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BIOMIMETICS IN MODERN ORGANIZATIONS – LAWS OR METAPHORS?

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ABSTRACT

Biomimetics, the art and science of imitating nature and life for technological solutions is discussed from a modern organization theory perspective. The main hypothesis of this article is that there are common laws in nature that are applicable to living, social and likewise organizational systems. To take advantage of these laws, the study of nature's principles for their application to organizations is proposed – a process which is in product and technology design known as bionic creativity engineering. In a search for most interesting concepts borrowed from nature we found amoeba organizations, the theory of autopoiesis or self-creation, neural networks, heterarchies, as well as fractals and bioteaming which are described and reviewed. Additionally other concepts like swarm intelligence, stigmergy, as well as genesis and reproduction, are introduced. In the end all these ideas are summarized and guidelines for further research are given.

KEY WORDS

biomimetics, organization theory, autopoiesis, network science, bionic creativity engineering

CLASSIFICATION

JEL: B52, L22, M14

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INTRODUCTION

Since the beginning of human history humans were inspired by nature and tried to incorporate such ideas into (better) solutions for everyday life. Biomimetics, biognosis, biomimicry, or bionic creativity engineering is the art and science of imitating nature and life for technological solutions. Many common products today like fasteners (George de Mestral, 1948), waterproof paint (Wilhelm Barthlott, 1982), windmill rotor turbines (Frank Fish, 2006) etc. were inspired by nature.

For example, after a walk in 1948, Swiss inventor George de Mestral had to clean his dog from all the burs it acquired during the walk. He discovered tiny hooks on the burdocks, and was amazed on how they got stuck on the dog's fell. After analyzing them under a microscope he invented a fastening system as a locking tape that was imitating the burs. It consisted of one cloth strip covered with tiny hooks and another covered with tiny loops. After the necessary preparations, he patented a new type of fastener, which he named *Velcro*, from "vel" – velvet, and "cro" – from the French word "crochet" – a small hook. Even if fashion designers did not accept his invention at first, such fasteners were used in lots of situations from the first heart implantation to space journeys like the Apollo mission from 1972, and as we know are in common use today [1; pp. 79-81].

Similarly in 1982 the botanist Wilhelm Barthlott discovered a waterproof surface on lotus leaves which was able to clean itself through waterdrops that fell on it. The secret was in tiny micro- and nano-structures that had a special angle that forced the water to turn into drops and wash all the dirt away. Barthlott patented his discovery and named it the "lotus effect" which was successfully applied to a biomimetic paint called *Lotusan* [1; p. 83].
Another success story of biomimetics includes the one of the functional morphology professor Frank Fish. He was wondering why humpback whale fins have little bumps all over the edges. He created a model based on the fin and discovered it sliced through the water with less resistance than a similarly sized smooth-edge fin. He applied his idea to windmill rotor turbines, and the results showed better performance than usual smooth-edge blades [1; p. 85].

In information systems there are also obvious metaphors borrowed from nature. For instance, genetic optimization algorithms use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover; neural network classifiers and recognition systems are inspired by the human brain and nervous system; while ant colony and swarm intelligence optimization and problem solving systems simulate social insect colonies.

As argued, there are lots of such examples in technology, information systems and product engineering but what about organization theory? Do nature's laws also apply to organizations, and if yes, can we use these laws to improve them?

In the following we shall introduce nature-inspired concepts defined in modern organizations, some of which are discussed in section 2. In section 3 the outlined concepts are analysed and discussed in order to show if they are laws of nature or metaphors. In the ending section 4 final conclusions and guidelines for future research are provided.

EXISTING CONCEPTS

The social sciences have a long history of applying biological metaphors to their research. "*All theories of organisation and management are based on implicit images or metaphors that persuade us to see, understand, and imagine situations in partial ways. Metaphors create insight. But they also distort. They have strengths. But they also have limitations. In creating ways of seeing, they create ways of not seeing. Hence there can be no single theory or*

metaphor that gives an all-purpose point of view. There can be no 'correct theory' for structuring everything we do." [2]. One of the metaphors Morgan's book describes is the one of observing organizations as biological organisms. Such living systems, and likewise organizations, adapt to environmental conditions, have their life cycles, needs, homeostasis, evolution, health, illness etc. [3].

On the other hand, the theory of autopoiesis or self-creation, a theory aiming on describing the essence of life, was introduced to the social sciences and formal organization theory by Niklas Luhmann [4, 5]. Autopoiesis, when following Maturana and Varela, is what distinguishes living from any other systems. This metaphor is especially interesting since it underlines that structures of nature replicate themselves in social and organizational systems.

Are organizations and living systems equivalent, similar or are the similarities just in the eye of the observer? In the following subsections we will try to discuss few representative biomimetic ideas in modern organizations that will hopefully yield better insight: (1) the amoeba organization, (2) neural networks and heterarchies, (3) the fractal company, (4) bioteaming, (5) swarms and stigmergy, and (6) genesis and reproduction. One should mention here that these are of course not the only ideas found in organization theory literature, but others exist like the fishbone diagram [6] or the spider's web [7].

THE AMOEBA ORGANIZATION

The concept of the amoeba organization (or single cell organization) was firstly introduced in the company W.L. Gore & Associates in 1958. At that time the whole organization of this company was futuristic and science fiction in the eyes of commoners. Wilbert L. (Bill) Gore who founded it together with his wife Vieve had been additionally proclaimed anti-manager. The organization resided on principles like complete decentralization, self-organizing teams, flat hierarchy and organizational chaos [8].

The concept of the amoeba is a biocybernetic metaphor since its original ancient Greek meaning implies change or changeability. Especially a known subform of the *Amoeba Proteus* the so called *Amoeba Chaos Chaos* underlines the connection between chaos theory and this kind of organization. The amoeba organization relies on two simple but strong principles: (1) the organization is a process, not a structure, and (2) the organization is a complex (chaotic) system [8].

The metaphor implies that amoebae are simple single-cell organisms that are effective and functional, change their form even if the core organization remains constant, and they are able to learn from and react to outer impulses. If we take these ideas into an organizational context we get small (in the case of W.L. Gore & Associates a unit may have 150-200 employees) divisional or operational units consisting of self-organizing teams with a very flat (or not existing) hierarchy where team leaders are chosen depending on the particular situation.

If an amoeba senses a potential victim it dynamically creates a pseudo-hand and absorbs the victim. Likewise teams are established if a new opportunity is sensed in the environment of the organization and (like a pseudo-hand) try to take advantage of it. Similar to the amoeba, organizational units change their shape by changing their internal relations, teams and members. Still the structure of the unit remains consistent.

In the case when a unit outgrows the limit of employees, a new unit gets established. Likewise the amoeba reproduces itself through division [8].

Another example of an amoeba organization can be found in the Japanese Kyocera Corporation that reorganized its 50 divisions into 400 amoebas (Figure 1) [9]. Amoebas in this

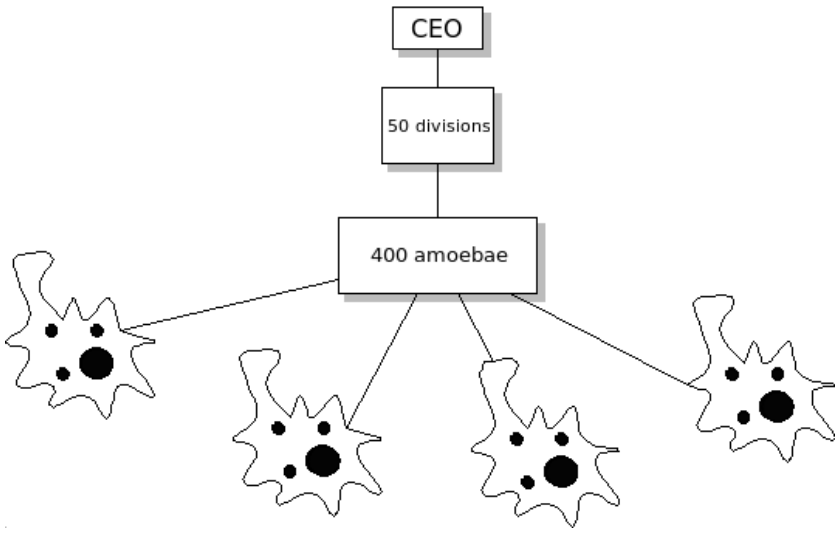

Figure 1. The amoeba organization of Kyocera Corporation [9].

company are self-organizing units that are responsible for their own business. Every amoeba has its own finance and human resource management. Amoebae do business together in an internal market environment, and are constantly in search for better customers. Depending on the situation in the environment they can be divided into smaller units or integrated with other amoebae [10; pp. 179-202].

The amoeba organization represents an organizational suprastructure [11; pp. 129-131] that is founded upon autonomy, flexibility and self-management [12, p. 263]. One can also observe that an amoeba organization does not exist by itself but is incorporated into some type of hierarchical structure [12; p. 264] which implies its superstructural nature.

AUTOPOIESIS IN ORGANIZATIONS

Autopoiesis, a pseudo-Greek word coined from *αυτό* (auto) for self and *ποί*ησις (poiesis) for creation, production or forming was first coined by the Chilean biologists Humberto Maturana and Francisco Varela [7] to label the type of phenomenon which they had identified as the definitive characteristic of living systems [13].

Using the metaphor of autopoiesis, German sociologist Niklas Luhmann developed his theory of social systems based primarily on communication. He introduced the concept of autopoiesis to formal organization theory as well, basing his reasoning on a special subset of communication – decisions that, following Luhmann, build up the organization [8].

When discussing autopoiesis in the context of organization theory, one needs to make a clear distinction of two basic concepts. First there is the concept of organization used in three ways: (1) organization in an institutional sense – denoting a system of consciously coordinated people's activities with a common goal [14; p. 5], (2) organization in Maturana's and Varela's sense – denoting the instrumental participation of components in the constitution of a unity [15; p. 315] or basically a system of relations that build up a unity and (3) organization in Luhmann's sense – denoting a system of decisions [16; p. 106].

As second, there is the concept of structure that is used in two ways: (1) structure in the (traditional) sense – denoting a system of relations between organizational units, as well as (2) structure in the sense of Maturana and Varela – denoting the medium upon which the organization (in Maturana's and Varela's sense) of a unity functions. To prevent possible

confusion we shall use the terms organization and structure in their traditional senses if not stated otherwise.

As mentioned before, the concept of autopoiesis was first introduced to characterize living systems, as opposed to any other system. The original idea was to develop a new perspective of perception and cognition by stating that cognition is a phenomenon of the living. Thus it was necessary to find out what characterizes living systems which led to the notion of autopoiesis that became the core of the new perspective [13].

Varela gave the following definition of autopoietic systems:
"An autopoietic system is organized (defined as a unity) as a network of processes of production (transformation and destruction) of components that produces the components that:

- through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and
- *constitute it (the machine) as a concrete unity in the space in which they* [*the components*] *exist by specifying the topological domain of its realization as such a network.*" [17; p. 13] adapted from [18].

Maturana stated that "*... autopoietic systems operate as homeostatic systems that have their own organization as the critical fundamental variable that they actively maintain constant.*" [15; p. 318]. Thus the concept of autopoiesis, at a most basic level, involves organizational preservation and componental (re-)production [13].

According to Luhmann, social systems are meaning processing systems and this is what distinguishes them from other types of systems such as biological ones [19; p. 104]. "*A social system comes into being whenever an autopoietic connection of communications occurs and distinguishes itself against an environment by restricting the appropriate communications. Accordingly, social systems are not comprised of persons and actions but of communications.*" [20; p. 145]. Social systems are networks of communication that produce further communication and only communication and are thus autopoietic systems [19; pp. 104-105].

Luhmann argues that there are three types of social systems: interactional, organizational and societal which differ mostly in terms of the ways they constitute themselves as well as the ways they select and form their boundaries. Interactional systems are comprised of communication between a set of people by making a distinction between people one talks *with* and people one talks *about*. Societal systems do not rely only on communication taking place, but also on previous (*stored*) communication. Organizational systems are special since they are formed of a special type of communication – decisions that set up the possible future states of the system.

As one can see from these various aspects there are a few crucial concepts one should have in mind before any discussion about autopoiesis. First, there is a distinction between structure and organization (in Maturana's and Varela's sense). While structure is something that is visible (observable) from the outside, organization is unobservable and inside of the system. Structure comprises of a set of components or elements that are exchangeable (meaning that components change during time) and the mutual interactions between these components. Organization comprises of the relations between these components and is stable over time. That means that structure does change but organization remains stable even if the components that make up the structure change over time due to interaction of the system with its environment.

This connection between an autopoietic system and its environment is denoted as structural coupling. "*The result of structural coupling is an autonomous and strictly bounded system,*

that has nevertheless been shaped extensively by its interactions with its environment over time, just as the environment has been shaped by its interactions with the system." [21].

The mechanics of the process of autopoiesis as described by Maturana and Varela are kept strictly within the bounds of an autopoietic system. Thus autopoietic systems are closed in terms of operational and organizational closure [21]. While in living systems structure is comprised of biological processes, in social systems structure is according to Luhmann comprised of communication. Organization (in Maturana's and Varela's sense) is then comprised of the particular relations between certain communicative events.

Another important concept is the reproduction of components. While one can easily depict this process in living systems (e.g. living beings feed themselves with food from their environment that eventually, after certain processes, becomes an integral part of the living being facilitating thereby regeneration of the process) in social systems this reproduction is less obvious. If we follow Luhmann, then communicative events are reproduced by previous communicative events, or in the case of organizations (in Luhmann's sense) decisions reproduce new decisions.

NEURAL NETWORKS AND HETERARCHIES

Neural networks are a new generation of computer software designed to function similar to the human brain. Such software consists of processing elements called neurons. Every processing element is able to send and receive signals to other elements. Some scientists see an interesting similarity between such structures and communication in organizations. Some communication lines grow stronger over time if used intensively whilst other channels weaken or even cease to exist.

The idea of a heterarchical organization comes from the neuropsychological research of the human brain conducted by Warren McCulloch in 1945. He concluded that the human brain must have a heterarchical organization as opposed to previously defined hierarchical models. He described this organization as a neural network which is specifically designed for parallel information processing [22; p. 3].

The concept of a heterarchical organization (or network organization) is based on the following principles: an organization consisting of organizational units that are mutually connected through information links (often based on modern information technology), are mutually independent, heterarchically organized (as opposed to hierarchy), and operate internally and externally (with their environment) in most cases sharing some common goal. Organizational units can in this context be either individuals, teams, departments, divisions and even entire organizations, or groups of organizations by the fractal organization principle [14; pp. 149-151] as argued further. If we apply such a concept to an organization, we get a structure which interrelationships are not strictly defined, but rather activated, or self-regulated depending on the particular situation.

An interesting metaphor for this kind of organization is the fishnet organization, depicted on Figure 2. If we observe a fisher's net on the coast, it seems completely nonhierarchical. But if we take one node and lift it up, we get a hierarchical structure. By lifting further nodes and putting down the old ones, we can see the dynamical creation of new and the destruction of old hierarchical structures. Thus the fishnet organization tries to combine the modern concept of heterarchy and the usual human habit of tendency to hierarchy and order [23].

FRACTAL PRINCIPLES AND THE FRACTAL COMPANY

The concept of a fractal company (Ger. *die Fraktale Fabrik*) was first introduced by Hans-Jürgen

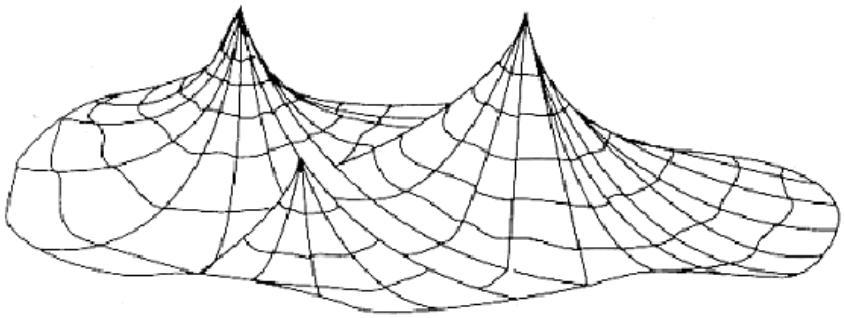

Figure 2. The fishnet organization (taken from Johansen, R. and Swigart, R.: *Upsizing The Individual In The Downsized Corporation P: Managing In The Wake Of Reengineering, Globalization, And Overwhelming Technological Change*. Perseus Publishing, 2000.)

Warnecke [24] who claimed that organizations are similar to complex systems that are characterized by fractals. This concept was in a way an answer to similar Japanese and American concepts adapted to the European market [25; p. 1].

The term fractal was introduced by Mandelbrot to denote an object that has a certain degree of statistical self-similarity on every observed resolution and is generated by an infinite number of recursive iterations. By observing a fractal one can recognize a certain pattern. By taking a closer look (possibly under a magnifier) the same or similar pattern can be observed on lower and lower levels.

A fern twig has some characteristics of a fractal (one twig is similar to the smaller twigs it consists of, which in turn consist of even smaller twigs). By applying this concept to organizational structure one could observe fractals in the form of individuals, departments, divisions, process flows, decisions and other organizational subsystems. The main objective is to find the fundamental pattern that will yield deeper insight to the organization as a whole and align to this pattern on lower and lower levels.

In Warnecke's sense a fractal is an autonomous organizational unit that has its objectives and a function that can be clearly described. Typical characteristics of a fractal are self-similarity, self-organization and self-optimization [25; p. 1].

Self-similarity means that the goals of particular fractals (from the individual in the organization, until the organization as a whole) match into a harmonic mutual objective. Self-organization means that particular fractals have their own autonomy concerning ventures and decisions according to the self-similarity rule, e.g. objectives have to be harmonized with upper and lower fractals. Self-optimization means that fractals continuously optimize their self-initialized work and decision making [26; p. 34]. Figure 3 shows the fractal principle where the spiral connecting the individual fractals represents the business process.

BIOTEAMING

Bioteaming, the most obvious biomimetic application in organizations [27, 28] deals with virtual, networked business teams that operate on the basis of natural principles which underpin, as the authors claim, nature's most successful teams. Some of these teams include single-cell and multicellular organisms, the human immune system, the nervous system (including the brain), micro-organisms such as bacteria and social insects (ants, bees and termites), jellyfish, geese, monkeys, dolphins, big cats, forests, rivers, ecosystems, the Earth (as Gaia) etc. [27; p. 18.].

In essence, bioteaming is a set of simple rules and procedures for self-organizing, virtual, heterarchic teams written by managers for managers and thus gained considerable attention in the business community. Terms like symbiosis, swarming and clustering are used to provide

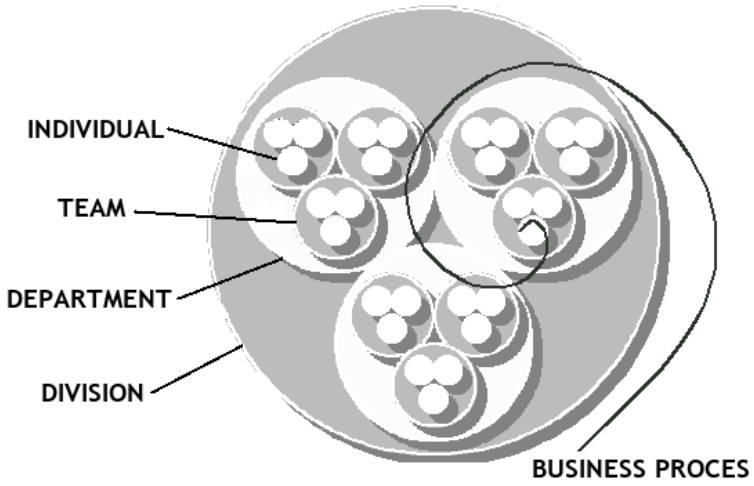

Figure 3. The fractal principle.

a suitable biomimetic terminology for decentralized teamwork, social networking, empowerment and other well known practices. Still bioteaming presents a set of elaborate practices that can easily be implemented into organizations.

SWARMS AND STIGMERGY

The term swarm intelligence was first introduced by Beni, Hackwood and Wang [29-34] in the context of cellular robotics. Swarm intelligence can be defined as "*any attempt to design algorithms or distributed problem solving devices inspired by the collective behavior of social insect colonies or other animal societies*" or simply as "*the emergent collective intelligence of groups of simple agents*." [35; p. 7]. A swarm is a "*collection of autonomous individuals relying on local sensing and reactive behaviors interacting such that a global behavior emerges from the interactions*" [36], whilst on the other hand the term swarm prediction is used in the context of swarm behaviour forecasting problems.

It is somewhat amazing to analyze animal swarms (like ants, birds, eels, grasshoppers, honey bees, termites, herrings etc.) which self-organize to fulfil the most complex tasks and they have been fascinating scientists and artists for many years. "*Any single insect in a social insect colony seems to have its own agenda, and yet an insect colony looks so organized*" [37]. Agents self-organize through direct (antennation, trophalaxis, mandibular contact, visual contact, chemical contact etc.) or indirect interactions fulfilled through stigmergy [35; p. 14].

We can here draw an interesting analogy to organization and especially teamwork in organizations. Interactions between people self-organizing to achieve a common (higher) goal can be analyzed from a swarm intelligence perspective. "*Perhaps the most powerful insight from swarm intelligence is that complex collective behavior can emerge from individuals following simple rules.*" [37] By studying swarm intelligence and implementing such rules, managers can take advantage of three important characteristics shown by social insect colonies [37]:

1. flexibility (ability to adapt to a changing environment),
2. robustness (even if some individuals fail, the group can still perform),
3. self-organization (work is neither locally supervised nor centrally controlled).

The word stigmergy coming from old Greek *stigma* (sting) + *ergon* (work) and interpreted like "stimulation by work" was first introduced by Grassé to denote task coordination and regulation of a special type of termites (*Macrotermes*) during nest reconstruction. Stigmergy is achieved through indirect agent interaction whereby agents modify the environment which in turn serves as an external memory. Thus work can be continued by any individual depending on the actual state of the environment. On the other hand, the same, simple, behavioural rules can create different designs [35; p. 14].

Stigmergic processes can be an interesting metaphor for knowledge management systems. Especially new Enterprise 2.0 technology can be analyzed from such a perspective. By using insights from stigmergy research, adequate systems can be implemented that will push knowledge sharing and knowledge acquisition [38, 39].

GENESIS AND REPRODUCTION

Genesis coming from the ancient Greek word for birth or origin and reproduction being the biological processes by which new individual organisms are produced seem to be an interesting analogy to contemporary market processes of strategic alliances, joint ventures, spinouts, outsourcing as well as ad-hoc and virtual organizations.

Strategic alliances are formed since contemporary organizations are more and more unable to survive by themselves in a dynamic environment. They understand that they have to focus on what they do best, their core business, and outsource other operations to allies or joint ventures that are more specialized.

Since organizations try to achieve more and more innovation, they realize that there is neither time nor resources to take advantage of all opportunities creative minds can create. To keep their innovative human resources, organizations create spin-out companies for them to undertake entrepreneurship. These spin-outs eventually yield companies for themselves [40; pp. 1-3].

Ad hoc suprastructures are concepts that are built on top of existing organizational structures and they emerge as a response to some problem or change in the immediate environment of the organization [11; p. 119]. Ad hoc organizations are characterized by adaptability, readiness, individual initiative, desire for experimentation, creativity, and outside growth and support [41; p. 7]. They usually disappear when the environment problem is solved.

A virtual organization is a target-oriented suprastructure of geographically separated entities (organizational units) that are specialized for a predefined area of activity, and interconnected through space, time and organizational limitations, mostly using information, communication and network technology for efficient and flexible cooperation and exchange of knowledge. Virtual organization is one of the most widespread examples of ad hoc organization in expert literature. Barnatt [42] says that these organizations exist in cyberspace, that they develop proportionally with the development of information and communication technology and that they can be found in conventional organization structures. Under the term cyberspace he understands the media in which electronic communication and computer programs exist, and he argues that the understanding of the term is essential to the understanding of the virtual organization. Figure 4 shows the concept of a virtual organization [42].

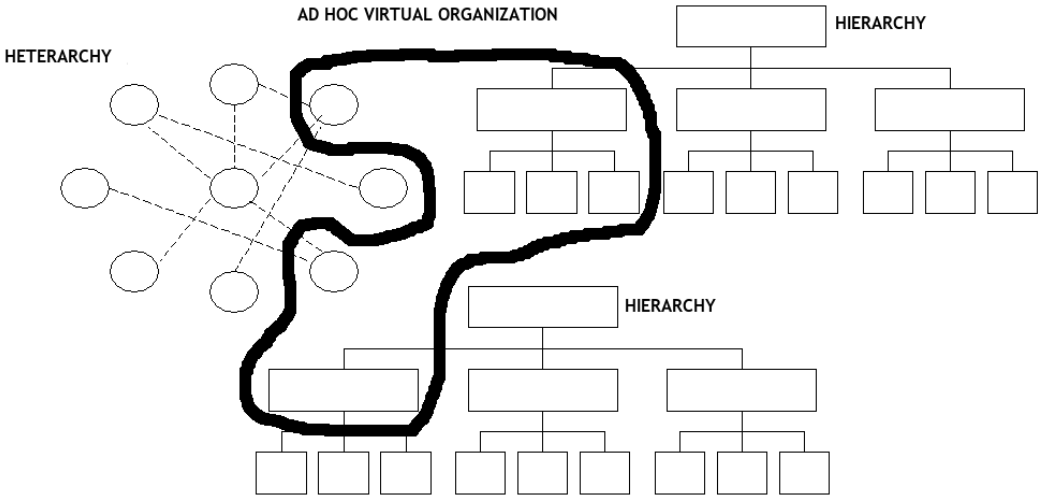

Figure 4. The virtual organization [42].

If we, for a moment, imagine that organizations are living beings we observe sexual and asexual reproduction depending on the number of entities involved in the creation of new entities. We are even able to observe different reproductive strategies like K-selection (few offspring) and r-selection (many offspring), sexual maturity, allogamy, autogamy and many other terms common in genesis and reproduction. Further conceptualizations are part of our future research.

DISCUSSION – METAPHORS OR COMMON LAWS?

After examining the identified concepts one could conclude that there is a potential application area for biomimetics in organization theory. To clarify our standpoint we analyzed each outlined metaphor for its practical and theoretical implications. From a practical viewpoint we established a descriptive scale of three levels of possible application:

- *Metaphor* – the concept is clearly a metaphor that cannot be directly implemented into practice but could serve other objectives like employee motivation,
- *Analytic* – the concept provides methods that can be applied in practice in order to analyze the current organization (and eventually find inconsistencies, problems, potential opportunities etc.),
- *Systemic* – the concept provides methods that can be applied in practice in order to establish new organizational systems.

From a theoretical viewpoint we established a descriptive scale of three levels of possible use as well:

- *Descriptive* – the concept can be used to describe (possibly metaphorically) some organizational phenomenon,
- *Analytic* – the concept provides actual methods to analyze some (particular) organizational phenomenon,
- *Systemic* – the concept provides (holistic) methods to understand organizational phenomena.

An outline of our findings is given in Table 1.

Table 1. Outline of biomimetic concepts in organizations.

Biomimetic concept	Nature	Organization	Implications for practice	Implications for theory
Amoeba organization	Single cell organism	Small divisional self-organizing unit	metaphor	descriptive
	Changing form	Changing teams and team members	metaphor	descriptive
	Pseudo-hand	Self-establishment of teams	metaphor	descriptive
	Absorption	Taking advantage of opportunity	metaphor	descriptive
	Division	Establishment of new units	metaphor	descriptive
Autopoiesis	Living organization (biochemical processes)	Formal organization (decision making processes)	n/a	analytic systemic
	Reproduction of components (molecules)	Reproduction of components (organizational roles)	n/a	analytic systemic
	Maintenance of boundary	Restriction of communication	n/a	analytic systemic
	Structural coupling (habitat, language, external perturbations etc.)	Structural coupling (organizational culture, cooperation style, market condition etc.)	n/a	analytic systemic
Neural networks & heterarchies	Neurons	People / Organizational units	analytic	analytic
	Axon	Communication channel	analytic	analytic
	Signal	Communication	analytic	analytic
	Parallel processing	Organizational information processes	analytic systemic	analytic systemic
Fractal principles & the fractal company	Self-similarity (geometrical structures)	Self-similarity (organizational units, goals, decisions, process flows etc.)	n/a	descriptive analytic?
Bioteaming	Ant colony (super organism)	Team	metaphor	descriptive analytic? systemic?

Biomimetic concept	Nature	Organization	Implications for practice	Implications for theory
Bioteaming	Autonomy in stimulus – action operations	Autonomy of team members	metaphor	descriptive
	One-way (broadcasting) communication	Team communication optimization	metaphor	descriptive
	Swarm intelligence	"Team intelligence"	metaphor	descriptive
	Self-organization	No central control	metaphor	descriptive analytic? systemic?
	Symbiosis	Trust external partners	metaphor	descriptive
	Clustering	Team member's relationships	metaphor	descriptive
	Tit-for-tat strategy	"What is in for me?"	metaphor	descriptive
	Genetic algorithms	Controlled experimentation	metaphor	descriptive
	Porous membranes	Selection of new team members	metaphor	descriptive
	Emergence	Team growth	metaphor	descriptive
Swarms & stigmergy	Swarm	Organizational unites, teams, divisions etc.	analytic systemic	analytic systemic
	Emergent behaviour	Simple rules	systemic	systemic
	Stigmergy	Knowledge sharing/acquisition systems	analytic systemic	analytic systemic
Genesis & reproduction (continued)	Genesis	Establishment of new organization	n/a	descriptive
	Reproduction	Joint ventures, spinouts, virtual organization	n/a	descriptive analytic?
	Mating	Strategic alliance, mergers, acquisitions	n/a	descriptive analytic?
	Reproductive strategy	Brand management strategies	n/a	descriptive analytic?
	Sexual maturity	Organizational life-cycle considerations	n/a	descriptive analytic?

Most biomimetic concepts are metaphors or not (directly) applicable in practice. Still there are some concepts (neural networks and heterarchies, swarms and stigmergy) that can provide at least analytical methods. On the other hand, from a theory-oriented view there seem to be descriptive, analytical as well as systemic methods more equally distributed. The question marks in the table indicate fields of potential new research that has to be conducted in order to yield adequate methods.

The amoeba organization is a nature-inspired organizational form that allowed organizations to do business without unnecessary bureaucracy in a dynamic environment by using the metaphor of a known singe-cell organism. On the other hand, this metaphor provided organization theorists with suitable means to explain and examine such an organizational form.

The theory of autopoiesis gained major attention in the field of biology as well as social and organizational studies. Still there lacks a common foundation between those perspectives outlined in some critics of the theory. Such a foundation needs to be addressed in future research. Due to the fundamental works of Niklas Luhmann [8, 19, 21], partially Milan Zeleny [10, 43] and others, this theory seems very promising in organization theory and the social sciences. Efforts to examine this theory for its practical implications, as well as to formalize it with adequate research methodology, yet have to be done.

The neuropsychological research of the human brain firstly introduced a heterarchical neural network model that was successfully applied to flat, non-hierarchical, networked organizational forms [22; p. 3]. These new forms have become a major trend in modern organizational theory but were applied in practice as well. Network principles have a major role in contemporary science – computers, social systems, information transfer, the human brain, traffic and likewise organizations seem to conform to them.

Fractal geometry is a common law of nature and through the development of complexity theories led to a new revolution in science. The application of fractal philosophy to organizations from a theorist's as well as from a practitioner's view, still needs research and additional efforts. The fractal organization is as yet a metaphor that nevertheless could give interesting insights into the inner laws of organizations.

Bioteaming seems to be a very promising concept, but lacks formal theoretic background. The (over)use of biomimetic metaphors is maybe interesting (and successful) in industry but has to be established scientifically. On the other hand, bioteaming relies on well-established concepts like virtual organizations, social networking and distributed teamwork which of course makes it usable in a dynamic organizational environment.

The potential use of ideas from swarm intelligence as well as stigmergy research could yield new insights into the internal functioning of organizations and especially teamwork. We envision that research in this area will lead to better collaboration policies established upon simple laws and stigmergy that will (hopefully) strengthen productivity and effectiveness of high-performance teams as well as provide foundations for new types of knowledge management systems.

Genesis and reproduction, when put into an organization theory perspective, could give new methods for analyzing contemporary phenomena like strategic alliances, joint ventures, spin-outs, outsourcing as well as ad-hoc and virtual organizations, as outlined before. In this phase of such a conceptualization we are unable to conclude if this biomimetic metaphor will lead to any practical results.

As one can see from this reasoning, in all the analyzed cases some kind of nature-inspired idea was applied to a particular part of organization theory. Biomimetics is applicable to organization theory especially in cases where complex interactive living systems are analyzed

for their organizational characteristics. The mutual interactions between living systems as well as their internal processes seem to have extraordinary similarity to organization in a social context. Due to the turbulent environment contemporary organizations face today, they have to increasingly take the laws of complex non-linear systems into consideration in order to be successful. Nature seems to have found just the right tools to do that, and has additionally millions of years of experience.

CONCLUSIONS AND GUIDELINES FOR FUTURE RESEARCH

Nature was inspiring human beings since the beginning of history. In this paper we outlined several concepts inspired by nature that led to considerable advances in modern organization's theory and practice. We claim that biomimetics, the art and science of imitating nature to achieve solutions, has a major applicative area in contemporary social sciences and especially in modern organization theory. Several cases of biomimetic applications showed gaps that should be filled through future research and practice.

In technology and information systems a biomimetic application is achieved through imitating some (mostly physical) characteristics of some biological system. In modern organizations most biomimetic applications deal with metaphors. Still there are implications in the shown cases that nature's structures replicate themselves in social and organizational systems. The use of metaphors is likely the first step in creating a more tangible biomimetic application in organization theory. The development of such applications can provide us with a suitable backdrop for understanding, analyzing and optimizing modern organizations.

To follow Zeleny [10, 43] who claimed that all living systems are necessarily social systems, it seems obvious that researchers from this field should observe nature in search for new concepts. Nature is a never-ending pool of creative ideas.

On the other hand, one should have in mind that there is still a very big question as to whether these ideas are metaphors (as Morgan's book suggests) or represent something more fundamental about the structures of nature. Very often, the slippage from one position to another has allowed commentators to suggest that because X looks like Y, X has to be like Y, and so the ideological and political implications are quickly naturalized. We take the standpoint that laws obtained from autopoietic theory, network science, swarm intelligence and other fields of research dealing with complex systems are applicable to organizations and can yield insights and methods for their optimization.

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BIOMIMETIKA U MODERNIM ORGANIZACIJAMA – ZAKON ILI METAFORA?

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SAŽETAK

Biomimetika, umjetnost i znanost imitiranja prirode i života za tehnička rješenja, razmatrana je sa stajališta moderne organizacijske teorije. Temeljna hipoteza članka je kako postoje zakoni prirode koji su primjenjivi u živim, društvenim i drugim organizacijskim sustavima. Kako bi se iskoristilo prednosti tih zakona, predlaže se proučavanje principa prirode i njihova primjena u organizacijama – proces koji je poznat kao bioničko kreativno inženjerstvo. U potrazi za najinteresantnijim konceptrom iz prirode, izdvojili smo ameba-organizaciju, teoriju autopoiesisa ili autokreacije, neuronske mreže, heterarhije kao i fraktale i biogrupiranje, što je sve opisano. Dodatno su uvedeni i drugi koncepti, poput inteligencije roja, stigmergije, kao i stvaranje i reprodukcija. Na kraju su navedene ideje izlistane, a smjerncie daljnjih istraživanja navedene.

KLJUČNE RIJEČI

biomimetika, teorija organizacije, autopoietika, znanost o mrežama, bioničko kreativno inženjerstvo