

# EMERGENCE AND INTERACTION OF NATURAL SYSTEMS

## The role of information, energy and matter in the perspective of a Unified Theory of Information

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### Abstract

The first part of the present paper deals with the concept of emergence irrespective of the nature of the systems to which the concept is applied. Emergence as a key concept of self-organization has synchronous as well as diachronous connotations which in the literature are referred to as scalar and specification hierarchies, respectively (e.g. Salthe, 1996). It is shown how a stage concept of evolution may be conceived that reconciles both of them.

The second part of the paper is focused mainly on the process of emergence of natural systems, that is – in our context – real-world systems which are simply physical (thus nonbiotic and nonsocial) and open and able to organize themselves. We begin our reflections with a short discussion of the concepts of energy, mass, matter and system. Then we analyze the concept of energetic-material metabolism (EMM) and the role of information in the process of emergence of new structures and systems. Finally we conclude that evolution of natural systems is basically (re)production of structural information, configuring space-time of the universe, based upon the sharing of EMM-processing.

### Keywords

Evolutionary systems, hierarchies, matter, energy, information, emergence

### Evolutionary Systems

The contemporary trend in science towards differentiation which often leads to the fragmentation of knowledge is counterbalanced by an opposite trend: the trend towards integration by the search for unification through generalizing theories. The inquiries into self-organization represent the outstanding paradigm which brings this trend to the fore.

Part of these attempts are efforts to redefine information so as to make it a consistent and concise concept approaching a **Unified Theory of Information** (Hofkirchner, 1999), which is considered feasible, by using the emerging **theory of evolutionary systems** as a starting point, and background theory.

Philosophically speaking, the concept of information is closely connected with the concept of emergence of novelty. The appearance of new qualities in the course of the history and structure of all entities – be it phase transitions in the realm of physics or transformations surveyed by social scientists – is dealt with by a systems approach which since the seventies has been converging with evolutionary thinking, thus gradually preparing a paradigm shift in the world view which involves philosophical considerations as well. The elaboration of a theory of evolutionary systems offers a promising prospect of anchors for joining informational concerns. Insofar as self-organizing systems give rise to novelty, information generation turns out to be a property of self-organizing systems. The core of a UTI has to be formed by a concept of information which is flexible enough to perform two functions. It must relate to the most various manifestations of information, thus

enabling all scientific disciplines to use a common concept; at the same time, it must be precise enough to fit the unique requirements of each individual branch of science. Thus a term is needed which combines both the general and the specific – the general as the governing laws of each form of information, the specific as those characteristics which make different types of information distinct from each other. These different types of information have to be related to, if not derived from, different types of self-organizing systems. In this way, this concept has to save research from what elsewhere has been called Capurro’s trilemma (see Capurro, Fleissner and Hofkirchner, 1997), that is, from falling back upon a reductionist way of thinking, or postulating holistic/dualistic positions which overestimate the divide between different qualities.

Information generation does not mean a process which can be formalized and mapped in a mathematical function and is therefore computable. Rather, it is a process by which novelty emerges. It is bound to a certain system which is capable of organizing itself. In the course of self-organization, novel qualities come into being which characterize several levels of information. One can speak of information in the situation where the deterministic connection between cause and effect is broken up,

that is, where a system’s own activity comes into play, and the cause becomes the mere trigger of self-determined processes in the system, which finally result in the effect which is constituted by the reaction of the system to an event, by the response of it to a stimulus, or by the solution to a problem – in short, where the system makes a decision and a possibility is realized by an irreducible choice.

## Emergence

Emergence, however, has two different connotations. The first is applied to nested hierarchies of systems in which processes of self-organization take place. The upward process links a system unit to a **supersystem** unit through emergence, that is, by virtue of activities carried out at the level of the respective system unit new features appear at the level of the respective supersystem unit. This kind of emergence is accompanied by a downward process. The downward process is a kind of domination, of exercising superiority, by which the supersystem level constrains and enables as well activities at the lower system level (see fig. 1).

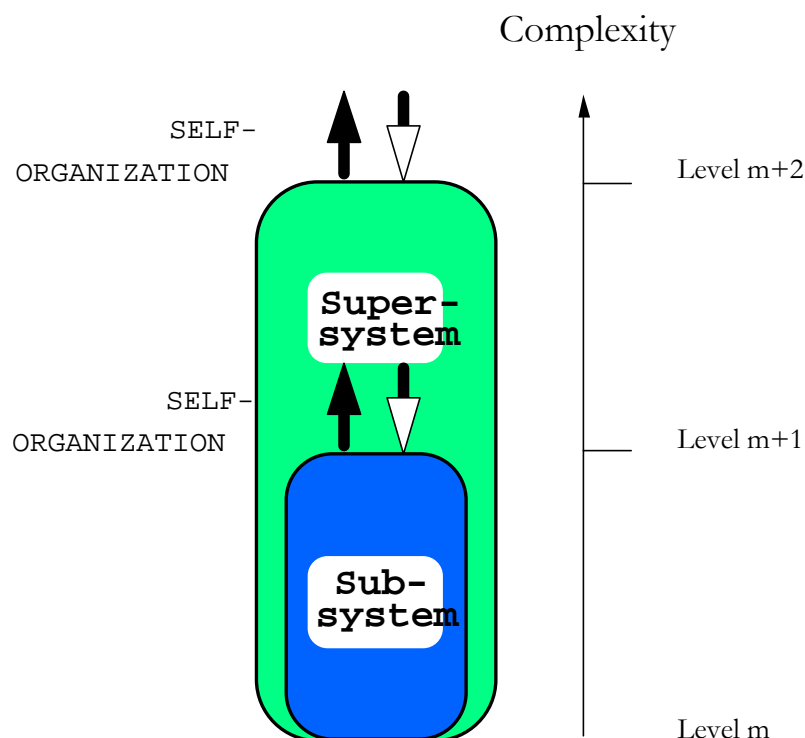


Fig. 1: Emergence as upward loop of self-organization cycles in encapsulated systems

The second connotation refers to evolutionary lineages in which processes of self-organization convey **metasystem** transitions (Heylighen). In the course of evolution one system is linked to another,

new one through emergence, that is, the first gives rise to the second and disappears (see fig. 2).

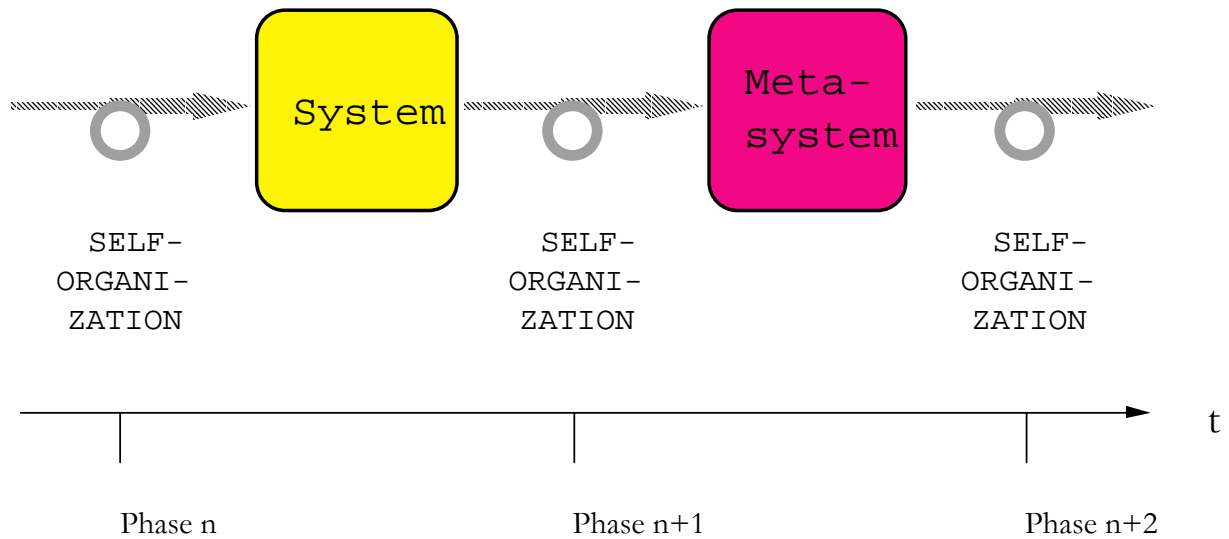


Fig. 2: Emergence as forward loop of self-organization cycles mediating change from one system to another

Both meanings of emergence can be brought together: insofar in diachronous processes systems which give rise to follower systems do this very process by locking their behaviors in at one another, the follower system is made up in a hierarchical manner so that synchronous processes are released – metasystems turn out to be supersystems in which the systems which diachronously constituted the new in Hegels sense

are synchronously “sublated” (“aufgehoben”) as parts. Thus, a stage model which combines both so-called scalar and specification hierarchies can be sketched (see fig. 3). The dimension from the bottom to the top represents the synchronous aspects, the dimension from the left to the right the diachronous ones.

# Stages of systemic Evolution

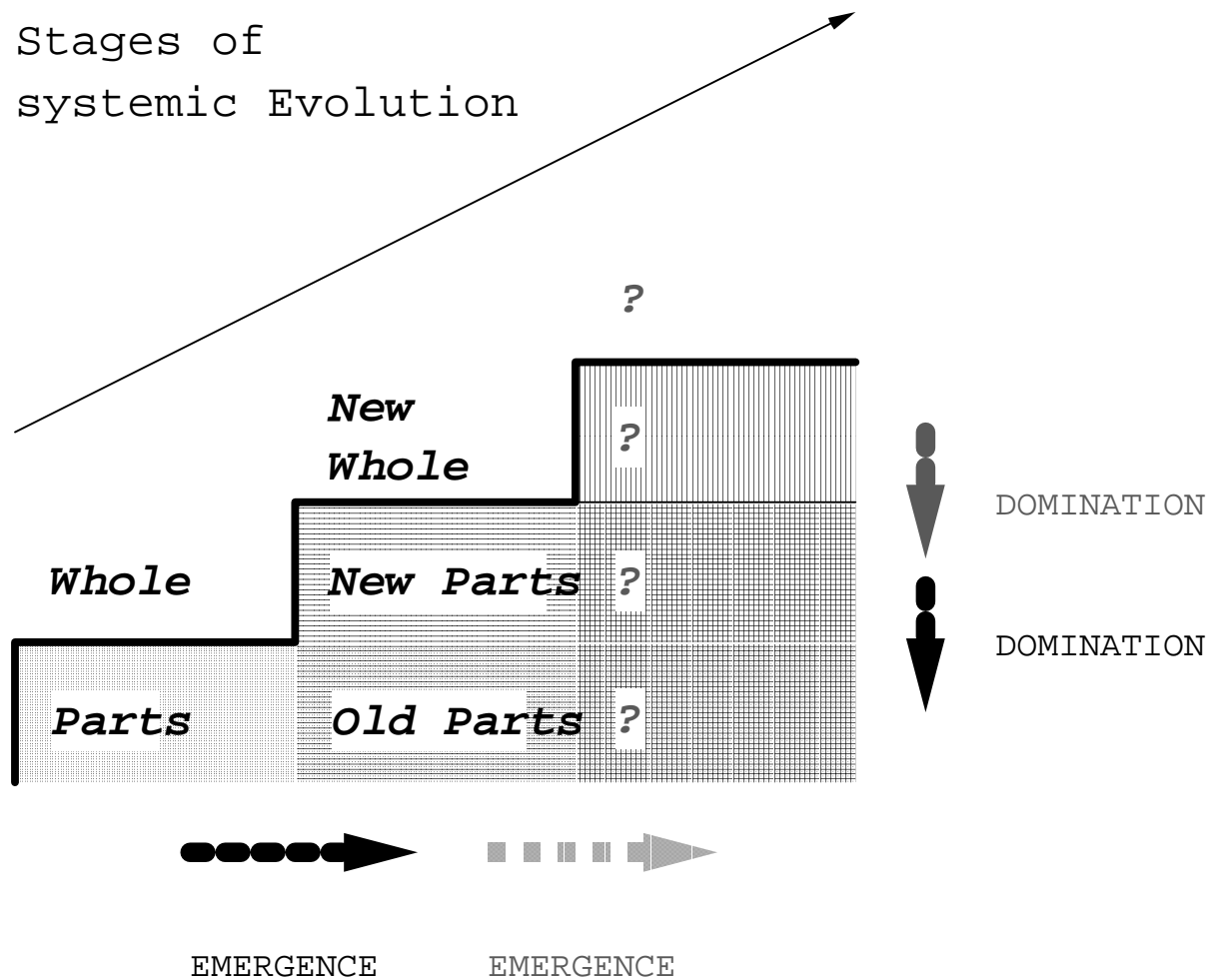


Fig. 3: Emergence as stages in the evolution of systems

## System, Energy, Mass and Matter

Historically **matter** is one of the oldest concepts directly related to the **form** of physical objects. On the other hand the term **energy** comes up only in the 19<sup>th</sup> century as a “counter-concept” to matter and, using the words of C.F. Weizsäcker, as a “substantialisation” of the 17<sup>th</sup> century’s idea of **force** (Weizsäcker, 1971).

**Energy**, is generally defined, as **mass in movement**. This very broad concept of energy has two basic and antagonic aspects:

- Energy as **heat** plays the role of some kind of universal “random generator” and

- Energy as **work** as “order generator” who produces organized **structures**.<sup>1</sup> However, heat, work, energy, matter and information are very closely related to the basic concept of open **system**. Here we should recall the important statement of Tom Stonier (1992): “... what mass is to matter, heat is to energy, organization is to information”. In agreement to this, we would like to say that **matter is organized movement of mass**. And, of course, to organize mass the energy needed for that appears as (system-specific useful) work. We remember also that heat

<sup>1</sup> P.W. Atkins (1984) uses heat and work very strictly in this sense. We distinguish (for the present purpose) between system-specific “useful work” and the most general traditional idea of work. But it is clear that the same energy can be destructive for a system and constructive for another.

and mass are supposed to appear nearly simultaneously (protons emerge  $10^{-11}$  seconds after the Big Bang) in the beginning of our Universe. So we can say that heat, as “unorganized movement of mass”, is the “mother” of all other kinds of energy which are ultimately expressed in forms of work, and so far, as ability to organize mass. In the present analysis we concentrate our attention specifically on *natural, open, non-linear, self-organized systems* and we exclude deliberately man made machines.

These kinds of systems are characterized by energy-material input of higher quality (Q1) and energy-material output of lower quality (Q2). The potential difference between these two qualities is exactly what makes self-organization working. The input-energy is used by the system to

- a) weaken or break up the bonds between the elements of the system - **generating disorder** - by production of **Entropy** and to
- b) reorganize the elements with the aim to reestablish the macroscopic structure - **generating order** - by realization of **Work** (Stonier, 1990).

Open physical systems are composed of **three basic dimensions** of space-time:

- the **microscopic** dimension of the individual **element**,
- the **mesoscopic** dimension of the **structure**, limited by the **structural boundary**,
- the **macroscopic** dimension of the **field of interaction**.

The **probabilistic** relationship between these three main dimensions is one of the most important characteristics of open systems and is especially important for the understanding of the **emergence** of new systems and so far for the understanding of **evolution**.

The concept **element** refers to the smallest unity of the structure, which is still relevant for the mesoscopic characteristics of a system. The elements constitute the **microscopic** dimension of the system. For example, if we talk about some complex organic molecule, the atoms (C, H, or others) can be classified as elements. This is not so in the case of an organism, such as a plant for example, where the concept of element makes sense only if it designates at least a cell.

The concept **structure** is related to the “body aspect” of a system. We situate the structural

boundary at the **mesoscopic** level of the system to describe its intermediate position between the micro- and macro-dimension of the whole system. Structural boundaries as interfaces between different mediums assume very important roles as mediators between the inner and the outer space of system-structures. The basic character of structure is its **structural inertia**, the resistance of organized matter against movement. The amount of energy required to overcome structural inertia is also called **entropy** and the amount of energy needed to organize (or *reorganize*) material structures is what we call **work**. The relationships between the two fundamental aspects of energy (heat and work) produces evolution of material systems and as direct consequence, the **arrow of time**.

The concept of the **field of interaction** is related to the **macroscopic** dimension of a system and needs a more detailed explanation. As we know, all open systems are submitted to a cycle of emergence, development, decay and death. During this cycle the structure of open systems undergoes characteristic transformations and **interacts** with its relevant environment through the exchange of energy and matter. This process, called “**energetic-material metabolism**” (EMM) of the system, imposes **specific changes** to its **inner** (microscopic) and **outer** (macroscopic) **space**. In other words: during “life time”, an open system transforms a part of its survival-relevant environment, creating a **specific macroscopic dimension of space-time** – the field of interaction – which turns out to be a characteristic and inseparable part of (at least) all open and self-organized systems (Fenzl et al., 1998).

At this point we need to distinguish between: a) **open systems**, exchanging energy and material to maintain their energetic-material metabolism (EMM), and b) **closed systems**, exchanging only energy with their relevant environment to maintain their energetic metabolism (EM). There is a third category, that of **isolated systems**, which is irrelevant for our considerations, because those systems don't have any kind of metabolism and are so far only a theoretical construction (Prigogine and Stengers, 1981).

Saying that the structure “produces” the interaction field means that a system can only interact with its **relevant environment** according to the **dynamics of its own structural organization**. The concept of relevancy is exclusively related to the environment which provides the necessary energy and material for the system-specific EMM. To be able to maintain its EMM, an open system needs to adapt

(re-organize) its relevant environment by introducing modifications and changes. The “units” of these changes in the field of interaction we call, in a very general way, **signals**, without distinction if these signals are intentional or not. Since signals are caused by a specific kind of structural organization, they obviously reflect its essential characteristics. This turns out to be a very important fact when we try to understand the process of **emergence**, or in other words, how and why systems start to interact to form a new, more complex system.

## Information

The concept of **information** is closely related to the idea of transformation, **emergence of novelty**.

The word itself is composed by *in* and *form*, something is put “in-to a form”. The evolution of open systems can be seen as a kind of synthesis between “self *formation*“ and alien induced *transformation*. We agree in general terms with those who define information as a measure of **quantity of form**, or as a measure of **structural organization**, mostly called **Structural Information (Is)** (Weizsäcker, 1971). There is also a large consensus through modern literature, that the concept of information is related to the idea of **emergence of difference**, which leads us to the concept of **bit**, as the unit of difference, and so far as unit of information (Stonier, 1990, 32).

Structural Information **describes the principles and parameters** upon which structural organization is based and requires at least the interaction of two main antagonistic characteristics of open systems:

- a) the **tendency** of the system **toward equilibrium**, or non-movement, satisfying its structural inertia and
- b) the **ability to surrender structural inertia**, responding to environmental changes by reorganizing and adapting of the micro-state, avoiding the general breakdown of the system structure.

Constant interaction between both main tendencies sustain a **steady state** of the system during a certain space-time and defines what we can call “inner and outer” space of systems.<sup>2</sup>

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<sup>2</sup>The importance of morphologic distinction between inner and outer space is generally accepted

As pointed out before, changes in the field of interaction reach the inner micro-space of systems structure as signals, which are internally “classified” by the present structural Information of the system into:

- signals without any importance for the self-organization and the reproduction of its specific movement<sup>3</sup>, and
- signals with “survival”-relevant character (Ayres, 1994) which are compared to the already “embodied” structural information and classified in useful or harmful for the maintenance of the system. We also can put it like this: the incoming signals (for example, waves) are modifying the system-specific organization of matter as well as they are modified by it. This process makes signals to information, giving them a system-specific sense. It may be called **actualization of structural Information** to focus at the dynamic aspect of the concept (Fenzl et al., 1998, Weizsäcker, 1971).

As a next step we assume that the emergence of new systems shows a consistent **internal “logic”**, which establishes a relation between the past, the present and the future. Structural Information plays an important role in this relationship and leads us directly to **irreversibility** and **probability** as basic characteristics of evolution processes (Prigogine and Stengers, 1993).

Structural Information is somehow a legacy from the system’s **past**, “condensed” in **present** structural organization. To survive in the **future**, systems need the necessary structural flexibility to respond to external changes by reorganizing their micro-state. Thus, a certain quantity of input energy has to be used to overcome structural inertia and structural information ( $I_{S1}$ ) from the past must be **actualized** to ( $I_{S2}$ ). In the case of open systems we have  $(I_{S1}) \rightarrow (I_{S2}) \rightarrow (I_{S3}) \rightarrow \dots (I_{SN})$ . Actualization of structural information is so far an irreversible process.

The fact that future changes in the relevant environment of the system are not determined by the present structural information, the future reaction of the system to these changes are necessarily probabilistic. In other words, the future is open.

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even in older literature and well treated by G.Roth, 1986.

<sup>3</sup>We include here also signals which may be of **vital importance**, but cannot be registered.

The important point is now to observe how the **mesoscopic dimension** at the level of the structural boundary changes in consequence of the actualization of its structural information. If there is absolutely no mesoscopic reaction, the incoming signals did not cause any sensible changes and don't make "sense" for the system. But if there is a feed-back reaction of the structure which causes some effect on macroscopic level, the system produces what we call **pragmatic information (Ip)**. Ultimately, (Ip) is the practical consequence at macroscopic level of the actualization of (Is).

What is the role of signals in the process of emergence of new systems?

Let's analyze the simple case of one open system ( $S_A$ ) interacting with its relevant environment. Signals are produced by changes of mainly two origins:

- The changes caused by the system-specific EMM activities in the relevant environment (field of interaction). These signals reflect the characteristics of the specific structural organization of system and so far they are considered as "fractions" of the structural information. We call the totality of these signals **potential information (Ip) of ( $S_A$ )**. The idea of potentiality is due to the fact that signals only constitute information when they are recombined by a specific system.
- The changes caused by other systems interacting with the same relevant environment. These signals reflect other and different types of structural organizations and are fractions of other kinds of structural information.

The fact that the EMM of ( $S_A$ ) must be maintained, signals of alien structural information are **imported** with input of energy and material. In fact, the EMM is ultimately responsible for the exchange of signals between open systems.

## Emergence of Natural Systems

Emergence means basically the arising of a new **coherency** between the behaviors of open systems which enables them to constitute a new, more complex system. This process implicates that the former systems become „parts“ of the new „whole“ and therefore we call them **elements** of the **new system**.

Why and how do open systems form a new coherency, losing at least part of their individuality?

Let's now look at the most simplified case of the emergence of coherency between two open systems ( $S_A$ ) and ( $S_B$ ). If their system-specific signals are available for both in a **common relevant environment**, there are the following main possibilities:

- a) They import signals from each other, but they don't react and produce no pragmatic information: There is no interaction between both systems.
- b) Only one system (for example,  $S_A$ ) reacts by repulsion, attraction, or some intermediate reaction. The other system does not react in any way. In this case we call it aggregation of ( $S_A$ ) to ( $S_B$ ), or slavery, a specific case of coherency.
- c) Both systems react to each other, they establish some kind of relationship which can vary widely from total attraction to total repulsion, from mutual destruction to the emergence of a new more complex system.

Two or more systems share a common part of their fields of interaction, using the same relevant environment to maintain their EMM respectively, start to establish a coherent behavior. This process is only possible if these systems meet in a specific space under specific energetic conditions. Initially, it is necessary to state that emergence requires what we can call a **field of emergence**, where energetic and/or material conditions are appropriate for a new form coherency. Generally, these conditions are related to limitations of energy (in the case of closed systems) and energy and material (in the case of open systems).

Thus, we can say that emergence occurs if a certain number of open systems **starts to share a common part of their EMM**. This process requires exchange of signals and information processing systems.

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