Creating Large Life Forms with Interactive Life

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This paper demonstrates how very complicated Life forms can easily be created using the interactive Life program introduced by James Gilbert [1]. By having control over just a single cell, called the *intelligent cell*, a glider gun can be created in under 250 generations. Note that the standard rules of Life apply to the intelligent cell as well as the other cells.

Ever since John Conway introduced the game of Life in 1970 [2], amateur and professional mathematicians have been obsessed by finding new complicated structures, and finding new applications for the seemingly chaotic behavior of Life forms. Perhaps its addictive nature stems from the simplistic rules: each cell on a square lattice is either on (alive) or off (dead). The *Moore neighborhood* of a cell is the eight surrounding cells (counting diagonals) [3]. If a dead cell has exactly three neighboring cells which are alive, then the cell becomes alive in the next generation. On the other hand, a living cell must have either two or three living neighbors to remain alive, otherwise the cell will die in the next generation.

Figure 1 shows four generations of the Life form known as the "glider." Because every four generations, this glider moves one space diagonally, we say that this glider moves at 1/4 the speed of light. (In the Life model, light is said to travel at 1 square per generation.)

The first open problem that Conway asked was whether any Life form could be proven to have unbounded growth. This was solved by Bill Gosper's discovery of the glider gun, a formation that spews a glider every 30 generations [4]. Other glider guns have since been discovered, but none have been as efficient as the original, now referred to as the "p30 glider gun."

Using glider guns, one in fact can engineer even more complex Life forms. Any computer circuit, and even a Turing machine, can be con-

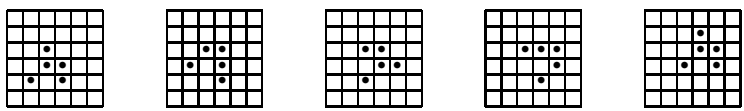

Figure 1. Four generations of a glider.

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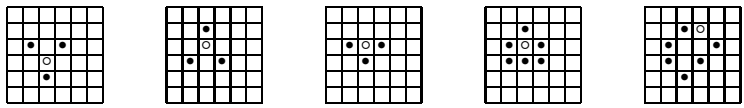

Figure 2. Four generations of i-Life stemming from Y-start.

structed using the existence or nonexistence of a glider as a binary bit [5]. Since there are Turing problems which are undecidable, there will be some Life formations for which the final outcome is unpredictable.

The original Life model has also been used to study chaos and evolution. If one starts with an infinite plane of "primordial soup," in which each cell is randomly either alive or dead, then after several hundred generations or so, the random patterns will tend to group themselves into clusters of Life. Sooner or later, a glider will be formed, which will inevitably crash into a different cluster. This process has been studied as a model for evolutionary processes [6]. In theory, if we start with a large enough section of the plane and wait long enough, higher Life forms such as the glider gun, and even a Turing machine, would evolve out of the randomness. Of course, it would take trillions of trillions of generations for this to happen, which is why there is the parallel between Life evolution and the standard theory of evolution.

James Gilbert [1] suggested the following variation to Conway's Life: The rules for Life apply to all cells except one. Ed Pegg coined this the *intelligent cell* [7]. This cell can, between each generation, choose either to stay put, or to move to an empty cell in its Moore neighborhood. However, the laws of survival still apply to the intelligent cell—it must have either two or three live neighboring cells after its move or it will die in the next generation.

Figure 2 gives an example of a sequence of generations in interactive Life, or i-Life for short. The hollow dot is the intelligent cell, and the starting position is called the "Y-start." This is the simplest formation from which the intelligent cell can form anything interesting. In the first generation, the cell moves up one space, and a new Y formation is formed, showing that the cell could dance up and down to form a period two oscillator. But instead, the cell opts to wait two generations for the surrounding pattern to grow. Finally, the cell moves to the Northeast, forming a stable loaf formation.

We can use an abbreviated notation to show the motion of the intelligent cell. The symbol $\odot$ can be used to show that the cell did not move, whereas an arrow can show the direction of motion. Thus, $\{\uparrow\odot\odot\nearrow\}$ gives the sequence of moves shown in Figure 2.

This final loaf position is very important, because it acts as a gateway to all the other patterns which can be formed. Only a small number of positions can be achieved from the Y-start without going through a

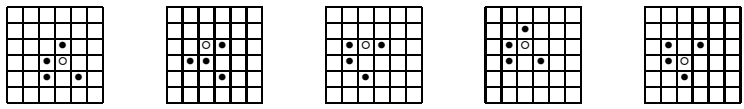

Figure 3. Intelligent cell riding a glider.

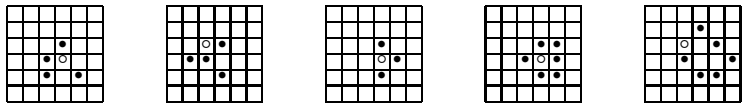

Figure 4. Changing from a glider to a loaf.

loaf position in some orientation. This particular gateway loaf is said to have NNE orientation, based upon the position of the interactive cell from the center of the loaf.

When i-Life was in development, the types of questions that were raised dealt with how much control the intelligent cell had over its environment. It is clear that it can craft a wide variety of Life forms, but can it spawn independent Life forms in a controlled manner? Could the intelligent cell create and manipulate Life forms such as gliders?

The first major discovery was that indeed the intelligent cell can "ride" a glider. Starting with the NNE gateway loaf at the end of Figure 2, the 12 move sequence {↓↗↑↓↖↖↘↓↙↙⊙↖} forms a glider, with the intelligent cell in the middle of the glider. From this stage, the intelligent cell can propagate the glider with the sequence {↖⊙⊙} shown in the first four frames of Figure 3. It is interesting that when the intelligent cell is riding the glider, it accelerates to 1/3 the speed of light.

The last frame of Figure 3 demonstrates that the entire glider can be flipped from top to bottom merely by moving down. The cell could dance up and down, as in the Y-start formation, to form another period two oscillator. At first it might seem that it could thereby steer the glider anywhere, but it could only steer the glider Northwest or Southwest.

However, the cell can quickly convert this glider back into a gateway loaf. This is seen in the sequence {↖↘⊙↖}, shown in Figure 4. Since this loaf is rotated from the loaf in Figure 2, if we make a glider starting from this loaf, we will have rotated the glider by 90 degrees. Hence, it is possible to steer the glider around in the plane.

However, it is not enough to be able to control the glider's movements if we are to develop higher Life forms. We need to be able to "spawn" small Life forms, in hopes that these will later combine to form larger structures. The simplest Life form is the blinker, in which three cells alternate between being aligned vertically and horizontally. Starting from the NNE gateway loaf again, the sequence {↓↗↑⊙⊙→↓↙↘↑↘⊙↗}

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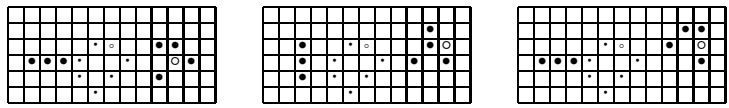

Figure 5. The newly formed blinker.

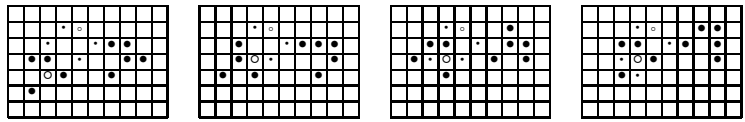

Figure 6. Spawning a new glider.

will produce a blinker, and the intelligent cell reboards a glider as shown in Figure 5. The small dots show the original position of the gateway loaf. Using this procedure, blinkers can be placed anywhere in the plane, in preparation for forming larger Life forms.

However, this alone is not sufficient. One must be able to spawn a glider, since larger Life forms can be synthesized with gliders. In fact, David Buckingham showed that all Life forms with 14 cells or less can be synthesized with at most 14 gliders [8]. There are still some unusual Life forms for which there is no known glider synthesis, but it is conjectured that all Life forms do in fact have a glider synthesis, and so it is only a matter of time before the glider synthesis is discovered for these unusual objects.

In order to spawn a glider from a NNE gateway loaf, one can use the 17 move sequence {↓↗↑↓←⊙↙←⊙↓↓↙↗↓↑↙↗}. This produces not only a glider, but the intelligent cell boards a second glider and chases down the first, as shown in Figure 6. In fact, the second glider must change directions in the next generation if it is to avoid crashing with the first glider. (Recall that boarded gliders accelerate to 1/3 the speed of light.) Again, the small dots reveal the original location of the gateway loaf.

There is a 16 move sequence that also spawns a glider, {↓↗↑⊙⊙⊙⊙→←↗⊙←⊙↗←⊙}, but it takes an additional 15 moves for the new glider to form.

Since most, and possibly all, Life forms can be synthesized with gliders, we can prove that these Life forms can be created by the intelligent cell. Although glider synthesis requires the gliders to all collide simultaneously, this can be achieved by forming the gliders sufficiently far away from the point at which they will collide. The fact that riding a glider accelerates it to 1/3 the speed of light enables this to be accomplished in theory, although the time required becomes an exponential function of the number of gliders. The p30 glider gun can be synthesized with 13 gliders, but this would be a very inefficient way of creating a glider gun.

A better way to produce large Life forms is to fire a single glider into a set of simple stable Life forms. For example, a glider can crash into a blinker to form a block, a loaf, a pond, a ship, traffic lights, or a pi. However, one could ask whether these Life forms could be spawned directly by the intelligent cell. If so, what is the most efficient way of creating these Life forms?

The best way to answer this question was to actually calculate which Life forms can be spawned in 20 moves or less. Note that the new Life form may not be completely formed at the end of the 20 moves, but may take a while to develop while the intelligent cell does something else. Using the computer program *Mathematica*, 25,466,828 ways were found in which the intelligent cell can make 20 moves or less starting from the gateway loaf. Of these, only 13,730 had the intelligent cell riding a glider, and at least three other cells which could develop into a Life form. These 13,730 cases had to be visually examined to determine if either the boarded glider would crash within the next few moves, or if the remaining cells would develop into a stable formation. The result of this search not only found the optimal sequence for spawning the blinker and glider mentioned above, but also produced optimal sequences for the following Life forms. All of these sequences begin with the NNW gateway loaf.

Block: {↓↗↑↖↓↙⊙↓↖↗↖↘↗} – 13 moves.

Loaf: {↓↗↑↓↖↖↓↖↘↘↖↘⊙↖⊙} – 15 moves, develops in the next move.

Hive: {↓↗↑↖↓⊙↙←↓→↓→↗↖↘→} – 16 moves, develops in 6 more moves.

Boat: {↓↗↑↖↓⊙↙↘⊙↖←⊙↗↓↑⊙←} – 17 moves.

Tub: {↓↗↑↖↓↙→↗⊙←⊙←⊙→↘↗←↖} – 18 moves.

Pond: {↓↗⊙→↘↑↙↙←↙↖→←↖↘↑↙↖} – 18 moves, develops in the next move.

Ship: {↓↗↑⊙←↗↙↖↑⊙⊙↗⊙↑⊙⊙↓⊙↗} – 19 moves.

Elevener: {↓↗⊙→←↗⊙↙↙⊙↖↓↗⊙↖↘⊙↗↘} – 19 moves.

Long Boat: {↓↗↑↖↓⊙↙↘←↗⊙↙↖↓↖↙↙⊙⊙} – 19, develops in 34 more moves.

Eater: {↓↗⊙→↘↑↙↓↓↙⊙↑⊙←↓⊙↑↙↗↙} – 20 moves, debris clears in next move.

Barge: {↓↗⊙→⊙→←↙→↓↗←↗←↙←↖↑→↙} – 20 moves, debris clears in 4 more moves.

Paperclip: {↓↗↑↖↓⊙↙↘←↗→⊙↙→↑↖↙↓↑} – 19 moves, develops in 31 more moves.

Mango: {↓↗↑↖↓⊙↙↘↘↑↓↖↗↑→↘↙⊙↗↗} – 20 moves.

LWSS: {↓↗↑⊙←↗⊙↑↖→→→↓⊙↘↘←↙⊙} – 19 moves, debris clears in next move.

bi-Blocks: {↓↗⊙→⊙→⊙↑←↘↓→↙⊙↑↖↖↗↗↙} – 20 moves, debris clears in 7 moves.

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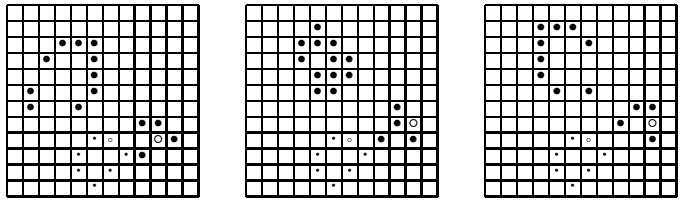

Figure 7. The newly formed LWSS.

Block on Boat: {↓↗↑↖↙↑↘↙↙↑↘↘↖↗⊙↗↗⊙⊙⊙} – 20 moves.

Up Boat on Boat: {↓↗⊙→⊙→←↙⊙←↓↑↗↑↗↙↖↘→↗} – 20 moves, develops in 8 more moves.

The last three are actually pseudostill-lives, one of which will actually turn out to be important later. LWSS stands for the Light Weight Space Ship, which travels vertically at half the speed of light, and is shown in Figure 7.

The LWSS adds to our arsenal for creating large Life forms—not only can we fire gliders at still Life to form larger structures, but now we can fire a LWSS at a stable Life form.

There are a few other Life forms that can be created in 20 moves or less, but they are formed in tandem with another Life form. For example, the Toad cannot be created by itself in 20 or fewer moves, but the 20 move sequence {↓↗↑↖↓↙→↙←↗↗↙↑⊙⊙↖⊙→⊙↘} creates both a Toad and a block. (The 26 move sequence {↓↗↑⊙↙←↘←⊙↖⊙↖→←↑⊙↓↘↓↑↑⊙←⊙⊙↗} creates just the Toad, but this is probably not an optimal sequence.) The other Life forms found in the search that were formed as part of a group are as follows.

Aircraft carrier and Block: {↓↗↑⊙⊙⊙←↖⊙↘↘↖↘←↓⊙→↘↑↘} – 20 moves.

2 ship-tie-ships: {↓↗↑↓←↓↓↘→↑⊙⊙↘⊙⊙} – 16 moves, develops in 3 more moves.

2 bi-loafs: {↓↗↑↓←⊙↙↑↗↘↙↗↙↗↓⊙↑←→} – 19 moves, develops in 5 more moves.

Up-Boat-with-Tail and Hive: {↓↗↑⊙↙←→↘↖←←↑⊙←↘↘→⊙} – 18 moves, develops in 2 more moves.

Since the extra still Life can easily be annihilated with a glider or LWSS, this shows how the intelligent cell can create some of the more elaborate Life forms.

We are now ready to put these routines together to form a p30 glider gun. The classical way of forming the glider gun uses two blocks, two ships, and two gliders. However, the two gliders must strike the two ships only five steps apart. There are actually the following two ways we can get the gliders to form almost simultaneously.

1. Use a routine that produces debris that eventually forms a pure glider after a fairly large number of moves. I refer to this as a *glider fuse*. For example, the routine {↓↗↑⊙⊙⊙↘⊙↙↘↙↘⊙⊙⊙↙↙⊙⊙} uses only 19 moves, but the debris will form a single glider in 103 moves—more than enough time to move to another location and fire the second glider.

2. If a LWSS hits a bi-Block in the right way, a single glider is produced going in almost the opposite direction as the LWSS was traveling. As a result, a glider can be sent by "remote control."

In fact, both methods are used in the following 247 move routine that starts from a WWN gateway loaf.

{←↗→↘←⊙↘↖↖↘↙↙↓⊙↙↙↑↗↙} – Form debris which will turn into a bi-Block.

{↙⊙⊙↙⊙⊙↙⊙⊙↑↖⊙⊙↓↙⊙⊙} – Move into position for block.

{↙↗⊙↖→↖←⊙⊙⊙←⊙↘↘↙↗↖↓↖} – Form a block. By this time the bi-Block is formed.

{↖⊙⊙↖⊙⊙↖⊙⊙↖⊙⊙↓↙⊙⊙↙⊙⊙↙⊙⊙↙⊙⊙↙⊙⊙} – Move into position for ship.

{↙↗⊙↖→↖←⊙↓↖↘↙←⊙⊙↖⊙←⊙↑→↖↘} – Spawn a ship.

{←↙↗⊙↘↑↘↓↑↙↙↗↑↖↖⊙↙} – Need to get glider in a different orientation.

{↙⊙⊙↙⊙⊙↙⊙⊙↑} – Get into position for next ship.

{↖↘⊙↙→↙←⊙↑↙↗↖←⊙⊙↙⊙←⊙↓→↙↗} – Spawn second ship.

{↗⊙⊙←} – Get into position for the second block.

{↖↘⊙↖↓↖↑↗↓↘⊙↓↗↖↗↙↖} – Spawn second block.

{↖⊙⊙↖⊙⊙↖⊙⊙→↗⊙⊙} – Get into position for LWSS.

{↗↑↙↘←↘→⊙↑↘⊙→↗↓↓↓←⊙↙↙↑↖⊙} – Launch LWSS.

{↑↓↑↗⊙⊙↗⊙⊙} – Get into position for fused glider.

{↗↙⊙↗⊙←↗⊙↑⊙↑↙↙↑↙↓↘↘↘↗→⊙↙→↘} – Launch fused glider, which will form a single glider in 63 more moves.

The total number of moves is 247, the result of which is shown in Figure 8. At this point, the work required for making the glider gun is finished. But it will take an additional 116 moves before the first glider appears, and the intelligent cell will have to get out of the way before that occurs.

As the LWSS travels to the right, it will hit the bi-Block, and form a single glider aimed towards the right ship. Meanwhile, the formation in the upper left-hand corner will combine with the nearby blinker to produce a second glider aimed at the left ship. These two gliders will strike the ships exactly five moves apart, so that the glider gun is formed.

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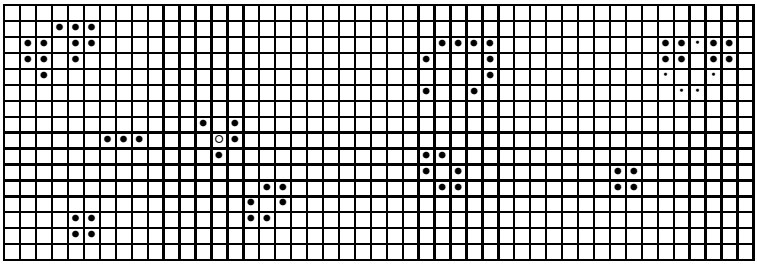

Figure 8. Formations which will develop into a glider gun.

Using [1], one can watch the glider gun being created. One cannot help but to marvel at the control that a single cell has over its environment. If this cell is thought of as the "finger of God," then it is clear how complex life forms can be quickly created.

In comparison, how long would it take for a glider gun to evolve from a primordial soup of random cells? In [9], a run of 5 billion random objects were analyzed, and no glider guns were formed. However, a cis-queen bee shuttle appeared 21 times, and the trans-queen bee shuttle appeared 18 times of the 5 billion. Since a glider gun is created when two queen bee shuttles are formed at just the right distance from each other, we can say that the probability of a glider gun forming is at most the square of the probability of either queen bee shuttle forming. This gives an upper bound of $(21 + 18)^2/(5 * 10^9)^2 = 6.084 * 10^{-17}$. This means that if a generation occurs every second, it would take over 500 million years before a glider gun is evolved, compared to only a little more than four minutes for the intelligent cell. Hence, by controlling just one cell, Life forms that would take millions of years to evolve can quickly be created in minutes.

References

[1] J. Gilbert, "Maze of Life," http://www.clickmazes.com/life/ixlife.htm.

[2] M. Garder, "The Fantastic Combinations of John Conway's New Solitaire Game 'Life,'" *Scientific American*, **223**(4) (1970) 120–123.

[3] B. Hayes, "The Cellular Automaton Offers a Model of the World and a World Unto Itself," *Scientific American*, **250**(3) (1984) 12–21.

[4] M. Garder, "On Cellular Automata, Self-reproduction, the Garden of Eden and the Game of 'Life,'" *Scientific American*, **224**(2) (1971) 112–117.

[5] P. Chapman, "Life Universal Computer," http://www.igblan.com/ca/.

[6] A. Flammenkamp, "Top 60 of Game-of-Life Objects," http://wwwhomes.uni-bielefeld.de/achim/freq_top_life.htm.

[7] E. Pegg, Jr., http://www.mathpuzzle.com/playme.htm.

[8] M. Niemiec, "Life Credits," http://home.interserv.com/~mniemiec/lifecred.htm.

[9] A. Flammenkamp, "Natural Grown Oscillators out of Random Soup," http://wwwhomes.uni-bielefeld.de/achim/oscill.htm.

https://doi.org/10.25088/ComplexSystems.14.3.275