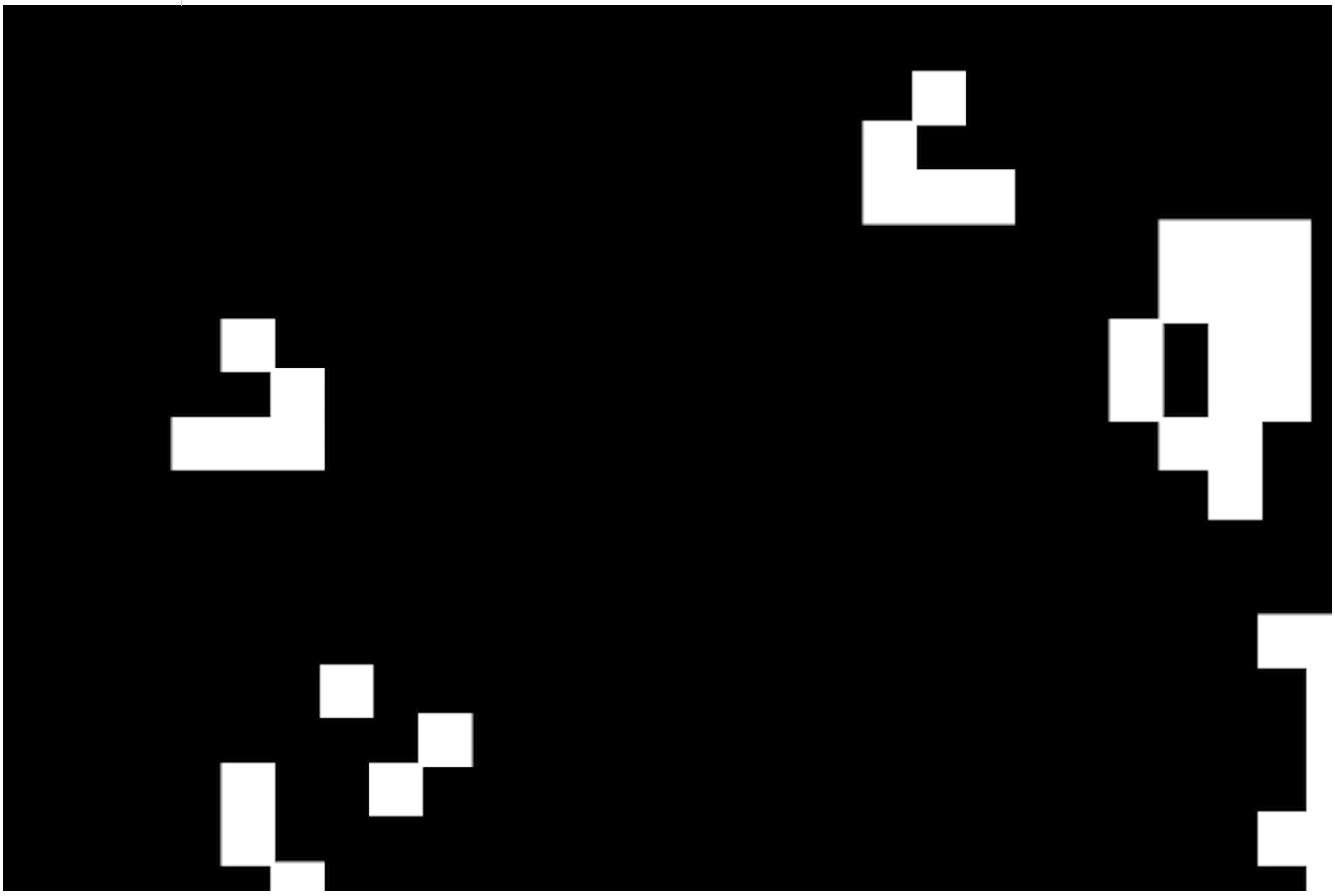
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The Lasting Lessons of John Conway's Game of Life

Fifty years on, the mathematician's best known (and, to him, least favorite) creation confirms that "uncertainty is the only certainty."

By Siobhan Roberts

Dec. 28, 2020

In March of 1970, Martin Gardner opened a letter jammed with ideas for his Mathematical Games column in Scientific American. Sent by John Horton Conway, then a mathematician at the University of Cambridge, the letter ran 12 pages, typed hunt-and-peck style.

Page 9 began with the heading "The game of life." It described an elegant mathematical model of computation — a cellular automaton, a little machine, of sorts, with groups of cells that evolve from iteration to iteration, as a clock advances from one second to the next.

Dr. Conway, who died in April, having spent the latter part of his career at Princeton, sometimes called Life a "no-player, never-ending game." Mr. Gardner called it a "fantastic solitaire pastime."

The game was simple: Place any configuration of cells on a grid, then watch what transpires according to three rules that dictate how the system plays out.

Birth rule: An empty, or "dead," cell with precisely three "live" neighbors (full cells) becomes live.

Death rule: A live cell with zero or one neighbors dies of isolation; a live cell with four or more neighbors dies of overcrowding.

Survival rule: A live cell with two or three neighbors remains alive.

With each iteration, some cells live, some die and "Life-forms" evolve, one generation to the next.

Among the first creatures to emerge was the glider — a five-celled organism that moved across the grid with a diagonal wiggle and proved handy for transmitting information. It was discovered by a member of Dr. Conway's research team, Richard Guy, in Cambridge, England. The glider gun, producing a steady stream of gliders, was discovered soon after by Bill Gosper, then at the Massachusetts Institute of Technology.



John Horton Conway, investigating "Life" in 1974. Kelvin Brodie/The Sun News Syndication

"Because of its analogies with the rise, fall and alterations of a society of living organisms, it belongs to a growing class of what are called 'simulation games,'" Mr. Gardner wrote when he introduced Life to the world 50 years ago with his October 1970 column.

Life swiftly eclipsed Dr. Conway's many other mathematical accomplishments, and he came to regard his missive to Mr. Gardner as "the fatal letter."

The Game of Life motivated the use of cellular automata in the rich field of complexity science, with simulations modeling everything from ants to traffic, clouds to galaxies. More trivially, the game attracted a cult of "Lifenthusiasts," programmers who spent a lot of time hacking Life — that is, constructing patterns in hopes of spotting new Life-forms.

To mark the 50th anniversary, the ConwayLife.com community — which hosts the LifeWiki, with more than 2,000 articles — created an Exploratorium, a large, explorable stamp-collection pattern.

Patterns that didn't change one generation to the next, Dr. Conway called still lifes — such as the four-celled block, the six-celled beehive or the eight-celled pond. Patterns that took a long time to stabilize, he called methuselahs.

The tree of Life also includes oscillators, such as the blinker, and spaceships of various sizes (the glider being the smallest).

In 2018, there was a much-celebrated discovery of a special kind of spaceship, the first elementary knightship, named Sir Robin. Made of hundreds of cells, it moves two cells forward and one sideways every six generations. It was discovered by Adam P. Goucher, a British algorithmist, building on an earlier partial find by Tomas Rokicki, a developer of Golly, a program for exploring the distant future of large Life patterns.

And the hunting party continues. In September, Pavel Grankovskiy, of Russia, discovered the Speed Demonoid spaceship. In December, John Winston Garth, of Alabama, discovered the Doo-dah spaceship. Both are contenders for pattern of the year, in what has been a good year for new Life discoveries.

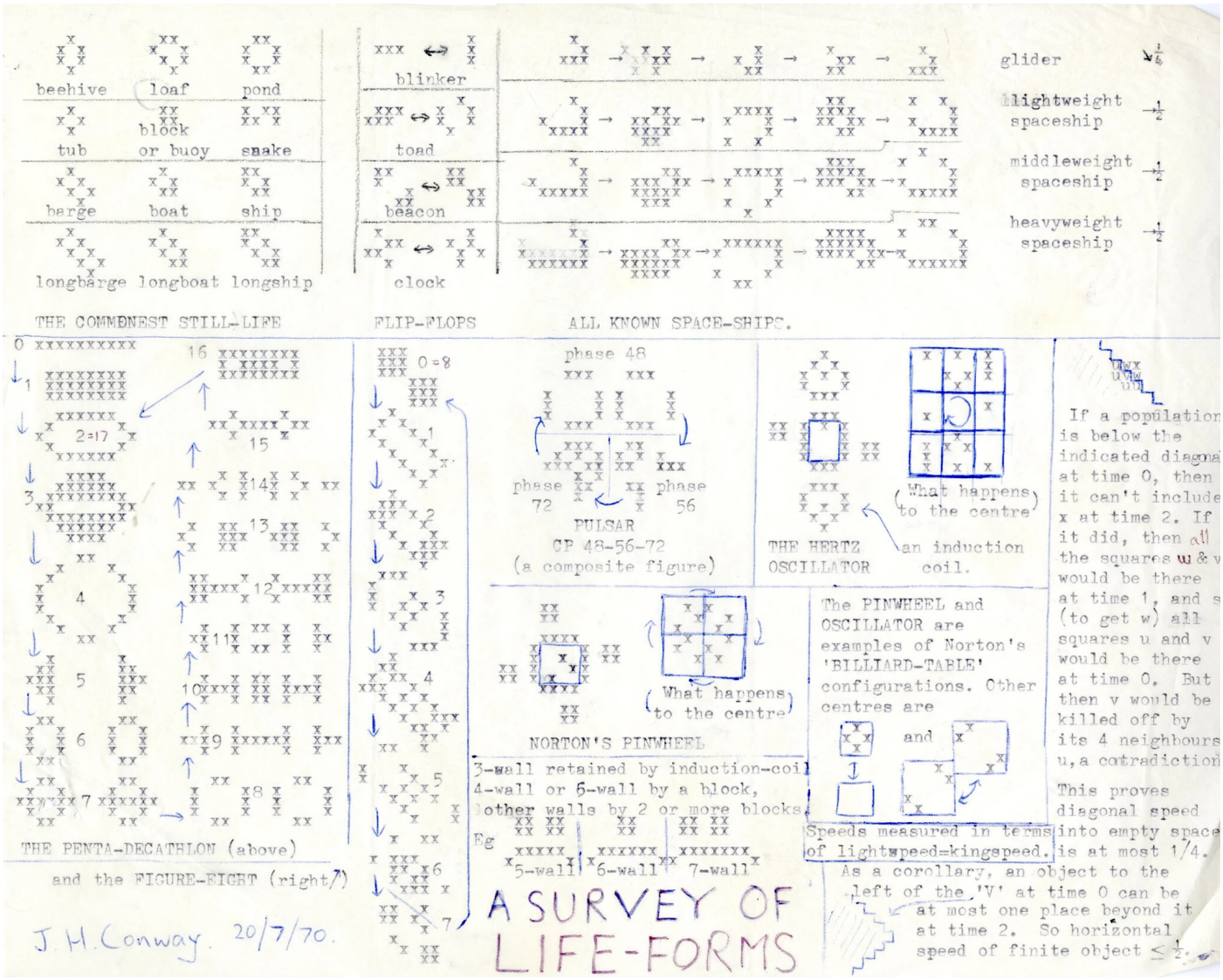
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Life ultimately became way too popular for Dr. Conway's liking. Whenever the subject came up, he would bellow, "I hate Life!" But in his final years he learned to love Life again. He narrated a documentary, with the working title "Thoughts on Life," by the Brooklyn-based mathematician and filmmaker Will Cavendish, exploring the deterministic Game of Life versus the Free Will Theorem, a result Dr. Conway proved with his Princeton colleague Simon Kochen.

"I used to go around saying, 'I hate Life,'" Dr. Conway says in the film. "But then I was giving a lecture somewhere, and I was introduced as 'John Conway, Creator of Life.' And I thought, 'Oh, that's quite a nice way to be known.' So I stopped saying 'I hate Life' after that."

Recently, some of Life's most steadfast friends reflected upon its influence and lessons over half a century.



The Martin Gardner Literary Interests/Special Collections, Stanford University Libraries

Bill Gosper

— Mathematician and programmer, Stanford, Calif.

Life is the world's most wholesome computer game! True, it used to be dangerously addicting to some of us, but not so much now that nearly all of the theoretically possible gun and oscillator periods have been found. It took 40 years to find the coveted Snark, a stable pattern that reflects gliders 90 degrees.

But there are still open questions: for example, what spaceship vector velocities are possible, or what constructions are possible with glider collisions. A startling recent theorem states that any construction, no matter how large, can be accomplished with a reverse caber-tosser built from a certain fixed number of gliders — that number was 32, but as of September it is now down to 17.

These days it has become harder and harder for an amateur to find a newsworthy pattern without fancy software and hardware. Perhaps Life can remain a gateway drug, luring newcomers into the effectively inexhaustible universe of different Lifelike rules.

Brian Eno

— Musician, London

I first encountered Life at the Exploratorium in San Francisco in 1978. I was hooked immediately by the thing that has always hooked me — watching complexity arise out of simplicity.

Life ought to be very predictable and boring; after all, there are just three simple rules that determine the position of some dots on a grid. That really doesn't sound very interesting until you start tweaking those rules and watching what changes.

Life shows you two things. The first is sensitivity to initial conditions. A tiny change in the rules can produce a huge difference in the output, ranging from complete destruction (no dots) through stasis (a frozen pattern) to patterns that keep changing as they unfold.

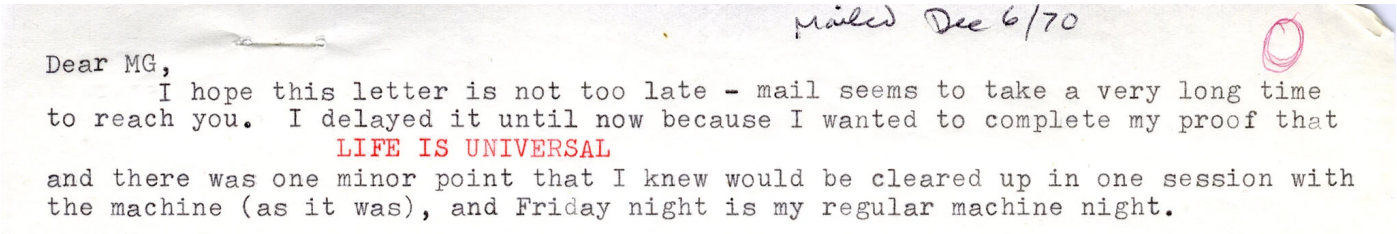
The second thing Life shows us is something that Darwin hit upon when he was looking at Life, the organic version. Complexity arises from simplicity! That is such a revelation; we are used to the idea that anything complex must arise out of something more complex. Human brains design airplanes, not the other way around. Life shows us complex virtual "organisms" arising out of the interaction of a few simple rules — so goodbye "Intelligent Design."

Melanie Mitchell

— Professor of complexity, Santa Fe Institute

Given that Conway's proof that the Game of Life can be made to simulate a Universal Computer — that is, it could be "programmed" to carry out any computation that a traditional computer can do — the extremely simple rules can give rise to the most complex and most unpredictable behavior possible. This means that there are certain properties of the Game of Life that can never be predicted, even in principle!

In this moment in time, it's important to emphasize that inherent unpredictability — so well illustrated in even the simple Game of Life –- is a feature of life in the real world as well as in the Game of Life. We have to figure out ways to flourish in spite of the inherent unpredictability and uncertainty we constantly live with. As the mathematician John Allen Paulos so eloquently said, "Uncertainty is the only certainty there is, and knowing how to live with insecurity is the only security." This is, I think, Life's most important lesson.


mailed Dec 6/70

Dear MG,

I hope this letter is not too late - mail seems to take a very long time to reach you. I delayed it until now because I wanted to complete my proof that LIFE IS UNIVERSAL and there was one minor point that I knew would be cleared up in one session with the machine (as it was), and Friday night is my regular machine night.

The Martin Gardner Literary Interests/Special Collections, Stanford University Libraries

Daniel Dennett

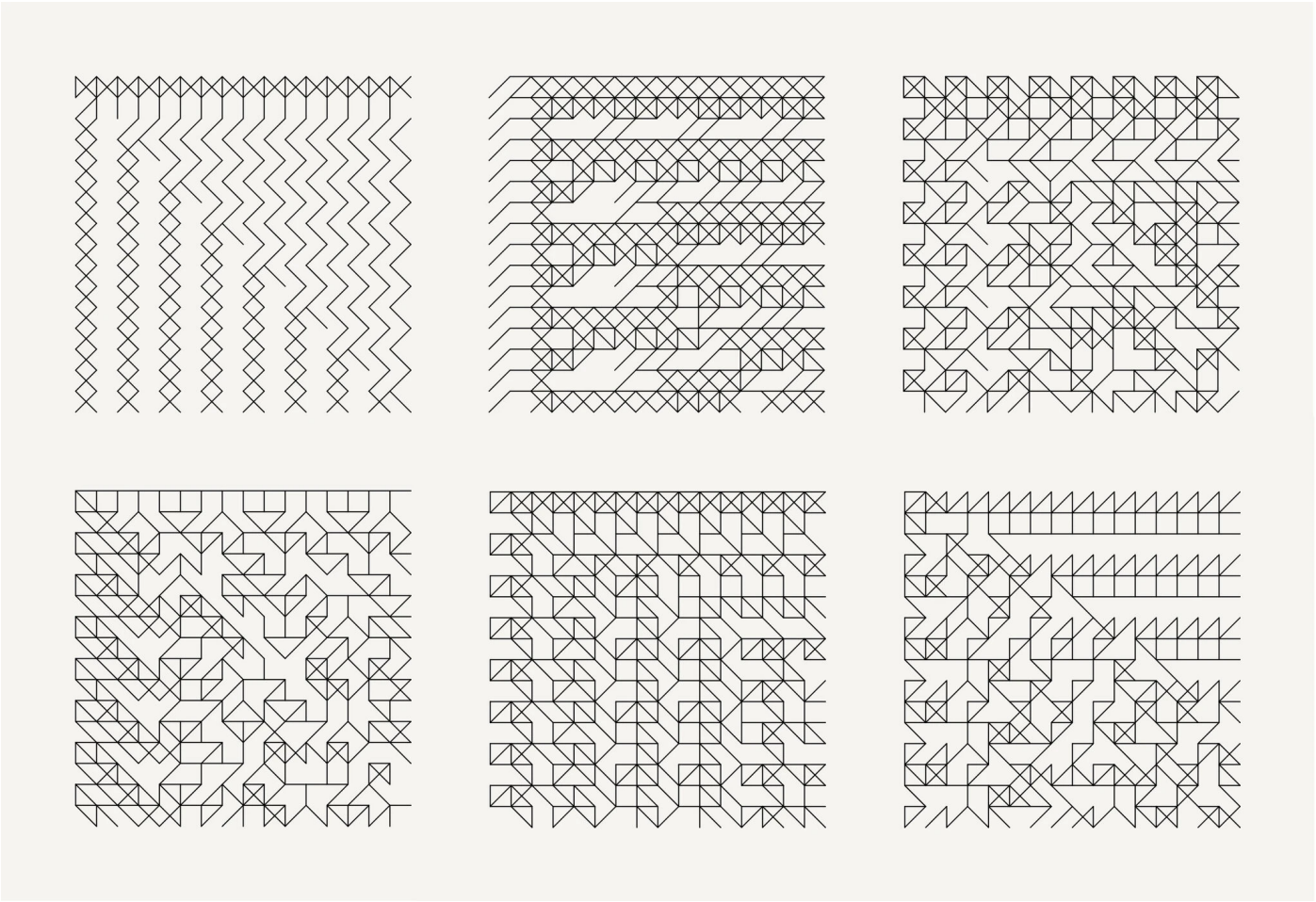
— Professor of philosophy, Tufts University

I use the Game of Life to make vivid for my students the ideas of determinism, higher-order patterns and information. One of its great features is that nothing is hidden; there are no black boxes in Life, so you know from the outset that anything that you can get to happen in the Life world is completely unmysterious and explicable in terms of a very large number of simple steps by small items. No psionic fields, no morphic resonances, no élan vital, no dualism. It's all right there. And the fact that it can still support complex adaptively appropriate structures that do things is also important.

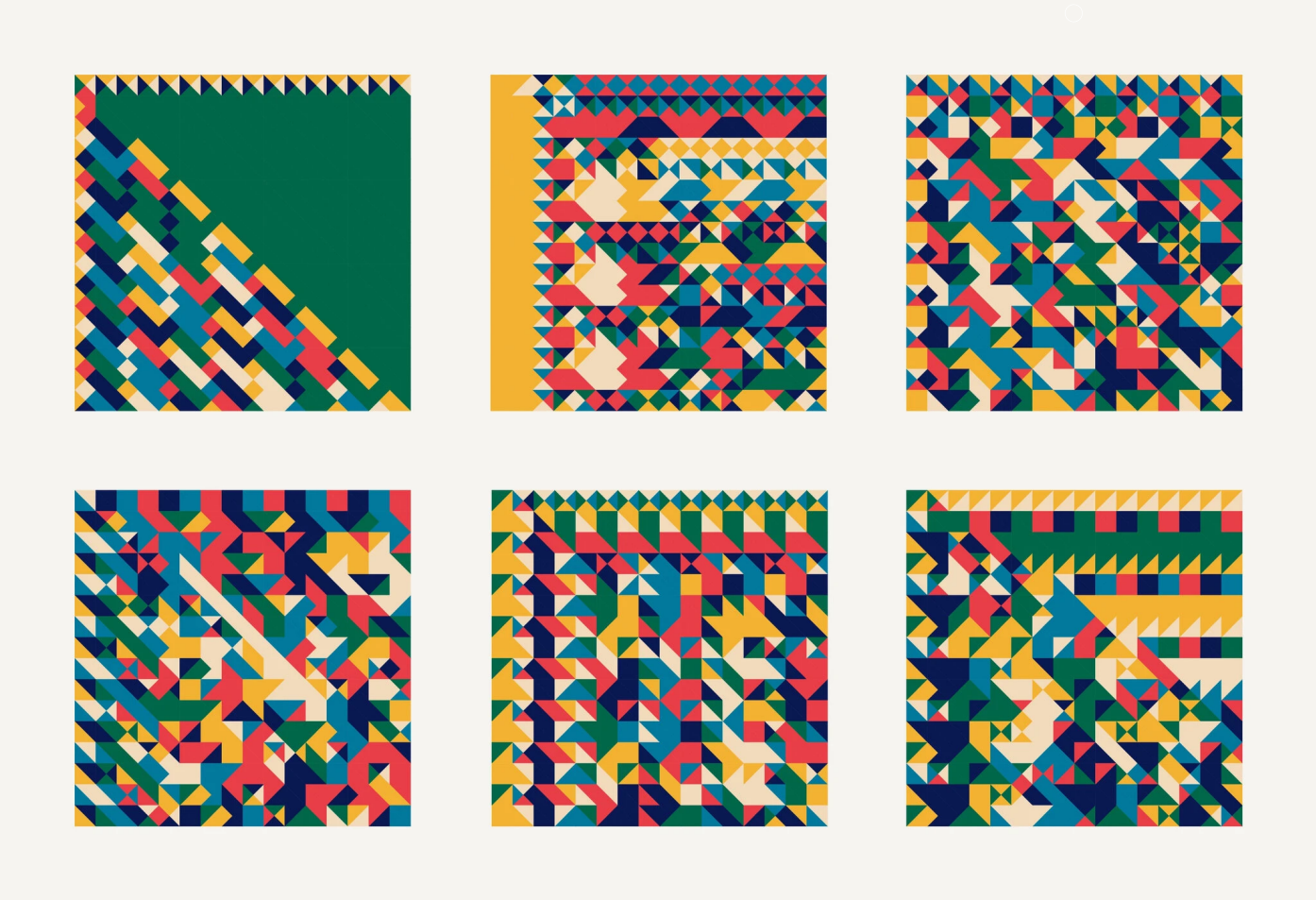
In Thomas Pynchon's novel "Gravity's Rainbow," a character says, "But you had taken on a greater and more harmful illusion. The illusion of control. That A could do B. But that was false. Completely. No one can do. Things only happen."

This is compelling but wrong, and Life is a great way of showing this.

In Life, we might say, things only happen at the pixel level; nothing controls anything, nothing does anything. But that doesn't mean that there is no such thing as action, as control; it means that these are higher-level phenomena composed (entirely, with no magic) from things that only happen.



The Norwegian artist Kjetil Golid's Crosshatch Automata are part of an exhibition, "The Game of Life, Emergence in Generative Art," at the Kate Vass Gallery in Zurich. The line patterns (above) represent cellular automata in which cells are defined by lines in four different orientations. The colors of a given cell are determined by its line dividers and adjacent colors (below, the result). Kjetil Golid



Kjetil Golid

Susan Stepney

— Professor of computer science, University of York, England

In the Artificial Life community, Life is a foundational piece of work. It sits in the background, influencing the way people think of life "in silico."

Life probably maintains its interest for two reasons. One is that the whole field of cellular automata is very important, because computationally it can be used to model so many different things — for example, physical systems from fluid dynamics to coupled magnetic spins to chemical reaction-diffusion systems.

The other reason is that it's just cool and pretty and great to look at. When you speed it up, it flows and boils and bubbles; it actually comes to look alive.

I did some work with students looking at Life on a Penrose tiling grid, rather than the square grid. I wanted to know whether it was the rules or the grid that was the important thing. We found some interesting oscillating patterns and snakelike patterns. Basically, what we showed is that there is something in those rules; the rules are producing the interesting dynamics. Penrose Life still generates interesting behaviors, even in a different environment.

Stephen Wolfram

— Scientist and C.E.O., Wolfram Research

I've wondered for decades what one could learn from all that Life hacking. I recently realized it's a great place to try to develop "meta-engineering" — to see if there are general principles that govern the advance of engineering and help us predict the overall future trajectory of technology. One can look at microprocessors or airplanes, but they involve all sorts of details of physics and materials. In Life there's 50 years of "engineering development," just applied to configurations of bits. It's the purest example I know of the dynamics of collective human innovation.

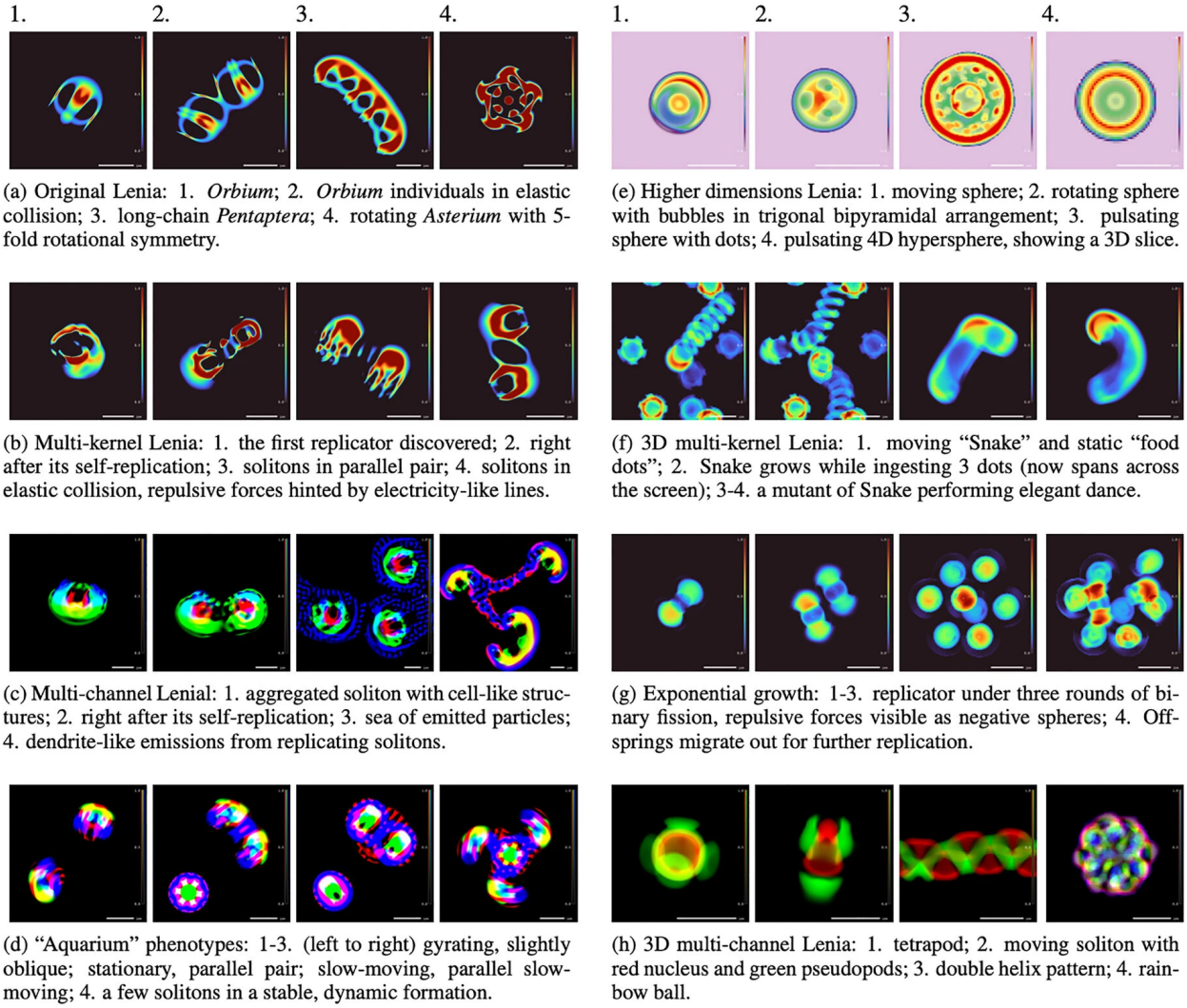
Bert Chan

— Artificial-life researcher and creator of the continuous cellular automaton "Lenia," Hong Kong

Although the Game of Life is not the proudest invention of Conway, according to himself, it did have a big impact on beginner programmers, like me in the 90s, giving them a sense of wonder and a kind of confidence that some easy-to-code math models can produce complex and beautiful results. It's like a starter kit for future software engineers and hackers, together with Mandelbrot Set, Lorenz Attractor, et cetera.

Life enthusiasts have discovered or engineered many wonderful patterns inside Life. Some of the most amazing ones are a digital clock, a simulation of Life inside Life, and self-replicators. The engineering is so ingenious and delicate that a single mistake of misplacing one cell among perhaps a million cells will make the whole machine fail. On the other hand, when I was investigating Lenia — a continuous extension of Life — I found that its patterns are fundamentally different from those in Life. Lenia patterns are fuzzy, thus not easy for engineering (they are mostly evolved instead), but are harder to destroy. Although having the same root, Life and Lenia have nearly opposite nature: designed versus organic, precise versus adaptive, fragile versus resilient.

These are interesting findings in research, but if we think about our everyday life, about corporations and governments, the cultural and technical infrastructures humans built for thousands of years, they are not unlike the incredible machines that are engineered in Life. In normal times, they are stable and we can keep building stuff one component upon another, but in harder times like this pandemic or a new Cold War, we need something that is more resilient and can prepare for the unpreparable. That would need changes in our "rules of life," which we take for granted.



(a) Original Lenia: 1. *Orbium*; 2. *Orbium* individuals in elastic collision; 3. long-chain *Pentaptera*; 4. rotating *Asterium* with 5-fold rotational symmetry.

(e) Higher dimensions Lenia: 1. moving sphere; 2. rotating sphere with bubbles in trigonal bipyramidal arrangement; 3. pulsating sphere with dots; 4. pulsating 4D hypersphere, showing a 3D slice.

(b) Multi-kernel Lenia: 1. the first replicator discovered; 2. right after its self-replication; 3. solitons in parallel pair; 4. solitons in elastic collision, repulsive forces hinted by electricity-like lines.

(f) 3D multi-kernel Lenia: 1. moving "Snake" and static "food dots"; 2. Snake grows while ingesting 3 dots (now spans across the screen); 3-4. a mutant of Snake performing elegant dance.

(c) Multi-channel Lenial: 1. aggregated soliton with cell-like structures; 2. right after its self-replication; 3. sea of emitted particles; 4. dendrite-like emissions from replicating solitons.

(g) Exponential growth: 1-3. replicator under three rounds of binary fission, repulsive forces visible as negative spheres; 4. Offsprings migrate out for further replication.

(d) "Aquarium" phenotypes: 1-3. (left to right) gyrating, slightly oblique; stationary, parallel pair; slow-moving, parallel slow-moving; 4. a few solitons in a stable, dynamic formation.

(h) 3D multi-channel Lenia: 1. tetrapod; 2. moving soliton with red nucleus and green pseudopods; 3. double helix pattern; 4. rainbow ball.

Bert Chan

Rudy Rucker

— Mathematician and author of "Ware Tetralogy," Los Gatos, Calif.

When Life started out, we didn't yet have the notion of mathematical chaos. The unfolding of the successive generations of a Game of Life board is completely deterministic. If you start with the same setup, you always get the same outcomes. The odd thing is that, even though the results of a given game of Life start-position are predetermined, there is no easy shortcut to predict these outcomes. You just have to run the damn thing through all its steps.

That's what chaos is about. The Game of Life, or a kinky dynamical system like a pair of pendulums, or a candle flame, or an ocean wave, or the growth of a plant — they aren't readily predictable. But they are not random. They do obey laws, and there are certain kinds of patterns — chaotic attractors — that they tend to produce. But again, unpredictable is not random. An important and subtle distinction which changed my whole view of the world.

William Poundstone

— Author of "The Recursive Universe: Cosmic Complexity and the Limits of Scientific Knowledge," Los Angeles, Calif.

The Game of Life's pulsing, pyrotechnic constellations are classic examples of emergent phenomena, introduced decades before that adjective became a buzzword.

Fifty years later, the misfortunes of 2020 are the stuff of memes. The biggest challenges facing us today are emergent: viruses leaping from species to species; the abrupt onset of wildfires and tropical storms as a consequence of a small rise in temperature; economies in which billions of free transactions lead to staggering concentrations of wealth; an internet that becomes more fraught with hazard each year. Looming behind it all is our collective vision of an artificial intelligence-fueled future that is certain to come with surprises, not all of them pleasant.

The name Conway chose — the Game of Life — frames his invention as a metaphor. But I'm not sure that even he anticipated how relevant Life would become, and that in 50 years we'd all be playing an emergent game of life and death.



Dr. Conway in his Princeton office in 1993. Dith Pran/The New York Times

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