a pervasive law which Nature uses to organize itself."

Over the past few years, a new "science of networks" has rapidly spread across the physical, biological, and social domains, bringing the simplicity of common characteristics to diverse complex systems.

Our field work at the leading edge of global organizational development confirms that this new "linked" science applies directly and immediately to highly-complex organizations. It is practical theory that is ready to be pulled into the rough-and-tumble of the vast economic catastrophe that continues to unfold.

It is our hope that a true theory-based, data-driven, testable science of "organization networks" will enable an historic step-change increase in human organizational capabilities. Great ambition—but even modest improvements—in collaboration could have widespread application and deep impact. We believe this new knowledge can substantially improve our collective ability to work together better, a clear imperative imposed by the era's digital information technologies, accelerating globalization, and deepening human power to modify ourselves and the world around us.

"The Networking People"

For the past 25 years, we have been studying, writing about, and developing practice for and about networks and networking. In our work, we have been collecting and telling thousands of stories about people working together in networks. We have chronicled the appearance of networks in grassroots movements (*Networking*, 1982, and *The Networking Book*, 1986), in global corporations (*The Age of the Network*, 1994), in the remarkable small-business networks of Emilia-Romagna, Italy (*The TeamNet Factor*, 1993), and in the dizzying reach of today's dispersed-but-connected work groups (*Virtual Teams*, 1997, 2000). In May, 2004, with Ann Majchrzak and Arvind Malhotra, we published the results of a study of 54 high-performing, highly-distributed, global teams from 26 large organizations in the *Harvard Business Review*[1].

We have found and shared best practices, recognized and elaborated on new tools, and created many practical methodologies to implement networks at all scales from teams to global giants. We have moved from being futurists to mainstream as the network paradigm was become widely adopted in both scientific and popular thinking circles. From this work, we became known as "the networking people."

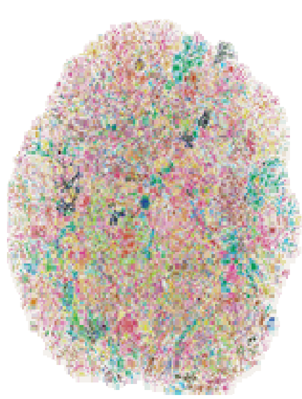
In our specialized field of organization networks, standard network science based on graph theory and mostly random models has never held much explanatory power or attraction for us. Nor have we found the tantalizingly powerful but ultimately scale-limited tools of social network analysis (SNA) applicable to the large-scale organizational entities that have been our focus. Then the quantum physicists showed up, following their noses into network data sets scattered across the scientific domains.

So what's new about networks according to the latest research? In a phrase, they are *organic, scale-free, small worlds*. The new network science grasps complex networks by their nodes and maps their links, generating useful metrics related to configurations that help identify hubs, shortcuts, and all manner of characteristics that are directly applicable to organizations.

This was, to us, a surprise: the appearance of a quantitatively based, probabilistic, general network science that applies to human systems. The science of scale-free and small-world networks corresponds to the dynamic and open-systems view of organizations we already hold.

The network science that appeared around the year 2000 came already threaded with mathematic rigor, tested by data across scientific domains, and verified through previously unmanageably large data sets that had been explored with the immense computing power now available. Data-driven and conceptual, it has a personality, or, rather, personalities. Two people's work (exemplified by books each has written) represent the dual main streams of the new thinking. In 2002, Albert-László Barabási published *Linked: The New Science of Networks*[2]; and in 2003, mathematician-turned-sociologist Watts released *Six Degrees: The Science of a Connected Age*[3]*.* Both very readable, these books have become seminal works in this infant field. We've picked up strands from each and woven them into our view of networks as organizations.

Hubs in Scale-Free Networks



The explosion of the Internet and the Web has wrought tsunami-like effects on our shared world. Ironically, that's the epicenter of the quake that unleashed one major wave of the new network thinking. In the late-1990s, Barabási, then a thirty-something professor at the University of Notre Dame, was wondering about the large-scale structure of the web. Thus, he and his colleagues set an automated crawler roaming the Internet. Its job was to gather data about how pages on the web—*nodes*—were connected by URLs—*links*.

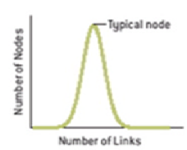
The crawler counted the number of links connected to each node, a basic network quantity known as its "degree." The greater a node's number of links, the higher its degree. In checking the distribution of degrees, the researchers expected to find a normal bell curve with its average peak between dwindling extremes. That is, they expected to find the pattern predicted by the then-dominant assumptions of standard network science. Instead, they found something very different. The data fit a *power-law* curve, meaning a pattern of a few nodes with many links and many nodes with few links. Barabási and friends had discovered *hubs*, highly connected nodes, and thereby unleashed a wave of new thinking.

Why? Not because they discovered hubs as the core structure of the web, which, we all know, is one vast, weird, and seemingly chaotic system. Rather it was because Barabási and his team immediately turned their attention to other types of networks. Would they, too, show the power-law pattern, characteristic of what Barabási came to dub “scale-free” networks? Over the next several years, they tested network data in biology, sociology, ecology, and communication, among other fields. What they found was dramatic confirmation that many, if not most, natural networks are scale-free. They identified a universal class of metrics that applied across radically different domains of science. They found that networks are real-world systems that develop according to general principles, regardless of their domains.

Why does this matter? Because the world around us is very, very complex. With networks, we can begin to get a real, practical, measurable handle on complexity. And our network knowledge is likely to build very rapidly because what we learn in one domain can easily pertain in another. Tools helpful in analyzing, visualizing, and simulating networks of one sort may relate to networks of a completely different sort.

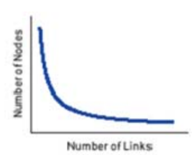
Figure 1: Random and Scale-Free Networks

Bell Curve Distribution of Node Linkages

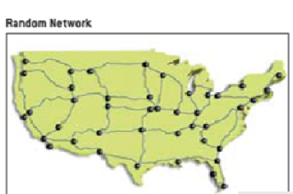


- Average-linked nodes and no extremes
- Random Principles
  - *Fixed inventory of nodes*
  - *Random attachment of links*

Power Law Distribution of Node Linkages

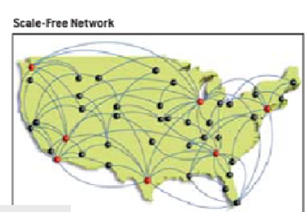


- A few highly-linked hubs and many nodes
- Power Law Principles
  - *Growth over time*
  - *Preferential attachment of links*



Road system example of random network

Airline system example of scale-free network



Albert-László Barabási and Eric Bonabeau, “Scale-Free Networks,” *Scientific American*, May, 2003.

The standard view of networks projects either randomness or a regular pattern of nodes and links, as in images of fishnets and spider webs. Yes, these arrangements do reflect the structure of *some* networks, just not the pattern of *all* networks, and particularly not complex ones. Barabási compares patterns in two transportation networks to illustrate the differences: the road system is more like a random network (for example, approximately the same distances between exits) while the airline system is more like a scale-free network organized literally in a pattern of major and minor hubs (see Figure 1). As we have found, organizations are more like airline than road systems.

Some key examples Barabási and his principal colleague, graduate student Réka Albert, used in their instant-classic paper[4] demonstrate this cross-domain variety (see Figure 2, summarizing their findings in a table from an excellent 2003 *Scientific American* article "Scale-Free Networks" by Barabási and Eric Bonabeau).[5] Examples include molecules linked by biochemical reactions to form a cellular metabolism network, and proteins that link in regulating a cell's activities to comprise a protein regulatory network. People are nodes in several of the networks studied, as scientific collaborators on research papers, actors who have been in the same film (literally the source of the popular social game, "Six Degrees of Kevin Bacon," which Barabási writes about), and patterns of sexual contact. Food-chain networks, power grids, linguistic patterns of word co-occurrences, and the technology of the Internet were all included in their groundbreaking demonstration of the wide applicability of scale-free networks.

Figure 2: Scale-Free Networks Are Everywhere

Network	Type	Nodes	Links
Cellular metabolism	Biology	Molecules involved in burning food for energy	Participation in the same biochemical reaction
Protein regulatory network	Biology	Proteins that help to regulate a cell's activities	Interactions among proteins
Sexual relationships	People	People	Sexual contract
Hollywood	People	Actors	Appearance in the same movie
Research collaborations	People	Scientists	Co-authorship of papers
Internet infrastructure	Technology	Routers	Optical and other physical connections
World Wide Web	Knowledge	Web pages	URLs

"Scale-Free Networks" by Albert-László Barabási and Eric Bonabeau, Scientific American, May, 2003.

Barabási not only showed that hubs are common in many networks, but also how a few general principles underlie them. Through simulation, he and his colleagues generated scale-free network models from just two principles—growth and “preferential attachment.”

- Growth reverses an unexamined assumption of the earlier standard network model, which treated the number of nodes as constant, generating what is essentially a closed, relatively static system. The new model, however, suggests that a network displaying the characteristic power-law hierarchy of hubs grows node-by-node and is a dynamic, open system.
- Preferential attachment essentially states that well-connected nodes are more likely to attract links from new nodes than less-richly connected nodes. In the currency of links, this has been characterized as the tendency for “the rich to get richer.” Generally speaking, seniority gains as the network grows, with older nodes having more time to collect links.

While the scale-free power law may seem esoteric, its practical use is familiar to us in the many renditions of the “80/20” principle. This general rule-of-thumb includes such distributions as 20% of the population controlling 80% of the wealth, or 20% of pea pods producing 80% of the peas. Both of these are in fact among Vilfredo Pareto’s early 20th-century empirical observations that gave raise to the “rule.” This is the power law at work and in use today.

Shortcuts in Small-World Networks

But it’s not just about hubs. Complementing the work of Barabási and his colleagues, two professors, Watts, a sociologist at Columbia University, and Steven Strogatz, a mathematician at Cornell University, tackled the small-world mystery that had been building for decades. As the question is popularly put, why do only “six degrees,” in network terms the number of links in a path, putatively separate us from every other person on the planet? This apparent small-world property of human networks was first revealed by Stanley Milgram. In an ingenious 1967 experiment[6], Milgram counted how many steps it would take for a letter from a random person in Omaha to reach a specific lawyer in Boston along a path of strong first-name-basis connections.

The small-world paradox arises because people interact primarily with their families, friends, and neighbors. Social networks know this property as “clustering.” If most of the people I talk to converse with one another, then how do I step out of a circular world? How could I reach someone on the other side of the globe in a few steps? A brilliant clue was offered by Mark Granovetter, summarized in the elegant title of his now-famous 1973 paper, “The Strength of Weak Ties.”[7] He showed that people more often find their jobs through acquaintances or friends-of-friends, rather than through their close circle of connections, reaching across clusters and making worlds small.

Watts and Strogatz began their intense journey by trying to unravel the mystery of how huge numbers of fireflies suddenly start blinking in sync. In their search, they discovered a general solution to the paradox—shortcuts. What they showed mathematically (reported in the prestigious journal *Nature*[8] in 1998), was that small worlds exist between the two poles of network structure—the regular lattice and the completely random network. They found that when they added even a few links randomly to a regular lattice network, its degree of separation dramatically decreases. However, after adding an initial number of "weak ties," the effect of adding more shortcuts rapidly decreases. The average degree doesn't decrease much after a certain point.

When they tested their theory with data, they confirmed their small-world predictions, starting with the Kevin Bacon network information. As Barabási and associates wondered about scale-free networks, so did Watts and company wonder if the small-world hypothesis would extend beyond human groups into other types of networks. Remarkably, that answer also was yes. Networks as different as the U.S. Western Systems power grid and the neural network of a very simple organism called *C. Elegans* were shown to exhibit both clustering and small-world properties.

While knowing more about the nature *of* networks has value in itself, both Barabási and Watts have equally emphasized the dynamics that happen *on* these networks. For example, scale-free networks are particularly robust against accidents because critical hubs are relatively scarce, but they are vulnerable to direct attack. Hubs require both more capability and more protection. Dynamics of cascading network failure were dramatically illustrated in the massive northeastern U.S. blackout on August 15, 2003. Barabási appeared in the New York Times the next day with a piece on network complexity, "We're All on the Grid Together."[9] Watts' collaborator Strogatz had a New York Times' piece on the same high-profile page a week later, "How the Blackout Came to Life."[10]

Fads and epidemics, innovation and diffusion, search, decision-making, viruses biological and digital, adaptation, recovery, and communications of all sorts are just some of the dynamics that the new network science illuminates.

Hubs and Shortcuts in Organizations

On the face of it, organizations *are* networks. We easily can describe them as configurations of nodes and links. But what nodes to grasp? Usually, we recognize organizations as networks of *people*. Holding tight to that truth, we are suggesting an additional type of human network exists—an evolved configuration of *positions*. Our core view is that organizations comprise networks of people and positions, and that we habitually conflate these two very different types of networks. The new network thinking applies to both types, but it is in looking anew at the formal structures of positions and their interdependent relationships that an *organization* network science is realized.

Immediate benefits accrue from using this new perspective. Data is already embedded in institutional information systems, as in Eleum's case, or is easily obtained. For researchers and leaders, there is little gap between discovery and application in the field. Eleum's leaders found they could make use of the findings every step of the way.

Hubs in the Hierarchy

One quick way to see the value of the network perspective is to look at the leadership implications of hubs in the formal structure. For example, we asked a U.S. Army Major General serving with Joint Forces to sketch a network of his assignments when he was functioning just four levels down from the U.S. President. He produced a set of diagrams that looked two levels up and two levels down—over ten years and through a number of commands. His network maps, based on the historical sequence of his position, illustrate how key relationships, particularly horizontal connections, increase with seniority. It takes only a few minutes of discussion for senior leaders to see possibilities such as this one. They've watched increasing connections happen to themselves; most, like the general, even can draw their networks over time. That organizations have hubs, which are nodes with many links, is immediately and intuitively obvious to senior executives—because they occupy hub positions themselves.

To suggest that 20% of the management positions in organizations handle 80% of the coordinating links accords with leadership experience. A scale-free network, meaning one that has no fixed limits, predicts a hierarchy of hubs. It's easy to imagine a few senior managers as the organization's global hubs, upper and middle-managers as regional hubs, and front-line supervisors as local hubs, connecting to the 80%-majority of positions that provide direct production and service functions. Now we know that, at least in Eleum (the company we've described and analyzed in other papers), this is not an accurate picture of reality: Hubs appear across multiple levels of the hierarchy, even though they comprise only a small fraction of total leadership positions.

Network scientists have learned that scale-free networks are generally robust against accidents but vulnerable to attack. In cross-domain studies, networks show their vulnerability when something disables even a few key hubs. We interpret an "attack" on *leadership* hubs as exceptional stress on highly-connected managers, whether by constant travel, poor organizational design, wasteful meeting practices, or unfortunate online collaboration behavior. When crises appear, hub leaders are even more vulnerable, as a severe accident claiming lives took place in one of Eleum's plants just before the new organization's launch demonstrated. Such all-consuming disasters use executive time in ways that leave normal pathways and by-ways frustrated, disrupted, and more at risk.

The reverse of catastrophe is the spread of positive innovation or cultural change. How can you find key players to promote new ideas and mete out scarce resources? Draw an Eleum-style network map that shows hubs and produces a database of metrics for every position. Such a map offers strategic and tactical benefits. Among other advantages, it:

- Suggests alternative strategies for enterprise-wide communication, engagement, and organizational development;
- Enables patterns of diffusion of new ideas through hub-threaded networks showing who to engage for greatest effect in change efforts;
- Helps target leadership training and HR support to those who need it most, particularly for virtual working;
- Encourages rethinking standard policies around performance reviews, as this leadership burden is very unequally distributed;
- Sparks new thinking in uniform information management policies. A one-size-fits-all approach, where everyone receives the same, base-level technology, is inadequate for hubs. Though their numbers are by definition small, their information management fluency in today's organization is critical. Conversely, providing everyone with capabilities at the level that hubs require would be highly wasteful.

The realization that hubs are a key to organizational performance suggests a plan of action.

1. Identify the hubs who keep the organizational network together and alive;
2. Support their ability to conduct interactions and sustain relationships in accord with their link load; and
3. Act to prevent burnout, overload, and stress that naturally come with higher numbers of links, more interactions, and increasing commitments.

Providing more sophisticated technology to such people and reducing stressors on them are not perks. They are network requirements: they allow the system to protect and enable its vital hubs.

Shortcuts in Small Worlds

Organizations also reflect insights from another branch of the new network science: "small worlds." How long it takes to travel from node to node, known as path length, is critical to many aspects of organizational life: speed of decision-making, ability to share information, and, as we mentioned above, diffusion of new ideas and technologies. The average path lengths of very steep hierarchies are longer than in more collapsed organizations that typically function more quickly. Generally, the steeper the organization is, the slower its response, with less adaptability to change. This is not news to most people working in such organizations.

To cope with extra-long decision-making path lengths, organizations have invented a work-around: the dotted-line, matrix-reporting relationship. Added to traditional solid lines, matrix reporting relationships provide alternative pathways for decisions and influence. Systematic dotted-line reports (matrixed organizations) are among the most important organizational innovations to arise in the face of accelerating complexity and rate of change. Just as networks in other domains naturally create shortcuts to pick up speed, so do organizations create theirs.

In hierarchies, the logic of decision-making, influence-generation, and message-passing is that the higher the position in the organization, the greater the burden. As ambiguity increases, coordination needs rise; more message-passing and decision-making push up the chain of command and overload the traditional system. Shortcuts may be essential parts of an evolutionary strategy by organizations to reduce stress on key hubs, going beyond mere relief from congestion at the top.

Shorter path lengths also arise from multiple group memberships. Managers are typically members of numerous small groups, starting with their own management teams. Teams and other small groups harbor strong relationships among a "cluster" of people who interact because of their positions. Often members of many such teams, managers provide the shortcuts that reduce organizational distance. In this way, they bring clusters closer together; they lower their average "degree of separation." Similarly, cross-functional project teams provide another response to rising complexity. Here decision-path lengths among functions condense when compared with the classic, serial, bureaucratic decision-making. Instead of going up and down the functional chains of command, these groups *cross* functions.

Human organizations have evolved—from communities of small groups to pyramidal hierarchies to bureaucratic assemblies of specialties, and, now, to networked organizations. This doesn't mean that small groups, hierarchies, and bureaucracies have gone away.

However, what is happening now is that organizations are evolving more adaptive forms that take advantage of the radically new types of connective technologies appearing in this digital age. With the new network models, we can represent older forms of organizations (e.g., a hierarchy network) while incorporating the newly linked groups emerging in the 21st century.

Network Metrics

In our working paper, "Principles for Reorganization," we discuss and demonstrate three key network metrics that are also key organizational properties.

- Level (links from a node to the root node),
- Size (the number of nodes), and
- Span (the number of links, a node's degree),

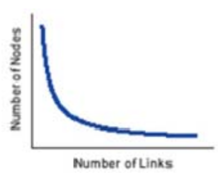
We have calculated and applied these three in the extensive Eleum case study of hierarchy, but they only scratch the surface of possible organizational network metrics available for exploration – especially as new link types are added to the mutually-exclusive reporting relationship. Four further measures suggest themselves as likely basic to understanding the network nature of organizations:

- Degree exponent, which indicates the shape taken by the power curve of hubs (assuming it is more "power" than "normal");
- Scale-free cutoff, meaning the point at which a node exceeds the maximum number of links it can maintain;
- Clustering coefficient, the indicator of how modular the network is; and,
- Path lengths, meaning the "degree of separation" between one node and another.

Let's take them one-by-one.

Degree Exponent

The key data for Eleum managers (as reported in our Eleum case study, "The Virtual Networked Organization" and further explored in "Organizing at the Edge of Chaos" together with the already cited "Principles of Reorganization") shows the fat tail of a few-nodes-with-many-links for both span (direct degree) and size (indirect degree). If many organizational network data sets turn out to be scale-free, the distribution will have a degree exponent in its mathematical formulation.



At one extreme of the exponent's value range, the curve presents a pattern of one (or a very few) huge hub(s) in a large population of link paupers. At the other extreme, links distribute essentially randomly across the population of nodes. Between these extremes is a hierarchy of hubs with gradients of connectivity. Many of the networks studied across scientific domains have a degree exponent between two and three, for reasons that are not yet clear to network scientists. What, we wonder, will organizational exponents be?

We suspect that the "right" distribution of hubs for organizations does not necessarily follow from the "bigger is better" presumption. For example, as we mentioned above, robustness against accidents follows from the hub structure, but so does vulnerability. The existence of only a few huge hubs may result in too many crises and too much susceptibility to catastrophic cascades ending in failure. It is likely that there is no one right answer, that we will find degree exponents associated with different hub patterns that fit different types of organizations (e.g., in different functions, industries, or institutions).

While we don't yet know what typical or "healthy" degree-exponent ranges might be, we do know that it's significant whether there is a graduated distribution of nodes or a few concentrated huge hubs. Of concern to particular leaders is whether and how they can manage the relationships their positions carry. This brings us to the outer edges of degree.

Scale-free Cutoff

The math of the power law suggests that a node could have infinite connections. Since there are always real-world limits to how many links one node can handle, "scale-free," which Barabási defines as having no theoretical limits, is a bit of a misnomer when applied to human networks. While links may be costless in the ephemeral world of mathematics, in the real world we pay a price, along with a maintenance fee, for our every relationship. Each of us, as human nodes in many networks, can attest to the overhead, rewards, and debts of connecting, interacting, and relating. In practice, as humans, we always have a cut-off to the scale-free curve, corresponding to the "saturation" point of hubs—that is, the maximum number of links. This could be a structural limit, a capacity limit, a cost limit, a personal limit, or a mix of them all. How many best friends can you really have?

We may have in effect calculated this metric for Eleum as a whole. By observation, the outer limit of span hubs is 45, although that number went down as the company reviewed its hub positions. As we were going over the initial data with one hub manager deep in the organization, he stopped at the list that ranked positions with the largest span and quietly said, "That person with 45 reports? He just quit. Said the job was too stressful."

For size hubs, the "cutoff" is the total size, the number of links from the root to each component position. However, a root, or any node, might have a larger degree as more link types are included in the analysis.

Clustering Coefficient

As we turn our attention from scale-free to small-world characteristics of networks, we seek a quantity that measures how cohesive the organization is: the "clustering coefficient." In mathematical terms, a number between zero and one signifies how likely it is that your neighbors (i.e., the positions one link away) are linked to one another. Put more colloquially, are your friends also friends with one another? Organizationally speaking, the closer people are to one another, the more "clustered" they are. A simple hub-and-spoke hierarchy, as represented by an organization chart, shows little clustering. With no cohesion beyond the chain-of-command, a clustering coefficient in theory approaches zero. Conversely, members of a team who all know one another and tightly interact show very high cohesion, a clustering coefficient approaching one.

Reality in a hierarchy, however, suggests a combination of reporting chains and teams. A direct reporting link usually associates a node with membership on a team led by the position's boss. One could, therefore, treat a leadership position and its direct reports as a small group whose members all know and converse with one another. Adding leadership teams as clusters to the analysis likely will yield a whole new class of insights, even before we explicitly add other group memberships to the data sets.

As we noted, a network comprising only the direct-reporting links should have a very low clustering coefficient. Add matrix links and the clustering metrics likely increase slightly. Tune in the process links and clustering increases somewhat more. However, what really bring this quality of organizations to life are the relationships we have as members of multiple groups. Opening the network picture to group-membership links starts to fill out the full texture of the organization's inner life, its small world.

Clustering is the measure of a network's modularity, an indicator of how much internal structure it has. High clustering is not necessarily good, nor is its opposite necessarily bad. An organization with only highly autonomous teams has great difficulty with global information sharing and decision-making. With little clustering, local decisions and information sharing are lost in the high volume of global exchanges. Natural networks, as network scientists are discovering, usually operate between extremes.

With hubs and clusters in hand, we are ready to journey the small worlds of the organization network.

Average Degree of Separation

The famous experiment-turned-play-turned-movie-turned-cliché, "Six Degrees of Separation," is at the heart of this final metric. It simply means that the presumed average number of connections between you and everyone else on the planet is six. Path lengths are simply the count of links that connect one node with another to get from here to there.

Small organizations have naturally short path lengths. The design imperative in large organizations is to connect many positions with many specialties into an architecture of *short* path lengths. The *maximum* path length between two nodes is known as the network's *diameter*. The *average* length takes into account shortcuts, and is the measure of the *small-world* nature of networks.

A few shortcuts, as Watts and Strogatz discovered, can have great impact on average path lengths. But increasing the number of shortcuts yields a rapidly diminishing impact. By this logic, including directed dotted-line reporting links should reveal shorter path lengths in Eleum's degree of separation calculation, which in turn may translate practically into faster decision-making.

As with other network metrics, small worlds take on different meanings as we dial through different organizational frequencies (see our working paper Organizational Networks: Core Concepts). To illustrate this point, we start with the primary-reporting link. Following the solid reporting arrows from any position to the root node defines a node's *level,* identifying where it sits in the hierarchy. The maximum number of links in the direct reporting path to the "boss," the root node, defines the *depth* of the network's hierarchy.

Where a network as a whole has its *average* path length, a particular position must cope with a *particular* number of levels, both up and down. We suspect that, when actually measured, an organization will show more levels than it thinks it has, as was the case at Eleum. There, even with an assumed design criterion of five levels, they ended up with eight in the original configuration. And an organization that shows a moderate average number of levels may contain both units with very steep hierarchies together with units of comparatively flat hierarchy. The topology of real hierarchies, as Eleum shows, is much more interesting and practically important than the predictable regular structures we assume them to be. (See "Organizing at the Edge of Chaos" and "Principles of Reorganization" for more on the concepts, data, and application of these findings.)

Tuning to the process links displays a different set of pathways. We can interpret the longest, directed, solid-line set of process links as the system's *critical path*, with shortcuts enabling parallel processes that yield faster processing and adaptation to change. If we take our visualization into the realm of information links and personal relationships, we will see yet another set of path lengths and insights into "the conversation" of the organization.

In the world of networks, shorter generally correlates with faster. But, not all faster *command* decisions are necessarily better. Nor is faster *coordination* necessarily an unmitigated good when it pushes human limits and compromises safety. Even faster *communication* may overload the system and prevent critical information from coming through and being acted on in a considered way. In time, associating particular path lengths with other performance measures may give us normal ranges for given situations—and optimal speeds.

However, with the speed warning flashing, there is nevertheless an unrelenting need to find ways to lower average path lengths in the face of change and increasing complexity. This is particularly true for large organizations, and most particularly for very large organizations with global, national, and regional scopes, those with the most developed traditional hierarchy-bureaucracy structures. Especially now.

From Art to Science

- Levels
- Size
- Degree
- Degree exponent
- Scale-free cutoff

- Clustering coefficient
- Average path lengths

Each of these measures has meaning for organization networks as a whole. They also have meaning in detail for each person holding a position in the organization, and for leaders in hub positions in particular.

This set of measures is common to most cross-domain network studies, enabling comparisons to be made among organization networks and a wide array of physical, biological, and social networks.

Measuring aspects of the network enables us to make accurate distinctions, to compare one node or network—read position or organization—with another. Most important for the development of a “real” management science, metrics enable us to test theories by making predictions, then analyzing outcomes and comparing with real-world data.

Together theory and measures help us develop and test principles through simulation. For leaders of the future, simulation is a means to develop and test alternative models before committing everyone to a particular reorganization. A simulation will obligingly test the impact of adding even a single link, such as a matrix reporting relationship, which might have a noticeable impact on path length and predicted decision speeds.

> *Without quantitative measures, we have only today’s art, not tomorrow’s science, of organizations.*

Growing Organizations

Organizations are natural networks. They are truly organic, an idea embedded in the etymology of the word itself. This organic nature now has a powerful network theory to give it concreteness and metrics.

In the commercial world, great organizational oaks begin from start-up acorns. A few people have a bright idea and start a new company, perhaps in a kitchen or garage, or today exchanging ideas in an online chat or a blog. As the business grows, more hands and specialties are required and new people are hired. And, as they join, the organization’s structure becomes more complex and demands more explicitness and formality. As growth accelerates, the organization passes through a series of size breakpoints—first at around five, next at about 25, and then a big step to between 100 and 200 people. Each size breakpoint brings a set of well-understood leadership challenges.

Over time, growth of the new business reaches its eventual size limit in the context of its market environment, but the dynamics of growth do not cease even as it operates near its maximum size. Positions come and go all the time. In *re-organizations*, organizations move, aggregate, and disaggregate units large and small with the goal of meeting challenges and developing opportunities that constantly changing environments present.

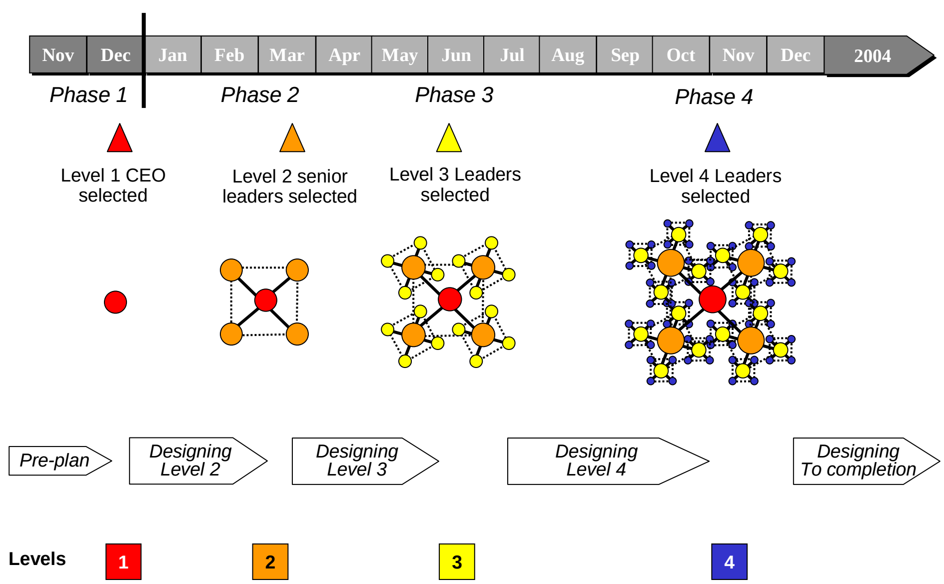
Because so many of the roles and components are known and labeled before the process begins, reorganizations represent a particularly clear set of dynamics that unfold much more rapidly and more explicitly than is typical for a startup. But, contrary to the appearance of a sudden announcement of a new organizational script with its completed structure and newly-appointed leadership actors, reorganizations are in no way instantaneous phenomena. They grow, position by position, over time.

Eleum's parent, a vast, vigorous global enterprise elder, completed an extremely complex reorganization just prior to our study. It went from a traditional makeup of scores of nationally-based companies to a new design comprising a few regional companies, one of which was to be Eleum. To do so, it had to generate a new level—up—one that included the prior nationally-based companies.

> *Nature generates new levels both by growing upward (synthesis) and by subdividing down (analysis). Generally speaking, it is easier to generate levels down than up. Evolution unfolds by generating new levels up.*

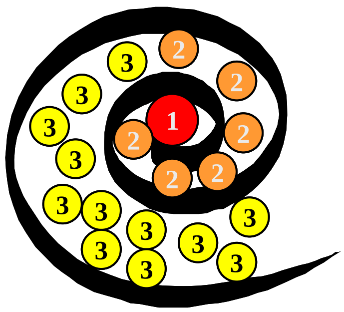
The following reenactment is based on the actual process used at Eleum (see Figure 3).

Figure 3: Eleum's Modular Growth



The birth of Eleum's nine-month reorganization began with the naming of a single new position, the appointment of the regional CEO, who defines Level 1 in the network.

Over the next few weeks, the new CEO engaged with others in the process to define the first level down, the Level 2 (L2) positions, the senior vice presidents, discuss names of people to play the role, and interview potential candidates. As each new L2 leader signs on to play a role, another position lights up on Eleum's reorganization network map.



After three months, the handful of L2 leaders were announced; they in turn led the design process to define the L3 organization, typically the vice-president level of a large enterprise. Announcement of the sixty or so L3 positions initiated an open process of staffing, and, two months later, the L3s were chosen. They then engaged in the Level 4 design and staffing. At nine months, the completed regional organization of thousands went live.

The growth process unfolding the Eleum organization resembles a spiral. New levels grow out from one core root position in increasingly larger circles over time. The organization fills out a level with each turn of the spiral as new positions attach to an already established leadership position. Growth is rapid because the hierarchy is modular, as each L2 leader develops L3 organizations in parallel, and each L3 leader in turn develops L4 organizations at the same time in the following phase, and so on.

In this real-world case, we can tag organizational positions with their levels. Nature usually is not so accommodating. Can we get to level structure using the scale-free principles? Can we get to hierarchy theoretically, through first principles?

Simulating Network Growth

Barabási simulates the development of scale-free networks from just two principles: growth and preferential attachment. Are these two principles at work in the development of organizations?

For network scientists, growth is a big deal. It introduces more complexity into the network picture, but it is much more descriptive of the real world. A bunch of nodes do not instantly appear in nature; they grow into a network node by node, over time. Natural scale-free networks persist and maintain their essential integrity as nodes are added, lost, and rewired. Networks in the new model are open systems that interact in their environments. By contrast, the older random network model typically assumes a static population of nodes in a largely closed system.

We have known for more than a half-century that organizations are open systems. As systems, they grow and persist while dynamically adding and deleting positions and rewiring the connections among them. So often do some organizations rewire that people at Apple once jokingly referred to themselves as a "*re*organization." Generally, however, the pattern of organizational evolution is more like "punctuated equilibrium" in biological evolution. Sharp, intense bursts of environmentally-induced change interrupt periods of relative stability, bringing with them new capabilities at a new level of organization—or catastrophic collapse.

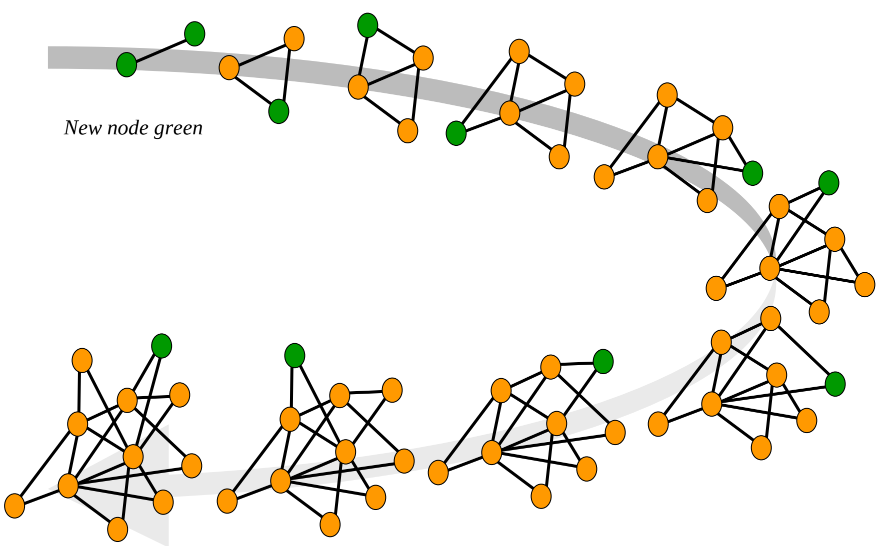
Most of us have had parts in this movie, experiencing the roller-coaster of growth and change in a particular institution. But what about the second principle: preferential attachment? This is a little harder to see in organizations, but it is there.

This principle states quite simply that a new node will, with some probability, prefer to link to an existing node with more connections than to one with fewer. As the network grows, hubs have the attraction of popularity, giving the earliest-joining nodes a seniority advantage in becoming and remaining hubs.

We can see this principle at work in a simple simulation of the development of a scale-free network, one position at a time. In both his book, *Linked*, and his *Scientific American* article, “Scale-Free Networks,” Barabási presents a visual example of a network growing step-by-step from two to 11 nodes (see Figure 4).

In his scenario, each new node practices preferential attachment, making two links to existing nodes, usually (i.e., with some probability) to the already-most connected nodes in the neighborhood. As the process unfolds, hubs quickly show up in the ten-step sequence. In this simulation, probabilities being what they are and choices made, two nodes have seven connections (the major hubs), two have five links (the minor hubs), and the other seven nodes have but two links (not hubs at all). This not only shows the development of hubs in a few steps, but signals to us that we can apply the concept even to small groups.

Figure 4: Barabási’s “Birth of a Scale-Free Network”



“Scale-Free Networks” by Albert-László Barabási and Eric Bonabeau, Scientific American, May, 2003.

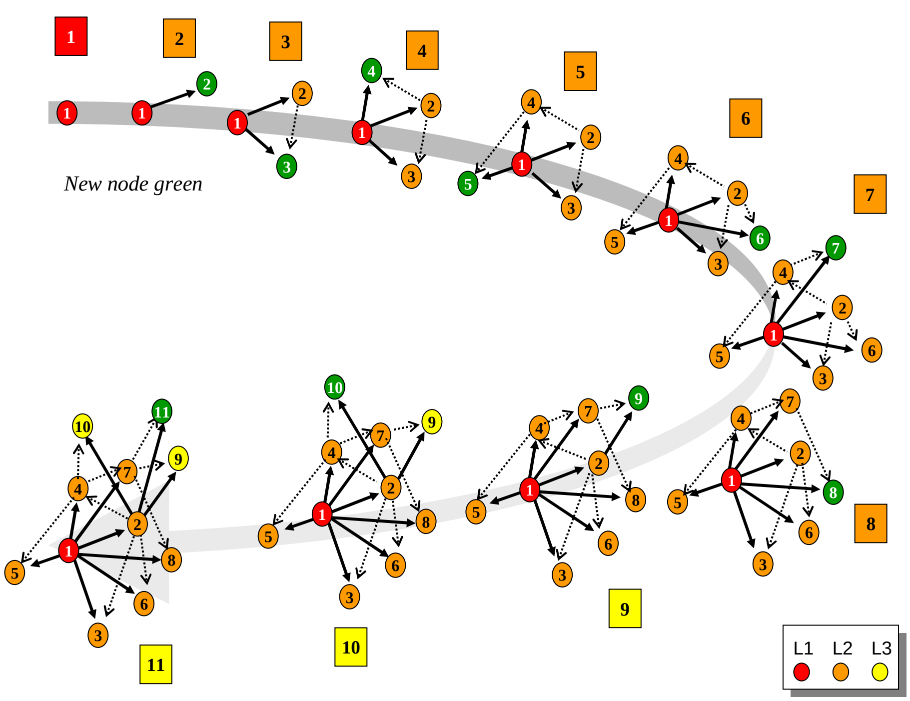
As we looked at the flow of Barabási’s scenario, we saw echoes of Eleum’s reorganization play. We remembered the fast-paced story that unfolded after the CEO appointment. Discussions of strategy and design with senior leaders developed into a series of quite specific conversations that resulted in filling the first level of organization with key people. The second turn of the spiral led to discussions about positions at the next level. Before you knew it, one appointment had led to an organization of thousands, as we recounted earlier.

Growing Hierarchy Preferentially

To test whether the logic of preferential attachment works with organization nodes and links, we changed a couple of basic parameters in the Barabási reference model. First, to represent reporting (whole/part, parent/child) relationships, we needed to use directed links instead of the undirected links used in the reference model.[11] Then, because we were using directed links, we could start one step earlier in the sequence and begin the process with a single root node, a "CEO node," instead of the two nodes that start the Barabási sequence.

Following preferential attachment in this scenario, the first link went to the most highly connected node in the neighborhood, while the second link went (usually but not always) to the next most highly connected node. To distinguish these two links, we represented the first as a solid-line primary direct reporting relationship, and the second as a dotted-line secondary matrix reporting relationship. The direction reflected the parent-child logic of hierarchy.

Figure 5: Birth of a Matrix Network



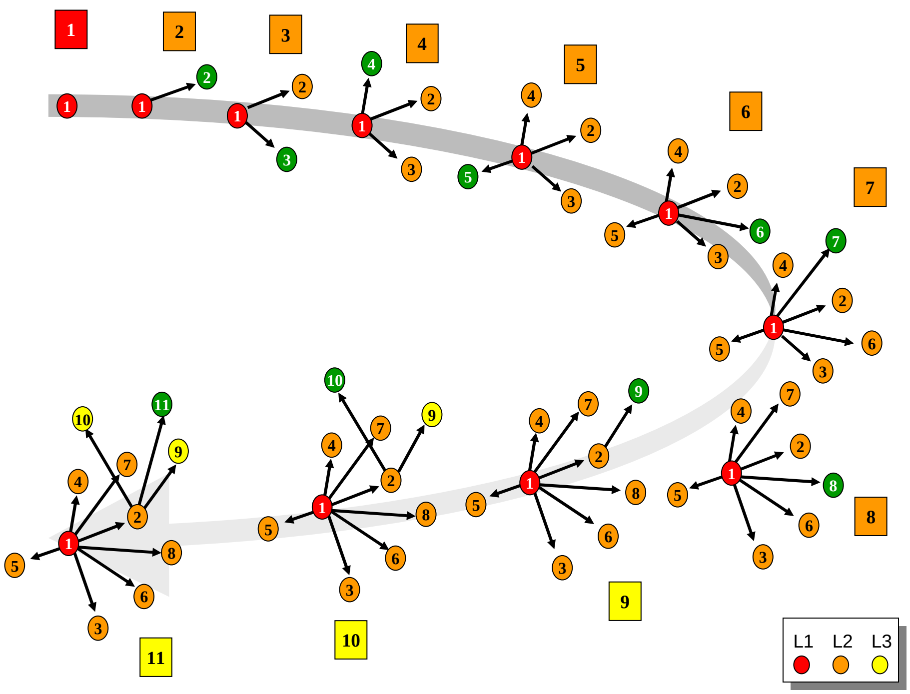
In retracing Barabási's simulation (see Figure 5), we numbered each node, tagging it like an employee badge number sequentially assigned by order of hiring. The tag gave each node a unique "name," and the growth scenario became personal as you followed the fortunes of any node in the growing network. The play unfolded one step, one node, at a time. With each step, the configuration changed.

- Our play began with our first node, #1, "Mike," who we designated the "CEO node" and the sole player at Level 1 in the hierarchy.
- Node #2, "Jean," could only make its one solid-line reporting link with the CEO, thus becoming the first Level 2 position. Because the root node received the first reporting link, it immediately became the likely central hub.
- Node #3, "Janet," along with each successive node, had two links to make (following the Barabási reference model) and for node #3, the choice was easy: establish a direct reporting link with #1, Mike, and a secondary link with #2, Jean. Node #4, "Tor," did the same.
- New node #5, "Henry," also swore primary allegiance to #1, but faced a choice about where to place his secondary link. Luck seemed to be on #4's side, whereby Tor got this early matrix link and started on his way to becoming a minor hub player.
- As nodes #6, #7, and #8 join, the first link was with the CEO, but there were more choices about where to send the second link.
- Then, at step nine, something different happened. Without knowing the actual simulation parameters underlying the Barabási sequence, it appeared that node #1, the CEO, stopped accepting direct reports after seven. So, when node #9 joined, it directed its primary link to #2 (who just happened to have the most secondary reports). This made #9 the first Level 3 node.
- The final two nodes also made the primary connection to #2 and were thereby Level 3 nodes.

Ignoring directionality and weight (solid/dotted), the same hub structure emerged from these two directed link types (Figure 5) as in the Barabási reference scenario of two undistinguished undirected links (Figure 4). However, by giving links direction and distinguishing the direct (solid-line) links, a core hierarchy stood out from the richer network of hubs that came with the matrix (dotted-line) link. In addition, each node was color coded to indicate its level (path length to the root).

To see just the hierarchy generated by the direct reporting link, simply remove the matrix links (see Figure 6). You can now retrace the Barabási reference sequence using just one link. After establishing the root, each succeeding L2 node attaches to the root position until it reaches an apparent constraint, or saturation, at seven reports. The ninth node attaches to a L2 node and establishes a new level, 3. At the end, there is one node with seven reports, one with three reports, and nine with no reports. The logic here is of a sets-within-sets whole/part hierarchy, the same as the tree structure of a typical organization chart. We have generated a simple model of managers and staff from first principles.

Figure 6: Birth of a Hierarchy Network



So, even with just *one link* for each new node, the hub pattern appears. And, the eleven-node network generates three levels. It appears that levels can emerge from growth and preferential attachment with *directed* links, where at least one link connects each node to some other node with an exclusive parent-child relationship. If this is so, abstract theory would neatly complement the data we have gathered from Eleum and analyzed to show hubs and levels (see in particular our working paper Principles for Reorganization).

In the Eleum development example, new positions linked to existing managers that constituted the previously defined higher level of organization. It spun out just like the simulated demonstration of growth in a scale-free network. Each position in Eleum's decision-making design had one certain link, the direct solid line, to another (higher level) position. Sometimes a position also had a dotted-line link to another (higher level) position. Imagine running this simulation out to 5000 positions. How would its metrics compare with Eleum's actual hierarchical configuration?

It is not difficult to see how reporting links reflect preferential attachment in the real world. People in positions naturally attach to the highest-level, most highly connected leader they can. For new nodes, the boss who hires you surely generates a high probability of attachment. For the whole organization, the pull for this tendency emanates from the CEO, the sun in the center of the system. And the result, at least for Eleum, is a roughly scale-free, multi-level hierarchy.

Hierarchical Networks

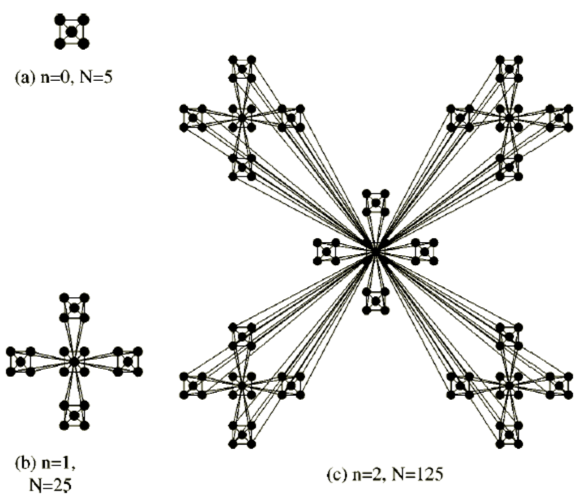
Learning about network principles will not just be one-way. Organization networks are likely to hold clues that apply to networks generally. In an organization, you actually can talk to the nodes, get their opinions as to whether the structure works or not. The position approach has the special advantage of being interview-able (which nodes of molecule networks and power grids are not). And at the current conceptual frontier of the new network science, understanding how hierarchy fits in, the multi-level property is especially evident in organization networks.

After a spate of publications establishing his groundbreaking concept of scale-free networks, Barabási began to explore how the hierarchy topology, which is clearly evident in many real-world networks, can integrate with what he saw as the two central generic properties of networks: (1) scale-free distribution of degree and (2) clustering. Clustering is also clearly present in real-world networks and had long been established as a central metric in network studies of people in particular. However, theoretical models developed to demonstrate either scale-free properties or clustering are each, according to Barabási, less successful in representing the other property. Barabási believes level structure is the missing property that integrates with the other two properties in a single model of "hierarchical organization in complex networks."[12]

Barabási has proposed a general model to explain the hierarchical development of scale-free networks. He creates an iterative construction that starts with an all-to-all connected five-node network, then replicates these four times and connects all the new peripheral nodes to the original central node, then replicates again and ties new peripheral nodes to the original center (see Figure 7). When he analyzes the model, hierarchical by construction, he obtains both scale-free and clustering results. Tellingly, the key measure of modularity varies by a node's degree (number of connections for each node) and is independent of network size (number of nodes).

How might this apply to organizations? The unfolding of organizational modules via successive iterations of management groups tracks with a plausible organizational development scenario, such as the nine-month gestation of Eleum from single cell CEO to completed 5000-node person-position organization organism. The thicket of lines that connects the central node to most of the lower-level nodes reflects our idea of a "size hub," the mechanism in the model most responsible for the scale-free characteristic. This is the "prerogative of command" whereby a manager-leader has the implied power to direct a decision to any position at any level in the organization on a direct reporting pathway to the manager-as-root point of reference. These links also represent a root leadership right to one-to-many communications with everyone in the organization.

Figure 7: Generating an Iterative Hierarchy Network



"The iterative construction leading to a hierarchical network. Starting from a fully connected cluster of five nodes shown in (a) (note that the diagonal nodes are also connected—links not visible), we create four identical replicas, connecting the peripheral nodes of each cluster to the central node of the original cluster, obtaining a network of *N*=25 nodes (b). In the next step, we create four replicas of the obtained cluster, and connect the peripheral nodes again, as shown in (c), to the central node of the original module, obtaining a *N*=125-node network. This process can be continued indefinitely."

Hierarchical organization in complex networks, Erzsébet Ravasz and Albert-László Barabási, PHYSICAL REVIEW E **67**, 026112 (2003)

Most strongly stated, the Barabási model might be called the "kingship model," where each node, each position, each person, is treated as a "subject" (employee) of the king (root leader). This is, indeed, a very real human organizing model, and still a modern one, too, as each new dictator testifies.

Another way to the same goal of building a hierarchical network by iteration might be called the "management model." Here the central nodes of the newly generated (L2) modules connect to the original (L1) central node (primary reporting links), while a new level (L3) of modules has a center node connecting up to an L2 center node. Quite simply, this is the logic of an org chart. This also exactly follows the real process and resulting structure we observed in Eleum (see Figure 3).

These few reporting links, added to the large number of the links generated by the Barabási method, probably would not change the overall scale-free metric of the whole multi-level kingship network very much. We can still add a link between every new peripheral node and the L1 leader, and also expand the model by generating similar links to each sub-root-manager within that node's sphere of influence (i.e., the sub-orgs linked to a given manager position), although with a different kind of link than the singular direct reporting relationship. This link also registers what we dubbed the "size span" in our Eleum analysis, the sum of all primary direct (1-degree) reports (span) and indirect reporting links in paths to each manager root, that is, each management node's network tree size.

However, this last step of adding more links to the central node is not necessary to validate the coexistence of hubs, clusters, and hierarchy in the simpler management model. We have shown these properties likely exist together both by the real data from Eleum and by the logic of Barabási's scale-free growth-plus-preferential attachment principles to drive an organizational growth model with a root and directed links (see Figures 4, 5, 6).

Hubs in the Diamond

In the model of organizational networks, we find all three properties cited by Barabási as central to natural networks.

- First, an organization, almost by definition, reflects a hierarchy (level structure) architecture, confirmed both by theory and observation.
- Second, clustering arises naturally in the formation of management teams that are implied by the sparse reporting structure. This clustering proliferates as we include other types of formal groups and a position's multiple position-based memberships in them.
- Hubs, reflecting the third general characteristic of real-world networks, scale-free degree distribution, are the surprise property of simple hierarchy.

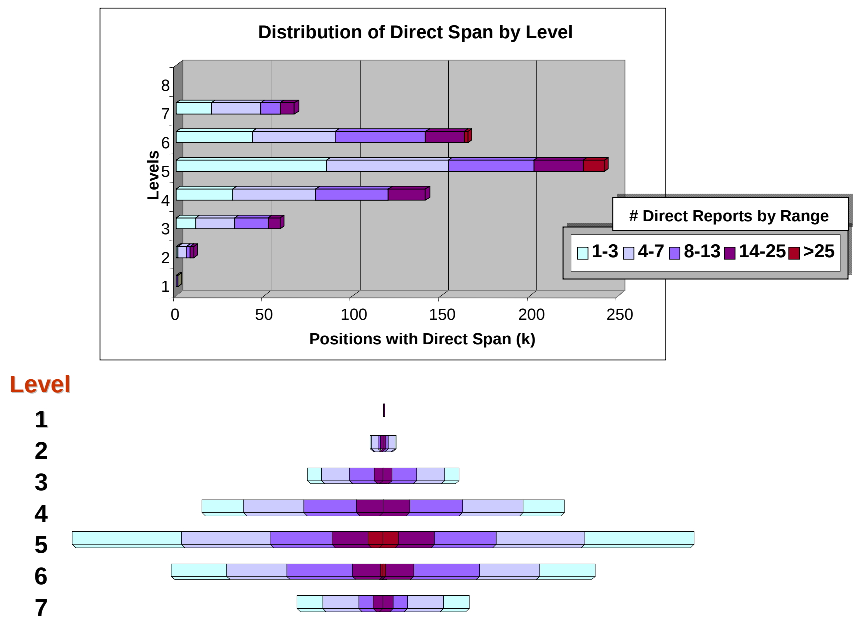
While we expected to find hubs as we added various additional types of links to the direct-paycheck-link hierarchy reporting structure (specifically by adding matrix, process, membership, and information relationships), we did not suspect them in the most desiccated form of organization network, the one-link-one-node hierarchy. Did we find hubs? We think so. And they are distributed through a diamond-shaped hierarchy.

Visually, it is obvious. Flying through a modeled mesh of thousands of hierarchically connected nodes, the eye easily picks out hubs at every level. When we crunch the data, hubs clearly identify themselves and separate out of the management pack in a long tail of increasing degree up to some cut-off point.

As a practical, useful matter, hubs exist in the hierarchy, at least for Eleum. To Eleum's leaders, the existence of hubs was self-evident from the data, since it was theirs, freshly grown, having been generated from their own HR system. The results stimulated management actions every step of the way in our pilot exploration, as we have detailed in the Eleum story and data set, behavioral consequences that add to the evidence that there are indeed real hubs in the hierarchy (see "The Virtual, Networked Organization").

Continuous growth is central to the new network paradigm. Natural networks that show scale-free characteristics evolve and change over time. Some of the positions carried forward in Eleum's design were first defined more than a century earlier as the company's industry was just beginning. The whole organization in its many components has evolved over the years, shaped in the marketplace by evolutionary forces of selective competition. Eleum, in the new regional configuration, represents the most recent organizational transformation of this company's core business, and the emergence of a new level of complexity to deal with the increasingly complex global environment.

Figure 8: Hubs in the Diamond



Hubs in the multi-level diamond hierarchy hold the whole together (see Figure 8). Having hubs is likely no accident.

Footnotes

[1]"Can Absence Make a Team Grow Stronger," by Ann Majchrzak, Arvind Malhotra, Jeffrey Stamps, and Jessica Lipnack, *Harvard Business Review,* May, 2004.

[2] *Linked: The New Science of Networks,* by Albert-László Barabási, Perseus Publishing, 2002.

[3] *Six Degrees: The Science of a Connected Age,* Duncan Watts, W.W. Norton, 2003.

[4] "Statistical mechanics of complex networks," by Réka Albert and Albert-László Barabási, in *Reviews of Modern Physics*, January, 2002. Download the paper from Barabási's Center for Complex Network Research website.

[5] Albert-László Barabási and Eric Bonabeau, "Scale-Free Networks," *Scientific American*, May, 2003. (PDF from his site.)

[6]"The small world problem," by Stanley Milgram. Psychology Today, (2):60--67, 1967.

[7] "The Strength of Weak Ties," by Mark Granovetter, *American Journal of Sociology,* 78(6): 1360-1380. 1973. See his revised paper, "The Strength of Weak Ties: A Network Theory Revisited," in *Sociological Theory*, Volume 1, 201-233, 1983.

[8] Watts, D. J. and S. H. Strogatz. 1998. Collective dynamics of 'small-world' networks. *Nature* 393:440-42. See the paper.

[9] "We're All on the Grid Together," by Albert-László Barabási, *New York Times*, 16 August 2003.

[10]"How the Blackout Came to Life," by Steven Strogatz, *New York Times*, 25 August 2003.

[11] The "from-to" direction of the links represented correspond to standard notation practice in depicting logical hierarchies, as in from-parent to-child (from-whole to-part) relationships; i.e., the boss is a parent node to the child nodes of direct reports. This corresponds to a real-world interpretation of how new positional nodes are generated: a boss creates a new job (position) and hires someone to fill it

[12] Erzsébet Ravasz and Albert-László Barabási, *Hierarchical organization in complex networks* Physical Review E **67**, 026112, 2003 (download). A.L. Barabási, Z. Deszo, E. Ravasz, S. H. Yook, and Z. Oltvai, *Scale-free and hierarchical structures in complex networks,* Sitges Proceedings on Complex Networks, 2004 (download). One of the best summaries is in Albert-László Barabási and Zoltán N. Oltvai*, Network Biology: Understanding the Cells's Functional Organization,* Nature Reviews Genetics **5**, 101-113, 2004 (download).