and its criticisms. Constructivist Foundations 10(2): 169–176. ▸ http://constructivist.info/10/2/169

Luhmann N. (1995) Social systems. Translated by John Bednarz, Jr. and Dirk Baecker. Stanford University Press, Stanford CA. German original published in 1984.

Maturana H. R. (1981) Autopoiesis. In: Zeleny M. (ed.) Autopoiesis: A theory of living organization. Westview Press, Boulder CO: 21–33. ▸ https://cepa.info/557

Maturana H. R. (2014) Understanding social systems? Constructivist Foundations 9(2): 187–188. ▸ https://constructivist.info/9/2/187

Maturana H. R. (2015) What is sociology? Constructivist Foundations 10(2): 176–179. ▸ http://constructivist.info/10/2/176

Mayr E. (1969) The biological meaning of species. Biological Journal of the Linnean Society 1: 311–320.

Räwel J. (2017) The relationship between social and biotic evolution: The evolution of autopoietic systems. Cybernetics and Human Knowing 24(1): 33–53.

Räwel J. (2020) The origin of species through system differentiation: The evolution of living autopoietic systems. Kybernetes 49(10): 2365–2383. ▸ https://cepa.info/7540

Urrestarazu H. (2014) Social autopoiesis? Constructivist Foundations 9(2): 153–166. ▸ http://constructivist.info/9/2/153

Jörg Räwel is a sociologist. His current research interests are the application of evolutionary theories in the social sciences, the development of social media communication theories, and the study of social change through the "digitalization" of society. He is a Research Fellow at the Next Society Institute at Kazimieras Simonavičius University in Vilnius. His most recent publication is: *Die nächste Gesellschaft: Soziale Evolution durch Digitalisierung* [*The next society: Social evolution through digitization*] (2022). https://independent.academia.edu/JörgRäwel

Funding: No external funding was received while writing this manuscript.
Competing interests: The author declares that he has no competing interests.

Received: 7 October 2022
Revised: 16 October 2022
Revised: 31 October 2022
Revised: 10 November 2022
Revised: 17 November 2022
Accepted: 18 November 2022

Is Natural Drift a Mechanism?

Sergio Rubin
Université Catholique de Louvain, Belgium
sergio.rubin/at/uclouvain.be

> Abstract • In its current formulation, natural drift, despite being non-adaptationist, apparently follows the machine metaphor. I scrutinize the notion of machines on the basis of the four Aristotelian causes and argue that, following Rosen's work, living systems are causal systems but not mechanisms and, therefore, not "machines." This leads to the question as to whether natural drift is a blind and reactive mechanism or whether it entails anticipation in the sense that organisms are able to distinguish the potential effects of their actions on their environment. This aspect has a bearing on the question of whether natural drift can account for the origin of Earth's habitability.

« 1 » The natural drift theory of evolution is not formulated as transcendentally explanatory of a reality or environment independent of organisms' actions. Neither does it explain evolution as guided by the unfolding of an informational genomic program shaped by natural selection and random mutations (teleonomy), nor by internal or external teleological agents. Furthermore, natural drift is not a revisionist theory of the modern synthesis of evolution either, nor does it belong to the extended evolutionary synthesis (as presented in Pigliucci & Müller 2010).

« 2 » Different from modern and extended synthesis, which assume that all traits are adaptations,[1] natural drift explains that all traits of organisms have evolved through the conservation and change of ontogenetic phenotypes, which are determined by behavior rather than genetics (Maturana & Varela 1984; Varela, Thompson & Rosch 1991: Ch. 9; Maturana & Mpodozis 1992, 2000). As such it is worthwhile casting a critical eye on its explanatory premises.

« 3 » Natural drift starts from the characterization of living beings as autopoietic systems.[2] This implies that living beings are autonomous and therefore their evolution depends not on adaptation, but on their way of living their epigenetic pathways in structural coupling with their environment. Following Humberto Maturana and Francisco Varela (1973), Jorge Mpodozis suggests that autopoietic systems are "machine[s]" (§3). By "machine" I understand that he did not mean an artefact but, rather, a self-producing system whose operation is determined by its structure, i.e., a system that embodies *causality*.

« 4 » For the precision that natural drift deserves, I will first clarify the "machine metaphor" in relation to causal embodiments of autopoiesis, and thus natural drift. Then I will discuss the implications that the concept of natural drift could have for the origin of Earth's habitability.

« 5 » Originally from Descartes, the machine metaphor has its mathematical foundation in Newtonian mechanics. The metaphor is meant to respond to the question of how natural systems undergo change from a unique perspective of causation. It claims that the causality of *all* natural systems is a mechanism of *state transition sequences*, which are the function of only past and present rather than *future* states. The machine metaphor can be traced back to three of the four Aristotelian causes, since the material (initial conditions), efficient (dynamical equations) and formal causes (parameters) are treated *independently* of one another, and only the final cause is entirely excluded from the system description.

1| The view that all traits are adaptations has been criticized and categorized by Stephen Jay Gould and Richard Lewontin (1979) as the adaptationist program.

2| According to Aloisius Louie, a system is "a collection of material or immaterial things that comprise one's subject of study. When the 'subject of study' is in the world of sensory phenomena with their causal entailment, the system is called a natural system. When the object of study is the world of ideas with their inferential entailment expressed in some language, the system is called a formal system" (Louie 2020: 2). The natural system that Louie refers to corresponds to what Mpodozis affirms in his Footnote 1 (as what is proper to a system).

« 6 » Unlike Newtonian causality, Aristotelian causality is meant to answer the "*why*" question.[3] It includes the final cause and all four causes are *dependent* on one another. The answer to "why" is a content-based answer in contrast to "how," which is a method-based answer. For example, asking *why* the Earth is habitable is quite different from asking *how* the earth is habitable.

« 7 » In his presentation, "Natural Evolutionary Drift," Maturana pointed out that the notion of autopoiesis goes back to Aristotle.[4] His usage refers to the difference between praxis and poiesis when referring to the end of an action.[5] Mpodozis, together with Claudia Cecchi, Alexander Vargas and Christián Villagra (Cecchi et al. 2004), discussed how Aristotle's causal categories had allowed Darwinists to reject the final cause by moving from final to formal causation (labeled "information" in the genomic sequence).[6]

« 8 » In a paper, together with Juan Carlos Letelier and Gonzalo Marín (Letelier, Marín, & Mpodozis 2003), Mpodozis also pioneered showing the equivalence of autopoietic systems with Robert Rosen's Metabolism, Repair (M,R)-system. The (M,R)-system is a mathematical construct that models the self-production organization (autopoiesis), based on Aristotle's four causal categories. It shows why the causality of mechanisms is not sufficient for self-production to occur (Rosen 1991). This is so, because mechanisms are open to efficient causation,[7] thus ubiquitously algorithmic, and hence computable, i.e., they can be expressed as a list of purely syntactic rules and rule manipulation, but also because mechanisms as such do not entail the final cause, while in the (M,R)-system it is entailed as anticipation (Rosen 1985a; Louie 2012).[8] Furthermore, anticipation as prediction-based behavior is neither teleonomic nor teleological (Rosen 1991: 46–49, 131–134),[9] making living systems causal systems but not mechanisms and therefore not "machines" (Rosen 1985b).

« 9 » Maturana suggested that "a living system, due to its circular organization, is an inductive system and functions always in a predictive manner" (Maturana 1980: 15f). Recent advances in theoretical biology agree with Maturana's view and consider living beings as autopoietic systems that cope with environmental fluctuations through predictive behavior (Friston 2013). There is empirical evidence that microbes anticipate fluctuations in their environment (Mitchell et al. 2009), parasites vary antigenically to escape immune-system operations (Bangs 2018), and the trees of the Amazon rainforest produce their own clouds and pump atmospheric water before dry periods (Wright et al. 2017). The behavior of these different lineages of autopoietic systems (microbes, parasites and trees) does not seem to be blind (responsive/reactive), but anticipative, overall. So, does Mpodozis's suggestion that autopoietic systems are "machines" not preclude the possibility of accounting for all these phenomena in terms of natural drift? Let me approach this concern through the question of Earth's habitability origin.

« 10 » The organisms' distinctions concerning the potential effects of their actions on their environment is crucial to answer the question of why Earth is habitable. One can explain it from purely geological mechanisms, which assumes that habitability is rather independent of and preceding the activity of living beings. An alternative argument explains habitability as a product of natural selection (Doolittle 2017; Lenton et al. 2018), either caused by chance (Watson 2004), or by exaptation (Volk 2004).[10] Within these explanations, organisms are seen as not having anticipated the consequences of their actions. They are reactive and blind. In other words, it is a sheer coincidence that the Earth is habitable.

« 11 » Lynn Margulis (1997) opposed this view in favor of autopoiesis as being central to explaining Earth's habitability. Together with Michel Crucifix (Rubin & Crucifix 2021, 2022) we have advanced her scientific claim by arguing that habitability, evolution, and anticipation are linked processes, and that natural drift should be an alternative explanation to natural selec-

3| For example, *why* does a house exist? Because of bricks, woods, etc. (material cause, initial condition), an architectural plan (formal cause, parameters), and the masons' construction (efficient cause, dynamical laws). Regarding the final cause, see Footnote 10.

4| Presentation, "Natural Evolutionary Drift," by Humberto Maturana at IFCC, Chile, 20 January 2015, https://youtu.be/xp_bG3AjRZw

5| This action referring to an end is important to clarify why the machine metaphor is misleading for our understanding of evolution.

6| A discussion of the sequence hypothesis (information and program in the genomic sequence) within a constructivist context can be found in Rubin (2017).

7| This means that the system is heteropoietic, i.e., built/construct from outside, but also allopoietic, i.e., they have as product of their functioning something different from themselves.

8| Stuart Kauffman (2019) has also suggested that evolution is non-mechanistic (non-algorithmic), yet without granting anticipation. Maturana (2008) rejected anticipation based on the idea that it is a violation of causality, and hence of structural determinism. However, anticipation as prediction-based behavior does not violate causality or structural determinism. For example, we can think of a behavioral disposition of a tiger, such as hiding in the weeds and not making the slightest noise, to hunt a deer. Such a behavioral disposition is structurally determined and can be considered a form of prediction (or at least distinction) of the potential effects of its actions on its own consecutive flow of actions, and the consecutive configuration of the environment.

9| In sections 3E, 5I and 11G of *Life Itself*, Rosen develops, in great formal detail, an explanation of why final causation can and must dispense with teleology. For Rosen, "a final cause of an effect is defined in terms of *something entailed by the effect*" (Rosen 1991: 133, emphasis in original). For example, for the question, *why* does a house exist, Rosen suggests that "to make finality respectable, it suffices to replace 'a house is entailed, as effect, of its final cause by an intention to reside in it' usage by 'a house itself entails further effects, some of which are synonymous with residence therein. To look at what is entailed by and effect'" (ibid).

10| The term "exaptation" was proposed by Stephen Jay Gould and Elisabeth Vrba (1982), as a replacement for "pre-adaptation," which they considered to be a teleologically loaded term. In the discourse of the Gaia hypothesis, exaptation is known as a by-product. For example, oxygen is a by-product of photosynthesis. Yet, at the planetary scale, it is linked to glaciations, but also to carbon cycling among other phenomena that influence habitability.

tion and adaptationism. Yet, as natural drift theory stands now, despite not being adaptationist, it apparently follows the machine metaphor (§3 in the target article), i.e., organisms are not able to distinguish the potential effects of their actions on their environment.

« 12 » Since autopoietic systems are the object and subject of natural drift, the equivalence of autopoiesis and the (M,R)-system, if well posed, has much to say about the causal embodiments of autopoiesis and therefore whether natural drift is a mechanism, and hence algorithmic. The pertinent question is whether we can better approach habitability by appealing to natural drift as a blind mechanism or rather as involving anticipatory effects for the constitution and conservation of living planetary systems. Q1

References

Bangs J. D. (2018) Evolution of antigenic variation in African trypanosomes: Variant surface glycoprotein expression, structure, and function. Bioessays 40(12): 1800181. https://doi.org/10.1002/bies.201800181

Cecchi C., Vargas A., Villagra C. & Mpodozis J. (2004) Answering Cuvier: Notes on the systemic/historic nature of living beings. Cybernetics & Human Knowing 11(4): 11–19. ▸ https://cepa.info/3251

Doolittle W. F. (2017) Darwinizing Gaia. Journal of Theoretical Biology 434: 11–19.

Friston K. (2013) Life as we know it. Journal of the Royal Society Interface 10(86): 20130475. https://doi.org/10.1098/rsif.2013.0475

Gould S. J. & Lewontin R. C. (1979) The spandrels of San Marco and the Panglossian paradigm: A critique of the adaptationist programme. Proceedings of the Royal Society B: Biological Sciences 205: 581–598.

Gould S. J. & Vrba E. S. (1982) Exaptation: A missing term in the science of form. Paleobiology 8(1): 4–15.

Kauffman S. A. (2019) A world beyond physics: The emergence and evolution of life. Oxford University Press, London.

Lenton T. M., Daines S. J., Dyke J. G., Nicholson A. E., Wilkinson D. M. & Williams H. T. (2018) Selection for Gaia across multiple scales. Trends in Ecology & Evolution 33(8): 633–645.

Letelier J. C., Marin G. & Mpodozis J. (2003) Autopoietic and (M, R) systems. Journal of Theoretical Biology 222(2): 261–272. ▸ https://cepa.info/3627

Louie A. H. (2012) Anticipation in (M, R)-systems. International Journal of General Systems 41(1): 5–22.

Louie A. H. (2020) Relational biology and Church's thesis. Biosystems 197: 104179.

Margulis L. (1997) Big trouble in biology: Physiological autopoiesis versus mechanistic neo-Darwinism. In: Margulis L. & Sagan D. (eds.) Slanted truths: Essays on Gaia, symbiosis, and evolution. Springer-Verlag, New York: 265–282. ▸ https://cepa.info/6215

Maturana H. R. (1980) Biology of cognition. In Maturana H. R. & Varela F. J., Autopoiesis and cognition. Reidel, Dordrecht. Originally published in 1970. ▸ https://cepa.info/535

Maturana H. R. & Mpodozis J. (2000) The origin of species by means of natural drift. Revista Chilena de Historia Natural 73(2): 261–310. ▸ https://cepa.info/680

Maturana H. R. & Varela F. J. (1973) De máquinas y seres vivos. Autopoiesis: La organización de lo viviente [Of machines and living beings. Autopoiesis: The organization of the living]. Editorial Universitaria, Santiago. ▸ https://cepa.info/541

Maturana H. R. & Varela F. J. (1984) El árbol del conocimiento: Las bases biológicas del entendimiento humano [The tree of knowledge: The biological basis of human understanding]. Editorial Universitaria, Santiago. ▸ https://cepa.info/573

Mitchell A., Romano G. H., Groisman B., Yona A., Dekel E., Kupiec M., Dahan O. & Pilpel Y. (2009) Adaptive prediction of environmental changes by microorganisms. Nature 460(7252): 220–224.

Pigliucci M. & Müller G. B. (2010) Evolution: The extended synthesis. MIT Press. Cambridge MA.

Rosen R. (1985a) Anticipatory systems: Philosophical, mathematical & methodological foundations. Pergamon Press, Oxford.

Rosen R. (1985b) Organisms as causal systems which are not mechanisms: An essay into the nature of complexity. In: Rosen R. (ed.) Theoretical biology and complexity. Academic Press, Orlando: 165–203.

Rosen R. (1991) Life itself: A comprehensive inquiry into the nature, origin, and fabrication of life. Columbia University Press, New York.

Rubin S. (2017) From the cellular standpoint: Is DNA sequence genetic "information"? Biosemiotics 10(2): 247–264. ▸ https://cepa.info/8014

Rubin S. & Crucifix M. (2021) Earth's complexity is non-computable: The limits of scaling laws, nonlinearity and chaos. Entropy 23(7): 915. ▸ https://cepa.info/8131

Rubin S. & Crucifix M. (2022) Taking the Gaia hypothesis at face value. Ecological Complexity 49: 100981. https://doi.org/10.1016/j.ecocom.2022.100981

Varela F. J., Thompson E. & Rosch E. (1991) The embodied mind: Cognitive science and human experience. MIT Press, Cambridge MA

Volk T. (2004) Gaia is life in a wasteworld of by-products. In: Schneider S. & Boston P. (eds.) Scientists debate Gaia: The next century. MIT Press, Cambridge MA: 27–36.

Watson A. J. (2004) Gaia and observer self-selection. In: Schneider S. & Boston P. (ed.) Scientists debate Gaia: The next century. MIT Press, Cambridge MA: 201–208.

Wright J. S., Fu R., Worden J. R., Chakraborty S., Clinton N. E., Risi C., Sun Y. & Yin L. (2017) Rainforest-initiated wet season onset over the southern Amazon. Proceedings of the National Academy of Sciences 114(32): 8481–8486. https://doi.org/10.1073/pnas.1621516114

Sergio Rubin has a doctoral degree in biology and is the author of scientific articles that cover topics such as cell molecular biology, environmental microbial ecology, theoretical biology, neuroscience and Earth system science. Currently he is working at the Georges Lemaître Centre for Earth and Climate Research, Earth and Life Institute, of the Université Catholique de Louvain, Belgium.

Funding: No external funding was received while writing this manuscript.
Competing interests: The author declares that he has no competing interests.

Received: 11 October 2022
Revised: 14 November 2022
Revised: 21 November 2022
Revised: 25 November 2022