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Information flows in hierarchical networks and the capability of organizations to successfully respond to failures, crises, and disasters

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Abstract

In this paper we discuss the problem of information losses in organizations and how they depend on the organization network structure. Hierarchical networks are an optimal organization structure only when the failure rate of nodes or links is negligible. Otherwise, redundant information links are important to reduce the risk of information losses and the related costs. However, as redundant information links are expensive, the optimal organization structure is not a fully connected one. It rather depends on the failure rate. We suggest that sidelinks and temporary, adaptive shortcuts can improve the information flows considerably by generating small-world effects. This calls for modified organization structures to cope with today's challenges of businesses and administrations, in particular, to successfully respond to crises or disasters.

Keywords: Hierarchical networks; Robustness; Failure and attack tolerance; Information flows; Redundancies; Space-filling structures; Social organizations; Complex systems; Decentralized control

1. Introduction

The optimal management of organizations is a challenging task. Organizations are complex systems, and can be modeled by multi-agent concepts [1–3], which may be viewed as generalizations of many-particle models [4–6]. Such multi-component systems with non-linear interactions often display a complex dynamics, which may be hard to control. A favorable aspect of this complexity, however, is the potential for adaptive responses to changing conditions, which depends on the internal interactions. In particular, the structure of organizations and their information flows can make a big difference regarding their flexibility and performance.

Here, it is important to take into account experimental results on the problem solving performance of groups [7,8]. Small groups may find solutions to difficult problems faster than any of their constituting individuals, because groups profit from complementary knowledge and ideas. Similar effects are known from

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computational physics, where N computer processors can find optimal solutions of NP hard problems in less than $1/N$ of the time of a single processor [9,10]. This superlinear speedup has, for example, been found for biologically and economically inspired optimization algorithms.

Small groups also have a potential to assess situations and future developments better than their single members [11]. The actual performance, however, sensitively depends on the organization of information flows, i.e., on who can communicate with whom. If communication is unidirectional, for example, this can reduce performance. However, it may also be inefficient if everybody can talk to everyone else. This is, because the number of potential (bidirectional) communicative links grows like $N(N-1)/2$, where N denotes the number of group members. As a consequence, the number of information flows explodes with the group size, which may easily overwhelm the communication and information processing capacity of individuals. This explains the slow speed of group decision making, i.e., the inefficiency of committees. It is also responsible for the fact that, after some transient time, (communication) activities in large (discussion) groups often concentrate on a few members only. Note that a similar effect is observed in insect societies such as bee hives. When a critical colony size is exceeded, a few members develop hyperactivity, while most colony members become lazy [12].

These findings indicate that there may be an optimal size of companies and organizations [13]. Considering the limited communication and information processing capacities of individuals, the optimal number of group members seems to be 7 (or less) [14,15]. This implies the need for bundling and compressing information flows, which is presently satisfied by hierarchical organizations. The focus of this paper will be to discuss the strengths and weaknesses of hierarchical systems, and what could be alternative forms of organization. It is actually a challenging task to organize large groups and institutions efficiently. This problem closely connects to the theory of networks [16,17]. Some of the relevant questions are:

- How robust is the communication or organization network with respect to failure of nodes (due to illness, holidays, quitting the job) or links (due to difficult personal relationships or communication problems)? How suitable is the organization for crisis management?
- How well does an organization interconnect interrelated activities?
- What is the degree of information loss when communication within an organization network is imperfect?

2. Space-filling organization

Let us imagine that an organization or company has to cover a certain field around its main focus or competency. It is, then, important to cover all areas or functions of this field by complementary activities and responsibilities of its (staff) members. So, how should the field be subdivided into different areas?

One requirement is obviously space-covering. Another one is the potential to satisfy certain functions, which may be represented by different directions in space. Finally, the potential to interconnect neighboring fields and interrelated activities is of importance for the collaboration and functionality of an organization.

Here, we will focus on regular space-filling (or, more exactly speaking, area-filling) kinds of subdivision, as they are particularly suited for a modular organization structure. For some applications, a two-dimensional organization seems to be quite natural, in particularly, if geographical space must be covered as in disaster management. In contrast, three-dimensional, space-filling structures are found in the tree-like organization of arterial, water or respiratory supply systems of many biological species [18]. Generalizations to irregular space-filling structures fulfilling scaling laws [19] or to multi-dimensional forms of organization are possible. However, as these are difficult to visualize in terms of organigrams, their relevance for practical applications may be questioned.

Regular area-filling kinds of subdivision can be either

- triangular,
- quadratic, or
- hexagonal.

The best approximation of a circular field of competency around a certain focus of activity would be reached by a hexagonal form of organization. It allows one to distinguish or visualize either 2, 3 or 6 directions or