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INFORMATION AND SELF ORGANISATION OF COMPLEX SYSTEMS

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Abstract: How higher complexity arises from lower complexity? How open systems start interacting in a coherent way, producing new structures, building up cohesion and new structural boundaries? What is the role of Information in such a process? To answer these questions we need to refine some of the concepts we use to describe complex systems. We assume that the basic driving forces of self organisation 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 Information. So far, the present theoretical reflections are focused on the emergence of complex systems and on the role of Energy Flows and Information in a self-organising 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 could produce the **emergence** of new **structures and systems**

Keywords: Information, Complexity, Energy, Matter, Signs

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1. Basic physical concepts

To respond the basic question of the following paper we find it necessary to give a more precise definition of the concepts we use to describe the process of emergence of complexity. In the following sections, we talk about open systems, in general, without dealing with specific physical, biological or social systems.

We try to describe a very basic process, which assumes different qualities on 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. Mass, Matter and Energy

Historically, **matter** is 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 19^{th} century as a „counter-concept" to matter and, using the words of C.F.Weizsäcker, as a „substantialisation" of the 17^{th} century's concept of **force**.[1]

Energy is often defined as **mass in movement.** And we can distinguish at least:

a) Energy as **Heat,** playing the role of a universal „random generator" and
b) Energy as **Work, as** a kind of „order generator", producing organised **structures**.[2]

At this point, we would like to recall Tom Stonier (1992):"what mass is to matter, heat is to energy, organisation is to information". In agreement to this, we say that matter is *organised mass*, and of course, to organise 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 Big Bang) with the beginning of the Universe. So we can say that heat, as "unorganised movement of mass", is the "mother" of all other kinds of energy we know. All the other types of energy are ultimately expressed in forms of work, and so far, as **ability to organise mass to matter**.

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

Finally, in our understanding, the concepts of work and entropy are *system specific* in the sense that they only make sense "inside" the system and cannot be exported. So far, entropy for example cannot be "exported" as entropy, but only as unorganised energy.

3. Open self organised System

In the present analysis we concentrate our attention specifically on***, open self-organised systems***.

These 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 or relevant environment,** limited by the **system boundary.**

Element

The concept **element** is related to the smallest part 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 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.

Structure

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 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 characteristic of the structure of a system is its **structural inertia**, the resistance of organised matter against movement (changes). The amount of *energy* required to overcome structural inertia (entropy) produces heat which is lost by dissipation, and the amount of energy needed to organise (or *re*organise) material structures is what we call *work*. The antagonism between these two fundamental aspects of energy is the basic driving force of self-organisation.

Field of interaction

The concept of **field of interaction (**or system-relevant environment) constitutes the **macroscopic** dimension of a system. As we know, all open systems are submitted to the same cycle: emergence, development, decay and death. During this cycle the structure of open systems suffers characteristic transformations **interacting 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 potential difference between these two qualities is exactly what makes self-organisation work.

The input-energy is used by the system to:

a) Weaken or break up the bonds (the cohesion) between the elements of the system dissipating energy (*Entropy*).

b) Reorganise the elements with the aim to (re) stabilise the mesoscopic structure by *realisation of Work* (Stonier, 1990).

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

4. Energetic-material metabolism (EMM)

The complete process of input-transformation (throughput)-output, 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, which turns out to be a characteristic and inseparable part of (at least) all open and self-organised systems.

The fact, that we **include** the **field of interaction** into the concept of system, means that we can distinguish between the **structural -** 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 the one hand, the process of EMMM *produces* its corresponding interaction field. 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 organisation,** or, according to the dynamics and needs of its own EMM, which functions according to the structural organisation of the system and needs to **adapt the environment to its specific requirements.** These changes caused in the field of interaction we call, in a very general way, **signs**, without distinction if these signs are intentional or not. Since signs are produced by a specific type of structural organisation, they naturally **reflect essential characteristics of the structure** which produces them.

5. Information

What are the concept and the role of Information in the evolution of open, self-organised systems?

What is the relationship between Energy, Mass and Information?

Before trying to define the concept of Information and analyze its role in the process of emergence, it is necessary to focus briefly some underlying concepts, like sign, signal, symbol and data, to explain how we use these concepts in our analysis.

6. Signs

Basically, a sign is **something that stands for something else**. Also 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 necessary person.

Some authors (like Korzybski and S. I. Hayakawa in "General Semantics") use the concept of *symbol*, meaning what other authors call signs.

Generally we can say that people working with linguistics would say that *words* are signs: 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 would like to use the terminology in the way of: A sign stands for something else **"in some respect"** and do not represent all of the things or experiences to which they refer. In our context we would use as example a footprint, or all kinds of changes in the environment which can be computed by the system.

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7. Signals

There are mainly two definitions for *signal*, which satisfy the purpose of our present analysis:

- *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 are also 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 a specific open system, the human society. So far, we do not link the concept to some kind of meaning, in the sense of human *understanding*.

In our context, changes (differences) of the energy/matter input "mean" something for the system if they cause perceptible changes in it.

8. Symbols

Even if we consider that the concept of symbol is directly linked to human communication and cultural phenomena, it is important to mention that often the concepts of symbol and sign are used in a confusing way. So, we will not extend on its definition, because it only has a limited utility in our context.

But even so, we would use the word in the following sense: **a symbol stands for something <u>more</u> than for something "in some respect"** and represents more than the thing to which it literally refers.

In other words, a symbol is a complex association of different meanings and its interpretation depends largely on the cultural background of the symbol itself.[3]

9. Data

People working with computer science generally define 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 arrive separately in pieces.

Generally, the word data is used for scientific purposes and means a certain number of facts which are somehow linked together.

10. 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 organisation.** But it seems that even on inorganic level 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 something 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 statements:

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 organised 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 (Weizsäcker, 1979)
e) Ayres, (1994) distinguishes between two basic forms of Information:
   - D-Information (D - doubt)
   - SR-Information (SR - survival relevant)
f) Information is not matter nor energy (Wiener 1973)
g) Structural Information measures the complexity of a system (Stonier, 1990)

A short resume of the literature about Information theories shows that we can identify the following most used concepts:

- structural Information
- potential Information
- kinetic Information
- actual Information
- pragmatic Information
- bound Information
- free Information
- functional Information

In a very general way, all these concepts can be grouped basically into 3 different types of Information.

Structural Information (Ist). Information, which represents the structural organisation or the functionality of a system like bound Information for example.

Pragmatic Information (Ipr). Information, which represents the way how systems move, act or appear at a mesoscopic level for an external observer. To this group we can count kinetic, pragmatic and actual Information.

Potential Information (Ipo). Information that exists only in potential form, such as a set of signs not yet organised into Information.

It is important to point out that we assume that 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]

11. Emergence and Self Organisation

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?

First of all, let's focus on the difference between emergence and self organisation.

The concepts

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

For example, water has emergent properties different from its interconnected parts (molecules of H and O). These properties disappear if the molecules are separated again. 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 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".

Important aspects of emergence are the so called multiscale interactions and effects in self-organised systems. For example, small-scale interactions 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-organisation means *appearance of new system structures* without explicit pressure from outside the system, or involvement from the environment. In other words, the constraints on the organisation of the system are internal phenomena, resulting from the interactions among the components and usually independent of their physical nature. Self organisation can produce structural changes maintaining a stable mesoscopic form of the system, or show transient phenomena.

The research on self-organisation 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 organising processes.

As we can see, following these generally accepted definitions, emergence deals with the appearance of new *properties*, while self organisation deals with the appearance of new *structures*.

Anyhow, we can easily state that hardly one comes without the other.

12. The relation between sign, signal, information and data

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Since open systems require permanent interaction with their environment to maintain its metabolism, the *input – processing – output* of energy flows are essential and nothing can reach the internal space of such a system without energy flows.

Following the previously discussed definitions, we assume that:

- ***signs*** are produced (as changes, differences) in the relevant environment by metabolic activities of the system,
- the signs are carried and transmitted by energy flows as ***signals*** to be transformed into system specific ***information***
- information is than *actualised* as structural changes (actualisation of information) and stored in the system as ***data***.

We consider that signs are all kinds of changes in the specific environment of a system, which can be transmitted by energy flows and processed by the internal structure of the system.

Since the whole metabolic process covers not only input, the output of the system also produces changes, i.e. signs in the environment. These signs are transmitted as signals, or in other words, signs always need to be "transformed" into an energetically transportable form.

13. The emergence of coherent interaction and self organisation

We 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 (FI-a) and (FI-b) maintaining its specific energetic metabolism. So, whatever triggers the two systems to a coherent interaction, the basic reason is the necessity to sustain its energy flows. This means that the two systems need to share and exchange something to guarantee this basic condition: *they need to cooperate*.

On the other hand, the metabolic activities of each system cause permanent changes, ("planting signs") in its fields of interaction. These signs are "something which stands for something else", i.e., they stand for the type of structural organisation which caused them. As example we can use geological deposits or fossil structures in rocks caused by extinguished organisms. So far, the system permanently needs **to adapt itself to external changes and (at the same time) to impose changes** to its environment according to the pattern of its structural organisation.

Now, what happens in the system during such a metabolic process and how the concept of information is related to it?

1. The **structural information (Ist)** represents the internal organisation of the system structure**,** the principle on which the coherency and cohesion of the elements is based on and should be understood as some kind of basic „frame orientation" for the elements of the structure[1]. Within this frame all elements are free to choose their individual movement. So, the structure is able to maintain its coherency (and cohesion) and its flexibility to react and adapt itself to the permanent changes of the field of interaction.

2. The totality of all environmental changes (signs, Sa) caused by the metabolism of the system (A) is called **potential Information (Ipt) of (A).**

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The totality of all environmental changes (signs, Sb) caused by the metabolism of the system (B) is called **potential Information (Ipt) of (B).**

The term "potential" is used to underline the fact that these signs are rather some kind of „pieces" of information than information in the sense of our definition.

3. As we know, open systems need to **import** energy and matter (E-m) in a certain **quality** and quantity and **export** (E-m) in **inferior** quality.

The input-flow of energy (and matter) **imports signs** (changes, events, differences..) from the interaction field as **signals** which are decoded by the system structure. This process produces re-adaptation of internal structure and **actualisation** of (Ist). The incoming signals must show a minimum of compatibility with the type of structural organisation and the type of its elements, otherwise, external changes would not be able to cause actualization of (Is). Actualisation of the structural information produces structural changes which correspond to an addition of **data** to the former (Ist).

4. The process of actualization organises signals to **system-relevant information** and produces some reaction and changes at the level of the structural boundary, the mesoscopic dimension of the system. We call the principles which guide these changes **pragmatic information (Ipr).** Such a phenomena is easy to observe: the whole body of a system acts in a different way when compared to the parts of which it is composed of. For example, a complex molecule has different qualities and different ways to interact with its environment when compared to the way individual elements would do.

As a consequence of the process of actualisation, the system starts interacting differently with its environment.

5. Pragmatic information (Ipr) produces new changes in the interaction field by setting new type of signs (Sa-2, Sb-2). So we can describe a whole cycle of the feed-back process and see that structural and pragmatic information form a kind of dialectic unity. Their relationship is intermediated by the structural boundary of the system. The first one acts at the microscopic level and the second on the correspondent macroscopic level of the system.

Now we analyse the situation of the two systems when they approach each other and their relevant environments begin to overlap.

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**. The resulting 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** (Sa and Sb) by the specific metabolic activities of (A) and (B).

Once the channel is established, all participating systems import signals from commonly shared signs. For example, (A) imports signals from signs produced by (B), the imported signals are decoded and the structural Information of (A) is actualised. If the following pragmatic reaction of (A) "transforms" at least partly, the signals received from (B) we can say that (A) begins to react on (B).

If we consider that the same process occurs in (B) with respect to (A), the first step towards 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 can establish cohesive links.

So far, open systems don't need to be in direct structural contact to interact; self organisation is intermediated by processes beyond their respective structural boundaries and by corresponding internal changes:

a) the exchange of energy and matter with their relevant environment
b) the permanent actualisation of structural information and production of pragmatic information

14. Conclusion

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

So, structural Information is transmitted in "small energetic units" (signals) and must be "re-assembled", or in other terms, **decoded** by the **structure** of the receiver system. The exchange of signals between systems needs some *overlapping* of their respective relevant environment to create channels, able to transmit the signs through the activity of its metabolism. The incoming signals are classified:

- **Signals without any importance** for self-organisation and reproduction of its specific movement.
- **Signals** which may be import for some systems, but cannot be decoded.
- **Signals with survival relevant** character. These signals are compared to the already "embodied" structural information and classified in **useful** or **harmful** for self-organisation (Ayres, 1994). We also can say in a more "physic" way, that the incoming signals (ex. waves) are modifying - and being modified by - the system-specific organisation of matter.

Finally we state that:

1. All natural open systems contain structural information according to their specific type of organisation. This is independent of any observer.

2. The interaction between open systems is ultimately based on exchange of pragmatic information, which cannot be transmitted *directly* like a "copy". Pragmatic information must be *decomposed* into signs, transmitted as signals by energy (and material) flows and *(re)assembled* by the receiving system.

3. S*urvival relevant* signals can be classified and organised into pragmatic information by the receiver system according to its specific structural organisation. So far, signals are "understood" and the reorganised structural information obtains a system-specific *sense.*

4. During this process, the energy flow carries signals (based on signs which stand for the organisation pattern of the transmitter-system) into the receiver. The signals establish some kind of "basic language" which makes interaction between systems possible.

15. References

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