Interactions and Interaction Mechanisms as Generators of Complex Systems

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Abstract: - The concept of interaction is widely used in almost all disciplinary and interdisciplinary contexts. However, such a concept is often used in simplistic ways. We concentrate on scientific aspects, particularly systemic, identifying fundamental conceptual issues and interdisciplinary extensions. For example, a process of interacting is usually considered to occur iteratively in the same way, except for parametric variations, between fixed pairs or entities when one's behavior is assumed to depend on another's behavior. This simplistic view then has effects on the models adopted. A more appropriate concept of interaction should include aspects such as the occurrence of variable interacting pairs, variable interactions, and multiple, in this case, clustered, pairs. Furthermore, their desynchronization, the occurrence of incomplete interactions; interchanging, the exchange of roles, the acquisition of multiple roles, passive interactions such as the maintenance of covariance and correlation, and the establishment of fields of interaction and their mutual influence should be included. The interaction observed-observer is considered here not as a perturbation but in reference to the cognitive expectancies of the observer. This is assuming stable validity of the same model and between the understanding by the active observer and the phenomenon that reacts to being treated as if it were what the observer had in mind. A more appropriate and comprehensive concept of interaction is required. This is particularly true in systems science when dealing with processes of self-organization and emergence, whose models are widely based on simplistic concepts of interaction. The usage of more appropriate representations, based, for instance, on clustering and networking, of interacting in models is expected to allow the implementation of approaches suitable to activate, deactivate, and vary interactions in complex systems, e.g., collective phenomena.

Key-Words: - Clustering, Emergence, Incompleteness, Interaction, Network, Observer, Pairs, Roles.

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1 Introduction

In science and common language, the concept of interaction is widely used, understood generically as a process occurring when in generic populations one's behavior is intended to depend on another behavior. The concept is widely used in almost all disciplinary contexts, from interaction between drugs to social interaction, from human-machine interaction to interaction between animal species. This applies to ecosystems, cultures, ethnicity, and approaches leading to interdisciplinary interactions when considering problems and solutions of one discipline in another, for instance through similar representations, changing meanings given to the variables, modeling, and approaches. Therefore, a possible better, deeper understanding of the concept of interaction is expected to be a benefit in modeling, particularly when dealing with complex systems.

Here we will concentrate on scientific aspects, particularly systemic, identifying fundamental conceptual issues that are then interdisciplinary extensible. In physics and systems science, interaction is considered the generating engine of systems. What makes them different from their components is that they allow collective phenomena such as cooperation, self-organization, and emergence. In a conceptual way and in classical (that is, leaving aside the quantum one) physics, the crux of the interaction between entities lies in its having various levels of flexibility and probability in the becoming, contrary to the materiality of the objects, which are assumed to consist of stable, fixed (at an adequate level of description and not for the liquid and gaseous states) links between their components. Examples of such flexibility occur in a limited way for organized systems, such as automata and electronic devices, having a finite number of states that can be acquired in a deterministic way, albeit at different threshold levels. Examples of such flexibility occur in a nonlimited way for complex systems generated by and where processes of emergence take place, such as climate systems; dissipative structures, e.g., whirlpools in fluid dynamics; double pendulum; living systems; collective systems such as swarms, flocks, industrial district networks, markets; and social systems, such as audiences, cities, companies, families, hospitals, school classes, and temporary communities, such as passengers and customers at the supermarket. For instance, instead of the properties possessed by the materiality of functionalities acquired by systems, i.e., their functioning, complex systems continuously acquire autonomous behavioral properties, e.g., so-called swarm intelligence, consistence of patterns, maintaining equilibrium levels, coherence as long-range correlations (correlation is not decaying with distance), network properties, polarization and global ordering, power laws, remote synchronizations, scale invariance (features do not change if scales are multiplied by a common factor), and self-similarity (similarity to a part of itself) [1, 2], and other characteristics such as belonging to the basin of an attractor.

The process of interaction, i.e., the ability of the constituent elements to interact, is critical in all of these systemic interaction dynamics.

On closer examination, however, the concept of interaction seems to be considered in a superficial way, ignoring aspects and involving improper and inadequate uses of the concept of system, its properties, and the related acquisition and processes of emergence. For example, consider the modeling of multiple and quasi-systems that are intended to be coherent temporarily incoherent, resuming the same or different coherence sequences of different (possibly even fuzzy), non-regular, in-homogeneous versions of the same system. The attribution of quasiness is assumed to make theoretically more realistic representations and models [3] dealing with the incompleteness of complex systems [4].

Interactions, in a nutshell, are multiple between more or the same elements that have collective simultaneous roles of action and reaction; irregular and in-homogeneously occurring; and variable modalities of occurring in intensity, combinations, and duration. A better understanding of the concept of interaction is required to deal with complex systems where processes of emergence occur. This would contribute to the devising of approaches to act on these interaction processes, for example, in order to combine, deactivate, orient, and vary them. A possible consequential line of research should replace the usual approach of macroscopic nature by considering emergent effects rather than the interacting mechanisms (intended as combinations of interactions, see Section 2.3) of interacting populations. We introduce some possibilities for further research.

Section 2 mentions some usually neglected aspects, such as processes of interactions occurring between variable interacting pairs, the desynchronization of interactions, the occurring of incomplete interactions, and the occurring of passive interactions, understandable as relations, e.g., the keeping of covariance and correlation. We mention how the interaction, intended as occurring between couples of sender-receivers, detection-reaction, is an elementary simplification, and we elaborate on their multiple interfering, multiple, variable interchanging roles. When dealing with populations of interacting entities, e.g., collective behaviors, it may be effective to imagine being in interaction with virtual entities, such as communities and clusters of real-life entities. We consider the occurrence of domains as fields of possible interactions and their reciprocal influences. We consider the case of isolation as interaction-less environment, such as in the case of an environment at thermodynamic absolute zero.

Section 3 mentions interactions established by the observer with the phenomenon under consideration and, in particular, the cognitive interaction taking place when assuming suitability of the iteration of the same model if not for parametric changes and, accordingly, understanding the data detected. It is a non-material disturbance introduced by the observer, influencing the interactions that subsequently occur continuously according to understandings deemed adequately identical over time. The interaction is between the phenomenon understood by the active observer and the phenomenon that reacts to being treated as if it were what the observer had in mind.

We conclude by mentioning how a more appropriated understanding and modeling, for instance, based on statistics, clustering, and networking, of the process of interacting may allow more effective modeling of complexity to set the perspective of having effective approaches. For example, by introducing perturbations suitable to activate, deactivate, and vary interactions, e.g., processes of self-organization and emergence [1], such as the establishment of unwanted collective behaviors, e.g., hurricanes and queues.

2 Generic considerations on the concept of interaction

The term "inter" can have a variety of meanings. The concept of "inter", for example, presupposes reciprocal, related active roles between pairs of entities in processes such as interaction and interchange. In general, interaction refers to the process of interacting when one's behavior is influenced by the behavior of another because they are mutually processed. Such dependence can arise as a result of energy exchanges (e.g., collisions), matter exchanges (e.g., trade of goods), dissipation, and information exchanges (e.g., signals) ([2], pp. 76-79; 108-110). We should consider how interaction occurs—that is, how the entities process and react to what is exchanged and detected.

In processes of interaction, action-reaction becomes more and more indistinguishable within interacting populations and in the long term. Interaction between two stable entities of the same nature is a simplified case. The received (the action or detection) may not coincide with the sent or detected, for instance due to environmental effects, and the interaction can continue in desynchronized ways due, for example, to reaction times. Entities may be in-homogeneous, have different natures, be in variable numbers, change over time, and the mode of interaction may be multiple and change.

In interacting, entities have the duty to process the input received and transform it into a reaction. The processing of transforming the received input into reactions is materialized into the assumption of a corresponding behavior or sending of a reaction output.

2.1 A closer look

The process of interaction between entities is understood to occur when the properties and behavior of one are considered to depend, for instance, partially, completely, regularly, or irregularly, on those of the other. More precisely, the interaction can be considered a relationship when specified by fixed ratios between entities (such as temporal, for example, synchronization, and quantitative, for example, proportion). In such a case, there is a detection of mutual dependence and not necessarily of the mechanisms producing such dependence.

Another way of understanding interaction is to consider it as an interaction in progress, for example, as an exchange of the material, as in economics, energy, and information. In the case of action-reaction effects, such as collisions between balls and activation through sensors, which can be described with fixed rules (not necessarily deterministic but also of a probabilistic nature), the interactions are contextualized forms of relationship (for example, the collision of two balls affected by their irregularities due, for example, to wear).

In the most specific case, the interaction, the interacting, is intended to take place between entities endowed with autonomy when the inter-exchanged (both matter and energy) and information (inter-exchanged or detected) are autonomously processed by the entities, such as when birds of a flock cognitively decide the reaction based on the reciprocal positions, speeds, and directions detected. Therefore, the interactions are established by the *inter-actors* and only partially regulated by relational rules as constraints. Furthermore, there are many varieties of modalities (equivalent or non-equivalent) by which such constraints may be respected. Especially in complex systems, there are regular and irregular combinations of the various possibilities in a multiple and time-varying way. Therefore, in the face of the same interchange, the reactions may not be the same.

At an elementary level, the interaction is understood between two entities, even if it occurs at different intensities and according to time intervals that may be different. However, the interaction may occur between, on one hand, the same entity and itself (it is a matter of self-interactions, for instance when processing non-input information such as changes in propriety, e.g., self-regulation and control, and having simultaneous multiple interacting, even conflictual, roles, such as devices simultaneously being detectors and controllers, sellers and quality controllers) and, on the other hand, between different entities, variable over time. Moreover, a couple or multiple couples can interact to keep a state of stability, e.g., the interaction is finalized to keep stable equilibrium.

In the simpler case, while one member of the interacting pair is stable, the other changes. The ability to interact is supposed to depend on the reception or detection of something. This is a matter of reaction or processing. Besides, the reaction may be the answer to a request, such as considering a specific (vectorial) variable and its current (scalar) value. Usually, interaction is assumed to be private, i.e., distinguished from other interactions, but usually only in simplified situations. In such a simplified understanding, interacting entities of populations [5-7] are supposed to react or decide to sequences of supposed initiated interactions, e.g., flocks.

However, all types of interactions can occur simultaneously and in variable, partial, or global

combinations with each other. In processes of interaction, action-reaction becomes more and more indistinguishable within interacting populations and in the long term. Interaction between two stable entities of the same nature is a simplified case. The received (the action or detection) may not coincide with the sent or detected, for instance due to environmental effects, and the interaction can continue in desynchronized ways due, for example, to reaction times. Entities may be in-homogeneous, have different natures, be in variable numbers, change over time, and the mode of interaction may be multiple and change.
In interacting, entities have the duty to process the input received and transform it into a reaction. The processing of transforming the received input into reactions is materialized into the assumption of a corresponding behavior or sending of a reaction output.
Ideally the classic process of interaction may be intended as the situation depicted in the *logical machine* of subsequent systems of equations such as (1) and (2) below.

$$\begin{cases} x_k = f_h(y_{k-1}) \\ y_k = f_h(x_k) \end{cases} \qquad (1)$$

at time k the interaction f_h from y_{k-1} leads to x_k, and from x_k to y_k;

$$\begin{cases} x_{k+1} = f_{h'}(y_k) \\ y_{k+1} = f_{h'}(x_{k+1}) \end{cases} \qquad (2)$$

at time $k+1$ the interaction $f_{h'}$ from y_k leads to x_{k+1}, and from x_{k+1} to y_{k+1};

…

where k: $1,\ldots, n$ is the total observation time and $f_{h(' \ldots)}$ specific interactions involved, known ex-post or known in advance in possible specific cases. In the simplest cases $f_{h(' \ldots)}$ are equal, e.g., action-reaction, to less than parametric and environmental variations.
The situation is schematically represented in Figure 1.

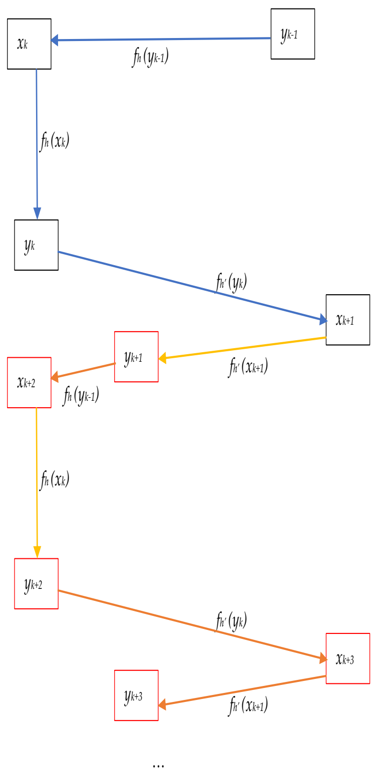

Fig. 1 Representation of the classic process of interaction as logical machine given by the iterations of the systems of equations (1) and (2). Different colors indicate different cycles.

However, this ideal understanding overlooks the fact that the action-reaction processes are not in real time but take place according to time intervals greater than zero and usually different. Reactions can occur when the entity that initiated the interaction may now be in a different state and may be involved in one or more new interactions both as reactant and/or as activator; the reaction acts then on entities that are currently in states that are not the ones that occurred at the beginning of the action. This creates multiple and non-synchronized action-reaction networks.
Furthermore, we may consider cases of open or incomplete interactions when, at the initial time, the pair is undefined and the available matter-energy is just available to be used as a tentative initial action to react to. In the latter case, it is a matter of implicit, not completed interaction.
In concepts such as interrelation, correlation, and covariance, the interdependence is rather passive as detected or having the role of maintaining or representing reciprocal, fixed relations, for instance due to fixed links, e.g., electronic connections, multiple synchronizations, and in analogical devices. Passive interdependence is specified by concepts such as covariance, correlation, and

ergodicity. This is different from coherence, which must be actively maintained in the face of variations in the other interacting elements ([2], pp. 26–31), [8, 9] being maintained, decided by the inter-actors and then the possibly of non-identically replication.
In processes such as interchange, the concept of "inter" assumes the prevalence of specific or generalized reciprocal equivalence.

2.2 Interaction between what?

We should ask, "interaction between what"? What is supposed to be able to interact, that is, to receive, detect, and properly send back or make available reactions? In the previous cases, what is supposed to initiate the interaction, *sent* such as matter and energy, or what is detected, such as position or speed for agents in a crowd, may have an equal or different nature of the corresponding reaction: material-energetic or positional-concerning speed. Otherwise, for instance, two interacting devices of different natures may exchange interacting acoustic and optical signals. Interactions may occur between entities of different natures that have themselves different natures.
Furthermore, in a population of interacting entities, there is a deluge of unmarked information and signals having multiple roles, i.e., without the label of a specific action or reaction mark. Entities must have a way to consider and select data that is supposed to be sent-detected, initiating an interaction or as a reaction to previously received data. The intense network of action-reaction occurring in a population is virtual in the sense that it depends on the selection processing used, for instance, considering the metrical or topological closer entity as supposed to be the other of the supposed interacting couples in the dynamics of the network.
We may consider such multiple networks as if they were generated by hypothetical entities. We mention how, in this view, dominions of interactions could be intended to come first, as before the existence of matter property or pre-property [2, 146–151]. For instance, the quantum vacuum is intended as a pervasive field of potentialities ready to collapse, as are the probabilistic features of Quantum Mechanics (QM), where the quantum vacuum is intended to precede matter, space, and time [10]. Dealing with processes of interaction, it is usually assumed availability of materiality sufficient to support interactions that could also be between fields (see Section 2.3).
In such a network, there is room for multiple strategies, such as considering interactions between multiple combinations [9–13] of entities. This seems suitable when considering collective phenomena such as flocks and swarms. Furthermore, we deal with data of multiple natures, such as considering in a flock the position, the direction, the speed, and the altitude of a bird. This suggests that it may be appropriate to consider the properties of clusters, in case having birds in common. It may be effective to imagine being in interaction with a virtual entity, such as communities and clusters of real entities [9].
The general process of multiple interacting within a population should also be considered to occur with irregularities and incompleteness due, for instance, to contextual or environmental reasons. Possible properties of the occurring irregularities and incompleteness in interacting, such as statistical, may characterize the specification of collective behaviors.
We specify that the incompleteness may relate to the incomplete occurring of a process, being terminated early, partial consideration of the values of variables, and partial consideration of combinations, all for any reason. Such incompleteness has a phenomenological nature. However, it may be considered as an aspect of the general so-called theoretical incompleteness [3, 14] considered in mathematics (continuum in geometry and the Gödel's theorems); in physics (uncertainty principle and homologous components); as related to undecidability of the classic halting problem for the Turing machine; in the theory of computation (incomputable numbers, e.g., π and $\sqrt[3]{5}$—that is, the computation is endless); and when in modeling, one of the three following conditions is not fulfilled: availability of a full, formal description of the relations between the state variables in finite number; availability of a complete and explicit (analytically representable) description of the interaction between the system and its environment; and the sufficiency of the knowledge from the previous two points to deduce all possible states and structural characteristics which the system can take (finite phase space).
Systems can be considered complete if they are fully described by a finite number of variables and models.
Systems can be considered theoretically incomplete when a single model is not sufficient for their representation; the system variables (degrees of freedom) are not only variable in number, but continuously acquired; nonequivalent properties are continuously acquired (non-finite phase space). This is the case with complex systems, the emergence of which necessitates the occurrence of such theoretical incompleteness [3, 14].

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The interaction intended as a couple of sender-receiver and action (detection)-reaction is an elementary simplification. Not only should we consider the multiple interfering, interchanging roles of senders and receivers, acting simultaneously as sender for an interaction and receiver for another, but also that the interaction is initiated by one entity looking for data in or from another one or more, of which, for example, an average value is considered, and decide to react accordingly (such averaging may occur in the same or different ways, such as considering interacting clusters having a stable or variable number of elements).

2.3 Interaction Mechanism

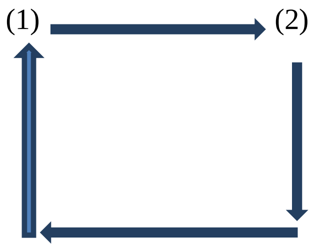
Furthermore, the interaction initiated, such as a behavioral change, can be intercepted and processed by several entities, which can then react collectively. In a population of interacting entities, the interacting pairs are not fixed, as one may use the reaction of another to activate the subsequent action. Actions and reactions are not distinguishable, being in reality shared, interchangeable roles.

The inadequacy and also the impossibility of considering fixed couples in interaction, substantially stable interaction processes, and the occurring, rather, of simultaneous interfering multiple, variable processes of interaction involving the same element, which simultaneously plays the role of triggering actions and reacting in different interactions with different timings, require the introduction of adequate modeling of interaction. Considering, for instance, their occurring in probabilistic aggregations, in a manner according to distributions with or without regularity, and again in an ergodic, or in any case, correlated way.

We should specify the generic term "interaction" with an "interaction mechanism" intended as combinations of detected, supposed, or virtual interactions [4].

The ideal logical machine mentioned above may be replaced by populations of variable, multiple interactions, and incomplete pairs of interacting elements, establishing crossing interaction mechanisms. In the following, we consider an idealized population of elements $x, x', x'', \dots; y, y', y'', \dots$; and of interaction rules f_h between pairs transforming the state of one depending on the state of the other, at the instants k: $1, \dots, n$ total observation time. Ideally, a generic example of an interaction mechanism may be intended by the multiple, sequential, non-regular, combined occurring of multiple systems (1) and (2), occurring that can take place with or without general or localized, partial regularities.

At the time k there is a concluding step of a cycle of a *logical machine*



Then we may consider the following case example:

$$\begin{cases} x_{k+1}=f_{h'}(y'_k) \\ y'_{k+1}=f_{h'}(x_{k+1}) \end{cases} \quad (3)$$

At time $k+1$ the interaction $f_{h'}$ leads from y'_k to x_{k+1}, and from x_{k+1} to y'_{k+1}.

$$\begin{cases} x'_{k+1}=f_{h''}(y'_k) \\ y'_{k+1}=f_{h'}(x'_{k+1}) \end{cases} \quad (4)$$

At time $k+1$ the interaction $f_{h''}$ leads from y'_k to x'_{k+1}, and the interaction $f_{h'}$ leads from x'_{k+1} to y'_{k+1}.

$$x''_{k+1} = f_{h''}(y'_{k+1}) \quad (5)$$

At time $k+1$ the interaction $f_{h''}$ from y'_{k+1} leads to x''_{k+1}.

$$\begin{cases} x'_{k+1}=f_{h'}(y'_k) \\ y'_{k+2}=f_{h''}(x'_{k+1}) \end{cases} \quad (6)$$

At times $k+1$and $k+2$ the interaction $f_{h'}$ leads from y'_k to x'_{k+1} and $f_{h''}$ from x'_{k+1} to y'_{k+2}.

$$\begin{cases} x''_{k+2}=f_{h''}(y'_k) \\ y'_{k+2}=f_{h'}(x''_{k+1}) \end{cases} \quad (7)$$

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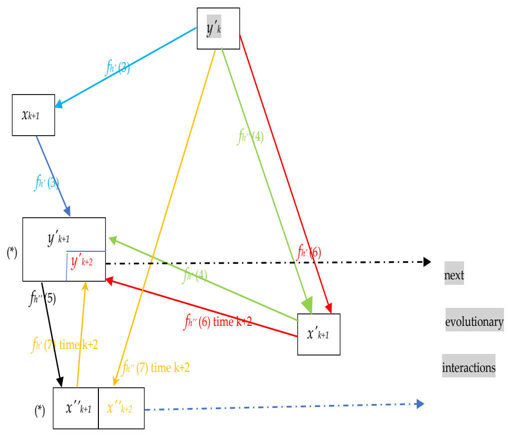
At time k+2 the interaction $f_{h''}$ from y'_k to x''_{k+2} and the interaction $f_{h'}$ leads from x''_{k+1} to y'_{k+2}.

Categories of such interaction mechanisms and their properties, such as modes of occurrence, may be considered to correspond to kinds of collective behaviors. This possibility should be studied in suitable simulations with the aim of studying typical situations for the establishment of coherence and emergent properties.



(*) the same elements are represented in different times and colors depending on the generative or perturbing interaction

Fig. 2. Representation of the interactions as by the systems of equations (3), … (6) establishing an elementary interaction mechanism in times k, $k+1$ and $k+2$.

Representations and simulations of interaction mechanisms (starting from their simple linear combinations, weighted treatments according to criteria, e.g., sequentially, type, in combinations, and others) are expected to make explicit and allow inferring rules on how to process simultaneous or non-simultaneous incoming multiple interactions, e.g., perturbations.

2.4 Fields and domains

In physics, the so-called fundamental interactions or fundamental forces allow us to describe physical phenomena at all scales of distance and energy, and are not attributable to other interactions or forces. The four fundamental interactions are gravitational interaction, electromagnetic interaction, weak and strong nuclear interactions, which produce forces at subatomic distances. We mention how, in modern physics, the concept of interaction replaces that of force, interpreted in terms of particle exchange.

Furthermore, interaction may relate to the taking place of reciprocal influences through fields such as in physics, the electromagnetic and gravitational fields, e.g., planets in the solar system; and through cognitive fields consisting of admissible, compatible, and expected possible behaviors of the other considered element of the interacting pair, e.g., positions in aggregates of moving pedestrians or in vehicular traffic. In this regard, in the social sciences and psychology, the psychologist Kurt Lewin (1890-1947) introduced the concept of force field [15]. Such cognitive processing occurs in living or artificial entities provided with suitable detectors and sufficient cognitive processing abilities, e.g., birds in flocks and driver-less cars. The processing may be varied, in-homogeneous, and even suspended.

If, on one hand, the interaction changes the behavior and properties of the individual interacting entities, the interference, on the other hand, changes the interaction itself or its effects. Interference refers, for instance, to phenomena of mutual, partial superposition, and combination between different interactions. Besides, in the inter-linkage of networks, the related interdependence between links may be fixed or variable, context-sensitive [13]. Rather than considering fields of interaction, we may consider domains [16] as given by the multiple simultaneous interaction options available in each point of the phase space (where it is possible to mathematically describe the evolution over time of the system). In such domains, we may have many potential, failed, and incomplete interactions, such as single-sided microscopic Brownian-like motions, which may be intended to have no coupled reactions.

However, while the settling of complete, ideal systems (constantly systems over time; having regular, even if non-linear, evolution) particularly applies to artificial, designed systems keeping the property of functioning, quasi systems (intended as not always being systems, the same system, not only systems, and having processes of losing and recovering properties, such as their global and local coherence) [2], they can be considered emergent as a particular, lucky case occurring in an ideal, completely, variably networked world of entities linked by mutual multiple possible interactions in a space of admissible, compatible, and equivalent evolutionary possible options. Furthermore, with varying degrees of freedom and constraints, such as in flocks and swarm dynamics, such a structurally dynamic networked world is intended to be composed of multiple, superimposed variable over time, local networks. Such a hypothetical general network is so undefined that it may not be really useful if not to realize the predominance of relations and interactions over entities, in such a way to introduce the opportunity to consider systemic domains.

Mentioning the concept of field in physics, it was originally used to describe the effect of forces produced by suitable material sources. Subsequently, the introduction of electromagnetism allowed us to consider phenomena such as transmutations of a kind of field into another kind of field (for instance, a magnetic field from the current generated by an electric field) and as well propagation of fields (for instance, in the case of electromagnetic waves). It was, accordingly, considered the opportunity to consider the fields as the primary entities of physics rather than the sources. The latter could be considered equivalent to specific space-temporal strong concentrations of intense fields [17-19]. The primacy of field or sources, nowadays identified with elementary particles, is still under study in constructing physical theories and elaborated when considering the concept of "matter," the subject of endless discussions. The issue here is that fields and domains of interactions may be so strong as to prevail on their supposed sources. However, they are considered represented in their possible generative role, e.g., fields generated by fields.

We considered the possible mechanisms of interaction as due to exchanges of matter or energy (differentiated only in classic physics) sufficient for the interaction to occur. In the case where there is no such sufficiency, we may speak of attempted and failed interaction. In the case of fields, we may consider their interactions to influence the behaviors of entities within. *We can think of the domain of interactions as a set of spaces with the potential to collapse into interaction mechanisms, and then use the material to make systems emergent. We should also consider situations where implicit mechanisms of interaction are standing, for instance, in a meta-stable state and occurring or collapsing in the face of environmental events*.

2.5 Isolation

Isolation is considered to occur not only when exchanges of matter or energy do not occur or are unsuccessful, but also when there is no reception. For example, when there are no effects, there are no receivers, there are no elaborations of the delivered and there is no detection. Furthermore, in the same way as properties may be detected *only* by something having properties, isolated entities may not be detected, meaning their properties cannot be detected, such as, in principle, their existence.

An idea of such a world with no properties is given by an absolute zero world, the temperature at which a thermodynamic system has the lowest energy and no heat energy for or from molecular motion is available. In the classical understanding of the world, entities such as molecules are completely isolated, and no exchanges of energy are possible. It is a matter of ideal interaction-less environments. However, at absolute zero temperature, all molecular motion does not completely cease, since molecules still vibrate thanks to what is called zero-point energy, and quantum systems fluctuate in their lowest energy state.

3 Observing, interfering and interacting

Is an observation an interaction only when it produces noise or interference [20]?

The act of observing ongoing phenomena may indeed require interference by using, for instance, illumination, gauges of any kind that influence what needs to be measured, and influence on the environment, such as temperature. Furthermore, beyond the obvious, we recall the uncertainty principle, such as introduced in 1927 by Werner Heisenberg (1901–1976) stating that in the measurement of homologous components, e.g., position and momentum, the increasing accuracy in knowing the value of one variable correspondingly involves a reduction in knowing the value of the other one; and the complementarity principle, introduced by Neils Bohr (1885–1962), stating that the corpuscular and wave aspects of a physical phenomenon never occur simultaneously. Inevitably, interference establishes loops of interactions between the observer and the observed.

The active role of such observing may not only perturb, but also induce corresponding reactions in the observed treated as if it were what the observer had in mind. This induces reactions and subsequent corresponding adjustments, thus constituting an interaction, a dialogue between the observer and the observed, as it was what the observer had in mind. However, can it be different? There is a balancing, a dialogue between objectivistic and constructivist approaches, as considered in the following Section 3.1, between ideal and data-driven approaches. Such interactions may then, in turn, be observed for *n*-levels. The properties of subsequent observations can be thought of as a type of meta-knowledge.

However, the act of observing may not involve any interference when using data ex post, such as historical and related to the occurrence of the phenomena over time, possibly considered in relation to others. We may understand such data as passively identical, equally (if not for perturbances and relativism of scale and point of view) available, to be properly detected and selected or as answers related to questions considering their temporal configurations, e. g., statistical properties, topological regularities. The latter case is typical for simulated experiments and phenomena where no experiments are possible, such as in cosmology, where we assume we cannot interfere.

3.1 Cognitive perturbance and its interfering

We consider here the case of cognitive perturbance and its establishing interactions.

The interactive aspect of observing we are considering here is not related to perturbances generated by the observer in the act of observing, but related to its cognitive activity and the consequent actions on the observed. We may understand and model the temporal evolution of a process as well as possible in an objectivistic way, that is, regular and invariable if not for environmental and detectable perturbations. However, we consider observing not as taking ideal, context-independent ideal pictures or making sequences of ideal photos, ignoring the meaning of the sequencing, but as inevitably interconnected with its use to decide and predict, that is, model and create expectancies. On the other hand, the cognitive understanding and modeling of sequences cannot avoid saying something about their temporal evolution in terms of the properties of their temporal progression. Underneath, there is the assumption of continuity and stability as an intrinsic property of nature and not of its evolution, for instance, through mutually irreducible jumps and in discrete ways, even phenomenological, as for phase transitions and quantum effects.

For instance, the assumption of forms of continuities in using the same, if not for parametrical changes, compatible, admissible models is, to all intents and purposes, a non-material disturbance introduced by the observer. Other examples include treating complex systems as non-complex systems and acting accordingly; treating computations that are not fully computational as computations and thus ignoring the importance of deciding the level of approximation and the sub-symbolicity to use, such as neural networks, genetic algorithms, and cellular automata [21]. Whereas such sub-symbolic computations emerge from explicit and complete computational processes (algorithms), they are not explicit algorithms.

In this way, cognitive aspects of observing may be understood in court as cognitive interference or, better yet, cognitive interaction in that the observer observes the phenomenon as due to the same model, varied only by parameters, adopted. It seems like an inadequate and misleading application of the Occam's razor principle. The natural approach seems based on reusing the same approaches in a chain of admissibility/compatible/parametric changes, leaving as a last resort the change of the way of thinking, as for the cybernetics of the second order ad abduction [22, 23].

Unfortunately, it does not work for complexity, where self-organization and emergence processes occurring in phase transition-like modalities involve acquiring multiple sequences of non-equivalent and not mutually reducible properties. For example, irregular and discontinuous behavior in flocks; cognitive, biological, and physical in living systems; and environmental and sociological in social systems such as cities and beehives [1, 2, 7] necessitate multiple non-equivalent models, non-converging to the best one, such as the DYnamic uSAge of Models (DYSAM) ([2], pp. 201-204; [7], pp. 64–75) based on machine learning, ensemble learning, and evolutionary game theory.

The fact that the observer expects something to be established, occur, and be treated by the same previous model (assuming the existence of the best model) influences how data is detected and understood, for example, as approximations, temporal deviations due to impurities and perturbances rather than discordance with the model; acting on the observed; and planning experiments. It applies in social systems where continuing to interact with someone in a certain way will, in the long run, push them to react and then behave as if they are so.

For instance, it is the case for medical problems that are simultaneously physiological, biochemical, physical, and psychological, and yet social, cultural (refusing treatment for any reason), hygienic, nutritional, religious, environmental, stress-related problems, and many more. It is not a question of the aspects of the medical issue as considered by objectivism, but of the systemic medical concern that cannot be disassembled. Insisting on treating it only with a pharmacological approach will make it so.

It is a matter of non-material disturbance introduced by the observer, perhaps better understood as interference, influencing the interactions between

the observer and phenomena that occur continuously according to the observer. Such understanding influences subsequent real interactions carried out by the observed based on such understanding. Reactions to the phenomenon under study are intended by the observer as if the phenomenon were what s/he had in mind. This is of interest in detection and variations of processes of emergence [22]. A typical case occurs when considering a complex system as a non-complex system, for example, by treating non-linearity as adequately approximated by linear sequences [23].
On the other hand, experiments may be constructively intended as questions posed to nature, which responds by making them happen. No answers if there are no questions. Conversely, everything that happens can be understood as an answer to appropriate questions, to be invented. We may identify loops of cognitive interactions. Indeed, entity properties can be thought of as ready to manifest, to collapse as soon as they are detected, and to be cognitively realized through interactions with other properties and learning cognitive processing. Whatever has to happen somehow. However, as said above, we need to balance constructivism and objectivism, avoiding a continuous intractable constructivist attitude and an objectivistic assumption of definitive real approaches [24].

4 Further research

A further possible line of research, using simulations, to be implemented relates to considering a mesoscopic view [9] of the populations of interactions. In suitable simulations, we can consider clusters of interactions (in this case, belonging to the same interaction mechanism) as well as elements involved in particular interactions, such as those simultaneously subject to more recurrent interactions. This would be a good compromise between the macroscopic level currently in use in which the effects are considered and the microscopic one considered in the article and actually intractable. Sequences of instantaneous complete networks of all elements of the population (possibly variable over time) could be considered as a reference basis. Only active links should be considered in mesoscopic clusterizations. We can consider the properties of clusters and their meta-interactions. Iterated and recurrent dominant clusters' properties should be considered representative and subject to modifying interventions.

5 Conclusions

We presented comments and insights on the concept of interaction, with particular reference to its use in systems science dealing with the issues of complexity and emergence. A simplistic understanding of the concept of interaction constitutes an improper basis for the realization of models of complexity that find themselves having to represent what has remained simplified and neglected in the concept of interaction. In particular, when interaction is simplistically understood as occurring in fixed pairs and according to fixed modalities, ignoring phenomena of multiplicity, variability, and indefiniteness.

We considered the need to extend the concept of interaction by including multiple, variable processes of interaction involving the same element, which simultaneously plays the role of triggering actions and reacting in different interactions with different timings, requiring the introduction of adequate modeling of interaction considering, for instance, their occurring probabilistically, in aggregations, in a manner according to distributions with or without regularity, and again in any correlated ways as in quasi systems. Further research may consider simulated populations of interactions and their mesoscopic properties.
The study of such approaches is of interest for collective phenomena occurring, for instance, in the economy with catastrophic mass buying and selling; in social systems with mass migration phenomena and the establishment of manipulations; in biology with migratory capacity and resistance in collective aggregations of tumor cells leading to metastases; in physics with collective molecular, e.g., whirlpools, and particle behaviors, for instance in plasma, such as in the so-called Crookes tubes, ancestors of cathode ray tubes, and neon lamps; and the coherence of lasers. In this regard, we quote a phrase of two prominent physicists of condensed matter: "Physics was able to delay serious consideration of collective effects for nearly 300 years, and only in the last 30 years or so has it confronted complex collective phenomena involving multiple scales of space and time, unpredictable dynamics and large fluctuations' ([25], p. 392).
With regard to the effects of the interaction observer-observed, the issues are related to the role of the observer and the meaning and effects of observing, particularly as regards the cognitive dimension when expecting the constant validity of the same model and approaches. A possible perspective is to set up a modelling inspired, for

example, by that of the theory of cognitive operators [26] ([2], pp. 190–192), where to consider issues such as domains of interactions, interactions between interactions, observing observations and interactions, orienting interactions, and constituting anti-interactions capable of deactivating unwanted ones.
The perspective is to set effective approaches, such as the introduction of appropriate perturbances, suitable to activate, deactivate, and vary interactions such as processes of self-organization and emergence ([2], p. x of the Preface).

The present research article is dedicated to the memory of Professor Eliano Pessa with whom these issues were under study and to celebrate his valuable interdisciplinary contribution and expertise in the science of complexity.

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