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Goran D. Putnik
University of Minho, Portugal

Maria Manuela Cunha
Polytechnic Institute of Cávado and Ave, Portugal

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Morphology and Entropy in Networks

Ton van Asseldonk
TVA developments bv, The Netherlands

Erik den Hartigh
Delft University of Technology, The Netherlands

Leon Berger
Nyenrode University, The Netherlands

INTRODUCTION

This article concerns the relation between the *morphology* (concentration and connectivity) and the *entropy* of networked structures. We will introduce the network morphology concept, we will address two approaches to network characterization--traditional network measures and the concept of entropy--and we will link the entropy concept to the network characteristics. It will be shown that entropy will grow steeply if a certain balance between connectivity and concentration is disturbed.

It is known from theory that the morphology of a business network, be within an organization or between organizations, greatly affects the behavior of agents in the network (Ahuja, 2000; Burt, 1992; Coleman, 1988; Gulati, 1999; Powell, Koput, & Smith-Doerr, 1996; Walker, Kogut & Shan 1997). Also it is known that the morphology of networks is an important determinant of the extent of innovation diffusion (Abrahamson & Rosenkopf, 1997; Den Hartigh, 2005). It is therefore important to explore further some basic notions of network morphology.

BACKGROUND

Every network has a *morphology*. Morphology is defined as the form and structure of a network. The morphology of a network can be described by two separate elements: *connectivity* and *concentration*.

The connectivity of a network can be defined as the relationship between the number of nodes and the number of connections between the nodes. The higher the number of connections with respect to the number of nodes, the higher the connectivity.

Concentration defines the number of connections between a certain node and the others. The higher the number of connections from one node to all the others, the higher the concentration. The measurement of concentration has a relationship with the kurtosis of the distribution of connections among the various nodes.

MAIN FOCUS OF THE ARTICLE

Relation between Connectivity and Concentration

We have defined a network as a structure consisting of nodes and links. Concentration and connectivity provide information over the network; they have a certain relationship, as shown in Figure 1. Networks with a high connectivity and a high concentration cannot exist. This would imply that every node is connected to every other node, but still nodes exist that have more connections than others. The same reasoning can be done for medium concentration/high connectivity and medium connectivity/high concentration networks. They also cannot exist. Obviously, the border areas between high, medium, and low are somewhat fuzzy.

Let us relate these abstract network measures to economic networks, such as business organizations. The morphology concept can be applied to social systems by analyzing the links between social entities. Different configurations yield different levels of order/disorder. In this way, order in social systems can be seen as an expression of the existence of meaningful and purposeful relationships between functional elements of such a system. Without such relationships, the whole of the system can have no meaning or purpose. In such cases, the whole is identical to the sum of parts and no synergy or common purpose can exist. The principles of order through fluctuations were first formulated in thermodynamics. The central idea is that self-organiz-

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Figure 1. Relation between connectivity and concentration

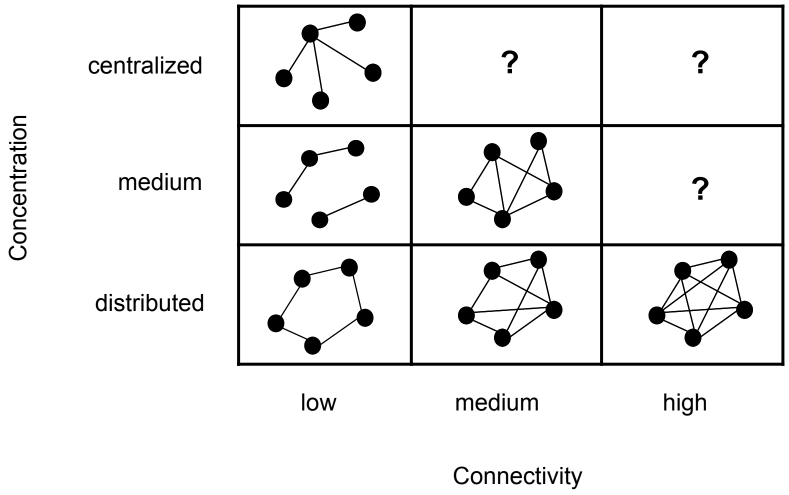
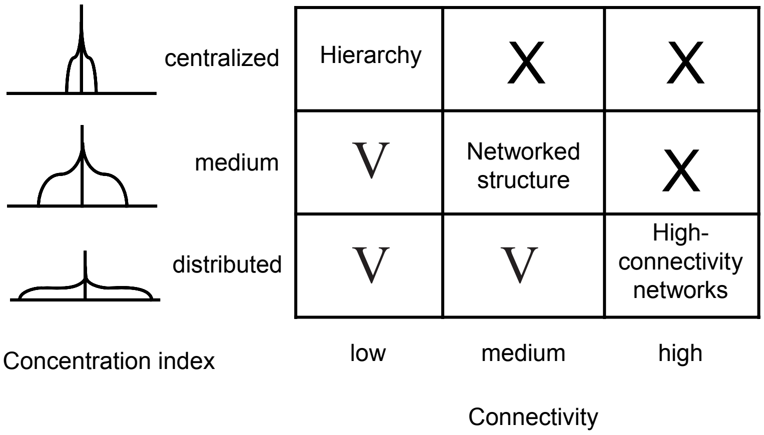


Figure 2. Connectivity and concentration in economic networks

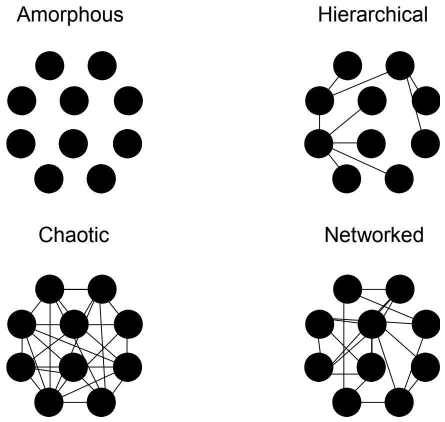


	low	medium	high
centralized	Hierarchy	X	X
medium	V	Networked structure	X
distributed	V	V	High-connectivity networks

ing systems do not solely thrive on order, they need a certain amount of chaos (Nicolis & Prigogine, 1989). If the system fixes itself in a certain configuration, it will no longer be adaptive. It follows that a certain amount of disorder should be present for the system to remain adaptive (Ashby, 1958). In other words, the system should have a certain level of entropy somewhere between order and chaos. In an optimally adaptive system, order and variety (chaos) are in an optimal balance (Nicolis et al., 1989). Neither can be reduced without reducing the system's adaptability.

It is a popular belief that networked structures exist because of the ability or even necessity for all agents to relate to all other agents. Yet it can be shown that a high connectivity factor of a system (the average number of links any agent in the network has) combined with a low concentration factor (there are no concentration points) leads to a very rich "solution space" and increasing inability to find a suitable solution (Van Asseldonk, 1998). In other words, if the number of degrees of freedom in relation to new solutions is larger than the complexity of the problem itself, the payback will rapidly decay as opposite to the conventional hierarchical situation. This, in turn, is an example of under-complexity, in which the solution space of the organization is too small for the complexity of the outside world. Here, there is a low connectivity factor, combined with a high concentration factor.

Figure 3. Example of an economic network structure (e.g., employees in an organization)



Example

Let us consider a social network of 10 entities, say employees in a business organization.

In Figure 3, four possible network characteristics of relations between these 10 entities are indicated. These links could be expressions of cooperation and/or communication between employees. For simplicity reasons we assume a digital situation: links exist or don't exist, they are bi-directional, and they are unidimensional. All cooperation and communication below a certain threshold is supposed not to be existent, and consequently the links drawn in figure indicate strong cooperation and/or communication.

In the first example, the amorphous structure, no links exist, and as no links exist between the entities there cannot be a common objective, or meaningful identity, associated with such organization. They are merely 10 individuals apparently arbitrarily isolated from the universe and put together on this article. This way of arranging entities we would not call organization, but a complete absence of any form of organization.

In the second example, the hierarchical structure, one of the entities is connected to most other entities. Apparently, this one entity is in the center of what the structure is intended for, and is apparently the beginning and the end of all activities undertaken by the structure. We will readily recognize the existence of hierarchy in this structure as the central entity apparently is necessarily governing the behavior of the other entities. In business organizations, such a structure is based on the principles of Taylor (1911), Fayol (1949), and Weber (1925).

In the third example, the chaotic structure, all entities are connected to all other entities. In this situation where apparently all entities interact with the same intensity with all other entities, there is no structure visible. Structure which would indicate a way in which these entities relate to each other in any peculiar way, and which could provide a clue with respect to the purpose, learning, and working of the organization. In fact, if all relations are equal, then apparently all entities are universal or completely identical and if this is the case, it is difficult to see why they would need to relate to each other, other than exploiting each other's capacity in response to some outside force.

In the fourth example, the networked structure, the connectivity is substantially higher than in the hierarchical structure but substantially less than in the third example. Here a rich pattern of connections exists, suggesting some sort of meaning of relations between the various entities of the organization. And this meaning will most likely reflect the purpose of the organizational structure as a whole, as well as the differences in identity and capabilities of the individual entities.

Approaches to Network Characterization

Different approaches may be taken to characterize networks. We will discuss the two that are helpful to the reasoning in the next paragraphs: traditional network analysis and the entropy measure. This can be applied to organizational structures by analyzing the structure of the distribution of links between organizational entities. Different configurations yield different levels of concentration and connectivity, and different levels of organizational entropy (an expression of order/disorder).

Traditional Network Analysis

Network analysis offers a means for bridging the gap between macro- and micro-level explanations of social structures. Research design for network analysis consists of four elements (Knoke & Kuklinski, 1982):

- The choice of sampling units (i.e., the actual network and the nodes that will be studied). The delimitation of network boundaries depends to a great extent upon a researcher's purposes. In our case, the sampling units consist of economic networks (e.g., business organizations, supply chains, or markets).

- The form of relations, referring to (a) the intensity or strength of the relation between two agents and (b) the level of joint involvement in the same activities. For simplicity, we assume relation to be digital: they either exist, or they don't, there are no "levels."
- The relational content (e.g., transaction relations, communication relations, sentiment relations, authority/power relations. Here also for simplicity we assume relations to be one-dimensional.
- The level of data analysis. Four conceptually distinct levels of analysis can be distinguished:

    1. The egocentric network, or the relations of a single agent within the network (generating n units of analysis at sample size n)
    2. The level of dyadic relationships (i.e., formed by a pair of nodes) (generating $(n^2-n)/2$ units of analysis at sample size n)
    3. The level of triad relationships (i.e., formed by three nodes and their linkages) (generating n/3 distinct triads at sample size n)
    4. The complete network, using complete information of relations among all agents

In this article, we study economic networks at the fourth level, searching for the characteristics of the network as a whole.

We are fully aware that the result of our choices in the elements mentioned above constitutes a very basic approach to network characterization. Hereby we largely ignore a broad spectrum of network theory in sociology and economics. Our approach connects however, to the more "mathematical" literature that tries to apply quantitative measures of network structures.

The standard traditional network measures are the ones we started with in the previous paragraph: connectivity and concentration, where connectivity is:

$$Connectivity = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} k_{ij}}{\left(n^2-n\right)/2} \qquad i \neq j$$

Concentration is a bit more complicated (Knoke et al., 1982). For even a simple measure, it is first necessary to have the relative centrality per agent or node in the network. For calculating this relative centrality we need g_{ij}, which is the number of geodesics linking i and j, and g_{imj}, which is the number of geodesics linking i and j that involve point m:

$$Centrality(p_m) = \frac{2\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{g_{imj}}{g_{ij}}}{n^2-3n+2} \qquad i \neq j$$

Subsequently we calculate the sum of the difference between the centrality of the most central actor $C(p^*)$ and the centrality of all other actors $C(p_i)$:

$$Centralisation = \frac{\sum_{i=1}^{n}\left(C(p^*)-C(p_i)\right)}{n^3-4n^2+5n-2}$$

Organizational Entropy

Measuring entropy is a simple and elegant way to characterize order or disorder in systems. We can use this measure as a way of characterizing the magnitude and nature of order in organization structures. Especially where electronic means of communication make it fairly easy to measure existence and density of communication between various players, it is also a measure that can rather easily be implemented.

Organizational entropy can be defined as:

$$\varepsilon = -\Sigma\,[P_i * \log P_i] \qquad (i = 1 \text{ to } m)$$

where P_n is the probability that a certain state will occur, in our case: the probability that a certain interaction link (above the threshold) will exist.

If we consider the four cases in the example from the previous paragraph, as a maximum $N*(N-1)/2 = 45$ links can exist (if we take every link as a two-way interaction). Using the formula we can now calculate the organizational entropy of the various examples:

- In the first example (unconnected nodes): $\varepsilon = -10 * (0 * \log 0) = 0$
- In the second example (hierarchical structure), 9 links exist: $\varepsilon = -10 * (9/45 * \log 9/45) = 1.40$
- In the third example (fully connected), 45 links

exist: $\varepsilon = -10 * (45/45 * \log 45/45) = 0$
- In the fourth example (networked structure), 20 links exist: $\varepsilon = -10 * (20/45 * \log 20/45) = 1{,}57$

The situation in which no links exist and the situation in which all links exist span the extremes, and have no practical meaning in organizational terms. Of the other two examples, the hierarchical structure has the lowest organizational entropy, and hence represents a higher level of order than the networked structure example from Figure 3.

We can see that networked structures as previously shown in terms of organizational entropy, are neatly positioned between structured order and total chaos. Hence networked organizations require a connectivity that is substantially higher than the procedural hierarchical organization, without ending into the other extreme where everything is connected to everything.

Network Morphology and the Entropy Measure

We have seen before that connectivity and concentration determine network morphology. Then we showed that networks might be characterized by their morphology and their order/disorder. In this paragraph we connect the network morphology with network entropy.

In order to establish this relation between connectivity (characterized by a connectivity index *Icn*), concentration (characterized by the concentration index *Icc*) and network entropy ε, let us consider a network with n nodes $(n>1)$, of which N nodes are fully connected to the other nodes $(N<n)$ with a total number of connections in the network K (it follows that $K \geq N*(n-1)$).

We define:

- The concentration index *Icc* as N/n
- The connectivity index *Icn* as K/n^2
- Entropy ε as $- \Sigma\, [P_{ij} * \log P_{ij}]$, with $i = 1$ *to* m, and $j = 1$ *to* m, in which P_{ij} is the chance of the existence of connection $i \rightarrow j$

Hence, entropy ε is $- \Sigma\, [P_{ij} * \log P_{ij}]$ for the fully connected nodes plus $- \Sigma\, [P_{ij} * \log P_{ij}]$ for the not fully connected nodes, or $\varepsilon = \varepsilon_N + \varepsilon_n$.

For the N fully connected nodes it goes:

- P_{ij} for the fully connected nodes is 1 (because for these nodes all connections exist);
- Therefore $\varepsilon_N = - N * [1 * \log 1] = 0$ (or, the contribution of the fully connected nodes to entropy is 0).

For the n-N not fully connected nodes it goes:

- The number of remaining connections in the network is $K - [N*(n-1)]$
- Since the total possible number of connections in the network is $n*(n-1)$, and since $N*(n-1)$ connections are used up by the fully connected nodes, the total possible number of remaining connections is $(n*(n-1) - N*(n-1))$ *or* $(n-N)*(n-1)$
- P_{ij} for the not fully connected nodes is $[(K-N*(n-1))/((n-N)*(n-N-1))]$
- Therefore $\varepsilon_n = - (n-N) * \{[(K-N*(n-1))/((n-N)*(n-N-1))] * \log [(K-N*(n-1))/((n-N)*(n-N-1))]\}$

It follows that:

Figure 4. Entropy vs. concentration and entropy versus connectivity

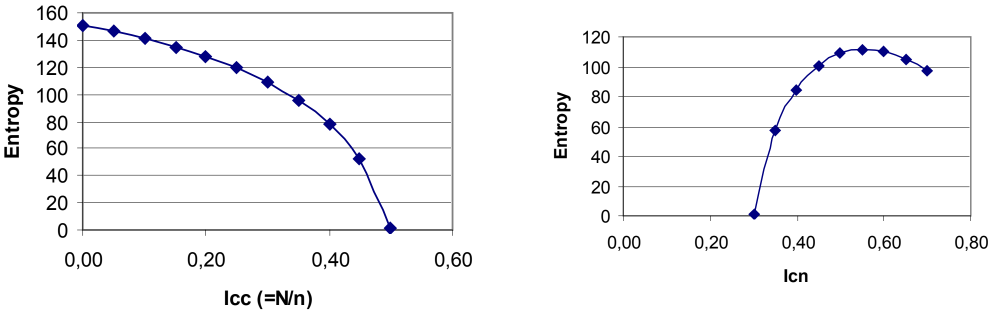
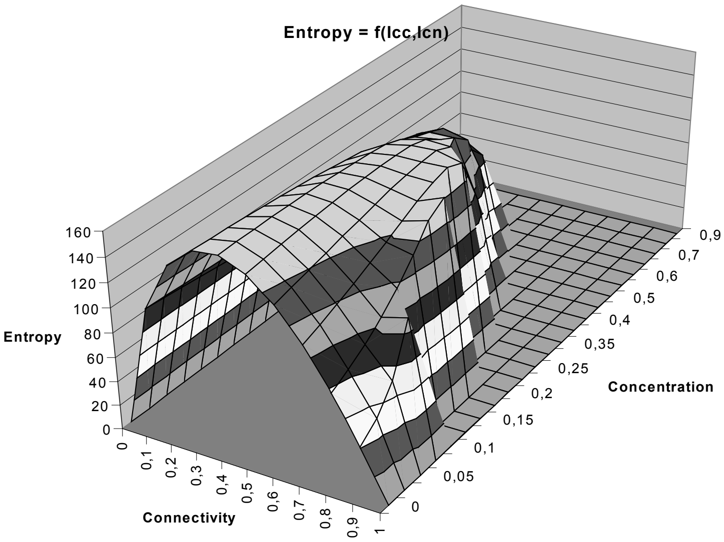


Figure 5. Entropy as a function of concentration and connectivity



- The total network entropy $\varepsilon = \varepsilon_N + \varepsilon_n = 0 - (n-N)*\{[(K-N*(n-1))/((n-N)*(n-N-1))]*\log\ [(K-N*(n-1))/((n-N)*(n-N-1))]\}$

Example

Let us consider an example of a network of *1000* nodes *(n = 1000)* and a total number of *500.000* connections *(K = 500.000)*. The connectivity for this network $Icn = 500.000/\ (1000)^2 = 0,5$. For various levels of the concentration index *Icc* the entropy is displayed graphically on the left side of Figure 4 (note that in this case the maximum value for Icc is *0,5* as at this level all network connections are used up by the fully connected nodes *(N)*). Analogously, we can explore the relation between entropy and connectivity. In this case we fix $Icc = N/n = 0,3$. Hence $N = 0,3 * 1000 = 300$. For various *Icn* this yields values of *K* based on the formula $Icn = K/n^2$. This is displayed graphically on the right side of Figure 4.

If the two parameters concentration (*Icc*) and connectivity (*Icn*) are combined, this yields Figure 5. Note that in the bottom left area of Figure 5, $P_{ij} < 0$, which is of course impossible. This is the area in which *K* is to small to cover all the connections necessary for N, let alone to leave free connections between the other *n-N* nodes.

Figure 5 demonstrates the strong increase of entropy if the relation between connectivity and concentration in a network gets lost during transformation from a hierarchical structure to a networked structure. This phenomenon can be easily observed if, in a meeting between people with no historical relation, the chairman is suddenly removed. It takes quite a lot of time before some form of order is restored and one or a small number of people take the (informal) lead.

CONCLUSION

From the previous we may conclude that it is possible to mathematically connect entropy (and hence network order/disorder) with the traditional network measures of connectivity and concentration (morphology). There is an important implication to be derived from this, namely that the management of organizational connectivity and concentration is crucial in keeping the network within a bandwidth between inflexible structured order and total chaos.

REFERENCES

Abrahamson, E., & Rosenkopf, L. (1997). Social network effects on the extent of innovation diffusion: A computer simulation. *Organization Science, 8*(3), 289-309.

Ahuja, G. (2000). Collaboration networks, structural holes, and innovation: A longitudinal study. *Administrative Science Quarterly, 45*(3), 425-455.

Ashby, W. R. (1958). Requisite variety and its implications for the control of complex systems. *Cybernetica, 1*, 83-99.

Burt, R. S. (1992). *Structural holes: The social structure of competition*. Cambridge, MA: Harvard University Press.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology, 94*, S95-S120.

Den Hartigh, E. (2005). *Increasing returns and firm performance: An empirical study*. Rotterdam: Erasmus Institute of Management.

Fayol, H. (1949) [Original work Administration Industrielle et Générale, Paris, 1916]. *General and industrial management*. London: Pitman Publishing.

Gulati, R. (1999). Network location and learning: The influence of network resources and firm capabilities on alliance formation. *Strategic Management Journal, 20*, 397-420.

Knoke, D., & Kuklinski, J. H. (1982). *Network analysis (series: Quantitative approaches in the social sciences, no.28)*. Beverly Hills: Sage Publications.

Nicolis, G., & Prigogine, I. (1989). *Exploring complexity: An introduction*. New York: W.H. Freeman and Company.

Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly, 41*, 116-145.

Taylor, F. W. (1911). *The principles of scientific management*. New York: Harper & Bros.

Van Asseldonk, T. G. M. (1998). *Mass-individualisation: Business strategies applying networked order to create economic value in heterogeneous and unpredictable markets*. Veldhoven: TVA management bv.

Van Asseldonk, A. G. M., Den Hartigh, E., & Berger, L. (2003). Morphology, entropy, and stability in networked structures. In G. D. Putnik & A. Gunasekaran (Eds.), *Business eExcellence I: Performance measures, benchmarking, and best practices in new economy* (pp. 255-260). Braga: University of Minho.

Van Asseldonk, A. G. M., Den Hartigh, E., & Berger, L. (2001). *Emergence: Creating strength without central power: Six cases in business and society* (Tech. Rep. No. R01-403). Veldhoven: TVA developments.

Walker, G., Kogut, B., & Shan, W. (1997). Social capital, structural holes, and the formation of an industry network. *Organization Science, 8*, 109-125.

Weber, M. (1925). *Wirtschaft und Gesellschaft*. Tübingen: J.C.B. Mohr.

KEY TERMS

Amorphous Structure: A network in which no links exist between the entities.

Chaotic Structure: A network in which all entities are connected to all other entities.

Concentration of a network defines the number of connections between a certain node and the others. The higher the number of connections from one node to all the others, the higher the concentration.

Connectivity of a network is defined as the relationship between the number of nodes and the number of connections between the nodes. The higher the number of connections in relation to the number of nodes, the higher the connectivity.

Entropy is a measure for disorder that can, for organizations, be defined as $\varepsilon = - \Sigma [P_i * \log P_i]$ *for (i = 1 to m)* where P_n is the probability that a certain interaction link in the organization will exist.

Hierarchical Structure: A network in which one of the entities is connected to most other entities.

Network Morphology: The form and structure of a network. It can be described by two separate elements: connectivity and concentration.

Networked Structure: A network in which the connectivity is substantially higher than in the hierarchical structure but substantially less than in the chaotic structure.