The intrinsic complexity of evolution: intelligence of matter, emergence, and evolution in the framework of systems science.

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Abstract: - The aim of this article is to introduce a more comprehensive framework that takes into account additional factors and concomitant options appropriate to the complexity of the multifaceted phenomenon of evolution -complexity that cannot be addressed or exhausted with a single model or approach, such as the classical theory of evolution. More specifically, the aim is to introduce a new conceptual framework for studying the intelligence of matter, evolutionary processes, and the acquisition of complex properties such as cognitive abilities. In this regard, we consider three orders of intelligence. The first consists by possession of properties. The second consists of the ability to acquire properties, as seen in systems. The third consists of the ability to acquire generative properties, enabling the iterative acquisition of further generative properties. Third-order intelligence is almost compatible with, if not representative of, cognitive intelligence. The first- and second-orders of intelligence are considered properties of non-living matter. However, the second order of intelligence is also a property of living matter, representing continuity between non-living and living matter. We introduce the inadequacy of considering evolutionary processes without understanding the intrinsic role of the orders of intelligence, their properties, and, in particular, the phenomena of emergence in systems complexity. We consider living matter both as evolving emergent matter and as emergent evolving matter. Considering evolutionary processes alone appears to be an oversimplification, if not a form of reductionism. This is particularly relevant in the context of cognitive intelligence, which can only recognize its own properties as intelligent, effectively allowing only self-modeling approaches. We introduce consequent considerations and implications for the evolution of cognition and the possible role of consciousness. We examine the simulability of the evolutionary process by AI through learning about imaginary and non-human worlds, opening perspectives on considering the properties of new worlds for interaction and design purposes. We conclude by specifying possible applications, such as measuring the generative power of AI as the acquisition of new properties, identifying research directions, and using the discussed approaches for social strategic design.

Key-Words: - Cognition; Consciousness; Emergence; Incompleteness; Intelligence; Openness; Property; Self-organization; System.

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1 Introduction

The basic hypothesis considered is that the theory of evolution alone is not sufficient [1] to explain its complexity, particularly in the acquisition of properties by living matter that are not only high-performing and optimized but also have strategic value to the point of acquiring cognitive properties such as cognitive intelligence.

The complexity of evolution cannot be ignored, and as such, it cannot be fully addressed using a single model but instead requires multiple concomitant approaches, including ideal and non-ideal models.

We consider how the mechanisms of evolution and emergence are not only non-goal-oriented but also inherently incomplete and intertwined, with various other equivalent and non-equivalent possible options.

The aim is to introduce a more comprehensive framework that accounts for additional factors and concomitant options, allowing for a more multifaceted and complex understanding of evolutionary processes.

The general purpose of this article is based on a conceptual framework that introduces and focuses on the *intelligence of matter*, understood as the possession and acquisition of properties, for example, through emergence.

More specifically, the aim is to introduce a new conceptual framework by which to study the intelligence of matter, evolutionary processes, and the acquisition of complex properties such as cognitive abilities.

In this framework, we consider processes of evolution and emergence as occurring in intertwined ways, with intelligence of matter and evolution structurally interconnected.

We highlight the continuity between the intelligence of matter and the cognitive intelligence of living beings, as well as its consequent self-referentiality, understood as matter knowing itself. However, the approach is based on the intelligence we possess and use -an intelligence that can only recognize itself. Just as our metabolic life may be unable to recognize different forms of life, our cognitive intelligence may be similarly limited in recognizing other forms of intelligence.

The theoretical framework on which this article is based is systems science, particularly complex systems, where multiple processes of emergence occur. We introduce and support research issues that consider evolutionary processes as intrinsically linked with the intelligence of matter, in which consciousness plays a role in overcoming problems of self-referentiality. For example, artificial intelligence (AI) approaches based on supervised learning can refer to other species or imaginary cases.

In Part 1, Section 2, for the benefit of the general reader, we recall some concepts used in physics and systems science that are relevant to the subsequent discussion, namely:

- 2.1 Interactions, networks and games, dealing with their definitions and relationships.
- 2.2 The phase space (an abstract space where each variable is associated with a coordinate axis).
- 2.3 Degrees of freedom (the number of variables that determine the coordinates of the phase space) and properties (as variables that, in our case, are acquired through processes of acquisition because the main property of systems is to acquire properties).
- 2.4 System closure and openness:
  - Logical closure refers to the properties of evolutionary models of deterministic systems.
  - Logical openness refers to the properties of evolutionary models of non-deterministic systems.
  - Logical and physical closure/openness refers, for instance, to thermodynamically closed systems that may be logically open if they are non-deterministic, such as gas or fluid in a sealed container acquiring properties depending on temperature or agitation dynamics).
- 2.5 Theoretical incompleteness (incompletable incompleteness in principle when, for instance, a single model is assumed to be insufficient to represent a phenomenon, and the degrees of freedom -the system variables- are continuously acquired and vary in number).
- 2.6 The process of *acquiring* rather than merely *possessing* properties (for instance, through dilution, effervescence, or phase transitions such as water turning to ice or the establishment of whirlpools). Systems of elements acquire properties when powered, for example, as sets of electronic components *become* devices such as computers, cell phones, and TV sets. This subsection briefly discusses the multifaceted concept of property. We mention the acquisition of dimensionality in geometry, where dimensionless points constitute a one-dimensional line (acquisition of a dimension).
- 2.7 Because it is used in the text, we briefly introduce the concept of matter.
- 2.8 We introduce some specifications regarding the concept of coherence intended, in short, as synchronization, multiple synchronizations, remote synchronizations, local couplings, covariances, correlations, and predominance of the same property at various levels, e.g., a flock remains as such despite continuous variations.

In Part 2, Section 3, we elaborate on the question of intelligence. We consider the ability to manifest possessed properties and acquire properties as an expression of what can be considered *generic intelligence* (of matter). We consider cognitive intelligence as the ability to acquire properties that generate new, specific, non-equivalent properties, such as collective intelligence. *Cognitive intelligence* is considered the ability to acquire properties that generate indefinite sequences of new generative properties, such as abduction and theories.

In Section 3.1, we consider the intelligence of matter in two forms:

- First-order intelligence (type a properties): Possessing properties such as capillarity, fractality, and self-similarity.
- Second-order intelligence (type b properties): Acquiring properties, such as the acquisition of coherence in the Belousov–Zhabotinsky reaction, Rayleigh–Bénard convective rolls, and whirlpools. Examples of this second case also apply to the intelligence of living matter, such as the establishment of anthills and beehives, or collective intelligence, such as defense from predators by flocking birds or attack strategies by swarming insects. The emergence of different but coherent properties, such as ecosystems, occurs at low levels of logical openness. These properties are considered *closed properties* (type a and type b), meaning they lack a self-generative nature.

The type b properties of second-order intelligence represent *continuity* between non-living and living matter. While they do not persist as invariants, like type a properties, they reappear in different forms while maintaining key characteristics.

- Furthermore, we consider third-order intelligence (type c properties) in living beings, characterized by the acquisition of open generative properties. These include problem-solving, the ability to invent and assign properties to materiality (engineering solutions and materials science), the invention and application of strategies, the recognition of ongoing games, the invention of games, and the performance of abduction (the invention of hypotheses), and anticipatory abilities. These properties generate new generative properties and exhibit high levels of logical openness. Such properties are considered open properties (type c), meaning they have a self-generative nature and generate new, subsequent properties (see Table 1).

We specify that we will use the terms “order” and “level” in reference to different meanings. The term order, used for example in relation to order of intelligence, referring to non-homogeneous, incompatible, irreducible versions of the same entity or property. The term level, used for example in relation to levels of logical openness, referring to measurable levels of the same entity or property. However, as emphasized in Section 3.2, we explore intelligence with our own cognitive intelligence, in a self-referential way, making us unable to recognize other possible forms of intelligence. Therefore, we outline possible research approaches that are compatible with forms of incomprehensibility (see Section 6).

We consider generic intelligence as the ability to acquire properties across orders of intelligence, up to the third order, which has a potential and abductive nature and is inevitably characterized by forms of “weakness,” temporal and contextual relativisms, and even pathologies.

In Section 3.3, we consider the intelligence of matter and the self-referential intelligence of the biotic, elaborating on the hypothesis that specific forms and orders of intelligence exhibit *continuity*. This hypothesis is supported by the absence of incompatibilities or inhomogeneities between them.

Subsection 3.3.1 elaborates on first- and second-order intelligences in non-living matter, dealing with A. possessed properties (type a) as first-order abiotic intelligence and B. acquired properties (type b) as second-order abiotic intelligence.

Subsection 3.3.2 elaborates on second- and third-order intelligence in living matter, dealing with C. acquired properties (type b) as second-order abiotic/biotic intelligence and D. acquired properties (type c) as third-order biotic intelligence.

We consider second- and third-order intelligence as evolutionary and inextricably linked to their material context. Cognitive intelligence is intended as the ability to acquire and generate new generative properties.

In Section 4, we elaborate on the evolution interconnected with the intelligence of matter. The general idea considered is that evolution is intertwined with acquisition processes at various levels of properties. This is because the evolutionary mechanism seems inadequate -at least on its own- to explain the complexity of property acquisition of type c properties. Third-order intelligence is intended generated at least by interconnected evolutionary and emergent processes.

This inadequacy arises from the assumption that selection and adaptation exhaust *all* possible options, whereas, in reality, they tend *to converge on more accessible or incidental optimizations*, neglecting more complex and more difficult-to-reach possibilities. The process is assumed to iterate through successive local, temporary optimizations. This would be conceptually equivalent to using data-driven approaches in very large, dynamic databases, as in Big Data, to identify concordance, correlation, and correspondence. *The intelligence that is missing in data-driven approaches corresponds to that which we consider missing in evolutionary processes*. To explain the creative and intelligent choices in evolution, we discuss the need to consider evolutionary directions as ‘chosen’-or rather 'invented'- through the intelligence of matter, rather than by trial and error only.

We consider the intelligence of the biotic as *one* possible extension of the intelligence of matter, with forms of continuity such as the recurrence and reappearance of properties. We view living matter as *evolving emergent matter*, e.g., living beings, and *emergent evolving matter*, e.g., collective behaviors and ecosystems.

In Section 5, we elaborate on the possible role of consciousness and its effects on evolution, combined with the intelligence of matter. The ability to orient evolution has a strategic nature of crucial interest, for instance, for social designers.

In Section 6 we introduce concluding remarks on applied research related to the combination of evolution and emergence in models and simulations.

In Section 7, we mention possible directions for future research.

In the Conclusions, we mention how practical applications concern cases in which phenomena are considered to have an evolutionary nature and thus to be completable, *originality of the contribution*, also considering their complex nature, to the benefit of the accuracy of the models, such as in biology and economy.

PART 1

2 Some basic introductory theoretical points

In this section, we revisit some basic introductory theoretical points from physics and systems science, which will be referenced below. These concepts can be reviewed before reading Part 2 or revisited as needed.

2.1 Interactions, networks and games

The generic definition of **interaction** relates to the process by which one's behavior affects another's behavior. As introduced by Ludwig von Bertalanffy, the founder of systems science [2], the classic model of a generic system consists of n elements, denoted as p_i ($i = 1, 2, \ldots, n$). This model assumes that the number and properties of these elements remain fixed, even though this assumption is unrealistic. For simplicity, the system can be represented by a set of ordinary differential equations:

$$\begin{cases} dM_1/dt = f_1\,(M_2, \ldots, M_n) \\ dM_2/dt = f_2\,(M_1, \ldots, M_n) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ dM_n/dt = f_n\,(M_1, M_2, \ldots, M_{n-1}), \end{cases} \qquad (1)$$

where:

- M_i ($i = 1, 2, \ldots, n$) is the measure of a property, e.g., speed or direction, related to each of the n elements p_i;
- The interaction between elements is represented by the *simultaneous* influence (given by the validity of the system of ordinary differential equations), through the f_n, of all other elements on a single one;
- The n elements p_i are assumed to interact through invariable rules of interaction f_n.

In this context, any change in a measure M_i is a function of all other M_s. Similarly, changes in any M imply a change for all the other measures. This makes the system a single, totally interconnected whole.

Examples of M_i include the speed, direction, and altitude of a bird in a flock.

This approach particularly applies when elements p_i are particles or agents interacting through f_n, representing, for instance, exchanges of energy, e.g., by collisions, and information. Furthermore, it is possible to consider their vector $\vec{v}$ [s, d, a] and f_n as vector functions.

This is the classic model of non-multiple system intended given by fixed, in number and in their occurrence, n elements p_i interacting through fixed rules of interaction f_n. The assumption is that model (1) identically and generally applies to model any general system.

While temporal sequences of system (1) specify the behavior of the system, the simultaneous validity of different versions of system (1) may be intended to analytically represent the more realistic concept of multiple systems [3], where variable in umber and occurrence elements p_i interact through variable rules of interaction and f_n changes to $f_{n,t}$. The expressions in system (1) become time-dependent as in (2) as composed of a variable number of different ordinary differential equations.

$$\begin{cases} dM_1/dt = f_{1,\,t}\,(M_1, M_2, \ldots M_n) \\ dM_2/dt = f_{2,\,t}\,(M_1, M_2, \ldots M_n, M_{n+1}) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ dM_n/dt = f_{n,\,t}\,(M_1, \ldots M_{n-1}) \end{cases} \qquad (2)$$

This conceptual understanding applies, for instance, to the so-called *active matter*, see Section 6, referring to collections of entities individually using free energy to acquire their own collective motion. This is the case of collective behaviors when analytically modelled, see Section 6, where simulations and digital approaches are considered. (1)

We mention the difference, for instance, between interaction and the case of *transformation*, when the composing elements structurally change throughout processes such as chemical and physical processes, as studied by the science of materials, e.g., burning candles melting.

Another approach is based on considering systems as consisting of networked elements where the network links represent their interaction. The approach is elaborated in network science [4].

We must notice how the definition of *interaction* considered above has significant correspondences with the *interplay* considered in game theory.

Game theory provides approaches to analyze and model configurations and situations in which, instead of particles, we consider parties or players making interdependent decisions.

This interdependence implies that each player takes the other' possible decisions into account when formulating strategies [5-8]. The theory has been subsequently studied and applied in several disciplinary contexts.

A solution to a game consists of the optimal decisions of the players, who may have similar, opposed, or mixed interests. The outcomes result from these interdependent decisions. A game reaches a solution when it is solved, and players win, lose, or draw.

Unlike the 'simple' process of interaction, which may be partially or totally multiple, simultaneous, synchronized, or non-synchronized, game theory considers *cooperative/competitive strategies*. In game theory, interaction is understood as an act of the ongoing game. Traditional game theory models are based on the assumption that players are fully rational and have complete knowledge of the game. In Section 3, we mention how recognizing ongoing games is a sign of cognitive intelligence.

It is possible to extrapolate and generalize by aiming to recognize the ongoing game played in interactions between entities such as molecules, the strategies they induce, and the game's purposes - such as the dynamics of diseases and degenerative processes.

Furthermore, evolutionary game models assume that agents may select or optimize through trial-and-error processes, acting as a learning process [9, 10].

The process is repeated several times, and strategies with little effectiveness tend to be discarded, allowing an equilibrium to emerge. *The process of interaction is considered almost unruled or subject to very few rules. The typical basic case is the so-called Brownian motion, i.e., the irregular, disordered, random, and unpredictable motion of a speck of pollen on water due to collisions with single and multiple water molecules, which in turn interact and collide with one another because of thermal energy. Because of these thermal interactions, a number of particles in a given medium, e.g., water, exhibiting such Brownian motion, have no preferred directions for their random oscillations. Over a period of time, as a result, the particles tend to spread uniformly in the medium.*

The process of playing games consists of ruled interactions, with adaptive and learning capabilities, to the point of assuming variable strategies with competitive or collaborative natures.

Interdependence in played games is expected to produce results or reach equilibrium, whereas interaction involves continuity. The outcome or solution of a game corresponds to the acquisition of properties in ongoing collective interactions, such as:

- Collective behaviors emerging in populations of entities that continuously and multiply interact. These behaviors arise *spontaneously*, i.e., without explicit prescriptions, acquiring varying forms of coherence, e.g., partial, uniform, or non-uniform, and different levels of simultaneity. For instance, swarms exhibit variable levels and sequences of predominance of these aspects;
- Collective systems formed through collective behaviors, characterized by one or more acquired properties that define the system, e.g., the morphological structures of swarms, hives, or termite mounds, which emerge and optimize *spontaneously* for specific functions.

As we will see (see Section 2.6 points 2.6.2 and 2.6.3), processes of self-organization may be conceptually understood as coherent sequences of different versions of the same phase transition, e.g., from water molecules in a fluid state to whirlpools. Similarly, processes of emergence can be seen as coherent processes of self-organization, e.g., from instantaneous sequences of coherent flight in insects to the formation of swarms.

2.2 The phase space

The phase space, a concept developed in the late nineteenth century by Boltzmann, Gibbs, and Poincaré, is an abstract space where each variable is associated with a coordinate axis.

In the literature, the *phase space* is defined as the space spanned by coordinates ψ_n. Every *state* of a system, intended as defined by a particular set of values of these variables ψ_n, will be represented by a point within this space.

It is possible to graphically represent this n-dimensional space (where n is the number of variables ψ_n) only when $n = 2$ or 3.

Moreover, the time evolution of the dynamical system can be represented in such a multidimensional space, where this representation does not correspond to the system's geometric motion.
All possible instantaneous states of a dynamical system are represented by points in the phase space of the system.
The time behavior of the system is thus represented by the movement of a point along a trajectory in such a space.
In the phase space, the trajectories are represented, with coordinates given by the system's variables (named *phase trajectories*).
An example of a phase space in a dynamical system is that of a pendulum. In this case, the phase space consists of two variables: 1) the angular variable *p*, which defines the position and moves along a circle, and 2) the speed variable *v*, which varies along a straight line. In this case, the phase space takes the shape of a cylinder [11], as shown in Fig. 1 and 2.

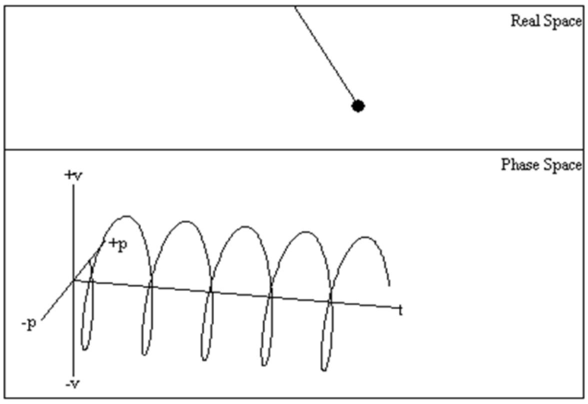

Fig. 1. Simplified motion of a pendulum in phase space.

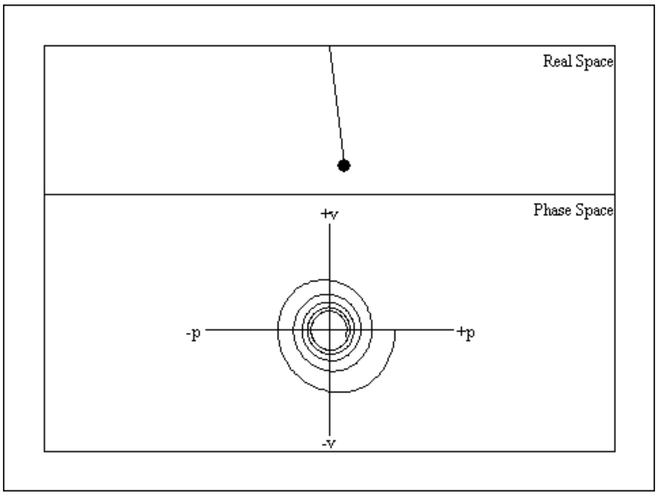

Fig. 2. Simplified motion of a pendulum in an XY "slice" of phase space.

2.3 Degrees of freedom and properties
The degree of freedom refers to the number of variables that determine the coordinates of the phase space.
All system states identify the system's phase space. The degrees of freedom of the system constitute the dimensions of the phase space.
As mentioned above, in a phase space, each degree of freedom of the system is represented as an axis in a multidimensional space.
For example, consider the number of independent ways in which a gas molecule can move as its degree of freedom. The degrees of freedom refer to the number of ways the gas molecule may, for instance, move, rotate, or vibrate in physical space, which is distinct from the abstract phase space.
As is well known, an observable in classical physics is a physical property that can be measured. At this point, we may consider that observables - measurable physical properties- are represented by variables, such as momentum and speed. As stated earlier, variables determine the coordinates of the phase space ([12], pp. 57-86).
We should ask ourselves:

1) Do the degrees of freedom correspond to measurable properties?
2) Do the measurable properties correspond to the degrees of freedom?

With regard to 1), we may confirm that the degrees of freedom are measurable properties. The number of such properties can be finite or unlimited and can be fixed over time or vary, either with regularity or not, for example, when properties are acquired through emergence processes (see Section 2.6).
With regard to 2), we may confirm, noting, however, that not all measurable properties must necessarily be considered as degrees of freedom establishing the phase space.
At this point, we can make several considerations:

a) Even considering the same physical phenomenon, equipped with significant structural variability, such as collective behaviors, it is possible to deal with sequences of phase spaces having variable, different dimensions;
b) Properties of such sequences, such as regularities, recurrences, and local or global randomness, may characterize the phenomenon under study;
c) The previous point relates to the fact that complex systems, such as collective behaviors, require multiple non-equivalent modeling.

The issues considered above are of interest here because the multiplicity of the degrees of freedom is not considered to be due to subjective decisions *by the observer, but to processes of acquisition of properties -considered as degrees of freedom- in complex systems through emergence processes*.

2.4 System closure and openness

Closed systems are conceived as isolated from their environment, ultimately reaching an equilibrium state, i.e., a final state unequivocally determined by initial conditions. The elements of closed systems tend to seek their most probable distribution.

We emphasize that, in standard macroscopic thermodynamics, a system is considered closed if it can emit and absorb energy and information, but not matter. In this case, and in contrast with open systems, such closed systems may reach the same final state in different ways, even if starting from different initial states. More generally, systems are considered closed to matter, energy flows, information (independent systems), or organization.

In open systems, there are stationary equilibrium states, where the system composition is maintained constant despite continuous component exchange with the environment. Unlike closed systems, open systems resist perturbations.

We emphasize that the classification of a system as open and closed should be based on specific attributes of that system itself. Moreover, a system can simultaneously be open and closed by referring to different aspects.

2.4.1 Logical closure

The concept of *logical closure* refers to the properties of evolutionary models of deterministic systems, characterized by:

1) Complete availability of formal analytical representations of the system's state variables and their intra-relationships;
2) Complete availability of formal analytical representations of interactions with the environment;
3) The knowledge of the two points above allows us to *deduce* all possible states the system can assume.

Furthermore, the degrees of freedom are assumed to occur in a finite and limited number, and to remain invariable over time, which is characteristic of the phenomenon under study.

2.4.2 Logical openness

The concept of *logical openness* [13, 14] refers to the properties of evolutionary models of non-deterministic systems, characterized by the violation of one or both of the two points 1) and 2) above.

Furthermore, the degrees of freedom are assumed to occur in a non-finite and non-limited number and to be variable over time, with properties of variability characterizing the phenomenon under study. This situation requires the use of multiple, variable, equivalent, and non-equivalent models.

Furthermore, the unlimitedness and variability of the degrees of freedom are a necessary condition for the establishment of emergence processes, which would otherwise possess fixed degrees of freedom, properties, and *structures, replaced in complex systems by coherence*.

2.4.3 Logical and physical closure-openness

We emphasize that closed systems, i.e., systems that do not exchange matter with the environment, can still be logically open if they exhibit non-deterministic behavior. For example, gas or fluid in a sealed container may acquire properties depending on temperature or agitation dynamics.

We also emphasize that open systems, i.e., systems that exchange matter-energy with the environment, can be logically closed if they operate in a deterministic manner, such as thermo-hydraulic heating systems regulated by a few invariable rules. *We mention that the openness of a system contemplates and admits its possible closure, while otherwise, the system is to be considered borderless rather than open.*

2.5 Theoretical incompleteness

The concept of *theoretical incompleteness* [15-18] refers to its non-completability *in principle* (for instance, in geometry, an axiom introduced by David Hilbert (1862–1943) states that there always exists at least a point between two points), and it is related to logical openness (see Table 1) because:

1) A single model is assumed to be insufficient to represent the phenomenon;
2) The degrees of freedom, the system variables, are continuously acquired and vary in number because the complex system continuously acquires equivalent and non-equivalent properties.

Examples include the properties and structural dynamics of complex systems such as collective systems, e.g., flocks, swarms, and ecosystems; chaotic systems that are highly sensitive to initial conditions, e.g., smoke diffusion and weather, where the morphologies and properties of attractors in the phase space and their basins characterize the system; and complex networks that acquire properties such as small-world characteristics, clustering, degree distribution, node multiplicity and variability, intra-connectivity, power laws, scale invariance, and self-similarity, e.g., social systems.

Dealing with complexity and phenomena such as emergence, self-organization, and acquisition of coherence, zipped, complete, explicit, and formal models are conceptually unsuitable due to logical openness and theoretical incompleteness, given the varieties of interactions and structures involved. Ideal models, such as deterministic chaos equations, equations of mechanics, equations of thermodynamics, field equations, e.g., Maxwell's electromagnetic field, and network models, e.g., ideal scale-free networks, are unsuitable. Conversely, non-ideal models, such as agent-based models, artificial life, and models using cellular automata and neural networks, are more appropriate.

Logical Closed Systems	**Logical Open Systems**
Fixed rules, variable parameters	Multiple, adaptive, changing rules
Deterministic	Nondeterministic, with levels of coherence
Low numbers of degrees of freedom	High numbers of degrees of freedom
Non-learning	Learning
Contradictions and inconsistencies avoiders	Ability to *use* contradictions, tolerate and restore local, temporary inconsistencies and losses of coherence
Decisive role of initial conditions, e.g., high dependence on initial conditions in deterministic chaos	Non-decisive role of initial conditions
Structurally complete, invariable	Capable of self-organization, evolution, and emergence

Table 1. - Logical closed systems and logical open systems.

The conditions of logical openness and theoretical incompleteness can be considered necessary, although not sufficient, conditions for the establishment of self-organization and emergence.

2.6 Acquiring properties

The multifaceted concept of "property" is not as trivial as it might seem. Generically, a property is understood as a characteristic of entities or phenomena. Their measurability is required to ensure their independence from the observer who, however, introduces it by considering it. However, the action of measuring may influence, at different levels, the entities and phenomena to be measured, e.g., the celebrated Heisenberg uncertainty principle. It is essential to consider properties as stable or variable over time. When dealing with complex systems, multiple modeling approaches are required to account for their structural dynamics, as seen in collective behaviors and ecosystems.

In simple terms, a very basic notion of property may be understood as the description of *observable* aspects and characteristics that any physical entity has or may have. Properties can apply to both matter, entity of non easy description (see Section 2.7), as well as to energy and information - distinguished in classical physics. Very well-known trivial examples of property include color, density, dielectric constant, elasticity, electrical conductivity, inductance, permeability, symmetry, solubility, temperature, thermal conductivity, volume, and weight.

We must also notice that the concept of property is used as the description of *observable*, *measurable* aspects and characteristics that entities have or may have. *Observable properties are usually represented by variables, which define the dimensions of the phase space and the degrees of freedom.*

We might ask: is it possible to conceptually consider propertyless entities and phenomena, i.e., entities that have no properties or qualities associated?

This question applies to dimensionless quantities defined as ratios that do not have associated units of measurement, expressed independently of the specific units used. This also applies when properties are either inapplicable (even if already known) or undetectable, with their non-identification being treated as their absence. However, the condition of being propertyless in absolute terms can be approximated or made less extreme by considering 'hidden' or 'dark systems.' These are *constructively* imagined to explain or model phenomena that are identified through sophisticated dynamic changes over large temporal and spatial scales, such as those seen in anthropology, evolution, astrophysics, effects of the shadow economy, and hidden natural systems such as Bénard convective rolls in atmospheric phenomena. Additionally, the "darkness" of complex systems can refer to their inherent complexity, lack of transparency, and limited accessibility of information.

However, within constructivism [19]*, we conduct invented experiments, framed as questions to nature, which nature answers by making them happen. There are no answers without questions. Moreover, events can become answers when retroactively regarded as responses to appropriately formulated questions*.

Furthermore, we note that the cognitive strategy considered by constructivism [19] distinguishes between trying to understand how something *really* is and how it is more effective to think that something *is* -i.e., how to model. The first case (real, objective *reality*) is a particular case of the latter.

Now, we will focus on observable properties, particularly on the modalities of transformation and acquisition, rather than on their simple objectivistic or non-objectivistic possession.

In physics, an acquired property is one considered not previously possessed. There are countless processes, such as transformation, combination, variation of properties, and the acquisition (generation) of new properties.

Elementary examples of acquired, rather than possessed or manifested, properties are given by dynamic properties that occur over time and are related to processes. These include dilution, effervescence, evaporation, freezing, mixing of liquids, oxidation, solidification, and countless other chemical and physical effects.

The acquisition of properties also occurs through the constitution and usage of devices, allowing *functioning* structures and systems to acquire properties not reducible to those of their components.

We will now focus on very general processes and phenomena leading to the acquisition of new general properties, such as:

- Phase transitions
- Self-organization
- Emergence
- Evolution
- Systems (entities having the property of acquiring properties).

2.6.1 Phase transitions

In physics, a phase is a set of states that share uniform physical properties, such as liquids, solids, and gases. A phase transition is a change in the arrangement or structure of components, e.g., atoms and molecules that results in the transformation of a system from one phase to another.

For instance, first-order phase transitions occur between the liquid, solid, and gaseous phases of substances, where coexistence between phases is possible. In contrast, second-order phase transitions -such as between magnetic and non-magnetic phases- do not allow phase coexistence.

The concept of *metastability* is also relevant here. It refers to the potential for a system to maintain or switch between phases in response to small fluctuations. For example, a jug of water at a low temperature, very close to zero degrees Celsius, may freeze immediately when in contact with an ice cube.

In general systems research, phase transitions are considered to occur not only in physical systems but also in other types of systems, such as:

- Learning systems, e.g., the transition from an inability to grasp an object to the ability to do so during a child's developmental stages;
- Economic systems, e.g., the 1987 stock market crash, where global markets dropped by tens of percent in just a few days;
- Social systems, e.g., the collapse of the Berlin Wall.

2.6.2 Self-organization

In physics, a process of self-organization can be defined as the recurrent acquisition of coherent sequences of variations in the *same* property (or its variations), even if extreme but restorable, where the persistence of the same property is predominant. Examples of self-organization include:

- The formation of whirlpools in liquids;
- The periodic color oscillations in chemical reactions like the Belousov–Zhabotinsky reaction [20, 21];
- The development of convective patterns in liquids heated from below, such as Rayleigh–-Bénard convection [22];
- The repetitiveness of swarm behavior, such as mosquitos flying around lights or pelicans flying around garbage piles, possibly in search of food.

Aspects of self-organization also relate to global ordering phenomena such as correlations, covariance, synchronization, and polarization [23].

2.6.3 Emergence

In systems science, processes of emergence have significant similarities to those of self-organization but also fundamental differences.

Similar to self-organization, emergence [24-28] can be defined as the (regular or quasi-regular, allowing tolerance for local and temporary deviations) recurrent acquisition of coherent sequences of variations of structurally *different*, yet admissible, compatible, and equivalent properties.

Unlike self-organization, emergence involves the predominant persistence of dynamic coherence between the different properties and their variations. Examples include flocks, swarms, and ecosystems.

Emergent processes are the main generators of complex systems and complexity in general.

Emergent *complex systems* are theoretically incomplete (see Section 2.5) because:

- They require multiple variable models, not just a single model, for their representation.

- The system variables and their degrees of freedom are variable in type and number and are continuously acquired.
- The acquired properties are predominantly non-equivalent (the level of non-equivalence is expressed, for instance, by percentages) but remain coherent. *Coherence is achieved through synchronized multiple synchronizations, remote synchronizations* [29], *local couplings, covariances, correlations*, *long-range correlations, and cross-correlations* (a statistical measure of the similarity between two time series, evaluating how one series correlates with another as a function of time displacement) [30]. See Section 2.8.
- The emergent properties acquired by a complex system consist of its multiple behaviors, variable coherences, resilience, consistency, and its ability to tolerate and restore local, temporary inconsistencies and losses of coherence.

Given their nature, complex systems cannot be fully *regulated* or *decided*. Instead, they can only be interactively oriented or influenced by acting on environmental conditions, available energy, using noise, and varying initial conditions.

It is important to note that the assumption that *emergence is equivalent to a phase transition, which is equivalent to bifurcation* (in simple cases, dealing with a single parameter, a bifurcation occurs when the value of a parameter crosses a critical value, separating two different non-linearly reducible structures), is incorrect, as noted in [31].

2.6.4 Evolution

Evolution is a process of acquiring properties, mainly by living beings, but it is also considered for non-living matter (see Section 4).

Evolution is understood as the change in the heritable characteristics of biological populations over successive generations, occurring through evolutionary processes such as natural selection. However, the notion of discontinuities in evolution refers to possible occurrences of discontinuities, such as mutations (permanent alterations in the DNA sequence of a gene) and genetic drifts (random changes in allele frequencies).

The theme of *discontinuity*, however, has different aspects. For example, in mathematics, when the right and left limits of a function are different, or when a system shifts from a linear to a non-linear regime. Additionally, discontinuities can occur when there is a shift from homogeneity to non-homogeneity, compatibility to non-compatibility, admissibility to non-admissibility, reversibility to irreversibility [34], reducibility-irreducibility, and commensurability-incommensurability.

The two aspects of continuity and discontinuity have an intermediate zone in which the nature of the transition between the two extremes is evaluated, whether sudden or gradual. In this regard, we consider the difference between the microscopic and the macroscopic, with the mesoscopic level representing *areas of continuous negotiation between the micro and macro levels*.

At this level, the micro is not completely neglected [35, 36], as in the so-called *philosophy of the 'middle way'* [37].

Evolution manifests these facets in variable ways.

Evolutionary directions are assumed to be chosen through trial and error (see Section 4, where we differentiate between emergence and evolution). *The iteration of the process is assumed to be exhaustive, leading to irreversibly taking paths considered to be optimized, while ignoring other non-linearly remote paths*.

2.6.5 Systems

The issue of property acquisition ultimately converges to the consideration of systems. Systems are defined as *devices* or *entities* that have the property to acquire properties, which is their peculiar characteristic.

In reference to the above, systems have the property of acquiring properties, for instance, through processes of phase transition, self-organization, and emergence (see Table 2).

Self-organization	Emergence
Synchronization and remote synchronization Variable regularities and periodicities Reoccurrences of self-similarities and regular iterations	Coherent multiple variable synchronizations Coherent multiple variable regularities and periodicities Coherence is the property of collectively interacting elements to acquire and maintain properties, as well as tolerate and restore local, temporary inconsistencies and losses of coherence

Table 2. - Hints at self-organization versus emergence.

As specified above, what characterizes systems and establishes their consistency is the internal dynamics of interaction and interplay between the constituent elements. Possible properties of this interaction, such as coherence and synchronization, *replace the structures* between non-interacting elements of non-systems, at least considered as such at the appropriate level of description. This makes the distinction not so clear. For example, the microscopic components of a piece of metal are considered stable in structure but may interact at a melting temperature. Similarly, the molecules of water are stable in the structure of ice but may interact at a boiling temperature. However, the search for examples of non-systems highlights the great predominance of systems compared to non-systems [38], even though, as mentioned, the levels of description vary.

Examples of properties acquired by systems are innumerable and become evident when systems degenerate into the set of their components deprived of the ability to interact. For example, when deprived of power supply in electronic devices (such as smartphones and computers) and electrical devices (such as household appliances and instrumentation), they lose the ability to function; when deprived of the ability to communicate in social systems and ecosystems; when deprived of the biochemical activity relating to the biotic (such as living matter degenerating into non-living); and when deprived of electromagnetic activity in matter.

Other examples of *general* systemic properties include:

- Allostasis, i.e., maintaining stability through continuous adaptive structural changes;
- Anticipation, i.e., systems containing a predictive model of themselves;
- Autopoiesis, i.e., the ability to regenerate recursively;
- Development, which differs from generic growth, rather constituting interrelated, coherent growths;
- Dissipation, i.e., maintaining coherence through a constant flux of matter from outside, such as a vortex in flowing water;
- Homeostasis, i.e., the ability to maintain characteristics despite changing environmental conditions;
- Resilience, i.e., the ability to adapt and self-repair in the face of disruptive events.

2.6.6 In geometry

Finally, as regards the acquisition of properties, assuming the existence of the *N-dimensional space* as given, we note among the countless possible cases the problem in geometry of the acquisition of dimensionality by a dimensionless geometric entity, such as points, which have no dimensions—i.e., no height, length, or width.

As is well known in geometry, David Hilbert (1862–1943) introduced an axiom of order stating that if A and C are two points, then there always exists at least a point B on the line AC such that it lies between A and C.

As a consequence, the generic straight line identifying the one-dimensional space has *no holes*, i.e., it is an infinite set of points, as introduced by Georg Cantor (1845–1918). This is unlike previous conceptions, such as the one considered by Bonaventura Cavalieri (1598–1647) in his book *Geometria indivisibilibus continuorum* (1635).

In mathematical analysis, the axiom of order gave rise, for example, to infinitesimal calculus, which considers the continuity of functions when considering infinitely small (or infinitesimal) changes.

The continuity between points is assumed to be the *generator of dimensionality*, for example, of the line that connects them and has dimension 1.

Considering the point as a primordial, basic element, the leap from dimensionless to dimensionality, i.e., the generation of entities with dimension 1, such as the line constituted by infinite sequences of dimensionless points, is achieved through the *continuity* between them, as described above.

Finally, we conclude by mentioning the non-trivial nature of assuming the existence of the *N-dimensional space* as given. We do not consider hypotheses about the conceptual possible generators of the space(s).

2.7 Matter

The classic concept of matter seems to have a philosophical nature and serves as a generic conceptual platform on which everything is assumed to be grounded. This contrasts with the concept of the vacuum, which is considered to have no properties at all.

The non-classic concept of matter, introduced by quantum field theory (QFT), considers the quantum vacuum as preceding matter, space, and time [39].

Conversely, the quantum vacuum is considered to confer properties on matter, rather than merely being the absence of matter.

Furthermore, in physics, particularly in statistical field theory, the approach of considering material entities (e.g., particles) as excited states of their underlying quantum fields has been used for a long time. The concept of a particle refers to spatial regions where a field has particularly high intensity [40-43].

We consider abiotic (non-living) and biotic (originating from living organisms) matter.

We distinguish between properties possessed and acquired by matter.

2.8 Coherence

Coherence relates to the recurrent acquisition of coherent sequences of variations of the *same* property, while allowing for temporary local changes, which enables the continuous restoration of the property. For example, flocks continuously change while they remain cohesive. A flock disintegrates when its coherence globally disappears and is not resumed for a significant amount of time.

Synchronization can be understood as the simplest form of coherence, where the way of changing is identically iterated.

Covariance refers to the extent to which two random variables X and Y covary, i.e., change together in the same way [44].

Correlation measures the *similarity in the ways two variables change,* such as the prices of two different products.

The concept of the domain of coherence may be considered to coincide with that of correlation length, i.e., the extent of the correlation, when the length coincides with the extension of the entire population under consideration. Diffused, long-range correlation is considered coherence. In this case, coherence can be seen as global dynamical ordering.

In complex systems, there is continuous acquisition of coherence(s), for instance, in ecosystems and living systems.

PART 2

3 The question of intelligence

The concept of intelligence has been explored in various disciplinary contexts, such as neuroscience and psychology [45, 46], with extensions to artificial intelligence (AI) based on computationally acquired capabilities. These capabilities are derived from various forms of neural networks, which are viewed as physical systems with emergent collective computational abilities, enabling them to classify and learn [47].

The use of the term "intelligence," in the field of AI, has led to its further specifications. One example is the transition from the so-called GOFAI to modern AI. The acronym GOFAI (good old-fashioned artificial intelligence) refers to the earliest approach to AI, based only on providing computers with capabilities for calculation, logical reasoning, and problem-solving, e.g., in 1997, IBM’s Deep Blue was able to defeat Garry Kasparov, the reigning world chess champion. GOFAI was the dominant paradigm of AI until the late 1980s. This approach was based on the assumption that intelligence was almost entirely synonymous with high-level symbol manipulation and problem-solving abilities. Therefore, the main goal of GOFAI was to provide machines with this type of intelligence, intended to be general and human-like.

We emphasize how this understanding was compatible with sophisticated versions of *behaviorism*, which understood *behavior as computable* and constituted by mechanisms and sequences of stimulus-reaction processes [48].

A completely different case is that of cognitive intelligence, which is based on cognitive psychology [49].

In cognitive science [50, 51], the *cognitive approach* consists of considering the internal processes of living beings, equipped with brains having sufficient levels of sophistication, as fundamental mediators between stimuli and responses. According to the cognitive approach, these internal processes consist of information-processing activities within cognitive systems.

The processes of cognitive systems involve a wide variety of aspects. In short, a cognitive system [52] should be understood as a system of interactions between activities such as attention, perception, experience, representations, language, the affective and emotional sphere, memory, the inferential system, and logical activity [53].

Cognitive intelligence -whether inductive, deductive, or abductive- involves activities such as abstraction, learning, designing and testing new approaches, and inventing theories, musical instruments, music, stories, games, paintings, languages, and functional devices, e.g., tools. It is about *using* rather than just *avoiding* errors (usable as sources of information, that is, properties of error combinations and sequences compared with the correct solution, informing on how the mistakes are made); it is about inventing and detecting scenarios and rules of ongoing games. It is no longer just about knowing how to play a game optimally and without errors but about knowing how to create variations, invent games, and recognize games in progress. It is about inventing approaches to explain and act and inventing purposes. It is about *abductively* knowing how to invent approaches to explain and act, inventing purposes, and finally studying itself.

At this point, we can also proceed by considering *orders* of intelligence, combinations of the two intelligences considered above: logical-computational and cognitivist.

We can note that logical-computational, ‘behaviorist’ intelligence can be considered *passive*, characterized by the *possession* of computational properties, problem-solving abilities, and symbol elaboration, as well as their extension, combination, and refinement. It does not incorporate integrated processes of structural change and would remain *invariable* if not for application modalities that can always be optimized.

The other type of intelligence considered above, the 'cognitivist' type, can be considered *active* and generative, understood as *acquisitive* and *generative* of properties such as *understanding*, realized as making usable models of becoming, making inventions, interpretations, and having multiple aspects such as relating to language, attention, perception, experience, representations, the affective and emotional sphere, the inferential system, logical activity, and to itself. Other examples of such properties are the ability to learn, represent, create variations, perform linguistic translations, ideate and use disciplinary representations, invent theories, perform abductive logic (invention of hypotheses), create musical instruments, develop devices with levels of autonomy (beyond mere automation) such as in robotics and AI, study memory and intelligence, and apply treatments to restore them in the case of pathologies. In this type of intelligence, it is possible to identify and experimentally detect presumed levels of intelligence through tests and experiments. However, their reductionist nature may overlook compensations, equivalences, or initial conditions that could lead to the emergence of specific dynamics, as seen in animal and plant intelligence.

As we will see, we must consider the intelligence that recognizes something else as intelligent. Are we considering an intelligence that regards only itself as intelligent? What can or cannot be considered intelligent?

It is important to note that intelligence [54] can only be elaborated in a self-referential way: we use intelligence to discuss it and to identify it. Regarding this self-referentiality, we can consider the case of meta-language and meta-intelligence. In short, we can say that a meta-language is a language that describes another language (the ‘object language’), as in [55].

Meta-intelligence can be extrapolated as intelligence applied to another intelligence, up to itself. In the literature, meta-intelligence is considered as the ability to coherently use multiple cognitive functions simultaneously, such as analytical intelligence, creative intelligence, practical intelligence, and wisdom-based intelligence [56, 57].

Returning to intelligence, however, we may see ‘defining’ approaches to intelligence introduced, albeit, as mentioned above, inevitably self-referential.

First, we must recognize that the notion of ‘definition’ actually applies to abstract, conceptual contexts, such as mathematics. A definition implies completeness and exhaustiveness, which are fully applicable in conceptual domains but may function in a more general, identifying way in other contexts—such as in classifications and categories (e.g., ecosystems, phenomena, and biological processes, which can occur in a great variety of ways). It is necessary to consider the context in which a definition is used to evaluate its level of exhaustiveness and applicability. This involves varying levels of precision and applicability in definitions, depending on their intended use.

The purpose is to support the idea that human intelligence is compatible with and an extension of the “intelligence of matter, having emerged through evolution and emergence,” as considered, for instance, in [58]. *This can explain why the world is (self-)comprehensible at the level relevant to evolution, while in other cases—where the strategy of understanding does not apply—it remains incomprehensible, particularly when no evolutionary basis exists, such as in existential aspects of life and death*, see, for instance, [59, 60].

3.1 Acquisitions of properties as orders of intelligence

We introduce the possibility of understanding the property of acquiring and practicing properties rather than just possessing properties as an expression of what can be considered *generic intelligence*. We will consider intelligence to lie in the ability to acquire properties in linear, non-linear, or irreducible relationships with the previous ones. The acquired properties are understood as extensions of the degrees of freedom available, *consisting of extensions of the dimensionality of the available phase space*.

In this regard, this way of considering intelligence is challenging for AI, because it can be measured by the level of extension of the dimensionality of the phase space allowed by the use of AI, i.e., the number of new properties acquired [61, 62]. Furthermore, we should differentiate between artificial intelligence, considered as the ability to practice available degrees of freedom autonomously and artificial intelligence, which is able to introduce new degrees of freedom.

3.1.1 Acquirable properties

We can distinguish between three types of properties, specifying the three orders of intelligence considered in the following:

a) Closed properties, having mostly *linear* combinability. They may be identically repeatable, except for parametric variations. However, they may also *combine* linearly to form subsequent properties that remain reducible to the constituent ones. Such properties are also dependent on the context, e.g., surface tension and capillarity; fractality and self-similarity in snow and coastlines (see Section 3.3.1, entry A). These properties can overlap, occurring at different and variable times. Other examples include algorithms and deduction. However, this reflects logical closedness; there is no increase in degrees of freedom, only their sum (see logical closedness, Section 2.3.1).

b) Closed properties, having *non-linear* combinability. They may non-linearly *combine* in subsequent properties irreducible to the constituent ones. They generate specific versions as irreducible correspondent properties.
The non-linearity particularly applies to the *acquisition* of non-equivalent properties (see Section 3.3.1, entry B). The generative aspect in non-living matter takes on the nature of *non-linear consequentiality* of material transformative, implicative acts. However, a distinction must be made between transformative actions having compatible consequences, in linear relation with the initial conditions, or not. The linearity applies to sequences of possessed properties, only showing parametric variations. Non-linearity with the initial conditions would correspond to the genetic drifts of evolutionary processes that must, however, be generators of new subsequent generative and not definitive, lasting properties. Equally characterizing is the possible *reversibility* or otherwise of the transformative actions, evolutionary in the second case. It involves the occurrence, for instance, of *bifurcations*, i.e., changes in the number or type of attractors [63], and when, in the simplest cases, a bifurcation occurs when the value of a parameter -the critical parameter- crosses a critical value; *symmetry breaking* when a symmetry transformation leaves the form of the evolution equations invariant but changes the form of their solutions, e.g., paramagnetism [64]. It involves the establishment of collective motions such as the collective motion of nano-swimmers (synthetic nanoscale objects converting available undirected energy into directed motion, e.g., magnetic and bimetallic); laser-induced collective motion of particles or atoms influenced by laser light; nematic fluids, a type of liquid crystal manifesting nematic behavior such as liquid crystals acquiring a unique orientation and used in display technologies; and rods on vibrating surfaces, shaken metallic rods acquiring single directionality, and simple robots [65]. The process of combination may have a transformative nature, such as due to processes such as phase transitions and self-organization, e.g., acquisition of coherence as for the Belousov–Zhabotinsky reaction, the Rayleigh–Bénard convective rolls; and self-organization as coherent variations of the same property (whirlpools). Another related case is given by the property of *self-assemblage* [66] when components, e.g., molecules, form ordered structures spontaneously, as for *protein folding* (see Section 4.1).
The same kind of properties apply to living matter, e.g., the establishment of anthills, beehives, and coral structures; the collective intelligence of flocks, e.g., the defense from predators by the collective behaviors of flocks of birds or attacks by swarms of insects; the acquisition of coherent properties in ecosystems; and the formation of stalactites; and termite mounts. Other examples include computational emergence—e.g., the acquisition of the property to learn by artificial neural networks (ANN), the evolutionary patterns of cellular automata, and induction. However, this involves low levels of logical openness, with a very limited increase in the degrees of freedom not reducible to the sum of the previous ones, but not establishing generative new properties (see logical closedness, Section 2.3.1).

c) Open, generative properties, self-generative of new, subsequent generative properties, non-equivalent variations, i.e., non-reducible, incommensurable with each other, from the original.
It involves self-replicative properties, i.e., properties acquiring new properties. This phenomenon is typical of processes such as the intrinsic ability to evolve in biotic matter, i.e., evolution itself, and cognitive intelligence (see Sections 3.2 and 4).
Abiotic cases include systems of interacting self-organized systems such as interacting Bénard rolls in fluid dynamics, e.g., in turbulences and in atmospheric phenomena [67, 68], and the Internet. As we will see in Section 4, this also applies to evolving abiotic matter, to artificial evolution. In this regard, we may consider the case of abiogenic systems capable of continuous and nonlinear evolution [69-71], dissipative systems far from equilibrium leading to the formation of more complex compounds, e.g., viruses, minerals [72].

On the other hand, we may consider the evolution of biogenic systems acquiring new properties through the intelligence of living matter (see Section 3.3.2). A case is the acquisition of cognitive intelligence, understood as the ability to acquire and invent new emergent properties considered intelligent as generators of new generative properties, e.g., acquisition of the ability to solve problems, the ability to invent and give properties to materiality (engineering solutions and materials science), the ability to invent and apply strategies, the ability to recognize ongoing games, invent games and variations, and perform abduction (invention of hypotheses). *Properties of type c) are, in turn, often property generators*.

However, it involves high levels of logical openness, with a significant increase in degrees of freedom irreducible to the previous ones, and the establishment of generative new properties (see logical openness, Section 2.3.2).

However, properties are considered related, combined with environmental properties such as energy, brightness, wetness, dryness, and gravity. *Artificial incoherences between properties and environmental properties are supposed to establish different evolutionary processes, such as for polluted environments and environments without gravity or with different gravities in space*, e.g., plant life, see, for instance, [73, 74].

We should consider dependence on initial conditions also, as in the Bak-Sneppen model of biological evolution [75-78].

3.1.2 Orders of intelligence

In reference to the three kinds of properties considered above, we introduce three orders of intelligence.

A first-order intelligence can be considered as the *manifestation* and *practice* of *possessed, intrinsic, and combinable properties* of type a) by matter.

A second-order intelligence can be considered as the non-linear combination and *acquisition of available, recurrent properties* of type b) by matter. However, as introduced above, the same level applies to living organisms and beings. This intelligence is also observed in collective phenomena, which acquire intelligent properties (collective intelligence), such as flocks exhibiting defensive attitudes in front of a predator, or synchronized light-reflecting herring, giving predators the impression of facing a large entity when it is actually a collective one making camouflage [79] and causing confusion in predators [80].

This is about collective intelligence [81, 82]. The acquisition of intelligent behaviors in this context is considered an emergent phenomenon [83].

With reference to the second- and third-orders of intelligence, we should distinguish between the acquisition of new closed properties and the ability to implement and perform newly acquired properties within a regime of logical openness -i.e., without predefined formalizability, completeness, or limitability. The acquiring and practicing of properties of types a) and b) can be understood as forms of *intelligence of matter*.

A third-order intelligence can be considered the acquisition of the property, type c), to generate, create, and use previously unavailable properties - such as those exhibited by cognitivist intelligence, which are typically associated with classical features of intelligence. We emphasize the uniqueness and singularity of this intelligence, which is not possessed by the intelligences of the first- and second-orders. This uniqueness and singularity are linked to the same characteristics of personality and identity (see Table 3).

In Table 3, the intelligence of matter is considered a fundamental property of matter in its specific forms -abiotic and biotic- generating properties of types a) and b), which manifest as first- and second-order intelligences. These two first orders of intelligence then support the acquisition, emergence, and evolution of properties of type c), manifesting as third-order intelligence in both living and non-living matter. The third-order intelligence is compatible, although probably not exhaustive, and does not coincide entirely with human-level intelligences, which emerge from cerebral and biological activity, including the perception, experience, and affective and emotional spheres. *Human intelligence is not standardized nor standardizable, but occurs in different versions, both phenomenologically and theoretically personalized*.

We can consider the following conceptual correspondences:
- First order of intelligence related to *logical closure*: predefined degrees of freedom.
- Second order of intelligence related to *low levels of logical openness*: acquiring finite and limited numbers of degrees of freedom.
- Third order of intelligence, evolution and the cognitive intelligence related to *high level of logical openness*: acquiring non-finite and unlimited numbers of degrees of freedom. Evolutionary abilities apply also to non-living matter, intended as generative, having consequences in non-linear relation with the initial conditions.

First order intelligence	Intelligence of abiotic matter	possessing, manifesting	closed properties of type a
Second order intelligence	Intelligence of abiotic/biotic matter	acquiring	closed available properties of type b
Third order intelligence	Intelligence of abiotic/biotic matter ——— Intelligence of the *non-living*, as generative of consequences in non-linear relation with the initial conditions ——— Intelligence of the *living*, evolution and the cognitive intelligence	acquiring and generative of	open generative properties of type c ——— abiotic evolution, e.g., crystal grow, viruses ——— biotic evolution, cognitive intelligence, e.g., abduction, strategies

Abiotic matter		
Intelligence of matter		
First order intelligence	Second order *abiotic-biotic* intelligence	
Properties type a	Properties type b	
Sequences of consequences	Sequences of consequences	
Biotic matter		
First order intelligence	Second order *abiotic -biotic* intelligence	Third order *abiotic-biotic* intelligence

Table 3. - A brief overview of orders of intelligence.

According to what has been introduced above, we emphasize the *continuity* between the orders of intelligence, their interdependence, the necessity of lower levels for the constitution of higher ones, and the non-reducibility of one to the other. This considers the correspondence between materiality and forms of intelligence, extending up to cognitive intelligence (see Sections 4.2.1 and 4.2.2), as shown in Table 4.

Third-order intelligence	
Cognitive intelligence, *acquiring* properties of type c)	
Second-order intelligence	
Intelligence of matter, *acquiring combined* properties of type b)	Intelligence of matter, *non-linearly acquiring, combining* properties of types b) and c)
First-order intelligence	
Intelligence of matter, *possessing* properties of type a)	

Table 4. - A brief representation of superimposed orders of intelligence.

3.2 The potential and abductive nature of cognitive intelligence and pathologies.

We consider three aspects of cognitive intelligence: its potential and abductive nature, and its inevitable "pathologies".

3.2.1 Potential nature

Cognitive intelligence involves both acquiring and implementing specific types of properties. For example, it includes the ability to devise innovative ways to solve problems without relying on certain resources, to formulate problems that are currently unsolvable, and to go beyond mere problem resolution -that is, to apply these properties in novel contexts.

Cognitive intelligence would thus have a potential nature -acquisition of potential, actualizable, and applicable properties, rather than being solely implementational or in action. It is about knowing how to do, create options more than doing specific activities.

We can thus distinguish between cognitive intelligence and cognitively practiced intelligence. The first consists of acquiring properties that were not previously available (having an emergent nature), while the second consists of the application of the previously acquired properties, assuming that the distinction is adequate.

In AI, this conceptually corresponds to considering the structure and levels of artificial neural networks (ANNs) capable of processing input by acquiring specific properties, e.g., classifying -the 'intelligence of an ANN', rather than their applications, such as pattern recognition allowing the distinction of a dog from a cat.

As discussed previously, we emphasize how the ability, or property, of acquiring properties can be considered the 'order' of intelligence of systems - intelligence from processes of emergence through matter, acquiring and not only possessing properties, extending to living matter, of which life itself is a continuous sequence of acquisition of properties.

3.2.2 Abduction

We specify that in second-order intelligence, the process involves acquiring properties that are already available rather than inventing properties that were previously absent. Moreover, the phenomenon of acquiring properties is repeatable, except for parametric variations.

The phenomenon of acquiring *new* properties not previously available characterizes third-order intelligence. This is the case of abduction [84, 85].

Results of the abductive phenomenon of property invention, such as theory building [86], typical of human cognitive intelligence, can occasionally recur in different places and times, can be transmitted through learning, and can recur in ways that are recognized as equivalent or not. As mentioned earlier, it is worth studying whether forms of such intelligence can also be identified in acquisitions of properties of a type different from human intelligence (see Sections 5 and 6).

We also emphasize the importance of considering intelligence not only abstractly but as a property materially linked to what manifests this property, whether it is biotic or not.

At this point, it is interesting to mention the possibility of theory-less knowledge (independent of abduction), when theory is considered replaced by suitable concordance, correlation, and correspondence -for instance, within Big Data, using data-driven approaches within very large databases [87-89].

However, the assumption that correlation supersedes causation and theorization has been determined to be an improper and untenable generalization [16].

3.2.3 Pathologies

Particularly in the case of biotic intelligence, the property of intelligence is inextricably linked to possible and inevitable 'pathologies' of different natures, such as psychological ones. For example, one might decide to pursue and insist on inadequate approaches, ignore certain research topics, or approach problems in an abstract or overly theoretical way, as if working in a controlled laboratory setting. Examples of other 'pathologies' include a preference for certain topics over others, a tendency to consider a variety of topics rather than focusing on one, intolerance toward precision, a focus on applicability, an emphasis on teaching, a preference for expressing oneself succinctly or using redundancy, and a tendency to favor either precise and concise expressions or imprecise and verbose ones. Furthermore, the influence of dreams and the unconscious cannot be ignored.

Such 'pathologies,' however, are not to be considered problems to be avoided or bypassed, *but rather aspects integrated into the process of effective application of intelligence*, which cannot be conceptually completely 'artificial' unless one also knows how to simulate such pathologies. Human intelligence, for example, without the unconscious mind, would be impaired by creative and limiting aspects [90] and separated from the ability to dream. For example, considering only rational, currently possible options, ignoring influences, associations and forced analogies with recollections of past and forgotten cases.

In this regard, we note the corresponding creative effect of noise in complex systems [91].

Cognitive intelligence will not be reducible to abstract intelligence because it is contextually living and *applied intelligence*, which not only has 'pathologies' but also effective processes such as compensation, irregular application, and

adaptation due to interaction with other people or other aspects such as affective and learning ones.
All this can be considered as a result of the fact that intelligence is not a precisely identifiable, definable function, separating intelligence from non-intelligence. It is to be understood as emergent, admitting sequences and coexistence of phenomena considered both intelligent and non-intelligent, much like the coexistence of phases in the phase transitions of the first order, such as water in the liquid state, steam, and ice.
This is in conceptual correspondence with the notion of 'quasi-systems,' where a system is not always a system, not always the same system, and not only a system [18]. We continuously deal with quasi-intelligences.
All of this relates to the idea that intelligence may be understood as the ability to acquire new emergent properties, which are considered intelligent in turn.
However, cognitive intelligence can be considered inherently emergent [92], because it arises from the interaction of various cognitive systems and the computational emergence of biological neural networks in the brain [93-95]. *Intelligence should not be understood as a property given by functioning, but rather as a phenomenon of emergence*.

3.3 Intelligences of matter

Starting from the fact that we can only consider intelligence self-referentially, beginning with and using our own, it is possible to identify and recognize specific forms of intelligence and orders of intelligence that are *assumed to be inferior or partial. However, our intelligence is sufficient to recognize that it is self-referential and inadequate for identifying or understanding a different kind of intelligence*. This reflects the difficulty of recognizing non-metabolic life forms different from our own -and even more so, recognizing their intelligences.
The underlying hypothesis considered here is that there is *continuity* between specific forms and orders of intelligence, a hypothesis supported by the fact that there are no incompatibilities or inhomogeneities between them. Is this an experiential fact or linked to the inevitable self-referentiality of the intelligence we are using? Can we identify alternative intelligences that are incompatible with each other?
We must abandon the presumptuous attitude that leads us to consider ourselves unique, with completely autonomous, *independent* intelligence, solely *compatible* with the world and sufficient to influence it to the point of 'deciding' its course.
Let us consider the provisional hypothesis that we can distinguish between the intelligence of abiotic and biotic matter and then examine the relationship of continuity between them (see Table 4).
In this regard, we may detect aspects of continuity between them in the fact that the modeling of biological emergence does not require new tools, irreducible to those used in modeling physical emergence [32, 96]. This implies that all theoretical approaches and results used to model physical emergence are also useful for studying biological emergence.
However, we must consider that the theoretical apparatus used to study physical emergence is inadequate for most problems that still await solutions. Examples include how to build:

- A theory of multi-level emergence [18, pp. 275-278];
- A theory of systems having variable kinds in addition to numbers of components [4];
- How to build a comprehensive theory of defect formation in phase transitions.

Further advancements and solutions will significantly improve our understanding and modeling of emergence, in both physical and biological contexts.

3.3.1 First- and second-orders of intelligences in non-living matter

The intelligence of matter is understood here as the possessing and acquiring of properties that, however, are non-generative of subsequent non-equivalent properties.
Because of its non-generative nature, the intelligence of matter is understood without cognitive capacities, although it can be considered as pre-cognitive intelligence. We then consider the cognitive intelligence of the biotic as its extension with forms of continuity, such as the reoccurrence and reappearance of properties. The cognitive intelligence of the biotic is understood as the possessing and acquiring of properties that, in turn, are generative of subsequent non-equivalent properties.
The difference between generative and non-generative properties can be represented in mathematics by the difference between functions whose computation leads to conclusive ending results, and generative operators of other functions such as sequences of derivations of any order and transforms, e.g., Fourier, Laplace, and series expansions such as Taylor-Maclaurin series, which lead to other versions.
In cognition, the possessing and acquiring of properties relate to the generic generative aspects of multiply linked generative reasonings.

A. Possessed properties of type a as first order intelligence

As mentioned in Section 2.7, matter is understood as a condensation of emergent properties acquired from the quantum vacuum. In this view, high levels of intensity allow the acquisition of macroscopic properties, such as dimensionality, mass, volume, and weight ([18], pp. 18-19, 54; [97]).

With this understanding of matter in mind, we can identify the classic macroscopic chemical-physical properties of matter of type a) (see Section 3.1), which are *manifested* in properties such as absorption, boiling point, brittleness, capacitance, capillarity (surface tension), color, concentration, consistency, density, dielectric constant, ductility, elasticity, freezing point, hardness, light reflection, permeability resistance, symmetry, solubility, thermal and electrical conductivity, viscosity, and weight. These properties may, however, be context-dependent, such as temperature or pressure-dependent, and the validity of periodic tables of the elements, as first introduced by the Russian chemist Dmitri Mendeleev in 1869. We just mention the properties considered by QFT that are not covered in this article.

As introduced in Section 3.1, this refers to matter with *closed, possessed, mostly linearly combinable properties*.

B. Acquired properties of type b) as second-order abiotic intelligence

However, matter and its macroscopic properties have a compositional behavior that involves the *acquisition* of other properties that may not be reducible to those possessed, as mentioned above.

Furthermore, matter is able to acquire generic properties that may apply to different types of matter, for instance, through countless types and forms of composition. This may be considered as a first order of intelligence of matter, as noted in [99] and Table 1.

Elementary examples of acquired rather than possessed and manifested properties are given by dynamical properties occurring over time and related to processes. These include:

- Dilution, effervescence, evaporation, freezing, mixing of liquids, oxidation, solidification, and countless chemical and physical effects.

More sophisticated cases relate to the acquisition of dynamical properties, such as:

- Self-similarity (fractality) in snowflakes and lightning, and in tree branching, ferns, and leaves in general, allowing for the availability of large surfaces in small volumes, such as alveoli in the lungs;
- Crystals and the non-periodic or repetitive structures of quasicrystals, as can be observed in normal crystals. In quasicrystals, there are patterns where the local arrangement of the material is regular and stable but not periodic;
- Phase transitions, e.g., water-ice-vapor and the acquisition of magnetism;
- Self-organization, as in structures formed in the absence of any internal or external fluctuations, such as the Bénard convective rolls and oscillatory phenomena such as the Belousov–Zhabotinsky reaction; including cases of symmetry breaking and bifurcations as mentioned above.

As discussed in Section 3.1, this is matter with *closed acquired properties of type b), meaning that they do not generate other properties.*

We will now focus on properties of type c), which have a cognitive generative nature and can, however, be considered homogeneous, if not transformative, extended aspects of acquired properties in the non-living case, that is, of matter.

3.3.2 Second- and third-order intelligence in living matter

We consider here the intelligence of the biotic, understood as identifying: 1) living matter in general (able to metabolically self-reproduce, self-regenerate, and self-repair); 2) communities established by living beings and acquiring autonomous properties, such as collective intelligence through collective behaviors, e.g., flocks, herds, schools of fish, and swarms acquiring intelligent-like behaviors, such as defense from predators, and ecosystems (acquiring intelligent-like properties that allow for the logistic and thermodynamic optimization of built nests, as in anthills, beehives, and termite mounds).

C. Acquired properties of type b) as second-order biotic intelligence

Some properties of biotic matter have a non-generative nature and belong to type b). These properties are related to second-order intelligence and are typically observed at the species level. These properties are only identically repeatable, barring parametric variations, and do not generate other properties.

It is highly unlikely that the occurrence of situations and the acquisition of properties, such as those listed below, can be explained solely by evolutionary and selective processes based on hereditary, adaptation, and optimization (see Section 4).

As discussed in Section 4, the improbability is due to the need to admit the occurrence of selection and adaptation not only among enormous numbers of possibilities, which would require a huge period of time *without guaranteeing* the identification of the optimal case, but also considering the *limited exhaustive capacity* of the generating selective process. This process stops when it reaches local optimizations and then resumes from there. Furthermore, the time periods would presumably have significantly different lengths, generating mutual inhomogeneity and incompatibility, which would hinder the general evolutionary process, leading to the generation of options with different levels of *local but sufficient* optimizations. *There would be levels of optimization never reached since the exploration of the context is not guaranteed to be exhaustive*.

Considerable examples of acquired properties of type b) by the biotic, related to second-order intelligence, are the following.

There are a huge number of cases in which intelligent choice is unlikely to be solely evolutionary for the reasons mentioned above.

Rather, we can consider a combination of the intelligence of matter, emergence, and evolution, providing privileged evolutionary directions within complex systems [100].

These are presumably mechanisms, in addition to the others considered above (occurrence of first-order intelligence properties, emergence, self-organization), of property acquisitions. Examples of these acquisitions include forms of *transversal, indirect memory* and learning-like processes rather than optimization, such as through sequences of trials and adaptivity; *continuous exploration* of the events occurring within the environment under study based on the well-known Bayes' theorem; processes of remote synchronization and local couplings; covariances, long-range, and cross-correlations (see Sections 2.6.3 and 2.8); pre-properties and re-emergence [18, pp. 146-151]; *reverse emergence* when emergent phenomena have effects on what they emerge from; and indirect information transfer mediated by the direct interaction between entities, as in collective behaviors (see the following quotation).In the case of indirect information transfer correlation is the expression of indirect information transfer mediated by direct interactions between individuals: two boids outside their range of direct interaction (whether acoustic, hydrodynamic, visual, or any other) may still be correlated if information is transferred from one to another through intermediate interacting bids. [101].

In the process of indirect information transfer, information is mediated through transfer processes and then disseminated and combined at various levels.

Furthermore, the configuration of elements after the loss of a property is not equivalent to a configuration that has never had such a property. Rather, it has time-dependent (decreasing with time) levels of compatibility and versatility toward the recurrence of such a property or, more likely, approximate variable versions of it. It involves reusing "coherence residues," as seen in disturbed flocks that subsequently re-stabilize by acquiring new long-range correlations (fuzzy coherence). The possible slight variable predominance of coherence residues may also play the role of initial conditions for new processes of transience or converge toward a new validity regime, as in *order parameters* introduced by Synergetics [102] and metastability.

Among countless examples where adequate research could identify specific constitutive mechanisms of the type cited above and considered in Section 4, we provide the following, in no particular order:

- Old bees leaving the hive to die to avoid disturbing the activity of the hive;
- Prey killed by being dropped from above by predator birds, such as the hooked beak of an eagle;
- Snakes 'aware' of the poison to be injected;
- Hunting strategies and spider webs;
- Butterflies with wings shaped like a snake, moth, or cobra;
- Anacondas (Eunectes Wagler) and pythons crushing their prey;
- Plants with thorns to avoid being eaten;
- Flowers and plants shaped like animals, such as birds;
- Pollination;
- Making camouflage;
- Confuse predators;
- Leaves shaped like animals;
- Shoals of herring that appear as a large being;
- 'Awareness' of offensive capabilities (e.g., poison and claws);
- Squid spraying ink as a defensive action;
- The spectacle of broken wings used to drive predators away from the nest;
- The emission of a foul-smelling liquid by birds;
- Behaviors of newborns seeking food from their mother (whether from the breast or regurgitated in birds);
- Umbrella birds: when it rains, the mother bird shelters the chicks under her wings;
- We also mention, among others, the evolutionary enigma of the human eyebrow,

which lacks an obvious function [103] beyond showing expressiveness.

There is a supposed ability to make limited inductions and learning. *Our intelligence recognizes these actions as intelligent*-that is, *we could have made the same decisions ourselves* 'if we were in charge,' *autonomously*, *using our cognitive intelligence*. *We recognize these decisions as though they were our own.*

There are low levels of logical openness.

D. Acquired properties of type c) as third-order abiotic-biotic intelligence

Abiotic matter is assumed to also possess the ability to evolve, as seen in viruses and minerals [69-72], which means they can possess limited type c) properties.

There are properties of biotic matter with a generative nature that are of type c) and related to third-order intelligence. As discussed above, evolution is considered as a property of type c), possessed by both abiotic and biotic matter (see Table 4).

Moving now to acquired properties of type c) in species with highly complex brains, especially in humans (*Homo sapiens*), these acquired properties have high levels of logical openness. In other words, the acquired properties generate new generative properties in different forms and combinations. The acquired properties have a generative nature of type c) and are related to third-order intelligence, all exhibiting high levels of logical openness.

While the property of acquiring properties is considered as an expression of what can be regarded as generic, basic first- and second-order intelligence, the ability to acquire and *invent* new emergent generative properties is considered cognitive third-order intelligence. Among countless examples, we cite in no particular order the ability to:

- Solve problems,
- Invent irresolvable problems,
- Make representations and abstractions,
- Perform symbolic processing,
- Have anticipatory abilities based on models,
- Have design abilities,
- Invent and assign properties to materiality (e.g., engineering solutions and materials science)
- Invent and apply strategies,
- Invent devices,
- Recognize regularities in ongoing games,
- Recognize emergence as the acquisition of different but coherent properties,
- Acquire autonomy (the ability to learn from experience and process -e.g., memorize, represent, and recall what has been learned),
- Perform abductions and constructivist thinking,
- Perform learning,
- Engage in symbolic (e.g., analytic) and sub-symbolic (e.g., based on artificial neural networks and cellular automata) modeling,
- Invent approaches,
- Detect scenarios and rules of ongoing games,
- Develop theories,
- Create games,
- Invent musical instruments, music, stories, games, paintings, languages, and working devices (e.g., tools),
- Define purposes,
- and finally, develop approaches that are capable of studying themselves.

All of these abilities are (self-)generative of other (self-)generative properties. There are high levels of logical openness.

The relationship between living and non-living matter is summarized in Table 5.

Order of intelligence	Second order intelligence	Third order intelligence
Properties	*acquiring* available closed non-generative properties of type b	acquiring, *inventing new*, non previously available properties of type c via emergence and evolution
Properties of type b) Closed properties. They may non-linearly combine into subsequent properties irreducible to the constituent ones. They generate specific versions as irreducible correspondent properties.	*Nonliving matter* acquisition of properties as bifurcations; phase transitions; self-organization, and symmetry breaking *Living matter* Examples include anthills; beehives; coral structures; spider webs; stalactites; termites and collective intelligence (defense from predators by collective behaviors of flocks of birds, attack by swarms of insects). _________ *Low levels of logical openness*	
Properties of type c) Open, generative properties: self-generating new properties and non-equivalent variations. *Non-linear* combinability.		*Nonliving matter* Acquisition of *emergent* generative properties by abiotic systems, e.g., *systems of self-organized systems*, e.g., Bénard rolls in atmospheric fluid dynamics and the Internet, and *evolutionary* generative acquisition of consequences in non-linear relation with the initial conditions, e.g., crystal growth, quasi-crystals, viruses, atmospheric and climate dynamics, geological evolution *Living matter* Evolution and intelligence of the living, as cognitive intelligence, e.g., ability to solve problems, to invent and give properties to materiality (engineering solutions and materials science), to invent and apply strategies, to recognize regularities, and emergence as acquisition of different but coherent properties, abduction. _________ *High levels of logical openness*

Table 5. - Second- and third-order intelligence in abiotic and biotic matter.

We note how a higher order of intelligence can also function according to the properties of a lower-order one. For example, an abductive intelligence can operate both inductively and deductively and an inductive intelligence can operate deductively, but the reverse is not true.

The purpose of this article is to establish a conceptual framework that focuses on the intelligence of matter and its extension in the biotic, in order to view emergence, evolution, and intelligence as structurally interconnected. This is always within the scope of the intelligence we possess: an intelligence that can only recognize itself.

The property of acquiring properties, typical of emergence and evolution, is conceptually replicated and extended to what can be considered generic intelligence.

4 Evolution, emergence, intelligence of matter, and cognition

The still-controversial concept of evolution [104, 105], though, is nevertheless significantly identifiable and usable. In short, we remind the reader that evolution is understood as:

- The change in genetic composition, in the heritable characteristics of biological populations over subsequent generations, resulting from the differential reproduction of individuals with certain alleles (versions of a genetic sequence at a particular region on a chromosome);
- The occurrence of natural selection, understood as the mechanisms and processes through which species adapt to their environments by selecting the most functional and robust options.

However, we underline that evolution is not goal-oriented. Species do not simply *improve* over time. Rather, they adapt to their changing environments through adaptations aimed at optimizing and maximizing their reproduction within a particular environment and at a particular time [106, 107].

Evolutionary mechanisms should be understood as applied to the first, causal optimizations achieved by natural selection, ignoring other unexplored options and possible related nonlinear combinations that could offer higher levels of optimization and potential. Natural selection overlooks levels reachable through compensations, alternative strategies, or approaches invented by third-order intelligence. Third-order intelligence is an evolutionary competitive advantage acquired through emergence and evolution in continuity with first- and second-order intelligences.

Evolutionary mechanisms could be conceptually equivalent to using data-driven approaches in very large, changing databases, as in Big Data, searching for concordance, correlation, and correspondence. This is intended as a replacement for theories and approaches characterized instead by the application of forms of intelligence (see entry "Abduction" in Section 3.2 and [108])*, such as the adoption of, even if elementary, forms of strategies, learning, and finalizations that constitute dominant evolutionary directions.*

The intelligence missing in data-driven approaches corresponds to that which we consider absent in evolutionary processes.

We emphasize here that the mechanisms of evolution and emergence processes are not only non-goal-oriented but also inherently incomplete, as introduced above. The various evolutionary phases, such as those of emergence, present various other equivalent and possible options. The phenomenological choices among them occur for various contextual reasons, such as energetic and environmental factors, the influence of previous configurations, perturbations, defects, and others. The worlds identified by the mechanisms of evolution and emergence are *among* other possible worlds, which are not necessarily equivalent to each other, as seen within the animal kingdom.

We note that the concept of evolution has given rise to different ways of modeling and applications [109-112].

We also mention how *emergent evolution* is based on the hypothesis that, during the process of evolution, there is the occurrence of the emergence of properties with not only evolutionary origins, such as mind and consciousness [113-115].

However, evolutionary models assume that agents constituting biological populations choose their strategies through a trial-and-error learning process. From a systemic point of view, these are mechanisms of property acquisition that are conceptually similar to phenomena of emergence when collective systems, e.g., flocks, swarms, and anthills, acquire properties such as:

- Coherence (dynamic creation and maintenance of a property, e.g., a flock changes continuously but remains a flock -the coherence of interactions replaces the structure);
- Development (often reduced to generic growth, when in reality, it involves interacting and coherent growth systems);
- Homeostasis (the ability to maintain characteristics in the face of changing environmental conditions);
- Resilience (the ability to adapt and self-repair in the face of disruptive events);
- Behavior that cannot be reduced to stimulus-reaction.

Non-Ideal Modeling	Ideal Modeling
Agent-based models	Deterministic chaos equations
Big data and their properties	Model equations, such as the Lotka–Volterra and Maxwell's electromagnetic field equations
Cellular automata	Equations of mechanics
Dissipative structures, artificial life	Equations of thermodynamics
Neural networks	Ideal scale-free networks
Dissipative structures	Basic equations of elasticity

Table 6. - Cases of non-ideal and ideal modeling.

The focal point we address here is the multifaceted systemic complexity of the process of evolution, which differs, for instance, from the usually considered *evolution of complexity* in organisms. The systemic complexity of evolution should not be neglected. This complexity, as systemic complexity in general, requires a dynamic usage of multiple ideal and non-ideal models (see Table 6), having variable predominance (see, for instance, Sections 2.5, 2.6.3, and [18]). Complexity is understood as given by the establishment of processes of acquisition and maintenance of emergent properties, with variable, reoccurring coherences and non-linearities.

The systemic complexity of evolution cannot be ignored, and as such, it cannot be exhausted using a single model, but requires several concomitant approaches, and ideal and non-ideal models. The main ingredient to be considered is the phenomenon of emergence, which characterizes complexity in general.

In this regard, we note the constitution, as a combination of emergence and evolution, of cases such as ecosystems and collective behaviors. *Evolutionary aspects concern the single interacting agents, while the emerging ones become environmental in nature. The two aspects influence each other. Evolutionary aspects allow the emergence of collective behaviors (such as allowing flight), while collective behaviors can influence and facilitate the constitution of evolutionary aspects (such as the establishment of regulatory capacities).* We note the generality of ecosystems, understood as systems and networks consisting of living entities and their environments. However, these are not easily distinguishable, because a system can behave both as an element of another system and as its environment by establishing multiple, overlapping, dynamic levels in partial modes.

We conclude this introduction to Section 4 by mentioning approaches based on the idea of simulating the process of evolution, understood as the selection of the fittest individuals for reproduction to produce the subsequent generation. In this regard, we should consider types of *artificial evolution*, such as the so-called neuroevolution, using evolutionary, bio-inspired algorithms, e.g., genetic algorithms, mainly imitating mutation, recombination, reproduction, and selection. Solutions considered possible to the optimization problem are treated as individuals in a population. After repeated applications, a fitness function identifies the quality of the solutions [116]. Neuroevolution aims to evolve neural network architectures with their weights to perform specific tasks and solve, usually analytically intractable, problems.

We also mention genetic algorithms, adaptive heuristic search algorithms inspired by the principles of natural selection and genetics, which are designed to optimize and solve search problems [117].

Among the applications of artificial evolution, we can mention *evolutionary game theory*, as in [7, 10, 118].

4.1 Intelligence of matter, evolution, and emergence

At this point, we introduce issues regarding the relationship between the intelligence of matter and evolution. As we have stated, evolution cannot ignore, but must *use*, the properties of matter. *Evolutionary mechanisms do not apply only to the final stages of previous ones but are always integrated with other concurrent, non-evolutionary properties of matter. Moreover, evolution adapts to intelligent matter, which also constitutes its environment.*

We consider that, as introduced above, the intelligence of matter is understood as given by both:

- *Possessed properties* of type a),

and

- *Acquired properties* of type b).

We consider here the hypothesis that evolutionary directions are chosen, at least with the role of the intelligence of matter, when there is emergence from compatibilities and equivalences; selections between admissible, compatible, and temporarily equivalent options; and in a framework of theoretical incompleteness, coherences, and correlations.

We consider these hypotheses to be further developed and studied.

We consider the reappearing *of properties of matter as dominantly contributing to the choice of evolutionary directions at different levels and combinations of dominance. This includes* preferring*, in the choices of evolutionary directions, the occurrence of coherence, equilibrium, regularity, symmetry, synchronization, self-similarity, constancy, stability, and repeatability, which are assumed to be evolutionary choice factors.*

For instance, examples in no particular order include:

- The fractal structure of pulmonary alveoli, which allows a large surface area in a small volume (of the lungs) for respiratory exchange with the environment [119].
- Fractality in neuroscience: The dendritic structures of neurons exhibit fractal characteristics, which optimize both connectivity and efficiency. Branching patterns of dendrites are fractal-like, allowing for enhanced communication between neurons. This fractal geometry is suitable for the formation of complex neural networks, influencing both the processing of information and its transmission through the brain [120].
- Fractality in nature, as seen in beehives and spider webs, displaying fractal-like structures.
- Symmetry occurs in a wide variety of cases as an evolutionary choice. Almost all forms of life, from single-cell eukaryotes and plants to complex, highly differentiated multicellular organisms, exhibit symmetries [121].
- Neural networks: We consider the formation of neural circuits in the brain when neurons self-organize based on activity-dependent mechanisms and influence learning and

memory activity through dynamic connections [122, 123].

- The ability of matter to self-organize, e.g., the Belousov–Zhabotinsky reaction, Rayleigh–Bénard cells, and whirlpools, reappears in collective behaviors, e.g., flocks and swarms, acquiring evolutionary properties, e.g., collective intelligence.
- Protein folding: Proteins often spontaneously fold (self-assemble) into specific three-dimensional structures due to interactions among their amino acid chains. The problem is to predict the 3D structure of a protein from its amino acid sequence [124].
- Cellular structures: Actin networks can self-organize into several types of structures in cells. The cytoskeleton, composed of microtubules and actin filaments, self-organizes as these structures dynamically assemble and disassemble [125].
- Nest architecture: Insects build complex nests through self-organizing processes, where geometrical regularities of matter, e.g., crystals, reappear, such as in anthills, beehives, and termite mounds, which are also suitable for temperature regulation and resource management, and dams built by beavers.
- Morphogenesis: Organisms, during evolution and development, undergo morphogenetic processes in which cells organize into organs and tissues. The formation of their pattern and their geometrical properties are influenced and shaped by chemical signals and physical interactions among cells [126].
- Slime molds (polyphyletic assemblages): The behavior of slime molds shows self-organization when individual amoebae aggregate to form a multicellular structure in reaction to environmental cues, leading to spore formation. Examples include cellular slime molds (Dictyosteliida), *Fonticula alba*, and plasmodial slime molds (Myxogastria), see for instance [127].
- Evolving capabilities of abiotic matter reappear in the evolution of biotic matter.
- Sociobiology [128] considers that some social and individual behaviors are at least partially inherited and affected by natural selection. The idea is that behaviors evolved over time, making living beings act in ways that have been evolutionarily successful. The inheritance would concern acquired properties of type b), such as the ability to self-organize, allowing collective behaviors to emerge.

A theoretical treatment of the extension, with forms of continuity such as reoccurrence and reappearance, of properties between non-living and living matter concerns evolutive capabilities, intelligence of matter, and emergence processes, which are responsible for the acquisition of properties in a way comparable to that of evolution with the following specifications:

- Evolution and emergence: On the one hand, evolution selects strategies through genetic drifts and trial-and-error learning processes; it is not goal-oriented; it arrives at a result with properties considered optimized with respect to the previous phase. On the other hand, emergence is due to multiple, non-linear interactions, as the acquisition of different but coherent properties, whose coherence gives rise to other unpredictable properties. Both are processes of property acquisition. Emergent and evolutionary steps are not *reducible* [129] to the previous ones, meaning that reversibility is not possible in principle, excluding any presumed backward linearity. Evolution applies to its subsequent phases, occurring as a process with aspects of permanence and continuity, albeit over very long durations (evolutionary times), while this does not happen for emergence, which rarely applies to itself, with its acquired properties having subsequent effects such as the acquisition of collective intelligence**.** *Because evolution can be understood as having a permanent character, while emergence does not, evolution, therefore, appears to have a greater generative power than that of emergence.*
- Focusing on the case of emergence, ‘physical and biological emergence’ are not considered different ([130], pp. 195–290).
- We cannot help but mention an old controversial approach, i.e., *emergent evolution*, see Section 4 [131].

The general idea considered here is that evolution occurs around and is intertwined with possessed properties, as well as the properties and their acquisition processes of type a) and b), in a continuous interrelation between emergence and evolution, correspondingly interrelating non-linear interactions and mechanisms of evolution.

This is in reference to the fact that the evolutionary mechanism seems inadequate, at least on its own, to explain the acquisition of type c) properties. *This occurs within the history of the Earth and its climate, which generates the interacting environment*.

At this point, we note research issues about the relationship between intelligence and evolution. Because the ability to adapt is crucial for evolution, we should consider a key aspect of intelligence, such as its role in effective adaptation to environments. We may consider issues such as:

- Is the combination of emergence and evolution convergent to forms of cognitive intelligence?
- Is it possible to consider emergence-evolution and generic intelligence separately?
- Does emergence-evolution have intrinsic forms of intelligence? (How could it not, because it generated the intelligence that recognizes itself?).

4.2 Evolution, intelligence of matter, and the acquisition of cognition

We now consider the ideal process of acquisition of properties of type c as a significant part of the acquisition of cognition [93] by living, evolved, intelligent matter.

We regard the intelligence of the biotic as *one* of the possible extensions of the intelligence of matter, with forms of continuity such as reoccurrence and reappearance of properties.

Cognitive intelligence, identified by, if not coinciding with, type c properties, is understood as part of the more general cognition, consisting of cognitive processes related to attention, language, logical inferences, memory, metacognition (self-cognition), and perception.

Properties of type c are suitable for realizing and understanding both properties possessed and manifested by matter (intelligence of first order) and properties of type b (intelligence of second order). This compatibility and suitability are not surprising, because they have been identified by third-order intelligence in a self-referential way.

We should elaborate on the mechanisms that are supposed to give rise to type c properties and third-order intelligence.

4.2.1 Cognitive biology

It has been hypothesized that there is a kind of biological-cognitive converter (BIOCC) through which living matter is supposed to acquire cognitive properties [133].

The hypothesis is made at least plausible by the validity of the occurrence of its opposite, i.e., the placebo effect, where medicines, painkillers in this case, have significant and persistent effects if patients are informed of their administration [134].

Through the BIOCC, living matter is supposed to acquire properties such as the ability to decide whether something is likable or not, as well as desires, implying behaviors, decisions (e.g., selections), and emotions, such as through the effects of neurotransmitters and dopamine. Well-known cases concern sexual attraction at reproductive age, attraction or repulsion to possible foods depending on their color, shape, and smell, judging behaviors as attractive or dangerous, and even the smile of a child.

Among many topics, the hypothetical BIOCC is considered by *cognitive biology*.

The topic of cognitive biology was considered introduced by Goodwin in 1977 [135].

Cognitive biology is an emerging interdisciplinary field that explores cognition as a biological function considered across various organisms, from single-celled bacteria to complex living beings [136, 137].

Unlike cognitive science, which primarily focuses on human cognitive processes, cognitive biology studies the fundamental cognitive mechanisms used by all organisms to interact with their environment [138].

The theoretical assumption is that every organism, whether single-celled or multicellular, continually performs proper actions of cognition coupled with intentional behaviors, i.e., a sensory-motor coupling. *The assumed principle is that if an organism perceives stimuli from its environment and responds appropriately, without just reacting automatically, then it is considered to possess cognitive abilities*.

On the one hand, cognitive science studies human thinking and its conscious mind, while on the other hand, the purpose of cognitive biology is the study of the generic, basic cognitive processes of any organism, see, for instance, [139-144].

4.2.2 Evolution of cognition

The evolution of cognition is a field of research that focuses on the sequence of events that led to the emergence of this multifaceted faculty (see, for instance, [145-147]), where the core objective is to understand how evolution gave rise to cognition, starting from the framework of conceptual continuity with the properties of matter.

The fundamental cognitive mechanisms are then understood to converge toward forms of cognitive intelligence [146]. *Should these be interpreted as a further evolutionary development or as a side effect?*

5 A role for consciousness?

Cognition is understood as the processing of information related to memory, perception, and reasoning through cognitive abilities (see Section 4.2.1) and intelligence.

Consciousness is known as the state of being aware, such as considering consciousness as the "*remembered present*," as introduced by Gerald Edelman [149, 150]. Consciousness is seen as representation, memory, and simultaneous cognitive processing of the present. In a nutshell, the theory is based on concepts such as reentry and recurrence, which relate to the continuous feedback loops of information processing between different brain areas; on memory influencing the process of combining immediate perceptions with recollections; and on representing the present [150, 151]. In artificial systems, the case is considered by recurrent neural networks (RNNs), which use their internal states, i.e., their memory, to process incoming inputs [152]. In this regard, we note long short-term memory (LSTM), an artificial recurrent neural network used for deep learning [153, 154], capable of retaining information for long periods. This memory stores, for instance, activation parameters, input, temporary data, and weights. Another case to be mentioned relates to recursive neural networks (RvNN), which have multiple layers between the input and output layers, applying the same set of weights recursively to a structured input. These are applied, for instance, in learning sequences and tree structures for natural language processing [155]. We should also mention the case of recursive cellular automata [156].

The self-reflexivity character of consciousness is also assumed when considering cognitive science as the science studying itself. On the other hand, the concept of consciousness has been explored to elaborate on the idea of *conscious, self-guided evolution*, assuming that the evolutionary process transformed from biological into cultural [157]. Furthermore, we note the evolutionary nature of consciousness as an acquired property of type c [158-161].

At this point, we also mention the presumed *irrelevance* of consciousness for evolution, as argued by some authors [162-164]. The assumption considered is that consciousness would be unnecessary for survival. If consciousness does not provide survival advantages, it may be unnecessary for evolution. This view holds that many organisms function effectively without the need for consciousness, indicating that being endowed with consciousness is not a property necessary for survival or fitness.

However, we consider how the self-reflexivity power of consciousness allows us to study cognitive problems such as:

- Identifying the limitations of our study of them, because we use cognitive resources that are only compatible and adequate with the intelligence of matter and originated from them.
- Also, being capable of reaching different levels, e.g., AI trained with rules and data from different worlds (other species or imaginary ones), thus detaching itself from the original generative evolutionary processes. This allows us to build artificial environments in which these limits can be overcome and then study their behavior and apply their properties.
- The relevance of consciousness for the combination of intelligence and evolution: Does evolution *delegate* intelligence [165]?
- Reflexive: Awareness of having awareness. Is this the only type of awareness? Is it impossible to recognize other possible ones?
- Is it suitable to consider cognitive intelligence without consciousness, and vice versa?
- Is it suitable to consider cognitive intelligence as formalizable, as an artificial consciousness [166, 167]? Can the ability to dream and unconsciousness be modeled? Are they understandable as properties of type b?

We conclude by mentioning how *we use our intelligence to self-define and judge, classify, and, of course, consider 'inferior', forms of intelligence. A superior intelligence may be understood as an amplification of our intelligence, not as another intelligence having the same field of application.*

6 Concluding remarks on applied research: the combination of evolution and emergence in models and simulations

The introduction of approaches to this problem is the research theme consequent to the considerations introduced above and related to *emergent evolving active matter*. Considering generic agents, the combination can occur in a great variety of possibilities. For example, there can be emergence processes for agents simultaneously subjected to evolutionary processes, e.g., ecosystems; and evolutionary processes for agents simultaneously subjected to emergence processes, as for evolutionary economics [168].

There are various approaches to model generic evolutionary and emergence processes in the so-called active matter [169].

One category concerns the Agent-based models (ABMs) as in [170] where it is possible to find simulation details and results, and nonequilibrium continuum dynamical models as in [171].

We mention now examples [65, 172, 173, 174] of analytical modeling of phenomena of emergence of collective behaviors, starting from the classic *equation of flocking* which describes how single entities in a group, e.g., flocks and swarms, adjust their velocities based on the velocities of others, see eq. 3

$$v_i(t+1) - v_i(t) = \sum_{j=1}^{k} a_{ij}(v_j(t) - v_i(t)) \quad (3)$$

where the weights a_{ij} quantify the influence of bird j on bird i, and in the conceptual framework intending evolution as a collective phenomenon far from equilibrium [175].

Then there are approaches that consider cases where there are both evolutionary and collective processes such as cooperation and emergence where there is emergent sensing of complex environments [176] and evolution of collective migration in cells and organisms [177, 178, 179].

Now considering the evolution, mathematical models of evolution are presented, for instance, in [180].

However, coming now to the thesis of this paper, and as introduced in Section 2.6, the complexity of phenomena of evolution and emergence, like any complex phenomenon, requires multiple modelling not *zippable* [30, 34] into a single model.

The mutual non-reducibility of the models represents, on the one hand, the non-reducibility of the phenomena themselves under study to single aspects, and on the other hand does not allow linear or non-linear combinations of models, but requires multiple approaches of the type considered, for instance, by the *DYnamic uSAge of Models* (DYSAM), as in ([18], pp. 201-204], and consisting in the use of multiple models as in approaches like: *ensemble learning*, whose basic idea is to combine an uncorrelated collection of models (specifically artificial neural networks) of the same phenomenon; *machine learning* trained on usage of different models; and *evolutionary game theory* (see Section 4), being this theory based on the von Neumann 'minimax theorem', and considering models as games.

The links between the models are not analytical, ideal, but phenomenological, non-ideal, generated, for example, by learning and having analogic nature.

7 Directions of research

Examples of open issues that can be addressed within the conceptual framework introduced by this article include, in no particular order:

- What is the origin of the intelligence of matter?
- Is the acquisition of type a property a necessary condition for the acquisition of type b property?
- Does the intelligence of the biotic, specifically human cognitive intelligence, recognize that of matter because it is an *extension* of it?
- Is the universe understandable because we are parts of it? Are we the universe that *knows itself*, albeit presumably only at a certain level? (It seems unlikely that our level is the definitive one, especially because evolution and emergence continue to work.)
- Is the acquisition of cognitive intelligence an evolutionary endeavor separable from the evolution of the brain and body of which it is a part?
- Is intelligence identified by cognitive intelligence? Is it a self-defined intelligence? Is a generic definition (a meta-definition of intelligence) possible?
- Consider meta-intelligence in correspondence with meta-language (see Section 3)
- The approach considered here starts from the intelligence of matter (first-order intelligence), materialized in that of the living (third-order, cognitive intelligence). Is it possible to introduce related formalizations or models?
- Is it possible to have cognitive intelligence that can be considered abstractly, as a property independent of the properties of the living being that possesses it?
- The possibility of different intelligences, probably unrecognizable to us. How can we recognize other intelligences? For instance, can we use artificial intelligence (AI) approaches based on supervised learning, referring to other species or the imaginary (see, for instance, the effective role of imaginary numbers in models of reality [97])?

Among the various possible lines of research, we can mention one related to training neural network-based AI systems using rules and properties of plant and animal cognition. This could simulate the cognitive behavior of other living beings in artificial environments and study their reaction processes.

Furthermore, training may relate to imaginary worlds, which could then address present decision-making problems related to the actual real world. This could help simulate different types of intelligence from ours and see how they would react to situations and problems in the real world.

- What is intelligent for one intelligence may not be so for another (incompatible intelligences).
- Properties of processes of interweaving between evolution and emergence.
- Models of interweaving between evolution and emergence combining, for instance, Evolutionary Algorithms [181], and models of emergence, e.g., ideal models as in Table 6 and Dynamical Systems Theory [182] for modelling, for instance, the phenomenon of "genetic reserve" referring to the genetic diversity within populations serving as a

reservoir for future, possible adaptation and survival in changing environments [183, 184].

And finally:

- Intelligence of evolution?
- Evolution convergent to intelligence?
- Intelligence and evolution as independent?
- What can be intelligent, even in incompatible ways, and what cannot?
- History of intelligence as a sequence of mutations, perturbations, and noise not coinciding with an evolutionary process.
- Evolution of intelligence.
- Intelligence and consciousness: Mutually necessary or independent?

8 Conclusions

This article was developed around the basic hypothesis that the theory of evolution is insufficient to explain the acquisition of properties by living matter, particularly cognitive properties such as cognitive intelligence. We have attempted to support this hypothesis.

In this regard, we specified the concept of intelligence of matter and its acquisition of properties within the framework of systems science, particularly considering processes of emergence. We introduced the question of intelligence as the ability to acquire properties that generate further properties and considered orders of intelligence. We mentioned the potential and abductive nature of cognitive intelligence, along with its non-rational aspects, such as the role of dreams, pathologies, and unconsciousness. We considered the continuity between the intelligence of matter and the cognitive intelligence of the biotic, as expressed through biological cognition, where *mechanisms of evolution should be integrated with emergence and the intelligence of matter*. Approaches were implicitly introduced that are not definitive but, at least, are representative of cognitive intelligence, even if not exhaustively so. All of this was considered with our self-referential intelligence, which can recognize only its own properties.

We also discussed how AI can be 'measured' by the extent to which it extends the dimensionality of its phase space, differentiating between artificial intelligence as the ability to practice available degrees of freedom autonomously, and artificial intelligence capable of introducing new degrees of freedom.

We examined the evolution and intelligence of matter, proposing a possible role for consciousness in overcoming problems of self-referentiality, using, for example, AI approaches based on supervised learning referring to other species or imaginary constructs.

This introduces possibilities for simulation and design, making self-guided, evolution-inspired approaches more significant.

The focus is on how evolutionary and emergence mechanisms materialize in cognitive and cultural components, representing the search for advantages and interests within the context in which evolution operates. In this framework, evolution acts as an attentive mother to species while remaining an indifferent stepmother to individuals. We also consider the questionable predominance of rationality, a notion that history frequently contradicts.

This approach is seen as having long-term strategic relevance, particularly for social, economic, and geopolitical designs of interest to policymakers.

Finally, we mentioned some research directions conceptually conceivable within the context introduced, assuming it as a general theoretical framework for cognitive biology. *Intelligence and understanding are natural phenomena, akin to rain and sleep. At a certain level, reflexivity is so strong that it retroactively influences nature itself (as in "reverse emergence," but not in the inadmissible concept of "reverse evolution"), manifesting as a genetic drift. Is this process itself natural, or is it an unexpected mutation (like the apple eaten by Eve in the Biblical tradition)?*

The simulability of the process of evolution by AI, through learning from imaginary and non-human worlds, opens up new perspectives for considering properties of worlds to interact with for design purposes. Practical applications concern cases in which phenomena are considered to have evolutionary and emergent nature allowing better accuracy of the models such as in biology and economy.

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