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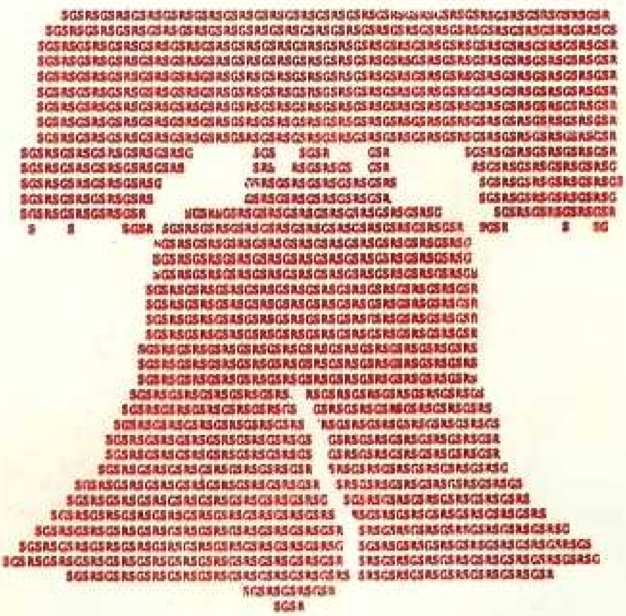

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CONCEPTS OF SELF-ORGANIZATION
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SELF-ORGANIZATION OF CONCEPTS

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Keywords: self-organizing systems; classification of organizational concepts; unity; duality; hierarchy; self-reference; self-reflexion; isomorphies; linkage propositions.

ABSTRACT

This paper provides a periodic classification of organizational concepts applicable to physical, chemical, biological, socio-cultural, and symbol systems. The concepts of self-organiation "fall" into two complementary organizational directions: local bottom-up integration vs. global top-down differentiation. The organizational concepts are situated in an organizational space comprising three organizational dimensions: structure, process, and regulation. In each of the three organizational dimensions we define an organizational metric based on seven fundamental organizational categories: unity, complementarity, conjunction, disjunction, sequential branching, modular closure, and modular recursion. Organizational space and organizational metric allow us to define organizational coordinates. Identical organizational isomorphies designate organizational linkage propositions. Based on a case-study a minimal set of 55 organizational isomorphies has been identified. To avoid long lists of disciplinary dependent notions (discinymes) a set of user-friendly transdisciplinary icons is proposed.

1. INTRODUCTION

The term "self-organization" is encountered frequently across many disciplines ranging from physics, chemistry, and biology to the social sciences (Jantsch, 1980a; Duouchel, 1983). Unfortunately this term, like a variety of notions containing the prefix "self-" or "auto-", belongs to the class of chameleon concepts which are characterized by a lack of precise definition. As mentioned by Gutsatz (1983) one can state almost as many defintiions for a chameleon concept as it has applications.

The present work attempts to put some order into the conceptual fuzzyness related to self-organization. In section 2 we give a brief and certainly incomplete overview of the existing notions and try to arrive at a generally acceptable definition of the concept self-organization. Based on a case-study in section 3 we identify and classify in section 4 the fundamental conceptual tools used for the description of self-organization and propose a coherent set of icons representing the respective transdisciplinary organizational isomorphies.

Miller's (1978) classification of 19 "critical subsystems" identified seven integrative or organizational levels of "living systems", Thom's (1980) classification of 18 morphological archetypes for verbes, Robbins' and Oliva's (1984) 51 GST core components and Troncale's (1978, 1982, 1984) list of 57 principal System Concepts are tentatives into similar directions.

Our research has been conducted accepting the basic hypothesis that isomorphies can be identified across all scientific disciplines. We have limited ourselves to identify conceptual isomorphies. A further investigation could be extended to isomorphies of formal descriptions. Each identified conceptual isomorphy represents a long list of disciplinary dependent notions (discinymes). Following Troncale (1985), who asks for "user-friendly" presentations of system concepts, we propose a coherent set of icons which permits a concentrated and economic manipulation of the highly complex subject.

2. WHAT IS SELF-ORGANIZATION?

2.1. Cybernetic approaches

2.1.1. Non-existence

Eminent cyberneticians like Heinz von Foerster (1960) and W. Ross Ashby (1962) argued that self-organizing systems are impossible things. Von Foerster's argument is based on the implicit definition of self-organization as decrease in thermodynamical entropy. In a convincing reductio ad absurdum he shows that self-organizing systems are logically impossible - unless we dispose of the Second Principle of Thermodynamics. Ashby on the other hand implies under the concept of self-organization reflexive expressions of the type: a system capable to define and to determine itself the objective or goal to be obtained (e.g., programs that program themselves or organizations that organize themselves). One can certainly conceive a program with the capacity to modify partially the proper rules of its functioning. But this capacity and the corresponding rules for the modification of rules are part of the program and inaccessible to modification by the program itself.

2.1.2. Order from Noise

Atlan (1972, 1979) distinguishes the concepts of organization and self-organization in the following way. If the system receives a series of organized inputs and the future organization of the system is already implied by the series of "organized effects" acting on the system, then we speak of organization. If the system reacts under the effect of random perturbations with an increase in complexity and diversity, we speak of self-organization. Based on Shannon's theory of Information, Atlan introduces two measures R and H and describes the evolution of these parameters under the influence of a "noisy" environment (order from noise principle).

2.1.3. Autonomy, Autopoiesis

For Varela and Maturana (1979, 1980, 1983) self-organization is only an "epiphenomenon" characteristic of autonomous units. "One can describe an autonomous unit by passing from a coupling via input to a coupling via closure. The coupling via closure demands the comprehension of the internal coherence of the unit (eigen-behavior). A unit with sufficient structural plasticity has a complex and diversified internal coherence. The self-determined diversity of internal coherence, observed under certain conditions of appropriate interactions, appears as novelty, unforeseeable, self-affirmation, short, as the behavior of a self-organizational unit."

2.2. Dynamical systems approaches

2.2.1. Dissipative Structures, Order from Fluctuation

Nicolis and Prigogine (1977, 1979) are probably the most frequently cited authors in relation to self-organization. Even though the term self-organization is part of the main title of one of the cited books, one searches in vain for a precise definition of this concept (the term does not even figure in the index). The implicit definition of self-organization employed by the authors could be summarized as follows: "self-organization denotes the capacity of a physico-chemical system, which exchanges only energy with its environment, to structure itself spatio-temporally. It is the exchange of energy which allows the persistence of dissipative structures". (Gutsatz, 1983).

2.2.2. Hypercycles, Darwinian Systems

Eigen and Schuster (1971, 1978) link their concept of self-organization to closed loops of cause and effect (e.g., the interplay of nucleic acids and proteins: "function" cannot occur in an organized manner unless "information" is present and this information only acquires its meaning via the "function" for which it is coding). "What is required in order to solve such a problem of interplay between cause and effect is a theory of self-organization. Hypercycles are a principle of natural self-organization allowing an integration and coherent evolution of a set of functionally coupled self-replicative entities."

2.2.3. Synergetics, longliving Master systems slave shortliving systems

Haken (1983) understands organization and self-organization as follows: "Consider, for example, a group of workers. We then speak of organization or, more exactly, of organized behavior if each worker acts in a well-defined way on being given external orders, i.e., by the boss. It is understood that the thus-regulated behavior results in a joint action to produce some product. We would call the same process as being self-organized if there are no external orders given but the workers work together by some kind of mutual understanding, each one doing his job so as to produce the product." In mathematical terms, a description of self-organization consists in including the external forces as parts of the whole system.

2.3.4. Singularities of global morphogenetic fields, catastrophes

The Catastrophe theory of Thom (1972) is often cited within the context of self-organization. This theory initially created for "the study of embryonic development" places itself on a global level trying to explain abrupt organizational change without entering into details of local processes.

2.3. Synthetic approaches

2.3.1. Holons, open hierarchical systems

Koestler's (1966, 1967) transdisciplinary research on creativity and evolution can be considered as a precursor of a systems oriented general theory of self-organization. One of Koestler's key concepts is the Janus-faced Holon, which represents two complementary tendencies: self-assertion in controlling its subsystems, and self-integration in subordinating itself to its metasystems.

2.3.2. Living systems, 19 critical subsystems

Miller's (1978) implicit concept of self-organization is based on the emergence of new levels of integration and the increase of complexity on a given level of integration during the process of evolution.

2.3.3. "La Methode" for dealing with complexity

Morin (1977, 1980) uses the term self-organization tangled within complex verbal loops coupling self-organization, self-reorganization, self-production, self-reproduction, and self-reference.

2.3.4. Autogenesis, the replicative model

Czany (1982, 1984) attempts to arrive at a general theory of evolution or self-organization based mainly on the concepts of function and specially the replicative function.

2.3.5. The Unifying Paradigm

Jantsch (1980a) defines self-organization as "the dynamic principle underlying the emergence of a rich world of forms manifest in biological, ecological, social, and cultural structures". According to Jantsch (1980b), the different conceptual schools of self-organization have not yet formed a "talking relationship". Dissipative structures, autopoiesis and hypercycles are isolated concepts related to the same underlying unifying paradigm.

2.3.6. The Maximum Complexity Principle

On a speculative basis we have formulated the hypothesis that any process of self-organization can be described as an increase in complexity governed by a generalized second principle of Thermodynamics (first law of genesis or maximum complexity principle) (Winiwarter, 1983a). A quantitative measure of systems complexity is composed of two complementary measures: an informational measure I for the variety of systems components and an energetic measure R for the internal coherence or synergy of the total system.

2.4. Related Concepts

2.4.1. Tangled Hierarchies

Hofstadter (1979) does not explicitly mention the concept of self-organization, but his refreshing book is certainly deeply related to the subject.

2.4.2. Fractals

Mandelbrot's 91982) universe of recursive isomorphic geometric structures opens a new look on our concepts of boundary and form. To jump from recursive structural isomorphies to recursive process isomorphies (hypercycles) and recursive dynamic isomorphies (isodynamics) and finally to recursive organizational isomorphies (self-organization) seems to us an evident step developed in this paper.

2.5. A general definition of self-organization

Self-critique: like many of the above cited authors we have to accuse ourselves of the same mental sloppiness having used the term self-organization in our papers without giving a clear definition. In the following we propose a general definition, which applies across all disciplines.

2.5.1. Self-organization denotes the emergence of organizational categories >X on a given level of description within a system, whose initial organization can be described with organizational categories $\leq$ X.

2.5.2. Organization denotes the spatial, temporal, and causal description of a system. (Structure + Process + Regulation).

2.5.3. Organizational Categories and Levels of description are defined in section 4.6 on organizational metric.

3. CASE STUDIES OF SELF-ORGANIZATION

3.1. Isodynamics of evolutionary processes

The empirical study of population-size distributions in physical, chemical, biological, socio-economic, and symbol systems has shown a surprising isomorphic regularity of their statistical structure suggesting the underlying isodynamics of all self-organizing systems (Winiwarter, 1983b, 1985).

If we accept this hypothesis of a common underlying dynamics or "driving process", then the concepts elaborated in the study of one self-organizing system should be transferrable to any other self-organizing system.

3.2. Candidates for case-studies

3.2.1. Exclusion of Prigogine's examples

Benard cells, Belousov-Zhabotinsky reactions and Brusselators are interesting organizing phenomena, but they do not fall into the category of self-organizing phenomena according to our definition. In the above mentioned experiments more or less complex man-made mechanisms have to be set up, which regulate the "self-organizing" system from the outside. Without thermostats, mixers, and pumps triggered by the experimentor, none of the above mentioned phenomena occurs in nature.

3.2.2. Embryogenesis in a fertilized egg?

This process corresponds to our definition of self-organization, but unfortunately the theoretical egg of Columbus has not yet been found. No theory today can claim to give a coherent description of morphogenesis. Nevertheless, Thom's classification of singularities within morphogenetic potential fields seem to us global concepts which could be generalized to any self-organizing system.

3.2.3. Ontogenesis of a massive star

In search for relatively well-described self-organizing systems, with a small alphabet of initial components, the evolution of a massive star seems a suitable candidate for a conceptual case-study. The different organizational phases and their transitions are well described in global macroscopic terms and local microscopic terms both formulated within the framework of well-established physical theories (gravitation, electro-magnetism, weak interaction, and strong interaction). We underline that our purpose was not to analyze the mathematical tools used in nuclear astrophysical theory; we wanted to extract the mental images and abstract concepts used to build and formulate a coherent model describing a process of self-organization. Details of our analysis are reported in a separate paper (Winiwarter, 1986a).

4. SELF-ORGANIZATIONAL TOOLBOX

Even restricting the conceptual tools to a minimum, we make the frightening experience that one needs at least 40 or 50 different conceptual tools in order to describe something which looks like self-organization. In the following we propose such a minimal set of concepts within a coherent classification scheme.

4.1. Self-organization

The organization of organization

The unifying concept of self-organization is equivalent to the following discinymes: Evolution, Emergence, Irreversible Process, Dissipative Structures, Autonomy, Autopoiesis, Autogenesis, Living Systems, Adaptive Systems, Learning Systems, Cognitive Systems, Autognostic or Self-image building Systems.

4.2. Local bottom-up Integration vs. Global top-down Differentiation

Organizational directions

The two complementary organizational concepts, Local bottom-up Integration/Global top-down Differentiation are equivalent to the following discinymes: Composition/Decomposition, Combinatiorial expansion/Generative condensation (Alvarez, 1985), Synthesis/Analysis.

In our case-study the organizational direction of Local bottom-up Integration corresponds to the gradual build-up of a nested hierarchy of local shells constituting heavy atomic nuclei from the initial alphabet of protons and neutons. The organizational direction of Global top-down Differentiation corresponds to the internal structuring of an initial amorphous cloud into a nested hierarchy of global shells until an innermost core.

Both complementary concepts seem to be essential and interdependent (at least in our case-study).

4.3. Structure

Spatial organization

The organizational concept of structure is truly transdisciplinary and equivalent discinymes are rare: Being, Statics, Architecture, Topology.

4.4. Process

Temporal organization

The organizational concept of process is also truly transdisciplinary. Equivalent discinymes are: Becoming, Kinetics, Course.

4.5. Regulation

Causal organization

Discinymes for the organizational concept of regulation are: Dynamics, Control, Rule, Cybernetics.

Structure, Process, and Control are called organizational dimensions defining a three dimensional organizational space.

4.6. Organizational Metric, Organizational Isomorphies

Formation of organization

In order to be able to speak of isomorphies, one has to define a metric within a space (cf. Thom, 1980). For the three organizational dimensions of organizational space we define the following metric:

$\times$	unity or elementary concept	(distance 1)
$\neg$	complementarity of elementary concepts	(distance 2)
$\wedge$	conjunction of complementary concepts	(distance 3)
$\vee$	disjunction of elementary concepts	(distance 4)
	sequential branching or tree of conjunctions and disjunctions	(distance 5)
$\Diamond$	modular closure of conjunctions and disjunctions	(distance 6)
	modular recursion, closed module of organizational level n becomes elementary concept of organizational level n+1	(distance 7)

Concepts of local bottom-up integration are located on the positive axes of the three organizational dimension of organizational space and concepts of global top-down differentiation are located on the negative axes. Thus, given a reference level n, any organizational concept can be assigned unique coordinates in organizational space.

Any concept with identical organizational coordinates module 6 in the organizational space is called organizational isomorphy.

Table 1 shows a two dimensional representation of the three dimensional organizational space.

In the following we list 55 fundamental organizational isomorphies occuring periodically on each organizational level. The proposed lists of discinymes for the respective isomorphies are far from being complete and have only illustrative purpose.

Unity

local	structure :	element, point, "atom", individual, unit
	process :	event, incident
	regulation:	state
global	structure :	universe, space, whole
	process :	trajectory, behavior
	regulation:	potential field, ensemble of laws

Complementarity

local	structure :	complementary elements, plus/minus, up/down, male/female
	process :	action/reaction
	regulation:	force/counterforce
global	structure :	polarized universe, polarized space
	process :	expansion/contraction, input/output
	regulation:	potential source/well

Conjunction

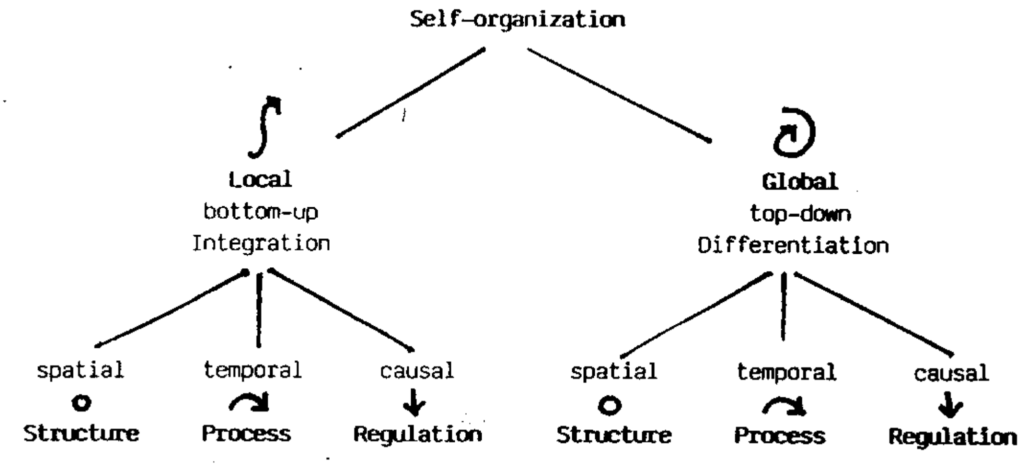
local	structure :	linked couple
	process :	interaction, linkage
	regulation:	equilibrium
global	structure :	boundary
	process :	pulse, cooperation, fusion
	regulation:	coupled potential source and well, basin of attraction

Disjunction

local	structure :	disjoint couple, furcation
	process :	separation, counteraction
	regulation:	decision, conflicting forces
global	structure :	opening, gap
	process :	bifurcation, conflict, fission
	regulation:	potential saddle point, repulsion

Complementarity, conjunction and disjunction can be subsumed under the notion of Duality theory.

Table 1. Toolbox of Organizational Concepts.



	Local Structure	Local Process	Local Regulation	Global Structure	Global Process	Global Regulation
Unity	element	event	state	space	trajectory	potential field
Complementarity	element/ complementary element	action/ reaction	force/ counterforce	polarized space	expansion/ contraction	source/ well
Conjunction	linked couple	interaction	equilibrium	boundary	pulse	attractor
Disjunction	furcation	separation	descision	opening	bi-furcation	saddle point
Sequential Branching	chain, tree	chain of reactions	sequential states	compartments	modulation	potential landscape
Modular closure	ring	reaction cycle	feed-back	core-space	limit cycle	potential niche
Modular Recursion	n ↓ n+1	n ↓ n+1	n ↓ n+1	n ↓ n+1	n ↓ n+1	n ↓ n+1

n, n+1 designate organizational levels

Sequential branching or tree

local	structure :	chain or tree of linked elements
	process :	chain of reactions, transformations
	regulation:	sequential state transitions
global	structure :	compartments, hierarchical levels
	process :	wave, undulation, fragmentation
	regulation:	multiple potential wells, competition

Modular closure

local	structure :	ring of linked elements, self-reference, form, auto-tatic
	process :	reaction cycle, self-production, auto-kinetic
	regulation:	feedback, homeostasis, self-control, auto-dynamic
global	structure :	enclosed space, in-form, core, nucleus, self-reflexion, self-image
	process :	limit cycle, eigen-behavior, autopoiesis
	regulation:	potential "niche", autonomy

Modular recursion or Emergence of organizational level

local	structure :	ring on organizational level n becomes elementary unit on organizational level n+1
	process :	reaction cycle at level n becomes event at level n+1
	regulation:	feedback loop at level n becomes state at level n+1
global	structure :	enclosed space at level n becomes space at level n+1
	process :	eigen-behavior at level n becomes behavior at level n+1
	regulation:	potential niche at level n becomes potential field at level n+1

Sequential branching (tree hierarchies), modular closure and modular recursion (nested hierarchies) can be subsumed under the notion hierarchy theory.

A general theory of organization would thus comprise a theory of unity, a theory of duality (complementarity, conjunction, and disjunction) and a theory of hierarchy (trees, modular self-reference, and modular recursion or self-reflexion). This classification reflects quite well the ensemble of theoretical papers presented at the 1985 SGSR annual conference.

4.7. Organizational Linkage Propositions

Any graph linking organizational isomorphies in organizational space is called organizational linkage proposition or organizational model.

The recursive character of our classification scheme allows the periodic application to itself, thus constituting an algorithm for the construction of hierarchically nested systems of self-organization.

If we accept the hypothesis that self-organization itself is a general systems isomorphy, the principles of self-organization apply not only to physical, chemical, or biological systems, but also to symbol systems like language. (Systems researchers are hesitant to apply their methodologies to their proper field - the well known syndrom of shoemakers walking around in rotten tennis shoes; since 15 years we still move "toward a system of systems concepts".)

We gave it a try and applied the characteristic sequence of organizational categories identified in our case-study of self-organization to the classification scheme itself. (If these conceptual tools organize physical objects, they must also be able to organize symbolic objects like concepts.) The miraculous outcome of this organizational self-application maps quite well with the thought process used in our case-study.

Concept of unity:	self-organization	see section 4.1
Complementarity of concepts:	local bottom-up integration/ global top-down differentiation	4.2
Conjunction of concepts:	space, structure	4.3
Disjunction of concepts:	time, process	
Sequential branching of concepts:	causality, regulation	4.5
Modular closure of concepts:	organizational isomorphy	4.6
Modular recursion of concepts:	organizational linkage propositions	4.7

5. THE COHERENCE PRINCIPLE

5.1. Interdependence of local bottom-up integration and global top-down differentiation

As we have shown in our case-study (Winiwarter, 1986a), the local building up of hierarchical microscopic structures can only be explained within the framework of a global fragmentation of the macroscopic system into a nested hierarchy of environments. The term coevolution of microscopic and macroscopic hierarchies would best describe this interdependence of local and global phenomena.

Generalizing the findings of our case-study we postulate the coherence principle:

> Any model of a self-organizing system describing more than one level of organization must fulfill the following requirements:
>
> The number of nested levels of local organizational concepts equals the number of nested global organizational concepts.

This principle states the inseparability of local and global phenomena.

In the social sciences and biology it is a current practice to use two or more nested levels of local organizational concepts (e.g., individual, organ, cell, gene), while refering to the global organizational concepts by only one descriptive level called environment!

Acccording to the coherence principle, the environment must be structured into as many nested organizational levels as used for the local description of a system.

5.2. Interdependence of Structure, Process, and Regulation

In section 4.6 we have identified 7 organizational categories which apply equally to the three organizational dimensions Structure, Process, and Regulation. According to the results of our case-study, these categories emerge in a directed sequence (from unity to complementarity, from complementarity to conjunction and disjunction, from conjunction and disjunction to sequential branching, from sequential branching to modular closure, from modular closure to modular recursion). We postulate the following coherence principle:

> The emergence of a higher valued organizational category occurs simultaneously in the three organizational dimensions Structure, Process, and Regulation.
>
> This principle states the inseparability of spatial, temporal, and causal phenomena.

6. CONCLUSION

The proposed classification scheme of organizational concepts can be considered as a heuristic tool for scientists building models for the evolution of complex systems. In this sense we consider our self-organizational toolbox not at the level of a theory, but at an abstract metalevel - a framework for a theory about theories. The applicability of the proposed approach has to be proven in de-abstracting the general concepts and translating them into the languages of disciplines (a project which goes far beyond the scope of this introductory paper).

The epistemological aspects of self-organization are presented in a separate paper (Winiwarter, 1986b). Probably the most important conclusion of our study is the finding that apparently self-organization observed in physical systems is based on the same directed sequence of organizational categories as the self-organization of concepts in our "mind". According to Einstein the most wonderful thing about nature is that we can describe it. Demystifying, we propose two solutions to this epistemological puzzle:

> Either we can describe nature because the organizational principles of our concepts are isomorph to the organizational principles in physical, chemical, biological, and socio-cultural systems, or we describe all natural phenomena according to the organizational principles of our concepts.

In the first case, human scientific "mind" is only a special form of natural self-organizaion on a recently emerged level. (Parmenides wrote that "things arise in space as thoughts arise in mind".) In the second case the origins of the organizational principles of our "mind" remain to be explained.

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