Processes of structured and non-structured interactions, phase transitions, self-organisation and emergence

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1. Systems

In the scientific literature, a System has been defined in various ways.

For instance as “A set of objects together with relationships between the objects and between their attributes” (Hall and Fagen, 1956) and “. . . a set of units with relationships among them” (von Bertalanffy, 1968).

A system has been intended as an entity *having* or *acquiring* properties different from those of what are considered elements by the designer (for artificial systems) or by the observer (for natural systems).

As we will see the observer selects the level of description where to detect a system as coherence between behaviour of component elements.

This in the framework of a *construcvistic*, theoretical role of the observer, generator of *cognitive existence* rather than of *relativism*.

1.1 Necessary conditions for the establishment of systems

There is a general consensus that models adopted by an observer (for natural systems) and a designer (for artificial systems) explicating the process of establishment of a system are based upon, as a *necessary condition*, the interactions between elements.

We may assume, in short, that two or more elements interact when *one's behaviour affects the other's* as detected by the observer.

Examples of such interactions are processes of mutual exchange of energy (e.g., collisions and magnetic fields, where vector fields exert a magnetic force on magnetic dipoles or moving electric charges), matter (e.g., economic interchange) or information (e.g., prey-predator).

Interactions may occur in different ways.

For example short and long-range correlations are interactions between elements on short or long time or distances scales (even simultaneously) which can display ***coherence*** as in the famous *binding problem* (regarding the *coherency* of the combination of information from distinct populations of neurons such as for visual, acoustic, olfactory, tactile or memory systems establishing a unified perceptual experience).

Coherence is a concept having several disciplinary meanings.

For instance, in physics, the coherence of two waves relates to how well correlated they are, allowing the possibility to predict the characteristics of one wave by knowing the characteristics of the other.

Examples of other disciplinary meanings relate to usages in philosophy when considering the consistency of concepts, in cognitive science for cognitive states, and in linguistics with reference to semantics.

In Systemics (see Section 3, intended as *c*orpus of systemic concepts, extension of systemic principles by using, for instance, analogies and metaphors) we consider coherence, as in the binding problem and collective behaviour, as the **dynamic establishment and perpetuation of a property *continuously* established by interacting components**.

For instance, the property of a set of boids establishing a flock is continuously established and this *continuity* is considered as the coherence of the collective or coherent behaviour of boids.

It should be stressed that systemic properties are not the *result* of interactions. Systems and their properties are established by the *continuous* interaction among elements (e.g., an electronic device acquiring a property when powered on, leading to interactions amongst the component elements) and not as a *state*, as in the formation of a new colour by mixing primary colours (e.g., Red-Green-Blue), weight or age.

A very important distinction relates to the particular kind of interacting elements assumed to establish a system:

- Elements assumed as indistinguishable (*homogeneous hypothesis*). In this case elements are assumed to be particles. Their interaction may be modelled by mathematical equations and often by very simple rules.

  An example is given by gases consisting of particles and adopting systemic properties such as pressure and temperature.

2) Elements assumed to be different, and distinguishable (*heterogeneous assumption*). In this case each element interacts in a different way. This is the typical case of autonomous agents *processing* interactions and not simply reacting. Here, the processing is performed by the cognitive system and is computed *each* time.

A typical example is given by families of human beings.

1.2 Sufficient conditions for the establishment systems

A sufficient condition for the establishment of a system is that elements interact by respecting suitable relationships, or modelled as such, in some particular ways.

Moreover, it must be stressed that at the moment there is no way of demonstrating that the following ways (see Sections 1.2.1-1.2.4) of establishing systems are the *only* ones.

This point is particularly important given that new levels of description have emerged, such as the quantistic one, requiring new conceptual approaches in which the very concept of interaction needs to be properly redefined.

1.2.1 The structured way

In the *structured* functional way of establishing organised systems, organisation is intended as a network of pre-established functional relationships which control the manners of interacting.

Rules of interaction are determined:

- by following a design or
- *constructivistically* intended as such by the observer.

In both cases they are *sufficient conditions* for establishing systems.

Structured rules define *completely* the way in which elements interact, i.e., they define *all* the degrees of freedom possessed by interactions between elements, at the specified level of description.

Examples of case a) -following a design - include mechanical devices, such as machines, and electronic devices, such as circuits.

Examples of case b) - *non-designed* systems- are natural entities modelled as organised systems by the observer, such as organs performing given functions in living beings and eco-systems.

1.2.2 Self-organising way

In a so-called *self-organising* way, i.e., when a structure or a change in structure is acquired (change of structure may be considered *regular* for self-organisation, *coherent* for emergence).

Phase transitions are examples of *single* processes of self-organisation triggered by environmental perturbations (e.g., change of temperature or pressure).

Structural changes are not prescribed from the outside, as for theoretical models of phase transitions, by adopting the *homogeneity hypothesis*, i.e., neglecting *any differences* between the components.

Processes of establishment of *collective phenomena* such as swarming and flocking are examples of self-organisation produced by *non-homogeneous* agents.

Moreover, the same theoretical models adopted for phase-transitions are used to model processes of self-organisation of collective phenomena established by non-homogeneous agents by identifying *order parameters* as in Synergetics.

Examples of systems modelled in this way are flocks, swarms, industrial districts, lasers, ferromagnetic and superconducting systems.

Emergence deals with modelling such processes by considering the *heterogeneity assumption* and the process of hierarchically acquiring new properties as properties of systems of systems.

Moreover, models based on Dynamical Systems Theory [$dx/dt = F(x)$] and proposed for modelling emergence are the same used for phase-transitions.

Such models are *unsuitable* because based on suitable combination of dynamical rules and fluctuations, e.g., produced by noise, quantum effects, impurities or other effects instead of using *heterogeneity-based* models.

Heterogeneity-based models are necessary when considering differences between components such as in biology, e.g., life, or for cognitive systems, e.g., learning.

Examples of this kind for modelling emergence are Agent-based systems, Artificial Life, Neural Networks, and Immune Networks.

1.2.3 Unstructured, non-self-organising way

In an *unstructured* although non self-organising nor emergent way, i.e., when an interaction does not follow structure nor models of self-organisation nor emergence.

In the case of a) autonomous systems, i.e., provided with cognitive systems, interaction is due to the processing of input by cognitive systems. In this case interaction derives from the cognitive processing modifying, for instance, information, emotions, knowledge, inference and the making of decisions, which can affect the behaviour of the autonomous systems.

In these cases the system is produced by the way of processing and affecting behaviour. One processing affects the other.

In case of suitable cognitive systems, coherence is ensured by the cognitive processing and this is a sufficient condition for the establishment of a system.

Examples are social systems (e.g., families, classrooms, and micro-communities such as an audience).

In the case of b) non-autonomous systems, such as systems in physics, new systems and corresponding new systemic properties occur, for instance, by Spontaneous Symmetry Breaking (SSB).

SSB occurs when the system reaches a number of different *equivalent* equilibrium behaviors, which all have the same probability. We cannot forecast *which* of them will be chosen on the basis of the model we have, because all minima are equivalent to one another (intrinsic emergence).

Such processes are modelled within the theoretical framework of Quantum Theory and are considered by some physicists not only as non-structured, but also as the real models of self-organisation.

Moreover, as mentioned above, they are unsuitable for the heterogeneous case.

1.2.4 Evolutionary way

In an *evolutionary* way, i.e., through a process considered for species, when elements of a specific species interact amongst themselves (e.g., competing for food or territory, and for reproduction), with individuals of other species (e.g., prey-predator or establishing symbiotic processes) and the environment, for instance, by adapting and modifying their behaviour.

We may distinguish the cases where the process of interaction is ruled by

a) fixed evolutionary rules establishing a system acquiring a new property with reference to components. For instance, ants possess fixed evolutionary rules corresponding to a simple cognitive system having a very limited or no ability to learn, i.e., to improve it. An anthill displays multiple but non-evolutionary acquired properties, such as shape, food recruitment, defence strategies and an *ant cemetery*.

b) variable evolutionary rules, for instance, through processes of mutation and learning. Previous cases may not only occur in well-separated, well-defined ways and at different times. They may also occur in any combination and at any time, e.g., simultaneously, alternately, or in short- and long-term correlations.

Theoretical approaches towards this multiple combination in the establishment of systems have been introduced, for instance, with the concept of *Collective Beings* based on *Multiple-Systems*.

Multiple Systems (MSs) are set of systems established by the *same* elements interacting in *different* ways, i.e., having multiple simultaneous or dynamical roles. Examples are the Internet where different systems play different roles in being used in continuously new ways (e.g., the same software codes and services can be used to perform different tasks) and dynamic infrastructures of electric power networks adopting emergent properties.

Collective Beings (CBs) are particular MSs established by autonomous agents possessing the *same* cognitive system allowing them to decide different, simultaneous or dynamic belonging to the various simultaneous or dynamic systems. Examples of multiple, *alternative* belonging can occur when human beings give rise to different systems in temporary communities, such as passengers on buses, audiences at performances, and queues in general. Examples of multiple, *simultaneous* belonging occur when *same* human beings give rise to different systems over time as for workers in a company, families, traffic on motorways, and mobile telephone networks.

2. Systemic and non-systemic properties

What are *non-systems*? Depending on the level of description and on the model adopted by the observer, an entity is not a system when its properties are ***states***, *considered as not necessarily being supported by a continuous process of interaction amongst its components*.

Systems are thus entities assumed to be *continuously acquiring* systemic properties.

Non-systems are entities considered by the observer as *possessing* non-systemic properties.

Only systems may acquire systemic properties, while systems and non-systems may possess non-systemic properties.

What is a property?

In general a property is intended as a *characteristic* of an entity detected at some level of description.

Examples are the numbers of the Periodic Table of elements introduced by the Russian chemist Mendelejev; the Avogadro number; the speed of light; the pressure-temperature where water is transformed into ice and the period of the earth's orbit around the sun.

In Systemics we consider properties within the framework of the constructivist approach.

In this view we do not find properties *as they are* in an objectivist view.

To clarify this point, we can metaphorically say that we design experiments, intended as *questions* to Nature, and Nature *answers* by making them happen.

There are no answers from Nature without questions.

Repeatability of experiments, i.e., the receiving of *same* answers, is a confirmation about the consistency and appropriateness making knowledge possible.

The ideal is to consider properties as *context-independent*, i.e., having universal and constant values.

Non-dependence upon the context of observation, i.e., the level of description, is the objectivist view and it is often confused with the *stability* of the context adopted.

The problem is that there are no properties without a level of description, no statements without a language.

It is not merely a *relativistic* point of view, but a *generative* one, assuming reality has to be linguistically generated as for constructivism.

In an objectivist world the perspective is to make the model *coincide* with the phenomenon.

Systemic *properties* are intended as characteristics which can *only* be taken on by entities, i.e., systems, established by interacting components, when they are designed or modelled as such by the observer.

Systemic properties are not the *result* of the interacting components, but supported, as a *necessary condition*, by the continuous interaction of components.

Examples of systemic properties, adopting a suitable level of description, are: adaptiveness, chaos, dissipation, emergence, life, learning and openness.

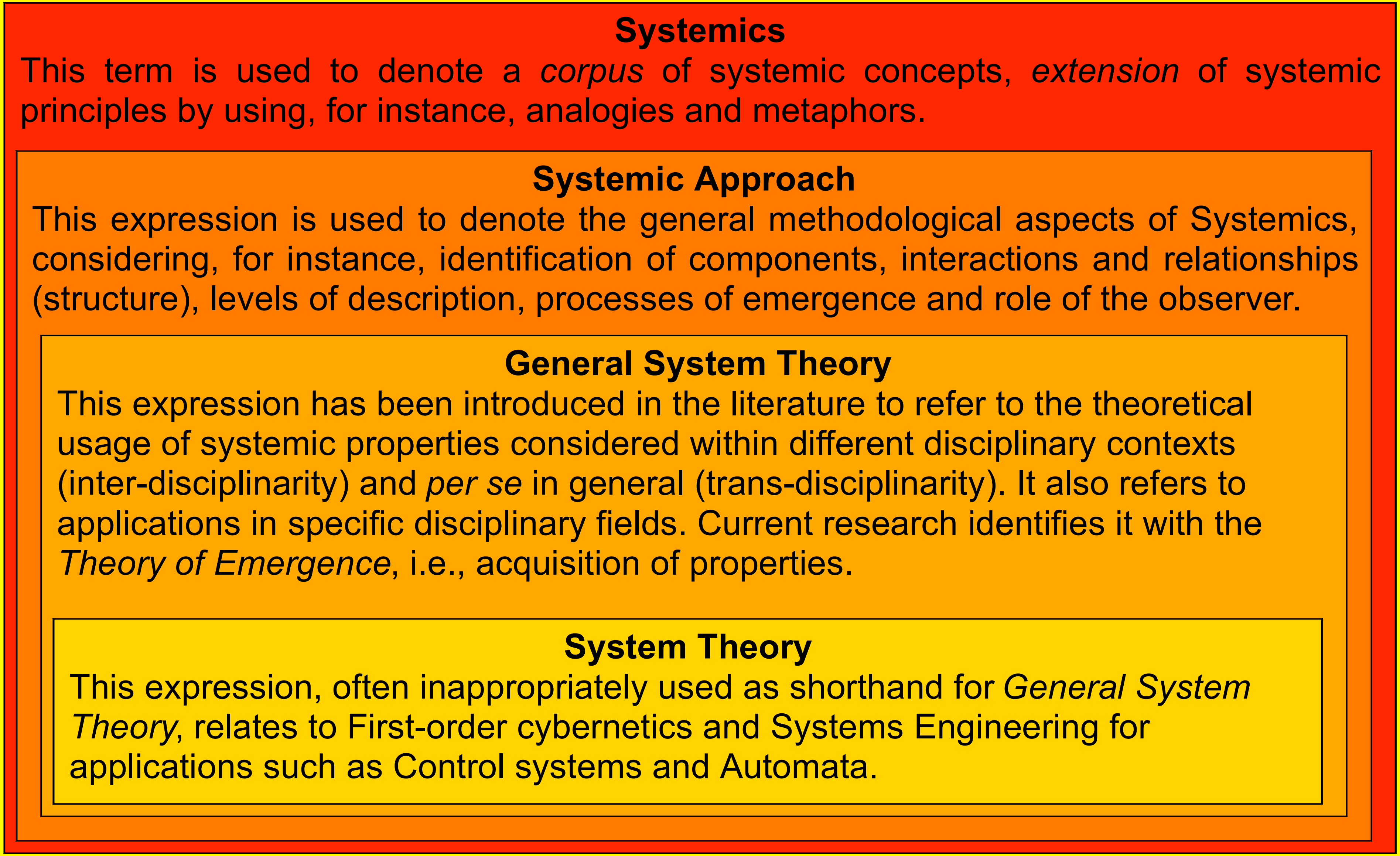
Examples of non-systemic properties, adopting a suitable level of description, are: weight, age, geometric measurements, spatial position and speed in classical physics, and numeric properties in calculus.

Falsification of Systemics can be considered equivalent to the possibility of finding systemic properties as properties of non-systems.

The reason why we distinguish between systemic and non-systemic properties is that there are different approaches for managing them at different levels of description.

A reductionist view is based on considering a systemic property as non-systemic, i.e., using an inappropriate level of description.

3. Systemics, *Systémique* in French, Sistêmica in Portuguese, Sistémica in Spanish, *Sistemica* in Italian, …



Systemics

This term is used to denote a *corpus* of systemic concepts, *extension* of systemic principles by using, for instance, analogies and metaphors.

Systemic Approach

This expression is used to denote the general methodological aspects of Systemics, considering, for instance, identification of components, interactions and relationships (structure), levels of description, processes of emergence and role of the observer.

General System Theory

This expression has been introduced in the literature to refer to the theoretical usage of systemic properties considered within different disciplinary contexts (inter-disciplinarity) and *per se* in general (trans-disciplinarity). It also refers to applications in specific disciplinary fields. Current research identifies it with the *Theory of Emergence*, i.e., acquisition of properties.

System Theory

This expression, often inappropriately used as shorthand for *General System Theory*, relates to First-order cybernetics and Systems Engineering for applications such as Control systems and Automata.

4. Towards a General Theory of Emergence: From Dynamic Models to Dynamics of Models

In the literature it is also possible to find different definitions related to different kinds of emergence which will not be discussed here, including *strong* and *weak*, *computational* and *phenomenological* emergence.

Some approaches are based on considering the concept of emergence related and, almost, identified with that of *self-organization*.

In physics, processes of so-called *order-disorder transitions* have been identified as *self-organization* processes and, thanks to the works of I. Prigogine, related, for instance, to *dissipative structures* and of H. Haken, related, for instance, to *Synergetics*, the terms *emergence* and *self-organization* being considered as synonyms.

In the scientific literature conceptual models based on **structural changes** and *compatible* with available theories of the processes have
been introduced. They deal with:

e) Phase transitions relating to single changes in structure, e.g., water-ice-vapour transition and ferromagnetism.

b) Processes of self organisations considered as phase transitions when a new acquired structure is dynamic and stable, i.e., repeated in a *regular* way. Examples are non-perturbed swarms, i.e., synchronised oscillators, established by suitable initial conditions, reaching stationary states in a non-perturbed way such as populations of synchronized fireflies.

c) Processes of emergence may be understood as phase transitions when newly acquired dynamic structures *coherently* continuously change over time. The process of emergence relates to changes in dynamic structures over time.

The new conceptual approach

From

dynamical systems $dx/dt = F(x)$

to

dynamical structures when F is changing with time.

This way of understanding processes of emergence is suitable for modelling collective behaviours of entities provided with cognitive systems allowing the collective system to process internal and external perturbations.

The active role of the observer is fundamental detecting, representing and modelling emergent properties.

Coherence is a property primarily generated by the cognitive system of the observer.

An innovative approach to model continuous and coherent change of structure have been introduced by considering *Meta-structures*, i.e., mathematical properties of suitable sets of meso-state variables abductivelly identified by the observer.

Conclusions

The aim of this presentation is to contribute towards the on-going process of clarification of concepts such as self-organisation and emergence.

In our opinion, this is a fantastic opportunity for the systems community to deal with such topics in a trans-disciplinary way, i.e., in a general, non-disciplinary way.

Disciplinary research is more and more systemic and, dealing with crucial topics, may display the power of systemic research enabling it to have, in the future, a prestigious academic role which specific scientific disciplines currently enjoy.

This includes the development of graduate programs, dissertations and research on systemic issues *per se* including the modelling of processes of emergence and acquisition of new properties.