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The Xenobots as Thought-Experiment
Teleology Within the Paradigm of Natural Selection

Abstract
The first organic robots built by Tuft and Vermont University researchers pose questions to philosophy and give it a new task. The xenobots embody what philosophers had attempted to define as teleology. This paper addresses the way telos can be redefined, once liberated from the suspicion of vitalism. While Darwinism, through a theory of evolution based on the environment, has contributed to the elimination of telos, here a new view of biology is described, which shows how evolution can be fully explained through the notion of feedback, or inner resistance in a system, as preliminary condition for natural selection to work.

Keywords
Telos*, Resistance, Environment, Feedback, Cybernetics.*

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On January 13, 2020 a team composed of Sam Kriegman, Douglas Blackiston, Michael Levin and Josh Bongard published in the Proceedings of the National Academy of Sciences of the United States of America an article about the invention of an artificial organism. The very definition of "artificial organism" sounds like an oxymoron. An organism is a natural system, a wet-ware machine that has nothing common with an artefact which, however similar to an organism in the behavioral and cognitive effects, is a hard-ware system. Yet, in this case, the artefact is an organic machine. The new entity, just by virtue of being totally composed of organic cells, appears to behave as organisms do: purposefully.

Now, the consequent philosophical issue is immediately clear: is the machine to be organic or is the organism to be mechanical? Should this invention be rather called a discovery?

If this experiment proceeds and succeeds in its aim – as it seems to – should we revisit the notion of *telos*, if it emerges as an endogenous algorithm? Will human beings still perceive themselves as such? To these questions, among others, this essay tries to bring some clarification.

1. *An experiment* in fieri

What these young computer scientists are doing is to scrape stem cells – specifically the ones of the skin and the heart – from a frog called Xenopus Laevis (from which the name Xenobots (*xenos* also meaning stranger in ancient Greek). The extraction does not need genomic manipulation. Then by the use of a super-computer, able to manage an evolutionary algorithm, data are collected about the way the structure of the extracted cells can function as a system. Random changes in possible structures are repeated through millions of combinations until one appears to work. In the end the organic artefact shows the same behavior as the silicon model: the whole behaves independently of the single cells, through internal symbiosis and systemic relationship with the environment.

What is new here is that the reverse engineering does not manipulate nor edit the cells, whose chemical substances and mechanical factors (pressure, temperature) appear to be spontaneously detected inside the cell and accordingly activate certain behaviors rather than others.

Each aggregated whole, the actual xenobot, has 3000 ½ mm spheres covered with thousands of cilia as propellers that protect them from bacteria and make them move forward inside the new environment, which is fresh water. Once gathered in a swarm they seem to repurpose their behavior and move together in one common direction. They are given sugar and can live a few months, before dying by disintegrating in water (Kriegman et al. 2020).

In order to test their ability to retroact on the environment and retain its inputs, the xenobots are implemented a RNA molecule responsible to sense light and change color in its presence. These cell networks do change color when light changes (Silver 2022). This function can be used to orientate their purpose. We could say that if their purpose can be manipulated, it means that they are capable of it.

Once free to move in the water they appear to push, collect or remove objects. In fact they can repair their wounds and recently they have shown to be able to replicate themselves, by cynetic replication, that is by moving and collecting scattered cells until they aggregate and often are added to the existing swarm (Kriegman at al. 2021). Though the second generation does not replicate itself, what the experiment shows is the observable spontaneous coordination among all the muscle cells which, pumping and contracting, bring the locomotion to the accomplishment of some design.

The increasing complexity of the conditions of their survival might produce either the emergence of sub-systems by feedback loops, or the very fading away of the whole system.

If the case is the first, we can imagine how, once that the external input is not directly produced by the experimenters-observers, they will construct their own identity on the constant challenge of the immediate circumstances they find. They might make decisions of their own once inside of a human body. If they are perturbed, let's say, inside of the ocean, they may develop a mutation which determines a stronger resistance to the threat, and may not be detected by the experimenters.

The fact that the first generation of xenobots looks and behaves in a way that is not similar to the frogs' (we might say that the egoist gene does not have any power here), is evidence that the automatic aggregation is not connected to natural selection. The artificial selection *uses* a teleological function it finds; and it is exactly this function that allows for the actual aggregation, however selected as one on millions.

Concerning the choice of skin cells and heart cells, the first, being responsible for the formation of an entity distinct from an outside, draw a line that includes a self while excluding all the rest (in Spencer-Brown's perspective), while the second are the ones that produce motion, through the rhythmic electrical impulse; this choice, however due to an external manipulation, is determined by the fact that these two elements are basic conditions for goal-seeking systems: the molecular surface tension or membrane provides greater resistance to external pressure; the second appears in the form of swarm intelligence, that is, non-random and non directionless motion.

Moreover, though the two dynamics are non-linear with one another, they can and do collaborate thanks to the elementary rules of a swarm, whose individual elements 1. adjust to the next member, 2. keep a similar speed and 3. keep a constant distance. This simple structure creates the super-system/entity that is a particular swarm.

In the next paragraphs we will focus on two issues: the goal-seeking system, as a condition for rather than the product of natural selection, and the lack of locus of the automatic goal-seeking impulse, as the evidence of a pervasive teleology.

2. *Teleology as resistance: alternative narratives to natural selection*

> Leduc would be the first to agree that living substance
> may not be synthesized for ages, if at all.
> But each advance brings the goal nearer…
>
> Bashford Dean (in Keller 2009)

It is the very plasticity shown by the xenobots that poses a question: if the artificial selection could eliminate the million combinations of cellular aggregations, it could not anticipate the one that appeared to work, that is, it worked blindly, without an algorithm. The one that worked emerged, it happened, it was not invented. What the evolutionary algorithm of the super computer Deep Green has provided for is to discover one of the feasible and not infinite possibilities of nature. In fact in the transition from the virtual to the embodied, these cell networks showed to keep their systemic resistance (surface tension) and motion (orientation) in place, making their autonomy immediately observable as independent from external random factors, rather depending on an internal structure that the system is able to activate, that of resistance or "robustness", in Evelyn Fox Keller's terms (Keller 2009: 20). It resists in the sense of being closed in itself and in the sense of detecting the presence of an outside and cope with it through motion. They constantly retroact on the environment by moving toward and away from some place. This teleological behavior paradoxically excludes at the same time intention and randomness, a paradox that natural selection ignores: getting rid of the final cause, natural selection proposes a deterministic relationship between systems and environment; nevertheless the removed teleology comes back in language; in fact expressions such as: “the environment selects”; “the system adapts to the environment”; “the bird grows hollow bones in order to fly” are metaphors still waiting for an account.

The authors analyzed below have tried to overcome the explanatory gap, by reintroducing teleology in terms of cybernetics of the second order, or endosymbiosis, or auto-poiesis. We start with Evelyn Fox Keller’s challenge to the Darwinist theory:

> [Early cells] lacked many features of the modern cell. But in order to persist – and to maintain their identity – long enough for natural selection to operate, they had to already have had primitive mechanisms to support metabolism, cell division, etc. There needed to have already come into being primitive embodiments of function that would work keep the cell going and to protect it from insult. [...] They survive not as a result of natural selection but as a consequence of the internal selection that follows automatically from their contribution to the persistence of the system. (Keller 2009: 8-9)

More recently, Detlef Weigel, from Plank Institute, challenges the XX century idea that mutations occur randomly with respect to the consequences. But by observing and being able to reproduce the process in the plant Arabidopsis thaliana, he and his co-authors state that:

> In contrast to expectations, we find that mutations occur less often in functionally constrained regions of the genome—mutation frequency is reduced by half inside gene bodies and by two-thirds in essential genes. (Weigel et al. 2022)

So far there was a lack of data about new mutations, that is, biologists could observe only the result of the selection and trace back its possible paths; now researchers, by reproducing artificially or simulating the process *while* it happens, can in fact observe that the mutation is not totally random, but it involves only those genes that do not endangers the survival of the genome (that is, the essential genes: the genes of growth and of action regulation, or the ones with strong repair mechanisms).

The process seems to be guided by an invisible hand that exerts a direction on it and is, not just the result of the survival, but its condition of possibility.

The lacuna left open in Darwin’s theory has been emphasized by the (now) observable fact that a living system actively contributes to its own persistence, embodying a function of self-protection, *before* the natural selection could operate. We should rather consider, Fox Keller continues, the recursivity of cybernetic causality, as a function that is not blind without being intentional, nor vitalistic, nor an intelligent design: the self-organizing cell is the model of that which keeps a homeostatic condition by virtue of feedback loops (Keller 2009: 20).

However, it is not the function itself that contributes to survival (the environment may not be fit for a specific organism anyway). So we might say that if it is selection that determines the probability of survival, it is an intrinsic function that – being reproduced – explains the fact of survival, by endowing the cell the necessary stability for natural selection to operate (Keller 2009: 9).

Fox Keller uses the example of Stephane Leduc: can the chemical and thermodynamic reactions that build a living morphology, be also a proto-organic teleology? After all the synthetic animals Leduc invented can swim by contraction… (Keller 2009: 17). What Leduc (and the xenobots as Leduc's legacy?) still contributes to the problem is that the cell network moulds itself not by assembling components but by recomposing and then emerging as a complex structure of non-linear systems and sub-systems that start cooperating with one another, through feedback loops. Fox Keller borrows from Herbert Simon the idea of evolution by composition (opposed to natural selection and emergent self-organization: in repeated feedback loops systems merge and build a base for more systems to be merged (Keller 2009: 20). We might add that the complex systems are not composed sub-systems and that the result is more than the sum of its parts, constituting an irreversible structure: cybernetic levels of the composition support supra-molecular chemistry levels, supporting endo-symbiosis levels, etc. The generative process works in evolution exactly for its being nonlinear: as one level of composition retroacts on the previous, by exploring new possibilities, it turns itself into a part of a wider composition (an organism becomes an organ). We imagine compositions within compositions within compositions, and so on. Using Margulis' image: living systems "are integrated colonies of ameboid beings" (Margulis 1995: 141).

> Molecules, and especially large molecules like proteins, are not simple billiard balls. They are sticky, they have binding sites. […] Molecules, like viruses, show a basic agency upon which other systems may be collected randomly, though not infinitely randomly exactly because of the tendency to aggregate (they are sticky) in stable forms, and even by virtue of being infectious – transmitting their properties and *exploring* new territories. (Keller 2009: 22-4)

This is where Lynn Margulis' insight starts: "Natural selection eliminates, maybe maintains, but it doesn't create" (Margulis 2011). When looking for evidence of the effectiveness of the Darwinist ground-concept, Lynn Margulis broke in with a new theory: endosymbiosis. After being controversial for years, it is now confirmed (Lake 2011).

Observing and studying Archaea bacteria, Margulis concludes that eukariot cells, when invaded by bacteria, instead of rejecting them or digesting them, they kept them and started a cooperation which transformed them into organs. Thanks to involution, organisms become parts of super-organisms, systems become sub-systems to make life stronger. She concludes that organisms are not separate from inanimate beings, but in continuous mutual adjustment. By extending physiology to the inorganic, setting aside the problem of the "origin" of life, according to an idea of continuity between living and nonliving, as the one is part of the other. In Margulis' words: "We are walking, talking minerals" (Margulis 1995: 49), she introduces, as a complement to selection, an extended notion of autopoiesis, from its elementary manifestation: river water evaporates into clouds, clouds becomes rain, rain fills river beds: systems caught in mutual systemic feedbacks. Similarly bacteria enter animal organisms to protect themselves from heat increase, and in return give them oxygen (Margulis 1995: 90). So it is not only the gene to be egoist but every system that uses other systems *in order to* survive. How to explain that the biosphere keeps its temperature between combustion and asphyxia, along the changes occurred in four million years? Life has responded to the increase in temperature by changing its surface to protect itself from excessive heat. It cooled the planet by removing heat-trapping gases (i.e., methane and carbon dioxide) from the atmosphere (Margulis 1995: 22). This stability has provided life, on condition to diminish the amount of salt in water. How? There must have been micro-organisms whose cells pumped out sodium, calcium and chloride (salt-absorbing substances), stabilizing the amount of salt. Or maybe salt-loving microbes in coral reefs blocked the expansion of salty sands (Margulis 1995: 22-3).

There is an earth physiology whose dynamics has less to do with being better fitted, and more to do with a weakness or an inadequacy that summons resistance through cooperation, or endosymbiosis, the only way to provide for the necessary homeostasis of the system. Xenobots are able to cope with their environment (water) before or beside showing qualities suitable to it. Evolution is the continuous alteration of what exists, a primordial effort to anticipate what may break apart a system and to repair what is threatened. Chance cannot fully explain the systemic autopoiesis that occurs in the long run, without hypothesizing the ability to anticipate and retroact on contingency. If contingency is Darwin's great discovery, the function of turning contingency into stability is Margulis' great discovery.

The cell needs to eat, and suffers if it doesn't. Darwinists may say: the cells with a weak need to eat won't survive, but it does not explain the "need" to eat, nor the emergence of increasingly complex super-organisms.

An admirer of Margulis' theory, Kevin Kelly has connected biology of cognition to cybernetics, emphasizing the spontaneous complexity of systems that emerge from webs of parts. The question is the same: "Life has a causality problem" (Kelly 1994: 312). Saying that elimination of the unfit "causes wings to be formed, or eyeballs to work, is essentially wrong" (Kelly 1994: 315). If "natural selection is not enough" then what else might be at work in evolution, and what may we import into artificial evolution that can produce self-organizing complexity? If random mutation cannot *generate*, where does the rule, the algorithm of the best possible combination, come from? These are questions that left Darwin himself perplexed and doubtful (Kelly 1994: 311), but that, in absence of a theory of DNA and of the tool of simulation, he could not answer. If observing in real time new species emerge and mutations produce evolution was impossible, once that AI enters the scope of research, computer simulation may rely on a *falsifiable* field of confrontation, giving the theory experimental evidence. And what becomes observable is self-creation, *autopoiesis*. Darwin's idea that finches would grow thicker beaks in a changed environment is a probability theory and not a biological theory (Kelly 1994: 236) and it does not touch on the question of the resistance to selection, the effort to keep a unity, the inner self-organization of parts.

In synthesis, alternative hypotheses consist of 1. symbiosis: the accidental merging of organisms; 2. nonrandom but cybernetic mutations; 3. self-selection: after Stuart Kauffman's research, the genome uses a circuitry (A watching on B, B on C, C on A) to resist perturbations and try to persist as a cohesive unity (Kelly 1994: 321-5). In any case, what this alternative hypothesis adds to Darwinian selection is the anticipation of a solution, or correction of a flaw, and the sharing of it (the mutation in one individual would have few probabilities to impose itself if not likely occurring in an amount of individuals that share the same problem, the same weakness to be corrected). The function Fox Keller talks about, and Margulis identifies with endo-symbiosis is the anti-chance factor of cybernetics: retroacting on the cause of weakening by modifying the direction of motion, or the quantity of energy. Retroaction, or feedback, implies active resistance.

So living systems (and to a certain extent also nonliving systems) regulate one another and therefore undergo the same variations according to the information received from outside, in cybernetic feedback loops.

The tendency of random phenomena to assume a pattern, or self-organization, has been also the concern of other thinkers like Katherine Hayles and Stuart Kauffman, whose reflections on Artificial Life have required the continuity between the wetware and the hardware: biology becomes a model for physics and now the xenobots may embody the exigency of conceiving of all nature as a myriad of nets, responding and retroacting to signs from the environment. Information and contingency appear to be part of the same natural process (Antomarini 2017: 191).

3. *The non locality of the telos and its contingency*

> I say that whatever happens in accordance
> with its antecedents is *assured,* but is not *necessary*.
>
> Gottfried Wilhelm Leibniz

To recapitulate: there must be a biological function X which precedes the probabilistic mechanism of natural selection and which appears plausible now that the experiments with xenobots show the cybernetic circuitry made of: xenobots + observers + water + detritus, microplastic and pollutants + drugs + human body + ocean, etc.: an increasingly complex and superimposed set of environments (Levin 2020) which are cooperating in turning parts of the environment into systems. The issue raised in this paper is that this function is not intentional, does not “choose” what is useful and rejects what is damaging, as there is neither an entity nor an individual origin of the choice.

By imagining xenobots dragging pollutants to a certain direction, or putting together scattered cells to form another xenobot, we also imply the existence of an indefinite number of superimposed teleological acts that seem to form a universal teleology only by virtue of their being many; that is, we assume a self-organized swarm intelligence: *Deus sive natura*. They can give a further corroboration to Margulis’ idea of endosymbiosis and the propensity of organisms to be held together to oppose the threat of destruction by the environment: a cell and its organelles, many cells, many organs made of differentiated cells, etc. and these "myriad moving beings – by reproduction and growth - break down and build matter on a global scale" (Margulis 1995: 49). They also respond to Kelly's question: if random mutation cannot *generate*, where does the rule, the algorithm of the best possible combination, come from? Once that we can observe evolution in action, we see the matter of fact of the *tèlos* and its rule as primeval function.

We imagine xenobots adjusting and modifying their behavior depending on what happens to them in the new habitat, which, as it may endanger them it also gives them the chance to be altered and refined. Contingency shapes their behavior, in a way that cannot be very different from an autopoietic system. So far as they produce themselves, they will become another invention of nature, to be added to the existing ones.

This opportunity to observe a living system in its real and not just simulated evolution, can be used as evidence of the way its cells *become* active *the very moment* they are chosen and collected in a certain amount. By cooperating, they keep their chemical parameters within the right ranges (Levin 2020) and this is enough to adjust to new circumstances and successive environments, which in their turn are exposed themselves to the retroaction these organisms perform on them.

Showing an effective swarm intelligence makes nonlocal teleology observable: they orientate their behavior *if* they act together. The locus of *tèlos* is not to be found in one of them, or any of their parts, but in the whole. They could be a crucial proof of the existence of the function of existence as resistance, and of resistance as collective act. Every system is a multiplicity of environments and is a symbiont of the wider systems it inhabits. At the same time, the observable process of swarm intelligence is what makes it unpredictable: their resistance will be developed depending on which circumstances will modify direction and choices. The function of resistance is plausible exactly because is systemic, not local, non-substantial, but a *condition of possibility* for survival (not being itself a guarantee of survival).

4. *From modern philosophy to cybernetics and back again*

The problem is not new, though, but one that now can be revived. To his friend Oldenburg, who in a letter written in 1665 had asked him to clarify the "difficult question of the manner in which each part of nature agrees with its totality and connects to all others" Spinoza answered:

> Imagine a worm who lived in the blood, capable of seeing and distinguishing the particles of blood, lymph, etc. and understanding the way in which each particle, in encountering another, recoils against it or transmits to it part of its movement. The worm would live in the blood as we do in this part of the universe. It would not see anything that it can call "blood" but would consider each blood particle as a totality and not as a part and would ignore the way in which all parts are governed by the universal nature of blood. (Spinoza 1955: 192-3)

If the worm is the xenobot, who "understands" (nonrandomly retroacts on) particles in the water (blood) and interacts with their movements, we have the image of nature that these new experiments suggest. And, to follow the analogy to the end, we as humans in the universe are like xenobots in the water. And if the xenobots are observed by humans, humans, as parts of the earth system, are tools the earth system uses to observe itself through its observers.

And it is inevitable that the necessity to assume a condition of possibility for natural selection brings us back to Kant, who in the *Critique of Judgement* had distinguished between a descending causality and an ascending causality. In the first phenomena existence is conceived as the effect of causes, that is the effect descends from causes. But in organic phenomena (which are not reducible to the mechanical), there must be a force (however not "living force" in the sense of Leibniz) which turns the effect into a second cause retroacting on its very cause (Kant 1987: 251-3). Using his famous example:

> In the first place, a tree generates another tree according to a familiar natural law. But the tree it produces is of the same species. Hence with regard to its species the tree produces itself: within its species, *it is both cause and effect,* both generating itself and being generated by itself ceaselessly, thus *preserving itself* as a species. (Kant 1987: 249; my italics).

So the xenobots are effects of a descending causality (experimenters) and subjects of an ascending causality, producing themselves as emergence. Moreover, in *Thoughts on a New Estimation of Living Forces*, he states that "motion is the outward phenomenon of force, but the striving for preserving this motion is the basis of the activity" (Kant 2012: 122).

Between epistemology and ontology, Kant's concern here seems to be that there must be a striving for preservation that is necessary for (thinking?) of life. Curiously it may converge with Spinoza's *conatus* or

Leibniz' *force vive*: notions that, in absence of technological support and testability, remained jeopardized by their metaphysical premises, and uninvestigated until now. In fact, now it is time to revisit those philosophical positions.

Conclusion

If the xenobots get so much attention, it is because they are fictional and real, a thought-experiment materialized and productive, an effect of research but an agent to be observed in what it can or cannot decide to do. Experimenters might gaze at *what* they are able to do and not observe *whether* they are able to do what was planned.

They elicit 1. a new definition of machine; if living things are not machines, and vice versa, systemic relationships between the mechanical and the living is now observable and the distinction is not tenable any more. 2. A new definition of information as a degree of excess with respect to the predictable. We can never know what effects can do (paraphrasing Spinoza: we do not know what bodies can do). 3. A new definition of *telos*: as active resistance, replacing "freedom" or "will", as considered to be a human prerogative. 4. A new definition of natural selection, as the effect of resistance.

A physical entity is an aggregate of energy that constantly makes and re-makes itself elsewhere. It makes choices and behaves successfully, without thinking. It is true that natural selection is not a philosophy of life, and the past philosophies of life did not acknowledge the automation of *telos*, which does not need a brain, but whatever the result of this crucial research, it is anyway a thought-experiment for philosophers in post-digital times and post-Darwinian times, as they end up raising the new questions: are humans instruments of what nature can do? Can what builds itself know itself while building itself?

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