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Systems, Resilience, and Organization: Analogies and Points of Contact with Hierarchy Theory

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Abstract

Aim of this paper is to provide preliminary elements for discussion about the implications of the Hierarchy Theory of Evolution on the design and evolution of artificial systems and socio-technical organizations. In order to achieve this goal, a number of analogies are drawn between the System of Leibniz; the socio-technical architecture known as Fractal Social Organization; resilience and related disciplines; and Hierarchy Theory. In so doing I intend to provide elements for reflection and, hopefully, enrich the discussion on the above topics with considerations pertaining to related fields and disciplines, including computer science, management science, cybernetics, social systems, and general systems theory.

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1. Introduction

In this paper I draw a number of analogies between the System of Leibniz^{1,2,3,4,5,6}, my work on fractal social organization^{7,8,9,10}, as well as on resilience^{11,12,13,14} and Hierarchy Theory^{15,16}. Aim of this effort is to provide elements for reflection and, hopefully, enrich the discussion on the above topics with considerations pertaining to related fields and disciplines, including computer science, management science, cybernetics, general systems theory and combinatorics.

The paper is structured as follows: in Sect. 2 my focus is the general systems theory of Leibniz. Fractal social organization is the subject of Sect. 3. Section 4 draws analogies between resilience, antifragility, and related concepts and the Hierarchy Theory of evolution. Conclusions are finally stated in Sect. 5.

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2. Analogies with the System of Leibniz

Building on top of the Aristotelian concept of entelechy, Leibniz introduces a gestalt^{6,17} called *monad*. The treatise of the monad translates into a series of dualisms: a monad is (i) a unitary and indivisible “Whole”; but it is also a network of constituent ancillary parts; (ii) it is a metaphysical conceptual entity, which admits multiple *physical* manifestations (“encodings”); (iii) it is a static, incorruptible model, residing in a limitless, unconstrained, time-and-space-less context; (iv) at the same time, it is also an object reified and deployed as a dynamic entity into a time-and-space resource-limited “world” subjected to: constraints; a limited span; strict energy requirements; and a corruptible structure. Due to the above duality, a monad is characterized by two quality components: (i) a static (immutable) quality component, representing the *intrinsic quality* of the model; (ii) a dynamic and context-dependent quality component, representing the extrinsic, or *contingent quality* of the physical representations of the model when set to operate in a given “world” or environment. The first component corresponds to the systemic class of the model according to some General Systems Theory classification—for instance the behavioral classification in¹⁸ or the behavioral/organizational classification of¹⁷. The second component corresponds to a monad’s instance’s ability to match the mutating constraints and circumstances expressed by the environments that instance is set to operate in.

Quality is an *essential* aspect in the Leibnizian System, in that quality determines the existence of monads. In fact, according to Leibniz, despite their residing in a meta-physical, timeless domain, monads may exist or cease to exist. The only one to decide on the fate of monads is the supreme monad, “God”, who is the monad representing the concept of “all that is²” and is the only entity able to assess both quality components of other monads. If a monad is ascertained as being sufficiently *qualified*, it is persisted—it “stays in the mind of God”; otherwise, it is not retained and ceases to exist. “Qualified” here refers to a monad’s *quality of emergence* (QoE), namely *how much* the Whole represented by that monad is greater than the sum of its parts. As discussed, e.g., in^{20,13}, QoE can not be assessed exclusively considering intrinsic qualities, hence a trial is necessary. The worth of the monads must be tested by observing the sustained action of their instances when deployed in a finite and mutating environment³. As many monads as possible will be retained, but no more than what is possible given the constraints and limitation of the world, also considering social aspects such as the possibility for coexistence (cf. tropism). “Compossibility” is the term used by Leibniz to refer to the possibility for coexistence.

The Leibnizian God is in fact the entity responsible for sorting out the monads worth persisting and discarding the “unworthy” ones; in other words, he is the *realizer* of such an ante litteram “survival of the fittest” strategy²¹. In order to persist, the monad must pass through several “sortings”. In fact, as I suggested in⁶, the role of God in Leibniz may be described as that of a “Universal Sort” process—a *mechanism*, meant to evaluate each and every monad’s two QoE components and to schedule for existence those monads that score best—up to some threshold expressed by the limitations of the current world. A pseudo-code for Ultimate Sort was formulated in⁶.

Code is in fact another key ingredient in the Leibnizian System. Code is the physical representation of a monad, and it also represents a scheme for the physical construction of an instance—its realization (*viz.*, reification). Leibniz foresaw the existence of a universal “language” for the expression of monads. He called such language *Characteristica Universalis* (℄). ℄ is a diagrammatic language employing pictograms. The pictograms are convenient representations of modular knowledge of any scale, with segments representing different properties—for instance compossibility or its opposite. Leibniz exemplified this through diagrams such as the one on the frontispiece of his *De Arte Combinatorica*.

The ℄ language is Leibniz’s way to encode monads as networks of other substances, together with their relationships. Pictograms represent *modules*, namely knowledge-components packaging other ancillary knowledge-components. As observed in⁶, pictograms are Leibniz’s equivalent of: Lovelace’s and Turing’s tables of instructions; subroutines in programming languages; boxes in a flowchart; or components in component-based software engineering. They represent a *hierarchy* of related concepts producing a Whole characterized by some degree of QoE²⁰.

² Interestingly enough, already in¹⁹ a similar concept was expressed, albeit of course in a poetic form. Among the lines at p. 1156 we have, e.g., “Such is my Lord and Master, the Lord of the Universe”; “Millions of universes are the limbs of His Being”; “His Wondrous Plays are enacted on millions of stages”; and “Millions of expanses are His; there is no other at all”.

³ The world’s finiteness is no counterargument to Leibniz’s thesis of ours being “the best of all possible worlds”²⁶. On the contrary, finiteness is the foundation to the evolutionary strategy²¹ by means of which that statement is made true.

A $\mathbb{C}\mathbb{U}$ “code” is the physical representation of a metaphysical concept—viz., of a monad. Such code is the representation of a model, expressed in terms of relationships with other models and in an abstract and static way, independent of whatever physical deployment environment and of scale. Compositional and modular by construction, $\mathbb{C}\mathbb{U}$ is the language of the “true characteristic [of the monads,] which would express the composition of concepts by the combination of signs representing their simple elements, such that the correspondence between composite ideas and their symbols would be natural and no longer conventional.”⁵ In other words, $\mathbb{C}\mathbb{U}$ is an isomorphic language, such that *concepts are preserved through their compositions*. Instances are thus “code” expressing a model; I am tempted to say they are a phenotypical representation of a genotype.

2.1. Analogies with Hierarchy Theory

From the above discussion, one can clearly see that the duality expressed in the System of Leibniz may be put into direct correspondence with the “double hierarchy” at the core of Hierarchy Theory (HT). In HT, two concurrent and intertwined hierarchies define the action of nature at all scales: a “genealogical hierarchy” (GH), responsible for the trustworthy transmission of hereditary characters through time, and a so-called “economic hierarchy” (EH), responsible for the physical construction of individual phenotypical instances of a genetic “model” as well as for guaranteeing the premises for a trustworthy transmission of the hereditary traits.

2.1.1. Genealogical Hierarchy

I conjecture that the purpose of GH may be put in relation with the Leibnizian concept of the intrinsic quality of a monad. As already mentioned, monads in Leibniz are pure, immaterial concepts; though this is what Leibniz refers to as “reality⁴”. Now, in order to exist, reality needs some form of materialization. In other words, a monad needs to be represented in a physical way—by means of a physical substance that encodes and “embodies” it. Putting it in a different way, in order for the class to exist, there must be a method to produce individual resilient instances of that class. Those instances constitute the *essence* of their class—and vice-versa: one cannot exist without the other. Instances become “identifiers” (or avatars; see Footnote 4) of their class.

This concept is nicely rendered in Algebra: given any non-empty set S and any partition of S defined by an equivalence relation R , for any instance $x \in S$ the equivalence class of x (namely the block of S x belongs to) is simply $[x]_R$: any element x is representative of the class it belongs to. The same conclusions may be reached considering that the definition of the projection function $\pi : S \rightarrow S/R$ is simply $\forall x \in S : \pi(x) = [x]_R$.

With the terminology of Hierarchy Theory, instances are **replicators** of their class. They must be resilient, because their demise would translate in the extinction of their class—their monad. The problem is then being able to persist the concept throughout time, while “moving” through a medium that affects the instances in several ways. This is one aspect of *resilience*, viz. “being at work while staying the same”. The term “replicator” implies the only effective strategy for a monad to “stay the same”: redundant copies of the model of the Whole and of its constituent parts must be created and propagated through time by means of an uninterrupted “chain” of replicas—think for instance of the incessant work of amanuensis monks. Of course in order to be effective, the strategy requires that each new copy, or *offspring*, be “compliant” to its parent. In mathematical terms, given a function $\mathbb{C}\mathbb{U}$, we can model a genealogical evolution of replicator instances as the orbits of a dynamical system, namely the recursive application of $\mathbb{C}\mathbb{U}$; and the effectiveness of the strategy corresponds to asking that, at any time t , the corresponding orbit of $\mathbb{C}\mathbb{U}$ be compliant to that of its predecessor. I plan to develop this in more detail as I did for the finite state automata and dynamical systems introduced in²² and²³.

Another way to discuss the effectiveness of the genealogical strategy is given by introducing the concept of *fidelity*, which we defined in^{12,24} as the “compliance between corresponding figures of interest in two separate but communicating domains”. Replicators are effective if, at any given time, there exists at least one replicator and that replicator is characterized by fidelity. In other words, the first-generation copies must be faithful representations of the model, the second-generation copies must be faithful representations of the first-generation copies, and so forth. A transitive closure of isomorphic transformations must be valid across all generations in order to guarantee that at any given time

⁴ Again this concept is already present, e.g., in Sikhism¹⁹. As an example, the term “avatar” stands for “a deliberate descent of a soul to earth in any form”.

t the “copy-at-time- t ” instance faithfully encodes the original model—or, in other words, that it represents the same concept. Only when this transitive closure holds, we can guarantee the transmission of the monad through time⁵.

Finally, I believe GH provides a convenient, “Pandaeans” interpretation of the Leibnitian concept of persistence-in-the-mind-of-God.

2.1.2. *Economic Hierarchy*

As a second conjecture, here I relate the Leibnitian concept of extrinsic (or contingent) quality with the Hierarchy Theory concept of EH. Leibniz considers matter as “a substance’s privative or passive aspects”¹. In fact, it is the moment a model is *real-ized* (*material-ized*, in fact) that it needs to confront oneself with physical limitations, deployment factors, design constraints, social interaction, and other factors. Furthermore, materialization means deployment in a multi-user environment whose cohabitants all compete for the same objective: maximize their chances for survival and for the persistence of their identity. Leibniz explains that, for any given “world”, places and energy are finite and represent resources to compete for. Those hard limitations call for economic considerations: redundancy, for instance, cannot be unlimited, as each replica is associated with a “cost”. Being a system-of-systems, any new individual is an *economic event* that reverberates in all the hierarchical levels the constituent sub-systems “reside” in. And every deployment choice at every level translates into the introduction of different sorting criteria—different weaknesses and strengths, that is, with respect to the varying environmental conditions.

Leibniz does not introduce explicitly the HR concept of **interactors**—“materializers” that interpret the model building instances and introduce physical differentiating factors; but he does recognize that a code does not exist *per se*, unless a reference “machine” exists and is able to interpret and translate it into dynamic behaviors or into some other, diverse but conceptually equivalent, form. Therefore Leibniz introduces the concept of an interpreter for $\mathbb{C}\mathbb{U}$ codes. It is the so-called Calculus Ratiocinator (CR), the reference “hardware” for the $\mathbb{C}\mathbb{U}$ “language”. CR is also the algebra or “validation environment” where instances are put to test and QoE is ascertained⁵.

2.1.3. *Emergence and Modularity in Leibniz*

As already mentioned, a monad is persisted in the “mind-of-God” only if it proves to be characterized by an adequate degree of intrinsic (systemic) quality and extrinsic (contingent) quality across a dynamic variety of conditions²⁰. Monads and their material instances across the global biota are continuously “sorted”—which constitutes for Leibniz one of the purposes of “God”. Said purpose is not only effective but also “necessary”, and results in ours being “the best of all possible worlds”²⁶. I believe that the treatise on Hierarchy Theory provides elements to better understand the “necessity” in the processes exercised by the Leibnitian “God”:

- First, “God” aims at guaranteeing that “the greatest amount of essence or possibility is brought into existence”. HT provides us with a reason for this: the greatest amount of essence or possibility corresponds to the *greatest area of morphospace*¹⁵. The greater such area, the more covered is the space of all possible events that may affect the hierarchies of the biota. Uncovered areas may in fact correspond to the most appropriate natural “configurations” with respect to an unprecedented or very rare environmental condition. In other words, seeking the greatest amount of essence or possibility aims at increasing as much as possible the amount of diversity and disparity in all levels of the natural hierarchies, diversity and disparity being the most effective “lines of defense” against events that may affect simultaneously a large amount of individual instances. The Permian-Triassic extinction event is an extreme case of diversity/disparity failure. The widespread adoption of a same “deployment solution”—the use of a mineralized skeleton—resulted in a common trigger ultimately producing one of the most devastating and widespread correlated failures of recorded natural history²⁸.

⁵ The concept of replicator has been exemplified in popular literature by characters such as “the Phantom” by Lee Falk²⁵. The Phantom is a man that embodies certain values—fighting injustice, greed, and violence. In order to guarantee the persistence of this ideal, the Phantom is a replicator: a genealogy of Phantoms exists, the current Phantom being the 21st in a line that goes back to 1536. Since then, each Phantom is faithful to an oath made by his predecessor, up till the original one who defined the oath and the genealogical strategy. As long as a living offspring exists and the “genetic oath” is faithfully renewed, the Phantom concept is persisted. As a result of this, people unaware of the origin of the Phantom consider it as “*the man who cannot die.*”

- Secondly, Leibniz “hints” at the fact that the process enacted by “God” results in the long run in greater and greater QoE: “When the tables of categories of our *art of complication* have been formed, **something greater will emerge.**”⁴
Nature’s ability to construct ever more complex—ever more *evolved*—entities is thus another “proof” of both the effectiveness and necessity of God’s behaviors. It is possibly this the “greater secret [that] lies hidden in our understanding, of which these are but the shadows”, which Leibniz referred to in³.
- The ability to develop ever greater QoE is possibly one of the reasons behind the interest that Leibniz showed throughout his life for the work of Thonis van Leeuwenhoek. Leeuwenhoek had developed a clever technique for the creation of microscope lenses. With his microscopes he was the first to observe microorganisms and spermatozoa; because of this he is now generally considered as the father of microbiology. Leeuwenhoek was also the grand developer of preformationism, the belief according to which all beings are the development of preformed miniature-versions he called “animalcules”. Animalcules are genotypical, first-order “code” producing a phenotypical second-order “code”—a more developed, living instance of the animal monad. Though obviously an incorrect and unscientific concept, preformationism contains *in nuce* the principle of *conservation of modularity*, viz. the property of conserving modularization when passing from a genotypical representation (viz. a concept, i.e., an abstract and general template) to a phenotypical representation (namely a particular “realization”, or concrete expansion, of the template). This property, which may be probably best represented through the mathematical concept of an isomorphism between genotypical and phenotypical algebraic domains, is in fact compatible with the Leibnizian vision of substances as “second-order scripts” produced by “first-order scripts”. This conservation of modularity possibly hints at the reasons why evolution “evolves”, and why nature “naturally” develops ever more complex substances²⁹.

3. Fractal Social Organizations

A second field useful for reflections in the context of Hierarchy Theory is in my opinion the bio-inspired distributed organization that I called Fractal Social Organizations (FSO)^{7,8,9,30,10}. FSO is a fractal organization: it is a hierarchy that “is not based on the classic top-down flow of control and bottom-up flow of feedbacks (autocracy) but rather on a peer-to-peer approach where every node in the hierarchy may play both management and subordinate roles depending on the situation at hand (sociocracy)”⁹, with a set of rules valid at each level of the hierarchy. The peculiar aspect of FSO with respect to other fractal organizations is indeed its set of rules—the so-called *canon* of the organization. The FSO canon states that, whenever an event occurs in a *focal level*¹⁵, the event is resolved by identifying roles to be assigned to a response protocol. At first, roles are sought in the focal level only (by means of semantic service description and matching^{30,31}). When roles cannot be appointed to holons in the focal level (that is, to its nodes), a so-called *exception* takes place, meaning that a “missing roles” event is propagated to the level immediately above the focal one. Because of this *upward causation*, the focality moves to this second level. Again, roles are sought in the new focal level, possibly leading to new exceptions and new propagation of focality. This “movement” traces entities from different hierarchical levels and enrolls them into a temporary new network, which I called “Social Overlay Network” (SON). The SON is the team of cross-level nodes that are to deal with the originating event (the event that occurred in the “first” focal level). FSO have been applied, albeit in a limited and simplified formulation, in the course of project “Little Sister”^{32,9}, and are at the core of recently launched VLIR-UOS project “SELFSEV”⁴¹.

FSO have been studied, to some preliminary extent, in⁷. In the cited paper I introduced a mathematical model, extending results already obtained in other works^{22,23}, in which the evolution of the entities in an FSO hierarchy is represented as a random walk among the set of all possible SONs resulting from the collaboration of all FSO entities.

I deem several facts to be relevant to the current discussion:

- The mentioned mathematical model takes as input a “flat” set of entities, irrespective of their hierarchical position. Despite this flat initial configuration, the space of all possible SONs produced by the model is hierarchical; modular; self-similar; and admits a fractal dimension⁷. Figure 1 exemplifies two FSOs.
- Representations of the space of all possible SONs may be considered as phenotypical representations of a genotypical “code”, or “seed”, given by a string identifying all the possible roles in the FSO.

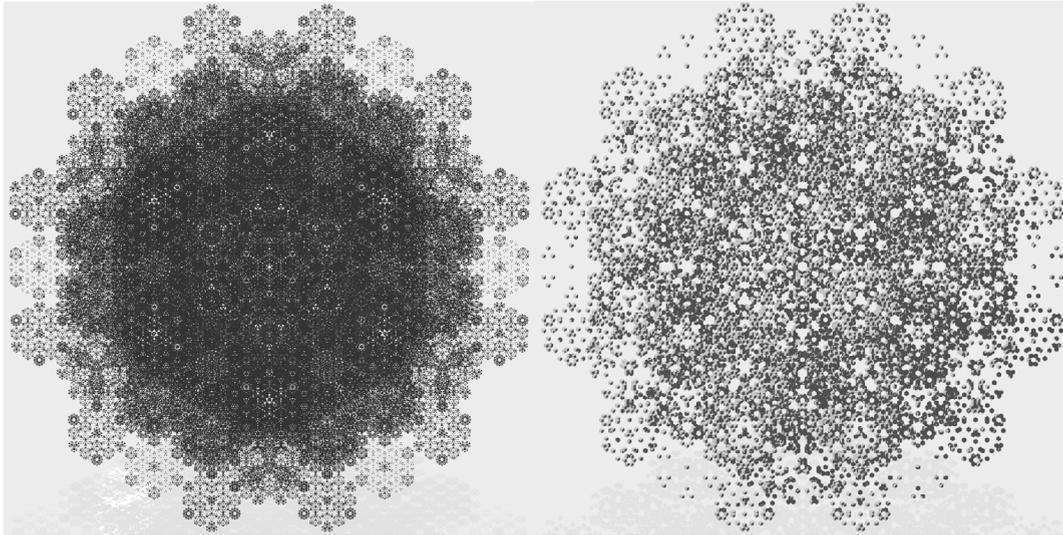


Fig. 1. Fractal social organizations 011112233334 (left-hand side) and 011123334. The modularity emerging in the geometrical representations is a direct consequence of the modularity in the “seeds”.

- A property of the FSO representations is given by *conservation of modularity*: if the FSO seed a is a sub-string of FSO seed b , then the FSO development of b includes, and *is a refinement of*, the FSO development of a . Figure 1 exemplifies this with $b = 011112233334$ and $a = 011123334$.

Because of the above observations, I argue that pictures such as those in Fig. 1 provide a geometrical interpretation of the Leibnizian concept of monad, at the same time offering an exemplification of the static hierarchy of the biota introduced by Hierarchy Theory.

4. Elasticity, Resilience, and Antifragility

A third focus of this paper is resilience and related concepts and methods. As remarked in¹¹, resilience may be defined as “a system’s ability to either absorb or tolerate change without losing one’s peculiar traits or expected behaviors”. As observed in the cited reference, this definition consists of two parts corresponding to the following two features: **evolvability**, i.e., the ability to “alter [ones] structure or function so as to adapt to changing circumstances”³³; and **identity persistence**: an evolving system’s ability to retain one’s features and characteristics in spite of exogenous and endogenous changes. The above two conditions closely correspond to the Aristotelian concept of entelechy. An entelechy is in fact a subject that “brings about their own changes from one state to another” and, at the same time, one that “exercises activity in order to guarantee one’s identity” or “to comply to one’s *definition*”³⁴. The above two constituent aspects are elegantly rendered by Sachs’ translation of entelechy as “being-at-work while staying-the-same”³⁵. This highlights the two constituent properties of a resilient system or being: (i) being able to persist one’s uniqueness—one’s identity—throughout time; (ii) being able to manifest/construct and persist oneself in the physical world. We end up with another dualism, strictly related to the System of Leibniz discussed in Sect. 2.

Now, manifesting/constructing one’s identity requires a design; and due to economic considerations related to physical and/or biological constraints, said design calls for the adoption of trade-offs regarding the practical organization of a system or being (cf. for instance³⁶ and³⁷ for practical examples of and justifications for the introduction of these design trade-offs). Thus “materialization” (in the sense elucidated in Sect. 2) inherently implies a hard coupling with a *reference environment*, namely an hypothesized set of average “operational” environmental conditions. Resilience refers then to the following two major abilities: (i) the (static) ability to absorb fluctuations in the experienced environmental conditions. This ability is known as *elasticity* and corresponds to being able to mask change through the adoption of a predefined amount of redundant resources; (ii) the ability to adjust dynamically one’s “materialization” and to operate actions, both individually and socially, such that changes are tolerated—I call said ability *entelechism*.

From a systemic point of view, elasticity corresponds to simple purposeful behaviors, namely behaviors that are non-teleological¹⁸. On the contrary, entelechism mandates complex cybernetic behaviors embedding feedback loops to guide one's action towards the intended goals¹⁸.

The difference between the two approaches may be better understood when considering a particular context. In the framework of information theory, for instance, a well-known result by Shannon³⁸ tells us that it is possible to transfer reliably a message across an unreliable channel by “sufficiently” replicating the message. The problem is of course learning what is the “right amount” of replicas. A strategy to deal with this problem is to monitor the channel and identify a “worst case”: we could find out for instance that five replicas of each message are sufficient to guarantee reliable transmission across the channel. That is a typical elastic strategy. The major benefit of elasticity is simplicity: the transmitter does not need to enact any complex behavior and it can be completely unaware of the actual condition of the channel—in other words, no interaction with the environment is either foreseen or required. Elasticity is pure and context-agnostic replication. Two are the negative aspects of elasticity: first, it is based on a “snapshot” of the environment taken in the past. In other words, it refers to a situation that possibly has changed; secondly, it equalizes all actual conditions to the worst case. Thus if the worst case only occurs occasionally, elasticity makes use of an unnecessarily high amount of resources.

From the above discussion I conjecture that the HT role of **replicator** closely corresponds to elastic strategies. This may become more apparent when considering the case of transmission through a temporal (or, better, a genealogical) channel rather than through a spatial channel.

A second strategy is to have the transmitter monitor the channel; extrapolate the unreliability of the channel during the next transmission time; and adopt a degree of redundancy best-matching the extrapolated conditions. This complex teleological behavior is one of entelechism. Entelechism implies a complex interaction with the environment and the ability to execute extrapolations. It also implies the ability to enact corresponding measures to reach the intended goal—in this case, reliable transmission. This extra complexity is the major negative aspect of entelechism.

From the above discussion one can see that entelechism is a strategy of open systems able to become aware of the environmental conditions and to exercise complex cybernetic behaviors on their environment; because of this, I propose here to associate entelechies with HT **Interactors**.

4.1. Computational Antifragility

As mentioned above, a key requirement of resilience is identity persistence. In some cases, however, preserving the identity of the system does not appear as the most desirable course of action. As the environmental conditions change, it may make more sense to *adjust* the identity of the system so as to adopt a “form” more profitable with respect to the original identity. Natural evolution provides a clear example of the benefits of such a strategy. Works such as³⁹ show a growing interest towards a different approach to resilience based on system identity evolution. In¹² I discussed this problem and hypothesized that a possible strategy should combine elasticity, entelechism, and (machine) learning. Computational antifragility is the name I use for this class of strategies^{12,40}.

Whatever the design direction, we need to look at nature and change the paradigm of resilience from “being at work while staying the same” to “being at work while getting better”, namely becoming a better system or being. With Leibniz's words we could say that, through “a certain divine mathematics”² we need to learn how nature makes it possible that “something greater will emerge”⁴.

5. Conclusions

Paraphrasing the Authors of¹⁵, I am convinced that “Incorporating insights from the hierarchy theory of evolution and from network theory provides a more complete theoretical framework for explaining complex patterns and processes of biological” (and artificial) “evolution”. Quoting Kenneth Boulding, this paper contributes to this process by “point[ing] out similarities in the theoretical constructions of different disciplines” and in particular providing preliminary elements for discussion about the implications of Hierarchy Theory on the design and evolution of artificial systems and socio-technical organizations. The engineering of resilient communitarian responses to crises and disasters and, in general, the design of more resilient and antifragile socio-technical systems and organizations constitute a natural direction for the profitable application of the insights gathered through this and other cross-disciplinary dis-

cussions. Recently started project “SELFSEV” provides another direction, in which a fractal social organization for the optimal management of the diabetes pandemic is being proposed⁴¹.

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