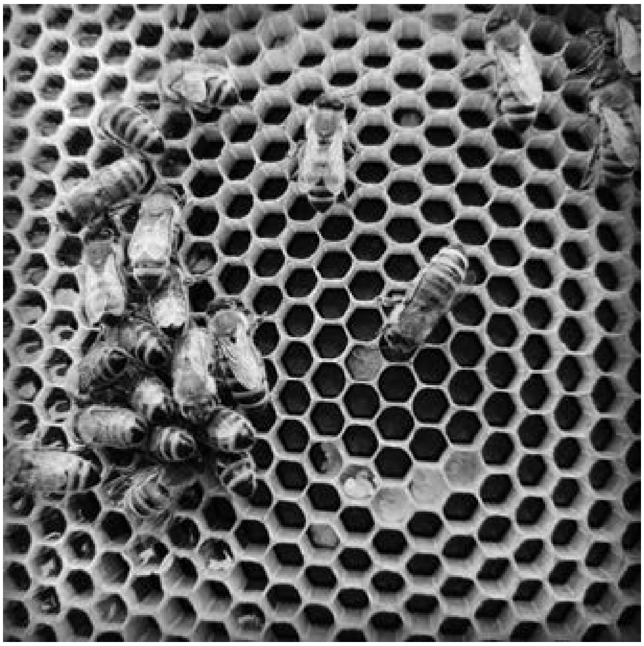

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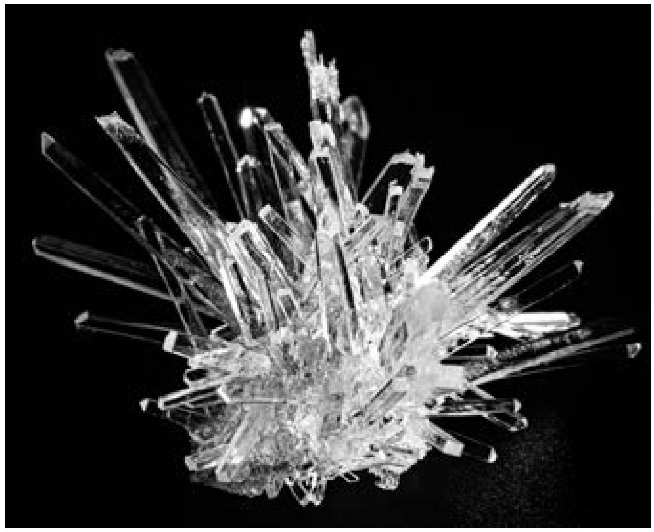

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Weaving Wonders With No Purpose at All

Ringo Starr has been almost universally liked for decades as probably the most affable member of the Beatles, the nicest guy in the universe who might have benefited from that incredible stroke of luck of being in the picture when the band decided to look beyond Pete Best. Every now and then you would read about him being one of the most underrated drummers in the history of rock, but he was rarely praised beyond his niceness and sense of humor.

But take a stroll down memory lane on the Internet nowadays —look up something like "Ringo genius"— and you'll be surprised not just by the sheer number of entries defending the proposition, but mostly by the depth, detail, and, indeed, passion of the arguments. Take, for, instance, the analysis of Ringo's creativity in the song *Tomorrow Never Knows*, as presented by George Hrab.[1] He describes the drumming as a "pattern" that provides "space" and something solid "upon which the song could be built." Hrab makes no mention of Richard Starkey's childhood, but the man himself does in an interview with fellow musician Dave Stewart, of Eurythmics fame. Recounting the year and a half spent as a sickly child in a hospital, Ringo recalls that when a drum kit arrived in his room, "I wanted to be a drummer from that day."[2]

Lovely as the anecdote may be, the truly interesting revelation came a few seconds earlier: "I learned to knit in the hospital." It appears that the future master of drum-

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ming patterns between straight and swing and some invention in between learned the basics of the warp and weft weaving forms at the same time. Mere coincidence? Probably… yet one is tempted to make a connection with remarks made by the Mexican historian of medicine, José Luis Díaz, regarding the reasons why the human brain is stimulated —arguably into overdrive— by musical patterns: "The brain works based on rhythmic cycles," he said in an interview on TVUNAM.[3] For its part, "musical language transmits emotions," but the musical emotion "is not a primary emotion; it is highly sophisticated." And that is why almost only human beings feel it. Yet, the human brain responds differently to these sorts of emotional "messages" than it does to more primitive emotional stimuli, such as fear, joy, or sadness.

Surely one big difference is that these basal stimuli are rather blunt, whereas music follows patterns, and these in turn excite the brain's rhythmic tendencies. In this sense, then, one could wonder whether something apparently as simple as the weaving patterns Ringo learned in his hospital stays helped him create "Beatles" patterns later in life. Taking this notion beyond Ringo's individual experience, perhaps other structures could produce similar emotional responses related not to musical rhythms but to visual aesthetics. Think of the visible metal network sustaining the Eiffel Tower or the arrangement of stone at Tulum's Maya ruins, or even the extraordinary effect produced by Escher's mesmerizing tessellations.

This last example is particularly interesting. A visit to the Escher Museum in The Hague is likely to trigger a healthy dose of emotional responses,[4] but among them will almost surely be profound admiration for the human being who designed these artistic patterns in the first place: Maurits Cornelis Escher himself. He did design some impressive tessellations, but he did not actually invent them. Indeed, patterns of repeating tiles can be found in nature, such as in honeycombs, mudcracks, scales on the skins of several animals, and a variety of crystal formations. Regardless of their relative aesthetic value, if these forms were to produce admiration… who should one admire?

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Let's go even further, much further, in opposing directions of the physical scale. The iridescent patterns formed by light bouncing off minute structures on the wings of some flying insects are surely admirable. So are the apparent arrangements of stars that night after night can deeply move those still fortunate enough to be able to regularly enjoy the night sky.

We admire the sky and the light reflected from the wings of insects, and historically societies have come up with "creators" to admire for these "designs." But, what if we accept the premise that there are no such creators… and indeed no design at all? What if these amazing things, and very many more, happened just…, well, just *because*?

At some level the question is philosophical, but it can also be addressed taking advantage of scientific reasoning. In the book *Fronteras de la Física en el Siglo* XXI (Frontiers of Physics in the Twenty-first Century), UNAM physicist Octavio Miramontes argues that the evolution of matter was inevitable. In other words, even if we started —conceptually— from the absence of matter, this *vacuum* is not *nothing*, for it is impossible to get rid of all manner of fields (electromagnetic, gravitational) and, crucially, fluctuations within these fields. "Quantum vacuum contains no particulate matter," writes Miramontes, "but it does contain fluctuations which cause virtual particles to materialize, only to disappear at once, in mutual annihilation."[5] These fluctuations produced the Big Bang, and only a few microseconds later, while the Universe underwent a rapid initial expansion, "matter condensed in its first manifestations," goes the text.

Still, from there to the wings of butterflies, there is a lot of explaining to be done, and quantum field fluctuations can take us only so far. For the purposes of this story, let's make a titanic fast forward to when planet Earth already exists,[6] properly equipped with the required inanimate context (oceans, some atmosphere, solid ground, climate) and perhaps a healthy dose of organic molecules floating about. Life is not there… not yet; but it will soon appear as the ultimate patterned structure: the living cell. The thing to keep in mind at all times, though, is that what followed happened spontaneously, without agency, as a result of no intervention, with no purpose at all. It was desired by no one, it was designed by no one.

How, then, did a soup of organic molecules render a living cell? At this point, Miramontes demands from us that we pay attention to two tenets of the science of complex systems: *self-organization* and *emerging properties*. Self-organization is a characteristic process of complex systems, which Miramontes describes as "a set of similar elements interacting among themselves to generate emerging properties at the global scale." Thus, self-organization "is an emerging order, generating without an intervening central control or a predefined plan.... This new order usually manifests itself as the spontaneous ... formation of space-time patterns where there were none before, and as the possibility of highly organized collective behavior, in the absence of predetermined designs."

There may not be a plan, design, or central control, but there are the laws of physics to begin with. In particular the Second Law of Thermodynamics puts a direction on all spontaneous processes: they must happen in such a way that the entropy of the whole system in the final state is no less than in the initial state. Not ever. But there is a catch: as stated in textbooks and taught in classes, the Second Law applies to systems that are thermodynamically closed, isolated, and in equilibrium. Alas, life occurs in systems thermodynamically open and very much in interaction with the environment and, consequently, far from equilibrium.

"These are two separate worlds," said Miramontes in a socially-distanced interview with us. Yet, even for open systems, if their energy input is cut and they are left on their own, they will tend to evolve toward states of lowest energy, and do so spontaneously. So, the question is whether the theoretical body of thermodynamics of dissipative systems away from equilibrium is good enough to account for the spontaneous emergence of single-cell living organisms from the soup of organic molecules. If this process is to be understood in the realm of complex systems, Miramontes's text identifies the presence of a physical frontier separating the organism from its environment as a crucial condition for the emergence of self-organization and higher complexity levels. This is precisely what the cell membrane does: it isolates the interior of the cell from the outside environment, sustains differences in concentration of vital elements on both sides, and allows life processes to take place based on flows of matter and energy. So, can science explain the appearance of the cell membrane?

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Mariana Benítez studies uni- and multi-celled organisms at the UNAM Center for Complexity Sciences. She told us that she has been pondering recently the artificial nature of the separation between biology, physics and chemistry when considering questions of this sort. In her research she frequently encounters processes from those three fields occurring simultaneously and in feedback: bacteria may aggregate due to surface tension, for instance (a purely mechanical effect), but these very bacteria will secrete substances that in turn modify the surface tension mid process. Nevertheless, the principles of non-equilibrium thermodynamics are there, she says. From genetic regulation networks (in the scale of cells) to resilience of ecosystems (a much bigger scale), "whether we make it explicit or not, we are using these very powerful principles."[7] She has seen examples of cells organizing in geometric patterns that minimize surface tension, and thus overall energy. One such example occurs in the eyes of flies, but Benítez told us that thermodynamics helps us understand why the final pattern is the one it is, "but we couldn't explain the whole process along each stage of development of the embryo, because it goes through a set of leaps in levels of organization along which it is hard to maintain continuity in explanation. Each leap in organization level seems to trigger different processes, so it will be important to develop broader conceptual frameworks."

Miramontes appears to agree: "We don't have yet the First, Second, or Third Laws of Complexity," he said. Nevertheless, at least regarding the standing problem of the spontaneous assembly of the cell membrane, the thermodynamic theory —historically conceived with systems of much less complexity in mind— is not fundamentally wrong, although still insufficient. For both Miramontes and Benítez, some of the missing pieces will come from the science of complex systems.

Miramontes identifies one particular path to pursue: "The transition from a molecule in the realm of the in-

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animate to one in the realm of the living is an informatic transition. The molecule becomes capable of storing and subsequently transmitting information." This happens at the molecular scale, lower than the cellular scale of the membrane problem, but, for it all to occur spontaneously, thermodynamics dictates that an increase in overall entropy must occur. Entropy is a rather uncomfortable variable, probably because it can be defined in different ways. Its original form was close to the more intuitive concept of energy, but most recent treatments define entropy precisely in terms of information. Moreover, seminal work from the 1980s aims at linking entropy with evolutionary theory.[8] According to Edward Wiley (University of Kansas) and Daniel Brooks (University of Toronto), "The addition of information to any system increases the entropy of that system" (a crucial condition for spontaneous phenomena); and, since "evolution may be described as a nonequilibrium process involving the conversion of information from one form to another,"[9] they propose a biological interpretation of entropy to account for the theory of evolution in terms of thermodynamics.

Much of the theoretical framework seems to be still in construction. We do know, however, that organic macromolecules found themselves enclosed within membranes of living cells. These membranes were the result of the spontaneous assembly of smaller molecules in patterns with favorable properties. The cells they allowed for eventually merged into multicellular organisms, which in turn produced more complex patterns capable of responding to stimuli from the environment and, in evolutionary time, adapting to it. Eventually, increasing levels of complexity rendered patterns of cells we now call *tissue* (muscle, connective, etc.), which is itself a word etymologically related to the Latin *texere*, meaning "to weave."

In a sense, the circle is then closing. Physics and biology from the last couple of centuries give us hints of how it could possibly be that the relatively simple pattern of molecules we call the cell membrane spontaneously formed, desired by no one and designed by no one. To better understand this foundational process, and the explosive chain of events that followed for eons up to the biological tissue that is somehow *us*, the scientists we read from and talked to point in the direction of new frameworks in the realm of the science of complex systems.

But the potential goes beyond explaining un-designed, amazing phenomena. Humankind has had some success making new designs by learning from nature. Lorena Caballero, a professor at the UNAM School of Sciences where she studies skin patterns on animals, entertained these ideas in an interview. "Systems that mimic nature must be adaptive and energetically optimized." She insists on identifying and analyzing the interactions of the component parts of the system of interest, saying, "Emerging spaces and bio-inspired processes will be possible from the angle of complexity."

Ringo explains the uniqueness of his drumming style on the basis that he was a left-handed individual playing drums set for right-handed people. This put him in situations in which patterns emerged as adaptive solutions of least effort. "I can't struggle like that," he told Dave Stewart. "It comes naturally to me or it doesn't come at all."

Un-designed, functional patterns obviously have come naturally to this world. Making sense of them, however, will probably demand novel forms of scientific research. VM

Notes

1 George Hrab is a drummer with The Philadelphia Hunk Authority. His take on Ringo can be found at https://www.youtube.com/watch?v=7CB8xToC-CU.
2 https://www.youtube.com/watch?v=3fbjHQxOZZU&t=201s.
3 https://tv.unam.mx/portfolio-item/musica-y-cerebro-2/, minute 12:23.
4 A virtual visit is possible at https://www.escherinhetpaleis.nl/.
5 O. Miramontes, "Evolución y materia compleja," in O. Miramontes and K. Volke, eds., *Fronteras de la física en el siglo XXI* (Mexico City: CopIt-arXives, 2013), http://scifunam.fisica.unam.mx/mir/copit/TS0011ES/TS0011ES.html.
6 Pun very much intended.
7 Interview with the authors.
8 For a thorough overview, see J. Collier, "Entropy in Evolution," in *Biology and Philosophy* 1 (1986), pp. 5-24.
9 E. O. Wiley and Daniel R. Brooks, "Victims of History —A Nonequilibrium Approach to Evolution," *Systematic Biology* 31, no. 1 (1982), pp. 1-24, https://doi.org/10.1093/sysbio/31.1.1.