Strange New Life Forms: Update

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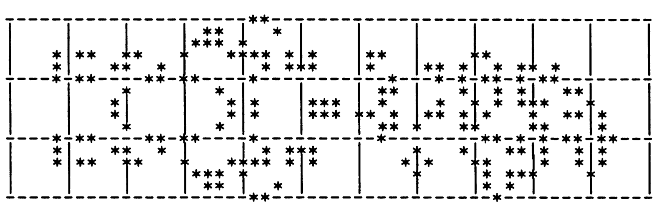
The Gathering for Gardner
Atlanta International Museum of Art and Design
Atlanta, Georgia

Dear Gathering,

Martin Gardner, by singlehandedly popularizing Conway's game of Life during the 1970s, sabotaged the Free World's computer industry beyond the wildest dreams of the KGB. Back when only the large corporations could afford computers because they cost hundreds of dollars an hour, clandestine Life programs spread like a virus, with human programmers as the vector. The toll in human productivity probably exceeded the loss in computer time.

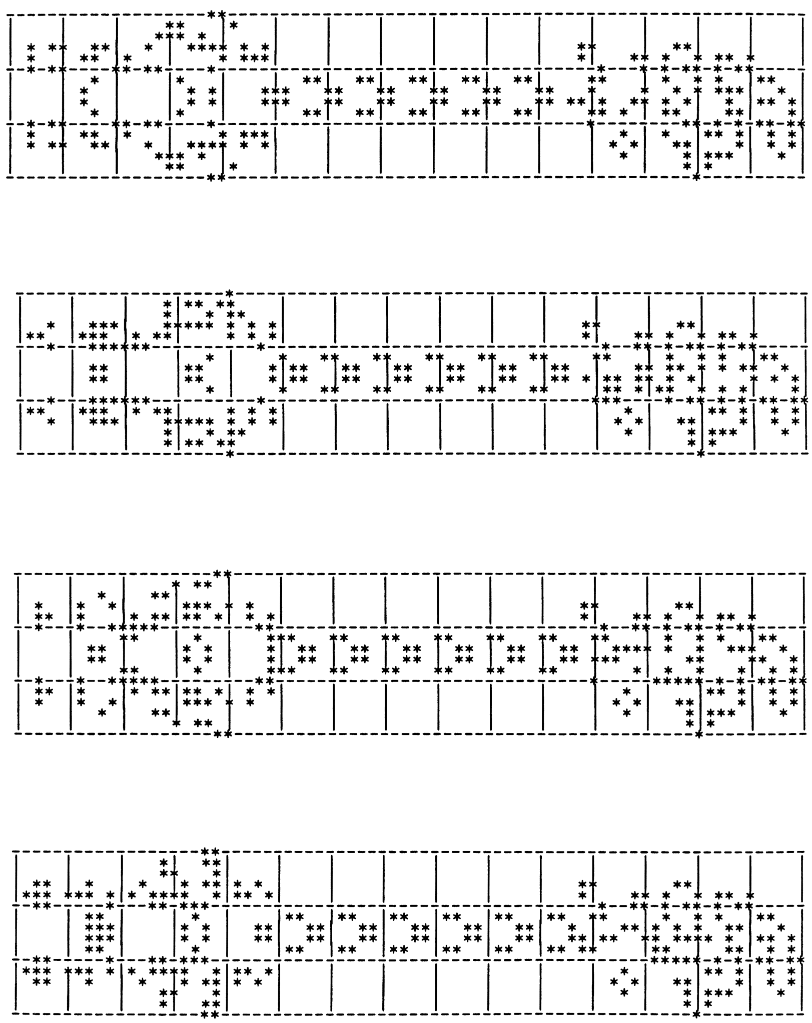
With the great reduction in computation costs, and the solution of most of the questions initially posed by the game, it would be nice to report that, like smallpox, the Life bug no longer poses a threat. Sadly, this is not the case. While the Life programs distributed with personal computers are harmless toys whose infective power is 100% cancelled by TV, new developments in the game are still spreading through computer networks, infecting some of the world's best brains and machinery.

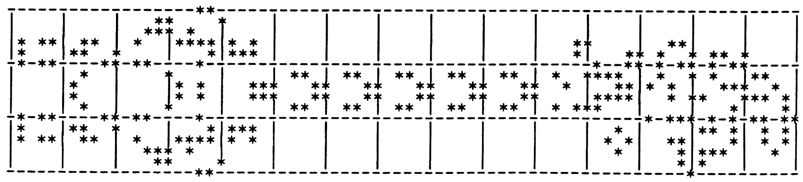
The biggest shock has been Dean Hickerson's transformation of the computer from simulation vehicle to automated seeker and explorer, leading to hundreds of unnatural, alien Life forms, of which the weirdest, as of late 1992, has to be
Time 0:

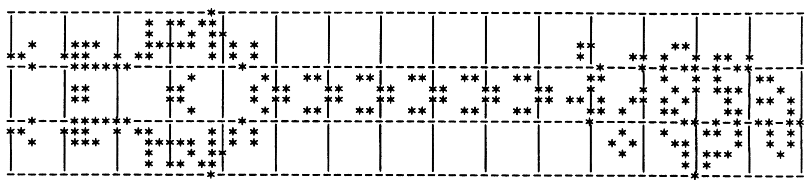


Note that it extends leftward with velocity $\frac{1}{4}$, with the left end (found by Hartmut Holzwart at the University of Stuttgart) repeating with period 4. But the (stationary) right end, found by Hickerson (at U.C. Davis) has period 5! Stretching between is a beam of darts that seems to move rightward at the speed of light. But if you interrupt it, the beam shortens in both directions at the speed of light, and then both ends explode.

Times 100–105:







So, if you're wondering "Whatever happened to Life?," here is a synopsis of recent developments computer-mailed by Hickerson when the ineffable Creator of the Universe and its Laws himself asked the same question.

Hickerson's Synopsis

There have been developments in various areas by different people:

Oscillator and spaceship searches	by myself, David Bell, and Hartmut Holzwart
Construction of oscillators	mostly by David Buckingham and Bob Wainwright
Glider syntheses	mostly by Buckingham and Mark Niemiec
New glider guns	by Buckingham, Bill Gosper, and myself
Large constructions	mostly by Buckingham, Bill Gosper, Paul Callahan, and myself

Oscillator and Spaceship Searches. In 1989 I wrote a program to search for oscillators and spaceships. For a few months I ran it almost constantly, and I've run it occasionally since then. It found many oscillators of periods 3 and 4 (including some smaller than any previously known, and a period 4 resembling your initials, JHC!), a few oscillators with periods 5 (including some with useful sparks) and 6, infinitely many period 2, speed $c/2$ orthogonal spaceships, infinitely many period 3, speed $c/3$ orthogonal spaceships, one period 4, speed $c/4$ orthogonal spaceship, one period 4, speed $c/4$ diagonal spaceship (not the glider), and one period 5, speed $2c/5$ orthogonal spaceship. More recently, David Bell wrote a similar program that runs on faster machines. (Mine runs only on an Apple II.) Lately, he and Hartmut Holzwart have been producing oodles of orthogonal spaceships with speeds $c/2$, $c/3$, and $c/4$. Also, Hartmut found another with speed $2c/5$. Some of the $c/3$s and $c/4$s have sparks at the back which can do various things to $c/2$ spaceships that catch up with them. (These are used in some of the large patterns with unusual growth rates mentioned later.)

Construction of Oscillators. Due mostly to the work of Buckingham and Wainwright, we now have nontrivial examples (i.e., not just lcms of smaller period oscillators acting almost independently) of oscillators of periods $1-16, 18, 26, 28, 29, 30, 32, 36, 40, 44, 46, 47, 52, 54, 55, 56, 60, 72, 100$, 108, 128, $75+120n, 135+120n, 66+24n, 246+24n, 50+24n, 230+40n, 282+376n$, $846+376n, 136+8n, 150+5n$, and all multiples of $30, 44, 46, 94$, and 100. We also have an argument, based on construction universality, which implies that all sufficiently large periods are possible. (No doubt you figured that out for yourself long ago.)

The multiples of $30, 44, 46, 94$, and 100 and the $75+120n$ and $135+120n$ are based on gliders shuttling back and forth between either oscillators (or periods $15, 30, 46$, and 100) or output streams of glider guns (of periods $30, 44, 46, 94$, and $900+200n$). The $66+24n, 246+24n, 50+40n, 230+40n, 282+376n$, and $846+376n$ use a device discovered by Wainwright, which reflects a symmetric pair of parallel gliders; it consists of a still life ("eater3") and two spark producing oscillators, of periods 5, 6, or 47. (Any greater nonmultiple of 4 would also work, but 5, 6, and 47 are the only ones we know with the right sparks.) Periods $136+8n$ and $150+5n$ use a mechanism developed by Buckingham, in which a B heptomino is forced to turn a $90°$ corner. The turn can take either 64, 65, or 73 generations; by combining them we can build a closed loop whose length is any large multiple of 5 or 8; we put several copies of the B in the track to reduce the period to one of those mentioned. For example, I built a p155 oscillator in which 20 Bs travel around a track of length $3100 (= 20 \times 64 + 28 \times 65)$ generations. For the multiples of 8, the 73 gen turn can emit a glider, so we also get glider guns of those periods.

Another amusing oscillator uses the glider crystallization that Bill mentioned in his centinal letter a few years ago. A period 150 gun fires toward a distant pair of pentadecathlons. The first glider to hit them is reflected $180°$ and collides with the second to form a honey farm. Subsequent gliders grow a crystal upstream; 11 gliders add a pair of beehives to the crystal. When the crystal reaches the guns, an eater stops its growth, and it begins to decay; two gliders delete one pair of beehives. When they're all gone, the process begins again.

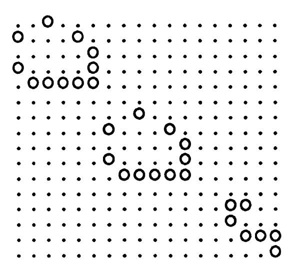
Glider Syntheses. Rich has already mentioned this. I'll just add that some of Buckingham's syntheses of still lifes and billiard table oscillators are awe-inspiring.

New Glider Guns. In addition to the long-familiar period 30 and period 46 guns, there's now a fairly small period 44 gun that Buckingham built recently. The other guns are all pretty big. The largest by far that's actually been built is Bill's period 1100 gun (extensible to $900+200n$), based on the period 100 centinal; its bounding box is 13,584 by 12,112. Buckingham mercifully outmoded it with a comparatively tiny, centinal-based $500+200n$.

The period $136 + 8n$ guns based on Buckingham's B heptomino turns are also smaller. For example, there's a period $168 = (8 \times 73 + 4 \times 64)/5$ gun that's 119 by 119 and a period $136 = (40 \times 73 + 16 \times 64)/29$ gun that's 309 by 277.

Buckingham has also found extremely weird and elegant guns of periods 144 and 216, of size 149 by 149, based on a period 72 device discovered by Bob Wainwright.

The period 94 gun is 143 by 607; it's based on the "AK47" reaction discovered independently by Dave Buckingham and Rich Schroeppel. A honey farm starts to form but is modified by an eater and a block. It emits a glider, forms a traffic light, and then starts forming another honey farm in a different location. If you delete the traffic light, the cycle repeats every $47 \times 2 = 94$ generations. A close pair of AK47s can delete each other's traffic lights, so we can build a long row of them that is unstable at both ends. In the period 94 gun, two such rows, with a total of 36 AK47s, emit gliders that can crash to form MWSSs, which hit eaters, forming gliders that stabilize the ends of a row. Here's how to turn 2 MWSSs into a glider:



In *Winning Ways*, you (JHC) described how to thin a glider stream by kicking a glider back and forth between two streams. Using normal kickbacks, the resulting period must be a multiple of 8. I've found some eater-assisted kickbacks that give any even period. (Sadly, they don't work with period 30 streams. Fortunately, there are other ways to get any multiple of 30.)

It's also possible to build a gun that produces a glider stream of any period ≥ 15. The gun itself has a larger period; it uses various mechanisms to interleave larger period streams. It's fairly easy to get any period down to 18 this way (period 23 is especially simple), and Buckingham has found clever ways to get 15, 16, and 17. (I built a pseudo-period 15 gun based on his reactions; its bounding box is 373 by 372.)

New Year's Eve Newsflash: Buckingham has just announced ". . . I have a working construction to build a P14 glider stream by inserting a glider between two gliders 28 gens apart! . . . This will make it possible to produce glider streams of any period." (Less than 14 is physically impossible.)

Returning to Hickerson's account:

Many of the large constructions mentioned later require a period 120 gun. The smallest known uses a period 8 oscillator ("blocker") found by Wainwright to delete half the gliders from a period 60 stream. Here it's shown deleting a glider; if the glider is delayed by 60 (or, more generally, $8n + 4$) generations, it escapes:

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.........O.
..........O
........OOO
...........
...........
...........
....OO.....
OO....OOOO.
OO..OO.OOO.
....O......
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There are also combinations of two period 30 guns that give fairly small guns with periods 90, 120, 150, 180, 210, 300, and 360.

We can also synthesize light-, middle-, and heavyweight spaceships from gliders, so we have guns that produce these as well. For example, this reaction leads to a period 30 LWSS gun:

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......O..
....O.O..
.OO..OO..
O.O......
..O.....O
......OO.
.......OO
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Large Constructions. Universality implies the existence of Life patterns with various unusual properties. (At least they seem unusual, based on the small things we normally look at. Even infinite growth is rare for small patterns, although almost all large patterns grow to infinity.) But some of these properties can also be achieved without universality, so some of us have spent many hours putting together guns and puffers to produce various results. (Figuring out how to achieve a particular behavior makes a pleasant puzzle; actually building the thing is mostly tedious.)

The first such pattern (other than glider guns) was Bill's breeder, whose population grows like t^2. Smaller breeders are now known.

Probably the second such pattern is the "exponential aperiodic," versions of which were built independently by Bill and myself, and probably others. If you look at a finite region in a typical small pattern, it eventually becomes periodic. This is even true for guns, puffers, and breeders. But it's fairly easy to build a pattern for which this isn't true: Take two glider puffers, headed east and west, firing gliders southwest and northeast, respectively. Add a glider that travels northwest and southeast, using a kickback reaction each time it hits one of the glider waves. Cells along its flight path are occupied with decreasing frequency: The gap between the occupations increases by a factor of 3 or 9 each time, depending on which cells you're looking at.

Bill also built an "arithmetic aperiodic" in which the gap between occupations increases in an arithmetic progression.

Both of these patterns have populations tending to infinity. I've also built some aperiodic patterns with bounded populations. These use a glider salvo to push a block (or blinker); the reaction also sends back a glider (or two) which triggers the release of the next salvo.

In *Winning Ways* you (JHC) describe how to pull a block three units using two gliders and push it three units using 30. I found a way to pull it one unit with two gliders and push it one unit with three gliders. Using this I built a sliding block memory register, similar to the one you described. (It has one small difference: the "test for zero" is not a separate operation. Instead, a signal is produced whenever a decrement operation reduces the value to 0.)

Most of my large constructions are designed to achieve unusual population growth rates, such as $t^{1/2}, t^{3/2}, \log(t), \log(t)^2, t\log(t)$, and $t\log(t)^2$, and linear growth with an irrational growth rate. In addition, there are several "sawtooth" patterns, whose populations are unbounded but do not tend to infinity.

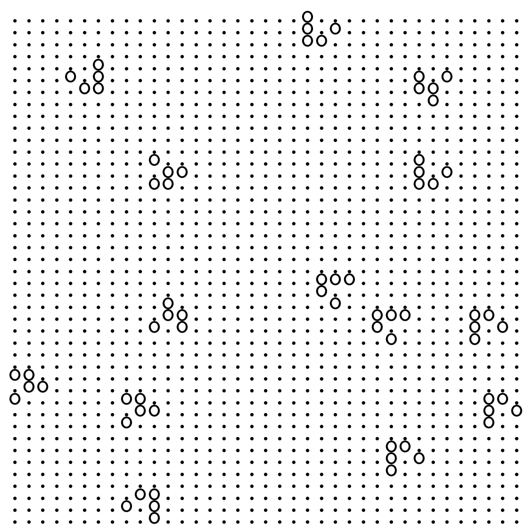
I also built a pattern (initial population $\leq$ 3000) that computes prime numbers: An LWSS is emitted in generation $120n$ if and only if n is prime. (This could be used to get population growth $t^2/\log(t)$, but I haven't built that.)

Paul Callahan and I independently proved that arbitrarily large puffer periods are possible. His construction is more efficient than mine, but harder to describe, so I'll just describe mine. Give a glider puffer of period N, we produce one of period $2N$ as follows: Arrange 3 period N puffers so their gliders crash to form a MWSS moving in the same direction as the puffers. The next time the gliders try to crash, there's already a MWSS in the way, so they can't produce another one. Instead, two of them destroy it and the third escapes; this happens every $2N$ generations. (Basically this mimics the way that a ternary reaction can double the period of a glider gun; the MWSS takes the place of the stable intermediary of the reaction.)

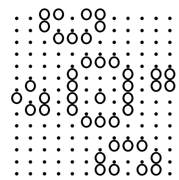
Dave Buckingham and Mark Niemiec built a binary serial adder, which adds two period 60 input streams and produces a period 60 output stream. (Of course, building such a thing from standard glider logic is straightforward, but they used some very clever ideas to do it more efficiently.)

—Dean Hickerson

To clarify, Buckingham's "awe-inspiring glider syntheses" are the constructions of prescribed, often large and delicate, sometimes even oscillating objects, entirely by crashing gliders together. The difficulty is comparable to stacking water balls in 1G. Warm ones. Following Dean's update, we were all astounded when Achim Flammenkamp of the University of Bielefeld revealed his prior discovery of Dean's smallest period 3 and 4 oscillators during an automated, months-long series of literally millions of random soup experiments. Thankfully, he recorded the conditions that led to these (and many other) discoveries, providing us with natural syntheses (and probability estimates) of rare objects.



Conway called such oscillators billiard tables, and along with the rest of us, never imagined they could be made by colliding gliders.



Finally, after a trial run of the foregoing around the Life net, Professor Harold McIntosh (of the Instituto de Ciencias at Puebla) responded: "The humor in that proposed introduction conjures up images of untold taxpayer dollars (or at least hours of computer time) disappearing into a bottomless black hole. That raises the question, 'Have other hours of computer time been spent more profitably?' (Nowadays, you can waste computer time all night long and nobody says anything.)

"Martin Gardner is a skilled presenter of ideas, and Life was an excellent idea for him to have the opportunity to present. Not to mention that the time was ideal; if all those computer hours hadn't been around to waste, on just that level of computer, perhaps the ideas wouldn't have prospered so well.

"In spite of Professor Conway's conjecture that almost any sufficiently complicated automaton is universal (maybe we can get back to that after vacations) if only its devotees pay it sufficient attention, nobody has yet come up with another automaton with anything like the logical intricacy of Life. So there is really something there which is worth studying.

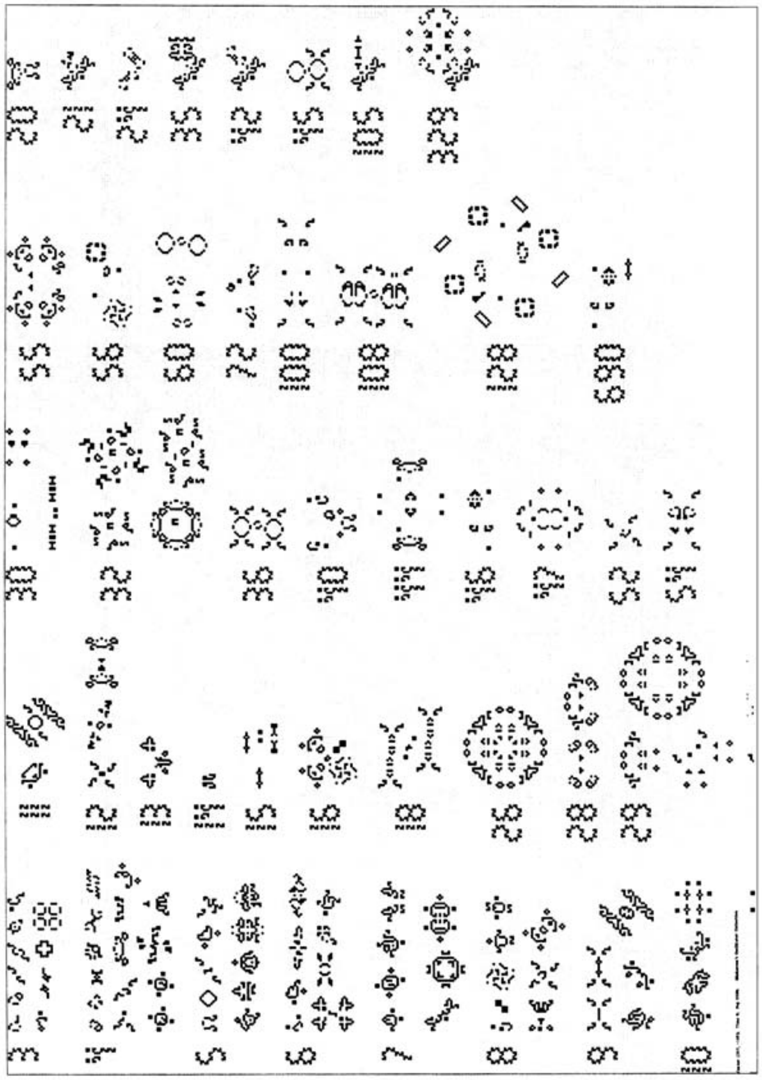
"It might be worth mentioning the intellectual quality of Gardner's presentation of Life; of all the games, puzzles and tricks that made their appearance in his columns over the years, did anything excite nearly as much curiosity? (Well, there were flexagons.)

"Nor should it be overlooked that there is a more serious mathematical theory of automata, which certainly owes something to the work which has been performed on Life. Nor that there are things about Life, and other automata, that can be foreseen by the use of the theories that were stimulated by all the playing around that was done (some of it, at least)."

The Life you save may not fit on your disk.

—Bill Gosper

Many remarkable discoveries followed this writing. See, for example, `http://www.mindspring.com/~alanh/life/index.html`



An early "stamp collection" by Dean Hickerson. These are representative oscillators of the (small) periods (indicated by the still-Life numerals) known by the end of 1992. As of the end of 1998, *all* periods have been found except 19, 23, 27, 31, 37, 38, 41, 43, 49, and 53.