Foreword: Emergence. An Interdisciplinary View

Introduction

What is there in this world? Matter; it is the basic fabric of the physical reality, would be the straight answer. What is what we see and experience? This is tantamount to asking "how can we know it ?". How can we know whether what we see is the result of the perpetual unfolding of a handful of simple rules repeated over and over again on the basic tenets of the physical reality, or is it that there are endless physical realities each with own distinct rules and specific connections with its neighboring physical realities? Formulated in this way, we have the issue aligned with two seemingly irreconcilable schools of thought, those who hold that there exists a finite set of fundamental laws which resonate at every level of the physical reality, the Reductionists, and those who claim that the laws applying at each level are unique and though consistent with them, irreducible to those of the lower levels, the Emergentists.

In sharp contrast to the blatantly simple Reductionist's hypothesis, i.e.: since all is composed of matter and only matter, all can be explained by the laws of matter, Emergentist's claim that matter is hierarchically organized in distinguishable levels of organization, and that such organizations are causally effective. Even more, the laws of matter do not apply at every level of organization. Different levels of organization have there own laws and features, they claim. The latter include, (i) the very existence of multiple levels of organization, (ii) the existence of individual agents at the lower level who operate following simple rules, and (iii) that the higher level aggregate behavior does not derive from the lower level simple rules.

A century before Emergence was even introduced as a scholarly term, Adam Smith wrote [1]: " … every individual … neither intents to promote the public interest, nor knows how much he is promoting it. … he intends only his own security; and by directing that industry in such a manner as its produce may be of greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention. … By pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it." It sounds astonishingly adequate for what it could be taken nowadays as a canonical example of Emergent phenomena.

Since then, Emergence has made a long way and its meaning has been crafted relentlessly till the point that today we have a meaningful theory of emergence at the various levels of organization that can be applied to almost all natural and social sciences alike. Here we sketch a descriptive overview of the phenomenon of emergence, aimed at serving as an introduction to the following contributions of this thematic interdisciplinary issue on Emergence.

1 Adam Smith, "The Wealth of Nations (1776)", p. 423, Modern Library, New York (2004).

Emergentism and Reductionism

Answering "What is there in this world?", requires in the first instance providing us with some criteria for picking out real “entities”. Customarily such reasonable criteria start out by providing some statement whose veracity is admitted not to be open to question, and then entities are tagged as real if they concur with such criteria, or can be derived from them via legitimate inferences. Finding precise formulations for criteria like this has turned out to be a difficult task, though.

Alternatively, one can opt for criteria exhibiting relative reliability, closer to the kind used by working scientists in deciding whether their results are trustworthy. Among them, the one referred to as *robustness,*[2] is laudable for its versatility. It reads as: *Entities are robust if they are accessible (detectable, measurable, derivable, definable, producible, and the like) in a variety of independent ways*. It is clear that robustness applies to both, “objects” and the “structural features” stemming from the specific ways these objects arrange themselves as a consequence of their mutual interactions. Consequently, robustness can equally be applied to material stuff, its properties, its internal connectivity, and can also be utilized for the demarcation of parts and the whole of the systems under consideration. Furthermore, the constraints imposed by the fact that the means of accession must be many, diverse and independent implies that the concept of accessibility is not restricted to “experimental manipulation”, but it should also be extended over the realm of logical or mathematical derivation, and to the many spots in between.

The above outlined approach sets on firm grounds the analysis of the so-called causal relationships derived from the “mutual interactions” among the constituent parts, along with their internal connectivity which reflects the “structural features” of the actual arrangement of the material stuff of the system. Causal relationships yield patterns of causal networks. These networks, under some constraints, arrange into higher-level patterns known as *levels of organization*, which consist of hierarchical divisions of stuff (not necessarily only material stuff) organized by part/whole relationships. This constitutes a central concept for the present issue.

The formation of the first starts, the nucleosynthesis which made the heavier-than-hydrogen nuclei, the coalescence of electrons from the plasma into the vicinity of these nuclei, liberating the photons to make the light and releasing the Cosmic Microwave Background Radiation, and yielding the atoms which subsequently bound to each other to make molecules, and so on, yield specific *levels of organization* each having a radically distinct organization of matter, increasing in complexity and bearing their own rules and causal relationships.

The notion that at (sufficiently) complex levels of organization, under certain constraints, novel properties (and/or substances) may arise out from the mutual interactions of the constituents’ parts of the lower level of organization and yet the former are irreducible to the latter is referred to as *Emergence* [3].

For instance, the electrons and nuclei of a metallic crystal are organized by its electronic, fermionic band structure with the one-electron-per-state (spin-orbital) rule which dictates the conductive (or insulating) properties of the electric conducting (or insulating) state. At a higher level of organization, under special constraints, the nuclear vibrations (phonons) can interact with the (valence) electrons resulting them

2 W. C. Wimsatt, “The Ontology of Complex Systems. Levels of Organization, Perspectives, and Causal Thickets”. Can. J. Philo. Suppl. Vol. **20,** 207–274 (1994). doi:10/1080/00455091.1994.10717400.

3 M. Bunge; “Emergence and Convergence. Qualitative Novelty and the Unity of Knowledge”, Toronto University Press, Toronto, Canada (2014).

arranged in the so-called Cooper pairs. Cooper pairs behave as bosons (resulting from the singlet-spin pairing of two fermions) and can coalesce, at sufficiently low temperatures (the constraint), into a single-for-all *robust* and coherent Bose-Einstein condensate, which can conduct electricity without resistance giving rise to the superconducting state. Thus, we see that the interactions between the constituent parts of the lower level of organization, electrons and nuclear phonons, yield, under certain constraints, an entirely new and unexpected kind of matter (bosons "made" from the fermions) with the subsequent emergence of an unexpected property, superconductivity, at the higher level of organization.

Emergentism claims that the world is entirely made of a layered strata of levels of organization, physical structures which may be either simple or complex. But, the complex ones are not mere aggregates of the simpler ones. Each layer (level of organization) hosts the appearance of "novel qualities", arising from but not present in the lower layers. And even though, one may think that lower level properties constitute primitive causal powers, it is at each higher level of organization, not below, where the laws connecting its emergent physical structures and properties should be looked for. Emergent laws are simply not present at the lower level of organization.

In order to put Emergentism in its proper perspective let us briefly comment on its "antagonist" methodology for analyzing the world, the Reductionism. Here the explanatory strategy consists of breaking down complex physical systems to the point where no further breaking is possible. Such indivisible parts should, by assumption, exhibit less complicated properties and thereby will likely reduce collective complex behavior to combinations of simpler smallest units.

Leibniz's calculus [4], a landmark advancement in mathematics, illustrates well these ideas, for he presented a procedure to reduce complex processes down to their infinitely small, infinite "simple" components, i.e.: the "infinitesimals"; so small that are devoid of any complexity. According to Leibniz all complex processes can be chopped down into a series of infinitely small, infinite simple tractable events. Then, the overall process is simply described by properly adding up the outcomes of these events.

The promise of Reductionism is that the (re)construction of complex collective behavior of physical systems starting from the properties of their smallest components is doable. Namely, Reductionism advocates for the quest of a discrete world and of explanations framed at the lowest-scale size from which complexity arises from simple operations repeated a myriad of times. All what remains to do is then to find out the algorithm underneath these operations. [5]

This is the dream of reductionists, the idea that there should exist a unique all-embracing ultimate fundamental theory, where all nowadays existing theories should converge to and merge in it. The earlier successes of reductionism in the analysis of phenomena (not all phenomena) susceptible of decomposition, have given the false impression that investigating the interactions of the lower-level components is more informative than investigating the organizational features of these components at the higher-level. If the lowest, most fundamental level of organization can be found and the properties of its parts understood, theoretically described and codified in precise laws, then starting from these informations one should, by simply applying legitimate inferences, be able to find all possible higher levels of organization and fully describe their intrinsic properties. After all, is it not the most fundamental goal

4 Leibniz published his calculus in 1684. See: J. Echeverría, "Leibniz, el archifilósofo", Plaza y Valdés, Madrid (2023). ISBN:978-84-17121-72-3

5 D. Chandler, "Is the Universe a giant(quantum) computer?", Nature, **620**, 943–045 (2023)

of science to give an intelligible theoretical description of "disparate" phenomena by accounting for them all on the basis of the "primogenial" principles assisted by logically correct inference rules ? Namely, to find the explanation for the world and for all it contains.[6]

It sounds like a commendable aim, but it faces a number criticisms that should be given serious consideration. We enumerate some below.

First, it is well documented the existence of observable and measurable phenomena at the macroscopic (high) level which are insensitive to the finer microscopic (lower) level details, i.e.: they are robust at their level of organization. These properties are well understood and have been successfully codified by means of high-level laws, which have been found to be irreducible to the more fundamental laws of the lower level. The existence of such properties is utterly relevant for they pose a challenge to the usefulness (perhaps uselessness is more appropriate) of the tentative unique all-embracing ultimate fundamental theory, because it shows that for at least some fundamental facts of nature, the all-embracing ultimate fundamental theory is irrelevant.[7]

Second, higher levels of organization have always much longer response times than the lower levels. Consider biological time scales: biochemical ~1 second; metabolic ~1 minute; epigenetic ~1–10 hours; developmental ~days–years; evolutionary ~10^3–10^6 years. Thus, since reducing biology to quantum mechanics requires solutions of its Hamiltonian with an energy accuracy $\Delta E \sim \hbar/\Delta t$, where $\hbar = 1.054 \times 10^{-34}$ Joule×second is the reduced Planck constant, it turns out that even for the shortest response-time biological processes we are requiring an energy accuracy of ~10^{-34} Joule. This is at least ten orders of magnitude more accuracy than what the currents measurements of electron dynamical processes could offer.

Third, theories are expressed in terms of consistent mathematical logical systems. Now, Gödel's second incompleteness theorem proves that for such mathematical systems there are always "truths" that cannot be demonstrated within the system by its own axioms and rules of inference[8]. They are inevitably incomplete for there always be "truths" in the system that require methods of proof and points of view that transcend the system itself. The direct implication is that all theories formulated in terms of consistent mathematical systems are infinite in the sense that new discoveries (the "truths" mentioned above) will always be possible, so they will come sooner or later, leaving the existence of the unique all-embracing ultimate fundamental theory in a delicate position, to say the least.

Fourth, the process of theory reduction, whichever it is, assumes that the set theories being reduced can always be totally ordered.[9] That is true for classical theories presupposing a Boolean propositional logic, but it is not for quantum theories, for instance. The latter, thus, constitutes a set of theories which cannot be totally ordered, and consequently, cannot be reduced.[10]

6 S. Hawking in his "Brief History of Time" (Bantam Press, London, UK, 1998) wrote: "... I still believe there are grounds for cautious optimism that we may now be near the end of the search for the ultimate laws of nature". Chapter 11.

7 R. B. Laughlin and D. Pines; "The Theory of Everything", Proc. Natl. Acad. Sci., **97**, 28–21 (2000)

8 K. Gödel; "Some Basic Theorems on the Foundations of Mathematics and their Implications", Collected Works. Vol. II. Unpublished Essays and Lectures. S. Feferman et al., eds. Pages 304–323. Oxford University Press, New York (1995)

9 H. Primas; "Chemistry, Quantum Mechanics and Reductionism", Lecture Notes in Chemistry, Vol. **24**, Springer-Verlag, Berlin (1983).

10 H. Primas; "Theory Reduction of Non-Boolean Theories", J. Math. Biology, **4**, 281–302 (1977)

On the other hand, Emergentism is customarilly defined in terms that oppose to bottom-up causal relationships between the levels of organization, because of the fundamental discontinuity of the physical laws among the various levels of organization of the physical systems. [11] Thus, the world is seen as stratified in a number of distinct levels of organization, with a strong hierarchical rule for the decomposition of the higher- into lower-level ones. Namely, "decomposition" is allowed but "reconstruction" is (often) forbidden. Furthermore, Emergentism claims that it is in principle impossible to derive the higher-order behavior even from complete knowledge of the lower-level behavior. In order words, only after having had observed the emergence of a higher-level emergent property, we realize that even having had a complete knowledge of all properties of the lower-level components along with their mutual interactions, one could never have predicted[12] all properties of the higher-level organization.

This conceptualization of Emergence, though, has received substantial criticism. Perhaps, the most acute objection, formulated by Kim, states that emergence could equally well be described as epiphenomenal, i.e.: secondary phenomena seen at the higher level concurrent with the setting of the lower level "necessary conditions", but not necessarily having caused by them. [13] The full formulation is subtle and knotty, but can be (over)simplified to something like this. Assume (i) no magic, (ii) that all composite systems are made of simpler parts, and (iii) that these parts plus their causal powers (i.e.: physical properties) constitute the substrate of any physical interaction. Then, all properties of higher order organizations (make of these same parts and nothing more, no magic !) must ultimately be realized by these more basic interactions among the parts. This objection has a close connection with the concept of supervenience: the "relationship" that emergent properties have to the base properties that give rise to them. The "relationship" implies that there cannot be emergent properties without a change of the physical substrate properties, a change that can only be produced by the emergent properties themselves, and consequently leads to a circular erroneous argument with properties of the parts explaining the properties of the composite which explain the properties of the parts, and calls for a clarification of the part/whole (composite system) issue.

Humphreys has provided one,[14] not the only one. He argues that parts should and are changed by virtue being engaged in interactions with each other when included in larger composite entities. Thus, what were once independently identifiable parts cease to exist anymore, breaking the circularity mentioned above so that we get emergence back into sound conceptual ground. [15]

Two additional remarkable advancements made recently are also worth mentioning. The first and perhaps the most influential advancement made in the field is the inclusion of the dynamic perspective for the study of distinctive and discontinuous changes in aggregate behavior triggered by lower level dynamics. Specifically, phenomena like the growth of snow crystals (fractality), or the transition to the superconductivity state at low temperatures, provide a set of so-called self-organization processes [16] that concur with the general criteria of emergence phenomena: high-level organization properties emerging from parts lacking such properties.

11 J. A. de Azcárraga; "Reduccionismo y Emergencia, de nuevo", Rev. Esp. Fis., **38** 29–36 (2024)
12 Notice that within this context "predict" stands for "not being any physical procedure for the determination of the higher- from the lower-level".
13 J. Kim, "Making Sense of Emergence", Phil. Stud., **95**, 3–36 (1999)
14 P. Humphreys, (a) "How Properties Emerge", Philosophy of Science, **64,** 1–17 (1997). doi:10.1086/392533. (b) "Emergence not Supervenience", Philosophy of Science, **64,** S337–S345 (1997). doi:10.1086/392612.
15 P. A. Corning, "The Re-Emergence of Emergence: A Venerable Concept in Search of a Theory", Complexity, **7**, 18–30 (2002)
16 F. Eugene Yates, A. Garfinkel, D. O. Walter, G. B. Yates (eds.) "Self-Organizing Systems: The Emergence of Order", Springer, New York (2012)

The analytical solution of the equations of motion for these processes is impossible, but they can nevertheless be modeled as step-by-step iterative simulations. Such simulations which proceed to iterate millions of times simple algorithms often yield surprisingly complex behavior that could not even be imagined by the analytical solutions. The concurrent development of appropriate computational methods has enabled the advancement of sophisticated graphical processing techniques for visualizing these highly non-linear dynamical processes "in action" and, more importantly, has provided the means to create "model" systems with full control over the inter-part interaction parameters.

This has paved a new way to think about emergence. It involves algorithms that iterate simple local operations on each of the multiple cells arranged in large arrays, a construction known as the *cellular automata*. Computation demonstrates that often complex dynamical regular patterns do spontaneously show up. [17] It is this logic of generating complex patterns out of simple iterated operations that has became a new paradigm of emergence. Even more, the analogy of this logic with that of the many natural processes that involve local interactions has spawned claims that it could offer a better frame to understand complex phenomena in general. [18]

In this vein, the exploration of non-equilibrium dynamic systems has revealed interesting behaviors. Probably the best well-known case is that of the "attractors", discovered by Lorenz in 1963 while studying the computational modeling of fluid flow behavior in the atmosphere. He was interested in modeling the way air moves when heated from below and cooled from above.

The model describes [19] how three key properties of this system, x: the rate of air flow, y: the temperature difference between the ascending and descending air columns, and z: the distortion from linearity of the vertical temperature profile. The calculations reveal a pseudo-chaotic behavior for all three properties over time, but the parametric-plot trajectory shows that it remains confined within a finite domain and traces out an orderly twisted butterfly like pattern [20], as seen in Figure 1.

17 P. Larrañaga, V. P. Soloviev. "Elements of Complex Networks", Rev. Int. Estud. Vascos, 68, 2 (2023).
18 S. Wolfram, "Twenty Years of a New Kind of Science", Wolfram Media, Inc., (2023)
19 See the caption of Figure 1 for the detailed equations-of-motion.
20 This brings to the fore the importance of modern graphical processing techniques for properly visualizing these highly non-linear dynamical processes "in action".

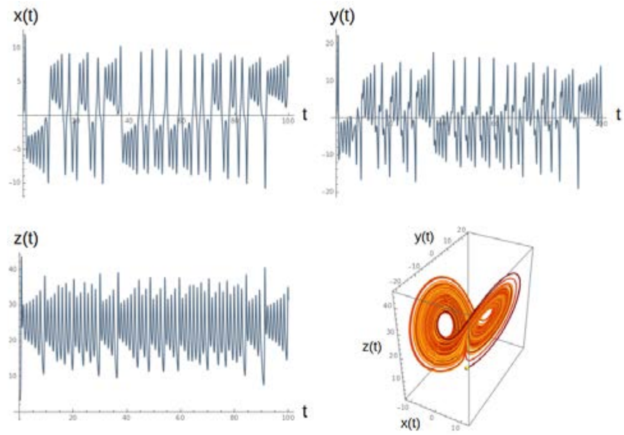

Figure 1. Plots of the x(t), y(t) and z(t) functions and the parametric t-plot of the solutions of the three coupled differential equations-of-motion: dx(t)/dt=a[x(t)–y(t)]; dy(t)/dt=–x(t)z(t)+bx(t)–y(t); dz(t)/dt=x(t)y(t)–z(t), with a=3.0, b=26.5, and the initial conditions, x(0)=0.4, y(0)=0.1, z(0)=4.1. Properties x, y and z and time, t, in arbritary units.

This (Lorenz) attractor is the most widely cited exemplary of what has come to be known as deterministic chaos, which nowadays is part of the more general complexity theory.[21] These methods provide well-defined physical and mathematical examples of processes that generate complex regular patterns from unorganized and often randomly distributed interactions among their parts. In many respects they can be legitimately categorized as emergent phenomena because the generated regular higher level patterns resulting from otherwise unorganized dynamic interactions at the lower level, are no mere summations of lower-level properties, and exhibit characteristics that have no lower-level counterparts. Furthermore, it seem highly likely that the "self-organization", which can arise unbidden in systems fed with either energy, as above, or matter, as in the Brusselator [22], (see Appendix), that prevents them from achieving a static equilibrium may have a part to play in life's orderliness, though it must be kept in mind that life is more that the emergence of "wavy properties" over time.

The second refers to the so-called asymptotic reasoning procedure [23]. In short, there are theories coupled by taking the limit of some critical parameter. Namely, Take Limit(ε⟶0)Tf = Tc, where Tf stands for a finer (more fundamental) theory and Tc for a coarser theory. When the limit-taking operation is "regular," it represents a case of theory reduction, Tf is reduced to Tc at ε=0, but when it is "singular", one can talk only about "inter-theoretic relations". Exemplars of the former include Quantum Mechanics (finer) and Classical Mechanics (coarser), for $\varepsilon=\hbar$, and Special relativity (finer) and Newtonian Mechanics (coarser) for $\varepsilon=(v/c)$ with "v" being the velocity of bodies that are moving slowly compared to the speed of light "c"; and of the latter, Schödinger Quantum Mechanics (finer) and Molecular Electronic Structure Theory (coarser) for $\varepsilon=m/M$, with "m" being the mass of the electron and "M" of the proton.

21 S. Thurner, R. Hanel, P. Klimek, "Introduction to Theory of Complex Systems", Oxford University Press, New York (2016).

22 G. Nicolis and I. Prigogine, "Self-organization in nonequilibrium systems: From dissipative structures to order through fluctuations". Wiley, New York (1977). See also: A. M. Turing "The Chemical Basis of Morphogenesis", Phil. Trans. Roy. Soc. Lond., **B237**, 37 (1952), for an in-depth discussion of the additional effect of spatial diffusion for the emergence of morphogenesis.

23 R. W. Batterman, The Devil in the Details", Oxford University Press, New York (2002)

Notice the essential role of the singular nature of the limiting behavior of some properties which may change abruptly at the limit, because they show a limiting behavior radically at variance to the one exhibited in the limit. Notice also, that this does not require different levels of physical organization, all takes place at one single level. This is why it is occasionally referred to as epistemological emergence.

The asymptotic reasoning (AR) has spurred some vivid debate about the explanatory values of theories.[24] Thus, in accordance to AR, the finer theory cannot account for an explanation of the coarse regime properties possessing a singular behavior at the ε⟶0 limit, as pictorially illustrated in Figure 2. One clearly needs to bridge the gap in order to extend the explanatory adequacy of the finer theory over the coarser regime.

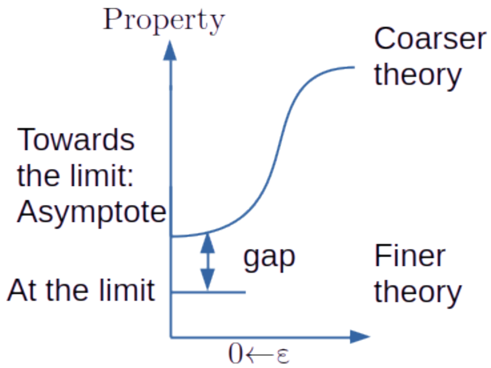

Figure 2. Limiting process of a "Property" which depends on parameter, ε, when it is taken to zero.

The critics challenge the ascribed explanatory inadequacy to the finer theory by claiming that it should contain, at least in an approximate sense, the elements of physical interpretation of the coarser theory. Hence, one can replace the elements of physical interpretation of the coarser theory by those of the finer and, if such interpretation provides understanding then the finer theory is perfectly explanatory adequate. [25] The discussion, however, has come (apparently) to an end [26] by pointing out that such replacements are not necessarily conductive to "understanding". The alternative provided by AR consists of assimilating key aspects of the coarser theory into the finer theory to build the gap's bridge at the asymptote domain.

The case of the electronic structure theory is paradigmatic in this respect. By including classically behaving nuclei into the quantum Schrödinger equation renders an adequate explanation of the chemical bond [27], and furthermore open avenues for new concepts like adiabatic and non-adiabatic molecular quantum states which in turn provide adequate explanations for many phenomena associated with the dynamics of the chemical bonds.

Following these developments, the concept of emergence has spread to many fields, both in natural and social sciences alike. [28] It is regularly applied whenever spontaneous generation of regular and stable robust patterns arise from the concerted unorganized interactions of component parts, and whenever

24 M. Redhead, " Discussion Note: Asymptotic Reasoning", Studies in History and Philosophy of Modern Science, **35**(B), 527–530 (2004)
25 G. Belot, " Whose Devil ? Which Details ? ", Phil. Sci., **72**, 128–153 (2005)
26 R. W. Batterman, "Response to Belot's " Whose Devil ? Which Details ? "", Phil. Sci., **72**, 154–163 (2005)
27 G. Frenking and S. Shaik, "The Chemical Bond", Vol I, II; Weinheim, Germany (2014)
28 O. Artime, M. De Domenico, "From the Origin of Life to Pandemics: Emergent Phenomena in Complex Systems", Phil. Trans. R. Soc. A **380**, 20200410 (2022).

singular behavior of the limiting relationship between finer and coarser theories turns out to be relevant to the phenomena of interest, in such a way that it prevents theory reduction and prompts emergence of key bridging features at the limiting asymptotic region.

Without trying to be exhaustive, let us comment briefly on the specific manners in which emergency enters in a number of social sciences disciplines.

Thus, admitting that human behavior is not predictable as it is physical phenomena, and that Economy is deprived of “universal” empirical regularities, the well documented existence of so called “stylized facts”, i.e.: common patterns observed across different economic data sets, lends support to the usage of the theory of complex systems in order to construct global economy models. [29] In particular, financial crisis could be associated with “critical points”, and one can speak about the “turbulence” exhibited by financial data. Consequently, emergence pops out as an efficient explanatory element. However, due caution must be exercised for such adequacy suffices to justify a “formal” analogy between economic systems and complex systems’ behavior, but in any case can one justify a “material” analogy. Formal analogy serves descriptive purposes and entails (some) predictive power. But it lacks explanatory power, in a causal sense, because it does not inform about what causal relation makes up the fabric of the system of interest. Hence, it prevents knowing which interventions could be effective towards achieving a given goal. To this end, a material analogy between the economic reality and the complex system’s tenets, must be constructed alongside the formal one. This requires additional “idealizations” of the economic system. Some models are prone to such idealizations, others are not. [30]

However, other social sciences disciplines, have recently opted for examining emergent phenomena without grounding in complexity theory. Law studies constitute a canonical exemplar of this move. Thus, in the recent essay by Tamanaha [31], five additional emergent traits are identified in order to rationalize the transition from simple rules of social intercourse (relations among individuals) to the more complex and holistic rule-of-law societies [32]. All five Tamanaha’s traits pose tough challenges to the configuration of law, and portrait rule-of-law societies as emergent wholes whose existence requires profound social transformations. Such transformations involve the rise of social organizations, and come concomitant with the setting of legally regulated societies. However, its emergent nature confers a distinctive differential status to the rule of low society. Legally regulated societies can exist alongside an authoritarian policy that does not operate constrained to legal regulations.[33]

Consideration of emergence theory has been found suitable to account for and put into proper perspective some of the legal challenges posed recently by the implementation of advanced machine learning powered artificial intelligence (AI) using technologies, which basically belong to the private law domain [34].

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29 T. Cooley, ed. “Frontiers of Business Cycle Research”. Princeton University Press, (1995).

30 P. Palacios, J. S. Jhun, “Statistical Mechanical Models of Finance”, in The Routledge Handbook of Philosophy of Scientific Modeling, London (2024).

31 B. Tamanaha, “Law’s Evolving Emergent Phenomena: From Rules of Social Intercourse to Rule of Law Society”, Washington Univ. Law Rev., 95, 1149–1186 (2018).

32 Stripped of all technicalities, this refers to a governance whose actions are bound by rules fixed and announced beforehand. Such rules should make it possible to foresee with fair certainty how the authority will exercise its coercive powers in all given circumstances, so that it enables individuals to plan their actions based on this knowledge. See: L. Fuller, ”The Morality of Law”; p. 38–39, Yale University Press, USA (1969).

33 R. Geuss, “History and Illusion in Politics”, Cambridge Univ. Press, London (2010).

34 S. Esayas, ”The Important Role of Emergence in Conceptualizing the Challenges of New Technologies to Private Law”, Eur. Private Law Rev. 31, 779–822 (2023).

In particular, two legal aspects have been considered in this respect, (i) the attribution problem and (ii) the intellectual property law problem.

Consider the first case first. The autonomy of AI systems stems from their ability to learn and act accordingly in circumstances not foreseen by their creators. This can clearly be seen as an emergent property. For that reason, attributing liability under such instances may lead to the fallacy of division, consisting in attributing properties of the whole to its parts. Notice that in tort law this scenario could result in a "victim without perpetrator" case, and lead to deny compensation in a situation involving AI technologies, whereas there would certainly be a compensation in a functionally equivalent case involving conventional technologies. The surge of AI using technologies obscures establishing the "proof of causation".

For the latter case, imagine a telescope coupled to an AI assistant program which instructs autonomously the telescope where to aim at. Now, imagine that it discovers an unknown planet, and subsequently by analyzing the received spectral light probes its "atmosphere", which yields sound evidences for the presence of living organisms on that planet. Then, the AI assistant calls ChatGPT to write a manuscript which submitted for publication. After going through the usually demanding peer-review procedure, the manuscript is accepted and published. Stretch your imagination a bit further to imagine that such research is awarded the Nobel Prize. Now ask yourself, to whom will be presented the Prize in Stockholm ? Cases like this, perhaps less dramatic, are or will surely be ubiquitous in creative and/or innovative arts, for example. The problem of ascribing authorship and intellectual property arises from the fact that the operation of the AI programs cannot be traced down directly to a single identifiable "human source", which clashes with the current intellectual property law's fixation on human actors as the center of all creativity.

The discussion based of emergent properties merges the law and technology approaches, and as such can help identify the circumstances under which technological changes give rise to legal problems. In particular, it may explain how the aggregation of a number of perfectly compliant acts may result in a whole which is not compliant with the law. This emphasizes the need for recognizing emergence as an important asset to put in proper perspective complex law problems.

In sociology, emergence theory has been mainly engaged with the so-called "Collectivist theory" of social phenomena, and has recently spurred great interest as a promising response to the so-called "Methodological Individualistic" approach with contends that the micro-to-macro emergence of social phenomena commences from the individuals' actions, so that the explanation of emergent social behavior(s) should not be seen as incompatible with reduction to individual level explanation.

Contemporary sociology theorists, though, draw explicitly on emergence which within this context, is referred to as the "Collective view of social behavior emergence". Nowadays, at least three distinct flavors can be distinguished. Namely, firstly, Blau's structuralist view [35] maintains that the major terms of macro-sociological analysis refer to emergent properties of population structures that have no equivalent in micro-sociological prospection. Secondly, Bhaskar's transcendental realism [36] holds that social reality is stratified, and if ontologically dependent on it supervenient individuals' actors it is irreducible to them,

35 P. M. Blau and R. K. Merton, "Microprocesses and Macrostructure", p. 83–100, in "Social Exchage Theory", K. S. Cook , Ed., Sage, Newbury Park, USA (1987).

36 R. Bhaskar, "Emergence, Explanation and Emancipation", p. 275–310, in "Explaining Human Behavior", P. F. Secord, Ed., Sage, Beverly Hills, USA (1982).

and even it is autonomous from them. Bhashar maps 1:1 emergentism and realism, meant that realistic explanations correspond to genuinely emergent phenomena, and that emergent phenomena require realistic explanations. Thirdly, Archer in her morphogenetic dualism approach [37] argues that social behavior emerges from individual behavior which are prior to the emergent behavior. Once such social behavior has emerged, it becomes autonomous of its emergence base, and such autonomy entails independent causal influences in its own right. It is the emergence “over time” (morphogenesis) that makes emergent structures real and allow them to constrain individuals via downward causation.

All three approaches have been thoroughly revised and some of their deficiencies and shortnesses, such as lack of clearness in account is downward causation mechanisms, or supervenience relation between societal and individual levels, have been recently highlighted. [38]

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37 M. S. Archer, “Realistic Social Theory: The Morphogenetic Approach”, Cambridge Univ. Press, New York, USA (1995).

38 R. Keith Sawyer, “Emergence in Sociology: Contemporary Philosophy of Mind and Some Implications for Sociological Theory”, Am. J. Sociology, 107, 551–585 (2001)

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Summary

The ubiquitous reductionism approach that has plagued (almost) all areas of all sciences, fueled by the utilitarian character of some contemporary research programs, has brought in too much emphasis on reporting "unrelated" observations, and stripping off the bigger picture view, consisting in integrating the observations into newly emergent patterns. [42] In this vein, Emergentism has lately made its (re)debut and helped to lift up the tight constrained views of the reductionistic approach and to open sights to a broader and richer domain for the scientific endeavor. After all, "unrelated" knowledge is confusing and utterly useless, to say the least. The bigger picture matters.

Emergentism appears in various diverse disciplines. [43] Despite the slight differences of meaning among them, the concept of emergence is agreed to refer to the arising of robust, novel properties and patterns due to some singular ways of organizing the parts of the system into the whole. The process of organization needs to generate complexity at a higher-level, from which the new properties emerge by averaging out irrelevant details and bolstering the essence of the robust new property or pattern. Emergent phenomena share a number of features [44] that identify them as emergent: (i) Radical Novelty, (ii) Robustness and Coherency, (iii) Complexity at the higher levels of organization, (iv) Ostensiveness: emergents are "ostensively" recognized by showing themselves. This sets a common ground for natural and social sciences alike which enables direct interdisciplinarity to be exercised in a natural way.

All in all, this issue collects a number of selected scholar contributions aimed (i) at illustrating how emergent phenomena is projected out from a number of diverse disciplines, and (ii) at showing that once stripped off from subjective impressions, serendipitous novelty, [45] or merely epiphenomenal concurrence, emergence studies deserve to be push beyond any sort of well-trodden metaphorical value into the realm of rigorous scholar investigation.

42 "There are rushing waves … mountains of molecules, each stupidly minding its own business … trillions apart … yet forming white surf in unison". Quoted from: R. P. Feynman; "The Value of Science", Engineering and Science, **19**, 13–15 (1955).

43 E. Onnis; "Emergence: A Pluralistic Approach", Theoria, **38**, 339–355 (2023). doi:10.1387/theoria.23972.

44 J. Goldstein; "Emergence as a Construct: History and Issues", Emergence: Complexity & Organization, **1**, 49–72 (1999). doi:10.1207/s15327000em0101_4.

45 J. Holland; "Emergence: From Chaos to Order", Addison-Wesley,Reading, MA, USA (1998).

Appendix

The Brusselator is a canonical example of a chemical oscillator, a class of complex systems exhibiting fundamental differences with respect to the more familiar mechanical oscillators. When a chemical reaction oscillates never goes through its equilibrium state. Indeed chemical oscillation phenomena appears at far-from-equilibrium conditions. In this vein, Prigogine et al., at Brussels, pointed out that open systems, i.e.: systems that can exchange either matter or energy with their environments, when kept far from equilibrium could also get self-organized by dissipating energy or matter to compensate the entropy reduction in the system, and so sustain oscillations mediated by a continuous exchange of matter/energy with the environment. The spatial or temporal structures that arise in this way are called dissipative structures.

The Brusselator consists of an open chemical system undergoing the (i)–(iv) reactions, annotated below:

(i) $A \rightarrow X$
(ii) $2X+Y \rightarrow 3X$
(iii) $B+X \rightarrow Y+D$
(iv) $X \rightarrow E$

The overall reaction is $A+B \rightarrow D+E$, and the concentrations of all these four species are kept constant, A and B are supplied and D and E are removed from the reactive domain. The concentrations of the intermediate species X and Y are allowed to vary in time. Consequently, the rate equations (equations-of-motion) for species X and Y are:

(v) $dx(t)/dt=-a+x(t)^2y(t)-b\,x(t)-x(t)$
(vi) $dy(t)/dt=b\,x(t)-x(t)^2y(t)$

Notice that we have set all rate constants $k_i=1$, (i=i–iv), for convenience.

The solution of the coupled rate equations (v)-(vi) with, two sets of steady concentrations for species A and B, and two initial concentrations for X and Y are shown in Figure A1. It is observed that the concentrations x(t) and y(t) of the X and Y species, respectively, behave differently with respect to the steady fixed concentrations of A and B, irrespective of their initial concentrations, x(0), y(0). Thus, when a=1.0, b=2.2, both X and Y concentrations, after in initial jump, acquire an oscillatory behavior with equal frequency and intensity for both x(0)=y(0)=0 and x(0)=y(0)=2, as shown in the top two panels of the left hand side of Figure A1. Similarly, when a=1.05, b=1.70, after the initial jump, the concentrations of X and Y behave identically irrespective of the initial concentrations x(0)=y(0)=0 and x(0)=y(0)=2, as shown in the top two panels of the right hand side of Figure A1. However, the behavior is radically different, while the former features a sustained oscillations, the latter features a flat constant concentration over time.

The bottom panels of Figure A1 shown the corresponding t-parametric plots of y(t) vs. x(t). Thus, the bottom left panel shows y(t) vs. x(t) for a=1.0, b=2.2 and both x(0)=y(0)=0 (blue curve) and x(0)=y(0)=2 (red curve). Note that despite they begin at very different points (highlighted by their corresponding dots) both trajectories end up in the so-called limit circle around the attractor which is located at the (x=a, y=b/a) point.

Conversely, for the steady concentrations a=1.05, b=1.70 both trajectories fall onto the attractor, irrespective of their initial point, as shown in the bottom right panel.

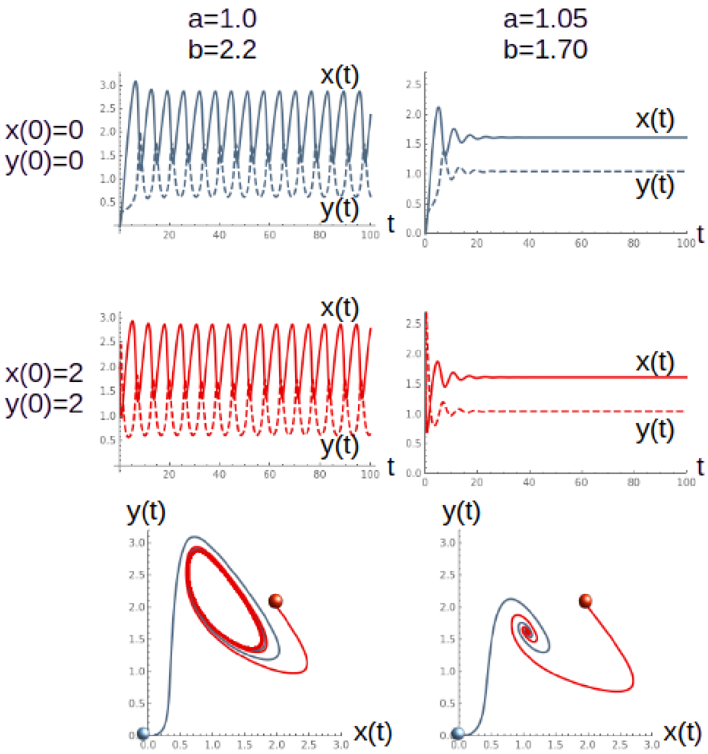


Figure A1: Plots of the x(t) and y(t) functions solution of the coupled equations-of-motion (v)-(vi), top four panels, for selected steady concentrations a and b of species A and B, and initial concentrations x(0), y(0). The t-parametric plots of the corresponding trajectories, bottom two panels. The initial points are highlighted by the dots. Concentrations and time in arbitrary units.

The criticality of this behavior is established at $b_C=1+a^2$. Thus, for $b>b_C$, the system presents an oscillatory pattern for the concentrations of both X and Y, species over time, while for $b<b_C$ they are in a steady constant concentration regime. Namely, the system "self-organizes" responding differently to external conditions above and below the critical parameter.

When spatial diffusion is taken into account, the modified equations-of-motions can be expressed as:

(vii) $dx(r,t)/dt=-a+x(r,t)^2\ y(r,t)-b\ x(t)-x(t)+\mathcal{D}x\ (\partial^2x(r,t)/\partial r^2)$

(viii) $dy(r,t)/dt=b\ x(r,t)-x(t)^2\ y(r,t)+\mathcal{D}y\ (\partial^2y(r,t)/\partial r^2)$

where the $\mathcal{D}$'s stand for the Fick's diffusion coefficients, and r for the spatial coordinate. The solutions, x(r,t), y(r,t), of the coupled differential equations (vii)-(viii) reveal that in addition to the limit cycle, non-uniform steady states may also appear. Turing was the first to draw attention to these kind of states in chemical reactive open systems in his seminal paper about morphogenesis, where the limit cycle becomes also space dependent and leads to the so-called chemical waves.

Emergentzia. Hitzaurrea

Sarrera

Zer dago mundu honetan? Materia; "errealitate fisikoaren oinarrizko egitura da" izango litzateke zuzeneko erantzuna. Zer da ikusten eta nabaritzen duguna? Horren baliokide izango litzateke honako galdera hau: «nola jakin dezakegu?». Nola jakin dezakegu ikusten duguna errealitate fisikoaren oinarrizko printzipioen gainean behin eta berriz errepikatzen diren arau sinple batzuen etengabeko garapenaren emaitza dela, edo errealitate fisiko infinituak daudela, bakoitza bere arau propioekin eta aldameneko errealitateekin konexio espezifikoekin? Modu honetan formulatuta, itxuraz bateraezinak diren bi pentsamendu-eskolarekin topatzen gara gai honen inguruan: errealitate fisikoaren maila guztietan dauden funtsezko legeen multzo finitu bat dagoela babesten dutenak, erredukzionistak, eta maila bakoitzean aplikatzen diren legeak bakarrak direla eta haiekin koherenteak diren arren, behe-mailakoetara murriztu ezin diren legeak direla esaten dutenak, emergentistak.

Erredukzionisten hipotesi lotsagabeki sinplearekin kontrastean, hau da: den-dena materiaz eta bakarrik materiaz osatuta dagoenez, materiaren legeen bidez esplika daiteke den-dena, emergentistek diote materia antolamendu edo organizazio-mila bereizgarrietan hierarkikoki antolatua dagoela, eta antolamendu horiek kausalki eraginkorrak direla. Are gehiago, materiaren legeak ez dira aplikagarriak antolamendu-maila guztietan. Antolamendu maila bakoitzak bere lege eta ezaugarri propioak dituela diote. Azken horiek honako hauek hartzen dituzte barnean: (i) antolamendu-maila anitzen existentzia, (ii) arau sinpleei jarraiki diharduten behe mailako eragile indibidualen existentzia, eta (iii) goiko mailako portaera agregatua ez dela eratortzen behe-mailako arau sinpleetatik.

«Emergentzia» terminoa termino akademiko gisa erabiltzen hasi baino mende bat lehenago, Adam Smithek idatzi[46] zuen : «... norbanako bakoitzak... ez du interes publikoa sustatzeko asmorik, eta ez daki, halaber, zenbateraino ari den sustatzen ere. ...bere segurtasuna besterik ez du bilatzen; eta industria edo ahalegin hori bere produkzioa balio handiagokoa izateko moduan bideratzerakoan, bere onura besterik ez du bilatzen eta, kasu honetan, beste kasu askotan bezala, esku ikusezin batek gidatzen du helburu jakin bat sustatzeko, bere asmoaren zati ez zen helburu bat. ... Bere interesa bilatzerakoan, maiz sustatzen du gizartearen interesa, benetan gizartearen interes hori sustatu nahi duenean baino modu eraginkorrago batean». Ideia hori harrigarriki egokia da gaur egun fenomeno emergentetzat har daitekeena adierazteko.

Orduz geroztik, emergentziak bide luzea egin du eta bere esanahia atsedenik gabe bikaintzen joan da. Horren ondorioz, gaur egun organizazio-maila desberdinetan emergentziaren teoria esanguratsu bat daukagu, ia natur eta gizarte zientzia guztietara berdin aplika daitekeena. Jarraian emergentziaren fenomenoaren deskribapen orokor bat azalduko dugu. Helburua zera da, emergentziari buruzko diziplinarteko zenbaki tematiko honetarako ekarpenen sarrera gisa balio izatea.

Emergentismoa eta erredukzionismoa

46 Adam Smith, "The Wealth of Nations (1776)", p. 423, Modern Library, New York (2004).

«Zer dago mundu honetan?» galderari erantzuteko, beharrezkoa da, lehenik, «entitate» errealak hautatzeko irizpide batzuk eskaintzea. Orokorrean, arrazoizko irizpide hauek hasten dira eztabaidaezintzat hartzen den baieztapenen bat ematearekin, eta gero entitateak errealtzat etiketatzen dira baldin eta irizpide horiekin bat badatoz edo inferentzia legitimoen bidez haietatik erator baldin badaitezke. Hala eta guztiz ere, hauek bezalako irizpideetarako formulazio zehatzak aurkitzea zeregin zaila suertatu da.

Alternatiba gisa, fidagarritasun erlatiboa aurkezten duten irizpideen alde egin daiteke, beren emaitzak fidagarriak ote diren erabakitzeko asmoz, jardunean dauden zientzialariek erabiltzen dituztenetatik hurbilago daudenak. Horien artean, *«sendotasuna» (*[47] *)* deitzen dena laudagarria da bere moldakortasunagatik. Honela definitzen da: *Entitateak sendoak direla esaten dugu hainbat modu independenteren bidez eskuragarriak (atzemangarriak, neurgarriak, deribagarriak, definigarriak, produzigarriak edo antzekoak) baldin badira.* Agerikoa da elkarrekiko interakzioen ondorioz objektu hauek antolatzen diren modu espezifikoetatik eratorritako «objektuei» nahiz «ezaugarri estrukturalei» aplikatzen zaiela sendotasuna. Ondorioz, sendotasuna materiari, haren propietateei eta barne-konektibitateari ere aplika dakioke era berean, eta kontuan hartutako sistemen zatiak eta multzoa mugatzeko ere erabil daiteke. Gainera, sarbide-moduek ugariak, askotarikoak eta independenteak izan behar dutelako ezartzen diren murrizketek, eskuragarritasun kontzeptua «manipulazio esperimentalera» ez dela mugatzen inplikatzen dute, baizik eta deribazio logiko eta matematikoaren eremura eta bitarteko puntu ugarietara ere zabaldu behar dela.

Aurrez azaldutako ikuspegiak zati eratzaileen arteko «elkarrekiko interakzioetatik» eratorritako erlazio kausalak deitutakoen analisirako oinarri sendo bat ezartzen du, bere barne-konektibitatearekin batera, zeinak sistemaren elementu materialen benetako kokapenaren «ezaugarri estrukturalak» islatzen baititu. Erlazio kausalek sare kausaletako ereduak dakartzate. Sare hauek, murrizketa jakin batzuen pean, goragoko mailako patroitan antolatzen dira, *organizazio-maila* gisa ezagutzen direnak, eta materiaren banaketa hierarkikoak dira (ez nahitaez materia materiala bakarrik) zati/osotasun harremanek antolatuak. Hori erdiguneko kontzeptu bat da gai honetarako.

Lehen izarren eraketak, hidrogenoa baino pisutsuagoak diren nukleoak sortu zituen nukleosintesiak, nukleo horietatik hurbileko plasmaren elektroien koalezentziak, mikrouhineko hondoko erradiazio kosmikoak eta argia sortzeko fotoiak liberatuz, eta molekulak etab. sortzeko ondoren elkarrekin batu ziren atomoak produzituz, *organizazio maila* espezifikoak dakartzate, bakoitza materiaren antolamendu guztiz desberdinarekin, gero eta konplexutasun handiagokoa eta bere arau eta erlazio kausal propioak dituena.

Organizazio-konplexutasun (nahikoa duten) mailetan, murrizketa batzuen pean, beheko organizazio-maila eratzen duten zatien interakzioetatik abiatutako propietate (eta/edo substantzia) berritzaileak sor daitezkeenaren nozioa, eta hala eta guztiz ere, lehenak ezin direlarik bigarrenetara murriztu, *emergentzia*[48] deitzen da.

47 W. C. Wimsatt, “The Ontology of Complex Systems. Levels of Organization, Perspectives, and Causal Thickets”. Can. J. Philo. Suppl. **20,** 207-274 (1994). doi:10/1080/00455091.1994.10717400.

48 M. Bunge; “Emergence and Convergence. Qualitative Novelty and the Unity of Knowledge”, Toronto University Press, Toronto, Kanada (2014).

Adibidez, kristal metaliko baten elektroiak eta nukleoak banda elektronikoen eta fermionikoen egituraren arabera antolatzen dira, egoera bakoitzeko elektroi baten arauarekin (spin-orbitala), zeinak kondukzio-egoeraren (edo isolamenduaren) propietate garraiatzaileak ezartzen dituen. Antolamendu edo organizazio-maila goragoko batean, murriztapen berezien pean, bibrazio nuklearrek (fonoiek) elektroiekin elkarreragin dezakete (balentziakoekin), eta horrek eragiten du Cooperren pareak izenekoetan antolatzea. Cooperren pareek bosoi gisa dihardute (bi fermioien spin singlete parekatzearen emaitza gisa) eta fusionatu egin daitezke, tenperatura nahiko baxuetan (murriztapena), Bose-Einstein kontzentratu *sendo* eta koherente bakar batean, eta horrek elektrizitatea erresistentziarik gabe eroan dezake, superkonduktore-egoera eraginez. Horrela, antolamenduaren behe-maila osatzen duten zatien arteko interakzioek, elektroiek eta fonoi nuklearrek, murriztapen jakin batzuen pean, materia mota guztiz berri eta ustekabeko bat sortzen dutela ikus dezakegu (fermioietatik abiatuta «fabrikatutako» bosoiak) ustekabeko propietate baten ondoriozko agerpenarekin, superkonduktibitatea, goreneko antolamendu-mailan.

Emergentismoak esaten du mundua osorik antolamendu-mailez, sinpleak edo konplexuak izan daitezkeen egitura fisikoez, osatua dagoela. Baina konplexuak ez dira sinpleenen agregatu soilak. Geruza (antolamendu-maila) bakoitzak «kualitate berritzaileen» agerpena dauka, beheko geruzetatik sortzen direnak, baina haietan agertzen ez direnak. Eta beheko mailen propietateek botere kausal primitiboak osatzen dituztela pentsa daitekeen arren, goreneko antolamendu-maila bakoitzean da, eta ez behekoetan, non bilatu behar diren beren egiturak eta propietate fisiko emergenteak konektatzen dituzten legeak. Lege emergenteak ez dira ageri beheko antolamendu-mailan.

Emergentismoa bere perspektiba egokian kokatzeko, komenta dezagun laburki mundua aztertzeko daukan metodologia «antagonikoa», Erredukzionismoa. Kasu honetan, estrategia aplikatiboa honetan datza: sistema fisiko konplexuak deskonposatzea, gehiago deskonposatzea ezinezkoa den punturaino. Zati zatiezin hauek propietate ez hain konplikatuak eduki behar dituztela suposa dezakegu eta, beraz, litekeena da portaera konplexu kolektiboa unitate sinpleago eta txikiagoen konbinazioetara murriztea.

Leibnizen kalkuluak[49] , matematikan izandako aurrerapen historikoa izanik, ondo adierazten ditu ideia hauek, izan ere, prozesu konplexuak beren osagai «sinple» infinituki txiki eta infinituetara murrizteko prozedura bat aurkeztu zuen, hau da, «infinitesimaletara» murrizteko prozedura. Osagai horiek hain dira txikiak ez dutela inolako konplexutasunik. Leibnizen arabera, prozesu konplexu guztiak zati daitezke gertakari infinituki txiki, infinitu eta maneiagarrietan. Orduan, prozesu globala gertakari horien emaitzak egokiro batuz deskribatzen da sinpleki.

Erredukzionismoaren promesa da litekeena dela osagai txikienen propietateetatik abiatuta sistema fisikoen portaera (ber)eraikitzea. Hau da, erredukzionismoak mundu diskretu eta eskala txikienean kokatutako esplikazioak dituenaren alde egiten du, eta eskala horretatik konplexutasuna behin eta berriz errepikatutako eragiketa sinpleetatik sortzen da. Egiteko geratzen den gauza bakarra eragiketa horien oinarrian dagoen algoritmoa aurkitzea da. [50]

Hori da erredukzionisten ametsa, teoria bakar eta global bat existitu edo egon beharko duela, non gaur egun dauden teoria guztiek bat egin beharko luketen eta fusionatu beharko liratekeen. Deskonposiziogai

49 Leibnizek bere kalkulua 1684an argitaratu zuen. Ikus: J. Echeverría, «Leibniz, el archifilósofo», Plaza y Valdés, Madril (2023). ISBN:978-84-17121-72-3

50 D. Chandler, "Is the Universe a giant(quantum) computer?", Nature, **620**, 943–045 (2023)

izan daitezkeen fenomenoen (ez fenomeno guztien) analisian erredukzionismoak izan dituen lehen arrakastek honako uste faltsu hau eragin dute: behe mailako osagaien interakzioak ikertzea informatiboagoa dela osagai horiek goi-mailan dituzten antolamendu-ezaugarriak ikertzea baino. Antolamendu maila baxu eta funtsezkoena aurkitu baldin badaiteke eta bere zatien propietateak ulertu baldin badaitezke, teorikoki deskribatuz eta lege zehatzetan kodifikatuz, orduan, informazio horretatik abiatuta, sinpleki inferentzia legitimoak aplikatuz aurkitu beharko lirateke, goreneko antolamendu-maila guztiak, eta beraien propietate intrintsekoak deskribatu ahal izango lirateke. Azken batean, ez al da zientziaren helburu funtsezkoena fenomeno «desberdinen» deskribapen teoriko ulergarri bat ematea, guztiak printzipio «primigenioetan» oinarrituta esplikatuz, logikoki zuzenak diren inferentzia-arauen laguntzarekin? Hau da, munduaren eta munduak daukan guztiaren azalpen edo esplikazio hura aurkitzea.[51]

Helburu laudagarri bat dirudi, baina serioski kontuan hartu behar den kritika sorta bati egin behar dio aurre. Jarraian horietako batzuk azalduko ditugu.

Lehenik, ondo dokumentatua dago maila makroskopikoan (altuan) fenomeno behagarri eta neurgarriak direnen existentzia, baina maila mikroskopikoan (baxuan) xehetasun finenekiko sorgorrak direnak, hau da: sendoak dira beren antolamendu-mailan. Propietate horiek ondo ulertzen dira, eta arrakastaz kodetu dira maila altuko legeen bitartez, baina maila baxueneko lege funtsezkoenetara murriztu ezinak direla erakutsi dute. Propietate horien existentzia erabat esanguratsua da, guztia barnean hartzen duen funtsezko teoria bakar eta global tentatiboaren erabilgarritasunarentzako (agian egokiagoa da erabilgaiztasunarentzako) erronka bat planteatzen baitute propietate horiek, izan ere horrek zera erakusten baitu: naturako funtsezko egitate batzuetarako behintzat, behin-betiko funtsezko teoria globala, hutsala edo garrantzirik gabekoa da. [5][52]

Bigarren lekuan, goreneko antolamendu mailek beti dituzte beheko mailakoek baino erantzun-denbora askoz ere luzeagoak. Har ditzagun kontuan denbora-eskala biologikoak: biokimika ~segundo 1; metabolikoa ~minutu 1; epigenetikoa ~1-10 ordu; garapena ~egunak-urteak; ebolutiboa ~103-106 urte. Horrela beraz, biologia mekanika kuantikora murrizteak, bere Hamiltondarraren soluzioak eskatzen dituenez, zehaztasun energetiko batekin $\Delta E \sim \hbar/\Delta t$, non $\hbar$=1,0547×10–34 joule×segundo baita Planck-en konstante murriztua, erantzun-denbora motzena duten prozesu biologikoetarako ere ~10–34 jouleko zehaztasun energetikoa behar da. Horrek zera dakar gutxienez: elektroien prozesu dinamikoen egungo neurketek eskain ditzaketenak baino zehaztasun-magnitudeko hamar ordena gehiago.

Hirugarren, teoriak sistema matematiko logiko koherenteen terminotan adierazten dira. Hori bai, Gödelen osagabetasunaren bigarren teoremak erakusten duenez, halako sistema matematikoentzat, beti badira beren axioma propioen eta inferentzia-arauen bitartez sistemaren barruan frogatu ezin diren «egiak»[53]. Ezinbestean dira osagabeak, beti baitaude sistemaren barruan sistema bera gainditzen duten froga-metodoak eta ikuspuntuak eskatzen dituzten «egiak». Horren zuzeneko inplikazioa honako hau da: sistema matematiko sendoetan formulatutako teoria guztiak infinituak direla, beti izango baita posible aurkikuntza berriak egitea (lehen aipatutako «egiak»), eta horregatik goiz edo berandu egingo dira

51 S. Hawking-ek, bere “Brief History of Time” lanean (Bantam Press, Londres, UK, 1998), idatzi zuen: “Brief History of Time” (Bantam Press, London, UK, 1998) wrote: “… I still believe there are grounds for cautious optimism that we may now be near the end of the search for the ultimate laws of nature”. 11. Atala.

52 R. B. Laughlin y D. Pines; “The Theory of Everything”, Proc. Natl. Acad. Sci., **97**, 28–21 (2000)

53 K. Gödel; “Some Basic Theorems on the Foundations of Mathematics and their Implications”, Collected Works. Vol. II. Unpublished Essays and Lectures. S. Feferman et al., eds. Pages 304–323. Oxford University Press, New York (1995)

aurkikuntza horiek, guztia biltzen duen funtsezko teoria azken eta bakarraren existentzia egoera delikatu batean utziz, emeki esateagatik.

Laugarren lekuan, teorien murrizketa-prozesuak zera dakar: edozein delarik ere, murrizten diren multzoen teoriak beti ordenatu daitezkeela guztiz.[54] Hori egia da logika proposizional boolearra aurresuposatzen duten teorientzat, baina ez, ordea, teoria kuantikoentzat, adibidez. Azken horiek, beraz, guztiz ezin ordena daitezkeen teorien multzo bat osatzen dute eta, ondorioz, ezin dira murriztu.[55]

Bestalde, Emergentismoa antolakuntza edo organizazio mailen arteko erlazio kausal goranzkoen aurkakoak diren terminoetan definitzen da, sistema fisikoen antolaketa-maila desberdinen arteko lege fisikoen funtsezko haustura edo diskontinuitateagatik.[56] Horrela, mundua antolamendu-maila desberdinen sorta batean estratifikatuta ikusten da, goiko mailak beheko mailetan deskonposatzeko arau hierarkiko sendo bati jarraikiz. Hau da, «deskonposaketa» ahalbidetzen da baina (maiz) debekatu egiten da «berreraikuntza». Gainera, Emergentismoak baieztatzen du, printzipioz, ezinezkoa dela goi mailako portaera eratortzea, behe-mailako portaera osoaren ezagutzatik izanik ere. Beste hitz batzuekin esanez, goi-mailako propietate emergente baten agerpena behatu ondoren bakarrik konturatzen gara, nahiz eta behe-mailako osagaien eta haien elkarrekiko ekintza guztien ezagutza osoa eduki, inoiz ezin izango liratekeela iragarri goi-mailako antolamenduaren propietate guztiak[57].

Hala eta guztiz ere, emergentziaren kontzeptualizazio honek kritika garrantzitsuak izan ditu. Eragozpen edo objekzio larrienak, agian, Kim-ek formulatuak, adierazten duenez, emergenteak era berean epifenomeniko gisa ere deskriba daitezke, hau da, goi-mailan ikusi diren fenomeno sekundarioak, behe-mailako «beharrezko baldintzen» ezarpenarekin kointziditzen dutenak, baina ez nahitaez haiek eragindakoak izan direnak. [10][58] Formulazio osoa sotila eta konplikatua da, baina sinplifika daiteke (gehiegi) honako modu honetan. Jar dezagun (i) ez dagoela magiarik, (ii) sistema konposatu guztiak zati sinpleagoek osatuta daudela eta (iii) zati horiek, gehi beren botere kausalek (hau da, beren propietate fisikoek), edozein interakzio fisikoren substratua edo oinarria osatzen dutela. Orduan, goi-mailako organizazioen propietate guztiak (zati hauexek osatuak eta ez besterik, magiarik gabe!) azken batean zatien arteko interakzio oinarrizkoagoen bitartez egin behar dira. Objekzio hau estu lotuta dago bizirautearen kontzeptuarekin: propietate emergenteek berauek sortzen dituzten oinarrizko propietateekin duten «erlazioa». «Erlazioak» zera dakar: ezin dela propietate emergenterik izan substratu fisikoaren propietateetan aldaketa bat izan gabe, propietate emergenteek beraiek bakarrik eragindakoa izan daitekeen aldaketa bat, alegia, eta ondorioz, argudio zirkular oker baterantz garamatza, non zatien propietateek konposatuaren propietateak esplikatzen dituzten, eta zatien propietateak azaltzen dituztelarik, eta horrek osotasunaren (sistema konposatuaren) gaia argitzea eskatzen du.

Humphreys-ek bat eskaini du,[59] , baina ez da bakarra. Adierazten duenez, zatiek aldatu egin behar dute eta aldatzen dira, elkarrekiko interakzioaren arabera, entitate konposatu handiagoetan barne hartzen direnean. Horrela, lehen independenteki identifikagarriak ziren zatiak desagertu egiten dira, jada ez dira

54 H. Primas; "Theory Reduction of Non-Boolean Theories", J. Math. Biology, **4**, 281–302 (1977)
55 H. Primas; "Theory Reduction of Non-Boolean Theories", J. Math. Biology, **4**, 281–302 (1977)
56 J. A. de Azcárraga; "Reduccionismo y Emergencia, de nuevo", Rev. Esp. Fis., **38**, 29-36 (2024).
57 Har bedi kontuan, testuinguru honetan, «aurresateak» esan nahi duela «ez dagoela inolako prozedura fisikorik behe mailatik abiatuta goi-maila ezartzeko edo determinatzeko».
58 J. Kim, "Making Sense of Emergence", Phil. Stud., **95**, 3-36 (1999)
59 P. Humphreys, (a) "How Properties Emerge", Philosophy of Science, **64,** 1-17 (1997). doi:10.1086/392533. (b) "Emergence not Supervenience", Philosophy of Science, **64,** S337–S345 (1997). doi:10.1086/392612.

existitzen, aurrez aipatutako zirkularitatea puskatuz, eta modu horretan emergentzia berreskuratzen dugu lurzoru kontzeptual sendo batean. [60]

Aipatu beharra dago, halaber, orain gutxi bi aurrerapen gehigarri nabarmen egin direla. Lehena, eta eremu honetan eragin handiena izan duen aurrerapena, agian, behe-mailako dinamikak eragindako portaera agregatuan aldaketa bereizgarri eta etenen ikerketarako ikuspegi dinamikoa barne hartzea da. Zehazki, elur-kristalen hazkundea (fraktalitatea) bezalako fenomenoak edo tenperatura baxuetako superkonduktibitatearen egoerarako trantsizioak autoantolakuntza-prozesuak izenekoen multzo bat ematen dute ondorio gisa [61] emergentzia-fenomenoen irizpide orokorrekin bat datozenak: propietate horiek ez dituzten zatietatik sortzen diren goi-mailako propietateak.

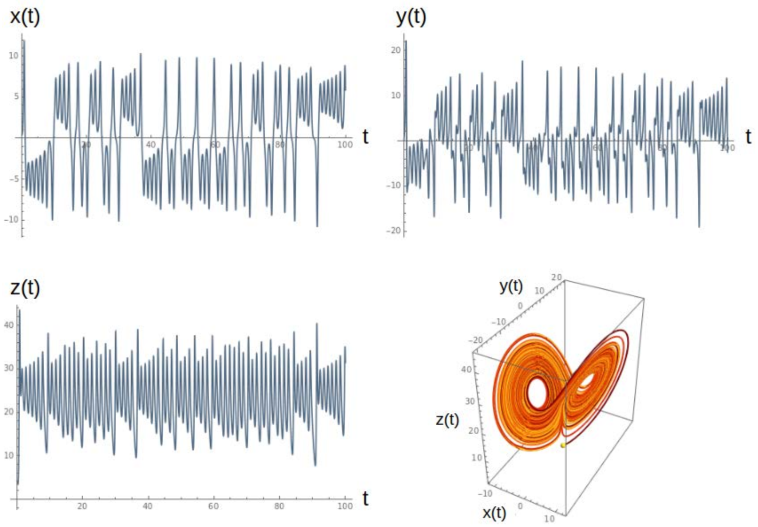
Prozesu hauentzako mugimendu-ekuazioen soluzio analitikoa ezinezkoa da, baina, hala eta guztiz ere, pausuz pausu modela daitezke simulazio iteratibo gisa. Simulazio hauek, algoritmo sinpleak milioika bider iteratzeari ekiten diotenek, maiz sortzen dute portaera harrigarriki konplexua, soluzio analitikoen bitartez ere imajina ezina dena. Metodo konputazionalen aldibereko garapenak, oso linealak ez diren prozesu dinamiko hauek «ekintzan» bisualizatzeko prozesamendu grafikoko teknika sofistikatuen garapena ahalbidetu du, baina, are garrantzitsuagoa dena, zatien arteko interakzio-parametroak guztiz kontrolatzen dituzten «ereduzko» sistemak sortzeko bitartekoak eman ditu.

Honek emergentziari buruz pentsatzeko modu berri bat ireki du. Matrize handietan kokatuta dauden gelaxka anitzetako bakoitzaren eragiketa lokal sinpleak iteratzen dituzten algoritmoak inplikatzen ditu, *automata zelularrak* bezala ezagutzen den eraikuntza batean. Kalkuluek frogatzen dute maiz agertzen direla espontaneoki patroi dinamiko erregular konplexuak. [62] Eragiketa iteratu sinpleetatik abiatuta patroi konplexuak sortzeko logika hori da emergentziaren paradigma berria bihurtu dena. Are gehiago, logika honek interakzio lokalak inplikatzen dituzten prozesu natural askoren logikarekin duen analogiak fenomeno konplexuak orokorrean ulertzeko esparru hobea eman dezakeenaren ustea sortu du. [63]

Zentzu honetan, desorekan dauden sistema dinamikoen esplorazioak portaera interesgarriak erakutsi ditu. Agian, kasu ezagunena «atraktoreena» izan daiteke. Lorenzek 1963an aurkitu zituen, atmosferan isurkien fluxuaren portaeraren modelizazio konputazionala ikertzen ari zen bitartean. Lorenz airea behetik berotzen denean eta goitik hozten denean mugitzen den modua modelizatzen interesatua zegoen.

Ereduak zera deskribatzen du:[64] sistema honen hiru propietate funtsezko, x: aire-fluxuaren abiadura, eta: goranzko eta beheranzko aire-zutabeen arteko tenperatura-aldea, eta z: tenperatura bertikalaren profil-linealtasunaren distortsioa. Kalkuluek portaera pseudokaotiko bat erakusten dute hiru propietateentzat denboran zehar, baina grafiko parametrikoaren ibilbideak erakusten du domeinu finitu batean sartua irauten duela eta tximeleta biratu baten forman ordenatutako patroi bat marrazten duela[65] , 1. irudian ikusten den bezala.

60 P. A. Corning, “The Re-Emergence of Emergence: A Venerable Concept in Search of a Theory”, Complexity, **7**, 18-30 (2002)
61 F. Eugene Yates, A. Garfinkel, D. O. Walter, G. B. Yates (eds.) “Self-Organizing Systems: The Emergence of Order”, Springer, New York (2012)
62 P. Larrañaga, V. P. Soloviev. “Elements of Complex Networks”, Rev. Int. Estud. Vascos, **68**, 2 (2023).
63 S. Wolfram, “Twenty Years of a New Kind of Science”, Wolfram Media, Inc., (2023)
64 Ikus 1. irudiko legenda, mugimenduaren ekuazioak bertan baitaude adierazita.
65 Honek agerian uzten du oso ez linealak diren prozesu hauek «ekintzan» egokiro bisualizatzeko prozesamendu grafikoko teknika modernoen garrantzia.



1. irudia. x(t), y(t) eta z(t) funtzioen grafikoak eta hiru mugimendu-ekuazio diferentzialen soluzio akoplatuen t grafiko parametrikoa : $dx(t)/dt=a[x(t)-y(t)]$; $dy(t)/dt=-x(t)z(t)+bx(t)-y(t)$; $dz(t)/dt=x(t)y(t)-z(t)$, a=3,0, b=26,5 izanik eta hasierako baldintzak x(0)=0,4, y(0)=0,1, z(0)=4,1. x, y eta z propietateak eta denbora t, unitate arbitrarioetan.

Atraktore hau da kaos determinista gisa ezagutzen denaren adibiderik aipatuena, gaur egun konplexutasunaren teoria orokorragoaren zati dena.[66] Metodo hauek elkarreragin desantolatutako eta, maiz, beren zatien artean aleatorioki banatuta daudenetatik abiatuta, patroi erregular konplexuak sortzen dituzten prozesuen ondo definitutako adibide fisiko eta matematikoak eskaintzen dituzte. Alderdi askotan, legitimoki sailka daitezke fenomeno emergente gisa, behe-mailan interakzio dinamiko desantolatuetatik abiatuta sortutako goi-mailako patroi erregularrak, ez direlako behe-mailako propietateen batura soila, eta behe-mailan ez dituzten ezaugarriak erakusten dituzte. Gainera, oso litekeena dirudi «autoantolakuntzak», energiaz elikatutako sistemetan espontaneoki sor daitekeelarik, aurreko kasuan bezala, edo materiarekin, Brusselatorean bezala[67] (ikus eranskina), eta oreka estatikoa lortzea eragozten diena, bizitzaren ordenan zeregin bat edukitzea, nahiz eta kontuan eduki behar den bizitza denboran zehar «propietate ondulatuak» agertzea baino gehiago dela.

Bigarrena arrazoiketa asintotikoaren prozedura deitutakoarekin dago lotuta[68] . Laburbilduz, badira hainbat teoria akoplatu batzuk parametro kritikoren baten muga hartzeagatik. Hau da, Take Limit $(\varepsilon\rightarrow0)$Tf = Tc, non Tf laburdurak teoria zehatzagoa adierazten duen (funtsezkoagoa) eta Tc laburdurak gutxi gorabeherakoago teoria bat. Muga hartzearen eragiketa «erregularra denean», teoriaren murrizketa-kasu bat adierazten du, Tf murriztu egiten da $\varepsilon=0$an Tc izanik, baina «singularra denean», «harreman interteorikoez» bakarrik hitz egin daiteke. Lehenaren adibideak mekanika kuantikoa (zehatzagoa) eta mekanika klasikoa (ez hain zehatza) dira, $\varepsilon=\hbar$ izanik, eta erlatibitate berezia (zehatzagoa) eta mekanika newtondarra (ez hain zehatza) $\varepsilon=(v/c)$ izanik, kontuan hartuz «v» argiaren abiadurarekin alderatuta, «c»,

66 S. Thurner, R. Hanel, P. Klimek, “Introduction to Theory of Complex Systems”, Oxford University Press, New York (2016).

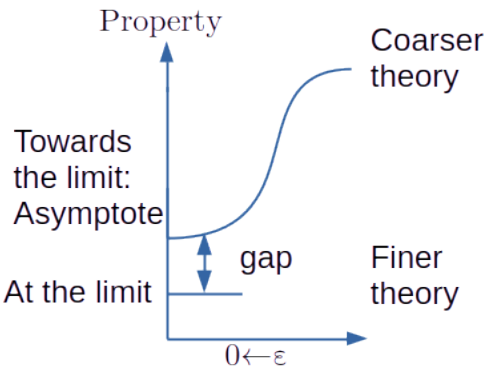
67 G. Nicolis e I. Prigogine, “Self-organization in nonequilibrium systems: From dissipative structures to order through fluctuations”. Wiley, New York (1977). Ikus ere: A. M. Turing “The Chemical Basis of Morphogenesis”, Phil. Trans. Roy. Soc. Lond., B237, 37 (1952), difusio espazialak morfogenesiaren emergentzian duen eragina ulertzeko.

68 R. W. Batterman, “The Devil in the Details”, Oxford University Press, New York (2002).

mantsoki mugitzen diren gorputzen abiadura dela; eta bigarrenarena, Schödinger-en mekanika kuantikoa (zehatzagoa) egitura elektroniko molekularraren (ez hain zehatza) $\varepsilon = m/M$rako, «m» elektroiaren masa izanik eta «M» protoiarena.

Ikus mugan bat-batean alda daitezkeen propietate batzuen mugako portaeraren izaera bereziaren funtsezko papera, mugan ikus daitekeenaz guztiz bestelako portaera erakusten baitute. Ikus, halaber, honek ez duela antolamendu fisikoko maila desberdinik eskatzen, baizik eta guztia maila bakar batean gauzatzen dela. Horregatik deitzen zaio batzuetan emergentzia epistemologikoa.

Arrazoiketa asintotikoak (AR) teorien balioaren inguruko eztabaida sutsua eragin du.[69] Horrela, AR arrazoiketa asintotikoaren arabera, teoria zehatzenak ezin ditu esplikatu $\varepsilon \to 0$ mugan portaera singularra daukaten erregimen lodiko propietateak, 2. irudian grafikoki adierazten den bezala. Bistakoa da beharrezkoa dela arrakala gainditzea erregimen lodiagoaren gainean teoria zehatzagoaren egokitzapen esplikatiboa zabaltzeko.



2. irudia. Zerora eramaten denean ε parametroaren mendeko den «propietate» baten muga-prozesua.

Kritikoek zalantzan jartzen dute teoria xehatuagoari egozten zaion gutxiegitasun esplikatiboa. Adierazten dutenez, gutxi gorabeherako zentzu batean gutxienez, teoria orokorragoaren interpretazio fisikoko elementuak eduki beharko lituzke. Beraz, teoria orokorragoaren interpretazio fisikoko elementuak teoria xehetuagoaren elementuengatik ordezkatu daitezke eta, interpretazio horrek ulerkuntza eskaintzen badu, orduan teoria xehetuagoa guztiz egokia da ikuspegi esplikatibotik. [70] Hala eta guztiz ere, eztabaida iritsi da (itxuraz) bere amaierara[71], adierazten baita ordezkapen horiek nahitaez ez dutela ekartzen «ulerkuntza». ARk eskaintzen duen alternatiba honetan datza: teoria gordineko gako-alderdiak teoria finagoan asimilatzean, domeinu asintotikoan arrakalaren gainean zubi bat eraikitzeko.

Egitura elektronikoaren kasua paradigmatikoa da zentzu honetan. Schrödingerren ekuazio kuantikoan modu klasikoan jokatzen duten nukleoak barne hartzerakoan, lotura kimikoaren esplikazio egoki bat lortzen da[72] eta, gainera, estatu kuantiko molekular adiabatiko eta ez adiabatikoen gisako kontzeptu berrietarako bideak irekitzen dira, eta haiek aldi berean esplikazio egokiak ematen dituzte lotura kimikoen dinamikarekin lotutako fenomeno askotarako.

69 M. Redhead, “Discussion Note: Asymptotic Reasoning”, Studies in History and Philosophy of Modern Science, **35**(B), 527-530 (2004)
70 G. Belot, “Whose Devil? Which Details?”, Phil. Sci., **72**, 128-153 (2005)
71 R. W. Batterman, “Response to Belot’s “Whose Devil? Which Details?””, Phil. Sci., **72**, 154-163 (2005)
72 G. Frenking, S. Shaik, “The Chemical Bond”, Vol I, II; Weinheim, Germany (2014)

Aurrerapen horien ondorioz, emergentziaren kontzeptua eremu askotara zabaldu da, hala natur zientzietan nola gizarte-zientzietan ere.[73] Osagai diren zatien elkarreragin kontzertatu eta desantolatuetatik abiatuta patroi erregular, egonkor eta sendoen berezko sorkuntza agertzen denean aplikatu ohi da, eta teoria zehatzagoen eta teoria orokorragoen arteko erlazio mugatzailearen portaera berezia intereseko fenomenoentzako esanguratsua suertatzen denean, eta modu horretan teoriaren murriztapena eragozten du eta eremu asintotiko mugatzailean zubi gisako gako-ezaugarrien agerpena eragiten du.

Sakonki adierazteko asmorik gabe, gizarte-zientzietako hainbat disziplinatan emergentzia sartzen deneko modu espezifikoak komentatuko ditugu laburki.

Horrela, fenomeno fisikoak ez bezala, giza portaera aurresangarria ez dela onartuz, eta ekonomiak erregulartasun enpiriko «unibertsalak» ez dituela, «gertakari estilizatuak» izenekoen ondo dokumentatutako existentziak, hau da, datu ekonomikoen multzo desberdinetan ikusitako patroi komunen existentziak, ekonomia globaleko ereduak eraikitzeko sistema konplexuen teoriaren erabilera babesten du. [74] Bereziki, finantza-krisialdia «puntu kritikoekin» lotu liteke, eta finantza-datuek erakusten duten «turbulentziaz» hitz egin dezakegu. Ondorioz, emergentzia elementu esplikatibo eraginkor gisa sortzen da. Hala eta guztiz ere, dagokion zuhurtasunez jokatu beharra dago, egokitzapen hori nahikoa baita analogia «formal» bat justifikatzeko sistema ekonomikoen eta sistema konplexuen portaeraren artean, baina inondik ere ezin da justifikatu analogia «material» bat. Analogia formalak helburu deskriptiboak ditu eta (nolabaiteko) ahalmen aurresangarri edo prediktiboa dauka. Baina ez dauka ahalmen esplikatiborik, zentzu kausalean, ez baitu gai honi buruz informatzen: intereseko sistemaren egitura zer harreman kausalek osatzen duen, alegia. Beraz, helburu jakin bat lortzeko zer esku-hartze izan daitezkeen eraginkorrak jakitea eragozten du. Horretarako, analogia material bat eraiki behar da errealitate ekonomikoaren eta sistema konplexuaren printzipioen artean, analogia formalarekin batera. Horrek sistema ekonomikoaren «idealizazio» osagarriak eskatzen ditu. Eredu batzuek badute idealizazio horietarako joera, beste batzuek ez, ordea. [75]

Hala eta guztiz ere, gizarte-zientzien beste diziplina batzuek, orain dela gutxi, konplexutasunaren teorian oinarritu gabe, fenomeno emergenteak aztertzeari ekin diote. Ikerketa juridikoek aldaketa horren adibide kanoniko bat osatzen dute. Horrela, orain dela gutxiko Tamanaha-ren azterlanean[76] , bost ezaugarri emergente osagarri identifikatzen dira elkarbizitza sozialeko (norbanakoen arteko harremaneko) arau sinpleetatik Zuzenbide-estatuan oinarritutako gizarte konplexuago eta holistikoagoetarako trantsizioa arrazionalizatzeko[77] . Tamanaharen bost ezaugarriek erronka zailak planteatzen dituzte zuzenbidearen konfiguraziorako, eta zuzenbide-estatuaren gizarteak multzo emergente gisa eta existitzeko eraldaketa sozial sakonak behar dituzten multzo gisa erretratatzen dituzte. Eraldaketa horiek organizazio sozialen sorkuntza inplikatzen dute eta legez araututako gizarteen ezarpenarekin lotuta datoz. Hala eta guztiz ere,

73 O. Artime, M. De Domenico, “From the Origin of Life to Pandemics: Emergent Phenomena in Complex Systems”, Phil. Trans. R. Soc. A **380**, 20200410 (2022).

74 T. Cooley, ed. “Frontiers of Business Cycle Research”. Princeton University Press, (1995).

75 P. Palacios, J. S. Jhun, “Statistical Mechanical Models of Finance”, in The Routledge Handbook of Philosophy of Scientific Modeling, London (2024)

76 B. Tamanaha, “Law’s Evolving Emergent Phenomena: From Rules of Social Intercourse to Rule of Law Society”, Washington Univ. Law Rev., **95**, 1149-1186 (2018).

77 Teknizismo guztiez erantzita, aldez aurretik finkatuta eta jakinarazita dauden arauak betetzen dituzten ekintzetan oinarritutako gobernantza bat adierazi nahi du horrek. Arau horiek zera aurreikustea ahalbidetu behar dute, ziurtasun nahikoarekin: autoritateak nola gauzatuko dituen bere botere koertzitiboak, sortzen diren zirkunstantzia guztietan. Modu horretan pertsonek mehatxuaren jakintza horretan oinarrituta planifikatu ahal izango dituzte beren ekintzak. Ikus: L. Fuller, “The Morality of Law”; p. 38-39, Yale University Press, USA, 1969).

bere izaera emergenteak estatus diferentzial bereizgarri bat ematen dio Zuzenbide-estatuaren gizarteari. Legalki arautatako gizarteak bizi daitezke lege-erregulazioen arabera ez diharduen politika autoritario batekin.[78]

Emergentziaren teoria egokia dela uste izan da, zuzenbide pribatuaren eremukoak izanik, ikaskuntza automatikoan oinarritutako adimen artifizialeko teknologia aurreratuen inplementazioak berriki planteatzen dituen erronka juridikoetako batzuk esplikatzeko eta perspektiban jartzeko[79] . Bereziki, honekin lotutako bi alderdi hartu dira kontuan: (i) atribuzioaren arazoa eta (ii) jabetza intelektualaren eskubidearen arazoa.

Har dezagun lehenik lehen kasua. Adimen Artifizialeko sistemen autonomia bere sortzaileek aurreikusi ez dituzten zirkunstantzietan ikasteko eta dagokion bezala erantzuteko gaitasunetik dator. Hori, argi eta garbi, propietate emergente gisa har daiteke. Arrazoi horregatik, kasu horiei erantzukizuna emateak banaketaren falaziara eraman gaitzake, hau da, osotasunaren propietateak zatiei egoztea. Adierazi beharra dago, kalteen zuzenbidean, agertoki horrek «egilerik gabeko biktimaren» kasu batera eraman gaitzakeela eta AAko teknologiak inplikatzen dituen egoera batean kalte-ordaina ukatzera, nahiz eta zalantzarik gabe emango litzatekeen kalte-ordaina teknologia konbentzionalak inplikatzen dituen funtzionalki baliokidea den kasu batean. AA erabiltzen duten teknologien gorakadak zaildu egiten du «kausalitate-froga» ezartzea.

Azken kasu honetarako, imajina dezagun norantz begiratu behar den modu autonomoan adierazten duen programa bati akoplatutako teleskopio bat. Orain, imajina dezagun planeta ezezagun bat deskubritzen duela eta, ondoren, jasotako argi espektrala aztertzerakoan, bere «atmosfera» zundatzen duela, eta planeta horretan organismo biziak daudenaren froga solidoak ematen dituela zundaketa horrek. Jarraian, AAko morroiak edo laguntzaileak ChatGPTri deitzen diola idazlan bat idatz dezan, gero argitaratzeko asmoz bidaltzen dena. Pareen berrikuspeneko ohiko prozedura zorrotza gainditu ondoren, idazlana onartu eta argitaratu egiten da. Zabal dezagun pixka bat gehiago gure irudimena ikerketa horrek Nobel Saria jasotzen duela imajinatzeko. Orain galdeiozu zure buruari: nori emango zaio saria Estockholmen? Kasu honen antzekoak, agian ez hain dramatikoak, maiz gertatzen dira edo gertatuko dira arte kreatibo eta/edo berritzaileetan, adibidez. Egiletza eta jabego intelektuala egozteko arazoa honetatik dator: AAko programen funtzionamendua ezin zaiola zuzenean egotzi «giza iturri» identifikagarri bakar bati. Horrek talka egiten du jabego intelektualari buruzko legeriak giza egileak sormen orokoren gune gisa jartzen dituen ideiarekin.

Propietate emergenteetan oinarritutako eztabaidak ikuspegi juridikoak eta teknologikoak batzen ditu eta, ondorioz, aldaketa teknologikoek arazo juridikoak eragiten dituzten zirkunstantziak identifikatzen lagun dezake. Bereziki, legearekin guztiz bat datozen ekintza askoren agregazioak legearekin bat ez datorren multzo bat sor dezakeela esplika dezake. Horrek emergentzia arazo juridiko konplexuak ikuspegi egoki batean kokatzeko aktibo garrantzitsu gisa onartzeko premia ikusarazten du.

Soziologian, emergentziaren teoria nagusiki fenomeno sozialen «teoria kolektibista» izenekoan zentratu da eta, orain dela denbora gutxi, interes handia piztu du «indibidualista metodologikoa» izeneko ikuspegiari emandako erantzun esperantzagarri gisa. Ikuspegi horrek fenomeno sozialen mikro-makro

78 R. Geuss, "History and Illusion in Politics", Cambridge Univ. Press, Londres (2010).
79 S. Esayas, "The Important Role of Emergence in Conceptualizing the Challenges of New Technologies to Private Law", Eur. Private Law Rev. **31**, 779-822 (2023).

emergentzia norbanakoen ekintzetatik abiatuta hasten dela adierazten du, eta horregatik portaera sozial emergenteen esplikazioa ez da esplikazio hori maila indibidualean murriztearekin bateraezintzat hartu behar.

Hala eta guztiz ere, egungo soziologiaren teorikoak emergentzian oinarritzen dira esplizituki, zeina testuinguru honetan «portaera sozialaren emergentziaren ikuspegi kolektibo» gisa izendatzen baita. Gaur egun gutxienez hiru aldaera desberdin bereizi daitezke. Lehen lekuan, Blauren ikuspegi estrukturalistak zera dio,[80] analisi makrosoziologikoaren termino nagusiak prospekzio mikrosoziologikoan baliokiderik ez duten populazio-egituren propietate emergenteei dagozkiela. Bigarren lekuan, Bhaskar-en errealismo transzendentalak[81] errealitate soziala estratifikatua dagoela adierazten du, eta baldin eta eragile indibidualen mendekoa bada ontologikoki, haietara murriztu ezina dela eta baita haiekiko autonomoa ere. Bhashar-ek 1:1 korrespondentzia ezartzen du emergentismoaren eta errealismoaren artean. Horrek esan nahi du esplikazio errealistak benetako fenomeno emergenteekin bat datozela eta fenomeno emergenteek esplikazio errealistak eskatzen dituztela. Hirugarren lekuan Archer dugu, dualismo morfogenetikoaren bere ikuspegiarekin[82] . Berak dioenez portaera soziala portaera indibidualetik sortzen da, zeina portaera emergentea baino lehenagokoa den. Behin portaera sozial hori sortu denean, bere emergentziako oinarriarekiko autonomoa bihurtzen da, eta autonomia horrek, bere eskubide propioaz, eragin kausal independenteak inplikatzen ditu. «Denboran zeharreko» emergentzia (morfogenesia) da egitura emergenteak errealak izatea eragiten duena eta kausalitate beheranzkoaren bitartez norbanakoak mugatzea ahalbidetzen diena.

Hiru ikuspegiak sakon berrikusi dira eta orain dela gutxi agerian geratu dira beren akats eta gabeziak, beheranzko kausalitate-mekanismoen esplikazioan argitasun-eza edo maila sozial eta indibidualaren arteko sortze-erlazioa. [83]

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80 P. M. Blau y R. K. Merton, “Microprocesses and Macrostructure”, p. 83–100, in “Social Exchage Theory”, K. S. Cook , Ed., Sage, Newbury Park, USA (1987).
81 R. Bhaskar, “Emergence, Explanation and Emancipation”, p. 275–310, in “Explaining Human Behavior”, P. F. Secord, Ed., Sage, Beverly Hills, USA (1982).
82 M. S. Archer, “Realistic Social Theory: The Morphogenetic Approach”, Cambridge Univ. Press, New York, USA (1995).
83 R. Keith Sawyer, “Emergence in Sociology: Contemporary Philosophy of Mind and Some Implications for Sociological Theory”, Am. J. Sociology, 107, 551-585 (2001)

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Laburpena

Zientzia guztietako arlo guztiak (ia) josi dituen ikuspegi erredukzionista nagusiak, gaur egungo ikerketa-programa batzuen izaera utilitarioak elikatua izaki, gehiegi azpimarratu du «erlaziorik gabeko» behaketei buruzko informazioa ematea eta ikuspegi globala kendu dio, hau da, behaketak patroi emergente berrietan integratzea.[87] Zentzu honetan, emergentismoa orain gutxi (ber)agertu da eta ikuspegi erredukzionistaren ikuspegi estuak eta mugatuak altxatzen lagundu du, enpresa zientifikoarentzako eremu zabalago eta aberatsago batera begiratzen laguntzeaz gain. Azken batean, jakintza «ez erlazionatua» nahasia eta guztiz alferrikakoa da, gutxi esateagatik. Ikuspegi globala garrantzitsua da.

Emergentismoa hainbat disziplinatan agertzen da.[88] Beraien arteko esanahi-diferentzia txikiak gaindituz, onartzen da emergentzia kontzeptua honako honi lotzen zaiola: sistemaren zatiak osotasun batean antolatzeko forma berezi batzuen ondoriozko propietate eta patroi sendo eta berritzaileen sorkuntzari. Organizazio-prozesuak konplexutasuna sortzeko beharra du goi-mailan, eta horretatik abiatuta propietate berriak sortzen dira garrantzirik gabeko xehetasunen batezbestekoa egiterakoan eta propietate berriaren edo patroi sendoaren esentzia indartzerakoan. Fenomeno emergenteek emergente gisa identifikatzen dituzten hainbat ezaugarri [89] elkarbanatzen dituzte: (i) berritasun erradikala, (ii) trinkotasuna eta koherentzia, (iii) goreneko organizazio-mailan konplexutasuna, (iv) Nabarmentasuna: emergenteak «nabarmen» atzematen dira erakusten direnean. Horrek natur eta gizarte zientzietarako lur amankomun bat ezartzen du, eta zuzeneko diziplinartekotasuna modu naturalean baliatzea ahalbidetzen du horrek

Azken batean, zenbaki honek ekarpen akademiko sorta bat biltzen du honako helburu hauekin: (i) hainbat diziplinatan oinarrituta fenomeno emergenteak nola proiektatzen diren azaltzea, eta (ii) zera erakustea: inpresio subjektiboetatik, ustekabeko berritasunetatik edo kointzidentzia epifenomenikoetatik erantzi ondoren[90], emergentziari buruzko ikerketek edozein balio metaforiko jorratutik haratago joatea eta ikerketa akademiko zorrotzaren eremuan barrena sartzea merezi dutela.

87 “There are rushing waves ... mountains of molecules, each stupidly minding its own business ... trillions apart ... yet forming white surf in unison” . Hemendik hartua: R. P. Feynman; “The Value of Science”, Engineering and Science, **19**, 13-15 (1955).

88 E. Onnis; “Emergence: A Pluralistic Approach”, Theoria, **38**, 339-355 (2023). doi:10.1387/theoria.23972.

89 J. Goldstein; “Emergence as a Construct: History and Issues”, Emergence: Complexity & Organization, **1**, 49–72 (1999). doi:10.1207/s15327000em0101_4.

90 J. Holland; “Emergence: From Chaos to Order”, Addison-Wesley,Reading, MA, USA (1998).

Eranskina

Brusselatorea osziladore kimikoaren adibide kanoniko bat da, osziladore mekaniko ezagunenekiko funtsezko diferentziak erakusten dituzten sistema konplexuen mota bat. Erreakzio kimiko batek oszilatzen duenean, inoiz ez da igarotzen bere oreka-egoeratik. Izan ere, oszilazio kimikoko fenomenoak orekatik oso urruneko egoeretan agertzen dira. Zentzu honetan, Prigogine et beste batzuek, Bruselan, zera adierazi zuten, sistema irekiek, hau da, beren inguruarekin materia edo energia elkartrukatu dezaketen sistemek, orekatik urrun geratzen direnean ere autoantola daitezkeela energia edo materia disipatuz sisteman entropiaren murriztapena konpentsatzeko, eta horrela inguruan materia/energia etengabeko elkartruke batek bideratutako oszilazioei eusteko. Modu honetan sortzen diren egitura espazial edo denborazkoei egitura disipatiboak deitzen zaie.

Brusselatorea honetan datza: (i)–(iv) erreakzioak jasaten dituen sistema kimiko ireki bat, jarraian adierazten denez:

(i) $A \rightarrow X$
(ii) $2X+Y \rightarrow 3X$
(iii) $B+X \rightarrow Y+D$
(iv) $X \rightarrow E$

Erreakzio globala $A+B \rightarrow D+E$ da, eta lau espezie hauen erreakzioak egonkor egoten dira, A eta B hornitu egiten dira eta D eta E domeinu erreaktibotik ezabatu egiten dira. X eta Y bitarteko espezieen kontzentrazioak denborarekin aldatzea uzten da. Ondorioz, abiadura-ekuazioak (mugimendu-ekuazioak) X eta Y espezieentzat honako hauek dira:

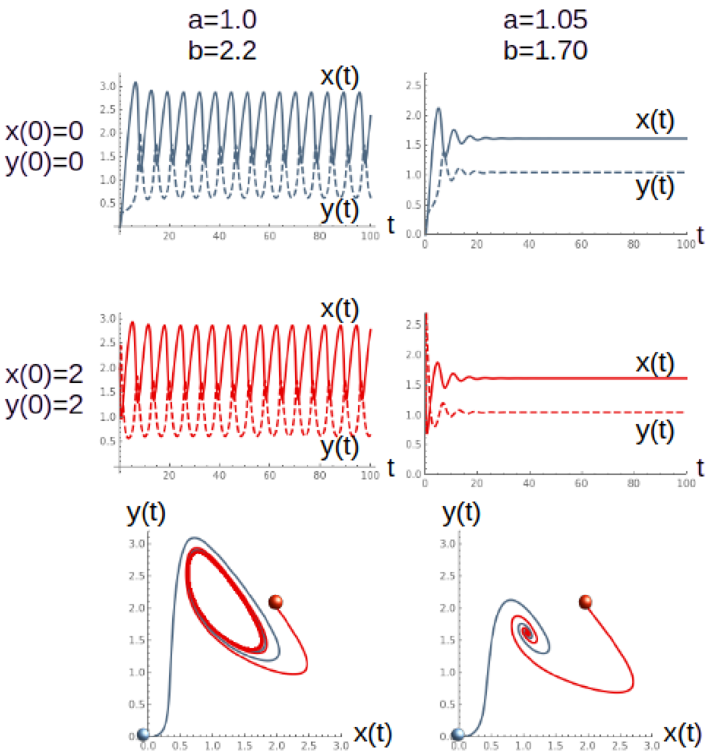
(v) dx(t)/dt=–a+x(t)2y(t)– b x(t)– x(t)
(vi) dy(t)/dt=b x(t)–x(t)2y(t)

Ikus, erosotasunez, abiadura-konstante guztiak ki=1, (i=i–iv) ezarri ditugula.

Akoplatutako (v)-(vi) ekuazioen soluzioa, A eta B espezieentzako bi kontzentrazio multzo egonkorrekin, eta hasierako bi kontzentrazio X eta Yrentzat, A1 irudian adierazten da. X eta Y espezieen x(t) eta y(t) kontzentrazioek, hurrenez hurren, A eta Bren kontzentrazio finko egonkorrekiko modu desberdin batean jokatzen dutela ikus daiteke, beren hasierako x(0) eta y(0) kontzentrazioak kontuan hartu gabe. Horrela, a=1.0, b=2.2 direnean, X eta Y bi kontzentrazioek, hasierako jauziaren ondoren, maiztasun eta intentsitate berdineko portaera oszilatzaile bat hartzen dute bai x(0)=y(0)=0 loturarekiko eta baita x(0)=y(0)=2 loturarekiko ere, A1 irudiaren goiko ezkerreko bi paneletan erakusten den moduan. Antzeko moduan, a = 1.05, b = 1.70 dienean, hasierako jauziaren ondoren, X eta Yren kontzentrazioek berdin jokatzen dute hasierako baldintzak, x(0) = y(0) = 0 y x(0) = y(0) = 2, edozein izanik ere, A1 irudiaren eskuineko aldeko goiko paneletan adierazten den bezala. Hala eta guztiz ere, portaera guztiz bestelakoa da, lehenak oszilazio eutsiak erakusten baititu, bigarrenak denboran zehar kontzentrazio konstantea eta laua erakusten duen bitartean.

A1 irudiko beheko panelek x(t) aurreko y(t)ren dagozkion grafiko t-parametrikoak erakusten dituzte. Horrela, beheko ezkerreko panelak y(t) erakusten du x(t)ren aurrean, izanik a=1.0, b=2.2 eta bai x(0)=y(0)=0 (kurba urdina) baita x(0)=y(0)=2 (kurba gorria). Ikus, nahiz eta oso puntu desberdinetan hasten diren (dagozkien puntuen bidez nabarmenduta), bi ibilbideek atraktorearen inguruko mugako zirkuluan amaitzen dutela, (x=a, y=b/a) puntuan dagoena.

Aldiz, a=1.05, b=1.70 kontzentrazio egonkorretarako, bi ibilbideak atraktorearen gainera erortzen dira,



hasierako puntua edozein delarik ere, beheko eskuineko panelean erakusten denez.

A1 irudia: (v)-(vi) mugimendu-ekuazio akoplatuen x(t) eta y(t) funtzioen soluzioen grafikoak, goiko lau panelak, A eta B espezieen a eta b kontzentrazio egonkor hautatuentzat eta hasierako x(0), y(0) kontzentrazioentzat. Dagozkien ibilbideen t grafiko parametrikoak, beheko bi panelak. Hasierako puntuak nabarmenduta daude. Kontzentrazioak eta denbora unitate arbitrarioetan.

Portaera horren kritikotasuna honetan ezartzen da: bc=1+a2. Horrela, b>bc izanik, denboran zehar X eta Y espezieen kontzentrazioetarako patroi oszilatzaile bat erakusten du sistemak, b<bc baldintzarako kontzentrazio-erregimen jarraitu egonkor batean dauden bitartean. Hau da, sistema «autoantolatu» egiten da parametro kritikoaren gainetik eta azpitik kanpoko baldintzei modu desberdinean erantzunez.

Hedapen espaziala kontuan hartzen denean, mugimendu-ekuazio aldatuak modu honetan adierazi daitezke:

(vii) dx(r,t)/dt=–a+x(r,t)2 y(r,t)–b x(t)–x(t)+𝓓x (∂2x(r,t)/∂r2)
(viii) dy(r,t)/dt=b x(r,t)–x(t)2 y(r,t)+𝓓y (∂2y(r,t)/∂r2)
non 𝓓 Ficken difusio-koefizienteak adierazten diren, eta r-k koordenatu espaziala ordezkatzen duen. (vii)-(viii) ekuazio akoplatu diferentzialen x(r,t), y(r,t) soluzioek erakusten dute, mugako zikloaz gain,

uniformeak ez diren egoera egonkorrak ager daitezkeela. Turing izan zen, morfogenesiari buruzko bere artikulu itzal handikoan, kimikoki erreaktiboak diren sistema irekietako egoera-mota honi buruz ohartarazi zuena. Artikulu hartan adierazi zuen mugako zikloa espazioaren mende dagoela eta uhin kimikoak deiturikoak eragiten dituela emaitza gisa.