EMERGENCE AND SELF-ORGANIZATION OF COMPLEX SYSTEMS:THE ROLE OF ENERGY FLOWS AND INFORMATION A PHILOSOPHICAL APPROACH

Norbert Fenzl

PhD, researcher at the Institute for Environment NUMA/UFPA/Belem/PA/Brazil. E-mail: nfenzl01@gmail.com

ABSTRACT

How order emerges from noise? How higher complexity arises from lower complexity? For what reason a certain number of open systems start interacting in a coherent way, producing new structures, building up cohesion and new structural boundaries? To answer these questions we need to precise the concepts we use to describe open and complex systems and the basic driving forces of self-organization. We assume that self-organization processes are related to the flow and throughput of Energy and Matter and the production of system-specific Information. These two processes are intimately linked together: Energy and Material flows are the fundamental carriers of signs, which are processed by the internal structure of the system to produce system-specific structural Information (Is). So far, the present theoretical reflections are focused on the emergence of open systems and on the role of Energy Flows and Information in a self-organizing process. Based on the assumption that Energy, Mass and Information are intrinsically linked together and are fundamental aspects of the Universe, we discuss how they might be related to each other and how they are able to produce the emergence of new structures and systems.

KEYWORDS: Complex Systems. Self-organization. Matter. Energy. Information.

EMERGÊNCIA E AUTO-ORGANIZAÇÃO DE SISTEMAS COMPLEXOS:O PAPEL DOS FLUXOS DE ENERGIA E INFORMAÇÕES UMA ABORDAGEM FILOSÓFICA

RESUMO

Como a ordem emerge do ruído? Quão alto a complexidade surge da baixa complexidade? Por qual razão um determinado número de sistemas abertos começa a interagir de modo coerente, criando novas estruturas, construindo coesão e novos laços estruturais? Para responder a essas questões é preciso determinar o conceito

usado para descrever sistemas abertos e complexos e as forças básicas de direção de auto-organização. Nós assumimos que os processos de auto-organização estão relacionados ao fluxo e a taxa de transferência da energia e matéria e a produção de informação específica ao sistema. Esses dois processos estão intimamente ligados: Fluxo de energia e matéria são os portadores fundamentais de sinais, que são processados pela estrutura interna e do sistema para produzir Informação estrutural especifica do sistema. Até então as atuais reflexões teóricas são focadas na emergência de sistemas abertos e no papel do Fluxo de Energia e Informação em um processo de auto-organização. Baseado na suposição de que Energia, Massa e Informação estão intimamente ligadas e são os aspectos fundamentais do Universo, nós discutimos como podem estar relacionado um ao outro e como são capazes de produzir a emergência de novas estruturas e sistemas.

PALAVRAS-CHAVE: Sistemas complexos. Autoorganização. Matéria. Energia. Informação

1 INTRODUCTION

To respond the basic question of the following paper we consider necessary to give a more precise definition of the concepts we use to describe the process of emergence and self-organization. On the other hand we need to say that we talk about open and complex systems in general abstract way, without dealing with specific physical, biological or social systems.

We try to describe a very basic process, which assumes different qualities at different levels of complexity. So far, concepts like information, signal, signs, and others are used independently of concepts like meaning or understanding in the sense of human communication.

2 BASIC PHYSICAL CONCEPTS : MASS, MATTER AND ENERGY

Matter is historically one of the oldest concepts closely related to the **form** of physical objects. On the other hand the term **energy** comes up only in the 19th century as a *counter-concept* to matter and, using the words of C.F.Weizsäcker, as a "*substantialisation"* of the 17th century's concept of **force**.[1]

Energy, on the other hand, is often defined as **mass in movement.** This general concept of energy has two basic and antagonic aspects:

a) Energy as **Heat**, playing the role of a universal "random generator" producing **chaos**, and

[1]C.F.Weizsäcker, Die Einheit der Natur. C.Hansen, München, 1971

b) Energy as **Work**, as a kind of order "generator", producing organized, system-specific **structures**.[2]

At this point we would like to recall the important statement of Tom Stonier (1992). He said: *what mass is to matter, heat is to energy, organization is to information*. In agreement to this, we say that matter is *organized mass*, or in more precise terms, *organized movement of mass*. So far, to organize mass the therefore needed energy appears as *system specific (useful) work*.

We remember also that heat and mass are supposed to appear nearly simultaneously (protons emerge approximately 10^{-11} seconds after the supposed Big Bang) with the beginning of the Universe. So we can say that **heat**, as unorganized movement of mass, is the *mother* of all forms of energy we know. All the other types of energy are ultimately expressed as **work**, or as **ability to organize mass to matter**.

Without going into thermo-dynamical details, for our further understanding we consider that input energy of open systems is basically used in two basic ways: a) to perform (system specific) **work** and b) to overcome **structural inertia**, the dissipated part of energy, called **entropy**.

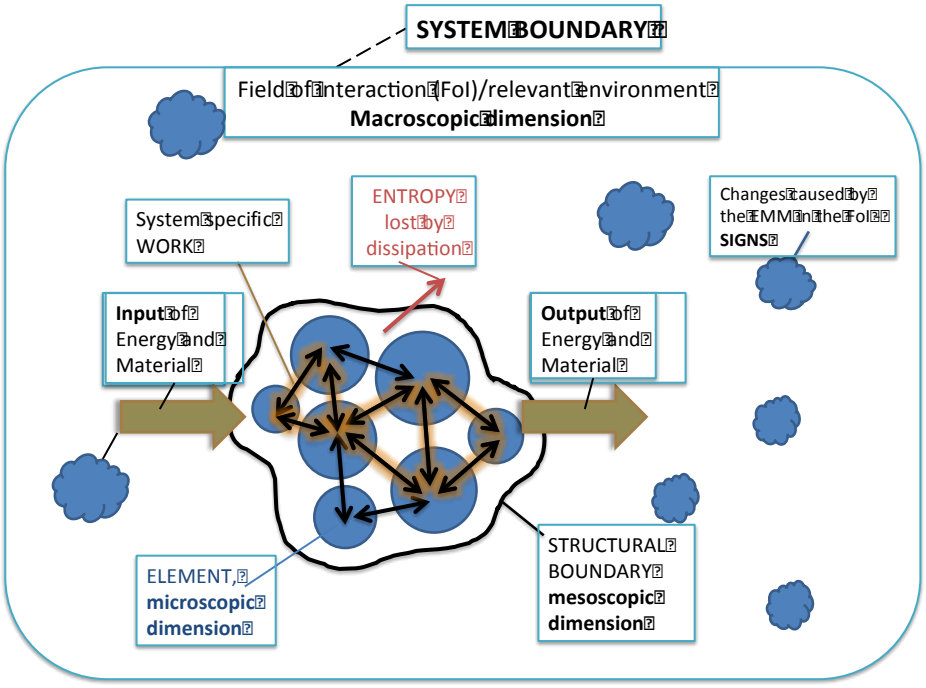
Finally in our understanding, the concepts of work and entropy are *always system specific* in the sense that they only make sense "inside" the system and cannot be exported. For example, entropy cannot be "exported" as entropy, but only as energy, or heat in a wider sense.

[2]P.W.Atkins in "The Second Law" (Scientific American Books, 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.

3 OPEN SELF ORGANIZED SYSTEMS

In the present analysis we concentrate our attention specifically on***, open, self-organized systems*** (Fig.1).

Fig.1 - Complex Systems



Fonte: (Autoria própria, 2018).

These systems are composed of three basic dimensions of space-time:

- The **microscopic** dimension on the level of the individual **elements**,

- The **mesoscopic** dimension of the whole **structure**, limited by the **structural boundary**.

- The **macroscopic** dimension of the **field of interaction or relevant environment,** limited by the **system boundary**.

These three dimensions of space-time **are inseparable parts** of open and complex systems. The dialectic relationship between these three dimensions is a basic characteristic of complex systems.

3.1 Element

The concept **element** is related to the smallest unity of the structure, which is still relevant for the mesoscopic characteristics of a system. The elements (also called parts) constitute the **microscopic** dimension of the system. For example if we talk about some complex organic molecule, the atoms (C, H, or others) are classified as elements. This is not 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, or a society, where element designs the individual member.

3.2 Structure

The concept **structure** is related to the *body aspect* of a system. Elements are linkes by *forces*, which guarantee the coherence and cohesion of the structure. The sum of these binding forces (from physical up to even psychological or cultural forces in the case of human society) characterizes the identity of a system and consequently makes the difference to the rest of the Universe by creating a **structural boundary**, which defines the **mesoscopic** dimension of the system.[3] Structural boundaries are interfaces, assuming a very important role as mediators between the inner and the outer space of open systems. The basic characteristic of the structure is its **structural inertia**, the resistance of organized matter against movement (changes).

During the vital flow and throughput of energy, part of the energy input is required to overcome structural inertia, producing **entropy** (heat), which is lost by dissipation. The remaining amount of energy, used to organize (or *re*organize) the systemic structures is what we call **system specific work**. The antagonism between these two fundamental forms of energy seems to be the basic driving force **of self-organization**.

3.2 Field of Interaction

The concept of **field of interaction** *(Wirkungsfeld)*, or **system-relevant environment**, constitutes the **macroscopic** dimension of a system. As we know, all open systems are submitted to the same basic cycle: emergence, development, decay and death. During this cycle the structure of open systems suffers characteristic transformations **interacting**

[3] *Meso* - to describe its intermediate position between micro- and macro-dimension of the whole system.

permanently with its **relevant environment** through the exchange of energy and matter, characterized by **energy-input of higher quality (E_1)** and **energy-output of lower quality (E_2)**.

The input-energy is used by the system to:

a) Weaken or break up the bonds (the cohesion) between the elements of the system – to overcome the structural inertia - *dissipating energy (Entropy).*

b) Reorganize the elements with the aim to (re) stabilize the mesoscopic structure by *realization of Work* (Stonier, 1990).

This is the basic process, which gives adaptability to the system with respect to environmental changes.

3.4 Energetic-Material Metabolism (EMM)

The complete process of *input-transformation (throughput)-output* of energy, called **energetic-material metabolism (EMM)** of the system, imposes **specific changes** to its **inner** (microscopic) and **outer** (macroscopic) **space**. During their ”life time” open systems transform part of their survival-relevant environment, creating a specific macroscopic dimension of space-time, the **field of interaction**, or also called **system-relevant environment**, which turns out to be a characteristic and inseparable part of all open complex systems.

The fact, that we include the **field of interaction** into the concept of system, means that we distinguish between the **structural – boundary** and the **system- boundary**. So, open systems cannot be reduced to their structural dimensions and what we call *system* is necessarily greater than the physical dimensions of its structure.

On one hand the process of EMM *produces* its corresponding interaction field. On the other hand, the same process *obliges* the system to react to all changes of its relevant environment. So far, the necessary structural changes are related to the external changes, which are partly caused by the system itself.

Maybe we can recall at this point the analogy between the relationships like: **particle/wave**, **body/mind** and **mass/field**.

A system only can interact with its **relevant environment** according to the **dynamics of its own structural organization**, or, according to the dynamics and needs of its own

EMM, which functions according to the structural organization of the system and needs to **adapt the environment to its specific requirements**. **The units** of these *so caused changes* in the field of interaction we call, in a very general way, **signs**, without distinction *if these signs are intentional or not*. A specific type of structural organization produces signs in its relevant environment and so far, they naturally **reflect essential characteristics of the structure, which** produces them.

4 INFORMATION

To define the concept of Information and analyse its role in the process of emergence of new systems, it is necessary to focus briefly on some underlying concepts, like sign, signal, and data.

4.1 Signs

Basically, a sign is **something that stands for something else**. But here we can find different approaches. For example, Korzybski defines sign as a *map, which means a territory*. As an example we can mention the different worldwide used signs to design bathrooms, airports, danger, etc. For C. S. Peirce, "a sign is something that stands for something else to someone in some respect". This definition is more complex and Peirce includes the *subject* in his concept.

Generally we can say that people working with linguistics would say that *words* are signs: So, a certain word (lets say *car*) has a *potential meaning* (what is written in the dictionaries) and a *specific meaning* (for a specific person) when used in a specific context. We use the terminology in the following way: Signs stand for something else **"in some respect"** and do not represent the entire thing or experience to which they refer. For example a footprint, or all kinds of changes in the environment, which can be computed or *recognized* by the structure of an open and complex system, is considered a sign in Complex System Theory.

4.2 Signals

The main two definitions for *signal* which are satisfying the purpose of our present analysis are:

- Detectable quantity of transmitted energy that can be used to carry information and

- Time-dependent variation of a characteristic of a physical phenomenon, used to convey information

In electronics the concept is mainly used to describe any *transmitted electrical impulse*.

Of course signals also are used in the scope of *human communication*. In this case signals generally design a type of *message* which can consist of one or more letters, words, characters, signal flags, visual displays, or special sounds, with prearranged meaning and which is conveyed or transmitted by visual, acoustical, or electrical means.

But as we stated initially we use the concept in a very general way, considering human communication only a quality of specific open systems, such as human beings or human society, for example. So far we do not link the concept to some kind of meaning, in the sense of human *understanding*.

In a most general context of complex systems, changes (differences) of the energy/matter input *mean* something for the system *if* they cause perceptible changes in its structural organization. So far, when signs are carried by the EMM input and cause a systemic reaction or structural changes in the system, they are codified as *signals.*

4.3 Data

People working with computer science define generally data as *information that has been translated into a convenient form to store, move or process*. Relative to today's computers and transmission technology, *data is information converted into binary digital form.*

In telecommunications, data sometimes means *digital-encoded information* to distinguish it from *analogue-encoded information* such as conventional telephone voice calls. Data can often be sent in packets that arrives separately in pieces.

In the present discussion data is used as the *unit of changes (delta* dI_s*)* structural Information is going through during its EMM.

4.4 The Concept of Information

The word **Information** itself is composed by *in* and *form*, something is put "in-to a form" and seems to be a kind of synthesis between "self ***form***ation" and alien induced trans***form***ation. So far, we agree in general terms, with all the authors who define Information as a measure of **quantity of form**, or as a measure of **structural organization.** But it seems that even on inorganic levels of evolution this is only one aspect of the information concept.[4]

On the other hand the concept of information is**,** at least since the works of Shannon and Weaver**,** closely related to the idea of transformation, **emergence of the new** or novelty.[5]

There is also a large consensus 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.[6]

Now, if we resume the different concepts of Information actually used, we can find at least the following useful definitions:

a) Transmission of Information (I) is related to the transmission of Energy (E) and Entropy (S). But (I) is not equal to (E) nor to (S) (Ebeling 1993, Wiener, 1973, Stonier, 1990);

b) The emergence of Information is only possible *in* self organized systems (Fenzl, Hofkirchner, Stockinger)[7];

c) Information reduces the *uncertainty* of a system. Information as a measure for *difference* (Shannon, Weaver, 1949);

d) Pragmatic Information requires novelty (in the sense of Shannon) and receptivity (in the sense of Weizsäcker, 1979) ;

e) Ayres, (1994) distinguishes between two basic forms of Information:

- D-Information (D - doubt)
- SR-Information (SR - survival relevant)

f) Information is neither matter nor energy (Wiener 1973);

g) Structural Information measures the complexity of a system (Stonier, 1990).

[4]C.F.Weizsäcker, op. cit.

[5]Shannon and Weaver's idea of information (see a mathematical theory of communication, University of Illinois Press, 1964) is strictly related to the aspect of surprise. They don't relate the concept to any kind of meaning.

[6]Bit: "binary digit" originally used by C.E. Shannon. See also W.Gitt "Information gehört zum Wesen des Lebens, Technische Rundschau, Nr.47, Nov. 1989, Bern. and T.Stonier, "Information and the Internal Structure of the Universe", Springer, 1990, p.32

[7] Fenzl,N., Hofkirchner,W., Stockinger, G.: Information und Selbstorganisation, Studienverlag Insbruck-Wien, ISBN 3-7065-1190-8.

Basically we consider the definition of Stonier (1990) the most adequate. But in a very general way, all these concepts can be grouped basically into 3 different types of Information.

1. **Structural Information (I_s):** Information, which represents the *structural organization* and the *functionality* of a system.
2. **Pragmatic Information (I_{pr}):** Information, which *appears at a mesoscopic level* and represents the *way system structures act on its relevant environment.*

   Potential Information (I_{pt}): Information that exists only in potential form, such as a set of signs, not yet received and organized to structural Information by the system (or co-systems).

It is important to point out, that the emergence of irreversible differences in evolution shows a consistent **internal logic:** we need to admit some logical relation between the past, the present and the future to be able to talk about information. This step leads us directly to **irreversibility** and **probability** as basic parts of evolution and of the concept of Information.[8]

Since open systems need to maintain its metabolism, they require permanent interaction with its environment. So far, the cycle of *input – processing – output* of energy flows is essential and nothing can reach the structural space of such a system without energy flows.

Following the previously discussed definitions, we resume that:

- *Signs* are produced (as changes, differences) in the relevant environment by metabolic activities of a system,
- If signs, carried and transmitted by EMM energy flows are strong enough to cause structural changes, they are codified as *signals* and produce the actualisation of *structural information*.

[8]Prigogine & Stengers: Das Paradox der Zeit, Piper, 1993.

5 EMERGENCE AND SELF ORGANIZATION

After these general statements, we will try to answer the following question: For what reason a certain number of open systems start interacting in a coherent way, producing new structures, building up cohesion and new structural boundaries?

5.1 The concepts

Emergence is the *appearance of a new system or property* of a system, which cannot be deduced or previously observed as a functional characteristic of the elements of the system. Generally, higher-level properties are regarded as emergent.

For example, water has emergent properties different from its interconnected molecules of H and O. Individually, H and O are systems by their own, but their individual properties have no similarity with the properties of water. Like Crutchfield (1994) said, "the whole is greater than the sum of the parts." In other words, the whole exhibits patterns and structures that arise **spontaneously** (not predictable) from the interaction of the parts. Or to use the words of Green (1993): "Emergence indicates there is no code for a higher-level dynamic in the lower-level parts".

In the case of O and H we already have a physical-chemical explication for the causes of the emergence of water under certain circumstances. But if we want to generalize and understand (in an abstract and general way) how interactions between two or more complex systems emerge we need to understand the role of EMM and Information building in such a process.

Important aspects of emergence are the so-called multi-scale interactions and effects in self-organized systems. For example, small-scale interactions can produce effects on large-scale structures, able to act back at the small scales. Prigogine (1993) said that macro-scale emergent order enables the system to dissipate micro-scale entropy creation.

Self-organization means *appearance of new system structures* **without explicit pressure from outside**. Even considering the fact that the EMM acts permanently like a river flowing through the system maintaining permanent dynamic structural movement, self-organization is an internal phenomenon, resulting from the interactions among the elements, usually independent of their physical nature. Self-organization can produce structural changes maintaining a stable mesoscopic shape of the system, or show transient phenomena.

The research on self-organization tries to find general rules about the growth and evolution of systemic structures, the forms it might take, and seeks for methods that predict the future results of self-organizing processes.

6 THE EMERGENCE OF COHERENT INTERACTION BETWEEN COMPLEX SYSTEMS

How and why two complex systems start to interact? Let's consider two open systems (A) and (B), part of the same space-time without any initial relation between each other. Each system operates with its own field of interaction (F_a) and (F_b) maintaining its specific energetic metabolism.

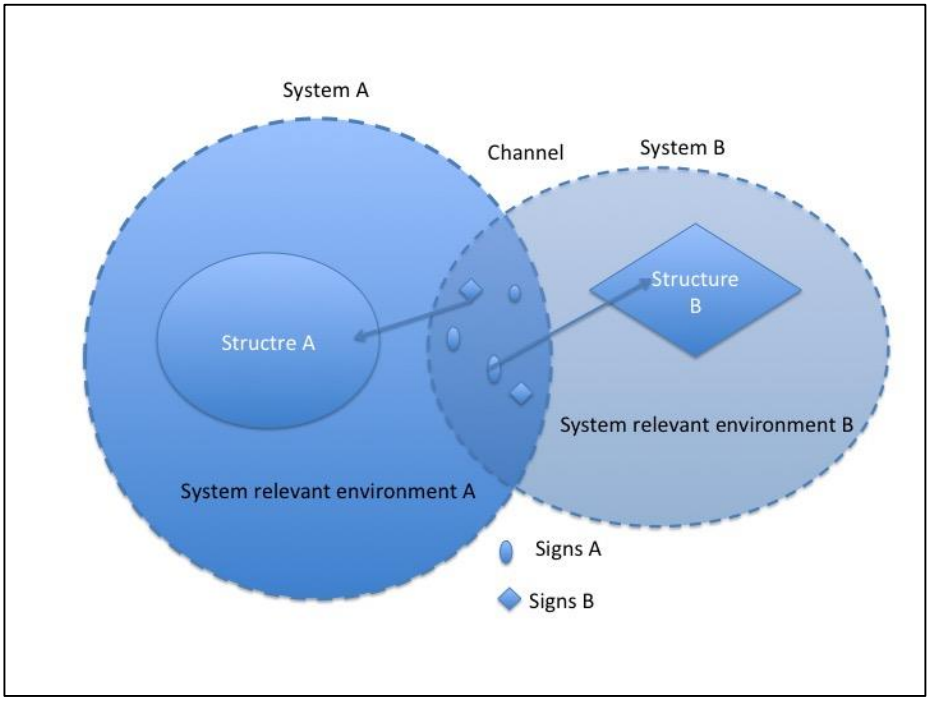
The first and basic condition to establish a coherent **Interaction** between two (or more) open systems is accomplished if there is some **overlapping of their interaction fields**. **F_a <-> F_b**.

If the two fields F_a and F_b approach and overlap, a new space – a *common field of interaction* - F_{ab} emerges. In such a case, the two systems *are sharing a common source of energy and material* to sustain their specific EMM.

On the other hand, the metabolic activities of each system cause permanent changes, ("planting signs") in its fields of interaction. As stated before, these signs are "something which stands for something else", in other words they stand for *the type (pattern) of structural organisation, which caused them*. As example we can use geological deposits, fossil structures from extinguished organisms or simple footprints of an unknown person in the sand.

This so created common space has the function of a **channel** and can be compared to a "pool of signs", shared by both systems (A) and (B) which is continuously provided with **new signs** (S_a and S_b) by the specific metabolic activities of (A) and (B) (Fig.2).

Fig.2 - Interaction of 2 Complex Systems



Fonte: Autoria própria, (2018).

Once the channel is established, both systems import signs from the commonly shared pool of signs. For example, (A) imports signs produced by (B), which are codified into signals, causing actualization of structural Information of (A). If the following pragmatic reaction of (A) "traduces" the signals received from (B) we say that (A) *reacts* on (B).

If we consider, that the same process occurs in (B) with respect to (A), and (B) *reacts* on (A), the first step of a coherent interaction between both systems is accomplished.

Now, each system reacts to the other in its specific way, but they have at least two main possibilities in common: **attraction** or **repulsion** with all possible intermediate reactions.

In the case of attraction, systems with compatible reactions start to "behave" in a coherent way and establish cohesive links.

Finally we can say that open systems don't need to be in direct structural contact to interact; self-organization is intermediated by processes beyond their respective structural boundaries and by corresponding internal changes due to:

a) The exchange of energy and matter with their relevant environment;

b) The permanent actualisation of structural information (I_s) and production of pragmatic information (I_{pr}).

7 CONCLUSION

To maintain the necessary flexibility to survive **external changes**, open complex systems must be able to **respond internally** by reorganizing its micro-state and **externally** by organizing their environment (macro-state) according to their own patterns of structural organization by **setting signs**, the smallest possible changes that structural transformation is able to imprint to its relevant environment.

So, structural Information is transmitted in ”small energetic units” (signs), and must be ”re-assembled”, or in other terms, **codified** by the **structure** of the receiver system. The exchange of signals between systems requires some *overlapping* of their respective relevant environment (field of interaction) to create channels, able to transmit the signs through the activity of its EMM.

The incoming signals are compared to the already ”embodied” structural information and classified in **useful** or **harmful** to the (Ayres, 1994). We also can say in a more ”physical” way, that the incoming signals (p.ex. waves) are modifying - and being modified by - the system-specific organization of matter.

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