Spaceships in Conway's Game of Life

Of Blinkers, Jellyfish, and Everything...
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A Word from the Texinfo Editor

"I think that it's extraordinarily important that we in computer science keep fun in computing. When it started out, it was awful lot of fun."
– Alan J. Perlis

Well, when it began I was a 16 year old hacker at Hittorf Gymnasium, Recklinghausen, sitting in front of an Apple][, with my eyes staring into the whole new world beyond the terminal screen.

In one of the first lessons in Pascal programming our exercise was to write a program defined by a certain set of rules, which incorporated a 2-dimensional array structure, loop statements and lots of arithmetic comparisons. By that time, I didn't know anything about *cellular automata*, nor did I know the German word – *zellulärer Automat*. All what mattered was, that is was easy to code, and awful lot of fun to watch how cells die, get born or whole "objects" move across the grid. Though it was sometimes painfully slow, under the Apple Pascal's p-system.

To make things even more enjoyable, we agreed to write a graphics front end in our spare time we wrote such a beast, using Apple Pascal's *turtlegraphics* unit. "We" were *Christian Weber*, now a physician, *Bernd Paffenholz*, now a mathematican and I, a computer scientist. The offspring of this project was a real *Game of Life*: Two players put their black and white colored beasts (cells) onto the playground, then the "clock" was started and Life began. The player with more beasts left than the other's won the race.

These rules, obviously, lead to a certain strategy of game playing:

1. try to find a certain pattern of cells with a desired behaviour, on your own, e.g. static ones, like the "block," or oscillating (hard to detect for your competitor), or moving (to destroy your competitors objects)
2. test these constructs against your competitor's ones
3. if your opponent wins, write a search program to find new, hopefully "better" constructs

The latter never happened, as far as I can remember, all this happened almost a decade ago. Now, I know that David never knew our version of the "Game of Life," but I was pretty amazed when I read his series of articles in *comp.theory.cellular-automata*. And thus started over to make this thing "a doodle."

Too bad, I guess I'd won every race with his online companion at hand!

Enjoy!

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1 Conway's Game of Life

1.1 Introduction

This is the first of a series of articles on recent results in Conway's Game of Life. There are many aspects of Life that are interesting and have recent developments, such as glider guns, spaceships, puffer trains, large period oscillators, and the construction of objects with desired properties.

I am restricting this set of articles to spaceships because of two reasons. Firstly, since the earliest days of Life around 1970, no truly new spaceships had been discovered until just about three years ago, and therefore this area is very new and exciting. And secondly, I have had a part in developing this area, and therefore know first hand about some of the results. But I will touch on several of the other areas as I go.

Almost all of the new spaceship results I will be describing were found by one of three people. Possibly others have independently discovered some of these things, and if so, we certainly should share credit with them. But until I know otherwise, the credit for the discoveries belongs to the people I mention. These people are *Dean Hickerson*, *David Bell* (myself), and *Hartmut Holzwart* (listed in order of involvement).

Most of the new spaceships were found by computer search. The size and complexity of most of the discoveries are such that they would not be expected to turn up by running random patterns, or by manually trying a set of possibilities. However, some of the "fine tuning" of the results are the work of human thinking and manipulating pieces of the found results.

1.2 Some Techspeak

Firstly, I should define some terminology. A spaceship is a finite pattern of live cells in Life that after a certain number of generations reappears, but translated in some direction by a nonzero distance. Translation is measured by the shortest king-wise connected path between two cells. So two cells adjacent to each other are one cell apart, whether or not the cells are adjacent orthogonally or diagonally. The process of translating after a certain number of generations is called moving or traveling.

The number of generations before the pattern reappears (but translated) is called the period of the spaceship. (This is analogous to the period of stationary oscillators.) Many spaceships appear to be the same pattern after a number of generations, but on closer examination are not really the same. Instead of being merely translated, they are also reflected (or flipped) as in a mirror. After twice that number of generations, the spaceship does reappear in its original form, with just a translation. The period always measures this full number of generations. Spaceships which show their mirror image after half their period are called glide- reflection spaceships.

Spaceships can travel orthogonally (straight left-right or up-down), or diagonally. All known diagonal spaceships travel the same distance left- right as they do up-down. There is no reason why a spaceship could not travel (for example) two units across and one unit up for its translation. However no example of such a spaceship is known. Theoretically, we could build ships with any translation by using a universal computer/constructor. But they would be very large and slow.

The translated distance divided by the period is the speed of the spaceship. Since the maximum speed of propagation of a signal in Life is one cell per generation, this speed is known as c (the speed of light). This speed is also the fastest possible growth of any finite object for a finite number of generations (think of a long line of ON cells). However, growth (or even just movement) of a finite object for an infinite time cannot occur at this speed. It was proven in the early days of Life that the maximum possible speed of any spaceship is c/2 for orthogonal spaceships, and c/4 for purely diagonal spaceships. More generally, if a spaceship moves A cells across and B cells up, then its period must be at least 2 * (A + B). This means (for example) that an orthogonal spaceship might move by one cell in two generations, or two cells in four generations, or three cells in six generations, and so on. But no spaceship (for example) can move by one cell in one generation, or two cells in three generations, or three cells in four generations.

Whenever I list spaceships or puffers, I will follow some standard rules. Since most known spaceships move orthogonally, that movement will not be explicitly mentioned. They will always be drawn so as to move from right to left. The few diagonal spaceships will be marked as such, and will move in the indicated direction.

To begin with and to be complete, I will list the original spaceships. These are the glider, the lightweight spaceship (LWSS), middleweight spaceship (MWSS), and the heavyweight spaceship (HWSS). These were all found very soon after Life was invented by Conway. They are:

Glider (diagonal to lower left, glide-reflective, period 4, speed c/4):

```
.O.
O..
OOO
```

LWSS (glide-reflective, period 4, speed c/2):

```
.O..O
O....
O...O
OOOO.
```

MWSS (glide-reflective, period 4, speed c/2):

```
...O..
.O...O
O.....
O....O
OOOOO.
```

HWSS (glide-reflective, period 4, speed c/2):

```
...OO..
.O....O
O......
```

```
O.....O
OOOOOO.
```

The glider is the most basic spaceship. Since it is so small, it appears spontaneously from random objects. Collisions between gliders produce many useful things. For example, two gliders can produce another glider, and three gliders can produce a LWSS or MWSS or a HWSS. Gliders can be produced indefinitely by many kinds of "glider guns." The first glider gun was found by *Bill Gosper* in 1970, and was the first example of a Life object whose population grew arbitrarily large.

The three orthogonal spaceships are very useful because of the presence of their "sparks." Sparks are cells at the edge of an object which die off, and which can perturb other objects without destroying the object which generates the spark. The commonest use of sparks from these spaceships is to perturb an "engine" to produce puffer trains, or to modify stationary objects when the spaceships pass by.

The three orthogonal spaceships above show an obvious pattern, and the casual Life-player might wonder why the pattern cannot be continued to make even larger spaceships. This will not work directly because the sparks do not die off anymore for larger ships, but wreck the ship.

The following for example, doesn't work because the spark at the top is actually a blinker, and doesn't die. Without the blinker, this object is known as an OWSS (overweight spaceship). This name is also given to even larger objects following the same pattern.

Non-working OWSS:

```
...OOO..
.O.....O
O.......
O......O
OOOOOOO.
```

It was discovered rather early that an OWSS can survive if it is "escorted" by other smaller spaceships. The escorting spaceships are positioned to prevent the formation of the deadly non-sparks. The following is an extreme example of this. This shows the largest overweight spaceship which can be safely escorted by only two other spaceships.

OWSS escorted by two HWSS (period 4, speed c/2):

```
....OOOO.......
...OOOOOO......
..OO.OOOO......
...OO..........
...............
...........OO..
.O.............O
O..............
O.............O
OOOOOOOOOOOOOO.
```

```
...............
...............
....OOOO.......
...OOOOOO......
..OO.OOOO......
...OO..........
```

There are many other combinations of spaceships that will support one or more OWSS. Some OWSS can be supported by a convoy of two spaceships on each side. But for very long OWSS, no convoy of small spaceships can work to stabilize it. However, it is possible to support an arbitrarily long OWSS by nesting different sized OWSS side by side to stabilize them all, with final small spaceships on the outside.

1.3 Tagalongs

The next topic related to spaceships is called a tagalong. A tagalong is something which follows behind one or more spaceships, and needs the spaceships in order to survive. Generally, tagalongs are attached to the sparks of a spaceship so that they don't destroy the spaceship. But some tagalongs attach right to the base ship itself, and some even need some modification of the base ships in order to work. A tagalong along with its base ship can be considered as a large spaceship.

One of the first tagalongs was found a couple of years into the history of Life. This is the *Schick engine*, found by *Paul Schick* in 1972. It uses the sparks from two adjacent LWSS to keep the engine going.

Schick engine tagalong (period 12, speed c/2):

```
OOOO.....
O...O....
O........
.O..O..OO
......OOO
.O..O..OO
O........
O...O....
OOOO.....
```

This tagalong is very useful, because it splits into two separate parts. The back part dies off on its own. But it can be perturbed by adjacent LWSS, MWSS, or HWSS in many ways to produce output which remains. It then becomes a puffer train. For example, adding one LWSS gives:

Simple puffer train producing pairs of beehives (period 24, speed c/2):

```
...........OO.
..........OOOO
.........OO.OO
```

```
..........OO..
OOOO..........
O...O.........
O.............
.O..O..OO.....
......OOO.....
.O..O..OO.....
O.............
O...O.........
OOOO..........
```

If a second LWSS is also placed at the bottom of the above object symmetrically to the top LWSS, then the puffer produces a stream of blinkers with period 12.

A tagalong can be changed into a puffer engine by perturbations as in the above example. The reverse can also happen. A puffer engine can be tamed and turned into a tagalong. This can generally be done by using passing spaceships to destroy all of the puffer output. Such an object will then be a large spaceship. I will give two examples.

The first example uses a well known puffer engine, the B heptomino. The first two puffers in Life were found by *Bill Gosper* and are both based on the B heptomino. The one given here is the second one he found, where a single engine is perturbed by two LWSS to become a very dirty puffer. It takes over 4600 generations for this puffer to settle down. It then produces a large collection of objects with period 140.

Dirty puffer train based on B heptomino (eventual period 140, speed c/2):

```
.....
.OO..
OO.OO
.OOOO
..OO.
.....
.....
....O
...OO
..OO.
...OO
.....
.....
.....
.....
.OO..
OO.OO
.OOOO
..OO.
```

By adding another LWSS, this dirty puffer is tamed and becomes a spaceship with period 20. This object has a rather large spark which can then be perturbed with other spaceships to produce simple useful outputs such as gliders.

Period 20 spaceship based on B heptomino (period 20, speed c/2):

```
..........O..O........
.OO......O............
OO.OO....O...O........
.OOOO....OOOO.........
..OO..................
......................
...........O..........
....O...O....O........
...OO....O...O...OO.OO
..OO.....O........O..O
...OO.............OOO.
............O..O......
.............OO.......
......................
......................
.OO...................
OO.OO.................
.OOOO.................
..OO..................
```

The second example is based on a puffer discovered by *Bob Wainwright* in 1984. The period of this puffer is only eight, which is the minimum puffer period known. (There are several other different period 8 puffers known.) The one shown here produces a row of blinkers.

Period 8 puffer train producing blinkers (speed c/2):

```
...O.....
.O...O...
O........
O....O...
OOOOO....
.........
.........
.........
.OO......
OO.OOO...
.OOOO....
..OO.....
.........
.....OO..
...O....O
..O......
..O.....O
..OOOOOO.
```

By using a passing HWSS, the blinkers can be deleted, producing a true spaceship which can be made as large as desired by moving the trailing HWSS back.

Period 8 spaceship (speed c/2):

```
...0.............
.0...0...........
0................
0....0.....00....
00000.....00.0000
...........000000
............0000.
.................
.00..............
00.000...........
.0000...000.000..
..00.............
.................
....00...........
...0....0........
..0..............
..0.....0........
..000000.........
```

By using different puffers, and deleting the output in many many different ways, a very large number of spaceships can be produced. But they all have a few things in common. All of these orthogonal spaceships use the LWSS, MWSS, or HWSS as essential components. Therefore they must all have a speed of c/2, and a period which is a multiple of four. The question arises as to whether there are some spaceships which move at different speeds, have other periods, or don't make use of the normal spaceships. The answer is YES, and is why this area has been exciting in the last few years.

Before proceeding to these new things, I will recap two tantalizing early results which showed that possibly such ships might be found.

This first one was noticed by many people, and is the pi heptomino. The following is generation 1 of the pi heptomino. It reappears 30 generations later, with a translation of 9, for a very obscure speed of 3c/10.

Generation 1 of pi heptomino, a non-working spaceship:

```
..0
.00
0..
.00
..0
```

Unfortunately, it also produces a large amount of other debris which then quickly destroys the object. That debris can be controlled by carefully placed blocks in its path, or by placing many copies of the pi heptomino side by side. But all such constructions must be carried out to infinity to work forever. No one has figured out how to make a finite object based on this work.

The second tantalizing result was discovered by *Charles Corderman* in 1971 while doing an exhaustive search of polyominoes. A small object was discovered which translated itself diagonally by 8 cells, with some other debris remaining. The debris doesn't interfere immediately with the object, and so it translates itself again. Only after many such translations does the debris catch up to the engine and destroy it. Corderman found that by perturbing the debris in various ways, or by placing multiple copies of the engine alongside each other, the engine can survive forever. However, in none of these cases was it a spaceship. It was instead a puffer, and left debris behind. The following is one of the simplest of these puffers, and leaves just blocks behind.

Switch Engine puffer train (diagonal to upper left, glide-reflective, period 288, speed c/12):

```
.O.O........................
O...........................
.O..O.......................
...OOO......................
............................
..........................OO
..........................O.
```

The above object is one of the smallest known objects whose population grows arbitrarily large. (All of these are based on the switch engine and have only 11 ON cells.) The only known diagonal puffer trains are all based on the switch engine. But no one succeeded in taming the debris completely to create a spaceship until *Dean Hickerson* did this in April, 1991. He did this by placing a large number of switch engines together so as to eliminate all debris. His original ship required 13 switch engines, but his smaller one given here only uses 10 of them. The number of them needed can possibly be reduced even further, but this isn't known.

The spaceship is just a little too wide to be seen in an 80 column width, so the description below is compressed in the following manner. Each dollar sign represents 10 empty cells. Just use an editor to replace each dollar sign by 10 periods, and you will be able to reconstruct the picture of the full object.

Cordership (diagonal to upper right, symmetrical, period 96, speed c/12):

```
$$$.....OO$$$$$
$$$.....O...OO$$$$......
$$$....O......O.......OOO$$$.....
$$$..OOOOO...O.....OOO$$$........
$$$.....O...O......OOO$$$........
$$$..O..O$.O$$$.........
$$....OO.......OO$$$$$..
$$....OO$$$$$$.
$$$$$$$$.......
$$$$$........O$$........
$$$$$........O$$........
$$$$$........O$$........
$$$$$......OO$$.........
$$$$$.....OOO$$.........
$......OO$$$........OO$$.........
$......OO$$$$$$.........
$$$$$$$$.......
```

```
$$$$$$$$.......
$$$$$$$$.......
$$$$$........0$$........
$$$$$.......0$$.........
$$$$$........0$$........
........00$$$$$$$.......
........00$$$......0$$$$
$$$$.....0.0$$$.........
$$$$....00.00$$$........
$$$$.......00$$$........
$$$$.00$$$$....
$$$$...0..000$......0.0.......000.........
$$$$.00.0$$.0.....000$..
00$$$$.0..0$$.....000$..
00...0.......0$$.........0$$.........0$...
....0.0.....000$$.........00$$$$.
...0..0..0000.00$$$$$$$.
.........0..000$$$0$$$$.
......0..00..0$$.........00.00$$$......0..
....0.0.00$$$....0$$$.........0..
.....0$$$$.0$$$......0..
$$$$.....0$..0.00$$00...
$$$$.........0.0......0.000$........000...
$$$$$.0....0.0....0$........00...
$$$$........0...0.0......00$$....
$$$$$00..0..0...0$$.....
$$$$$.0...00.0$$........
$$$$$.......0.0$$.......
$$.......0$$.........0.0$$....0..
$$......000$$$$$....0.0.
$$.....00.00$$$$$..0..0.
$$......000$$$$$........
$$.......0$$$$$.........
$$.....0.0$$$$$.....0..0
$$....0000$$$$$...000.00
$$....0$$$$$.....0..00..
$$$$$$$$0..0...
$$....00.00$$$$$..0.0...
$$...0.....0$$$$$.......
$$....0...0$$$$$........
$$.......0...0.......0$$$$.......
$$$0.0.....000$$$$......
$$.........0..0..0000.00$$$$.....
$$$.....0..000$$$$......
$$$..0..00..0$$$.........00......
$$$0.0.00$$$$...00......
$$$.0$$$$$.....
$$$$$$$$.......
$$$$$$$$.......
$$$$$$$$.......
$$$$$$$$.......
$$$$$$$$.......
$$$$$$$.00$....
$$$$$$$.00$....
```

```
$$$$$...0$$$...
$$$$$..000$$$..
$$$$$.00.00$$$.
$$$$$..000$$$..
$$$$$...0$$$...
$$$$$.0.0$$$...
$$$$$0000.........00$$..
$$$$$0$..00$$..
$$$$$$$$.......
$$$$$00.00$$$..
$$$$.........0.....0$$$.
$$$$$0...0$$$..
$$$$$...0$$$...
$$$$$$$$.......
$$$$$.....00$$$
$$$$$.....00$$$
```

The Cordership has lots of debris that dies away. Gliders can hit this debris and do interesting things. In particular, gliders can be turned by 90 or 180 degrees by hitting the debris appropriately. Dean Hickerson has used this fact to create some interesting constructions, such as reflecting gliders back and forth forever between two Corderships that are slowly pulling apart.

The Corderships form one of several new classes of spaceships, ending a period of about 20 years when no new classes were found. However, it was not the first of these new classes. The next part of this series will begin exploring these new classes in earnest, starting with the c/2 period 2 spaceships.

2 Spaceships of Period 2

This is the second in a series of articles concerning Conway's Game of Life. In this article, I will describe the early history of the discovery of the new classes of spaceships, and then survey the results for all the known period 2 spaceships. All period 2 spaceships must be orthogonal, and must travel at the speed of c/2. This follows from the speed restrictions mentioned in my previous article.

In July of 1989 Dean Hickerson started writing a Life search program for his Apple IIe. It was written in 6502 assembly language and Applesoft BASIC. Dean's Life search program looks for patterns that repeat themselves after a small number of generations, with or without translations. (Translations are used when you want to find spaceships instead of oscillators.)

During a search, the program recursively attempts to set cells ON or OFF, and for each cell that is set uses transition and implication rules in order to detect contradictions in the current state of cells. This allows the program to quickly stop and backtrack over impossible situations, and thus reduce enormously the size of the search. This program was described in the xlife 3.0 distribution.

Search programs typically attempt to set the cells in a column-by-column order. Since a cell's fate in N generations is usually dependent on the state of all cells within a distance of N, contradictions cannot usually be detected until the state of the next N columns has been specified. This means that looking for oscillators or spaceships is much harder for larger periods. The current useful limit on search programs of this type is for period 5. Some searches in small areas have been done for periods 6 and 7.

Another effect of the order of setting cells column-by-column is that objects which have many rows are harder to find than those with fewer rows. (The number of columns can be very large and has little effect on the search.) The current search programs can usefully look for objects which have about 10 rows (20 rows if symmetry is used), but this limit can be raised somewhat for low-period searches, such as up to 14 rows for period 2.

Since the useful number of rows being searched is limited, many of the spaceships which are found are of one of two types. They are either wide and short or are thin and long. These terms refer to the dimensions of the spaceship with respect to the direction that it travels. Therefore a thin and long spaceship looks like an "arrow," whereas a wide and short spaceship looks like a "wave." However, for many smaller space ships where both dimensions fit within the row limit and are of comparable size, they can look like "blobs."

Using his program, and looking for short, wide spaceships, Dean Hickerson found the first period 2 spaceships on July 28, 1989. These were the first examples of a new class of spaceship. He does not remember which specific spaceship was found first, but the following ship was among the first ones found, and is the smallest known period 2 spaceship.

Smallest known period 2 spaceship (speed c/2):

```
.....O.O
....O..O
...OO...
..O.....
```

```
.OOOO...
O....O..
O..O....
O..O....
.O......
..OOOO.O
...O...O
....O...
....O.O.
........
...OOO..
...OO...
...OOO..
........
....O.O.
....O...
...O...O
..OOOO.O
.O......
O..O....
O..O....
O....O..
.OOOO...
..O.....
...OO...
....O..O
.....O.O
```

Within a few hours of finding the first period 2 ship, Dean had discovered a grammar for constructing an infinite number of different short, wide, period 2 spaceships. A grammar is an "alphabet" of "components," along with rules for the possible sequences of connections between components. Components are simply the identifiable pieces of a ship which reappear over and over in different ships in different combinations. There are three components in the above spaceship, as will be seen below.

The complete grammar describes the components, the allowed sequences of the components, and the manner in which the components are joined together. The following are the components of Dean's first grammar.

```
   [A]          [A']        [B]     [B']     [C]      [C']
.....O.O     .......O       X        X       X         X
....O..O     ....OOOO      ...     .O..    .....     .O...
...OO...     ....OO..      OOO     .O.O    OOO..     .O.O.
..O.....     ..O.....      OO.     O...    OO...     O....
.OOOO...     ..OOOO..      OOO     .O.O    OO...     O...O
O....O..     .O......      ...     .O..    OOOOO     .O..O
O..O....     OOO..O..       X        X     ..O..     .O.O.
O..O....     .OOO....                        X        X
.O......     ..O.....
..OOOO.O     ...OOO.O
...O...O     ...O..OO
....O...     ....OOO.
```

```
....O.O.      ......O.
    X              X
```

```
[D]      [D']        [E]       [E']        [F]      [F']
 X         X          X           X         X        X
...      .O..       ...O.O      ....O      ...O     .O.O
OOO      .O.O       ..O..O      ..OOO      .OOO     O..O
OO.      O...       ..O...      .OOO.      OOO.     O...
OO.      O...       .O..O.      O..O.      .OOO     O..O
OOO      .O.O       OOO...      O....      ...O     .O.O
...      .O..       .OOO..      O..O.       X        X
 X         X        ...O..      .O.O.
                      X          X
```

```
  [G]        [G']
 X             X
.O.O..      ...O...
O..O..      .OOO...
O.....      OOO....
O.....      .OO....
.O..OO      ..OO..O
..OOOO      ...OO.O
......      .......
..OOOO      ...OO.O
.O..OO      ..OO..O
O.....      .OO....
O.....      OOO....
O..O..      .OOO...
.O.O..      ...O...
 X             X
```

The components occur in pairs identified by the same letter, but with or without a quote mark (e.g., A and A'). Such pairs are related in that they are the two phases of the same section of a period 2 spaceship. So that, for example, if a period 2 spaceship contains component B in generation 0, then in generation 1 it must contain component B' in the same position within the ship.

Besides the listed components, there are other components which are their mirror images. The mirroring is done by flipping the component across a horizontal line. The mirrored component names are the same as for the original components, except that they end with a trailing dash. So that, for example, the mirror image of component A' is A'-. Mirror images for symmetrical components such as B would be duplicates and so are not used.

The components that make up a spaceship are strung together like beads on a string, stacked one above the other. A sequence of components specifies the order of components, arranged from top to bottom. When doing this, the components must be correctly aligned horizontally. The 'X' characters in the component diagrams specify the proper alignment. When two components are stacked together, they must be placed adjacent to each other so that the 'X' characters are in the same column. The rows containing the 'X' characters are not part of the components, and should be removed.

The following shows an example of stacking two components correctly.

Section B F' of a period 2 spaceship:

```
 X
....
000.
00..
000.
....
.0.0
0..0
0...
0..0
.0.0
 X
```

The final part of the grammar specifies the allowed sequences of components. Only certain sequences of components can be used to make a valid spaceship. The following rules specify these allowed sequences.

The sequence must begin with A or A'.

The sequence must end with A- or A'-.

Each pair of adjacent symbols must appear in one line of the following table, with the first symbol found before the vertical bar, and the second symbol found after the vertical bar.

```
A   C'  E-  E'  F'  G   |  B   C   D

A'  C   E   E'- F   G'  |  B'  C'  D'

            B   C-  D   |  A-  C'- E   E'- F'  G

            B'  C'- D'  |  A'- C-  E-  E'  F   G'
```

The simplest example of a sequence which follows these rules is A B A-, which represents the c/2 period 2 ship given above. Another example of a spaceship created using these rules is A D E B' A'-, which represents the following spaceship.

One of many period 2 spaceships constructed by the above grammar (speed c/ 2):

```
.......0.0
......0..0
.....00...
....0.....
...0000...
..0....0..
..0..0....
```

```
..O..O....
...O......
....OOOO.O
.....O...O
......O...
......O.O.
..........
.....OOO..
.....OO...
.....OO...
.....OOO..
..........
......O.O.
.....O..O.
.....O....
....O..O..
...OOO....
....OOO...
......O...
....O.....
....O.O...
...O......
....O.O...
....O.....
......O...
....OOO...
...O..OO..
...OOO.O..
..O.......
.OOO......
OOO..O....
.O........
..OOOO....
..O.......
....OO....
....OOOO..
.......O..
```

Small tagalongs were soon found for several of these components. (These tagalongs can also be attached to many of the other period 2 spaceships.) The one for component C was found by *Robert Wainwright*, and the one for component A was found by *Bill Gosper*.

C component with tagalong (left), A component with tagalong (right):

```
 X                              ........O.
.........                       .....O.O.O
OOO......                       ....O..O..
OO.......                       ...OO.....
OO....O..                       ..O.......
OOOOO.O.O                       .OOOO.....
.O.....O.                       O....O....
 X                              O..O......
```

```
O..O......
.O........
..OOOO.O..
...O...O..
....O.....
....O.O...
    X
```

Dean Hickerson also looked for thin, long period 2 ships in those first weeks. These spaceships are much harder to find, and so he only found one basic ship before moving on to search for other things. This spaceship is shown below.

First long period 2 spaceship (speed c/2):

```
.............O.......
...........OO........
........OOOO.O.......
........OO.......OO..
......O...OO.O...OOOO
......OOOO.O.O.O....O
...O.O......OO.......
..OOOOOO.OO.OO.OO....
.OO.....OO...O.......
OO....OO....O........
.OO....OOOO..........
.....................
.OO....OOOO..........
OO....OO....O........
.OO.....OO...O.......
..OOOOOO.OO.OO.OO....
...O.O......OO.......
......OOOO.O.O.O....O
......O...OO.O...OOOO
........OO.......OO..
........OOOO.O.......
...........OO........
.............O.......
```

At the end of September, 1989, Dean discovered an extensible tagalong for the above ship that is now named a wicktrailer. This tagalong allows the ship to be made as long as desired. Such a tagalong can be described as having a period, which is the number of generations it takes before a unit of the tagalong reappears in the same place.

Period 2 ship with wicktrailer (period 20 extensible tagalong) (speed c/2):

```
............................O.........O.........O..
.............O...........OOOO......OOOO......OOOO..
...........OO..........OOO.O.....OOO.O.....OOO.O...
........OOOO.O........OO...O....OO...O....OO...O...
........OO.......OO...O....OO...O....OO...O....OO..
```

```
......0...00.0...0000.0.....000.0.....000.0.....000
......0000.0.0.0....0000......0000......0000......0
...0.0......00.........0.........0.........0.......
..000000.00.00.00..................................
.00.....00...0.....................................
00....00....0......................................
.00....0000........................................
...................................................
.00....0000........................................
00....00....0......................................
.00.....00...0.....................................
..000000.00.00.00..................................
...0.0......00.....................................
......0000.0.0.0....0..............................
......0...00.0...0000..............................
........00.......00................................
........0000.0.....................................
...........00......................................
.............0.....................................
```

The tagalong can be attached to the other "foot" of this ship in a similar manner to produce a symmetrical ship of any length, or with two unequal length wicks. The tagalong can also be attached to the "foot" of the other period 2 ships on component A'. Doing this allows the construction of a ship which is as wide and as long as desired.

There is a hidden motivation in looking for new ships and their tagalongs. Besides the elegance of new ships, Dean was hunting for new puffer trains. Puffer trains allow for the construction of interesting large Life objects, including devices which perform logic operations or numeric calculations. There are only a small number of basic types of puffer trains, and new methods for making puffer trains would be useful. For every new spaceship which is found, there is the possibility that it contains a new set of "sparks" that has not been seen before. Such a new set of sparks might allow a new type of puffer engine to work, or might be useful to catalyze a reaction in a new manner. So far this has not been successful.

Another way that a new puffer train might be constructed is by perturbing an extensible tagalong such as the one in the above ship. If the perturbation results in a reaction that travels at a speed less than or equal to the ship (c/2 in this case), and that reaction leaves debris behind, then a puffer train results. Unfortunately, this process has so far not worked with any extensible tagalong. The reaction either breaks off, or travels faster than the ship and ends up destroying the ship. For example, deleting one cell from the end of the wicktrailer, or adding one cell to it almost always results in one of either two reactions which travel at 6c/7 or 11c/12 and catch up to the ship and destroy it.

After Dean found the above results, he went looking for other things, and so the class of period 2 spaceships wasn't further developed for a while. Meanwhile, I had heard of Dean's search program, read his notes about it, and wrote my own program in C, and started making my own discoveries. I sent a copy of the program to Hartmut Holzwart. He made some modifications to it (such as speedups, new symmetries, and different search orders), and then also started making many new discoveries. But it wasn't until June of this year that we started looking for period 2 spaceships.

On June 7, 1992, I was experimenting with a new search feature, and found three new components for period 2 ships. The most interesting component is a repeatable diagonal component which bends the ship backwards with a slope of 3/6. The other two larger components just provide a connection to an already known ship component, and terminate the end of the new component. The following shows a ship using all three components, with the diagonal one repeated twice.

Period 2 spaceship with repeatable "barber pole" component (speed c/2):

```
........................O
......................OOO
.....................OO..
.....................O...
...................O.O...
.................OOO.....
................OO..O....
................O.O......
................OOO......
................O.OOO....
...............OO........
..............OO.O.......
.................O.O.....
.............O...........
.............OO.O........
.............O.O.........
............OO...........
...........OO.O..........
..............O..........
..........O..............
..........OO.O...........
..........O.O............
.........OO..............
........OO.O.............
...........O.............
.......O.................
.......OO.O..............
.......O.O...............
......OO.................
...OO.OOO................
...O....O................
...O.....................
....O..O.................
.....OO..................
......OO.................
...OOO.O.................
..O...OO.O.O.............
.O...O..O..O.............
.O..O.O.O................
.O.......O...............
..O..OO...O..............
...OO.OOOOOO.............
....OO...O.O.............
....O.O..................
...O.....................
```

```
....O..O.................
....O.O..................
.........................
...OOO...................
...OO....................
...OOO...................
.........................
....O.O..................
....O....................
...O...O.................
..OOOO.O.................
.O.......................
O..O.....................
O..O.....................
O....O...................
.OOOO....................
..O......................
...OO....................
....O..O.................
.....O.O.................
```

The diagonal component can obviously be repeated arbitrarily often to make an “arm” as long as desired. The same arm can also be constructed on the other side of the ship to make it symmetrical, creating a bow shaped ship.

One interesting thing about a long string of these diagonal components is that both phases appear identical to each other, but shifted. This makes the arm act somewhat like a “barber pole” with a pattern appearing to move up (or down) the arm as the ship moves.

A few days later I found a second repeatable diagonal component. This component is actually a tagalong since it just attaches to a “foot” of an intact period 2 ship. The slope of this tagalong is 8/13. This tagalong is called the “glancing head” because it resembles a head with two eyes looking sideways. The following shows two copies of this tagalong, one attached to the base ship and the second to the first tagalong. Again, this arm can be made as long as desired.

Period 2 spaceship with repeatable “glancing head” tagalong (speed c/2):

```
.......................O
.....................OOO
....................OO..
....................O...
..................O.O...
................OOO.....
...............OO..O....
..............O..O......
..............O..O......
..............O.........
...............O..O.....
................OO......
.................OO.....
...............O.O......
```

```
.............OOO.O......
............OO..........
............O...........
..........O.O...........
........OOO.............
.......OO..O............
......O..O..............
......O..O..............
......O.................
.......O..O.............
........OO..............
.........OO.............
.......O.O..............
....OOOO.O..............
....OO..................
..O.....................
..OOOO..................
.O......................
OOO..O..................
.OOO....................
..O.....................
...OOO.O................
...O..OO................
....OOO.................
......O.................
....O...................
....O.O.................
...O....................
....O.O.................
....O...................
......O.................
....OOO.................
...O..OO................
...OOO.O................
..O.....................
.OOO....................
OOO..O..................
.O......................
..OOOO..................
..O.....................
....OO..................
....OOOO................
.......O................
```

By using a piece of Dean Hickerson's wicktrailer, one foot can be turned into two feet. This allows the construction of a "binary tree" spaceship, which branches an arbitrary number of times. Here the wicktrailer tagalong can be attached to any foot, and two copies of the glancing head tagalong can be attached to the two feet of the wicktrailer. The following shows a simple example of connecting these tagalongs together to make a branching spaceship.

Period 2 binary tree spaceship (speed c/2):

```
.......................................O..
.....................................OOO..
....................................OO....
....................................O.....
..................................O.O.....
................................OOO.......
...............................OO..O......
..............................O..O........
..............................O..O........
..............................O...........
...............................O..O.......
................................OO........
.................................OO.......
...............................O.O........
............................OOOO.O........
.......O..................OOO.O...........
....OOOO.................OO...O...........
....OO...................O....OO..........
..O....................O.O.....OOO.O......
..OOOO...............OOO.........O.O......
.O..................OO..O..........OO.....
OOO..O.............O..O...........OO......
.OOO...............O..O..........O..O.....
..O................O............O.........
...OOO.O............O..O........O..O......
...O..OO.............OO.........O..O......
....OOO...............OO.........OO..O....
......O.............O.O...........OOO.....
....O.............OOO.O.............O.O...
....O.O..........OO...................O...
...O.............O....................OO..
....O.O........O.O.....................OOO
....O........OOO.........................O
......O.....OO..O.........................
....OOO....O..O...........................
...O..OO...O..O...........................
...OOO.O...O..............................
..O.........O..O..........................
.OOO.........OO...........................
OOO..O........OO..........................
.O..........O.O...........................
..OOOO....OOO.O................O..........
..O......OO..................OOO..........
....OO...O..................OO............
....OOOO.O..................O.............
.......OOOO.O.............O.O.............
..........O.O...........OOO...............
............OO.........OO..O..............
...........OO.........O..O................
..........O..O........O..O................
.........O............O...................
.........O..O..........O..O...............
.........O..O...........OO................
..........OO..O..........OO...............
```

```
...........OOO.........O.O................
.............O.O.....OOO.O................
...............O....OO....................
...............OO...O.....................
................OOO.O.....................
..................OOOO.O..................
.....................O.O..................
.......................OO.................
......................OO..................
.....................O..O.................
....................O.....................
....................O..O..................
....................O..O..................
.....................OO..O................
......................OOO.................
........................O.O...............
..........................O...............
..........................OO..............
...........................OOO............
.............................O............
```

Since each branch can be extended to be as long as necessary by using more glancing head tagalongs, enough room can be created to build a fully populated binary tree ship, containing 2^N nodes.

The wicktrailer is even more versatile than is shown above. A longer section of the wicktrailer has even more feet. There is room for the glancing head tagalong to be attached to each one of those feet, and for more glancing head tagalongs to be attached to those tagalongs. Counting each section of wicktrailer as a node, this means that not only can full binary trees be constructed, but full N-ary trees can also be constructed, for any N. The following illustrates the construction details that allow such a spaceship to be made.

Period 2 N-ary tree spaceship details (speed c/2):

```
.............................O.........O.........O..........
...........................OOO.......OOO.......OOO..........
..........................OO........OO........OO............
..........................O.........O.........O.............
........................O.O.......O.O.......O.O.............
......................OOO.......OOO.......OOO...............
.....................OO..O.....OO..O.....OO..O..............
....................O..O......O..O......O..O................
....................O..O......O..O......O..O................
....................O.........O.........O...................
.....................O..O......O..O......O..O...............
......................OO........OO........OO................
.......................OO........OO........OO...............
.....................O.O.......O.O.......O.O................
..................OOOO.O....OOOO.O....OOOO.O....O...........
................OOO.O.....OOO.O.....OOO.O.....OOO...........
...............OO...O....OO...O....OO...O....OO.............
```

```
...............O....OO...O....OO...O....OO...O..............
.............O.O.....OOO.O.....OOO.O.....OOO.O..............
...........OOO.........OOOO.O....OOOO.O....OOOO.O...........
..........OO..O...........O.O.......O.O.......O.O...........
.........O..O...............OO........OO........OO..........
.........O..O..............OO........OO........OO...........
.........O................O..O......O..O......O..O..........
..........O..O...........O.........O.........O..............
...........OO............O..O......O..O......O..O...........
............OO...........O..O......O..O......O..O...........
..........O.O.............OO..O.....OO..O.....OO..O.........
.......OOOO.O..............OOO.......OOO.......OOO..........
....OOOO.O...................O.O.......O.O.......O.O........
....OO...O.....................O.........O.........O........
..O......OO....................OO........OO........OO.......
..OOOO....OOO.O.................OOO.......OOO.......OOO.....
.O..........O.O...................O.........O.........O.....
OOO..O........OO............................................
.OOO.........OO.............................................
..O.........O..O............................................
...OOO.O...O................................................
...O..OO...O..O.............................................
....OOO....O..O.............................................
......O.....OO..O...........O.........O.........O...........
....O........OOO........OOOO......OOOO......OOOO............
....O.O........O.O.....OOO.O.....OOO.O.....OOO.O............
...O.............O....OO...O....OO...O....OO...O............
....O.O..........OO...O....OO...O....OO...O....OO...........
....O.............OOO.O.....OOO.O.....OOO.O.....OOO.........
......O.............OOOO.O....OOOO.O....OOOO.O....O.........
....OOO................O.O.......O.O.......O.O..............
...O..OO.................OO........OO........OO.............
...OOO.O................OO........OO........OO..............
..O....................O..O......O..O......O..O.............
.OOO..................O.........O.........O.................
OOO..O................O..O......O..O......O..O..............
.O....................O..O......O..O......O..O..............
..OOOO.................OO..O.....OO..O.....OO..O............
..O.....................OOO.......OOO.......OOO.............
....OO....................O.O.......O.O.......O.O...........
....OOOO....................O.........O.........O...........
.......O....................OO........OO........OO..........
.............................OOO.O.....OOO.O.....OOO.O......
...............................O.O.......O.O.......O.O......
.................................OO........OO........OO.....
................................OO........OO........OO......
...............................O..O......O..O......O..O.....
..............................O.........O.........O.........
..............................O..O......O..O......O..O......
..............................O..O......O..O......O..O......
...............................OO..O.....OO..O.....OO..O....
................................OOO.......OOO.......OOO.....
..................................O.O.......O.O.......O.O...
....................................O.........O.........O...
```

```
....................................00........00........00..
.....................................000.......000.......000
.......................................0.........0.........0
```

A side effect of this construction is that for any sized square, no matter how large, there exists a period 2 spaceship whose cells occupy at least some constant percentage of the area of the square (around 10%).

Later, another repeating diagonal tagalong was discovered, which also allows N-ary tree ships to be built. Here the slope is 4/17, which is shallower than the previous tagalong. This tagalong has the name "staring head," and looks similar to the main component of the base ship. The following illustrates this tagalong and how it may be connected.

Period 2 spaceship demonstrating "staring head" tagalong (speed c/2):

```
..........0.........0.............
.......0000......0000......0......
....0000.0.....000.0.....000......
....00...0....00...0....00........
..0......00...0....00...0.........
..0000....000.0.....000.0.........
.0..........0000.0....0000.0......
000..0.........0.0.......0.0......
.000.............00........00.....
..0.............00........00......
...000.0.......0..0......0..0.....
...0..00......0.........0.........
....000.......0.........0.........
......0.......000.......000.......
....0..........0..0......0..0.....
....0.0........000.......000......
...0..........0.........0.........
....0.0......000.......000........
....0.......000..0....000..0......
......0......0.........0..........
....000.......0000......0000......
...0..00......0.........0.........
...000.0........00........00......
..0.............0000.0....0000.0..
.000...............0.0.......0.0..
000..0...............00........00.
.0..................00........00..
..0000.............0..0......0..0.
..0...............0.........0.....
....00............0.........0.....
....0000.0........000.......000...
.......0.0.........0..0......0..0.
.........00........000.......000..
........00........0.........0.....
.......0..0......000.......000....
......0.........000..0....000..0..
```

```
......O..........O.........O......
......OOO.........OOOO......OOOO..
.......O..O.......O.........O.....
.......OOO..........OO........OO..
......O.............OOOO......OOOO
.....OOO...............O.........O
....OOO..O........................
.....O............................
......OOOO........................
......O...........................
........OO........................
........OOOO......................
...........O......................
```

Using his modified version of my program, Hartmut Holzwart recently did a search for large long period 2 spaceships. He found several dozen such ships with many possible variations. In this article I will give only a representative sample of these spaceships.

Following are three variations on relatively small period 2 ships. These are related to the first long spaceship found by Dean Hickerson.

Several similar small period 2 spaceships (speed c/2):

```
............       .............       ............O
............       .............       .........OOOO
.........O.O       .........O.O.       .........OO..
........O..O       ........O..O.       .......O...OO
.......OO...       .......OO....       .......OOOO.O
......O.....       ......O......       ......O......
.....OOOOOO.       .....OOOOOO.O       .....OOOOOO.O
..OO.......O       ..OO.......OO       ..OO.......OO
.O...OOO.O..       .O...OOO.OO..       .O...OOO.OO..
O...O....O..       O...O....OO..       O...O....OO..
O.....O....O       O.....O...OO.       O.....O...OO.
OOO...OOOOO.       OOO...OOOO.O.       OOO...OOOO.O.
............       .............       .............
OOO...OOOOO.       OOO...OOOO.O.       OOO...OOOO.O.
O.....O....O       O.....O...OO.       O.....O...OO.
O...O....O..       O...O....OO..       O...O....OO..
.O...OOO.O..       .O...OOO.OO..       .O...OOO.OO..
..OO.......O       ..OO.......OO       ..OO.......OO
.....OOOOOO.       .....OOOOOO.O       .....OOOOOO.O
......O.....       ......O......       ......O......
.......OO...       .......OO....       .......OOOO.O
........O..O       ........O..O.       .......O...OO
.........O.O       .........O.O.       .........OO..
............       .............       .........OOOO
............       .............       ............O
```

A section of the wicktrailer can be attached to the two center feet of the middle ship above, creating feet which are separated by a one cell gap. Hartmut found that a repeatable tagalong can be attached to that pair of feet. This tagalong is unusual in that unlike most other tagalongs which work by having cells turned on by the base ship, this tagalong works by having some cells turned off by the base ship. The following shows the base ship, the wicktrailer, and two copies of the repeatable tagalong.

Period 2 spaceship with repeatable tagalong (speed c/2):

```
............................O.........O
.........O.O..............OOO.......OOO
........O..O.............OO........OO..
.......OO................O.........O...
......O........O.......O.O.......O.O...
.....OOOOOO.OOOO.....OOO.......OOO.....
..OO.......OO.O.....OO.O......OO.O.....
.O...OOO.OO...O.....O.O.OO....O.O.OO...
O...O....OO...OO....OO..OO....OO..OO...
O.....O...OO...OOO..O.....OO..O.....OO.
OOO...OOOO.O.....O..OO..OO.O..OO..OO.O.
....................OO.O......OO.O.....
OOO...OOOO.O.....O..OO..OO.O..OO..OO.O.
O.....O...OO...OOO..O.....OO..O.....OO.
O...O....OO...OO....OO..OO....OO..OO...
.O...OOO.OO...O.....O.O.OO....O.O.OO...
..OO.......OO.O.....OO.O......OO.O.....
.....OOOOOO.OOOO.....OOO.......OOO.....
......O........O.......O.O.......O.O...
.......OO................O.........O...
........O..O.............OO........OO..
.........O.O..............OOO.......OOO
............................O.........O
```

By using two feet at the ends of two separate spaceships, this tagalong can be used to connect the two ships into one larger ship. Since the tagalong has feet of its own, two copies of it can be used to attach another copy of the tagalong to them too.

The following spaceships are related, and are both extensible. Here extensible means that they contain recognizable components which can be repeated to make the ships wider. (This will be explained in more detail a little later.) The first spaceship here is important because it demonstrates a new end component for grammar-based ships.

Two similar extensible period 2 spaceships (speed c/2):

```
............O.O          ............O.O..
...........O..O          ...........O..O..
..........OO...          ..........OO.....
.........O....O          .........O.......
........OOOOO.O          ........OOOOOO...
.....OO........          .....OO.......O..
....O...OOO....          ....O...OOO.O....
```

```
...O...O.......      ...O...O....O....
...O.....O.....      ...O.....O....O..
...OOO...O.....      ...OOO...OOOOO...
.........OO.O..      .................
...OOO......O..      ...OOO.....OOOOO.
..O............      ..O........O....O
.O...O.........      .O...O.....O..O..
O..O...........      O..O........O...O
O....O.........      O....O.......O...
OOOOO..........      OOOOO.........OOO
...............      .................
OOOOO..........      OOOOO.........OOO
O....O.........      O....O.......O...
O..O...........      O..O........O...O
.O...O.........      .O...O.....O..O..
..O............      ..O........O....O
...OOO......O..      ...OOO.....OOOOO.
.........OO.O..      .................
...OOO...O.....      ...OOO...OOOOO...
...O.....O.....      ...O.....O....O..
...O...O.......      ...O...O....O....
....O...OOO....      ....O...OOO.O....
.....OO........      .....OO.......O..
........OOOOO.O      ........OOOOOO...
.........O....O      .........O.......
..........OO...      ..........OO.....
...........O..O      ...........O..O..
............O.O      ............O.O..
```

The following shows a tagalong for a slightly modified base ship. Here the tagalong works in the normal manner, by having new cells created by the base ship. This tagalong is not repeatable, however.

Period 2 spaceship with tagalong (speed c/2):

```
............O..............
.........O.O.O.............
........O..O...............
.......OO.....O...........O
......O.......OOO.......OOO
.....OOOOOO....OOO.....OO..
..OO.......O....O......O...
.O...OOO.O.......OOO.O.O...
O...O....O.......O..OO.....
O.....O....O......OO...O...
OOO...OOOOO........OOOO....
...........................
OOO...OOOOO........OOOO....
O.....O....O......OO...O...
O...O....O.......O..OO.....
.O...OOO.O.......OOO.O.O...
..OO.......O....O......O...
```

```
.....OOOOOO....OOO.....OO..
......O.......OOO.......OOO
.......OO.....O...........O
........O..O...............
.........O.O.O.............
............O..............
```

The following spaceship is one of the more complicated ships found by Hartmut Holzwart. It has a curious pattern of several long rows of ON cells within it. Possibly this hints at a pattern that could reappear at a larger scale in even larger ships. This spaceship is also extensible.

One of the more complicated period 2 spaceships (c/2):

```
..............O.O.........
...........O.O..O.........
..........O..O...........O
.........OO....O...O.O.OO.
........O....O...OOO.O.O.O
.......OOOOO.O...O..O.....
....OO...........OOO.OO...
...O...OOOOOOOO...O....O..
..O...O............OOO....
..O.....OOOOOOOOO..O...O..
..OOO...O............OOO..
..........OOO.O.O....OOOO.
..OOO.....O..OO.O.......O.
.O.....O...OO.............
O...OO.O....OOOOO.........
O...O.....................
O...OO.O....OOOOO.........
.O.....O...OO.............
..OOO.....O..OO.O.......O.
..........OOO.O.O....OOOO.
..OOO...O............OOO..
..O.....OOOOOOOOO..O...O..
..O...O............OOO....
...O...OOOOOOOO...O....O..
....OO...........OOO.OO...
.......OOOOO.O...O..O.....
........O....O...OOO.O.O.O
.........OO....O...O.O.OO.
..........O..O...........O
...........O.O..O.........
..............O.O.........
```

Not all of the spaceships that Hartmut found are extensible. (I have mostly selected those that were.) The following is one of those which is not known to be extensible.

Another complicated period 2 (non-extensible) spaceship (speed c/2):

```
...........O.O...........O.O
..........O..O.........OOOOO
.........OO...........O...O.
........O...O........OO...O.
.......OOO.O........O...O...
....OO.............OOOO...O.
...O...OOOOO......O....OOO..
..O...O...........OOO.......
..O.....OOOO...O.O.....OOO..
..OOO...O.....OOOOOOOOO...O.
..........O..OO........OO...
..OOO.....OO.OO...OO.O..O.O.
.O.....O...OO......O..OO.O..
O...OO.O...O........OO.O.O..
O...O.....O..O..............
O...OO.O...O........OO.O.O..
.O.....O...OO......O..OO.O..
..OOO.....OO.OO...OO.O..O.O.
..........O..OO........OO...
..OOO...O.....OOOOOOOOO...O.
..O.....OOOO...O.O.....OOO..
..O...O...........OOO.......
...O...OOOOO......O....OOO..
....OO.............OOOO...O.
.......OOO.O........O...O...
........O...O........OO...O.
.........OO...........O...O.
..........O..O.........OOOOO
...........O.O...........O.O
```

2.1 Extending Spaceships

I will now explain how many of the above ships are extensible. This could be done by extending Dean's grammar to include all the new components and how they attach to each other. But since the attachments of these new components are so obvious, an example seems easiest. The following spaceship demonstrates the new components and how they may be connected. All the components are separated from each other by a gap of one cell. You should recognize several of these from the collection of spaceships above.

Example components to make Hartmut's ships extensible (speed c/2):

```
.......O......
....OOOO......
....OO........
..O...........
..OOOO........
.O............
OOO..O........
.OOO..........
..O...........
...OOO.O......
```

```
...O..OO......
....OOO.......
......O.......
....O.........
....O.O.......
...O..........
....O.O.......
....O.........
......O.......
....OOO.......
...O..OO......
...OOO.O......
..O...........
.OOO..........
OOO..O........
.O............
..OOOO........
..O...........
....OO........
....OOOO.O....
.......O.O....
.........OO...
........OO....
.......O..O...
......O.......
......O.......
......OOO.....
..............
......OOO.....
.....O........
....O...O.....
...O..O.......
...O....O.....
..O.OOOO......
.OOO..........
..O.OOOO......
...O....O.....
...O..O.......
....O...O.....
.....O........
......OOO.....
..............
......OOO.....
.....O........
....O...O.....
...O..O.......
...O....O.....
...OOOOO......
..............
...OOOOO......
...O....O.....
...O..O.......
....O...O.....
.....O........
```

```
......OOO.....
..............
......OOO.....
.....O........
....O...O.....
...O..O.......
...O....O.....
...OOOOO......
..............
.....OOOOO....
.....O....O...
.....O..O.....
......O...O...
.......O......
........OOO...
..............
........OOO...
.......O.....O
......O...OO.O
......O...O...
......O...OO.O
.......O.....O
........OOO...
..............
........OOO...
........O.....
........O.....
.........O..O.
..........OO..
...........OO.
.........O.O..
......OOOO.O..
......OO......
....O.........
....OOOO......
...O..........
..OOO..O......
...OOO........
....O.........
.....OOO.O....
.....O..OO....
......OOO.....
........O.....
......O.......
......O.O.....
.....O........
......O.O.....
......O.......
........O.....
......OOO.....
.....O..OO....
.....OOO.O....
....O.........
...OOO........
```

```
..000..0......
...0..........
....0000......
....0.........
......00......
......0000....
.........0....
```

Below the standard base period 2 spaceship, there is a small component that I found which attaches to the foot of a ship, and provides a bridge to the new components. Below that is a symmetrical component with a leading "plus sign" of five cells. This component featured in many of Hartmut's first period 2 ships. But it turns out that the plus sign is optional and can be removed, splitting the large component into two smaller components. This is shown next. Following that are the same smaller components shifted with respect to each other by two cells. Finally, there is a "jellyfish" component, then the bridge and another base ship.

To summerize, all the components with three cells in a row along the edge can join together, and the components with five cells in a row along the edge can join up together, possibly shifted.

As an example of extending one of Hartmut's spaceships, we can take the complicated spaceship above with the several rows of ON cells. By adding more of the same kind of components already present in the ship, we can create the following new spaceship.

Example of extending a period 2 spaceship (speed c/2):

```
..............0.0.........
...........0.0..0.........
..........0..0...........0
.........00....0...0.0.00.
........0....0...000.0.0.0
.......00000.0...0..0.....
....00...........000.00...
...0...00000000...0....0..
..0...0............000....
..0.....000000000..0...0..
..000...0............000..
..........000.0.0....0000.
..000.....0..00.0.......0.
.0.....0...00.............
0...00.0....00000.........
0...0.....................
0...00.0....00000.........
.0.....0...00.............
..000.......00..0.........
.............00...........
..000.........00.0........
.0.....0.......00.........
0...00.0..................
0...0.........00..........
0...00.0......00.0........
.0.....0.....00...........
```

```
..OOO.......OO..O.........
...........OO.............
..OOO.......OOOOO.........
.O.....O..................
O...OO.O....OOOOO.........
O...O......OO.............
O...OO.O....OO..O.........
.O.....O.....OO...........
..OOO.........OO.O........
...............OO.........
..OOO.....................
.O.....O.......OO.........
O...OO.O......OO.O........
O...O........OO...........
O...OO.O....OO..O.........
.O.....O...OO.............
..OOO.......OOOOO.........
..........................
..OOO.......OOOOO.........
.O.....O...OO.............
O...OO.O....OO..O.........
O...O........OO...........
O...OO.O......OO.O........
.O.....O.......OO.........
..OOO.....................
...............OO.........
..OOO.........OO.O........
.O.....O.....OO...........
O...OO.O....OO..O.........
O...O......OO.............
O...OO.O....OOOOO.........
.O.....O..................
..OOO.......OOOOO.........
...........OO.............
..OOO.......OO..O.........
.O.....O.....OO...........
O...OO.O......OO.O........
O...O..........OO.........
O...OO.O..................
.O.....O.......OO.........
..OOO.........OO.O........
.............OO...........
..OOO.......OO..O.........
.O.....O...OO.............
O...OO.O....OOOOO.........
O...O.....................
O...OO.O....OOOOO.........
.O.....O...OO.............
..OOO.....O..OO.O.......O.
..........OOO.O.O....OOOO.
..OOO...O............OOO..
..O.....OOOOOOOOO..O...O..
..O...O............OOO....
...O...OOOOOOOO...O....O..
```

```
....OO...........OOO.OO...
.......OOOOO.O...O..O.....
........O....O...OOO.O.O.O
.........OO....O...O.O.OO.
..........O..O...........O
...........O.O..O.........
..............O.O.........
```

These new components can be combined with the branching ship components to form "loopy" structures. So we can construct spaceships with arbitrarily large holes inside them. The following is a simple example of such a spaceship.

Period 2 spaceship with hole (speed c/2):

```
..........................O..............
.......................OOOO..............
.....................OOO.O...............
....................OO...O...............
....................O....OO..............
..................O.O.....OOO.O..........
................OOO.........O.O..........
...............OO..O..........OO.........
..............O..O...........OO..........
..............O..O..........O..O.........
..............O............O.............
...............O..O........O..O..........
................OO.........O..O..........
.................OO.........OO..O........
...............O.O...........OOO.........
.............OOO.O.............O.O.......
............OO...................O.......
............O....................OO......
..........O.O.....................OOO.O..
........OOO.........................O.O..
.......OO..O..........................OO.
......O..O...........................OO..
......O..O..........................O..O.
......O............................O.....
.......O..O........................O.....
........OO.........................OOO...
.........OO..............................
.......O.O.........................OOO...
....OOOO.O........................O.....O
....OO...........................O...OO.O
..O..............................O...O...
..OOOO...........................O...OO.O
.O................................O.....O
OOO..O.............................OOO...
.OOO.....................................
..O................................OOO...
...OOO.O..........................O.....O
...O..OO.........................O...OO.O
```

```
....OOO..........................O...O...
......O..........................O...OO.O
....O.............................O.....O
....O.O............................OOO...
...O.....................................
....O.O............................OOO...
....O.............................O.....O
......O..........................O...OO.O
....OOO..........................O...O...
...O..OO.........................O...OO.O
...OOO.O..........................O.....O
..O................................OOO...
.OOO.....................................
OOO..O.............................OOO...
.O................................O.....O
..OOOO...........................O...OO.O
..O..............................O...O...
....OO...........................O...OO.O
....OOOO.O........................O.....O
.......O.O.........................OOO...
.........OO..............................
........OO.........................OOO...
.......O..O........................O.....
......O............................O.....
......O..O..........................O..O.
......O..O...........................OO..
.......OO..O..........................OO.
........OOO.........................O.O..
..........O.O.....................OOO.O..
............O....................OO......
............OO...................O.......
.............OOO.O.............O.O.......
...............O.O...........OOO.........
.................OO.........OO..O........
................OO.........O..O..........
...............O..O........O..O..........
..............O............O.............
..............O..O..........O..O.........
..............O..O...........OO..........
...............OO..O..........OO.........
................OOO.........O.O..........
..................O.O.....OOO.O..........
....................O....OO..............
....................OO...O...............
.....................OOO.O...............
.......................OOOO..............
..........................O..............
```

Recently I found that the “barber pole” diagonal tagalong can be used as a bridge between two spaceships. This is shown below.

Barber pole component connecting two period 2 spaceships (speed c/2):

```
.......O.................
....OOOO.................
....OO...................
..O......................
..OOOO...................
.O.......................
OOO..O...................
.OOO.....................
..O......................
...OOO.O.................
...O..OO.................
....OOO..................
......O..................
....O....................
....O.O..................
...O.....................
....O.O..................
....O....................
......O..................
....OOO..................
...O..OO.................
...OOO.O.................
..O......................
.OOO.....................
OOO..O...................
.O.......................
..OOOO...................
..O......................
....OO...................
....OOOO.O...............
.......O.O...............
.........OO..............
........OO...............
.......O..O..............
......O..................
......O...O..............
......OO.OOO.............
.........OO..............
..........O.O............
..........OO.O...........
..........O..............
..............O..........
...........OO.O..........
............OO...........
.............O.O.........
.............OO.O........
.............O...........
.................O.......
..............OO.O.......
...............OO........
................O.O......
................OO.O.....
................O........
....................O....
```

```
.................OO.O....
..................OO.....
...................O.O...
...................OO.O..
...................O.....
.......................O.
....................OO.O.
....................O....
.....................O.O.
.....................O...
......................OOO
.........................
....................O.OOO
...................OO..OO
...................O.O...
...................OO....
...................O.....
..................OOO....
..................O......
..................O......
...................O..O..
....................OO...
.....................OO..
...................O.O...
................OOOO.O...
................OO.......
..............O..........
..............OOOO.......
.............O...........
............OOO..O.......
.............OOO.........
..............O..........
...............OOO.O.....
...............O..OO.....
................OOO......
..................O......
................O........
................O.O......
...............O.........
................O.O......
................O........
..................O......
................OOO......
...............O..OO.....
...............OOO.O.....
..............O..........
.............OOO.........
............OOO..O.......
.............O...........
..............OOOO.......
..............O..........
................OO.......
................OOOO.....
...................O.....
```

Finally, I have discovered two different repeatable tagalongs for period 2 spaceships, and a small tagalong for them which makes the ship a period 6 spaceship. This is the only method known for making a period 6 spaceship.

Period 2 spaceship with repeatable tagalongs and period 6 tagalong (speed c/2):

```
.....O.O.......................................................
....O..O.......................................................
...OO..........................................................
..O............................................................
.OOOO..........................................................
O....O.........................................................
O..O...........................................................
O..O...........................................................
.O.............................................................
..OOOO.O.......................................................
...O...O.......................................................
....O..........................................................
....O.O........................................................
...............................................................
...OOO.........................................................
...OO..........................................................
...OOO.........................................................
...............................................................
....O.O........................................................
....O..........................................................
...O...O.......................................................
..OOOO.O.......................................................
.O.............................................................
O..O...........................................................
O..O...........................................................
O....O.........................................................
.OOOO..........................................................
..O............................................................
...OO..........................................................
....O..O.O....O.O....O.O....O.O.....O....O.O.....O....O.O......
.....O.O..O..O..O.OO.O..O..O..O.OO.O.O..O..O.OO.O.O..O..O.OO.O.
........O...OO........O...OO.......O...OO.......O...OO.......OO
.........O......O......O......O.....OOO....O.....OOO....O......
..........OOOOO.O.......OOOOO.O.......OOOO.O.......OOOO.O....OO
..................OO............OO...........OO...........OO.O.
..........OOOOO.O.......OOOOO.O.......OOOO.O.......OOOO.O......
.........O......O......O......O.....OOO....O.....OOO....O......
........O...OO........O...OO.......O...OO.......O...OO.........
.....O.O..O..O..O.OO.O..O..O..O.OO.O.O..O..O.OO.O.O..O..O.OO...
....O..O.O....O.O....O.O....O.O.....O....O.O.....O....O.O......
...OO..........................................................
..O............................................................
.OOOO..........................................................
O....O.........................................................
O..O...........................................................
O..O...........................................................
.O.............................................................
```

```
..0000.0........................................................
...0...0........................................................
....0...........................................................
....0.0.........................................................
................................................................
...000..........................................................
...00...........................................................
...000..........................................................
................................................................
....0.0.........................................................
....0...........................................................
...0...0........................................................
..0000.0........................................................
.0..............................................................
0..0............................................................
0..0............................................................
0....0..........................................................
.0000...........................................................
..0.............................................................
...00...........................................................
....0..0........................................................
.....0.0........................................................
```

In the above, the two types of period 2 tagalongs are repeated twice. The two pre-blocks at the right form the period 6 tagalong. The pre-blocks can be removed to make a normal period 2 spaceship. The final three sets of two-bit sparks can also be removed and the ship will still work.

There are a few more known period 2 components that I have not mentioned in this article. The number of possible components is probably infinite. As we search larger and larger areas, we find more and more components, so that cataloging them becomes impossible. Instead of trying to catalog everything, we can search directly for objects which meet certain conditions, such as spaceships which have sparks of a desired kind. An example of this is given by the first "barber pole" spaceship in this article. The component at the front which connects the diagonal component to the rest of the ship is larger than the others, and is messy. It was searched for explicitly in order to connect the diagonal component to a known spaceship.

Considering the long time interval of 20 years between the classic spaceships and these new classes, you might be surprised at the number of new spaceships that have been found in the last few years. But I am not done yet! The next article in this series will survey the period 3 c/3 spaceships. These were the first spaceships found which travel at a "non-standard" speed.

3 Spaceships of Period 3

This is the third in a series of articles concerning Conway's Game of Life. In this article, I will survey the results for all the known period 3 spaceships, and give some applications of them. All period 3 spaceships must be orthogonal, and must travel at the speed of c/3. This follows from the speed restrictions mentioned in my first article.

When Dean Hickerson started looking for spaceships using his search program, the first spaceships he found were of period 2. But he soon also tried looking for period 3 spaceships. In August 1989 he found a grammar for constructing an infinite number of short wide c/3 period 3 spaceships. (This grammar is used similarly to the grammar for period 2 spaceships that was in my previous article.) These period 3 spaceships were the first orthogonal spaceships found which didn't travel at the "normal" speed of c/2.

In Dean's grammar, the components are labeled using letters, or letters followed by either a single quote or a double quote (e.g., A, A', and A"). Any three components with the same letter are related, and represent the same section of a period 3 spaceship in three successive generations. Therefore, if component A appears in generation 0 of a spaceship, then component A' must appear in the same location in generation 1, and component A" must appear in the same location in generation 2.

A component name followed by a dash represents the mirror image of a component. The mirroring is done by reflecting the component across a horizontal line. For example, component B"- is the mirror image of component B".

The components in Dean's grammar are the following:

```
[A]     [A']    [A"]    [B]     [B']    [B"]    [C]       [C']      [C"]
..O.    ..O.    ..O     ..O.    ..O.    ..O     ...O...   .......   ...O...
.O.O    .O.O    OO.     .O.O    .O.O    OO.     ..O....   .OOO...   ..O.O..
.O.O    OO..    OO.     .O.O    OO..    OO.     .OO....   .OOO...   ..O....
.O..    ..O.    ..O     .O..    .O..    ..O     ...O.O.   ...OO..   ..O...O
....    OO..    O..     OO..    O.O.    O..     .OOO..O   .O.O.OO   ....O.O
OO..    OOO.    O.O      X       X      X       .OO..O.   .O.O...   .OO..O.
 X       X      X                               .......   O......   .O.....
                                                OOO....   OOO....   OO.....
                                                .O.....   O......   .O.....
                                                  X         X         X

 [D]      [D']     [D"]     [E]    [E']   [E"]   [F]     [F']   [F"]
  X         X        X       X      X      X       X       X      X
..O.O    ......   ..O..     .O.O   ....   .O.O   .OO..   .O.O   ..O..
..OO.    ...OO.   ...OO     O.O.   O..O   ..O.   ..O..   ..O.   ....O
.....    ..O..O   .O...     OOO.   O.O.   OO..   ..O.O   .OO.   ..OO.
OO.OO    .OOO..   .O.OO     ....   O...   .O..   ..OO.   ....   ..OO.
OO...    O..O..   O..OO     .O.O   .O..   .OOO   .OO..   O..O   .....
O....    O..O..   O..O.       X      X      X    OO...   O...   OO...
OO.O.    .OO...   .OOO.                          X       X      X
.O.O.    ....O.   .O...
  X        X         X
```

```
[G]
 X
0..0
00..
.0..
.000
  X
```

```
[G’]
 X
0...
000.
....
.0.0
  X
```

```
[G"]
 X
0.0
00.
0..
.0.
  X
```

```
[H]
   X
..00..
...0..
...0.0
...00.
.000..
0.0...
0.0...
0.....
.0....
  X
```

```
[H’]
    X
...0.0
....0.
...00.
......
..0..0
.0....
00....
.0....
.000..
  X
```

```
[H"]
   X
...0..
.....0
...00.
...00.
......
000...
000...
......
.0.0..
  X
```

```
[I]
  X
.0.0.
.....
000..
00...
.....
..000
.0.00
.0...
.0...
.....
00...
 X
```

```
[I’]
  X
.0...
0....
0.0..
0.0..
.000.
..0.0
.0..0
00...
.....
00...
000..
 X
```

```
[I"]
  X
.000..
.0....
00....
.0....
......
.....0
.0000.
.00...
......
.0.0..
.0.0..
 X
```

```
[J]
  X
..0.....
..000...
..0.....
........
00...0..
00000...
00...0.0
..0..00.
00.0....
.0......
..000...
........
..000...
.0......
00.0....
..0..00.
00...0.0
00000...
00...0..
........
..0.....
..000...
..0.....
  X
```

```
[J’]
   X
..00....
..00....
...0....
..0.....
.0..00..
0...0000
.0....0.
...0.000
.00.....
.00..0..
...00...
........
...00...
.00..0..
.00.....
...0.000
.0....0.
0...0000
.0..00..
..0.....
...0....
..00....
..00....
   X
```

```
[J"]
  X
.0.0....
....0...
...0....
..000...
.0.00...
00..0..0
........
.0...000
.0.000..
.0..0...
..000...
........
..000...
.0..0...
.0.000..
.0...000
........
00..0..0
.0.00...
..000...
...0....
....0...
.0.0....
  X
```

```
[K]
  X
.0.0.
.....
000..
00...
.....
..000
.0.00
0....
0....
.....
000..
.0...
  X
```

```
[K’]
  X
.0...
0....
0.0..
0.0..
.000.
..0.0
.0..0
00...
.....
0....
000..
0....
  X
```

```
[K"]
  X
.000..
.0....
00....
.0....
......
.....0
.0000.
.00...
.00...
.0....
00....
.0....
  X
```

The components are strung together by stacking them above each other, similarly to the way that period 2 components are stacked. (The X’s indicate the horizontal alignment of components, and should be removed.)

The rules which give the allowed sequences of components to make a valid spaceship are the following.

The sequence must begin with A, A', A", B, B', B", C, C', or C".

The sequence must end with A-, A'-, A"-, B-, B'-, B"-, C-, C'-, or C"-.

Each pair of adjacent symbols must appear in one line of the following table, with the first symbol found before the vertical bar, and the second symbol found after the vertical bar.

```
                    A    | D    E
                    A'   | D'   E'
                    A"   | D"   E"
                    I    | D
                    I'   | D'
                    I"   | D"
                    D-   | A-   I-
                    D'-  | A'-  I'-
                    D"-  | A"-  I"-
                    E-   | A-
                    E'-  | A'-
                    E"-  | A"-
          B    F-   H-   | E-   G'-  H"-  I    K
          B'   F'-  H'-  | E'-  G"-  H-   I'   K'
          B"   F"-  H"-  | E"-  G-   H'-  I"   K"
E    G'   H"   I-   K-   | B-   F    H
E'   G"   H    I'-  K'-  | B'-  F'   H'
E"   G    H'   I"-  K"-  | B"-  F"   H"
               C    K    | J
               C'   K'   | J'
               C"   K"   | J"
                    J    | C-   K-
                    J'   | C'-  K'-
                    J"   | C"-  K"-
               D'   G-   | F-
               D"   G'-  | F'-
               D    G"-  | F"-
                    F    | D'-  G
                    F'   | D"-  G'
                    F"   | D-   G"
```

The simplest spaceship which can be constructed by these rules is A E B-, which is shown below. This spaceship has 25 ON cells in every generation. There is no known period 3 spaceship which has fewer ON cells than 25. (Any such spaceship must be spread out very thinly.)

Smallest known period 3 spaceship (speed c/3):

```
..O..
.O.O.
.O.O.
.O...
.....
OO...
.O.O.
```

```
O.O..
OOO..
.....
.O.O.
.OO..
..O..
..O.O
..O.O
...O.
```

Another example spaceship created using these rules is C J C-, which represents the following symmetrical spaceship.

One of many period 3 spaceships constructed by the above grammar (speed c/3):

```
...O....
..O.....
.OO.....
...O.O..
.OOO..O.
.OO..O..
........
OOO.....
.O......
..O.....
..OOO...
..O.....
........
OO...O..
OOOOO...
OO...O.O
..O..OO.
OO.O....
.O......
..OOO...
........
..OOO...
.O......
OO.O....
..O..OO.
OO...O.O
OOOOO...
OO...O..
........
..O.....
..OOO...
..O.....
.O......
OOO.....
........
.OO..O..
.OOO..O.
```

```
...0.0..
.00.....
..0.....
...0....
```

Dean Hickerson also tried looking for long and thin period 3 spaceships. He found two basic spaceships, which are given below. They have the same front ends. Dean has named the leftmost spaceship the "turtle."

The "turtle" and another related period 3 spaceship (speed c/3):

```
.000.......0        .........0...
.00..0.00.00        ........0.0..
...000....0.        ........0....
.0..0.0...0.        .000....0...0
0....0....0.        .00..0....0.0
0....0....0.        ...000.00.00.
.0..0.0...0.        .0..0.0.000..
...000....0.        0....0.....0.
.00..0.00.00        0....0.....0.
.000.......0        .0..0.0.000..
                    ...000.00.00.
                    .00..0....0.0
                    .000....0...0
                    ........0....
                    ........0.0..
                    .........0...
```

For many people, the turtle spaceship is the most aesthetically pleasing new spaceship that has been found so far. Besides being pretty, it has a feature which makes it useful. In generation 2, it produces a two bit spark at the back. This spark can be used in several ways.

The first use of the spark is that it makes a good attachment point for tagalongs. Dean quickly found a repeatable tagalong for the turtle ship. This tagalong can be said to have a period of 28, which is the number of generations for it to reappear in the same location. This tagalong is not self-terminating, however. A different kind of tagalong is required to terminate the repeating one. The following shows the base ship, four copies of the repeating tagalong, and a small terminating tagalong.

Period 3 spaceship with repeatable tagalong and ending tagalong (speed c/3):

```
...................0........0.......0..........0...........
.................00........0.0......0.0......00............
.000.......0.....00.......00........0.0......00.........0.0
.00..0.00.00.......0........0.......0..........0.......0000
...000....0......0...0....00............0....0...0....00...
.0..0.0...0...0.0...0000..000000...00..0..0.0...0000..00...
0....0....0..0.00...0.0..0.0...0.0..0.00...00...0.0..0.....
0....0....0..0.00...0.0..0.0...0.0..0.00...00...0.0..0.....
```

```
.O..O.O...O...O.O...OOOO..OOOOOO...OO..O..O.O...OOOO..OO...
...OOO....O......O...O....OO............O....O...O....OO...
.OO..O.OO.OO.......O........O.......O..........O.......OOOO
.OOO.......O.....OO.......OO........O.O......OO.........O.O
.................OO........O.O......O.O......OO............
...................O........O........O.........O...........
```

The same repeating tagalong can also be attached in a different way to the base ship, as shown below. Also shown is an alternate terminating tagalong.

Period 3 spaceship with repeatable tagalong and another ending (speed c/3):

```
..................O.........O........O.........O.O
.................O.O......OO........O..OOO...O..O.
.OOO.......O.....O.O......OO.......OO....O.O.O..OO
.OO..O.OO.OO.....O..........O..........O.O........
...OOO....O..........O....O...O....OO.OO..........
.O..O.O...O...O.OO..O..O.O...OOOO..OOO............
O....O....O..O...O.OO...OO...O.O..O.OO............
O....O....O..O...O.OO...OO...O.O..O.OO............
.O..O.O...O...O.OO..O..O.O...OOOO..OOO............
...OOO....O..........O....O...O....OO.OO..........
.OO..O.OO.OO.....O..........O..........O.O........
.OOO.......O.....O.O......OO.......OO....O.O.O..OO
.................O.O......OO........O..OOO...O..O.
..................O.........O........O.........O.O
```

The tails of the terminating tagalong above have alternate forms which also work, and which are simple permutations of the positions of the cells in the final few columns. The following diagrams show these permutations for the bottom 5 rows and rightmost 9 columns.

Alternate endings for tail of final component:

```
.........      .........      ......O.O
O.....O.O      O...O..OO      O...O..O.
O.O.O..O.      O.O.O..O.      O.O.O..OO
O...O..OO      O.....O.O      O........
.........      .........      .........
```

The second use of the spark from the turtle spaceship (and the sparks from other c/3 spaceships) is that they can interact with faster spaceships to produce various reactions (which is not possible for period 2 spaceships). For example, a LWSS catches up to a period 3 spaceship with a relative speed of c/6, and can then interact with it. The following shows a simple case of this, where the spark from the turtle ship destroys the pursuing LWSS, and so saves the turtle.

Period 3 spaceship uses its spark to destroy a pursuing LWSS:

```
.OOO.......O.........
```

```
.00..0.00.00.........
...000....0......0..0
.0..0.0...0.....0....
0....0....0.....0...0
0....0....0.....0000.
.0..0.0...0..........
...000....0..........
.00..0.00.00.........
.000.......0.........
```

The following demonstrates two useful reactions found by Dean Hickerson. Here two turtle spaceships are pursued by a salvo of five LWSSs and a MWSS. The three lower spaceships collide with the lower turtle spaceship to produce a glider. This glider then collides with the debris created by the collision of the upper spaceships with the upper turtle spaceship to produce a MWSS which travels in the reverse direction.

Salvo of c/2 spaceships hits c/3 ships to produce backwards MWSS (speed c/ 3):

```
.000.......0$$$$$.
.00..0.00.00$$$$$$.
...000....0$.........00$$$$.
.0..0.0...0$........0000$$$$
0....0....0........0000.....00.00$$$$
0....0....0........0...0.....00$$$$..
.0..0.0...0........0$$$$........0000.
...000....0.........0..0$$$$....0...0
.00..0.00.00$$$$$......0....
.000.......0$$$$$.......0..0
$$$$$$$...
$$$$$$$...
$$$$$$$...
$$....000.......0$$$........
$$....00..0.00.00$$$........
$$......000....0$$$.........
$$....0..0.0...0.....00$$$..
$$...0....0....0....00.000...0000$$..
$$...0....0....0.....00000...0...0$$.
$$....0..0.0...0......000....0$$.....
$$......000....0$....0..0......0000$.
$$....00..0.00.00$$...0...0$
$$....000.......0$$...0$....
$$$$$.........0..0$
```

Dean found the above reaction in order to construct a Life pattern which had a population growth like log(t), according to a method suggested by Bill Gosper. This is done by shooting one salvo of c/2 ships at the pair of c/3 ships, and waiting until the returning MWSS arrives. When it does, then shoot out a glider somewhere, and send another salvo of the c/2 ships. Since the period 3 ships quintuple their distance from the salvo gun every cycle, the number of gliders grows at a rate which keeps dividing by 5, and this causes the population to grow like log(t). However, after finding the reaction shown above, Dean found other simpler ways to create this behavior, and so this construction has not been completed. Later in this article is another simpler reaction which produces the same result.

After finding the period 3 spaceships given above and their tagalongs, Dean Hickerson went on to other things, and (like the period 2 spaceships), nobody looked for further period 3 spaceships for a while.

In March, 1992 I started looking for period 3 spaceships and their tagalongs, eventually doing an exhaustive search for long thin symmetrical spaceships in an area up to 18 cells wide and 79 cells long. I found several new spaceships, and many tagalongs. I have been the only person doing a search for period 3 spaceships since Dean's earliest searches. Therefore the rest of the spaceships and tagalongs in this article were found by me, and so I will omit mentioning the discoverer of each spaceship.

The first new spaceship found was the following.

Small symmetrical period 3 spaceship (speed c/3):

```
.....O.......
....O.O....O.
....O.O...O.O
....O.....OO.
..........O..
...OO......O.
....O.OO...O.
...OO.OOOOO..
.O..OOO......
OO...........
.O..OOO......
...OO.OOOOO..
....O.OO...O.
...OO......O.
..........O..
....O.....OO.
....O.O...O.O
....O.O....O.
.....O.......
```

The following spaceship was the first new spaceship found using a new search feature which allows searching in a large number of rows, but limits the number of ON cells in any column to a specified number of adjacent rows. This ship has the same number of ON cells as the smallest known period 3 spaceship, and thus ties in minimum size (but it has more ON cells in the other phases).

Second smallest known period 3 spaceship (speed c/3):

```
.....O..
....O.O.
...OO...
....O.O.
```

```
....OO..
.......O
...O..O.
..O.....
.OO.....
.O.O....
OO......
........
.O......
.O.O....
.O.O....
..O.....
```

The spaceship above has two nice properties. First, it is more spread out than any other period 3 spaceship. This makes it the best candidate for being constructed from a set of glider collisions. If it could be constructed, then a spaceship gun for it could be built. So far none of the new spaceships have been able to be constructed from gliders. (David Buckingham is an expert at constructing objects from gliders. He despairs of constructing most of the new spaceships because they are what he calls "space dust." Only a small number of the new spaceships are simple enough to be constructed from gliders using known techniques. David says he does have a method that would allow the above spaceship to be constructed, but he hasn't completed the construction.)

The second nice property of the spaceship is that it contains a different set of sparks that can have new tagalongs attached to them. The following shows a repeatable tagalong for this ship. Surprisingly, this tagalong was not found by a search program, but was found manually. This was possible because most of the tagalong resembles a component of the base ship.

Period 3 spaceship with small repeatable tagalong (speed c/3):

```
............O..
...........O.O.
..........OO...
.....O.....O.O.
....O.O....OO..
...OO.........O
....O.O...O..O.
....OO...O.....
.......O.O.....
...O..O...O..O.
..O...........O
.OO........OO..
.O.O.......O.O.
OO........OO...
...........O.O.
.O..........O..
.O.O...........
.O.O...........
..O............
```

Since the tagalong has a pair of the same sparks as the base spaceship, it can be attached to itself an arbitrary number of times. Because there is always a choice of two sets of sparks that another copy of the tagalong can attach to, you can make a ship that weaves back and forth as desired.

This tagalong is even more versatile than is described above. A section of it can be repeatedly attached to itself to make a arbitrarily long "arm." This allows a binary tree spaceship to be built for period 3 spaceships (therefore sharing this capability with period 2 spaceships). An example of such a spaceship is shown below. One of its phases is very striking in appearance (one of the most unlikely-looking spaceships known).

Period 3 "binary tree" spaceship (speed c/3):

```
...........................O...............
..........................O.O..............
.........................OO................
..........................O.O..............
..........................OO...............
.............................O.............
.........................O..O..............
........................O..................
.......................OO..................
..................O.....O.O................
.................O.O....OO.................
...............OO..........O...............
.................O.O...O..O................
.................OO...O....................
....................O.O....................
................O..O...O..O................
...............O...........O...............
..............OO........OO.................
...............O.O......O.O................
...............OO......OO..................
..................O.....O..................
..............O..O.......O..O...........O..
.............O...............O.........O.O.
............OO............OO..........OO...
..O..........O.O..........O.O..........O.O.
.O.O.........OO..........OO............OO..
.O.O............O.........O.O.............O
.O..........O..O...........O..........O..O.
...........O.........................O.....
OO........OO........................OO.....
.O.O.......O.O.......................O.O...
.OO........OO........................OO....
..O...........O.........................O..
...O..O...O..O......................O..O...
.......O.O.........................O.......
....OO...O........................OO.......
....O.O...O..O...............O.....O.O.....
...OO.........O.............O.O....OO......
....O.O....OO..............OO.........O....
.....O.....O.O..............O.O...O..O.....
```

```
..........00................00...0.........
...........0...................0.0.........
............0..0...........0..0...0..0.....
................0.........0...........0....
.............00..........00........00......
.............0.0..........0.0......0.0.....
............00............00......00.......
.............0...............0.....0.......
..............0..0.......0..0.......0..0...
..................0.....0...............0..
...............00......00............00....
...............0.0......0.0..........0.0...
..............00........00..........00.....
...............0...........0.........0.....
................0..0...0..0...........0..0.
....................0.0...................0
.................00...0................00..
.................0.0...0..0............0.0.
................00.........0..........00...
.................0.0....00.............0.0.
..................0.....0.0.............0..
.......................00..................
........................0..................
.........................0..0..............
.............................0.............
..........................00...............
..........................0.0..............
.........................00................
..........................0.0..............
...........................0...............
```

The base ship can be extended in the same manner as is done to the tagalong to make it wider. One interesting thing about the above spaceship is that many perturbations to it will simply break off and not destroy the rest of the spaceship. The reason for this is that the repeating component has a self-repairing feature. If the dangling cell next to the edge cell of an arm is removed (or equivalently, the end component is removed leaving another similar component at the end), then the ship will regenerate the missing cell.

The following shows a slightly extended base spaceship with the dangling cell removed which will regenerate in generation 3.

Regenerating period 3 spaceship (speed c/3):

```
..0.......
.0.0......
.0.0......
.0........
..........
00........
.0.0......
.00.......
```

```
..O.......
...O..O...
.......O..
....OO....
....O.O...
...OO.....
....O.....
.....O..O.
.........O
......OO..
......O.O.
.....OO...
......O...
.......O..
```

Other early tagalongs found were the following. These are the same except for where they attach to the base ship. They have sparks at the back which allow them to be repeatedly attached to each other. These tagalongs can be mixed with the one just above.

Two period 3 ships with related repeatable tagalongs (speed c/3):

```
..............O............
.............O.O...........
.....O.......O.O.......OO.O
....O.O......O........O...O
...OO............O.......O.
....O.O...O.OO..O..O.O.O...
....OO...O...O.OO...OO.....
.......O.O...O.OO...OO.....
...O..O...O.OO..O..O.O.O...
..O..............O.......O.
.OO..........O........O...O
.O.O.........O.O.......OO.O
OO...........O.O...........
..............O............
.O.........................
.O.O.......................
.O.O.......................
..O........................
```

```
..............O............
.............O.O...........
.....O......OO.........O.O.
....O.O.......O........OO.O
...OO.......OO........O....
....O.O.....OOOOOO...OO....
....OO...OO..O...O.O.......
.......O.OO..O...O.O.......
...O..O.....OOOOOO...OO....
..O.........OO........O....
.OO...........O........OO.O
.O.O........OO.........O.O.
OO...........O.O...........
..............O............
.O.........................
.O.O.......................
.O.O.......................
..O........................
```

These tagalongs are similar to the back ends of the original repeating tagalongs that Dean Hickerson found for his turtle spaceship. This means that all these tagalongs can also be attached to that spaceship.

Another early tagalong is the following, which I called the "fly." It turns out that many tagalongs look similar to this one, but this was the first one found with this appearance. It can be repeatedly attached to itself, as shown here. The front part of this tagalong resembles the front of the turtle spaceship, but is wider.

Period 3 spaceship with repeatable "fly" tagalong (speed c/3):

```
..........................0.0...0...........................
.........................00.0.0..0..........................
...........000........0.........0...........................
...........00..0.00...0..0000...............................
.....0.......0000..0.0..00....00............................
....0.0....0..0...000.....000...............................
...00.....0....0..00..00..0..0..............................
....0.0...0....0..000.0.0....00.............................
....00...00....0..0000.....0........................00...0.0
.......0.00....0..0000.....0...........0............000.0..0
...0..0...0....0..000.0.0....00.......0..........00....00.0.
..0.......0....0..00..00..0..0.......00..0.00...0000000.00..
.00........0..0...000.....000............00..0.0........0...
.0.0.........0000..0.0..00....00.....00.0...0...0....00.....
00.........00..0.00...0..0000........0000....0......00....0.
...........000........0.........0...0..00....0..00....00.0..
.0.......................00.0.0..0..0.000....0..000...00....
.0.0......................0.0...0...0.000....0..000...00....
.0.0................................0..00....0..00....00.0..
..0..................................0000....0......00....0.
.....................................00.0...0...0....00.....
.........................................00..0.0........0...
.....................................00..0.00...0000000.00..
......................................0..........00....00.0.
.......................................0............000.0..0
....................................................00...0.0
```

Here are two short, wide period 3 spaceships which show more components that could be added to Dean's grammar. These ships have additional sparks that are useful for perturbing following spaceships and for attaching tagalongs to. The spaceship on the right is the only known period 3 spaceship with a spark on the edge. This ship was found by an explicit search starting with that spark. But the edge spark has not been too useful so far.

Two more period 3 spaceships with useful sparks (speed c/3):

```
...0....      .....0.0...
..0.0...      .....0.....
..0.0...      ..000......
..0.....      ..00.0.....
........      .0..00.....
.00.....      ..0000.....
..0.0...      .....0.....
.0.0....      ..0.0..0...
.000....      00.00.0....
........      000........
..0.0...      .....0.....
..00....      .00...000..
...0....      .000..0....
...0.0..      ........0..
...00...      ....0000...
.000....      .....0.....
0.0.....      .....00....
```

```
O..O....       ......O.OOO
O.OO....       .......O...
...O....       ..........O
O..O....       ......O....
.OO.....       ....OOOOO.O
..O...O.       ...O...OO.O
...OO..O       ..O...O....
...OO...       ...O...O...
....O...       .....O.....
...OO...       ...OOO.....
..O...O.       ..O..O.....
.OO.OO..       ......OO...
..O.....       ..OOO.OO...
..OO....       ..OO...OO..
...O....       ......O.O..
....O...       ....OOO....
               ....OOO....
               ....OO.....
               ......O....
               ....OO.....
               .....O.O...
               ......O....
```

I found a salvo of two LWSSs that could hit the back of the first ship above and which generates a glider. Dean Hickerson then extended that to a salvo of four LWSSs that could hit two period 3 ships to generate a backwards- traveling MWSS. This is shown below.

Four LWSSs hit two period 3 ships to produce backwards MWSS:

```
....O.........................................................
..OO..........................................................
..OO..........................................................
....O.........................................................
..O...........................................................
..O.O.........................................................
..O.O.........................................................
...O..........................................................
.OO...........................................................
..O...........................................................
..OOO.........................................................
...O..........................................................
.....O........................................................
...OO.........................................................
...OO.........................................................
..............................................................
OOO...........................................................
OO..OO........................................................
..O...........................................................
.OO...........................................................
.OO...........................................................
.O..O.........................................................
.....O........................................................
```

```
..00000......................................................
......00.....................................................
......00..00.................................................
...0000..00.00...............................................
..0...0...0000...........................................00..
..000......00...........................................00.00
..0..0...................................................0000
...0......................................................00.
...0.0.......................................................
....0........................................................
.............................................................
.............................................................
.............................................................
.............................................................
.............................................................
.............................................................
.............................................................
.............................................................
.............................................................
.......................0.....................................
......................0.0....................................
......................0......................................
.....................0..0..............0..0..................
.....................000......00......0......................
.....................0...0...0000.....0...0..................
......................0000..00.00.....0000...................
.........................00..00..............................
.........................00..................................
.....................00000...................................
........................0....................................
....................0..0.....................................
....................00.......................................
....................00.......................................
.....................0.......................................
...................00..00....................................
...................000.......................................
.............................................................
......................00.....................................
......................00.....................................
........................0....................................
......................0......................................
.....................000.....................................
.....................0.......................................
....................00.......................................
......................0......................................
.....................0.0.....................................
.....................0.0.....................................
.....................0.......................................
.......................0.....................................
.....................00......................................
.....................00......................................
.......................0.....................................
```

This pattern is similar to the one found earlier by Dean, but uses two fewer spaceships. It has another important advantage over the earlier pattern. The returning MWSS is on a different path than the incoming LWSSs. This means that multiple salvos of LWSSs can be heading for the period 3 ships, at the same time as multiple returning MWSSs can be heading backwards.

In August 1992, the above reaction was used by Dean Hickerson to implement an example of a "sawtooth" pattern (his seventh). A sawtooth is a pattern whose population is unbounded, but which doesn't tend to infinity (the graph of the population looks like a zig-zag pattern, with fixed lower points and increasing higher points). In this sawtooth, a salvo gun tries to shoot salvos of the four LWSSs at the receding period 3 spaceships, but 5 of the salvos are inhibited if a MWSS has just arrived. So a stream of salvos grows towards the period 3 ships and is reflected back towards the gun. When the first MWSS reaches the gun, the salvos are turned off, and stay off until the last returned MWSS arrives. Since the period 3 spaceships are receding, each cycle requires more salvos before being turned off, and thus the population keeps reaching higher maximums. But the population always returns to the same low number of ON cells when the salvos are used up.

The following shows a weaving wicktrailer tagalong that looks reminiscent of the wicktrailer for period 2 spaceships. It can be said to have a period of 34. The three apparently different cycles are actually the same pattern, just in the 3 different phases.

Period 3 spaceship with wicktrailer (speed c/3):

```
..0................0.....................00..........0...............
.0.......0.0......00.........000....................00...............
00..0.0..0......00000.......0..........00..0......00000.000.......0.0
....00.00......0......0...00....0.....0..........0........0.0...0..0.
00.0..000.....0..0..00....000...0.0..00....000...0.0..00....0.0.0..00
0000...00...0..0.0...0..........0......0...00....0.....0..000........
0000...00...0.........00..0......00000.......0..........0............
00.0..000..........................00.........000....................
....00.00...............00..........0................................
00..0.0..0...........................................................
.0.......0.0.........................................................
..0..................................................................
```

The wicktrailer can be attached to some other spaceships if it is slightly modified at the front. Here is a wicktrailer attached to Dean's second long spaceship, along with another related tagalong. Compare the top tagalong with the spaceship above to see the slight modification required.

Period 3 spaceship with two independent tagalongs (speed c/3):

```
.........0........0..................
........0.0......00..................
........0......00000.000.............
.000....0...0.0........0.0...........
.00..0....0.0.0.0..00....0.0.0..00...
...000.00.00...0....0..000...0..0....
.0..0.0.000..........0.........0.0...
0....0.....0.........................
0....0.....0.........................
.0..0.0.000..........0...0.0.........
```

```
...OOO.OO.OO...O....O.O.OO.O.........
.OO..O....O.O.O.O..OO................
.OOO....O...O.O......OOOOOO.O.....O..
........O......OOOOO...O........O.O.O
........O.O......OO......O..O.O.O.OO.
.........O........O......O...........
..........................OO.........
```

Only one cycle of the wicktrailer is shown above because there is no room for more cycles without removing the bottom tagalong. The bottom tagalong does not appear to be extensible.

Sometimes a tagalong is not really a tagalong, but becomes a required part of a spaceship. An example of this is shown below. Here there is a large tagalong for the turtle spaceship, with what appears to be two copies of the wicktrailer attached to the back of the tagalong. But if either of these wicktrailers is removed, then the tagalong will self destruct. So this is really a single large tagalong.

Period 3 spaceship with a tagalong with required wicktrailers (speed c/3):

```
...............................O...............
..................O...........OO...............
..O..............O..........OOOOO.OOO..........
.O.O......OO....OO..O.OO...O........O.O........
.O...OO..OOO........OO..O.O..O..OO....O.O.O..OO
.O.O...O..O.....OO.O...O...O.O...O..OOO...O..O.
...O..O..OOO....OOOO....O.........O.........O.O
OO..OOO..OOO.OO..OOO....O......................
OO..OOO..OOO.OO..OOO....O......................
...O..O..OOO....OOOO....O.........O.........O.O
.O.O...O..O.....OO.O...O...O.O...O..OOO...O..O.
.O...OO..OOO........OO..O.O..O..OO....O.O.O..OO
.O.O......OO....OO..O.OO...O........O.O........
..O..............O..........OOOOO.OOO..........
..................O...........OO...............
...............................O...............
```

There are many more tagalongs for Dean's two symmetrical spaceships. Here is a small selection of them. You can see several components used repeatedly. Also of interest is that the front and back parts of the turtle ship appear in various widths.

Several period 3 spaceships with tagalongs (speed c/3):

```
.....................OO.....
.....................OOO.O..
...................O....OOO.
.................OOOOOOO.OO.
.OOO.......O....O........OO.
.OO..O.OO.OO....O.OO.OO.OO..
...OOO....O....O..OO..OO...O
```

```
.O..O.O...O....OOO.O.OO...O.
O....O....O..O...O..OO......
O....O....O..O...O..OO......
.O..O.O...O....OOO.O.OO...O.
...OOO....O....O..OO..OO...O
.OO..O.OO.OO....O.OO.OO.OO..
.OOO.......O....O........OO.
.................OOOOOOO.OO.
...................O....OOO.
.....................OOO.O..
.....................OO.....
```

```
.................O...........OOO...O...........
................O.O.........O.....O..O.........
................O...O.OO..OO....O.O...O........
.OOO.......O....O.O..O....OOO...O...O.....O.OO.
.OO..O.OO.OO......O..OO...OO....O.O.O..OO.O.O.O
...OOO....O....OO..OO.O..........O...O......O..
.O..O.O...O....OO..OOOO........................
O....O....O..O..O..OOOO...O....................
O....O....O..O..O..OOOO...O....................
.O..O.O...O....OO..OOOO........................
...OOO....O....OO..OO.O..........O...O......O..
.OO..O.OO.OO......O..OO...OO....O.O.O..OO.O.O.O
.OOO.......O....O.O..O....OOO...O...O.....O.OO.
................O...O.OO..OO....O.O...O........
................O.O.........O.....O..O.........
.................O...........OOO...O...........
```

```
..............................OO..O....
.................O............OO..O.OOO
................O.O..............OO....
................O...O.OO..OOOOOOO...O..
.OOO.......O....O.O..O....O..O....O....
.OO..O.OO.OO......O..OO...OOOO.OOOOO...
...OOO....O....OO..OO.O....OO.OO..OO...
.O..O.O...O....OO..OOOO....O.....OOO...
O....O....O..O..O..OOOO....O.....O.....
O....O....O..O..O..OOOO....O.....O.....
.O..O.O...O....OO..OOOO....O.....OOO...
...OOO....O....OO..OO.O....OO.OO..OO...
.OO..O.OO.OO......O..OO...OOOO.OOOOO...
.OOO.......O....O.O..O....O..O....O....
................O...O.OO..OOOOOOO...O..
................O.O..............OO....
.................O............OO..O.OOO
..............................OO..O....
```

```
..............................OO..O...........................O.........
.................O............OO..O..................OO......O.O........
................O.O..............OO.........................O........O.O
................O...O.OO..OOOOOOO......OOO.........OO..O...O..OO.O.O..O.
.OOO.......O....O.O..O....O..O....O....OO..O.OO...O......OOOOO.....O..OO
```

```
.00..0.00.00......0..00...0000.00000.....0000..0.00....00......0........
...000....0....00..00.0....00.00..00...0..0...000..0...00...00..........
.0..0.0...0....00..0000....0.....0000.0....0..00.........0..00..........
0....0....0..0..0..0000....0.....0...00....0..000.......................
0....0....0..0..0..0000....0.....0...00....0..000.......................
.0..0.0...0....00..0000....0.....0000.0....0..00.........0..00..........
...000....0....00..00.0....00.00..00...0..0...000..0...00...00..........
.00..0.00.00......0..00...0000.00000.....0000..0.00....00......0........
.000.......0....0.0..0....0..0....0....00..0.00...0......00000.....0..00
................0...0.00..0000000......000.........00..0...0..00.0.0..0.
................0.0..............00.........................0........0.0
.................0............00..0..................00......0.0........
..............................00..0...........................0.........
```

```
.....................0..............................0...0.0.0...............
.........0..........00..00.........00...0......00.00..0000.00...............
........0.0......0.00.0.........0.000..0.0.....00.0.0.00....0.0.............
........0......000.00...0.0....0...0...0.0....0....0......00..00.0.......0.0
.000....0...0.0.0..00.....0..0.0..00...0.....00..0.0......000..0...0....0000
.00..0....0.0.0....0....000.0....000..00.0.0..0..00............00.00...00...
...000.00.00...00.000...000.0.....00.....0.........0..............00..0.0...
.0..0.0.000........00.........000.00.0....00.......0.0..........0.0...0.....
0....0.....0....................0..0.0..........................0...0.0.....
0....0.....0....................0..0.0..........................0...0.0.....
.0..0.0.000........00.........000.00.0....00.......0.0..........0.0...0.....
...000.00.00...00.000...000.0.....00.....0.........0..............00..0.0...
.00..0....0.0.0....0....000.0....000..00.0.0..0..00............00.00...00...
.000....0...0.0.0..00.....0..0.0..00...0.....00..0.0......000..0...0....0000
........0......000.00...0.0....0...0...0.0....0....0......00..00.0.......0.0
........0.0......0.00.0.........0.000..0.0.....00.0.0.00....0.0.............
.........0..........00..00.........00...0......00.00..0000.00...............
.....................0..............................0...0.0.0...............
```

Here are more period 3 spaceships found by the exhaustive search. The first two are rather small, whereas the right one is much larger. I call the one the left the "dart," and the middle one the "brain" because of their appearances.

Three more period 3 spaceships (speed c/3):

```
........0.      .00........      ........0.0......................
.......0.0      0..0.....00      ........0...000..................
......00..      000...000..      ......00.....00..................
.........0      0..0.0000..      ......00...0......0........00....
.....0...0      .000...0...      .........0.00..00.0.......000....
..0..0....      .0..000....      .....0...0......0..00.0.0..0.....
.0.0..0000      ...0....00.      ..0..0......0...0000...00..00...0
0..0......      ...00000.0.      .0.0..000000........0..0..00..000
.0.0..0000      ...........      0..0..................0...00..0..
..0..0....      ...00000.0.      .0.0..000000........0..0..00..000
.....0...0      ...0....00.      ..0..0......0...0000...00..00...0
.........0      .0..000....      .....0...0......0..00.0.0..0.....
```

```
......00..      .000...0...     .........0.00..00.0.......000....
.......0.0      0..0.0000..     ......00...0......0........00....
........0.      000...000..     ......00.....00..................
                0..0.....00     ........0...000..................
                .00........     ........0.0......................
```

The large spaceship on the right is important for the following reason: Whenever a spaceship is found which appears to be composed of components which are only loosely interacting (as in the above spaceship), then a good thing to try is to remove the components from the back end, and see what happens to the spaceship. In almost all cases, the ship will be destroyed. However, occasionally this doesn't occur, and something interesting will happen. (The best result is that a puffer engine might be found). In the case of the above spaceship, removing the tail component creates a period 9 spaceship, as shown below.

Period 9 spaceship (speed c/3):

```
........0.0..................
........0...000..............
......00.....00..............
......00...0......0........00
.........0.00..00.0.......000
.....0...0......0..00.0.0..0.
..0..0......0...0000...00..00
.0.0..000000........0..0..00.
0..0..................0...00.
.0.0..000000........0..0..00.
..0..0......0...0000...00..00
.....0...0......0..00.0.0..0.
.........0.00..00.0.......000
......00...0......0........00
......00.....00..............
........0...000..............
........0.0..................
```

The spaceship creates a blinker at the back which unfortunately reacts with the tail again, and gets eaten. Along with some tagalongs which have the same tail end as this ship, this is the only method known to make a period 9 spaceship.

Following are two other small tagalongs which turn the period 9 ship back into a period 3 spaceship. Here the rightmost 3 columns from the spaceship above have been extracted, with the new tagalongs appended.

Alternative small tagalongs to make the period 9 spaceship into period 3:

```
.......0.       ........0.
......0.0       .......0.0
.00..00..       .00....0..
000...0..       000...0..0
.0....00.       .0....000.
```

```
.00..0.0.      .00..0....
00..000..      00..000...
00..0....      00..0.....
00..000..      00..000...
.00..0.0.      .00..0....
.0....00.      .0....000.
000...0..      000...0..0
.00..00..      .00....0..
......0.0      .......0.0
.......0.      ........0.
```

The large spark in the period 9 spaceship is useful. Running a LWSS into it can produce various debris. One of these reactions produces a loaf. When the loaf is properly hit with other LWSSs, it can be pulled backwards. This mechanism was found by Dean Hickerson, and is shown below.

Period 9 spaceship turns LWSS into a loaf which is then pulled backwards:

```
........00...0............................................................
.......000....0...........................................................
......0...000.............................................................
.....00.0.00.0...0.........0..............................................
......0.0......000........00..............................................
.....000..0....0..00.0.00.0...............................................
..0.00.0........0...000...0..............00............................00.
00....000000....0..00.....0.............0000...........00.............0000
00..................00....0............00.00..........00.00..........00.00
00....000000....0..00.....0.............00......0..0...0000...........00..
..0.00.0........0...000...0.....0000...........0........00....0000........
.....000..0....0..00.0.00.0.....0...0..........0...0..........0...0.......
......0.0......000........00....0..............0000...........0...........
.....00.0.00.0...0.........0.....0..0..........................0..0.......
......0...000.............................................................
.......000....0...........................................................
........00...0............................................................
```

Dean used a reaction like the above to construct another sawtooth pattern. In this sawtooth pattern, salvos of two LWSS are repeatedly shot at the receding period 9 spaceship. When the first LWSS reaches the period 9 ship, it is turned into a loaf. The loaf is then pulled back by the "tractor beam" of further LWSS reactions until it reaches the salvo gun where the loaf is deleted. The cycle is then repeated, but with more salvos needed since the period 9 spaceship has receded further.

Here are some tagalongs for the period 9 spaceship, most of which turn the spaceship into period 3. Like the other spaceships, there are many of these tagalongs and the following is only a selection.

The following shows an unusual two bit spark at the back.

Period 3 spaceship with tagalong (speed c/3):

```
........0.0............................................0........
........0...000...................000..............0.00.0.......
......00.....00...................00...0...0...00.0.000.0.......
......00...0......0........00.......000.0.00...00.0.............
.........0.00..00.0.......000.....0..00....0.0..00.000...0......
.....0...0......0..00.0.0..0..........00.00..00000..0....0......
..0..0......0...0000...00..00..0000.0..0.........00..00..000....
.0.0..000000........0..0..00..000.......000000000.0.0.......0...
0..0..................0...00..0.....................000...00..00
.0.0..000000........0..0..00..000.......000000000.0.0.......0...
..0..0......0...0000...00..00..0000.0..0.........00..00..000....
.....0...0......0..00.0.0..0..........00.00..00000..0....0......
.........0.00..00.0.......000.....0..00....0.0..00.000...0......
......00...0......0........00.......000.0.00...00.0.............
......00.....00...................00...0...0...00.0.000.0.......
........0...000...................000..............0.00.0.......
........0.0............................................0........
```

The two bit spark in the above spaceship can be replaced by a small tagalong that can be repeatedly attached to itself (in its next phase). But that small tagalong always needs terminating with the final tagalong shown here.

Period 3 spaceship with repeatable and terminating tagalongs (speed c/3):

```
........0.0............................................0....................
........0...000...................000..............0.00.0...................
......00.....00...................00...0...0...00.0.000.0...................
......00...0......0........00.......000.0.00...00.0.........................
.........0.00..00.0.......000.....0..00....0.0..00.000...0..............0.0.
.....0...0......0..00.0.0..0..........00.00..00000..0....0.......0.0....00.0
..0..0......0...0000...00..00..0000.0..0.........00..00..000...00.0..0....
.0.0..000000........0..0..00..000.......000000000.0.0.......0..0.0...00....
0..0..................0...00..0.....................000...00..000.00..0.....
.0.0..000000........0..0..00..000.......000000000.0.0.......0..0.0...00....
..0..0......0...0000...00..00..0000.0..0.........00..00..000...00.0..0....
.....0...0......0..00.0.0..0..........00.00..00000..0....0.......0.0....00.0
.........0.00..00.0.......000.....0..00....0.0..00.000...0..............0.0.
......00...0......0........00.......000.0.00...00.0.........................
......00.....00...................00...0...0...00.0.000.0...................
........0...000...................000..............0.00.0...................
........0.0............................................0....................
```

The following tagalong ends in a tail which has the same shape as the base ship, and therefore can be repeatedly attached to itself. Because of that special tail, this becomes a period 9 spaceship.

Period 3 spaceship with repeatable period 9 tagalong (speed c/3):

```
........0.0....................................................
........0...000................................................
......00.....00...................................0............
```

```
......OO...O......O........OO................OOO.O.O..O.......O
.........O.OO..OO.O.......OOO..........O.O.O...O..OOO.O......OO
.....O...O......O..OO.O.O..O...OO.....OOOO.OO.....OO.O.OO.OO.O.
..O..O......O...OOOO...OO..OO...O....OO......O..O.OO..O.OO...O.
.O.O..OOOOOO........O..O..OO.O....O..OO......O.O....O.OO.....O.
O..O..................O...OO.O...O..O...................O....O.
.O.O..OOOOOO........O..O..OO.O....O..OO......O.O....O.OO.....O.
..O..O......O...OOOO...OO..OO...O....OO......O..O.OO..O.OO...O.
.....O...O......O..OO.O.O..O...OO.....OOOO.OO.....OO.O.OO.OO.O.
.........O.OO..OO.O.......OOO..........O.O.O...O..OOO.O......OO
......OO...O......O........OO................OOO.O.O..O.......O
......OO.....OO...................................O............
........O...OOO................................................
........O.O....................................................
```

Note that this tagalong uses two previously known small tagalongs in order to make the connection to the base ship. The connection between the second of those tagalongs and the new one is tenuous, and is similar to several other ships and tagalongs. But the spacing between the two points of contact makes it difficult to connect the tagalong to them. The following is the best that has been found. Here two turtle ships plus wicktrailers are used to pull the tagalong.

Alternate attachment of period 9 tagalong to period 3 spaceships (speed c/ 3):

```
...................O................................
.................OO.................................
.OOO.......O.....OO.........O.O.....................
.OO..O.OO.OO.......O.......OOOO.....................
...OOO....O......O...O....OO........................
.O..O.O...O...O.O...OOOO..OO........................
O....O....O..O.OO...O.O..O..........................
O....O....O..O.OO...O.O..O..........................
.O..O.O...O...O.O...OOOO..OO...........O............
...OOO....O......O...O....OO......OOO.O.O..O.......O
.OO..O.OO.OO.......O.......OOOO.O...O..OOO.O......OO
.OOO.......O.....OO.........O.O.OO.....OO.O.OO.OO.O.
.................OO...............O..O.OO..O.OO...O.
...................O..............O.O....O.OO.....O.
.............................................O....O.
...................O..............O.O....O.OO.....O.
.................OO...............O..O.OO..O.OO...O.
.OOO.......O.....OO.........O.O.OO.....OO.O.OO.OO.O.
.OO..O.OO.OO.......O.......OOOO.O...O..OOO.O......OO
...OOO....O......O...O....OO......OOO.O.O..O.......O
.O..O.O...O...O.O...OOOO..OO...........O............
O....O....O..O.OO...O.O..O..........................
O....O....O..O.OO...O.O..O..........................
.O..O.O...O...O.O...OOOO..OO........................
...OOO....O......O...O....OO........................
.OO..O.OO.OO.......O.......OOOO.....................
.OOO.......O.....OO.........O.O.....................
.................OO.................................
...................O................................
```

The above construction can be widened by repeatedly adding another turtle ship, wicktrailer, and tagalong in a similar manner. This gives a spaceship with multiple period 9 sparks at the back which are closer together than can be accomplished using multiple copies of the original period 9 spaceship.

The following shows two more tagalongs of the period 9 spaceship. (The second one begins at the large gap near the end of the ship, and is 10 columns long.) Without the final tagalong, a single spark is produced at the center of the back. With the final tagalong, that spark is suppressed. The final tagalong shares a property with one of the period 2 tagalongs in my previous article, in that cells are turned OFF by the rest of the spaceship, instead of cells being turned ON. The final tagalong also has a spectacular set of parallel sparks.

Period 3 spaceship with two tagalongs (speed c/3):

```
........O.O...............................................................
........O...OOO...................OOO.............OOOO..O.O.......O.......
......OO.....OO...................OO...O...O...OO...O..OO.O.OO..OO........
......OO...O......O........OO.......OOO.O.OO...OO.O.............OO..O.....
.........O.OO..OO.O.......OOO.....O..OO....O.O..OO.OOOOOOOO.........O...OO
.....O...O......O..OO.O.O..O..........OO.OO..OOOOO..O...O....O..O.O.O.O.O.
..O..O......O...OOOO...OO..OO..OOOO.O..O.........OO..OO...OO....O......OO.
.O.O..OOOOOO........O..O..OO..OOO.......OOOOOOOOO.O.O.....OO....OOOOOOO.O.
O..O..................O...OO..O.....................OOO....O............OO
.O.O..OOOOOO........O..O..OO..OOO.......OOOOOOOOO.O.O.....OO....OOOOOOO.O.
..O..O......O...OOOO...OO..OO..OOOO.O..O.........OO..OO...OO....O......OO.
.....O...O......O..OO.O.O..O..........OO.OO..OOOOO..O...O....O..O.O.O.O.O.
.........O.OO..OO.O.......OOO.....O..OO....O.O..OO.OOOOOOOO.........O...OO
......OO...O......O........OO.......OOO.O.OO...OO.O.............OO..O.....
......OO.....OO...................OO...O...O...OO...O..OO.O.OO..OO........
........O...OOO...................OOO.............OOOO..O.O.......O.......
........O.O...............................................................
```

Finally I shall give a few results from the search that are really large spaceships on their own. This is because they were found from a slightly modified period 9 spaceship.

The following spaceship has an interesting "square" shaped component near the back with a cavity in the back. This cavity must be filled with something or the ship will not work. In this case, it is filled with a copy of the dart spaceship. This is an example of a "pushalong" instead of a tagalong. That is, an object that has to have a following spaceship instead of a leading spaceship. The following spaceship's purpose here is simply to prevent some cells from being turned ON.

Large period 3 spaceship with embedded "dart" spaceship (speed c/3):

```
........O.O.............................................
........O...OOO.....................O..OO..O.O.O......O.
......OO.....OO..........OOO......OO...OO..O.OOOO....O.O
......OO...O......O......OO.......OO......OO...OO...O..O
.........O.OO..OO.O........O..O.....OOOOOO...........O..
.....O...O......O..OO.O.OO.O...O..O....O...O........OOOO
..O..O......O...OOOO...OO..OOO.....OO...OOOO.....O.OO.O.
.O.O..OOOOOO........O..O..OOO.OOO..O.......O...OO....OOO
```

```
0..0..................0...00......0........0...00.......
.0.0..000000........0..0..000.000..0.......0...00....000
..0..0......0...0000...00..000.....00...0000.....0.00.0.
.....0...0......0..00.0.00.0...0..0....0...0........0000
.........0.00..00.0........0..0.....000000...........0..
......00...0......0......00.......00......00...00...0..0
......00.....00..........000......00...00..0.0000....0.0
........0...000.....................0..00..0.0.0......0.
........0.0.............................................
```

The following shows the void in the square component being filled with a non-spaceship, and reacting with it more substantially. This ends in the period 9 tail.

Very large period 9 spaceship (speed c/3):

```
........0.0...........................................................
........0...000.....................0..00..0.0........................
......00.....00..........000......00...00..0.0000.....0...000.........
......00...0......0......00.......00......00.........00...000........0
.........0.00..00.0........0..0.....000000......0..00.......00......00
.....0...0......0..00.0.00.0...0..0....0...0....0..000....0..000.00.0.
..0..0......0...0000...00..000.....00...0000...0..0...000......00...0.
.0.0..000000........0..0..000.000..0.......0..000..000....00.00.....0.
0..0..................0...00......0........0..0...............00....0.
.0.0..000000........0..0..000.000..0.......0..000..000....00.00.....0.
..0..0......0...0000...00..000.....00...0000...0..0...000......00...0.
.....0...0......0..00.0.00.0...0..0....0...0....0..000....0..000.00.0.
.........0.00..00.0........0..0.....000000......0..00.......00......00
......00...0......0......00.......00......00.........00...000........0
......00.....00..........000......00...00..0.0000.....0...000.........
........0...000.....................0..00..0.0........................
........0.0...........................................................
```

The following shows yet another way to fill the void. This ends in the same two bit spark that was found in one of the previously shown ships.

Period 3 spaceship (speed c/3):

```
........0.0.....................................................00......
........0...000.....................0..00..0.0.0.............0....0.....
......00.....00..........000......00...00..0.0000........00.0.0.0.......
......00...0......0......00.......00......00...00.......0...0...0.......
.........0.00..00.0........0..0.....000000.............0.....000........
.....0...0......0..00.0.00.0...0..0....0...0..........0000......0.00....
..0..0......0...0000...00..000.....00...0000...0.....0......0.00...000..
.0.0..000000........0..0..000.000..0.......0..0.0..0.000000.0.0....0..0.
0..0..................0...00......0........0..0...00..........0......000
.0.0..000000........0..0..000.000..0.......0..0.0..0.000000.0.0....0..0.
..0..0......0...0000...00..000.....00...0000...0.....0......0.00...000..
.....0...0......0..00.0.00.0...0..0....0...0..........0000......0.00....
```

```
.........0.00..00.0........0..0.....000000.............0.....000........
......00...0......0......00.......00......00...00.......0...0...0.......
......00.....00..........000......00...00..0.0000........00.0.0.0.......
........0...000.....................0..00..0.0.0.............0....0.....
........0.0.....................................................00......
```

Finally, here is a slightly different spaceship with a tagalong. Without the tagalong, the same two bit spark is produced as in the previous ship. This tagalong has yet another size of a back end similar to the turtle spaceship.

Period 3 spaceship with tagalong (speed c/3):

```
........0.0...................................0..................0.........
........0...000...........................0.00..................0.0.....0.0
......00.....00..........000..........0.00..0.0.................00......0..
......00...0......0......00..........00.00...0............00....0...0.00...
.........0.00..00.0........0..0....0..0...00000..........0.0.....000..00...
.....0...0......0..00.0.00.0...0...000.......0.00.......00.00...0....00.0..
..0..0......0...0000...00..000.........00..00.....0.....000.00....00000.0.0
.0.0..000000........0..0..000.000000000.0..0....0....0..00..0.000...0......
0..0..................0...00...............00....00..00...........000......
.0.0..000000........0..0..000.000000000.0..0....0....0..00..0.000...0......
..0..0......0...0000...00..000.........00..00.....0.....000.00....00000.0.0
.....0...0......0..00.0.00.0...0...000.......0.00.......00.00...0....00.0..
.........0.00..00.0........0..0....0..0...00000..........0.0.....000..00...
......00...0......0......00..........00.00...0............00....0...0.00...
......00.....00..........000..........0.00..0.0.................00......0..
........0...000...........................0.00..................0.0.....0.0
........0.0...................................0..................0.........
```

No method has been found to make a puffer train from period 3 spaceships. But the next best thing is something which I call a pseudo-puffer. A pseudo-puffer creates debris from a period 3 spaceship, but not by itself. It must be "fed" some input in the form of a c/2 spaceship stream. It can then turn that input into debris which can be manipulated by sparks from other period 3 spaceships.

The following is a pseudo-rake. (A rake is a puffer which produces a wave of gliders). In this construction, the reaction that converts a glider into a LWSS was found by Bill Gosper, and the reaction that converts 3 gliders into a LWSS was found by David Buckingham.

This picture is compressed to prevent lines which are too long. Here each dollar sign should be replaced by 10 periods to reconstruct the full picture.

Pseudo-rake producing gliders from spaceship stream (speed c/3):

```
$$$$$$$$$$$.....0.0..00$$
$$$$$$$$$$$....0...0.000....00$...
......0$$$$$$$$$$........0......00...00$...
....00$$$$$$$$..0...00$$..00000.0$.........
```

```
....OO$$$$$$$$....OO....OO.O.OOO$$.....OOO$$
......O$$$$$$$...OO....O....OOO$$$$........
....O$$$$$$$$$.O...O$$........OOO$$
....O.O$$$$$$$$$OOO$$......OOOOO.O$.....OO..
....O.O$$$$$$$$$$$........O......OO$....OO..
.....O$$$$$$$$$.OOO$$....O...O.OOO$.........
...OO$$$.....OO$$$$....O...O$$....O.O..OO$$
....O$$.....OO.......O.O$$$........OO....O....OOO$.....O$$$..
....OOO$$...OO......OO.O$$$........OO....OO.O.OOO$......OO$$$
.....O$$$...OO$$......OO$.........O...OO$.....OO$$$.
.......O$$$..O$$......O.O.......OO$$$$$$...
.....OO$$$$$$..O.......OO$$$$$$...
.....OO$$$...O$$......OOO$$$$$$$..
$$$.........OO$$$$$$$$$$.
..OOO$$.....OO......OO.O$$$$$$$$$$
..OO..OO$$..OO.......O.O$$$$$$$$$$
....O$$$.....OO.......O.O$.....OOO$$$$$$$..
...OO$$$$....OO$........O.......OO$$$$$..OO.....OO..
...OO$$$$.....O$......O.O.......OO$$$$$.O..O...O..O.
...O..O$$$$$$OO$$$$$.O.O$OO.OO....
.......O$$$$$$$$$$$...OO.........O.O.O.O...
....OOOOO$$$$$$$$$$$..O$O.O.O.O...
........OO$$$$$$$$$$$$O.........O.
........OO$$$$$$$$.O..O$$$....O$.O
.....OOOO$$$$$........OOOO$.........O$$..OOOO$$.....
....O...O$$$$$........O...O$........O...O$........O...O$.....OO.OO....
....OOO$$$$$$O$$..OOOO$.........O$.......O..O.O..O..
....O..O$$$$$$O..O$$$$..O..O$...OOO...OOO..
.....O$$$$$$$$$$$$$......
.....O.O$$$$$$$$$$$$$....
......O$$$$......OOO$$$$$$$$..OO..
$$$$$...O$$$$$$$$....OO..
$$$$$....O$$$$$$$$.......
$$$$$$$$$$$$$$..
$$$.........OOO$$$$$$$$$$
$$$$.O$$$$$$$$$$
$$$$O$$$$$$$$$$.
$$$$$$$$$$$$$$..
$$$$$$$$$$$$$$..
$$$$$$$$$$$$$$..
$$$$$$$$$$$$$$..
$$$$$$.....OO$$$$$$$.....
$$$$$$.....O.O$$$$$$$....
$$$$$$.....O$........OO$$$$$......
$OO$$$$$$$.O$$$$$........
OO.......O.O$......OO$$$$$..O..OO$OO$$$$...
OO......OO.O$.....O.O$$$....O$.......O..O$.OO$$$$...
.........OO$........O.......OO$$...O..O$......O.O$$$$$.......
$O$$.....OO.OO......OO.OO$OOOOO$......OO$$$$$.......
$$$.......O..O......OO.OO$OOO.OO$$$$$$$....
$O$$......O..O$$..OO.O$......OO$$$$$.......
.........OO$$.......OO$$....OO$......O.O$$$$$.......
OO......OO.O$$$$$$$O..O$.OO$$$$...
OO.......O.O$$......OO$$....OO$......O..OO$OO$$$$...
```

```
$00$$.....0..0$$..00.0$......0$$$$$........
$$$.......0..0......00.00$000.00$......00$$$$$......
$$$......00.00......00.00$00000$$$$$$$.....
$$$.......00$$...0..0$$$$$$$......
$$$$$$....0$$$$$$$.......
```

Gliders from several of these pseudo-rakes can be collided to produce some desired puffer output. In addition, a glider or the result of a collision can be perturbed by using some of the period 3 spaceships. For example, the following shows the brain spaceship perturbing a glider to produce a honey farm. This can be added to the pseudo-rake above to form a row of honey farms.

Period 3 spaceship perturbing a glider to make a honey farm:

```
.............0.
............0..
............000
...............
...............
..00...........
.0..0.....00...
.000...000.....
.0..0.0000.....
..000...0......
..0..000.......
....0....00....
....00000.0....
...............
....00000.0....
....0....00....
..0..000.......
..000...0......
.0..0.0000.....
.000...000.....
.0..0.....00...
..00...........
```

No period 3 spaceship with really good accessible sparks has been found. For perturbing purposes, such sparks should be on the edge of the spaceship so that debris can be perturbed as the spaceship passes by. But it appears that period 3 isn't large enough for such sparks to be far enough away from the ship to be useful for many things. Most perturbations end up destroying the spaceship. Compare this with the MWSS and HWSS, which are much more effective at perturbing things successfully.

The next article in this series will deal with two classes of the period 4 spaceships, in particular the c/4 orthogonal and diagonal period 4 spaceships.

4 Spaceships of Period 4

This is the fourth in a series of articles concerning Conway's Game of Life. In this article, I will show the results for two of the classes of period 4 spaceships and give a couple of applications of them.

Period 4 is the smallest period for which more than one speed is allowed for spaceships, and is the smallest period for which diagonal spaceships can exist. Period 4 diagonal spaceships must travel at c/4. Orthogonal period 4 spaceships can travel at either the speeds of c/2 or c/4. The new c/2 spaceships will be covered in the next article.

The diagonal period 4 spaceships can be covered quickly. Besides the glider, only one basic diagonal period 4 spaceship is known. This was found in December 1989 by Dean Hickerson, and is shown below.

Period 4 spaceship (symmetrical, diagonal to lower right, speed c/4):

```
....O..O..........
....OOO.O.........
...OO.............
..O.OO...O........
OOOO...OO.O.......
.O.O...OOOO.......
.O.......O........
O...OO....O.OO....
.O..OO......O.O...
...O.OO.........O.
....OO.O.....O..O.
...............OO.
.......OO........O
.......O..O....O.O
........O.......OO
...........O.O....
.........OOO..O...
............OOO...
```

Robert Wainwright found some small tagalongs that can be attached to one or two copies of this spaceship. These are shown below.

Pair of period 4 spaceships with several tagalongs (diagonal to lower right, speed c/4):

```
....................OOO...........
..................................
......OO............OO.O..........
......OO...O........O..OO.........
.........O..O........OO..O........
............O..O.OO..OO..OO.......
.........O.O...O.O.OO....OO.......
..........O....O...OO....O..O.....
```

```
.................OO.......O..O....
..................O........O...O..
..........O..O.....OOOO......O..O.
..........OOO.O.....OO.O......O..O
.........OO.............O.....O...
........O.OO...O......O..........O
......OOOO...OO.O......O.O.....OOO
..OO...O.O...OOOO.........OO......
..O....O.......O........O....O....
O.O...O...OO....O.OO.....O...O....
.OO....O..OO......O.O.....O.OO....
.........O.OO.........O...........
..........OO.O.....O..O...........
.....................OO...........
.............OO........O..........
.............O..O...O.O..........
..............O.......OO..........
.................O.O..............
...............OOO..O.............
..................OOO.............
```

At the left is a tagalong that can be attached to a single copy of the diagonal spaceship. At the upper left are two tagalongs. The one nearest the two copies of the diagonal spaceship requires sparks from both of those ships to survive. The block in the upper left is a tagalong to that tagalong. None of these tagalongs are extensible.

Now I shall turn to the main topic of this article, which is the c/4 period 4 orthogonal spaceships. From now on, all spaceships will be orthogonal ones, and I will not explicitly state this all of the time. I will also use the word "slow" to describe c/4 spaceships where necessary, since the period alone is not sufficient to force the speed.

In December 1989 Dean Hickerson found the first orthogonal c/4 spaceship. Finding it required Dean to use a manual "sliding window" search method in order to keep the number of rows in the search small enough. This spaceship is shown below.

First slow period 4 orthogonal spaceship found (speed c/4):

```
.................................OO
.................O...............OO
.......OO.......OOOOOO...........O.
.......O..OOO.O.......OO......O..O.
......O..........O..O.OO...O....O..
.....OOOO.O.O....O..OOO...OO.OOO.O
.....OO......OOO.......OOO......OO.
....O..............................
.OOO.O.............................
O..O...............................
.OOO.O.............................
....O..............................
.....OO......OOO.......OOO......OO.
.....OOOO.O.O....O..OOO...OO.OOO.O
```

```
......O..........O..O.OO...O....O..
.......O..OOO.O.......OO......O..O.
.......OO.......OOOOOO...........O.
.................O...............OO
.................................OO
```

Dean Hickerson then found a small tagalong to that first spaceship. The following shows one copy of this tagalong attached to one side of the base ship. (Another copy could be attached to the other side to preserve the symmetry.) This tagalong is not extensible.

Period 4 spaceship with small tagalong (speed c/4):

```
.................................OO......O.O.
.................O...............OO.....OOO.O
.......OO.......OOOOOO...........O.....OO....
.......O..OOO.O.......OO......O..O..O...O....
......O..........O..O.OO...O....O...O..O.....
.....OOOO.O.O....O...OOO...OO.OOO.O.O...O....
.....OO......OOO.......OOO......OO...OOO.....
....O...................................OO....
.OOO.O.......................................
O..O.........................................
.OOO.O.......................................
....O........................................
.....OO......OOO.......OOO......OO...........
.....OOOO.O.O....O...OOO...OO.OOO.O..........
......O..........O..O.OO...O....O............
.......O..OOO.O.......OO......O..O...........
.......OO.......OOOOOO...........O...........
.................O...............OO..........
.................................OO..........
```

Unlike the period 2 and period 3 spaceships, Dean did not discover an infinite number of these spaceships, and no grammar was found. The reason for this was that the current search programs begin to bog down at period 4 when a reasonable number of rows is searched. There do not appear to be any really small period 4 c/4 spaceships and so finding them requires a long search. This is particularly true when looking for short, wide spaceships to construct a grammar from. No such search has been successful, only spaceship searches for thin long spaceships have succeeded.

Since Dean's initial search, the only person who has had success in finding new c/4 spaceships has been Hartmut Holzwart. He has done this with a copy of my search program which he has modified to increase its speed and capabilities. All of the basic spaceships in the remainder of this article and all but one of the tagalongs were found by Hartmut Holzwart. For this reason, I do not need to name the discoverer of each spaceship.

To show how progress in Life can jump by huge bounds in a small time, all of the remaining results in this article were found since July 1992.

Hartmut Holzwart's first new period 4 c/4 spaceship was the following. It has the same front as Dean's spaceship, but then quickly diverges. The tail of the ship has feet which appear often in other ships.

Second slow period 4 orthogonal spaceship discovered (speed c/4):

```
....................0...................
.......00........0000........00.........
.......0..000..0000.....0000.0..........
......0.......00..0....0.......0.....0..
.....0000.0.0...0..0....00....0000.0..00
.....00........0..00.0..0..0.0.0.000....
....0..........00.0.........0..0........
.000.0.....0.0.....0.0.000......00......
0..0.......0.........0.000..............
.000.0.....0.0.....0.0.000......00......
....0..........00.0.........0..0........
.....00........0..00.0..0..0.0.0.000....
.....0000.0.0...0..0....00....0000.0..00
......0.......00..0....0.......0.....0..
.......0..000..0000.....0000.0..........
.......00........0000........00.........
....................0...................
```

Just a few days later the following much smaller spaceship was found. This is dramatically different than the previous spaceships, but has the same tail as the previous spaceship. It has a very unlikely looking front end.

Smaller period 4 spaceship (speed c/4):

```
.......0.0...........
......0...0.........0
.....00...0......0000
.0...00..0.00....000.
.0..........000.0.0..
00..0........0...00..
.0.00...........000..
.0.00................
.0.00...........000..
00..0........0...00..
.0..........000.0.0..
.0...00..0.00....000.
.....00...0......0000
......0...0.........0
.......0.0...........
```

Following are some more spaceships which have the same front end, but the spaceship is slightly modified at the back to connect to what appear to be tagalongs. However, even though these back parts are only connected to the front parts by a blinker, they are necessary and so are not really tagalongs.

Several period 4 spaceships with non-tagalongs (speed c/4):

```
.........0..........................
.......0..00......0...............00
......0..0000....0.0......0.0..000..
.0...00...00.00.0..0.....0...0.00.0.
.0....00....0000.0.......0..000.....
00..0.........00.0.0.....0.0..00....
.0.00........000...0.....0.0..00.00.
.0.00.....000000..00.000.0..0.......
.0.00........000...0.....0.0..00.00.
00..0.........00.0.0.....0.0..00....
.0....00....0000.0.......0..000.....
.0...00...00.00.0..0.....0...0.00.0.
......0..0000....0.0......0.0..000..
.......0..00......0...............00
.........0..........................
```

```
.........0..............................00.....
.......0..00......0....................0.....00
......0..0000....0.0......0.0....0000.00.00..00
.0...00...00.00.0..0.....0...0....0..00.0..00.0
.0....00....0000.0.......0..0000.00.0.......0..
00..0.........00.0.0.....0.0..00..0.0......0..0
.0.00........000...0.....0.0..000.0.........0.0
.0.00.....000000..00.000.0..0...00.............
.0.00........000...0.....0.0..000.0.........0.0
00..0.........00.0.0.....0.0..00..0.0......0..0
.0....00....0000.0.......0..0000.00.0.......0..
.0...00...00.00.0..0.....0...0....0..00.0..00.0
......0..0000....0.0......0.0....0000.00.00..00
.......0..00......0....................0.....00
.........0..............................00.....
```

```
.........0............................
.......0..00......0...................
......0..0000....0.0......0.0.........
.0...00...00.00.0..0.....0...0..0.0...
.0....00....0000.0.......0..00000...0.
00..0.........00.0.0.....0.0..0......0
.0.00........000...0.....0.0..000000.0
.0.00.....000000..00.000.0..0.........
.0.00........000...0.....0.0..000000.0
00..0.........00.0.0.....0.0..0......0
.0....00....0000.0.......0..00000...0.
.0...00...00.00.0..0.....0...0..0.0...
......0..0000....0.0......0.0.........
.......0..00......0...................
.........0............................
```

A very small tagalong was found that can be attached to the back of the last spaceship shown above. This is shown below.

Period 4 spaceship with small tagalong (speed c/4):

```
.........0...................................
.......0..00......0..........................
......0..0000....0.0......0.0................
.0...00...00.00.0..0.....0...0..0.0..........
.0....00....0000.0.......0..00000...0........
00..0.........00.0.0.....0.0..0......0.00....
.0.00........000...0.....0.0..000000.0.00....
.0.00.....000000..00.000.0..0.............000
.0.00........000...0.....0.0..000000.0.00....
00..0.........00.0.0.....0.0..0......0.00....
.0....00....0000.0.......0..00000...0........
.0...00...00.00.0..0.....0...0..0.0..........
......0..0000....0.0......0.0................
.......0..00......0..........................
.........0...................................
```

The presence of the two repeated blinkers in the above spaceship raises the possibility that the back section of the spaceship might be repeatable, and therefore create an arbitrarily long spaceship. Unfortunately, this does not work.

However, the back end of the small tagalong does provide a spark for perturbing chasing c/2 spaceships (similar to the period 3 spaceships in the previous article). Dean Hickerson found the following reaction which turns a HWSS into a loaf. As described in my previous article, the loaf can be pulled backwards by a stream of LWSSs, and therefore this construction could be used as part of a sawtooth pattern.

Slow period 4 spaceship turns following HWSS into a loaf:

```
.........0............................................
.......0..00......0...................................
......0..0000....0.0......0.0.....................00..
.0...00...00.00.0..0.....0...0..0.0.............0....0
.0....00....0000.0.......0..00000...0..........0......
00..0.........00.0.0.....0.0..0......0.00......0.....0
.0.00........000...0.....0.0..000000.0.00......000000.
.0.00.....000000..00.000.0..0.............000.........
.0.00........000...0.....0.0..000000.0.00.............
00..0.........00.0.0.....0.0..0......0.00.............
.0....00....0000.0.......0..00000...0.................
.0...00...00.00.0..0.....0...0..0.0...................
......0..0000....0.0......0.0.........................
.......0..00......0...................................
.........0............................................
```

The following two spaceships show another slightly modified front part, with a different tenuous connection to the back parts. Once again, the back parts are required and are therefore not tagalongs.

Two more period 4 spaceships with non-tagalongs (speed c/4):

```
.......0.0...........................
......0...0.........0................
.....00...0.......0..00...00.........
.0...00..0.00...000......000....00...
.0..........000..0......00..0..000...
00..0........0...0......0....00...000
.0.00...........0....0...00...00000.0
.0.00...........0....0...00..........
.0.00...........0....0...00...00000.0
00..0........0...0......0....00...000
.0..........000..0......00..0..000...
.0...00..0.00...000......000....00...
.....00...0.......0..00...00.........
......0...0.........0................
.......0.0...........................
```

```
.......0.0.............................00......
......0...0.........0...............0..00......
.....00...0.......0..00...00....0..0..0.00.0000
.0...00..0.00...000......000...0.00...0........
.0..........000..0......00..0....0.00......0...
00..0........0...0......0....00............000.
.0.00...........0....0...00...0..00........000.
.0.00...........0....0...00.....0..............
.0.00...........0....0...00...0..00........000.
00..0........0...0......0....00............000.
.0..........000..0......00..0....0.00......0...
.0...00..0.00...000......000...0.00...0........
.....00...0.......0..00...00....0..0..0.00.0000
......0...0.........0...............0..00......
.......0.0.............................00......
```

The back parts of these spaceships are similar to the back parts of the previously shown spaceships. So these front and back parts are actually "components" that can be used for either of the two types of front end.

The following is an interesting spaceship with what appear to be tagalongs, but once again they are required for the ship to to work. They could be considered components, but very few spaceships reuse them.

Period 4 spaceship (speed c/4):

```
...........0..............
.........0..00...00.....00
.......000......0000...0..
```

```
.0..0...0.......0...0.00..
.0..0.0.00......0000..00..
00........0.00..0..0...0..
.0.00.0000.00.0..00.....00
.0..........00............
.0.00.0000.00.0..00.....00
00........0.00..0..0...0..
.0..0.0.00......0000..00..
.0..0...0.......0...0.00..
.......000......0000...0..
.........0..00...00.....00
...........0..............
```

Here are two more spaceships with the same beginning. The first one is interesting because of the large hole in its middle.

Period 4 spaceships (speed c/4):

```
..............0...0........................
............0..0..0.....000.0...0..........
.........0000...00...0...0..00..0..0000.00.
.0..0...0.00.0.000..000000..000.......0...0
.0..0.0.00......00..000.0.......0...000....
00.....................0.......0....0....00
.0.00.00........................0.0..00000.
.0.........................................
.0.00.00........................0.0..00000.
00.....................0.......0....0....00
.0..0.0.00......00..000.0.......0...000....
.0..0...0.00.0.000..000000..000.......0...0
.........0000...00...0...0..00..0..0000.00.
............0..0..0.....000.0...0..........
..............0...0........................
```

```
...........0..................00..............
.........0..00...00.....00....00..............
.......000......0000...0...0..00..00..........
.0..0...0.......0...0.00....00...00.00.0......
.0..0.0.00......0000..00......0..00000.....0..
00........0.00..0..0...0...0000..0..000000..00
.0.00.0000.00.0..00.....00....0..00....0.0....
.0..........00................................
.0.00.0000.00.0..00.....00....0..00....0.0....
00........0.00..0..0...0...0000..0..000000..00
.0..0.0.00......0000..00......0..00000.....0..
.0..0...0.......0...0.00....00...00.00.0......
.......000......0000...0...0..00..00..........
.........0..00...00.....00....00..............
...........0..................00..............
```

```
............................
```

```
...........OO....O..........
..........O.OO.OO.OO.O......
.O..O..O.O.....OOOOO.....O..
.O..O.O.OO.O.O.O.OOOOOOO..OO
OO...................O.O....
.O.OO.OOOOOOOOO.............
.O..........................
.O.OO.OOOOOOOOO.............
OO...................O.O....
.O..O.O.OO.O.O.O.OOOOOOO..OO
.O..O..O.O.....OOOOO.....O..
..........O.OO.OO.OO.O......
...........OO....O..........
............................
```

The spacing between the back ends of the last spaceship above allows for a large tagalong to be attached. This tagalong reuses the back components from a spaceship previously described.

Period 4 spaceship with large tagalong (speed c/4):

```
....................................O............
...........OO....O...............OOOO....O....OO.
..........O.OO.OO.OO.O.......OO..OOO...OO....O.O.
.O..O..O.O.....OOOOO.....O......O.O......O...O.OO
.O..O.O.OO.O.O.O.OOOOOOO..OO.O...OO....OOO...O.OO
OO...................O.O......O.OOOO.O.OOO...O.O.
.O.OO.OOOOOOOOO................O.O...O........OO.
.O..............................O................
.O.OO.OOOOOOOOO................O.O...O........OO.
OO...................O.O......O.OOOO.O.OOO...O.O.
.O..O.O.OO.O.O.O.OOOOOOO..OO.O...OO....OOO...O.OO
.O..O..O.O.....OOOOO.....O......O.O......O...O.OO
..........O.OO.OO.OO.O.......OO..OOO...OO....O.O.
...........OO....O...............OOOO....O....OO.
....................................O............
```

The following spaceship could be useful because it has a spark on each edge. This spark is similar to the one produced by the MWSS, and could be used to perturb debris. (Unfortunately, that spark does not extend farther out than the front of the spaceship, so it could only perturb active debris.)

Period 4 "MWSS" style spaceship with sparks on it's edge (speed c/4):

```
.......O..OO................
......O...OO.....OOO........
.....OO......O.OOOOOOO......
.O...OO..O..OOO..OOOOO......
.O.......O......O.....O....O
OO..O....O..O.OO......O..OOO
.O.OO......O....O.....O..OO.
```

```
.0.00.......................
.0.00......0....0.....0..00.
00..0....0..0.00......0..000
.0.......0......0.....0....0
.0...00..0..000..00000......
.....00......0.0000000......
......0...00.....000........
.......0..00................
```

A small variation on the above spaceship is reminiscent of the differences between a MWSS and LWSS. If one of the three identical columns which produce the spark is removed and the back of the spaceship shifted up by a column, then the spaceship still works, but doesn't produce any spark. So this converts the "MWSS" slow period 4 spaceship into a "LWSS" slow period 4 spaceship.

Period 4 "LWSS" style spaceship with no edge spark (speed c/4):

```
.......0..00...............
......0...00.....00........
.....00......0.000000......
.0...00..0..000..0000......
.0.......0......0....0....0
00..0....0..0.00.....0..000
.0.00......0....0....0..00.
.0.00......................
.0.00......0....0....0..00.
00..0....0..0.00.....0..000
.0.......0......0....0....0
.0...00..0..000..0000......
.....00......0.000000......
......0...00.....00........
```

Unfortunately, the obvious attempt to convert the spaceship into a "HWSS" period 4 spaceship by adding another column fails. No slow period 4 spaceship is known with side sparks like the HWSS.

Hartmut found an important tagalong to the above spaceship, which is shown below. This tagalong is similar to the back end of the base ship, and so like the base ship it can have a "MWSS" style spark on its edge. There is also a "LWSS" version of this tagalong without the spark.

Period 4 spaceship with repeatable "MWSS" tagalong (speed c/4):

```
.......0..00.......................0.........
......0...00.....00..............0...........
.....00......0.000000...........0.....0......
.0...00..0..000..0000..........0.......0.....
.0.......0......0....0....0.0..0.00000.0....0
00..0....0..0.00.....0..000.0.0..0....000.0.0
.0.00......0....0....0..00....000.........0.0
```

```
.0.00........................................
.0.00......0....0....0..00....000.........0.0
00..0....0..0.00.....0..000.0.0..0....000.0.0
.0.......0......0....0....0.0..0.00000.0....0
.0...00..0..000..0000..........0.......0.....
.....00......0.000000...........0.....0......
......0...00.....00..............0...........
.......0..00.......................0.........
```

Since the tagalong ends like the base spaceship, it can be attached to itself (in the previous phase) arbitrarily often. This was the first known way to make an arbitrarily large slow period 4 spaceship. This is shown below for two copies of the tagalong to make this connection obvious.

Period 4 spaceship with two copies of "MWSS" tagalong (speed c/4):

```
.......0..00.......................0............................
......0...00.....00..............0..............................
.....00......0.000000...........0.....0...........0.............
.0...00..0..000..0000..........0.......0.........0.00000.0......
.0.......0......0....0....0.0..0.00000.0....0..000.00000.....0..
00..0....0..0.00.....0..000.0.0..0....000.0.0...0..0.0000000..00
.0.00......0....0....0..00....000.........0.0..0000......0.0....
.0.00...........................................................
.0.00......0....0....0..00....000.........0.0..0000......0.0....
00..0....0..0.00.....0..000.0.0..0....000.0.0...0..0.0000000..00
.0.......0......0....0....0.0..0.00000.0....0..000.00000.....0..
.0...00..0..000..0000..........0.......0.........0.00000.0......
.....00......0.000000...........0.....0...........0.............
......0...00.....00..............0..............................
.......0..00.......................0............................
```

The tagalong can also be attached to many of the other spaceships and tagalongs which have similar "feet." Examples of this will be shown a little later.

The following spaceship is the smallest known c/4 orthogonal spaceship. The front end is interesting for two reasons. The first reason is that it is made up of two perturbed traffic lights predecessors. The second reason is that the leading edge of this spaceship does not continually advance, but falls back in one of its generations. This is very unusual. Almost all known spaceships travel monotonically.

Smallest known slow period 4 spaceship (speed c/4):

```
..........00.0.......
......000.0.000......
..0.0..........0...00
00....00.....0...0000
..0.00..0....000.0...
........0....0.......
..0.00..0....000.0...
```

```
OO....OO.....O...OOOO
..O.O..........O...OO
......OOO.O.OOO......
..........OO.O.......
```

The back end of the small spaceship above can attach to many tagalongs. One of the most useful ones is shown below. This tagalong produces five isolated sparks at the back in one of its generations. I call this tagalong "sparky" after a comment made about it by Hartmut Holzwart.

Small period 4 spaceship with "sparky" tagalong (speed c/4):

```
..........OO.O............OO..
......OOO.O.OOO........O.OOO..
..O.O..........O...OO.O....O..
OO....OO.....O...OOOO.O...OO..
..O.OO..O....OOO.O.....OOOO.O.
........O....O.............OOO
..O.OO..O....OOO.O.....OOOO.O.
OO....OO.....O...OOOO.O...OO..
..O.O..........O...OO.O....O..
......OOO.O.OOO........O.OOO..
..........OO.O............OO..
```

As might be expected, these sparks have various uses. Dean Hickerson found that running a LWSS into these sparks can produce many different results such as a block, a blinker, traffic lights, and the R pentomino. He also found a LWSS salvo which produces the loaf needed for yet another sawtooth pattern. A simplified form of this reaction is shown below.

Period 4 spaceship turns LWSS salvo into a loaf:

```
..........OO.O............OO......................................
......OOO.O.OOO........O.OOO......................................
..O.O..........O...OO.O....O......................................
OO....OO.....O...OOOO.O...OO......................................
..O.OO..O....OOO.O.....OOOO.O.....................................
........O....O.............OOO....................................
..O.OO..O....OOO.O.....OOOO.O.....................................
OO....OO.....O...OOOO.O...OO......................................
..O.O..........O...OO.O....O......................................
......OOO.O.OOO........O.OOO....O..O..........................O..O
..........OO.O............OO...O.............................O....
...............................O...O.........................O...O
...............................OOOO..........................OOOO.
............................................OOOO..................
............................................O...O.................
............................................O.....................
.............................................O..O.................
```

The above construction produces a loaf using three LWSSs. However, in the actual sawtooth based on this reaction, that loaf is not the actual one which is pulled by the "tractor beam." In the actual sawtooth pattern, each salvo actually consists of just the first two LWSSs shown above, and the third LWSS shown is actually the first spaceship of the next salvo. Amazingly, when the next few LWSSs in more salvos are added to the above pattern, that first loaf is repositioned so that the tractor beam becomes effective.

As expected, the sparks at the back of the tagalong can be used to attach further tagalongs. Following is a relatively small tagalong that can be attached.

Period 4 spaceship with a tagalong to a tagalong (speed c/4):

```
..........................................O..OO.
..........OO.O............OO..............O..OOO
......OOO.O.OOO........O.OOO..............O....O
..O.O..........O...OO.O....O.........OOOOO......
OO....OO.....O...OOOO.O...OO..........O.OO......
..O.OO..O....OOO.O.....OOOO.O...O.OOOO..........
........O....O.............OOO...O..............
..O.OO..O....OOO.O.....OOOO.O...O.OOOO..........
OO....OO.....O...OOOO.O...OO..........O.OO......
..O.O..........O...OO.O....O.........OOOOO......
......OOO.O.OOO........O.OOO..............O....O
..........OO.O............OO..............O..OOO
..........................................O..OO.
```

Two copies of the above spaceship can be used to provide the required back end for attaching a "MWSS" tagalong. This is shown below.

Two period 4 spaceships connected by "MWSS" tagalong (speed c/4):

```
..........................................O..OO...................
..........OO.O............OO..............O..OOO..................
......OOO.O.OOO........O.OOO..............O....O..................
..O.O..........O...OO.O....O.........OOOOO........................
OO....OO.....O...OOOO.O...OO..........O.OO........................
..O.OO..O....OOO.O.....OOOO.O...O.OOOO............................
........O....O.............OOO...O......................O.........
..O.OO..O....OOO.O.....OOOO.O...O.OOOO................O...........
OO....OO.....O...OOOO.O...OO..........O.OO...........O.....O......
..O.O..........O...OO.O....O.........OOOOO..........O.......O.....
......OOO.O.OOO........O.OOO..............O....O.O..O.OOOOO.O....O
..........OO.O............OO..............O..OOO.O.O..O....OOO.O.O
..........................................O..OO....OOO.........O.O
..................................................................
..........................................O..OO....OOO.........O.O
..........OO.O............OO..............O..OOO.O.O..O....OOO.O.O
......OOO.O.OOO........O.OOO..............O....O.O..O.OOOOO.O....O
..O.O..........O...OO.O....O.........OOOOO..........O.......O.....
OO....OO.....O...OOOO.O...OO..........O.OO...........O.....O......
..O.OO..O....OOO.O.....OOOO.O...O.OOOO................O...........
```

```
........O....O.............OOO...O......................O.........
..O.OO..O....OOO.O.....OOOO.O...O.OOOO............................
OO....OO.....O...OOOO.O...OO..........O.OO........................
..O.O..........O...OO.O....O.........OOOOO........................
......OOO.O.OOO........O.OOO..............O....O..................
..........OO.O............OO..............O..OOO..................
..........................................O..OO...................
```

Another small tagalong can be attached to the sparky tagalong. This tagalong only requires a loose connection to the base ship, and so it can also be attached to many other spaceships. The following shows two copies of it attached to the sparky tagalong using two different sparks.

Period 4 spaceship with small tagalongs (speed c/4):

```
......................................O.O....
..........OO.O............OO......OOOOOOO..OO
......OOO.O.OOO........O.OOO.....OOOO.....O..
..O.O..........O...OO.O....O....OO.OO.O......
OO....OO.....O...OOOO.O...OO......O..........
..O.OO..O....OOO.O.....OOOO.O................
........O....O.............OOO...............
..O.OO..O....OOO.O.....OOOO.O................
OO....OO.....O...OOOO.O...OO.................
..O.O..........O...OO.O....O.................
......OOO.O.OOO........O.OOO.....O...........
..........OO.O............OO...OO.OO.O.......
................................OOOO.....O...
.................................OOOOOOO..OO.
.....................................O.O.....
```

Unfortunately this tagalong cannot be attached to itself. However, since it has a back end which is common to many slow period 4 spaceships, many tagalongs can be attached to two copies of it. An example of this is shown below, where the previously described "LWSS" tagalong is pulled.

Two period 4 spaceships pulling "LWSS" tagalong (speed c/4):

```
..........OO.O............OO.................................
......OOO.O.OOO........O.OOO.................................
..O.O..........O...OO.O....O.................................
OO....OO.....O...OOOO.O...OO.................................
..O.OO..O....OOO.O.....OOOO.O................................
........O....O.............OOO...............................
..O.OO..O....OOO.O.....OOOO.O................................
OO....OO.....O...OOOO.O...OO......O..............OOOO........
..O.O..........O...OO.O....O....OO.OO.O.........O....OO......
......OOO.O.OOO........O.OOO.....OOOO.....O...O.O...........O
..........OO.O............OO......OOOOOOO..OO.....O....O.OO.O
......................................O.O.....OOOO...O.O.O...
.............................................................
......................................O.O.....OOOO...O.O.O...
```

```
..........00.0............00......0000000..00.....0....0.00.0
......000.0.000........0.000.....0000.....0...0.0...........0
..0.0..........0...00.0....0....00.00.0.........0....00......
00....00.....0...0000.0...00......0..............0000........
..0.00..0....000.0.....0000.0................................
........0....0.............000...............................
..0.00..0....000.0.....0000.0................................
00....00.....0...0000.0...00.................................
..0.0..........0...00.0....0.................................
......000.0.000........0.000.................................
..........00.0............00.................................
```

The advantage of this method of connecting spaceships is that the spacing between the pairs of base spaceships can be varied to suit the tagalong which is being pulled. Another example of this is shown later.

Following are several larger tagalongs to the sparky tagalong. Most of these react substantially with the sparks and therefore cannot be moved to another base spaceship.

Several period 4 "sparky" spaceships with large tagalongs (speed c/4):

```
...........................................0..00.
..........00.0............00.....00........0..000
......000.0.000........0.000...00..........0....0
..0.0..........0...00.0....0.....00...00000......
00....00.....0...0000.0...00.....0.0...0.00......
..0.00..0....000.0.....0000.0...0.00000..........
........0....0.............000...................
..0.00..0....000.0.....0000.0...0.00000..........
00....00.....0...0000.0...00.....0.0...0.00......
..0.0..........0...00.0....0.....00...00000......
......000.0.000........0.000...00..........0....0
..........00.0............00.....00........0..000
...........................................0..00.

...........................................0.0....
..........00.0............00.....00.....000000..00
......000.0.000........0.000...00.....0000.....0..
..0.0..........0...00.0....0.....00...00.0.0......
00....00.....0...0000.0...00.....0..0..0..........
..0.00..0....000.0.....0000.0...0.0000............
........0....0.............000....................
..0.00..0....000.0.....0000.0...0.0000............
00....00.....0...0000.0...00.....0..0..0..........
..0.0..........0...00.0....0.....00...00.0.0......
......000.0.000........0.000...00.....0000.....0..
..........00.0............00.....00.....000000..00
...........................................0.0....

.........................................0.0.0...
..........00.0............00.....00........0.00.0
```

```
......OOO.O.OOO........O.OOO...OO.....O.........O
..O.O..........O...OO.O....O.....OO..O...OO......
OO....OO.....O...OOOO.O...OO.....O..O..OO........
..O.OO..O....OOO.O.....OOOO.O...O.OOOO...........
........O....O.............OOO...................
..O.OO..O....OOO.O.....OOOO.O...O.OOOO...........
OO....OO.....O...OOOO.O...OO.....O..O..OO........
..O.O..........O...OO.O....O.....OO..O...OO......
......OOO.O.OOO........O.OOO...OO.....O.........O
..........OO.O............OO.....OO........O.OO.O
.........................................O.O.O...
```

```
..........OO.O............OO.....OO.............
......OOO.O.OOO........O.OOO...OO......O...OO...
..O.O..........O...OO.O....O.....OO...OOO.OOO...
OO....OO.....O...OOOO.O...OO.....O.O.....O...OOO
..O.OO..O....OOO.O.....OOOO.O...O.OOOOOOOOOOOO.O
........O....O.............OOO..................
..O.OO..O....OOO.O.....OOOO.O...O.OOOOOOOOOOOO.O
OO....OO.....O...OOOO.O...OO.....O.O.....O...OOO
..O.O..........O...OO.O....O.....OO...OOO.OOO...
......OOO.O.OOO........O.OOO...OO......O...OO...
..........OO.O............OO.....OO.............
```

```
..........OO.O............OO......OOO.O...OO...O..
......OOO.O.OOO........O.OOO......OO.....OOOO.OO..
..O.O..........O...OO.O....O...OO.O...O..O.O......
OO....OO.....O...OOOO.O...OO...OO.....O....OO...OO
..O.OO..O....OOO.O.....OOOO.O...O.OO...OOO.OOOOOOO
........O....O.............OOO....................
..O.OO..O....OOO.O.....OOOO.O...O.OO...OOO.OOOOOOO
OO....OO.....O...OOOO.O...OO...OO.....O....OO...OO
..O.O..........O...OO.O....O...OO.O...O..O.O......
......OOO.O.OOO........O.OOO......OO.....OOOO.OO..
..........OO.O............OO......OOO.O...OO...O..
```

```
......................................O........OO.......
..........OO.O............OO..........O...O...O.O.......
......OOO.O.OOO........O.OOO......OO..O.......O.OO......
..O.O..........O...OO.O....O...O.OOO...O.OO..O..OO......
OO....OO.....O...OOOO.O...OO...OO...O...O...O.O..OO.O...
..O.OO..O....OOO.O.....OOOO.O...OOOO..............O.O...
........O....O.............OOO.............OOO........OO
..O.OO..O....OOO.O.....OOOO.O...OOOO..............O.O...
OO....OO.....O...OOOO.O...OO...OO...O...O...O.O..OO.O...
..O.O..........O...OO.O....O...O.OOO...O.OO..O..OO......
......OOO.O.OOO........O.OOO......OO..O.......O.OO......
..........OO.O............OO..........O...O...O.O.......
......................................O........OO.......
```

The tagalong for the last spaceship shown above can also be used to connect two parallel spaceships using the small extension tagalong. For this to occur, a small modification of the small extension tagalong is required. This is shown below.

Two period 4 spaceships pulling a tagalong (speed c/4):

```
..........00.0............00.........................................
......000.0.000........0.000.........................................
..0.0..........0...00.0....0.........................................
00....00.....0...0000.0...00.........................................
..0.00..0....000.0.....0000.0........................................
........0....0.............000.......................................
..0.00..0....000.0.....0000.0........................................
00....00.....0...0000.0...00......0..................................
..0.0..........0...00.0....0....00.00.0..............................
......000.0.000........0.000.....0000.....0.0.......0........0.......
..........00.0............00......0000000..0..0....0.00....00........
......................................0.0.....0...0....00....0.......
...............................................000000.....0..0.......
...............................................0..0..0.00.000...0....
...............................................000........0....00....
.........................................................00.......000
...............................................000........0....00....
...............................................0..0..0.00.000...0....
...............................................000000.....0..0.......
......................................0.0.....0...0....00....0.......
..........00.0............00......0000000..0..0....0.00....00........
......000.0.000........0.000.....0000.....0.0.......0........0.......
..0.0..........0...00.0....0....00.00.0..............................
00....00.....0...0000.0...00......0..................................
..0.00..0....000.0.....0000.0........................................
........0....0.............000.......................................
..0.00..0....000.0.....0000.0........................................
00....00.....0...0000.0...00.........................................
..0.0..........0...00.0....0.........................................
......000.0.000........0.000.........................................
..........00.0............00.........................................
```

Going back to the small period 4 ship without the sparky tagalong, Hartmut found some other tagalongs as shown below.

More tagalongs for smallest slow period 4 spaceship (speed c/4):

```
..........................00.0.0...
..........00.0..........0....0.00.0
......000.0.000........0..........0
..0.0..........0...00.0....00......
00....00.....0...0000.0.000........
..0.00..0....000.0.....0...........
........0....0.....................
..0.00..0....000.0.....0...........
```

```
OO....OO.....O...OOOO.O.OOO........
..O.O..........O...OO.O....OO......
......OOO.O.OOO........O..........O
..........OO.O..........O....O.OO.O
..........................OO.O.O...
```

```
.........................O........OO.......
..........OO.O...........O...O...O.O.......
......OOO.O.OOO..........O.......O.OO......
..O.O..........O...OO.O...O.OO..O..OO......
OO....OO.....O...OOOO.OO...O...O.O..OO.O...
..O.OO..O....OOO.O...................O.O...
........O....O................OOO........OO
..O.OO..O....OOO.O...................O.O...
OO....OO.....O...OOOO.OO...O...O.O..OO.O...
..O.O..........O...OO.O...O.OO..O..OO......
......OOO.O.OOO..........O.......O.OO......
..........OO.O...........O...O...O.O.......
.........................O........OO.......
```

```
..................................OO..........O..OO.
..........OO.O.................O.O..O.........O..OOO
......OOO.O.OOO........O...OOOOO.OOOO.........O....O
..O.O..........O...OO.O.O....OOO....OO...OOOOO......
OO....OO.....O...OOOO.O...O......OO..OO...O.OO......
..O.OO..O....OOO.O.....OOOOOOOOOO...OO.OOO..........
........O....O......................................
..O.OO..O....OOO.O.....OOOOOOOOOO...OO.OOO..........
OO....OO.....O...OOOO.O...O......OO..OO...O.OO......
..O.O..........O...OO.O.O....OOO....OO...OOOOO......
......OOO.O.OOO........O...OOOOO.OOOO.........O....O
..........OO.O.................O.O..O.........O..OOO
..................................OO..........O..OO.
```

The following two tagalongs are almost identical to two of the tagalongs for the sparky tagalong already given. A small modification of their front ends allows them to be connected directly to the small period 4 spaceship, thus avoiding the use of the sparky tagalong.

Small period 4 spaceships with tagalongs (speed c/4):

```
.................................O.O....
..........OO.O................OOOOOO..OO
......OOO.O.OOO........O....OOOO.....O..
..O.O..........O...OO.O.O...OO.O.O......
OO....OO.....O...OOOO.O...O..O..........
..O.OO..O....OOO.O.....OOOOO............
........O....O..........................
..O.OO..O....OOO.O.....OOOOO............
OO....OO.....O...OOOO.O...O..O..........
..O.O..........O...OO.O.O...OO.O.O......
......OOO.O.OOO........O....OOOO.....O..
```

```
..........00.0................000000..00
.................................0.0....

..........00.0...............0..............
......000.0.000........0....0...00..........
..0.0..........0...00.0.0...0...00..........
00....00.....0...0000.0...0.......00.0.00...
..0.00..0....000.0.....000000000000.0..000.0
........0....0...........................0.0
..0.00..0....000.0.....000000000000.0..000.0
00....00.....0...0000.0...0.......00.0.00...
..0.0..........0...00.0.0...0...00..........
......000.0.000........0....0...00..........
..........00.0...............0..............
```

Here are several other large spaceships which begin the same as the small slow period 4 "traffic-lights" spaceship, but then quickly diverge. They have the usual back ends and therefore can attach to many tagalongs.

Some large period 4 spaceships (speed c/4):

```
.......0.........................0..........
.....00............0...........00......0....
.......0...00.....0.0....000.000...0...0....
.....000...000....00.....00.000.....0.0.00..
....00........0000...00...0.0.00000.00.0.0..
..0....0...0..0.00...000.0.0........000...00
00....0..0.0..000.............00000....00.00
..0..000.............0000000000..0.0..0...0.
....................0..........0......0.....
..0..000.............0000000000..0.0..0...0.
00....0..0.0..000.............00000....00.00
..0....0...0..0.00...000.0.0........000...00
....00........0000...00...0.0.00000.00.0.0..
.....000...000....00.....00.000.....0.0.00..
.......0...00.....0.0....000.000...0...0....
.....00............0...........00......0....
.......0.........................0..........

.......0...................................00............
.....00............0.........00.............0............
.......0...00.....0.0.......0..0..00.....00.00000........
.....000...000....00.......0......00.....000.000000......
....00........0000...00........00...00...0..0.00000......
..0....0...0..0.00...000...0.00000....0.0.0..0.....0....0
00....0..0.0..000.......0.0.00..0....0....0........0..000
..0..000.............00000....0000....0...0000.....0..00.
....................0....................................
..0..000.............00000....0000....0...0000.....0..00.
00....0..0.0..000.......0.0.00..0....0....0........0..000
..0....0...0..0.00...000...0.00000....0.0.0..0.....0....0
```

```
....00........0000...00........00...00...0..0.00000......
.....000...000....00.......0......00.....000.000000......
.......0...00.....0.0.......0..0..00.....00.00000........
.....00............0.........00.............0............
.......0...................................00............
```

```
.......0...................................00...........
.....00............0.........00.............0...........
.......0...00.....0.0.......0..0..00.....00.0000........
.....000...000....00.......0......00.....000.00000......
....00........0000...00........00...00...0..0.0000......
..0....0...0..0.00...000...0.00000....0.0.0..0....0....0
00....0..0.0..000.......0.0.00..0....0....0.......0..000
..0..000.............00000....0000....0...0000....0..00.
....................0...................................
..0..000.............00000....0000....0...0000....0..00.
00....0..0.0..000.......0.0.00..0....0....0.......0..000
..0....0...0..0.00...000...0.00000....0.0.0..0....0....0
....00........0000...00........00...00...0..0.0000......
.....000...000....00.......0......00.....000.00000......
.......0...00.....0.0.......0..0..00.....00.0000........
.....00............0.........00.............0...........
.......0...................................00...........
```

The last two spaceships shown above are related and are reminiscent of the "MWSS" and "LWSS" tagalongs shown before. But the MWSS-like spark is hidden just behind an edge, and so is not of much use.

The following spaceship is one of the more unusual slow period 4 spaceships because of the fact that it is reminiscent of two of the period 3 spaceships. The section in the last 13 columns appears at the front to be like the "dart" period 3 spaceship. And the part just in front of that appears to be like the back of of sequence of "turtle-like" back ends. And yet these period 3 shapes work here in period 4.

Large period 4 spaceship (speed c/4):

```
.......0...........................................0.0....
.....00............0.........00....................0...0..
.......0...00.....0.0.......0..0..00...............0..00..
.....000...000....00.......0......00.................0.0..
....00........0000...00........00...00.....00..........0..
..0....0...0..0.00...000...0.00000....0.000.......0....00.
00....0..0.0..000.......0.0.00..0....0....0....0.00....0.0
..0..000.............00000....0000....0..0...00......0.0..
....................0....................0...00...0000..00
..0..000.............00000....0000....0..0...00......0.0..
00....0..0.0..000.......0.0.00..0....0....0....0.00....0.0
..0....0...0..0.00...000...0.00000....0.000.......0....00.
....00........0000...00........00...00.....00..........0..
.....000...000....00.......0......00.................0.0..
.......0...00.....0.0.......0..0..00...............0..00..
```

```
.....OO............O.........OO....................O...O..
.......O...........................................O.O....
```

On 8 September 1992, Hartmut Holzwart found a period 4 component which can be repeatably placed alongside itself, and whose ends are terminated with spaceships which have the "MWSS" spark. This was found by a special search feature he implemented which looked for spaceships in a cylindrical area. This is the first known component for making short and wide c/4 period 4 spaceships.

First known component for short wide slow period 4 spaceships (speed c/4):

```
.......O..OO.................
......O...OO.....OOO.........
.....OO......O.OOOOOOO.......
.O...OO..O..OOO..OOOOO.......
.O.......O......O.....O....O.
OO..O....O..O.OO......O..OOO.
.O.OO......O....O.....O..OO..
.O.OO........................
.O.OO......O....O.....O..OO..
OO..O....O..O.OO......O..OOO.
.O.......O......O.....O....O.
.O...OO..O..OOO..OOOOO.......
.....OO......O.OOOOOOO.......
......O...OO.....OOO.........
.......O..OO.................
.................OOO..O......
................OOOO..O......
................O.....O.OO...
................O.OOO...OOO.O
.................O.O......O.O
................O.OOO...OOO.O
................O.....O.OO...
................OOOO..O......
.................OOO..O......
.............................
.................OOO..O......
................OOOO..O......
................O.....O.OO...
................O.OOO...OOO.O
.................O.O......O.O
................O.OOO...OOO.O
................O.....O.OO...
................OOOO..O......
.................OOO..O......
.......O..OO.................
......O...OO.....OOO.........
.....OO......O.OOOOOOO.......
.O...OO..O..OOO..OOOOO.......
.O.......O......O.....O....O.
OO..O....O..O.OO......O..OOO.
.O.OO......O....O.....O..OO..
```

```
.0.00........................
.0.00......0....0.....0..00..
00..0....0..0.00......0..000.
.0.......0......0.....0....0.
.0...00..0..000..00000.......
.....00......0.0000000.......
......0...00.....000.........
.......0..00.................
```

By combining the above small component with multiple copies of the "MWSS" repeatable tagalong, a slow period 4 spaceship can be made which is as wide and as long as desired. Therefore, like the period 2 and period 3 spaceships, a constant percentage of an arbitrarily large square can be filled with a spaceship. How this can be done is shown below.

Method for building long and wide slow period 4 spaceships (speed c/4):

```
......00............................................0...........
......000000.....................000..............0.............
.....0...0.....0000.............000000...........0.....0........
.00.00..0.00.00....00.........00.00000..........0.......0.......
0000....000..00...........0...0.0.....0....0.0..0.00000.0....0..
0..0.....000..0......0.00.0.00........0..000.0.0..0....000.0.0..
0.0............00..0.0.0......000.....0..00....000.........0.0..
.0..0.0.........................................................
0.0............00..0.0.0......000.....0..00....000.........0.0..
0..0.....000..0......0.00.0.00........0..000.0.0..0....000.0.0..
0000....000..00...........0...0.0.....0....0.0..0.00000.0....0..
.00.00..0.00.00....00.........00.00000..........0.......0.......
.....0...0.....0000.............000000...........0.....0........
......000000.....................000..............0.............
......00............................................0...........
.................................000..0...........0..0..........
................................0000..0...........0..0.00.......
................................0.....0.00.......00...00..0.0...
................................0.000...000.0.....0.000..00.0...
.................................0.0......0.0.....0...........00
................................0.000...000.0.....0.000..00.0...
................................0.....0.00.......00...00..0.0...
................................0000..0...........0..0.00.......
.................................000..0...........0..0..........
................................................................
.................................000..0...........0..0..........
................................0000..0...........0..0.00.......
................................0.....0.00.......00...00..0.0...
................................0.000...000.0.....0.000..00.0...
.................................0.0......0.0.....0...........00
................................0.000...000.0.....0.000..00.0...
................................0.....0.00.......00...00..0.0...
................................0000..0...........0..0.00.......
.................................000..0...........0..0..........
......00........................................................
......000000.....................000..............0.............
```

```
.....0...0.....0000.............000000...........0.....0........
.00.00..0.00.00....00.........00.00000..........0.......0.......
0000....000..00...........0...0.0.....0....0.0..0.00000.0....0..
0..0.....000..0......0.00.0.00........0..000.0.0..0....000.0.0..
0.0............00..0.0.0......000.....0..00....000.........0.0..
.0..0.0.........................................................
0.0............00..0.0.0......000.....0..00....000.........0.0..
0..0.....000..0......0.00.0.00........0..000.0.0..0....000.0.0..
0000....000..00...........0...0.0.....0....0.0..0.00000.0....0..
.00.00..0.00.00....00.........00.00000..........0.......0.......
.....0...0.....0000.............000000...........0.....0........
......000000.....................000..............0.............
......00............................................0...........
```

The following is another connecting tagalong that bridges the gap between the sparks of two slow period 4 spaceships. This tagalong was found by me, and so is the only result since Dean Hickerson's earliest slow period 4 spaceship that was not found by Hartmut Holzwart. In the following, two different spaceships provide the necessary sparks. The tagalong is nestled very close to the upper spaceship, but still only reacts in a single place.

Two period 4 spaceships with bridging tagalong (speed c/4):

```
.....................00......0.......................
................000..000.............................
..................0..00.0.0.....0....................
................00....000.......0...................
............00..0..000.0...00000.0....0..............
...........00.00.....0....00....000.0.0..............
............0...0.........0.........0.0..............
...........00...0....................................
............0...0.........0.........0.0..............
...........00.00.....0....00....000.0.0..............
............00..0..000.0...00000.0....0..............
................00....000.......0...................
..................0..00.0.0.....0...0.........0.0....
................000..000...........0.0.....000000..00
.....................00......0....0.0....0000.....0..
...............................00........00.0.0......
..............................00....0..0..0..........
....................................00000............
.............................0000....................
....................................00000............
..........0...................00....0..0..0..........
..........0...............00...00........00.0.0......
......00.0.000..........00...0....0.0....0000.....0..
0.00.00.00..0.0...00.0000..........0.0.....000000..00
0...00..0.00..000..0.00..00...0.....0.........0.0....
0.00....000.0.000......00..0.........................
........00.0...............0..0......................
0.00....000.0.000......00..0.........................
0...00..0.00..000..0.00..00...0......................
0.00.00.00..0.0...00.0000............................
```

```
......OO.O.OOO..........OO...O.......................
..........O...............OO.........................
..........O..........................................
```

Very recently Hartmut found a period 4 spaceship with a completely new front end. It still uses a pair of pre-traffic lights like one type of slow period 4 spaceships, but they are separated widely in this spaceship. The back end of this spaceship is similar to other back ends, and so this spaceship can support similar tagalongs.

Period 4 spaceship (speed c/4):

```
..O.OO...O.....................
OO...O...O..OO....O............
..O.O...O....O..OO.............
......OOO..OO.OO..O............
......OOO...OOOOO.O..OOO.O.O...
........O.....O.O.OO..OOOO...O.
.........OO......OO...........O
.........OO.......OOOOOOOOOOO.O
...............................
.........OO.......OOOOOOOOOOO.O
.........OO......OO...........O
........O.....O.O.OO..OOOO...O.
......OOO...OOOOO.O..OOO.O.O...
......OOO..OO.OO..O............
..O.O...O....O..OO.............
OO...O...O..OO....O............
..O.OO...O.....................
```

As has been seen in this article, the knowledge of c/4 period 4 spaceships is very rudimentary, and only a couple of methods of constructing large spaceships are known. The grammar for constructing such spaceships is very simple, and only contains a couple of components. Therefore this article has mostly been a catalog of sporadic results. (And so unlike previous articles, essentially nothing that is known has been left out.)

This will also be true for the next article in this series, which will cover the remaining class of period 4 spaceships. These are the ones which travel at the "normal" speed of c/2. Some of these new spaceships require the assistance of the standard LWSS, MWSS, or HWSS. But as you will see, this will not be true in general.

This is the fifth in a series of articles concerning Conway's Game of Life. In this article, I will survey the results for the new orthogonal period 4 c/2 spaceships.

The well-known LWSS, MWSS, and HWSS belong to the class of period 4 c/2 spaceships. Since they will appear often in this article, I will use the term "standard spaceship" to refer to any one of the LWSS, MWSS, or HWSS.

As might be expected, many larger spaceships require one or more standard spaceships as essential components. For many of these spaceships, the standard spaceships appear at the front, and the rest of the spaceship is then a tagalong to them. But for some of these spaceships, the front of the spaceship is not a standard spaceship, and yet one or more standard spaceships are still needed alongside or in back of the rest of the spaceship to support it.

Perhaps more interestingly, there are also many spaceships which do not require the use of any standard spaceships at all. So these can be thought of as truly different and new.

More obscurely, there are some spaceships which are not easy to categorize. This is because they have components which are not exactly like a standard spaceship, but which are obviously based on standard spaceships. I will treat these fuzzy cases along with the standard spaceships.

Period 4 c/2 spaceships can either be glide-reflective or not. As mentioned in my first article, a period 4 glide-reflective spaceship means that the original spaceship reappears in generation 2, except that it is reflected across a line parallel to its motion. (All of the standard spaceships are glide-reflective spaceships.)

Glide reflective spaceships are easy to search for using a search program because the effective period is actually only 2, and a mapping which performs the required mirroring is easy to implement. Therefore almost all of the new c/2 period 4 spaceships that have been found are glide-reflective. The search results shown here were done by Hartmut Holzwart and myself, with Hartmut providing the majority of the results.

Now I will begin the survey of period 4 c/2 spaceships by starting with the ones which require the use of standard spaceships.

One way to construct large spaceships is by reacting the standard spaceships together in various simple ways. These constructions are rather obvious, and mostly old, so I will only give two examples of them here. According to Bill Gosper, spaceships like these are the "world's most boring."

"Boring" period 4 spaceships (speed c/2):

```
..O..O          .OO...
.O....          OO.OO.
.O...O          .OOOO.
.OOOO.          ..OO..
......          ......
......          ..OOO.
..OOO.          .OOOOO
.OOOOO          OO.OOO
OO.OOO          .OO...
.OO...
```

Another way to make larger spaceships from the standard spaceships is to find tagalongs for them. Tagalongs are expected to exist because of the convenient sparks that the standard spaceships have. But many tagalongs do not have a period of 4. (For example, the Schick engine has a period of 12.) The first tagalong that was found that actually had a period of 4 is quite large, and so required a search program to find. I found this in April, 1992.

First period 4 tagalong for pair of LWSSs (speed c/2):

```
.....................0...
..................0000...
.............0..0.00.....
.............0...........
0000........0...0.00.....
0...0.....00.00.0.0.00000
0.........00.0.0.0..00000
.0..0..00..0...000..0.00.
......0..0.00............
......0...00.............
......0..0.00............
.0..0..00..0...000..0.00.
0.........00.0.0.0..00000
0...0.....00.00.0.0.00000
0000........0...0.00.....
.............0...........
.............0..0.00.....
..................0000...
.....................0...
```

Unfortunately this tagalong does not have any new side sparks for use in perturbing puffer output. However, the back of this tagalong does have two sparks similar to the LWSS, and spaced just like the leading pair of LWSSs. Therefore this tagalong can be repeatedly attached to itself (in the next phase) to make an arbitrarily large spaceship. The following shows three copies of the tagalong.

Two LWSSs pulling three copies of a period 4 tagalong (speed c/2):

```
.....................0..................0.0.................0.0...
..................0000.................0..0................0.00...
.............0..0.00..............00..00...................00.....
.............0...................0000........0.......0000..0..000.
0000........0...0.00...............00.00.............0...0.0000000
0...0.....00.00.0.0.00000......0.00...0......0......00......0.0000
0.........00.0.0.0..00000.....00.0..0.0.00000......00..0..0.00....
.0..0..00..0...000..0.00....0..0...0....0.......00.0....0000......
......0..0.00..............000.0....0..0.......0...0....000.......
......0...00..............00..00..............0...0...............
......0..0.00..............000.0....0..0.......0...0....000.......
.0..0..00..0...000..0.00....0..0...0....0.......00.0....0000......
0.........00.0.0.0..00000.....00.0..0.0.00000......00..0..0.00....
0...0.....00.00.0.0.00000......0.00...0......0......00......0.0000
0000........0...0.00...............00.00.............0...0.0000000
.............0...................0000........0.......0000..0..000.
.............0..0.00..............00..00...................00.....
..................0000.................0..0................0.00...
.....................0..................0.0.................0.0...
```

One problem with searching for new period 4 c/2 spaceships is that the standard spaceships keep appearing everywhere there is room. Special techniques have to be used to skip over these common results, so that new things can be found. One way to do this is to manually backtrack the search slightly past the point where a standard spaceship has been found, and then let the search progress from there. Doing this results in finding reactions with almost-standard spaceships. That is, the spaceships are slightly perturbed at the back. I named these ships "smashalongs," since it appears that the trailing tagalongs had run into the base ships instead of merely attaching to them.

Following are some of the "smashalongs" that I found. All of these start with the same convoy of a LWSS and an almost-LWSS. The first one shown has an interesting spark at its edge.

Period 4 "smashalongs" based on modified LWSSs (speed c/2):

```
....................O..............
..OO.............O.................
.OOOO..........O.OO...O............
OO.OO.OO.....OO........O...........
.OO.......OOOO...OO.OO.OO.O.OO.OOOO
......O......OO.O..OO...O.....OO...
.......O.O...OO.O...OO.OO.O.OOO.OOO
..OO.OO.OOO..O..O..........O.O..O..
.OOOO.OO....O..OO..O.OO...O.....O.O
OO.OO........OOO....O.O...O.....O.O
.OO...O.......OO....O..............
................OO.O...............
..................O................
```

The following smashalong can be extended at the back to make it larger by one or two columns, exactly like an LWSS can be extended to make a MWSS or HWSS.

Period 4 smashalong (speed c/2):

```
.........................O..O.....
....................O....O........
..OO.............O......O...O.....
.OOOO..........O.OO...O.O.OO......
OO.OO.OO.....OO...................
.OO.......OOOO...OO.OO.O.O.O.O.OO.
......O......OO.O..OO......OOOOOOO
.......O.O...OO.O...OO.OO.....OOOO
..OO.OO.OOO..O..O.......OOOOOO....
.OOOO.OO....O..OO..O.OO...........
OO.OO........OOO....O.O.O.O.......
.OO...O.......OO....O.............
................OO.O....O...O.....
..................O.....OOOO......
```

The next two spaceships require "escorts" of standard spaceships in order to survive. In the first ship, a pair of LWSSs are necessary, whereas in the second spaceship, a HWSS is inside of the the spaceship to stabilize it.

Two period 4 smashalongs with necessary escorts (speed c/2):

```
..............................00........
.............................0000.......
....................0.......00.00.......
..00.............0...........00......0.0
.0000..........0.00...0.............00.0
00.00.00.....00........0...........0.0..
.00.......0000...00.00.00.0.00.0000000..
......0......00.0..00...0.....00....0...
.......0.0...00.0...00.00.0.000.0000.0..
..00.00.000..0..0..........0.0..0...00..
.0000.00....0..00..0.00...0.....0..0....
00.00........000....0.0...0.....0..0....
.00...0.......00....0.........0000...00.
................00.0.........0000....00.
..................0.........00.00.......
.............................00.........
```

```
................................0......
...............................00000...
....................0........00...00...
..00.............0...........0....0....
.0000..........0.00...0..00000.........
00.00.00.....00..........00............
.00.......0000...00.00.0..0.......0000.
......0......00.0..00....00000...000000
.......0.0...00.0...00.00.....0.00.0000
..00.00.000..0..0.......0........00....
.0000.00....0..00..0.00..0.0...........
00.00........000....0.00000............
.00...0.......00....0.....0...0....0.0.
................00.0.......00...0......
..................0...........0..0000..
..............................0........
...............................0.00....
```

A MWSS spaceship can replace the HWSS as the escort in the last spaceship.

Here are two more of these smashalongs with the same beginning. After finding these, I stopped searching for more, so there are probably more.

Two more large period 4 smashalongs (speed c/2):

```
.........................................0........0.......
.........................................0.....0000.0.....
....................0............0..0.000.00.00......0...0
..00.............0..............0.00.00....000.000........
.0000..........0.00...0...000..00..00.0..........0.......0
00.00.00.....00........0.0.00.0.0.00........0.....0000000.
.00.......0000...00.00.0.....0..0..00..000.....000........
```

```
......O......OO.O..OO....OO......OO.OO........OOOOOO......
.......O.O...OO.O...OOOOOO..O.O.O...OO...OOO.OO.OOO.O.....
..OO.OO.OOO..O..O.........O...O....O...O.O....OO.......O..
.OOOO.OO....O..OO..O.OOOO.O.OOO....O..O..O.........O.....O
OO.OO........OOO....O.O.OOOO...O.O....O.OO.........O......
.OO...O.......OO....O.......OOOO.O.....OO..OO..O..O......O
................OO.O........OO..OO.O..OO.O....O..OO.OOOOO.
..................O...............OOOO..OO...O.O.....O.....
...................................OO..OO.O....OOO........
.................................................O..O.....
```

```
....................................OO......
....................O..O.........OO.........
..OO.............O....OOOOOO..OO.OO...OO....
.OOOO..........O.OO.......OOO.....O.O.O.....
OO.OO.OO.....OO........O.O....O.O...........
.OO.......OOOO...OO.OOOO.O.OO.OOOOOO.O.....O
......O......OO.O..OO.......................
.......O.O...OO.O...OOOOO.OOOOOOOOOOO......O
..OO.OO.OOO..O..O.........O..........OOOOOO.
.OOOO.OO....O..OO..O.OO.O.OO..OO.OO.........
OO.OO........OOO....O...OO...O...O...OO.....
.OO...O.......OO....O.O...O..O.O.O..O...O...
................OO.O..O...OOOO...O..........
..................O....O..OO.....OOO.OO.O...
..................................OO........
```

After finding the above series of spaceships, I went on to other things. Then Hartmut Holzwart began looking for more c/2 period 4 spaceships.

Here are several small spaceships found by Hartmut. The first one shown is interesting because the top part is an almost-spaceship which requires the HWSS for support. The HWSS can support one of these on each side. Two copies of the almost-spaceship alongside each other can not support each other because they require growth on the row between them.

Period 4 small spaceships (speed c/2):

```
.O......
O.....O.
O.....O.
OOOOO.O.
........
....OO..
..O....O
.O......
.O.....O
.OOOOOO.
```

```
...OO...
.O....O.
O.......
```

```
0.....0.
000000..
........
.....0.0
....0..0
.....0..
...00..0
.0.....0
0.......
0.....0.
000000..
```

```
0000.........
0...0.0......
0.....00.....
.0....00.....
......0......
...000000000.
...0........0
...0.........
....0...0...0
.............
0000.00......
0...00.0.....
0....0.0.....
.0..0........
```

The last spaceship above is a good example of my comments about almost- standard spaceships being used in a spaceship. The back end can be extended similarly to extending standard spaceships, using other standard spaceships as escorts. Following are two examples of this.

Two related period 4 spaceships (speed c/2):

```
                       ...........00......
0000........00...      0000......00.00....
0...0.0....00.000      0...0.0....0000....
0.....00....00000      0.....00....00.....
.0....00.....000.      .0....00...........
......0..........      ......0............
...0000000000....      ...000000000000000.
...0.........0...      ...0..............0
...0.............      ...0...............
....0...0........      ....0...0.........0
.................      ...................
0000.00.....00...      0000.00............
0...00.0...00.000      0...00.0...00......
0....0.0....00000      0....0.0..00.00....
.0..0........000.      .0..0......0000....
                       ............00.....
```

The following results are based on a convoy of two LWSSs and a MWSS which produce two copies of the spark produced by the second "boring" spaceship shown previously. The central MWSS in the convoy can also be replaced by an OWSS which is two cells longer than the MWSS. Hartmut found most of these results in the longer forms first, but I am only showing the shorter MWSS forms here.

The small tagalong below uses the sparks from the boring spaceship reaction, plus the end of the middle MWSS.

Period 4 small tagalong to standard spaceship convoy (speed c/2):

```
OOOO.........
O...O........
O............
.O..O.....O..
....O...OO.O.
.O...O..OO...
O......O....O
O....O.OOO..O
OOOOO...O.O..
.......OO.O..
.........O...
..........O..
OOOO.........
O...O........
O............
.O..O........
```

A larger tagalong for the convoy which only requires the sparks is the following.

Period 4 tagalong for standard spaceship convoy (speed c/2):

```
.OO......OO....
OO.OO...OOO....
.OOOO..OOO...OO
..OO....O....OO
.............O.
..OOO.....OO...
.OOOOO...O..O..
OO.OOO...O...O.
.OO......O....O
...........O...
.....OO..OOO...
........OOO.OO.
.OO....OO.O...O
OO.OO...OOO....
.OOOO..........
..OO...........
```

The following larger tagalong starts similar to the one just shown, but then diverges. It has a HWSS-like back end. In the same way that the standard spaceships come in different sizes, this back end can also be modified to have various sizes. By adding extra spaceships as escorts the back end can be made quite long.

Period 4 tagalong with HWSS-like back end (speed c/2):

```
.OO......OO..................
OO.OO...OOO..................
.OOOO..OOO....O..............
..OO....O.....OO.............
.................O.......OO..
..OOO.....OOOO....O...O.....O
.OOOOO...O..OOO....OO........
OO.OOO...O...O....OOO.......O
.OO......O..O..OO.O..OOOOOOO.
...........OO..OO...OO.......
.....OO..OO.OO...............
........OOOOOO...............
.OO....OO.O....OO............
OO.OO...OOO..................
.OOOO........................
..OO.........................
```

By adding two accompanying LWSS to that back end, sparks can be produced which are just like those produced by the front convoy. This allows an arbitrarily long spaceship to be constructed by repeatedly attaching the tagalong to itself. The following shows three copies of the tagalong.

Period 4 spaceship with three copies of repeatable tagalong (speed c/2):

```
$$$$.........OO$$.O..O.
.OO......OO$...OOOO....O.O$...OOOO$.........O.....
OO.OO...OOO$...O...O..O$.....OO.OO...OOO$...O...O.
.OOOO..OOO....O.........O......O..O...OO........OO....OO.O....OO.......OOOO..
..OO....O.....OO.........O..O..OOO....OO$.....OOOOOO$......
$.......O$O......OOOO$...OO..OO.OO$......
..OOO.....OOOO....O...O......O....OO..O...OO$....OO..OO...OO........
.OOOOO...O..OOO....OO$..O....O.....OO$O..O..OO.O..OOOOOOOO.
OO.OOO...O...O....OOO........O..OOO....O.OO...OOOOOOO...O...O....OOO........O
.OO......O..O..OO.O..OOOOOOOO.....OOOOOOO.O...OOOOOOO...O..OOO....OO.........
$.OO..OO...OO$.O....OOOO..OO.OOOOO.....OOOO....O...O......O
.....OO..OO.OO$........O.....O$$.....O$O.
........OOOOOO$......O......OO$OO....O.....OO.........O..O.
.OO....OO.O....OO.......OOOO...O....O$.OOOO..OOO....O.........O.....
OO.OO...OOO$...O...O..OO.O$..OO.OO...OOO$...O...O.
.OOOO$.........O........O$....OO......OO$...OOOO..
..OO$$.O..O$$$$........
```

The following tagalongs are larger and closer to "space-dust."

Several large period 4 tagalongs to standard spaceship convoy (speed c/2):

```
.00......00........0000........
00.00...000........0...00......
.0000..000....0....0...........
..00....0.....00....0..00...0.0
.................0.......0..0.0
..000.....0000....0...0....0...
.00000...0..000....00......00..
00.000...0...0....000...0.00...
.00......0..0..00.0..000..0..0.
...........00..00...00.....0..0
.....00..00.00..........000000.
........000000..........00.....
.00....00.0....00..000000......
00.00...000........0....0......
.0000..............0....0......
..00................0..........

..........................0..0......
.00......00..............0....00..00
00.00...000..............0..0.00.0..
.0000..000....0..........00.00.0....
..00....0.....00.....00...0.0.......
...................00...0..0.0...0.0
..000.....0000...0.0000..00......0.0
.00000...0..000.........00.0..0..0..
00.000...0...0....0.0.0...000000.000
.00......0..0..00.0...0.00.....00...
...........00..00.0..0......000.0000
.....00..00.00.....0..0....0.00.....
........000000......00....00.00.0...
.00....00.0....00........0...00.0...
00.00...000..............0...0......
.0000....................0000...0.0.
..00............................0...

...............0.0..0.0......
.00......0....0..0..0.0......
00.00...00000.0...0...00.....
.0000..00.00.......00..000...
..00....0..0...0.00.00.0000.0
..........00.0.00.00........0
..000.....0....0.000..0000...
.00000........000..00.0......
00.000.......000..000.000000.
.00..........0....0..........
..........0...........000....
.....00..00..0.000...0...0000
........00000..00....000..0..
.00....00.....00.00000..0..00
00.00...0....00.0....0.......
.0000....0....0000.00.0......
```

```
..00...........0.0.0.........
```

The following spaceship has another back end which comes in various sizes. The pair of LWSSs at the back are required in order to stabilize the tagalong. The back pair of MWSSs are required for this particular sized back end, but for smaller back ends, they are not required. I selected this particular sized spaceship to demonstrate an uncommon use of the MWSS to perturb some objects.

Period 4 tagalong to standard spaceship convoy with escorts (speed c/2):

```
........................0..0.....0..
.00......00............0.......0...0
00.00...000............0...0..0.....
.0000..000...000..0....0000...0....0
..00....0....000.0..0.........00000.
.............0.0.00.................
..000......0...00.....0.............
.00000...00.0...00..00.0............
00.000...0..0.0..0.0.00.00000000....
.00......0......00000...00000000....
..........00...0.0....000000000000..
.....00..000...0.00.0..........0...0
........000.00.0..0.....0..0..0.....
.00....00.0...0000.....0......0....0
00.00...000....00......0...0..00000.
.0000..................0000.........
..00................................
```

Hartmut also found the following tagalong which requires two LWSS escorts. This produces a nice spark at the back.

Tagalong for standard spaceship convoy (speed c/2):

```
.00......00.............0000.......
00.00...000.............0...0......
.0000..000....0.........0..........
..00....0.....00.........0..0..0...
.................0...........0000..
..000.....0000....0...0.........0..
.00000...0..000....00...........0..
00.000...0...0....000..............
.00......0..0..00.0..0000000000....
...........00..00...00........00.00
.....00..00.00................0....
........000000................0.00.
.00....00.0....00.......0000.......
00.00...000.............0...0......
.0000...................0..........
..00.....................0..0......
```

When I saw this spaceship, I realized that the back part of the tagalong could be extracted and slightly modified to run on its own by changing one column. This is shown below.

Period 4 spaceship (speed c/2):

```
..OOOO.......
..O...O......
..O..........
...O..O..O...
.......OOOO..
.O........O..
O.........O..
O............
OOOOOOOOO....
........OO.OO
........O....
........O.OO.
..OOOO.......
..O...O......
..O..........
...O..O......
```

The same basic spaceship was later found by Hartmut's search program in a smaller form, as shown below.

Smaller period 4 spaceship (speed c/2):

```
OOOO.......
O...O......
O..........
.O..O..O...
.....OOOO..
.O......O..
O.......O..
O..........
OOOOOOO....
......OO.OO
......O....
......O.OO.
OOOO.......
O...O......
O..........
.O..O......
...........
```

Hartmut found the following tagalong for the above spaceship. This tagalong is unusual in that most of it is actually of period 2. Most tagalong periods are either the same or are multiples of the base spaceship period. Having a tagalong which is a sub-multiple is very rare. By using this tagalong, many of the period 2 results from a previous article can be attached to this spaceship.

Period 4 spaceship with period 2 compatible tagalong (speed c/2):

```
OOOO...............
O...O...........O.O
O..............O..O
.O..O..O......OO...
.....OOOO.....O.O..
.O......O....O.O..O
O.......O...OOO.OO.
O...........O......
OOOOOOO.....OOO.OO.
......OO.OO..O.O..O
......O.......O.O..
......O.OO....OO...
OOOO...........O..O
O...O...........O.O
O..................
.O..O..............
```

By modifying the end of the base spaceship, the following much larger spaceship was found.

Larger period 4 spaceship (speed c/2):

```
...............O...OO.
OOOO........OOO..OO...
O...O......OOOO......O
O.........O.....OO.O..
.O..O..OOOO.OO.OO.O...
.....OOO.O..O.OO......
.O......O...O.OO......
O.......O..OOO........
O.......O..OO.........
OOOOOOO....O...O......
......OO...O..........
......O..O.O.OO.......
......O.O..O.OO....O..
OOOO......OO.OOO.O.O..
O...O......OO..O......
O............OO..OOO.O
.O..O..........O...O.O
```

Here are a series of spaceships with a different front part. The front part of these consists of two almost-spaceships and a HWSS. The HWSS serves no purpose except to support the almost-spaceships. Several of these spaceships have the capacity of having the back end sizes changed in the same way as the standard spaceships.

Period 4 tagalongs for convoy of HWSS and almost-spaceships (speed c/2):

```
.O......................
```

```
O.....O..OOOO.O.........
O.....O.O..............O
OOOOO.O...........OO...O
.........OO.OOO...OOO...
....OO.....O..O.....OO.O
..O....O......OO..O.OO..
.O...........O.O.O...OO.
.O.....O....OO..OOO.O...
.OOOOOO......OO...O.O...
..............O.OO......
...........O....O.OOO.OO
.O..O.....O....O..OO..OO
O....O.O.OO...OO....O.O.
O...OO.OO...OO..........
OOOO.....O...O..........
..........O.O...........

.O..........................
O.....O................OO...
O.....O..............OO.....
OOOOO.O..OO..O...OO..O......
..........OOOOO.OO.OO.OO.O..
....OO.......OO.O...O....O.O
..O....O...O.O..O...O....O..
.O.........O.O...O.......OOO
.O.....O..O........OO.......
.OOOOOO....O.....O.OOO...OOO
...........OO...OOO.OO...O..
..........OOO.......OOO.O...
.O..O.......O....O...OO.OOO.
O....O.O.OO.O...OOOOO....O..
O...OO.O..........OO..O..O..
OOOO..................O.O...

.O...........OO.O.O.........
O.....O......OOOO.O.........
O.....O..O..O...............
OOOOO.O..OO..OO.O.O....OO.O.
..........O..OO.O.O...O...O.
....OO...........OOO......O.
..O....O.........OOO.O.O....
.O..........OO..............
.O.....O...OO.OOO...O.......
.OOOOOO.....OOOOOOO..O......
.............OOO............
................OOO.OOO.....
.O..O.....O..OOO.......OOO.O
O....O.O.....O.O.........O.O
O...OO.O.OO..O..O...........
OOOO........OOO.OOO.........

.O...........OO.O.O..........
O.....O......OOOO.O..........
```

```
0.....0..0..0................
00000.0..00..00.0.0....00000.
..........0..00.0.0...0.....0
....00...........000.........
..0....0.........000.0.0....0
.0..........00...............
.0.....0...00.000...0........
.000000.....0000000..0.......
.............000.............
................000.000.0000.
.0..0.....0..000.......0....0
0....0.0.....0.0.............
0...00.0.00..0..0.......0...0
0000........000.000.......0..
```

```
.0...........00.0.0....
0.....0......0000.0....
0.....0..0..0..........
00000.0..00..00.0.0....
..........0..00.0.0....
....00...........000...
..0....0.........0.0..0
.0..........00....000.0
.0.....0...00.000....0.
.000000.....000000..000
.............000......0
................000....
.0..0.....0..000.......
0....0.0.....0.0.......
0...00.0.00..0..0......
0000........000.000....
```

```
.0....................00.00.
0.....0......000.....0000000
0.....0....0.....00....00000
00000.0...0.0...000...0.....
.........00..0.0.....0......
....00....00.00....0........
..0....0....0.00.0..........
.0..........0000............
.0.....0....0.0...0.........
.000000.....00..00..........
.............0..000.........
..........00................
.0..0....0...0..0..0....000.
0....0.0.000.......00..00000
0...00.0...000.00.0...0.0000
0000.........0.......000....
```

The last spaceship above has a very nice spark at the back corner. The spark is probably about as far away from the generating ship as is possible for period 4.

The following ship is another one whose front part has period 4, but which changes to period 2 at the back. As seen in a previous article, the back of this can support a repeatable period 2 tagalong. The back end can also support the period 3 tagalong from that article, making the final spaceship have a total period of 12.

Period 4 spaceship with period 2 back end (speed c/2):

```
.O...........OO.O.O..........
O.....O......OOOO.O..........
O.....O..O..O................
OOOOO.O..OO..OO.O.O....O.O...
..........O..OO.O.O...O..O.OO
....OO...........OOO.OO......
..O....O.........O.O.O...O...
.O..........OO....OOO.OO.O...
.O.....O...OO.OOO..........OO
.OOOOOO.....OOOOOO..OOOO.O...
.............OOO.........O...
................OOO..OO......
.O..O.....O..OOO.....OO..O.OO
O....O.O.....O.O.......O.O...
O...OO.O.OO..O..O............
OOOO........OOO.OOO..........
```

In this final spaceship with the same front end, the HWSS does have a role other than supporting the almost-spaceships. The back end of the HWSS is used to keep some cells OFF that would otherwise be turned ON.

Period 4 spaceship with tagalong (speed c/2):

```
.O...........O.O......
O.....O....OOO.OO.....
O.....O...O......OO...
OOOOO.O..OO..OOOOO....
..........O.O.....O...
....OO....OO...OO.OO.O
..O....O..O.O..OOO....
.O.......O..O..O.O....
.O.....O.O.....OO.....
.OOOOOO..O.....O......
.........O...O.OO..O..
..........OO.O.O...OO.
.O..O........O...OOOO.
O....O.O.OOOOOOOO.OOO.
O...OO.O.OO...........
OOOO.......OOOO.O.O...
..............O.O.O...
```

The following two spaceships have a front end which is an OWSS. In these spaceships, the OWSS is mutually supported by the rest of the spaceship, and so these are not really tagalongs.

The first ship shown seems to have the same variable-sized back end as other spaceships. But only the HWSS- like back end shown here will work.

OWSS featuring in period 4 spaceship (speed c/2):

```
.......OOO.O.O.........
......OOOO.O.OO...OO...
.....OO.......O..OOO...
......OOOOO.O..O.OO.O..
...OO....O...OOOOO.....
.O...........O...O.....
O.............OO.OO....
O......O.....O.....OOOO
OOOOOOO......OO..OOOOOO
................OOOOOO.
.......OO..OOOOO.......
......OOO........O.....
.....OO.O...OO.OOO.....
......OO...O.....O.....
.........OO...OO.......
```

The following spaceship is another one with a period 4 front part which has a period 2 back end.

Period 4 spaceship with period 2 back end (speed c/2):

```
.......OOO.O.O.............
......OOOO.O.OO...OO.......
.....OO.......O..OOO....O.O
......OOOOO.O..O.OO....O..O
...OO....O...OOOOOO...OO...
.O...........O...OO..O....O
O.............OO.OO.OOOOO.O
O......O.....O.............
OOOOOOO......OO..OOOOOOOO.O
................OOO.......O
.......OO..OOOOO......OO...
......OOO........O.....O..O
.....OO.O...OO.OOO......O.O
......OO...O.....O.........
.........OO...OO...........
```

The following cute spaceships were found by Hartmut. In the first one, a pre-beehive is pulled and pushed along by four LWSSs. In the second one, a piece of "trash" is pulled and pushed along.

Four LWSSs escort a pre-beehive (speed c/2):

```
OOOO.....O..O
```

```
O...O...O....
O.......O...O
.O..O...OOOO.
.............
.....OO......
.....OO......
.....OO......
.............
.O..O...OOOO.
O.......O...O
O...O...O....
OOOO.....O..O
```

Four LWSSs escort a piece of "trash" (speed c/2):

```
.........O...O
..OO....O.....
.OOOO...O....O
OO.OO...OOOOO.
.OO...........
..............
......OO......
.......O.O....
..OO....OOOO..
.OOOO....O...O
OO.OO...O.....
.OO.....O....O
........OOOOO.
```

While looking to stabilize a very large OWSS, I found the following escort. The following shows the largest OWSS that can be escorted by it.

Period 4 escorts for OWSS (speed c/2):

```
.....OO.........
..OO.OOO........
.OO..OO.........
..OO..OO........
...OO.OOO.......
......O.O.......
............OO..
.O.............O
O...............
O..............O
OOOOOOOOOOOOOOO.
................
................
....OOO.O.......
...OOOO..OO.....
..O.O...........
```

```
.OO.............
..OOOO.O........
...OOO.O........
```

The OWSS spaceship shown in the above spaceship can be made smaller in several different sizes. Besides supporting an OWSS, this escort can also survive by being "pushed" by a MWSS. So this could be called a "pushalong" instead of a tagalong. One MWSS can push two of these along if desired.

MWSS escorting a period 4 "pushalong" (speed c/2):

```
....OO.O....
.OOO...O....
.O..........
.O......O...
..OOO...O...
.....OO.....
............
............
.......OO...
......OO.OOO
.......OOOOO
........OOO.
```

That ends the survey of results which make use of standard spaceships. Now I will survey the results for the spaceships which do not use standard spaceships.

I found the first c/2 period 4 spaceship which does not use any standard spaceship at the beginning of May, 1992. The front of this spaceship has period 2, but then a period 4 change appears within a few columns. The spaceship has a nice two-bit spark at the back.

Period 4 spaceship (speed c/2):

```
.........O.............
......OO.O.............
......O...O....OO..OO..
...O.O..OO....OOO..OOOO
..OOOOO...O.O.OOO.O..OO
.OO.....OO.OO..........
OO....O......O.O..OO...
.OO....OOOOOOOO........
......O.........O..O...
.OO....OOOOOOOOO.......
OO....O........OOO.....
.OO.....OOOO.OO.OO..O..
..OOOOO.........OO..O..
...O.O..OOO..OOO.O.OO..
......O................
......OO.O.O...........
```

```
.........O.............
```

Hartmut Holzwart later found two tagalongs for the above spaceship. These are shown below.

Period 4 spaceships with tagalongs (speed c/2):

```
.........O......................
......OO.O......................
......O...O....OO..OO......O....
...O.O..OO....OOO..OOOO..OOO....
..OOOOO...O.O.OOO.O..OOOO...O...
.OO.....OO.OO.............OOOO.O
OO....O......O.O..OO.......OO.O.
.OO....OOOOOOOO.........OO..O...
......O.........O..O.....OO.O..O
.OO....OOOOOOOOO.........OO..O.O
OO....O........OOO......O.OO..O.
.OO.....OOOO.OO.OO..O..OO.O...OO
..OOOOO.........OO..O..O.....OO.
...O.O..OOO..OOO.O.OO...OOOOOO..
......O...................O.OO..
......OO.O.O....................
.........O......................

.........O......................O.O.
......OO.O....................O...O
......O...O....OO..OO......O..O...O
...O.O..OO....OOO..OOOO..OOO...O...
..OOOOO...O.O.OOO.O..OOOO...O...O..
.OO.....OO.OO.............OOOO.O..O
OO....O......O.O..OO.......OO.OOOOO
.OO....OOOOOOOO.........OO..O...O..
......O.........O..O.....OO.O..OO..
.OO....OOOOOOOOO.........OO..O.OO..
OO....O........OOO......O.OO..O....
.OO.....OOOO.OO.OO..O..OO.O...O...O
..OOOOO.........OO..O..O.....OOOOO.
...O.O..OOO..OOO.O.OO...OOOOOO.....
......O...................O.OOO....
......OO.O.O...................OOO.
.........O.........................
```

As previously described, one way to find spaceships which do not use any of the standard spaceships is to just perform the search, but then manually backtrack over the results whenever a standard spaceship turns up. This is time-consuming and error prone.

Hartmut Holzwart thought of and implemented a new search feature which avoids this problem completely. He made the observation that for all of the standard spaceships, there is a generation in which some cell has seven ON neighbors (the "eye" of the spaceships). By changing the program to suppress results in which any cell has more than six ON neighbors, all results which make use of standard spaceships are also suppressed. This makes it much easier to find these new spaceships (but at the cost of missing some possible spaceships).

Hartmut found the following series of spaceships using this new search feature.

Period 4 spaceship (speed c/2):

```
....OO.........................
.OO.......................OO.O.
OO..O.O................OOOO...O
.OO.O.O......OO......OO........
..O...OO....OOOO.....OO..OO...O
...OO.OOO.....O...O.O....O..OO.
....OO.......OOO..OO.O..O......
......O.OO.O.O.................
....OOO.....O...O.O...O.OO.....
....OOO.OO...OO..O...OO....O...
......O..OO.OO.O...O.O..OO.O...
..OO.OO.O...OOO.....OO.OOO.O...
.O.OO.................O.....O..
OO.....................OOO..O..
.OOOO....................O..O..
..OOO..........................
```

The back of the above spaceship can be slightly modified to attach to two different larger back ends.

Period 4 spaceships with larger back ends (speed c/2):

```
....OO...............................
.OO.......................OO.O.......
OO..O.O................OOOO...O......
.OO.O.O......OO......OO..............
..O...OO....OOOO.....OO..OO...O......
...OO.OOO.....O...O.O....O......OO..O
....OO.......OOO..OO.O..O......O.OO..
......O.OO.O.O...............O...OOOO
....OOO.....O...O.O...O.OO...OO.O....
....OOO.OO...OO..O...OO....O...OO.OOO
......O..OO.OO.O...O.O..OO.O.....OO..
..OO.OO.O...OOO.....OO.OOO.O.....OO..
.O.OO.................O.....O........
OO.....................OOO..O........
.OOOO....................O..O........
..OOO................................

....OO.........................................
.OO.......................OO.O.................
OO..O.O................OOOO...O...........O....
.OO.O.O......OO......OO.............O...OO.O...
..O...OO....OOOO.....OO..OO...O....O....O...O..
```

```
...OO.OOO.....O...O.O....O....O...OO.....O.O...
....OO.......OOO..OO.O..O......OO.OOO...OO.O.OO
......O.OO.O.O...............O.OO..O.OOO.O.O...
....OOO.....O...O.O...O.OO...OO..O........O.O..
....OOO.OO...OO..O...OO....O.........OO.O.O.O..
......O..OO.OO.O...O.O..OO.O......OOOOOOO.O.O..
..OO.OO.O...OOO.....OO.OOO.O.......OO....O.....
.O.OO.................O.....O.......O....O...O.
OO.....................OOO..O............O..O..
.OOOO....................O..O..................
..OOO..........................................
```

The following spaceships are nice because they have a new spark at the edge.

Period 4 spaceships with new edge spark (speed c/2):

```
................................O...
..............................O..O..
....OO..............................
.OO.........................OO.OO...
OO..O.O......................O.OO...
.OO.O.O......OO..........OOO.O.OOO..
..O...OO....OOOO........OO.O.O.O.OO.
...OO.OOO.....O...O........O.O...O..
....OO.......OOO..OO...OOO.O.OO...O.
......O.OO.O.O......OOO.OO.O........
....OOO.....O...O.O......O..O..O....
....OOO.OO...OO..O......OO..O...O...
......O..OO.OO.O...O..O.O.O.O.O.OOO.
..OO.OO.O...OOO.........O.O.O.O..O.O
.O.OO....................O..O.O.....
OO........................OOO.O.....
.OOOO.......................O....O..
..OOO........................OO..O..
...............................OO...
```

```
................................O...........
..............................O..O..........
....OO....................................O.
.OO.........................OO.OO......OOOO.
OO..O.O......................O.OO......O....
.OO.O.O......OO..........OOO.O.OOO..OO..O...
..O...OO....OOOO........OO.O.O.O.OOO.O.OO...
...OO.OOO.....O...O........O.O...O.O.O...O..
....OO.......OOO..OO...OOO.O.OO....O......O.
......O.OO.O.O......OOO.OO.O.......O..O...O.
....OOO.....O...O.O......O..O..O...OO..OO...
....OOO.OO...OO..O......OO..O...O.O.OO..O..O
......O..OO.OO.O...O..O.O.O.O.O.OO..O..O....
..OO.OO.O...OOO.........O.O.O.O..O..O.O.....
.O.OO....................O..O.O.....O.O...O.
```

```
00........................000.0......000....
.0000.......................0....0.....0...0
..000........................00..0......00.0
...............................00...........
```

Here are two more spaceships which only differ in the last few columns. Note the curious pattern of vertical rows of ON cells in these. Possibly there may be a way to make this extensible to continue the pattern, but this isn't known.

Two very similar period 4 spaceships (speed c/2):

```
..............................000.......0.......
....00.........................00.00...00.......
.00.........................00.0.000..0.........
00..0.0......................0.0.0.0..0..00.0.0.
.00.0.0......00..........000.0.0.....00...00...0
..0...00....0000........00.0.0.0...........0.0..
...00.000.....0...0........0.0..0..0...0.0......
....00.......000..00...000.0.00...0.....0.......
......0.00.0.0......000.00.0...00.0.00..........
....000.....0...0.0......0..0....0....0.........
....000.00...00..0......00..0....0.0.0..........
......0..00.00.0...0..0.0.0.0.0...0.....0.......
..00.00.0...000.........0.0.0.0.00....000....00.
.0.00....................0..0.0.0....0...00.000.
00........................000.0.0...00.....0....
.0000.......................0.0..0.0.0.0...0....
..000........................00.00.....0........
...............................000......00......
................................00..............
```

```
..............................000.......0......
....00.........................00.00...00......
.00.........................00.0.000..0........
00..0.0......................0.0.0.0..0..00.0..
.00.0.0......00..........000.0.0.....00...00..0
..0...00....0000........00.0.0.0...........0..0
...00.000.....0...0........0.0..0..0...0.0.....
....00.......000..00...000.0.00...0.....0......
......0.00.0.0......000.00.0...00.0.00.........
....000.....0...0.0......0..0....0....0........
....000.00...00..0......00..0....0.0.0.........
......0..00.00.0...0..0.0.0.0.0...0.....0......
..00.00.0...000.........0.0.0.0.00....000....0.
.0.00....................0..0.0.0....0...00.00.
00........................000.0.0...00.....0...
.0000.......................0.0..0.0.0.0...0...
..000........................00.00.....0.......
...............................000......00.....
................................00.............
```

The following two spaceships have a totally different front end. They are identical, except that first first spaceship has a large hole in it, and the second spaceship has a tagalong inside that hole.

Large period 4 spaceships without and with internal tagalong (speed c/2):

```
............................O.OO..............
..........................OOOOOO..............
.........................O.....OOOO.O.........
.........................O..OO..O....O........
.......OOO...............OO.O.OOOO.O.....O....
..OOOOOO...................OO.......OOOO.O....
..O...OO...OO..OO.OO........OO.......O........
..O...O.......OOOO..O..OO...OO.........OO.....
...OO.O..OO..........O..OO.O...OO.....O.......
....OOOO..O....OO.O.O..O..O............O......
........O...O..OO.O..OO.OOO............O...O..
..OO....OO..OOOO...O.O..O...............OOOOOO
OO.....O.OOO.O.....O.O.OO...................OO
O..O..OOO..O.O............O.................OO
O......OO.............O...O..............O..O.
.OO.....O...OO....OOOOO.....................O.
.........OOOOO.....O..OOO..............OO.O...
...O...O.O...O..O..O....OO...O.........O......
...O.O.O.O.....O.OO....O..O...O.......O..O....
..OO.OO...OOO.OOO.O....OOOO.O.O........OO.....
..O..O............O..O...OOO..O......O........
..O....O..................OO...O..O..O.OO.....
...O..OOOO...............O...O....O.O...O.....
.....O..OO...............O..OOOOO.OO..........
.........................OO...O....O..........
...........................OOO...O............
.............................O................
```

```
............................O.OO..............
..........................OOOOOO..............
.........................O.....OOOO.O.........
.........................O..OO..O....O........
.......OOO...............OO.O.OOOO.O.....O....
..OOOOOO...................OO.......OOOO.O....
..O...OO...OO..OO.OO........OO.......O........
..O...O.......OOOO..O..OO...OO.........OO.....
...OO.O..OO..........O..OO.O...OO.....O.......
....OOOO..O....OO.O.O..O..O.......OO...O......
........O...O..OO.O..OO.OOO......O.....O...O..
..OO....OO..OOOO...O.O..O.......O.......OOOOOO
OO.....O.OOO.O.....O.O.OO......O....O.......OO
O..O..OOO..O.O............O....O...O........OO
O......OO.............O...O....O..O......O..O.
.OO.....O...OO....OOOOO.........OO..........O.
.........OOOOO.....O..OOO..........O...OO.O...
...O...O.O...O..O..O....OO...O...O.O...O......
...O.O.O.O.....O.OO....O..O...O...O...O..O....
..OO.OO...OOO.OOO.O....OOOO.O.O........OO.....
```

```
..O..O............O..O...OOO..O......O........
..O....O..................OO...O..O..O.OO.....
...O..OOOO...............O...O....O.O...O.....
.....O..OO...............O..OOOOO.OO..........
.........................OO...O....O..........
...........................OOO...O............
.............................O................
```

The tagalong inside the above spaceship is only connected by a pair of two-bit sparks from the base ship. But no other spaceship is known which produces that same spark such that the tagalong can be pulled by it.

Two more spaceships found by Hartmut with another different front end are shown below. (The second spaceship actually uses a pair of LWSS to stabilize the back end, but I am including it here with the other one anyway.)

Two related period 4 spaceships (speed c/2):

```
....O..O...............
..OOO....OO............
.O......OOOO...........
OO.OO.O.O..O...........
.OO....O..OO.O.O.......
..O...O....OOO.O...OO..
...OOO......O..O.O.....
.....O.......O...O...O.
....O..O....O..O.O....O
........O...O.....OOO..
..OO.......OOO.O.......
.O.OO...O.O....O.......
OO...OO..OO............
.OO.....OO.............
..OOOOO................
.....O.................
```

```
....O..O.................
..OOO....OO.......OOOO...
.O......OOOO......O...O..
OO.OO.O.O..O......O......
.OO....O..OO.O.O...O...O.
..O...O....OOO.O.........
...OOO......O..O.O...OO..
.....O.......O...OOOOO...
....O..O....O..O.OO..O.OO
........O...O......O.OOOO
..OO.......OOO.O......OO.
.O.OO...O.O....O.........
OO...OO..OO.......OOOO...
.OO.....OO........O...O..
..OOOOO...........O......
.....O.............O..O..
```

The following is another reasonably small spaceship found by Hartmut. This one is interesting because each of the front two quarters of the spaceship is the same as the "pushalong" that I had previously described above. Here two copies of the pushalong are stabilized by the back half of the spaceship, instead of by a MWSS.

Period 4 spaceship (speed c/2):

```
................OO
..OOO.O........O..
.OOOO.O...OOOO.OOO
OO......O.O...OO..
.O.O....O......O..
..OOOO....OO...OO.
...OOO.OO....O.OO.
..........OOOO.O..
.........OO.....O.
......O..O.OOOO...
.....O......O.OO..
..OO.OO.OOO.......
.OO..OO....OOO....
OO..OO...O....O...
.OO.OOO..OO.......
....OO.........OO.
................O.
```

On July 10, 1992 Hartmut Holzwart found the following very important period 4 c/2 spaceship. This spaceship is small and simple enough that it might have been found manually or naturally. Unlike almost all of the new spaceships, there is hope that this spaceship can be constructed from gliders, and thus have a spaceship gun made for it. It has a nice set of sparks at the back. This spaceship is symmetric but is not glide-reflective.

Small period 4 spaceship (speed c/2):

```
..O.......
.OOOOO....
OO...OO.O.
.O.......O
..OO..O.O.
..........
..OO..O.O.
.O.......O
OO...OO.O.
.OOOOO....
..O.......
```

The two halves of the spaceship interact in only one place in one generation, and therefore one half of the spaceship can be supported by a standard spaceship if that single reaction is preserved. This is shown below.

Half of small period 4 spaceship supported by HWSS (speed c/2):

```
...0......
.00.......
.0..000..0
.0....000.
..000..00.
..........
....00....
..0....0..
.0........
.0.....0..
.000000...
```

The following shows the two halves of the ship split apart with an OWSS between them, so that the new and old ships support each other.

Small period 4 spaceship halves and OWSS supporting each other (speed c/2):

```
......0.......
....00........
....0..000..0.
....0....000..
.....000..00..
..............
...00000......
..0000000.....
.00.00000.....
..00..........
..............
..............
......0.......
....00...00.00
....0..0.00...
....0..0000...
.....00.0.....
```

Several other sizes of OWSS can also be supported by the halves of this new spaceship. Following is the largest OWSS that is known to be supported.

Halves of small period 4 spaceship and large OWSS supporting each other (speed c/2):

```
.....0.........
....00000......
...00...00.0...
....0.......0..
.....00..0.0...
...............
..0...........0
```

```
.O.............
.O............O
.OOOOOOOOOOOOO.
...............
...............
.....O.........
....OOO.OOOO...
...OO.OO.......
....O.....O....
.....OO.O......
```

After Hartmut found this new small spaceship, I tried looking for tagalongs for it. During this search, I stumbled across an almost-tagalong which attempted to produce blinkers as puffer output, but which self-destructed. Searching specially to make this partial result work, I found the following two related puffers.

Two related period 8 blinker puffers (speed c/2):

```
.............OOO.
............OOOOO
...........OO.OOO
............OO...
.................
.................
.........O.O.....
..O.....O..O.....
.OOOOO...O.O.....
OO...OO.OO.......
.O.......O.......
..OO..O..O.......
..........O......
..OO..O..O.......
.O.......O.......
OO...OO.OO.......
.OOOOO...O.O.....
..O.....O..O.....
.........O.O.....
.................
.................
............OO...
...........OO.OOO
............OOOOO
.............OOO.
```

```
.............OOOO.
.............O...O
.............O....
..............O..O
.................O
...............O.O
.............OO...
.............O..O.
.........O.OOO.OOO
..O.....O..O......
.OOOOO...O.O......
OO...OO.OO........
.O.......O........
..OO..O..O........
..........O.......
..OO..O..O........
.O.......O........
OO...OO.OO........
.OOOOO...O.O......
..O.....O..O......
.........O.OOO.OOO
.............O..O.
.............OO...
...............O.O
.................O
..............O..O
.............O....
.............O...O
.............OOOO.
```

These puffers produce a row of blinkers, with one blinker every 8 generations. The puffer output is the same as Robert Wainwright's blinker puffer. However, unlike the previous puffer, the engine is period 4, and only the puffer output is period 8. The blinker puffers will be used in my next Life article.

The next and last article in this series will deal with the only known period 5 spaceship, and with the methods for making spaceships which have an arbitrarily large period.

5 The only (known) period 5 Spaceship

This is the sixth and last in a series of articles concerning Conway's Game of Life. In this article, I will show the only period 5 spaceship known, discuss methods for creating spaceships with an arbitrarily large period, and show a couple of objects which are not truly spaceships, but which could be considered spaceship-like.

Period 5 spaceships could exist in one of three types. They could be orthogonal and have a speed of c/5 or 2c/5, or they could be diagonal with a speed of c/5. No period 5 spaceship with a speed of c/5 is known.

For a speed of 2c/5, only one basic period 5 spaceship is known. Dean Hickerson found this on July 23, 1991. This spaceship is amazingly small, which made its finding possible. If any other period 5 spaceships exist, they appear to be too large to find using the current search programs.

Dean's period 5 spaceship is shown below.

Only known basic period 5 spaceship (speed 2c/5):

```
......O.O..
...O....O..
..OOO....O.
.O.O.......
OO..OO....O
.OO..OOOOO.
...........
...........
...........
.OO..OOOOO.
OO..OO....O
.O.O.......
..OOO....O.
...O....O..
......O.O..
```

This basic spaceship is unique because its speed is not the inverse of an integer. All other known basic spaceships have a speed of c/2, c/3, c/4, or c/12, which are all inverses of integers. Period 5 is the smallest period where a non-integral inverse speed is possible.

Dean's spaceship has several nice sparks, to which tagalongs could be expected to be attached. But only a small number of tagalongs have been found for the spaceship, and these require two copies of the spaceship to be placed side by side so that the edge sparks are adjacent. These tagalongs are shown below.

Three tagalongs for period 5 spaceship (speed 2c/5):

```
.....OO..O...        .....OO..O.......        .....OO..O.........
.....OOO.....        .....OOO.........        .....OOO...........
.OOO.O.......        .OOO.O...........        .OOO.O.............
```

```
O.O.O.OOO.O..      O.O.O.OOO.O......      O.O.O.OOO.O........
O...OOOOOO...      O...OOOOOO.......      O...OOOOOO.........
O............      O................      O..................
.O.O.........      .O.O.............      .O.O...............
.............      .................      ...................
.O.O.........      .O.O.............      .O.O...............
O............      O................      O..................
O...OOOOOO...      O...OOOOOO.......      O...OOOOOO.........
O.O.O.OOO.O..      O.O.O.OOO.O......      O.O.O.OOO.O........
.OOO.O.......      .OOO.O...........      .OOO.O.............
.....OOO.....      .....OOO.........      .....OOO...........
.....OO..O...      .....OO..O.......      .....OO..O.........
.............      ...............OO      ...................
..........OO.      ..........OO...OO      ..........OO....O.O
..........OOO      ..........OOO....      ..........OOO..O...
..........OO.      ..........OO...OO      ..........OO...O..O
.............      ...............OO      ................O..
.....OO..O...      .....OO..O.......      .....OO..O.........
.....OOO.....      .....OOO.........      .....OOO...........
.OOO.O.......      .OOO.O...........      .OOO.O.............
O.O.O.OOO.O..      O.O.O.OOO.O......      O.O.O.OOO.O........
O...OOOOOO...      O...OOOOOO.......      O...OOOOOO.........
O............      O................      O..................
.O.O.........      .O.O.............      .O.O...............
.............      .................      ...................
.O.O.........      .O.O.............      .O.O...............
O............      O................      O..................
O...OOOOOO...      O...OOOOOO.......      O...OOOOOO.........
O.O.O.OOO.O..      O.O.O.OOO.O......      O.O.O.OOO.O........
.OOO.O.......      .OOO.O...........      .OOO.O.............
.....OOO.....      .....OOO.........      .....OOO...........
.....OO..O...      .....OO..O.......      .....OO..O.........
```

The first tagalong at the left was found manually by Robert Wainwright. The other two tagalongs shown are tagalongs for that tagalong. The one in the middle was found by me using my search program. The one on the right was also found manually by Robert Wainwright. The tagalong on the right will appear if one of the blocks in the middle tagalong is removed.

Obviously the tagalongs above could be used to create a very wide spaceship by joining many base spaceships together. But there is no known way to make a longer spaceship.

Except for the Corderships, all known spaceships with a period larger than 5 are composite constructions that require the use of at least one low period spaceship to support a tagalong or puffer engine. Because of the use of low period spaceships, the speeds of all these higher period spaceships are restricted to the same speeds as the base spaceships they use. So all known spaceships have speeds of c/2, c/3, c/4, 2c/5, or c/12, no matter what their period is.

The situation is even worse than the statement above, because except for a few period 9 c/3 spaceships, and a few period 6 spaceships made from a period 6 tagalong to a period 2 spaceship, all known multiple-period spaceships are based on the standard spaceships. Therefore, these other multiple-period spaceships all travel at the common orthogonal speed of c/2.

For the remainder of this article I will usually be showing puffer trains instead of spaceships. The reason for this is that usually puffer trains are more useful than bare spaceships because you can build things with them, and secondly the output of a puffer train can usually be destroyed to turn it into an actual spaceship if desired. Therefore, the objects shown will not have the puffer output deleted.

Much of the common puffer debris can be deleted easily by perturbations using standard spaceships. Examples of this are shown below.

Loaf, block, blinker, and gliders being deleted by passing spaceships:

```
...OO..
..OO.OO
...OOOO
....OO.
.......
.......
.......
..O....
.O.O...
O..O...
.OO....
.......
....O..
..O...O
.O.....
.O....O
.OOOOO.
```

```
OO.....
OO.....
.......
....O..
..O...O
.O.....
.O....O
.OOOOO.
```

```
.O.....
.O.....
.O.....
.......
...OO..
.O....O
O......
O.....O
OOOOOO.
```

```
...O.
.O.O.
..OO.
.....
.....
..OO.
.OOOO
OO.OO
.OO..
```

```
...O..
...O.O
...OO.
......
......
.O..O.
O.....
O...O.
OOOO..
```

Other debris such as beehives and loaves in the other orientation are not as easy to destroy. They and other debris can be destroyed by passing rakes (puffer trains which produce streams of gliders). Alternatively, in many cases the debris can be suppressed by perturbing the debris with a passing spaceship before it stabilizes into the beehive or loaf. So even though most of the objects are puffer trains, they can all be converted into spaceships of the same period by adding extra standard spaceships or rakes.

Many of the puffer trains and spaceships shown in the remainder of this article are rather large. Their pictures have been compressed when necessary by replacing sets of 10 adjacent periods with a dollar sign. Use an editor to replace each dollar sign by ten periods to restore the full picture.

There are many periods which are constructible using standard spaceships and a puffer engine or tagalong. Each puffer engine has a reasonably small period, which must be a multiple of 4 because of their use of standard spaceships to support the puffer engine. The puffer output can either be of the same period as the puffer engine, or a small multiple of it.

Following are five of the basic puffer engines or tagalongs which are used to produce puffer-based output. This list does not include the period 8 blinker puffers, which I will cover separately a little later.

Five basic puffer engines:

```
    A
0000.....
0...0....
0........
.0..0..00
......000
.0..0..00
0........
0...0....
0000.....
```

```
    B
.00.......
00.00.....
.0000.....
..00......
..........
..........
....0.....
...00.....
..00......
...00.....
..........
..........
..........
..........
....00000.
....0....0
....0.....
.....0....
```

```
  C
.00..
00.00
.0000
..00.
.....
.....
....0
...00
..00.
...00
.....
.....
.....
.....
.00..
00.00
.0000
..00.
```

```
        D
...00............
..00.0000........
...000000........
....0000.........
.................
.................
0000000000.......
0................
0................
.0...............
.................
.................
.................
...00............
..00.0000...00...
...000000..00.000
....0000....00000
.............000.
```

```
   E
.00.....
00.0000.
.000000.
..0000..
........
.....00.
........
..00....
.0....00
.0....0.
.00.....
...0....
........
...0....
.00.....
.0....0.
.0....00
..00....
........
.....00.
........
..0000..
.000000.
00.0000.
.00.....
```

These puffer engines labeled above with letters are described as follows.

- Puffer A: The Schick engine, with period 12. By itself, leaves no exhaust.
- Puffer B: Period 12 engine found by David Buckingham. By itself, produces a tub every 24

generations.

- Puffer C: Period 20 engine found by Bill Gosper. By itself, it becomes a period 140 puffer which leaves much debris (after about 2000 generations).
- Puffer D: Period 20 engine found by Robert Wainwright. By itself, produces a loaf every 40 generations.
- Puffer E: Period 32 engine found by Bill Gosper. By itself, produces 4 blinkers and a pair of bookends every 128 generations. This was the first puffer train found.

Based on these puffer engines, spaceships can be constructed which have periods of 12, 20, 24, 32, 36, 40, 48, 60, 64, 72, 80, 84, 96, 120, 128, and 140. These higher periods are created by perturbing the puffer debris produced by the basic puffer engine with extra standard spaceships. The most useful results to obtain are single gliders (rakes), since then the gliders can easily be combined to produce other useful results. I do not want to devote much room here for cataloging all these puffer trains since most of the results are old and are easy enough to rediscover. Two examples of puffer trains are given here, and several others are shown in the rest of this article.

Period 32 backwards glider puffer:

```
.................................00000.
.............0000................0....0
.0..........000000...............0.....
0..........00.0000................0....
0.....0.....00.........................
000000.................................
.......................................
.......................................
....000................................
.....00................................
..0....................................
.00....................................
00.....................................
.00....................................
.......................................
.......................................
.......................................
.00....................................
00.....................................
.00....................................
..0....................................
.....00................................
....000................................
.......................................
.......................................
000000.................................
0.....0.....0..........................
0..........0...........................
.0.........0.....0.....................
...........000000......................
```

Period 60 backwards glider puffer:

```
..................O....................
.................O.....................
.................O...O.................
.................OOOO..................
.......................OOO.............
.......................OO.OO...........
.......................OOO.............
.O........OO.....OOOO..................
O........OOOO....O...O.................
O...O...OO.OO....O.....................
OOOO.....OO.......O....................
.......................................
.......................................
.......................................
....O..................................
..OO...................................
..O....................................
..O....................................
...O.............................O.....
................................O......
................................O.....O
.O..............................OOOOOO.
O......................................
O...O..................................
OOOO.............OOOO..................
.................O...O.................
.................O.....................
..................O....................
```

By combining spaceships using reactions between gliders produced by the puffers, you can also generate the least common multiples of these periods. The simplest way of doing this is simply by running the two spaceships side by side. Better examples can be constructed by having the spaceships interact slightly in some manner.

All of the above results only produce a limited number of periods for puffer trains and spaceships. Dean Hickerson wondered whether it was possible to produce a puffer train which had an arbitrarily large period. This turned out to be possible, and now there are three different methods known to make these puffers. Most of the remainder of this article will describe these methods in detail.

The first two methods can only produce puffers whose periods are a base period times any power of two. For this reason, these are called "period doubling" methods. One of these two methods was thought of by Dean Hickerson, and the other method was thought of by Paul Callahan.

Dean Hickerson's method of period doubling uses glider puffers of period N. Three of these are used to collide triples of gliders together to produce a MWSS which then travels with the puffers. The next time a triple of gliders arrive together to attempt to create another MWSS, they collide with the already present MWSS. This collision destroys the spaceship and two of the gliders, letting the third glider escape. This produces a puffer of period 2N.

Since the creation of a spaceship requires gliders which travel both forwards and backwards, two types of such puffers are used in order to repeat this process for larger periods. The first type produces a glider which travels in the forwards direction, whereas the second type produces a glider which travels in the backwards direction. (Actually, only one type of puffer is required if a two-glider reaction known as a "kick-back" is used to reverse the direction of a glider. But doing this requires using another copy of the puffer, and so is less efficient.)

The following is a period 80 forwards glider puffer train composed of three sets of period 40 glider puffers, and a trailing spaceship to clean up the final reaction. Two of the period 40 glider puffers are forwards glider puffers, and the third period 40 glider puffer is a backwards glider puffer.

Period 80 puffer train producing forwards gliders:

```
$$$$$$...000$$$........
$$$$$$..00000$$$.......
$$.........0$$$.00.000$$$.......
$........00.......0...0$.....000$..00$$$$
$.......0000.....0$.........00000$$$$$...
$......00.00.....0....0$...00.000$$$$$...
$.......00.......00000$.....00$$$$$......
$$$$$$$$$$....
$$..0$$$$$$$$.
$$....0$$.....00$$.....00$$.....
$$00..0....00$$00$$...00.0000$$.
$.........0.....0.000..0$........0.00$$..000000$$.
$........00..0.0..00000.0$..00......0$$...0000$$..
$.........00...0.....00.00$.00....000$$$$.........
$$000.......0..0$...0...000$$$$$
$$$$$.0$$$$$..
$$$.00$........0$$$$$..
$........00$$$$$..00...00000.00$.........
$.......0000....0000$$$$..000..00..0000$$
$......00.00....0...0$$$$..0000..0...0$$.
$.......00......0$0000$$$...0.000$$......
$$......0..0.....000000$$$...00$$........
$$$....00.0000$$$$$$...
$$$.....00$$$$$$.......
$$$$$$$$........000$...
$$$$$$$$.......00000$..
$$$$$$$$......00.000........00..
$$$$$$$$.0.0...00.........0....0
$$$$$$$$.00$....0......
$$$$$$$$..0$....0.....0
$$$$$$$$$.......000000.
$$$$$$$$$$....
$$$$$$$$$$....
$$$$$$$$.........00$...
$$$$$$$$........00.00$.
$$$$$$$$.........0000$.
$$$$$$$$$00$..
$$$$$$$$$$....
$$$$$$$$$$....
$$$$$$$$.....000$......
$$$$$$$$.....0$........
$$$$$$$$......0$.......
```

```
$$$$$$$$$$....
$$..OO.......OOOOO$$$.......OOO$$........
$$.OO.OO.....O....O$$$........O$$........
$$..OOOO.....O$$$$..O$$.........
$$...OO.......O...O$$$$$$.......
$$$....O$$$$$$.........
$$$$$$$$$$....
$$.....OOO$$O$$......OOO$$......
$$....OO...O$........OOO$$....O$$........
$$...OO..O.O$....O..O.OOOO$$...O$$.......
$$....O.....O.....OO.....O.O.....OOO$$$$$
$$.....OO..O......OOO....O.......OOO$$$$$
$$.........O$....OO.O...OO$$$$$.
$$.......O$.........OO..O$$$$$..
$$$.O..O$.OO$$$$$......
$$..OO......O$$$$$$$$...
$$.OO.OO....O...O$$$$$$.........
$$..OOOO....OOOO$.........OOOOO.......OOO.....O$$$
$$...OO$$........O....O......O.....O...O$$........
$$$$$...O$..O...O$$$...
$$$$$....O...O$.O....O$$........
$$.OO$$$...O$...OOOOO$$.........
$.........O....O$$$$$$$.........
$........O$$$$$$$$$.....
$........O.....O$$$$$$$.........
.O..O.....OO......OOOOOO$$$$$$$$
O........OOOO$$$$$$$$$.
O...O...OO.OO$$$$..OOO..OOO.....O$$$.....
OOOO.....OO$$$$....O$.O.O$$$....
$$$$$......O...OO..OOO.OO$$$....
$$$$$$....OO$$$........
......OO$$.......OOO$$$$$$......
....O....OOO...OO$........OOO$$$$$$......
..OO....OOOOO...O.OOO$.OO..O..OO$$$$$$...
..O......OO..O...OOO$.......O..O$$$$$$...
..O.........OO....O$.......O...O$.........OOOOOO$$$........
...O..O$$$..O$$O.....O$$$.......
.....O$$.........OOOO$$.O$$$$...
$$$..O...OO$$...O....O$$$.......
.O..O$$.....O...O$$........OO$$$.........
O.........OO$.......O$$$$$$$....
O...O....OO.OOO$....O....O$...O$$$$$.....
OOOO......OOOOO$....OOOOO$..O...O$$$$$...
$.OOO$$$.O$$$$$........
$$$$.....O....O$$$$$...
$$$$.....OOOOO$$$$$....
```

The following is the other type of puffer required to continue the process. This is a period 80 backwards glider puffer. This also uses the same three period 40 glider puffers as in the above period 80 glider puffer, but the reactions of the three gliders are slightly different. Here there are three trailing spaceships instead of just one to clean up the debris.

Period 80 puffer train producing backwards gliders:

```
$$$$$.00000$$$$..
$$$$$.0....0$$$$.
$.......000$$$.0$$$$......
......0000......00000$....00000$..0...0$$$$.
......0...0....00.000$....0....0$...0$$$$...
......0.........00$.......0$$$$$$..
.......0..0$$.....0...0$$........00$$.......
$$$........0$$........0....0$$.....
$$$$$$......0$$$.
.........00...00$$$$$0.....0$$.....
........0.0......0$........0..0$$......000000$$......
........0......0..0$....00.0000$$$$$........
........000.......00$.........0$$$$$........
$.......00$......0000$$$$$.........
$$$.....0..0$$.......00$$$
$$$$$$......0.0$$.........
$$$$$$.00.....0$$.........
......0000.....00$$$$...00.0..000$$.........
......0...0...00.00$$$$..0..00$$$..
......0........0000$$$$.....00$$$..
.......0..0.....00......000000$$$...0$$$....
$$....0.....0$$$$$$$.......
$$....0$$$$$$$$...
$$.....0....0$$$$$$$.......
$$.......00$$$$.0.....00000$.......
$$$$$$.........0......0....0$......
$$$$$$.........000....0$$.
$$$$$$$.......0...0$......
$$$$$$$.........0$........
$$$$$$$$$........
$$$$$$$$..00000$.
$$$$$$$$..0....0$
$$$$$$$$..0$.....
$$$$$$$$...0...0$
$$$$$$$$0....0$..
$$$$$$$.........0$........
$$$$$$$.........000$......
$$$$$$$$$........
$$$$$$$$$........
$$$$$$$$$........
$$$$$$$$$........
$$$$$$$$$........
$$$$$$$$00000........00...
$$$$$$$$0....0.......00...
$$$..000$$$$.....0$.......
$$.0000......00000$$$$.....0...0.........0..
$$.0...0....00.000$$$$.......0.........0...0
$$.0.........00$$$$$.........0.....
$$..0..0$$$$$$......0....0
$$$$$.........0$......00$....00000.
$$......0$$$..00$.....0.0$.........
```

```
$$....000$$$.0.0$.....0$..0........
$$...0...0.........0$$$$.........0...0......
$$...0....000....00$$$$.........0$.
$$...00.0.000.....0.0..0$$$$....0....0......
$$.....0...00......00..0$$$$....00000.......
$$......0.0$$$$$$.........
$$$$$$$$$........
$$$$$$$$$........
$$.0000.....00$$$....00$$$
$$.0...0...00.00$$000.........0.0$$.........
$$.0........0000$.........00000........0$$$.
$$..0..0.....00$.........00.000$..00000$$...
$$$$$...00$.....0....0$$..
$$$$$$$0$$.......
$$$$$$$.0...0$$..
$........000000$$$$.........0$$....
$........0.....0$$$$$$$...
$........0$$$$$$$.........
0000.....00........0....0$$$.00$$$$
0...0...00.00........00$$$...0.0...00...000$$........
0........0000$$$$...0.........0...0$$.......
.0..0.....00$$$$$..00....0$$.......
$$$.......0$$.........0.0$$........
$.......0$........000$$$$$.........
...00.......0...0.0$......00000$$$$$........
..0.0...00...0000.0.00$....00.0.00$$00$$$...
..0$.00.000.0$.....00...0$........0....0$$$.
..000........00....00$......00...0$.......0$$$.......
$.........0$.........0.0$........0.....0$$$.
$$$........00$$000000$$$..
$$$$$$$$$........
$.000$$$$$$$$$....
0000......00000$....00000$$$$$$....
0...0....00.000$....0....0$$$$$$...
0.........00$.......0$$$$$$........
.0..0$$.....0...0$00000$$$$........
$$$..0$..0....0$$$$.......
$$$$.....0$$$$$..
$$$$......0...0$$$$.......
$$$$........0$$$$.........
```

This process can be repeated indefinitely to produce glider puffers of periods which are of the form 40 * 2^N. For example, to produce the forwards and backwards glider puffers of period 160, use two copies of the above period 80 forwards glider puffer and one copy of the period 80 backwards glider puffer. Position them so that the three gliders react in the same manner as in the back of the period 80 puffers, and add the spaceships at the back to clean up the reactions just as in the period 80 puffers.

Dean Hickerson's method of period doubling is very expensive in terms of basic components. Since three puffers of period N are required for period 2N, then for period M$2^N, a total of 3^N puffers of order M are required, where M is the order of the basic glider puffer. Dean Hickerson later found a method for producing a standard spaceship using just two gliders and a perturbing spaceship. This reduces the number of puffers needed from 3^N to 2^N. Dean stopped working on his method when he heard about Paul Callahan's construction method.

Paul Callahan's method of period doubling is more complicated in concept, but requires only a linear increase in puffers for each doubling. His method uses a row of beehives along with sets of three gliders which produce the moving spaceship. A set of three new gliders is produced every time one of the beehives is detected (and deleted) by another glider. When the created spaceship is destroyed by its interaction with another set of three gliders, a new beehive is produced at the back. Since the produced beehives are produced half as often as the consumed ones, the period is doubled.

The following shows how a period 48 beehive puffer train is doubled to form a period 96 beehive puffer. At the left is a period 48 beehive puffer train. The rest of the construction is used to delete those beehives and lay down new beehives with twice the separation. You can repeatedly add the rest of the construction to the end to similarly double the separation of the beehives as often as desired. The final beehives can easily be suppressed by using a spaceship to perturb the debris before it forms the beehive. For larger periods, extra gliders also begin to escape from the puffers, which can also be suppressed with spaceships. This will produce a true spaceship with an arbitrarily large period of the form 48 * 2^N.

Period 96 beehive puffer train:

```
$$$$$$$$$$$$$$$$.......OO$$$$$$$$$$....
$$$$$$$$$$$OOOOOO$$$$.........O....O$$$$$$$$$$..
$$$$$$$$$$$O.....O$$$$.......O$$$$$$$$$$........
$$$$$$$$$$$O$$$$$...O.....O$$$$$$$$$$..
$$$$$$$$$$$.O....O$$$$.......OOOOOO$$$$$$$$$$...
$$$$$$$$$$$...OO$$$$$$$$$$$$$$$........
$$$$$$$$$........OOOO$$$$$.O..O$$$$$$$$$$$......
$$$$$$$$$........O...O$$$$.........O$$$$$$$$$$$$
$$$$$$$$$........O$$$$$...O...O$$$$$$$$$$$......
$$$$$$$$$.........O..O..OO........O.O$$$....OOOO$$$$$$$$$$$.......
$$$$$$$$$$....OOO.........OO$$$OOO$O$$$$$$$$$$$.
$$$$$$$$$.........O..O..OO.........O$$$$.OO.OO.........OO$$$$$$$$$.........
$$$$$$$$$........O$$$$$.........OOO$OO$$$$$$$$$$
$$$$$$$$$........O...O$$$$.........OOOO$$$$$$$$$$$.......
$$$$$$.......OOOOOO$$.....OOOO$$$$$O...O$$$$$$$$$$$......
$$$$$$.......O.....O$$$$$.........O.O$......O$$$$$$$$$$$$
$$$$$$.......O$$$$...OO$$.OO$.......O..O.........OOOO$.........O$$$$$$$$...
$$$$$$........O....O$$$......OO.OOOO$.......O$$$OOOOOO$.........OO$$$$$$$$.
$$$$$$$OO$$$.........OOOOOO$$$$.......OO.OOOO$........OO$$$$$$$$..
$$$$$.....OOOO$$$$$...OOOO$$$$.........OO$$$$$$$$$$......
$$$$$.....O...O$$$$$$$$$$$$$$$$$$$$$...
$$$$$.....O$$$$$$$$$.....O.O....O$$$$$$$$$$$....
$$$$$......O..O..OO........O.O$$$$$$$.......OO...OO$$$$........O$$$$$$.....
$$$$$$.OOO.........OO$$$$$$$.......O....O.O$$$$........OO$$$$$$...
$$$$$......O..O..OO.........O$$$$$$$$$$$$$...OO$$$$$$....
$$$$$.....O$$$$$$$$$$$$$$$$$$$$$.......
$$$$$.....O...O$$$$$$$$$$$$.....OO$$$$$$$$......
$$$$$.....OOOO$$$$$$$$$$$O.O$..O.O$$..O$$$$$$...
$$$$$$$$$O.O$$$$$$$.......OO$....O$$..O.O$$$$$$.
$$$$$$........OO$$.OO$$$$$$$.......O$$$........OO$$$$$$..
$$$$$$.......OO.OOOO$.......O$$$$$$$$$$$$$$$$$$.
```

```
$$$$$$........000000$$$$$$$$$$$$$$$$$$$.........
$$$$$$.........0000$$$$$$$$$$$$$$$$$$$........0.
$$$$$$$$$$$$$$......0$$$$$$$$$$$$...0.0
$$$$$$$$$$........0.0$$$....00$$$$$$$$$$$$...0.0
$$$$$$$$$$.........00$$$....0.0$$$$$$$$$$$$...0.
$$....0000$$$$$$$$.0$$$$$$$$$$$$$$$$...
$$...000000$$$$$$$$$$$$$$$$$$$$$$$$....
$$..00.0000$$$$$$$$$$$$00$$$$$$$$$$$$..
$$...00$$$$$$$$$$$$...0.0$$$$$....0.0$...0$$$$$.
$$$.........0$$...0$$...0$$...0$....0.0$$.0$$$$$.....00$...0.0$$$$.........
.0..0$$$...0.0$$.0.0$$.0.0$$.0.0$....00$$$$$$$.......0$....00$$$$$
0$$$.......0.0$$.0.0$$.0.0$$.0.0$....0$$$$$$$$$$$$$$.....
0...0.......0$$......0$$...0$$...0$$...0$$$$$$$$$$$.....0$$$$.....
0000....0...000$$$$$$$$$$$......00$$$$$$$$$..0...0$$$$...
......00.....00$$$$$$$$$$$.....0.0$$$$$$$$$.0$$$$........
......000......0$$$$$$$$$$$......0$$$$$$$$$.0....0$$$$...
......00.....00$....0$$$$$$$$$$$$$$$$$$$....00000$$$..00$
0000....0...000...0........000.0$$$$$$$$$$$$$$$$$$$$$$$$.
0...0.......0....0.0.......0....0$$$$$$$$$$$$$$$$$$$$$$........000.........
0$......0.0........0000$$$$$$$$.00$$$$$$$$$$$$$$$........
.0..0$$....0.0$$$$$$$$0.0$$$$$$$$$$$$$$$........
$....0...0$$$$$$$$$.....0$$$$$$$$$$.........00$$$...000000........
$...0$$$$$$00$$$$$$$$$$$$$$........0.0$$$..0.....0.......
$...0....0$$$$$...0....0$$$$$$$$$$$$$$......0$$$....0$...
$...00000$$$$$...0$$$$$$$$$$$$$$$$$$........0....0.......
$$......0$$$$....0.....0$.......00$$$$$$$$$$$$$$$$.....00.........
$$....0...0$$$$..000000$.......0.0$$$$$$$$$$$$$$$$$......
$$...0$$$......00$$$....0$$$$$$$$$$$$.00$$$$$...
$$...0....0$$$0000$$$$$$$$$$$$$$$.....0.0$$$$$..
$$...00000$$00.00$$$$$$$$$$$$$$$$.....0$$$$$....
$$$$$.........00$$$$$$$$$$$$$$$$$$$$$..
$$$$$$.....0.0.........00$$$$$$$$$$$$$$$$$$$....
$$$$$$....00..0.......0.0$$$$$$$$$$$$$$$$$$$....
$$$$$$.....0.0$0$$$$$$$$$$$$$...00$$$$$.........
$$$$$.........00$$$$$$$$$$$$$.........00$0.0$$$$$........
$$$$$........00.00$$$$$$$$$$$$$......0000.........0$$$$$$
$$$$$.........0000$$$$$$$$$$$$$.....00.00$$$$$$$
$$$$$$00$$$$$$$$$$$$$.......00$$$$$$$..
$$$$$$$$$$$$$$$$$$$$$$$$$$$...
$$$$$$$.00$$$$$$$$$$$$$...00$$$$$$.....
$$$$$$$00.0000$$$$$$$$$$$0..0$....00$$$$$$......
$$$$$$$.000000$$$$$$$$$$.........0$.......0$$$$$$........
$$$$$$$..0000$$$$$$$$$$$0...0.......0......0$$$$$$.......
$$$$$$$$$$$$$$$$$$......0000....0...000$$$$$$$..
$$$$$$$$$$$$$$$$$$$..00.....00$$$$$$$..
$$$$$$$$$$$$$$$$$$$..000......0.......0..0$$$$$$
$$$$$$$$$$$$$$$$$$$..00.....00.......000.0$$$$$$
$$$$$$$$$$$$$$$$$$......0000....0...000........0.0$$$$$$.
$$$$$$$$$$$$$$$$$$......0...0.......0.........0$$$$$$....
$$$$$$$$$$$$$$$$$$......0$$$$$$$$......
$$$$$$$$$$$$$$$$$$.......0..0$$$$$$$$..
$$$$$$$$$$$$$$$$$$$......0000$$$$$$$...
$$$$$$$$$$$$$$$$$$$.....000000........0.00$$$$$$
$$$$$$$$$$$$$$$$$$$....00.0000.........00$$$$$$.
```

```
$$$$$$$$$$$$$$$$$$$.....OO$..O$$$$$$...
$$$$$$$$$$$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$$$$.....OO$$$$$$......
$$$$$$$$$$$$$$$$$$$$....OO.OO$$$$$$....
$$$$$$$$$$$$$$$$$$$$.....OOOO$$$$$$....
$$$$$$$$$$$$$$$$$$$$......OO$$$$$$.....
```

Both of the above methods of making arbitrarily large period spaceships only produce a few of the possible periods. Starting with a basic beehive or glider puffer train, the methods only produce periods which are a power of two times the base period, which is a geometric progression.

The newest method of making arbitrarily large periods is more versatile than either of the previous methods. For instead of a geometric progression, periods in an arithmetic progression can be constructed. The concepts and constructions for this method were the work of several people. The base blinker puffers were found by Robert Wainwright and myself, the impetus for playing with them was provided by Bill Gosper, the glider reactions that are needed to make it work were found by Dean Hickerson, and the final construction method for making the large period puffers was by me. I will spend most of the rest of this article describing this method in detail.

The method uses one of two different blinker puffers, and an interesting reaction which burns the blinkers cleanly at a rate faster than the blinkers are produced. These blinker puffers have been shown in previous articles, but I will show them again here for convenience. The first one was found by Robert Wainwright, and the second one by myself. These both produce identical output, consisting of a row of blinkers, with a period of 8.

Two period 8 blinker puffers:

```
.OO......        ............OO...
OO.OOO...        ...........OO.OOO
.OOOOO...        ............OOOOO
..OOO....        .............OOO.
.........        .................
.........        ..........OOO....
.OOOOO...        ..OO.O.OOOO.O....
.O.......        .O...............
.O.......        OO.OO............
..O......        .OOO.OO.O........
....O....        ..O....O.........
.........        .........O.......
.........        ..O....O.........
...OO....        .OOO.OO.O........
..OO.OOOO        OO.OO............
...OOOOOO        .O...............
....OOOO.        ..OO.O.OOOO.O....
                 ..........OOO....
                 .................
                 .............OOO.
                 ............OOOOO
                 ...........OO.OOO
                 ............OO...
```

The puffer on the left is generally more convenient because of its smaller size, but the puffer on the right does have some advantages, as we will see.

The reaction which burns the blinkers can be initiated by adding one ON cell to the end of a row of produced blinkers to turn the last blinker into a set of traffic lights at the end. This will leave some debris at the end, but the rest of the blinkers will then burn cleanly. A reaction of this kind where a repeating unit burns is called a "fuse" (whether or not the burning produces any debris). The burning used here is a clean blinker fuse.

A way to ignite the blinkers without leaving any debris at all is to hit one of the two end blinkers symmetrically with two gliders. These gliders will also ignite the blinker fuse if they hit any of the other blinkers in the row in the same manner, but in those cases one or more blinkers at the end of the row will be left. For example, hitting the fifth-from-the-end blinker will ignite the fuse but leave three blinkers remaining at the end of the row.

The following shows the gliders hitting the last blinker in the row.

Two gliders cleanly igniting blinkers produced by blinker puffer:

```
.OO....................
OO.OOO.................
.OOOOO................O
..OOO...............OO.
.....................OO
.......................
.OOOOO.................
.O......O...O...O...O..
.O......O...O...O...O..
..O.....O...O...O...O..
....O..................
.......................
.....................OO
...OO...............OO.
..OO.OOOO.............O
...OOOOOO..............
....OOOO...............
```

Once the fuse is lit, it burns with a period of 18 at a speed of 2c/3. When the fuse reaches the puffer engine, the reaction disconnects and the blinker puffer begins to lay down a new row of blinkers. The disconnected reaction can have one of three different outcomes (for each puffer). The outcome is dependent on how many blinkers are present at the time the blinkers are ignited. Some of these reactions leave some debris, some die out quickly, and some die out after making a large debris cloud. The one shown above terminates in a large debris cloud which dies out. This is the most useful behavior since the debris can be tweaked by spaceships to do useful things before it dies.

One of the three reactions for my blinker puffer is vigorous and almost reignites the new row of blinkers being laid down by the puffer train. It turns out that most reactions that reach the row of blinkers fail to reignite it. Even if the row is reignited, there are three different outcomes and so there is a 2/3 chance that the wrong kind of outcome will then occur. If the reaction happens to work, however, then a large period puffer (or spaceship) has been found.

By perturbing the vigorous reaction from my blinker puffer with two LWSSs I found the first large period puffer train based on these ideas. This is a relatively dirty puffer with period 292. The reaction products are two blinkers, two blocks, two loaves, two boats, six beehives, and four gliders.

Dirty period 292 puffer train:

```
.......................OOOO.
.......................O...O
.............O.........O....
...........O...O........O..O
............O...............
............O....O..........
............OOOOO...........
............................
............................
...........O................
..OO.O...OO.OO..............
.O..OOOOO.O.................
.O..O.OO.OO.................
.OO...OOO.OO........OO.O..OO
...O......OO.......O.O.OOOOO
........OO...OOO.O..........
...O......OO.......O.O.OOOOO
.OO...OOO.OO........OO.O..OO
.O..O.OO.OO.................
.O..OOOOO.O.................
..OO.O...OO.OO..............
...........O................
............................
............................
............OOOOO...........
............O....O..........
............O...............
.............O...O......O..O
...............O.......O....
.......................O...O
.......................OOOO.
```

One curious thing about this puffer train is that its period of 292 is NOT a multiple of 8. Instead, 292 is 4 (mod 8). This is highly unusual. Usually, puffer output from a compound reaction must be a multiple of the base reaction. In this puffer, though, it is not. How this is possible is explained by the fact that only the puffer output from the base engine is of period 8, whereas the base engine itself is actually only of period 4. When the fuse reaches the puffer engine and disconnects, the row of blinkers is restarted with a phase shift of 4 generations. This allows puffer trains to exist which are a multiple of 4 instead of a multiple of 8. This feature is what makes this blinker puffer useful even though it is larger. Robert Wainwright's blinker puffer engine is of period 8, and so can only be used to produce puffer output which is a multiple of 8.

The method of tweaking the disconnection clouds to re-ignite the new blinker row can produce many different puffer trains with many different periods. (Probably an infinite number of essentially different puffer trains can be constructed.) But the products of each puffer are different and hard to control, and even worse, there is no control over what the period is. For example, creating a puffer train with period 2000 by randomly tweaking (multiple times probably) the disconnection cloud is not obvious. At any rate it would be very time-consuming to search for.

As part of constructing a new type of sawtooth pattern using a blinker puffer, Dean Hickerson found the following useful reaction. By adding a spaceship to a blinker puffer, a glider can be produced by the disconnection cloud. The produced glider travels backwards and outwards, to the upper right. This reaction is shown below.

Creating a glider from disconnection cloud of blinker fuse:

```
........................OOOOOO.
........................O.....O
........................O......
.........................O....O
...........................OO..
...............................
...............................
...............................
...............................
...............................
...............................
...............................
..OOOOOO.......................
..O.....O......................
..O............................
...O....O......................
.....OO........................
...............OO.O..OO........
..OOOOO.......O.O.OOOOO........
.OOOOOOO..OOO.O................
OO.OOO.O......O.O.OOOOO........
.OO............OO.O..OO........
...............................
...............................
...............................
OOOOO..........................
O....O.........................
O..............................
.O...O.........................
...O...........................
```

Much earlier, and for another purpose, Dean Hickerson had found useful glider turning reactions using spaceships. Some of these are shown below.

In the first one, a forwards glider is converted into another forwards glider, but traveling towards the upper left. This is a 90 degree right handed turn. The upper HWSS does not hinder the glider coming in from a long distance.

Forwards glider converted into other forwards direction:

```
...........OO..
.........O....O
........O......
........O.....O
........OOOOOO.
...............
...............
...............
...............
...............
......O........
....OO.........
.....OO........
...............
...OO..........
.O....O........
O..............
O.....O........
OOOOOO.........
```

In the following, the forwards glider is converted into a backwards glider, traveling towards the lower right. This is a 90 degree left turn. The bottom right MWSS is only needed to delete a block which is created during the reaction. Once again, the upper HWSS does not hinder the glider coming in from a long distance.

Forwards glider converted into backwards glider:

```
..................OOOO..
.................OOOOOO.
................OO.OOOO.
.................OO.....
........................
........................
........................
........................
........................
........................
........................
........................
........................
........................
........................
........................
........................
......O.................
....OO..................
.....OO.................
........................
...OO...............OOO.
.O....O............OOOOO
O.................OO.OOO
O.....O............OO...
```

```
OOOOOO..................
```

In the following, a backwards traveling glider is converted into a forwards moving glider heading towards the lower left. This is a 90 degree right handed turn. The top MWSS is only needed to delete a block which is created during the reaction.

Backwards glider converted into forwards glider:

```
..............................................OOO.
.............................................OOOOO
............................................OO.OOO
.............................................OO...
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
..................................................
......O.O.........................................
.......OO.........................................
.......O..........................................
..O..O............................................
.O................................................
.O...O............................................
.OOOO.............................................
..................................................
..................................................
..........OO......................................
.........OO.OOOO..................................
..........OOOOOO..................................
...........OOOO...................................
```

Combinations of these reactions (and their mirror reflections) can be used to make a glider travel in any desired direction.

After seeing all of the above reactions, I thought of a method of using them along with the blinker puffers to create puffer trains with arbitrarily large periods. How this works is as follows.

Take a blinker puffer with the fuse lit. Add two spaceships on either side of it as shown above to turn the disconnection cloud into two gliders flying symmetrically outwards and backwards from the glider puffer. Use two copies of the last reaction above to turn those gliders into forwards and outwards traveling gliders. Then use two copies of the first reaction to turn the gliders into inwards and forwards traveling gliders. If the reactions are properly placed, then the two final gliders will converge onto the end of the new blinker row, and then re-ignite the blinker row using the method shown previously.

The quickest way to use these reactions in this manner produces the following period 1136 spaceship. This was built independently by myself and by Dean Hickerson, once I announced the construction method. In this object, the third glider turning reactions only needs two spaceships because the parallel reactions run into each other and thereby suppress the creation of the blocks that would need the other two spaceships to clean up.

Period 1136 spaceship using blinker puffer and glider turning reactions:

```
$$$$$$$$$$$..000000.........
$$$$$$$$$$$..0.....0........
$$$$$$$$$$$..0$....
$$$$$$$$$$$...0....0........
$$$$$$$$$$$.....00$
$$$$......00$$$$$$$.........
$$$$....0....0$$$$$$$.......
$$$$...0$$$$$$$$...
$$$$...0.....0$$$$$$$.......
$$$$...000000$$$$$$$........
$$$$$$$$$$$$.......
$$.......00.......00$$$$$$$$.........
$$.....0....0....0000$$$$$$$$........
$$....0.........00.00$$$$$$$$........
$$....0.....0....00$$$$$$$$...000000.
$$....000000$$$$$$$$$0.....0
$$$$$$$$$$$$0......
$$$$$$$$$$$$.0....0
$$$$$$$$$$$$...00..
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
00000$$$$$$$$$$$$..
0....0$$$$$$$$$$$$.
0$$$$$$$$$$$$......
.0...0$$$$$$$$$$$$.
...0$$$$$$$$$$$$...
..000$$$$$$$$$$$$..
.0000.......00.0..00$$$$$$$$$$.......
00.00......0.0.00000$$$$$$$$$$.......
.00....000.0$$$$$$$$$$$.....
$.0.0.00000$$$$$$$$$$.......
$..00.0..00$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
```

```
..OOOOOO$$$$$$$$$$$.........
..O.....O$$$$$$$$$$$........
..O$$$$$$$$$$$$....
...O....O$$$$$$$$$$$........
.....OO$$$$$$$$$$$$
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$.......
$$$$$$$$$$$$...OO..
$$$$$$$$$$$$.O....O
$$$$$$$$$$$$O......
$$....OOOOOO$$$$$$$$$O.....O
$$....O.....O....OO$$$$$$$$...OOOOOO.
$$....O.........OO.OO$$$$$$$$........
$$.....O....O....OOOO$$$$$$$$........
$$.......OO.......OO$$$$$$$$.........
$$$$$$$$$$$$.......
$$$$...OOOOOO$$$$$$$........
$$$$...O.....O$$$$$$$.......
$$$$...O$$$$$$$$...
$$$$....O....O$$$$$$$.......
$$$$......OO$$$$$$$.........
$$$$$$$$$$$.....OO$
$$$$$$$$$$$...O....O........
$$$$$$$$$$$..O$....
$$$$$$$$$$$..O.....O........
$$$$$$$$$$$..OOOOOO.........
```

The interesting thing about this construction is that the glider's initial backward-and-outward path is parallel to its final forward-and-inward path. This means that these path lengths can be increased by moving the turning reactions further away from the blinker puffer, and the gliders will still hit the end of the blinker row. This allows a puffer to be built with an arbitrarily large period by moving the turning reactions sufficiently far away.

Because of the timing constraints on the phase of blinker ignition, it turns out that the allowable changes are as follows. Move the LWSSs and all the spaceships behind them 9N units backwards, and 3N units outwards from the center line. This will increase the period by 96. This will also leave enough room to allow the creation of the two blocks that one of the turning reactions leaves, turning the construction into a puffer. Adding two more spaceships to the final result to delete those blocks will turn the puffer back into a spaceship.

The following shows the above repositioning for the case N=1. The spaceships have been moved 9 units backwards and 3 units outwards, increasing the period by 96. This results in a double-block puffer of period 1232. The block deleting spaceships have not been added.

Period 1232 puffer train leaving behind two blocks:

```
$$$$$$$$$$$$.OOOOOO.........
$$$$$$$$$$$$.O.....O........
$$$$$$$$$$$$.O$....
```

```
$$$$$$$$$$$$..O....O........
$$$$$$$$$$$$....OO$
$$$$$.....OO$$$$$$$.........
$$$$$...O....O$$$$$$$.......
$$$$$..O$$$$$$$$...
$$$$$..O.....O$$$$$$$.......
$$$$$..OOOOOO$$$$$$$........
$$$$$$$$$$$$$......
$$$$.....OO$$$$$$$$.........
$$$$....OOOO$$$$$$$$........
$$$$...OO.OO$$$$$$$$........
$$.......OO$.....OO$$$$$$$$...OOOOOO.
$$.....O....O$$$$$$$$$........O.....O
$$....O$$$$$$$$$$....O......
$$....O.....O$$$$$$$$$.........O....O
$$....OOOOOO$$$$$$$$$$..OO..
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
OOOOO$$$$$$$$$$$$$.
O....O$$$$$$$$$$$$$
O$$$$$$$$$$$$$.....
.O...O$$$$$$$$$$$$$
...O$$$$$$$$$$$$$..
..OOO$$$$$$$$$$$$$.
.OOOO.......OO.O..OO$$$$$$$$$$$......
OO.OO......O.O.OOOOO$$$$$$$$$$$......
.OO....OOO.O$$$$$$$$$$$$....
$.O.O.OOOOO$$$$$$$$$$$......
$..OO.O..OO$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
..OOOOOO$$$$$$$$$$$$........
..O.....O$$$$$$$$$$$$.......
..O$$$$$$$$$$$$$...
...O....O$$$$$$$$$$$$.......
.....OO$$$$$$$$$$$$.........
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$$$$$$$$$$$$......
$$....OOOOOO$$$$$$$$$$..OO..
$$....O.....O$$$$$$$$$.........O....O
$$....O$$$$$$$$$$....O......
$$.....O....O$$$$$$$$$........O.....O
$$.......OO$.....OO$$$$$$$$...OOOOOO.
```

```
$$$$...00.00$$$$$$$$........
$$$$....0000$$$$$$$$........
$$$$.....00$$$$$$$$.........
$$$$$$$$$$$$$......
$$$$$..000000$$$$$$$........
$$$$$..0.....0$$$$$$$.......
$$$$$..0$$$$$$$$...
$$$$$...0....0$$$$$$$.......
$$$$$.....00$$$$$$$.........
$$$$$$$$$$$$....00$
$$$$$$$$$$$$..0....0........
$$$$$$$$$$$$.0$....
$$$$$$$$$$$$.0.....0........
$$$$$$$$$$$$.000000.........
```

So far this allows for the construction of spaceships of any period which is 1136 + 96N. This is a great improvement over the period-doubling methods. But this is not all that can be done.

If the LWSSs and their neighboring HWSSs are moved 3N cells forwards and N cells inwards towards the center line, and the back four HWSSs are moved N units forwards and N units outwards, then the period is increased by 8. For this repositioning to work, the spaceships must be kept far enough away from the center line for the reactions to work, so that this cannot be used indefinitely by itself. But since the first repositioning method moves the spaceships outwards, by using the first repositioning method first, the second repositioning can then be applied as many times as is necessary.

This second repositioning method has the side effect that the final glider paths no longer hit the last blinker in the blinker row. Each increment of the period by 8 results in the gliders being shifted forwards to impact on the next blinker forwards. The blinker ignition will still work, but some blinkers at the end can be left unignited, and therefore will be added to the puffer's output. Besides the block deleting spaceships, another spaceship can be added to delete these leftover blinkers to turn the puffer back into a spaceship.

Here are two examples of combining these two repositionings. In this first one, the second repositioning method is applied to the period 1232 puffer train above to produce a period 1240 puffer train. In this particular case, since the final gliders impact the second to last blinker, no blinkers are left by the puffer.

Period 1240 puffer producing pair of blocks:

```
$$$$$$$$$$$$000000.........
$$$$$$$$$$$$0.....0........
$$$$$$$$$$$$0$....
$$$$$$$$$$$$.0....0........
$$$$$$$$$$$$...00$
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$..00$$$$$$$$.
$$$$$0....0$$$$$$$.........
$$$$.........0$$$$$$$$.....
$$$$.........0.....0$$$$$$$.........
```

```
$$$$.........000000$$$$$$$$
$$$$$$$$$$$$$.....
$$$$..00$$$$$$$$$.
$$$$.0000$$$$$$$$...000000.
$$.......00$.00.00$$$$$$$$...0.....0
$$.....0....0$00$$$$$$$$.....0......
$$....0$$$$$$$$$$....0....0
$$....0.....0$$$$$$$$$$00..
$$....000000$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
00000$$$$$$$$$$$$$
0....0$$$$$$$$$$$$.........
0$$$$$$$$$$$$$....
.0...0$$$$$$$$$$$$.........
...0$$$$$$$$$$$$$.
..000$$$$$$$$$$$$$
.0000.......00.0..00$$$$$$$$$$$.....
00.00......0.0.00000$$$$$$$$$$$.....
.00....000.0$$$$$$$$$$$$...
$.0.0.00000$$$$$$$$$$$.....
$..00.0..00$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
..000000$$$$$$$$$$$$.......
..0.....0$$$$$$$$$$$$......
..0$$$$$$$$$$$$$..
...0....0$$$$$$$$$$$$......
.....00$$$$$$$$$$$$........
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$....000000$$$$$$$$$$.....
$$....0.....0$$$$$$$$$$00..
$$....0$$$$$$$$$$....0....0
$$.....0....0$00$$$$$$$$.....0......
$$.......00$.00.00$$$$$$$$...0.....0
$$$$.0000$$$$$$$$...000000.
$$$$..00$$$$$$$$$.
$$$$$$$$$$$$$.....
$$$$.........000000$$$$$$$$
$$$$.........0.....0$$$$$$$.........
$$$$.........0$$$$$$$$.....
$$$$$0....0$$$$$$$.........
```

```
$$$$$..00$$$$$$$$.
$$$$$$$$$$$$$.....
$$$$$$$$$$$$$.....
$$$$$$$$$$$$...00$
$$$$$$$$$$$$.0....0........
$$$$$$$$$$$$0$....
$$$$$$$$$$$$0.....0........
$$$$$$$$$$$$000000.........
```

Here is another example. This is a period 1368 puffer train which leaves four blinkers. This is made from the period 1136 spaceship by two iterations of the first positioning, (increasing the period by 192), followed by five iterations of the second positioning (increasing the period by 40). As in the period 1136 spaceship, the reactions are close enough to the center line to suppress the creating of the two blocks.

Period 1368 4-blinker puffer train:

```
$$$$$$$$$$$$.....000000.........
$$$$$$$$$$$$.....0.....0........
$$$$$$$$$$$$.....0$....
$$$$$$$$$$$$......0....0........
$$$$$$$$$$$$........00$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$...000000.
$$$$.........00$$$$$$$$..0.....0
$$$$.......0....0$$$$$$$$0......
$$$$......0$$$$$$$$.......0....0
$$$$......0.....0$$$$$$$$...00..
$$$$......000000$$$$$$$$........
$$$$$$$$$$$$$$
$$$.........00$$$$$$$$$.........
$$.......00.........0000$$$$$$$$$........
$$.....0....0......00.00$$$$$$$$$........
$$....0$...00$$$$$$$$$$
$$....0.....0$$$$$$$$$$.........
$$....000000$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
.....00$$$$$$$$$$$$$...
```

```
...0....0$$$$$$$$$$$$$.
..0$$$$$$$$$$$$$.......
..0.....0$$$$$$$$$$$$$.
..000000$$$$$$$$$$$$$..
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$..00.0..00$$$$$$$$$$$$
$.0.0.00000$$$$$$$$$$$$
.00....000.0$$$$$$$$$$$$$........
00.00......0.0.00000$$$$$$$$$$$$$
.0000.......00.0..00$$$$$$$$$$$$$
..000$$$$$$$$$$$$$.....
...0$$$$$$$$$$$$$......
.0...0$$$$$$$$$$$$$....
0$$$$$$$$$$$$$.........
0....0$$$$$$$$$$$$$....
00000$$$$$$$$$$$$$.....
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$....000000$$$$$$$$$$$
$$....0.....0$$$$$$$$$$.........
$$....0$...00$$$$$$$$$$
$$.....0....0......00.00$$$$$$$$$........
$$.......00.........0000$$$$$$$$$........
$$$.........00$$$$$$$$$.........
$$$$$$$$$$$$$$
$$$$......000000$$$$$$$$........
$$$$......0.....0$$$$$$$$...00..
$$$$......0$$$$$$$$.......0....0
$$$$.......0....0$$$$$$$$0......
$$$$.........00$$$$$$$$..0.....0
$$$$$$$$$$$$$...000000.
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$$$
$$$$$$$$$$$$........00$
$$$$$$$$$$$$......0....0........
$$$$$$$$$$$$.....0$....
$$$$$$$$$$$$.....0.....0........
$$$$$$$$$$$$.....000000.........
```

So as can be seen above, you can make a puffer train (and spaceship) of any sufficiently large period which is a multiple of 8.

Can we do better than this? The answer is yes, if we switch to the larger blinker puffer which can produce spaceships of periods 4 (mod 8). I found a method for creating arbitrarily large periods using this other puffer engine. The following is a period 1044 puffer train which leaves a row of 9 blinkers and two more isolated blinkers.

Period 1044 puffer train leaving 11 blinkers:

```
$$$$$$$$....OOOOOO.........
$$$$$$$$....O.....O........
$$$$$$$$....O$....
$$$$$$$$.....O....O........
$$$$$$$$.......OO$
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$..OOOOOO.
$$$$$$$$$..O.....O
$$$$$$$$$..O......
$$$$$$$$$...O....O
$$$$$$$$$.....OO..
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$.......O..O$$$$........
$$$$......O$$$$$..
$$$$......O...O$$$$........
$$$$......OOOO$$$$.........
$$$$$$$$$.........
$....O$$$$$$$$....
$..O...O$$$$$$$$..
$.O$O......OOO$$$$$$.......
$.O....O...O...O...OOOOO$$$$$$......
$.OOOOO...O.......OO.OOO$$$$$$......
$.........O....O...OO$$$$$$.........
$.........OOOOO$$$$$$$.....
$O$$$$$$$$........
.OO.O...OO.OO$$$$$$$$......
O..OOOOO.O$$$$$$$$.........
O..O.OO.OO$$$$$$$$.........
OO...OOO.OO......OO.O..OO$$$$$$$....
..O......OO.....O.O.OOOOO$$$$$$$....
.........OO.OOO.O$$$$$$$$..
..O......OO.....O.O.OOOOO$$$$$$$....
```

```
00...000.00......00.0..00$$$$$$$....
0..0.00.00$$$$$$$$.........
0..00000.0$$$$$$$$.........
.00.0...00.00$$$$$$$$......
$0$$$$$$$$........
$.........00000$$$$$$$.....
$.........0....0...00$$$$$$.........
$.00000...0.......00.000$$$$$$......
$.0....0...0...0...00000$$$$$$......
$.0$0......000$$$$$$.......
$..0...0$$$$$$$$..
$....0$$$$$$$$....
$$$$$$$$$.........
$$$$......0000$$$$.........
$$$$......0...0$$$$........
$$$$......0$$$$$..
$$$$.......0..0$$$$........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.....00..
$$$$$$$$$...0....0
$$$$$$$$$..0......
$$$$$$$$$..0.....0
$$$$$$$$$..000000.
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$$.........
$$$$$$$$.......00$
$$$$$$$$.....0....0........
$$$$$$$$....0$....
$$$$$$$$....0.....0........
$$$$$$$$....000000.........
```

This basic result can be modified to produce other puffer trains. The four LWSSs in the back can be moved 6N units backwards and 6N units outwards. This increases the period by 120N, and leave 3N more blinkers in the row. Since the period increase is a multiple of 8, each of these new puffers will also have a period which is 4 (mod 8).

For example, here is the next puffer in this series, which has period 1164, and leaves 14 blinkers.

Period 1164 puffer train:

```
$$$$$$$$$OOOOOO.........
$$$$$$$$$O.....O........
$$$$$$$$$O$....
$$$$$$$$$.O....O........
$$$$$$$$$...OO$
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$........OOOOOO.
$$$$$$$$$........O.....O
$$$$$$$$$........O......
$$$$$$$$$.........O....O
$$$$$$$$$$.OO..
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$.......O..O$$$$$....
$$$$......O$$$$$........
$$$$......O...O$$$$$....
$$$$......OOOO$$$$$.....
$$$$$$$$$$.....
$....O$$$$$$$$$
$..O...O$$$$$$$$........
$.O$O......OOO$$$$$$$...
$.O....O...O...O...OOOOO$$$$$$$..
$.OOOOO...O.......OO.OOO$$$$$$$..
$.........O....O...OO$$$$$$$.....
$.........OOOOO$$$$$$$$.
$O$$$$$$$$$....
.OO.O...OO.OO$$$$$$$$$..
O..OOOOO.O$$$$$$$$$.....
O..O.OO.OO$$$$$$$$$.....
OO...OOO.OO......OO.O..OO$$$$$$$$
..O......OO.....O.O.OOOOO$$$$$$$$
.........OO.OOO.O$$$$$$$$........
..O......OO.....O.O.OOOOO$$$$$$$$
OO...OOO.OO......OO.O..OO$$$$$$$$
O..O.OO.OO$$$$$$$$$.....
O..OOOOO.O$$$$$$$$$.....
.OO.O...OO.OO$$$$$$$$$..
$O$$$$$$$$$....
```

```
$.........00000$$$$$$$$.
$.........0....0...00$$$$$$$.....
$.00000...0.......00.000$$$$$$$..
$.0....0...0...0...00000$$$$$$$..
$.0$0......000$$$$$$$...
$..0...0$$$$$$$$........
$....0$$$$$$$$$
$$$$$$$$$$.....
$$$$......0000$$$$$.....
$$$$......0...0$$$$$....
$$$$......0$$$$$........
$$$$.......0..0$$$$$....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.00..
$$$$$$$$$.........0....0
$$$$$$$$$........0......
$$$$$$$$$........0.....0
$$$$$$$$$........000000.
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$$.....
$$$$$$$$$...00$
$$$$$$$$$.0....0........
$$$$$$$$$0$....
$$$$$$$$$0.....0........
$$$$$$$$$000000.........
```

Dean Hickerson recently found another glider perturbing reaction which does not change the direction of a glider, but which does delay it and shift its path. This reaction is shown below. The spaceship on the right is only needed to delete an extraneous block produced by the reaction.

Forwards glider being delayed and path-shifted:

```
........00$$$$$$$..
.......00.000$$$$$$.........
........00000$$$$$$.........
.........000$$$$$$$
```

```
$$$$$$$$..
$$$$$$$$..
$$$$$$$........000.
$$$$$$$.......00000
$$$$$$$......00.000
......0$$$$$$$00...
....00$$$$$$$......
.....00$$$$$$$.....
$$$$$$$$..
...00$$$$$$$.......
.0....0$$$$$$$.....
0$$$$$$$$.
0.....0$$$$$$$.....
000000$$$$$$$......
```

This reaction can be used to modify the period of these new spaceships, allowing more of the periods which are 4 (mod 8) to be constructed. The following puffer train is made from the period 1044 puffer train by adding one (doubled) copy of the above reaction to it. This produces a puffer train of period 1732. It produces 16 blinkers and two blocks.

Period 1732 puffer train:

```
$$$$$$$$$$$$$$$........000000.........
$$$$$$$$$$$$$$$........0.....0........
$$$$$$$$$$$$$$$........0$....
$$$$$$$$$$$$$$$.........0$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$..0$$$$$$$$$
$$$$$$$$.0$$$$$$$$$.
$$$$$$$$.0.....0$$$$$$$$.....
$$$$$$$$.000000$$$$$$$$......
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$......000000.
$$$$$$$$$$$$$$$$......0.....0
$$$$$$$$$$$$$$$$......0......
$$$$$$$$$$$$$$$$.......0.....
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$.........00$$$$$$$$..
$$$$$$$$........00.000$$$$$$$.........
$$$$$$$$.........00000$$$$$$$.........
$$$$$$$$$000$$$$$$$$
$$$$$$$$$$$$$$$$$...
```

```
$$$$$$$$$$$$$$$$$...
$$$$......0000$$$$$$$$$$$$...
$$$$......0...0$$$$$$$$$$$$..
$$$$......0$$$$$$$$$$$$......
$$$$.......0$$$$$$$$$$$$.....
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$.00000$$$$$$$$$$$$$$$.......
$.0....0$.00$$$$$$$$$$$$$$...
$.0.......00000...00.000$$$$$$$$$$$$$$
$..0......0....0...00000$$$$$$$$$$$$$$
$.0000....0.........000$$$$$$$$$$$$$$.
........0.0.0.......0$$$$$$$$$$$$$$$..
..0.....000.0$$$$$$$$$$$$$$$$
00......00$$$$$$$$$$$$$$$$...
0..000$....0$$$$$$$$$$$$$$$..
0....000.........0.0.0.0.00$$$$$$$$$$$$$$......
.000..000.......0000...0000$$$$$$$$$$$$$$......
........0..000.0$$$$$$$$$$$$$$$.......
.000..000.......0000...0000$$$$$$$$$$$$$$......
0....000.........0.0.0.0.00$$$$$$$$$$$$$$......
0..000$....0$$$$$$$$$$$$$$$..
00......00$$$$$$$$$$$$$$$$...
..0.....000.0$$$$$$$$$$$$$$$$
........0.0.0.......0$$$$$$$$$$$$$$$..
$.0000....0.........000$$$$$$$$$$$$$$.
$..0......0....0...00000$$$$$$$$$$$$$$
$.0.......00000...00.000$$$$$$$$$$$$$$
$.0....0$.00$$$$$$$$$$$$$$...
$.00000$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$.......0$$$$$$$$$$$$.....
$$$$......0$$$$$$$$$$$$......
$$$$......0...0$$$$$$$$$$$$..
$$$$......0000$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$000$$$$$$$$
$$$$$$$$.........00000$$$$$$$.........
$$$$$$$$........00.000$$$$$$$.........
$$$$$$$$.........00$$$$$$$$..
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$.......0.....
$$$$$$$$$$$$$$$$......0......
$$$$$$$$$$$$$$$$......0.....0
$$$$$$$$$$$$$$$$......000000.
$$$$$$$$$$$$$$$$$...
```

```
$$$$$$$$.OOOOOO$$$$$$$$......
$$$$$$$$.O.....O$$$$$$$$.....
$$$$$$$$.O$$$$$$$$$.
$$$$$$$$..O$$$$$$$$$
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$.........O$...
$$$$$$$$$$$$$$$........O$....
$$$$$$$$$$$$$$$........O.....O........
$$$$$$$$$$$$$$$........OOOOOO.........
```

By adding one copy of the delaying reaction, the period is increased by 688. Since 688 is a multiple of 8, and the GCD of 688 and 120 is 8, by adding enough copies of this reaction (up to 14 of them) to the period 120 increasing method above, spaceships of all sufficiently large periods which are 4 (mod 8) can be built.

So overall, this means that spaceships can be built with any sufficiently large period which is a multiple of 4. Improving the coverage of periods to include nonmultiples of 4 will have to be based on truly new knowledge, since such spaceships cannot use any of the standard spaceships as components.

The glider reactions shown above are certainly not the best possible ones for building large period spaceships. There are probably much better reactions available (smaller and faster), both for igniting the blinker puffer's debris clouds, and for turning and shifting gliders. In addition, it should be possible to ignite the blinker row using only one glider with help from perturbations from an accompanying spaceship. This would suppress the need for one side of the glider reactions to make the spaceships. Unlike most of the results from these articles which require complicated search programs to find, improvements on making these large period spaceships could be found by anyone with access to a reasonable Life program.

I want to conclude this article with a few objects which are not exactly spaceships, but which are not puffer trains either. They occupy a middle ground between the two. Under a loose definition of spaceship which is "an object which moves into new areas without leaving any permanent output," these objects are spaceships. But they are strange ones, for they never repeat themselves since the number of ON cells keeps increasing. But they still have what is called a "period," which is the number of generations before a similar-looking object reappears, except for another unit added in the middle. These can be thought of as spaceships which "grow."

The first example of such a loosely defined spaceship is the following old result. A puffer at the front produces a row of blinkers, which are all consumed at the back by a smokeless reaction. But the eating reaction is slower than the generating reaction, so that the number of blinkers grows. This has a "period" of 156. After each period, the spaceship has one extra blinker.

A "blinker spaceship" which grows arbitrarily large:

```
...........O..O...............
..........O...................
..........O...O...............
```

```
..00......0000................
.0000.........................
00.00.........................
.00.....00.000................
.......0.....00.......0....000
......00.......0......0....0.0
.......0.....00.......0....000
.00.....00.000................
00.00.........................
.0000.........................
..00......0000................
..........0...0...............
..........0...................
...........0..0...............
```

This second more recent example by Dean Hickerson has a "period" of 72. Here two rows of blinkers are produced by a puffer. A glider at the back travels between the two rows, consuming all of the blinkers. Once again, the eating reaction is (much) slower than than the generating reaction, so that the spaceship grows. After each "period" there are 14 new blinkers.

A "blinker and glider spaceship" which grows arbitrarily large:

```
.0....................
0.....................
0....0................
00000.................
......................
......................
......................
.00...................
00.000.0..............
.0000000..000.000.000.
..00000...............
......................
.....00.............0.
...0...............00.
..0.........0......0.0
..0.....0..0..........
..000000...0.....0....
...........000000.....
......................
......................
......................
......................
..........00..00......
.........00.00.0......
..........00000.......
...........000........
............0.........
..........0...0.......
.........0............
.........0....0.......
```

```
.........00000........
```

The last example is a "PI ship," built by me. This is the first finite pattern in which the PI-heptomino's almost-spaceship behavior has been tamed. Here a puffer train produces two parallel rows of blocks. Between the rows of blocks is generation 1 of the PI-heptomino. The PI-heptomino reacts with each pair of blocks and deletes them, moving forwards with a period of 30 and a speed of 3c/10. Since this is slower than the rate of block creation by the puffer, the spaceship slowly gets larger. This has a "period" of 180.

A "PI and blocks spaceship" which grows arbitrarily large:

```
$$.....0000$$$$$$$$........
$$....000000$$$$$$$$.......
$$...00.0000$.......000000$$$$$$....
$$....00$$.0.....0$$$$$$...
$$$$.......0$$$$$$.........
$.....0$$$..0....0$$$$$$...
$...0...0$$$..00$$$$$$.....
$..0$.........00$$$$$$$$...
$..0....0........00...000$$$$$$$$...
$..00000........0..000...00$$$$$$$$.
$$.....0.0.......00.....00$$$$$$$...
$$......0...0.....00....0.0$$$$$$$..
0000$$.......0....0......0.0$$$$$$$.
0...0.........0$$0........0$$$$$$........00..
0$.00$$$$$$$$$........00.00
.0..0..00.....000$$$$$$$$$......0000
......000......000$$$$$$$$$......00.
.0..0..00.....000$.0$$$$$$$$........
0$.00$$$$$$$$$$...
0...0.........0$$$$$$$$$$..
0000$........0.0$$$.........000$$$$$
$$$......00$$......0.0$$$$$
$$$.....00.000$.........0...00$$$$$.
$...00$$.00000$.......0...0$$$$$....
$..00.00$$000......0$0$$$$$.........
$...0000$$.......0...0........0....0$$$$$....
$....00$$.......0$...00000$$$$$.....
$$$$...0....0$$$$$$........
$$$$...00000$$$$$$.........
$$$$$$$$$$$.......
$$$$$$$$$$$.......
$$$.0000$$$$$$$$..
$$$.0...0$0$$$$$$$
$$$.0.......00....0.0$$$$$$.........
$$$..0..0..0000...0..00........00$......00$$$.........
$$$.......00...0.....0.00......00$......00$$$.........
$$$..0..0..0000...0..00$$$$$$.......
$$$.0.......00....0.0$$$$$$.........
$$$.0...0$0$$$$$$$
$$$.0000$$$$$$$$..
$$$$$$$$$$$.......
```

```
$$$$$$$$$$$.......
$$$$....00000$$$$$$........
$$$$....0....0$$$$$$.......
$$$$....0$$$.0$$$$
$$$$.....0...0$$.....00$$$$
$$$$$$$....0$$$$..
$$$$.....0...0$$.....00$$$$
$$$$....0$$$.0$$$$
$$$$....0....0$$$$$$.......
$$$$....00000$$$$$$........
$$$$$$$$$$$.......
$$$$$$$$$$$.......
$$$.0000$$$$$$$$..
$$$.0...0$0$$$$$$$
$$$.0.......00....0.0$$$$$$.........
$$$..0..0..0000...0..00$$$$$$.......
$$$.......00...0.....0.00......00$......00$$$.........
$$$..0..0..0000...0..00........00$......00$$$.........
$$$.0.......00....0.0$$$$$$.........
$$$.0...0$0$$$$$$$
$$$.0000$$$$$$$$..
$$$$$$$$$$$.......
$$$$$$$$$$$.......
$$$$...00000$$$$$$.........
$$$$...0....0$$$$$$........
$....00$$.......0$...00000$$$$$.....
$...0000$$.......0...0........0....0$$$$$....
$..00.00$$000......0$0$$$$$.........
$...00$$.00000$.......0...0$$$$$....
$$$.....00.000$.........0...00$$$$$.
$$$......00$$......0.0$$$$$
0000$........0.0$$$.........000$$$$$
0...0.........0$$$$$$$$$$..
0$.00$$$$$$$$$$...
.0..0..00.....000$.0$$$$$$$$........
......000......000$$$$$$$$$......00.
.0..0..00.....000$$$$$$$$$......0000
0$.00$$$$$$$$$........00.00
0...0.........0$$0........0$$$$$$........00..
0000$$.......0....0......0.0$$$$$$$.
$$......0...0.....00....0.0$$$$$$$..
$$.....0.0.......00.....00$$$$$$$...
$..00000........0..000...00$$$$$$$$.
$..0....0........00...000$$$$$$$$...
$..0$.........00$$$$$$$$...
$...0...0$$$..00$$$$$$.....
$.....0$$$..0....0$$$$$$...
$$$$.......0$$$$$$.........
$$....00$$.0.....0$$$$$$...
$$...00.0000$.......000000$$$$$$....
$$....000000$$$$$$$$.......
$$.....0000$$$$$$$$........
```

6 Acknowledgements

This concludes my series of six articles on spaceships. I wish to thank several people for their help with information for these articles, and for reviewing them. These people include *Richard Schroeppel, Bill Gosper, Allan Wechsler, Hartmut Holzwart*, and *Nina Bell*. I especially want to thank *Dean Hickerson* for his huge help in supplying historical information and results, reviewing these articles thoroughly, and for starting off the search for the new spaceships.

As you have seen, Life certainly has more spaceship-related results than anyone dreamed of in its early days. I hope you have found this series of articles entertaining.

– David I. Bell

Addendum 1

New Period 2 Spaceships

This is an addendum to my series of articles concerning Conway's Game of Life. In this article, I will show the new results about spaceships that have been discovered since my series of articles was first posted in August through October of 1992.

There have been new discoveries made in many of the categories of spaceships which I had reported on in my articles. The order of presentation in this article will be based on the period of the spaceship. So I will begin with the period 2 spaceships, and end with the large period spaceships.

The vast majority of results in this article were found by Hartmut Holzwart. These are mostly period 2 and period 4 spaceships. (For period 4 spaceships, almost all the results are his.) I have contributed by finding some period 2 and period 3 spaceships, and working on large period spaceships. Dean Hickerson made a small but very significant contribution to these new results.

So now I will begin with the new results for period 2 c/2 spaceships. Hartmut Holzwart found the following spaceship last September. One of his repeatable tagalongs from my article 2 has been slightly modified to allow two of them to connect together. This allows a spaceship to be constructed which is as long and as wide as desired, and is quite dense.

Dense period 2 spaceship (speed c/2):

```
..............O...................................
...........OOOO...................................
...........OO.....................................
.........O...OO...................................
.........OOOO.O...................................
......O.O.........................................
.....OOOOOO.......................................
....OO.....O......................................
...OO....O........................................
....OO...OO.......................................
..........OOO.....................................
....OO......O.....................................
...OO.O...........................................
..OO..............................................
.OO..O............................................
OO................................................
.OOOOO............................................
..................................................
.OOOOO............................................
OO................................................
.OO..O............................................
..OO..............................................
...OO.O...........................................
....OO............................................
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..................................................
....OO.............O.........O.........O.........O
...OO..OO........OOO.......OOO.......OOO.......OOO
..OO..OOO.......OO........OO........OO........OO..
.OOO.O..........O.........O.........O.........O...
..OO..OOO.....O.O.......O.O.......O.O.......O.O...
...OO..OO...OOO.......OOO.......OOO.......OOO.....
....OO.....OO.O......OO.O......OO.O......OO.O.....
...........O.O.OO....O.O.OO....O.O.OO....O.O.OO...
....OO.....OO..OO....OO..OO....OO..OO....OO..OO...
...OO..OO..O.....OO..O.....OO..O.....OO..O.....OO.
..OO..OOO..OO..OO.O..OO..OO.O..OO..OO.O..OO..OO.O.
.OOO.O.....OO.O......OO.O......OO.O......OO.O.....
..OO..OOO..OO..OO.O..OO..OO.O..OO..OO.O..OO..OO.O.
...OO..OO..O.....OO..O.....OO..O.....OO..O.....OO.
....OO.....OO..OO....OO..OO....OO..OO....OO..OO...
...........O.O.OO....O.O.OO....O.O.OO....O.O.OO...
....OO.....OO.O......OO.O......OO.O......OO.O.....
...OO..OO...OOO.......OOO.......OOO.......OOO.....
..OO..OOO.....O.O.......O.O.......O.O.......O.O...
.OOO.O..........O.........O.........O.........O...
..OO..OOO.....O.O.......O.O.......O.O.......O.O...
...OO..OO...OOO.......OOO.......OOO.......OOO.....
....OO.....OO.O......OO.O......OO.O......OO.O.....
...........O.O.OO....O.O.OO....O.O.OO....O.O.OO...
....OO.....OO..OO....OO..OO....OO..OO....OO..OO...
...OO..OO..O.....OO..O.....OO..O.....OO..O.....OO.
..OO..OOO..OO..OO.O..OO..OO.O..OO..OO.O..OO..OO.O.
.OOO.O.....OO.O......OO.O......OO.O......OO.O.....
..OO..OOO..OO..OO.O..OO..OO.O..OO..OO.O..OO..OO.O.
...OO..OO..O.....OO..O.....OO..O.....OO..O.....OO.
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...........O.O.OO....O.O.OO....O.O.OO....O.O.OO...
....OO.....OO.O......OO.O......OO.O......OO.O.....
...OO..OO...OOO.......OOO.......OOO.......OOO.....
..OO..OOO.....O.O.......O.O.......O.O.......O.O...
.OOO.O..........O.........O.........O.........O...
..OO..OOO.....O.O.......O.O.......O.O.......O.O...
...OO..OO...OOO.......OOO.......OOO.......OOO.....
....OO.....OO.O......OO.O......OO.O......OO.O.....
...........O.O.OO....O.O.OO....O.O.OO....O.O.OO...
....OO.....OO..OO....OO..OO....OO..OO....OO..OO...
...OO..OO..O.....OO..O.....OO..O.....OO..O.....OO.
..OO..OOO..OO..OO.O..OO..OO.O..OO..OO.O..OO..OO.O.
.OOO.O.....OO.O......OO.O......OO.O......OO.O.....
..OO..OOO..OO..OO.O..OO..OO.O..OO..OO.O..OO..OO.O.
...OO..OO..O.....OO..O.....OO..O.....OO..O.....OO.
....OO.....OO..OO....OO..OO....OO..OO....OO..OO...
...........O.O.OO....O.O.OO....O.O.OO....O.O.OO...
....OO.....OO.O......OO.O......OO.O......OO.O.....
...OO..OO...OOO.......OOO.......OOO.......OOO.....
..OO..OOO.....O.O.......O.O.......O.O.......O.O...
.OOO.O..........O.........O.........O.........O...
..OO..OOO.......OO........OO........OO........OO..
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...OO..OO........OOO.......OOO.......OOO.......OOO
....OO.............O.........O.........O.........O
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...OO.O...........................................
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.OOOOO............................................
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...OO.O...........................................
....OO......O.....................................
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Hartmut also found two new "arm" components for period 2 spaceships. These arms are derived from the "glancing head" component, and have slopes of 5/17 and 5/13. The following spaceship shows two copies of both of these components.

Period 2 spaceship with arm components (speed c/2):

```
.............................O.O
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.......................OOO.OOO..
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....................OOO.O.......
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OOO...OOOOO.....................
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Hartmut also found the following spaceship, which has repeatable glide-reflective wicks trailing from the ends. Between the two main components is a large repeatable component which is only a slightly modified version of Dean Hickerson's long period 2 spaceship. The central component was found using Hartmut's cylindrical search feature of the life search program.

Period 2 spaceship with glide-reflective wick and repeatable component (speed c/2):

```
...............................................O........
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................OOOO..........OOOO..........O...........
................OO............OO............O...........
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......O........OO...O........OO...O........OO.O...O.....
......OOOOOOO....OO...OOOOO....OO...OOOOO....OO.....O...
...O.O.............O.O...........O.O..........OOOOOO....
..OOOOOOO.O............OO............OO........O.O......
.OO.......O............OOOO..........OOOO.........OOOO.O
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.OO....O.O.............................................O
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.OO.......O..O.O........................................
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Hartmut's cylindrical search also found several other repeatable components related to the one in the above spaceship. Most of these join each other in the same manner in one spot.

Period 2 spaceship demonstrating several repeating components (speed c/2):

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........OOO............
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......OOOO.O.O.O.OO....
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......OOOO.O.O.O.OO....
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........OOOO.O.........
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```

Hartmut looked for period 2 spaceships with even symmetry, and found that there are no spaceships with a width less than 28. The smallest minimum width spaceship which has even symmetry is the following. Removing one of the two middle rows will produce a spaceship with odd symmetry (but not the one of minimum width).

Period 2 spaceship with even symmetry of minimum width 28 (speed c/2):

```
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......O....O
.....OOOOO.O
..OO........
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O.....O.....
O..O..O.....
.O.O..OO.O..
.........O..
OOO.........
OO..........
OO..........
OOO.........
.........O..
.O.O..OO.O..
O..O..O.....
O.....O.....
O...O.......
.O...OOO....
..OO........
.....OOOOO.O
......O....O
.......OO...
........O..O
.........O.O
```

Hartmut found several modifications and tagalongs for the above spaceship. Two of these are shown below.

Period 2 spaceship with large tagalongs (speed c/2):

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.........OO.................O.....
........O...............OO.OO..O..
.......OO..O...........O.....O.O..
......O....O..........OO..OO......
.....OOOOO...........O............
..OO.....OO....O....OOO.OO.O.....O
.O...OOO..O..OOO...O.....O....OOOO
O...O.....OO.OO...OOO....OO...OO..
O.....O...O...O..O.....OO...O.....
O..O..O.....OOO.OOO....O..OO......
.O.O..OO.O..OO.....O...O.O........
.........O.....OOO.........OOO....
OOO............OO.....OOO..O..O...
OO...............O....OO...OO.....
OO...............O....OO...OO.....
OOO............OO.....OOO..O..O...
.........O.....OOO.........OOO....
.O.O..OO.O..OO.....O...O.O........
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O..O..O.....OOO.OOO....O..OO......
O.....O...O...O..O.....OO...O.....
O...O.....OO.OO...OOO....OO...OO..
.O...OOO..O..OOO...O.....O....OOOO
..OO.....OO....O....OOO.OO.O.....O
.....OOOOO...........O............
......O....O..........OO..OO......
.......OO..O...........O.....O.O..
........O...............OO.OO..O..
.........OO.................O.....
```

```
.........OO.................O...........
........O...............OO.OO..O........
.......OO..O...........O.....O.O........
......O....O..........OO..OO............
.....OOOOO...........O.................O
..OO.....OO....O....OOO.OO.O.....O.O.OO.
.O...OOO..O..OOO...O.....O....OOOO.O.O.O
O...O.....OO.OO...OOO....OO...OO..O.....
O.....O...O...O..O.....OO...O.....OOO...
O..O..O.....OOO.OOO....O..OO......O.....
.O.O..OO.O..OO.....O...O.O........O.O...
.........O.....OOO.........OOO..........
OOO............OO.....OOO..O..O..OOO....
OO...............O....OO...OO....OO.....
OO...............O....OO...OO....OO.....
OOO............OO.....OOO..O..O..OOO....
.........O.....OOO.........OOO..........
.O.O..OO.O..OO.....O...O.O........O.O...
O..O..O.....OOO.OOO....O..OO......O.....
O.....O...O...O..O.....OO...O.....OOO...
O...O.....OO.OO...OOO....OO...OO..O.....
.O...OOO..O..OOO...O.....O....OOOO.O.O.O
..OO.....OO....O....OOO.OO.O.....O.O.OO.
.....OOOOO...........O.................O
......O....O..........OO..OO............
.......OO..O...........O.....O.O........
........O...............OO.OO..O........
.........OO.................O...........
```

The second spaceship above differs by the addition of a short wide tagalong which attaches to the feet of the previous tagalong. This tagalong can also be used in other spaceships where the feet appear, to join the two spaceships. For example, an odd-symmetrical version of the tagalong is shown below which joins two old spaceships.

Period 2 spaceships joined by bridging tagalong (speed c/2):

```
.............O.............
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........OOOO.O.............
........OO.......OO........
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......O...OO.O...OOOO......
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...O.O......OO............O
..OOOOOO.OO.OO.OO..........
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In one of Hartmut's results there appeared an L-shaped repeating component which is very small and simple. I was asked to "tame" it by finding components which terminated the two ends. Amazingly, the component that I found for the front of the L components connects to them on both of its sides. The following spaceship shows the front component, two arms made of the L components, and the back component that I found. Also shown is one of a number of "feet" which can be attached to the L component.

Period 2 spaceship with simple "L" arms (speed c/2):

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............................O
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.......................O...OO
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I did not find a front component for a single arm of the L components. But I did find that the L component can be connected to the standard component that connects to the feet of many period 2 spaceships. This is shown below, where the L arm is connected to the back foot of the wicktrailer on a base spaceship.

Period 2 spaceship with L arm component connection (speed c/2):

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............................O.....................
.............O...........OOOO.....................
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........OOOO.O........OO...O......................
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...O.O......OO.........O........OO................
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I found another very messy connection of the L component to the feet of period 2 spaceships. This is illustrated below. The almost-symmetrical component in the middle is interesting, for it appears that it might be made larger somehow. But this has not been done yet.

Messy connection of L component with base period 2 spaceship (speed c/2):

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I found another "barber pole" component for period 2 spaceships. Like the previous barber pole component, this one appears the same in both phases, only shifted. The effect is not as obvious in this example, however, since the component is so large. The component can have feet attached to it at many places, as is shown below.

Period 2 spaceship with "barber pole" repeating component (speed c/2):

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.O...................
OOO..O...............
.OOO.................
..O..................
...OOO.O.............
...O..OO.............
....OOO..............
......O..............
....O................
....O.O..............
...O.................
....O.O..............
....O................
......O..............
....OOO..............
...O..OO.............
...OOO.O.............
..O..................
.OOO.................
OOO..O...............
```

```
.0...................
..0000...............
..0..................
....00...............
....0000.............
.......0.............
```

That was a summary of the new developments for period 2 spaceships. Now I will move on to period 3 c/3 spaceships. There are not many new results to report for period 3 spaceships. All of these results were found by me.

New Period 3 Spaceships

Ever since I found the period 9 tail to period 3 c/3 spaceships, I have wanted to turn that tail into a small component compatible with the rest of Dean Hickerson's period 3 grammar. At the beginning of 1993, I finally succeeded. The resulting spaceship is shown below.

Period 9 tail connecting to period 3 components (speed c/3):

```
.......0......
......0.0.....
......0.0.....
......0.......
.....00.......
.....0.0......
..............
....000.......
....00........
..............
......000.....
.....0.00.....
....0.........
....0.........
...000........
..0...........
..0..0........
..0..00.......
.....0........
....00........
.....00.......
..0.....0.....
..0..0.0......
.0.0..0.......
000...........
....000.0.....
...000..0.....
.00...........
.000..........
..............
```

```
.O.O..........
.O.O..........
.O..OO........
..O.OO........
..O...........
....O.........
..OOO.........
..OOO.........
......OO......
......OOO.....
..............
......OOO.....
...O..O.......
..O.O.O.......
.O..O.O.O.....
..O...O.......
...OO.........
..OO...O......
.OOOOO........
.O...OOO......
...O..........
...OO.........
..............
..O..O........
..O..OO.......
.OO...O.......
.O....O.......
.OO.OOO.......
..O...O.......
..OO...OO.....
...O.OOO.....O
....OO.O....OO
......O...O.O.
......OOOO..O.
............O.
............O.
............O.
......OOOO..O.
......O...O.O.
....OO.O....OO
...O.OOO.....O
..OO...OO.....
..O...O.......
.OO.OOO.......
.O....O.......
.OO...O.......
..O..OO.......
..O..O........
..............
...OO.........
...O..........
.O...OOO......
.OOOOO........
..OO...O......
```

```
...00.........
..0...0.......
.0..0.0.0.....
..0.0.0.......
...0..0.......
......000.....
..............
......000.....
......00......
..000.........
..000.........
....0.........
..0...........
..0.00........
.0..00........
.0.0..........
.0.0..........
..............
.000..........
.00...........
...000..0.....
....000.0.....
000...........
.0.0..0.......
..0..0.0......
..0.....0.....
.....00.......
....00........
.....0........
..0..00.......
..0..0........
..0...........
...000........
....0.........
....0.........
.....0.00.....
......000.....
..............
....00........
....000.......
..............
.....0.0......
.....00.......
......0.......
......0.0.....
......0.0.....
.......0......
```

This is a large solution to the problem, however. It only connects to Dean's grammar at about 13 cells from either end. The rest of it is made up of new components.

I then looked for a smaller solution. The following shows two things. Firstly, a shorter arm is demonstrated which connects to the p9 component. This is seen at the top and bottom. The component has the same two-bit spark as is produced by Dean's "turtle" spaceship. Secondly, between two copies of the period 9 component is a large symmetrical component. Using this you can make a wide spaceship with as many period 9 components in it as you want.

Period 3 spaceship with several period 9 components (speed c/3):

```
...O.........
..O.O........
.OO..........
...O.........
.OO..........
.OOO.........
.............
..O.O........
..OOO........
.............
.....OOO.....
.....OOO.....
.............
....OO.......
....OO.......
......O......
.............
...OOO.......
...O.OO......
......O......
..OOO.O......
.O....O......
.OO.OOO......
OO.O..O......
....OO.......
.O..OO.......
.O..O........
.O.OO........
..O.OO.O.....
.....O.O.....
.............
.....OO......
....O..O.....
...OOO.......
.......O.....
......O......
..O..........
.OO.O........
.O..OO.......
OO...O.......
O....O.......
OO.OOO.......
.O...O.......
.OO...OO.....
..O.OOO.....O
```

```
...OO.O....OO
.....O...O.O.
.....OOOO..O.
...........O.
...........O.
...........O.
.....OOOO..O.
.....O...O.O.
...OO.O....OO
..O.OOO.....O
.OO...OO.....
.O...O.......
OO.OOO.......
O....O.......
OO...O.......
.O..OO.......
.OO.O........
..O..........
......O......
.......O.....
...OOO.......
....O..O.....
.....OO......
.............
.....O.O.....
..O.OO.O.....
.O.OO........
.O..O........
.O..OO.......
...OO........
OO..OO.......
.OO..........
..OOOO.......
......O......
..OOO........
OO....O......
OO..O.O......
O..O.........
OO.OOO.......
....OO.......
..O...OO.....
..O.OOOO.....
..O..........
...O.........
....OOO......
...OO.O......
..O..........
.O..O........
..O.OOO......
.............
..OOO........
...OOO.O.....
.....O.......
.....O.......
```

```
.....OO......
.............
.....OO......
.....O.......
.....O.......
...OOO.O.....
..OOO........
.............
..O.OOO......
.O..O........
..O..........
...OO.O......
....OOO......
...O.........
..O..........
..O.OOOO.....
..O...OO.....
....OO.......
OO.OOO.......
O..O.........
OO..O.O......
OO....O......
..OOO........
......O......
..OOOO.......
.OO..........
OO..OO.......
...OO........
.O..OO.......
.O..O........
.O.OO........
..O.OO.O.....
.....O.O.....
.............
.....OO......
....O..O.....
...OOO.......
.......O.....
......O......
..O..........
.OO.O........
.O..OO.......
OO...O.......
O....O.......
OO.OOO.......
.O...O.......
.OO...OO.....
..O.OOO.....O
...OO.O....OO
.....O...O.O.
.....OOOO..O.
...........O.
...........O.
...........O.
```

```
.....0000..0.
.....0...0.0.
...00.0....00
..0.000.....0
.00...00.....
.0...0.......
00.000.......
0....0.......
00...0.......
.0..00.......
.00.0........
..0..........
......0......
.......0.....
...000.......
....0..0.....
.....00......
.............
.....0.0.....
..0.00.0.....
.0.00........
.0..0........
.0..00.......
....00.......
00.0..0......
.00.000......
.0....0......
..000.0......
......0......
...0.00......
...000.......
.............
......0......
....00.......
....00.......
.............
.....000.....
.....000.....
.............
..000........
..0.0........
.............
.000.........
.00..........
...0.........
.00..........
..0.0........
...0.........
```

The structure of the middle 3 rows in the above spaceship intrigued me, and I then looked for more components that joined in that same manner. The following shows the results. At the top is the smallest terminating component that contains that connection (about 20 rows). Below that is a symmetrical component which includes a middle piece which is also in some period 2 spaceships, but which here acts as period 3 (about 26 rows). Below that is another symmetrical component (about 40 rows). And at the bottom is another copy of the termination component.

Period 3 spaceship with components connected in common manner (speed c/3):

```
....O..
...O.O.
..OO...
...O...
..O.O..
..O....
.O.....
.O.O...
.O.O...
..OOOO.
....O.O
....O.O
...O...
...OOO.
.O.....
.OOO...
..OOO.O
....O..
....O..
....OO.
.......
....OO.
....O..
....O..
..OOO.O
.OOO...
.......
.O.OOO.
O..O...
.O.O...
..O..OO
.....OO
....OO.
...O.O.
..O....
...O.O.
....OO.
.....OO
..O..OO
.O.O...
O..O...
.O.OOO.
.......
.OOO...
..OOO.O
....O..
....O..
```

```
....00.
.......
....00.
....0..
....0..
..000.0
.000...
.......
.0.000.
0..0...
.0.0...
..0..00
.....00
....00.
...0.0.
...0...
..0..0.
..000.0
.0..0..
..00000
..0..0.
...0000
.00....
...0000
..0..0.
..00000
.0..0..
..000.0
..0..0.
...0...
...0.0.
....00.
.....00
..0..00
.0.0...
0..0...
.0.000.
.......
.000...
..000.0
....0..
....0..
....00.
.......
....00.
....0..
....0..
..000.0
.000...
.0.....
...000.
...0...
....0.0
....0.0
```

```
..OOOO.
.O.O...
.O.O...
.O.....
..O....
..O.O..
...O...
..OO...
...O.O.
....O..
```

A few months ago Hartmut Holzwart did a little searching for cylindrical components for period 3 spaceships. He found an interesting partial result, but could not finish it. Recently I looked at it and found a way to tame it.

Here is the finished object. It is a dense c/3 spaceship, which can be made as wide and as long as desired. Hartmut had found both of the repeatable components in the center. The thin stabilizing pieces on the sides of the front are just the terminating component of the spaceship shown above. At least one column of the repeating tagalongs is required to stabilize the front of the spaceship. So here is a case where the first column of tagalongs aren't really tagalongs, but extra copies of the same component are!

Dense period 3 spaceship (speed c/3):

```
....O...............................................................
...O.O..............................................................
..OO................................................................
...O................................................................
..O.O...............................................................
..O.................................................................
.O..................................................................
.O.O................................................................
.O.O................................................................
..OOOO..............................................................
....O.O.............................................................
....O.O.............................................................
...O................................................................
...OOO..............................................................
.O..................................................................
.OOO................................................................
..OOO.O.............................................................
....O...............................................................
....O...............................................................
....OO..............................................................
....................................................................
....OO.....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O.
....O..O..O...O..OO...O...O..OO...O...O..OO...O...O..OO...O...O..OO.
....O.OO.O.....O.....O.....O.....O.....O.....O.....O.....O.....O....
.....OOO..O......O.O..O......O.O..O......O.O..O......O.O..O......O.O
.....OO.....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O
.......O...O...O.......O...O.......O...O.......O...O.......O...O....
```

```
.....OO....O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O
......O.O..O...........O...........O...........O...........O........
.......O....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO
....................................................................
.......O....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO
......O.O..O...........O...........O...........O...........O........
.....OO....O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O
.......O...O...O.......O...O.......O...O.......O...O.......O...O....
.....OO.....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O
.....OOO..O......O.O..O......O.O..O......O.O..O......O.O..O......O.O
....O.OO.O.....O.....O.....O.....O.....O.....O.....O.....O.....O....
....O..O..O...O..OO...O...O..OO...O...O..OO...O...O..OO...O...O..OO.
....OO.....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O.
....................................................................
....OO.....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O.
....O..O..O...O..OO...O...O..OO...O...O..OO...O...O..OO...O...O..OO.
....O.OO.O.....O.....O.....O.....O.....O.....O.....O.....O.....O....
.....OOO..O......O.O..O......O.O..O......O.O..O......O.O..O......O.O
.....OO.....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O
.......O...O...O.......O...O.......O...O.......O...O.......O...O....
.....OO....O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O
......O.O..O...........O...........O...........O...........O........
.......O....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO
....................................................................
.......O....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO
......O.O..O...........O...........O...........O...........O........
.....OO....O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O
.......O...O...O.......O...O.......O...O.......O...O.......O...O....
.....OO.....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O
.....OOO..O......O.O..O......O.O..O......O.O..O......O.O..O......O.O
....O.OO.O.....O.....O.....O.....O.....O.....O.....O.....O.....O....
....O..O..O...O..OO...O...O..OO...O...O..OO...O...O..OO...O...O..OO.
....OO.....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O.
....................................................................
....OO.....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O.
....O..O..O...O..OO...O...O..OO...O...O..OO...O...O..OO...O...O..OO.
....O.OO.O.....O.....O.....O.....O.....O.....O.....O.....O.....O....
.....OOO..O......O.O..O......O.O..O......O.O..O......O.O..O......O.O
.....OO.....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O
.......O...O...O.......O...O.......O...O.......O...O.......O...O....
.....OO....O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O
......O.O..O...........O...........O...........O...........O........
.......O....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO
....................................................................
.......O....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO....OOOOOOOO
......O.O..O...........O...........O...........O...........O........
.....OO....O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O...O.OOO...O
.......O...O...O.......O...O.......O...O.......O...O.......O...O....
.....OO.....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O....OO..OO.O
.....OOO..O......O.O..O......O.O..O......O.O..O......O.O..O......O.O
....O.OO.O.....O.....O.....O.....O.....O.....O.....O.....O.....O....
....O..O..O...O..OO...O...O..OO...O...O..OO...O...O..OO...O...O..OO.
....OO.....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O....OO.O.O.O.
....................................................................
```

```
....OO..............................................................
....O...............................................................
....O...............................................................
..OOO.O.............................................................
.OOO................................................................
.O..................................................................
...OOO..............................................................
...O................................................................
....O.O.............................................................
....O.O.............................................................
..OOOO..............................................................
.O.O................................................................
.O.O................................................................
.O..................................................................
..O.................................................................
..O.O...............................................................
...O................................................................
..OO................................................................
...O.O..............................................................
....O...............................................................
```

The rows containing long strings of ON cells can be slid with respect to each other left or right by 2 cells, and the spaceship will still work.

I searched for a way to tame one copy of the front component of the above spaceship, without needing the required tagalong. This is shown below.

Period 3 spaceship with required tail (speed c/3):

```
....O....................................
...O.O...................................
...O.O...................................
...O.....................................
..OO.....................................
..O.O....................................
.........................................
.OOO.....................................
.OOO.....................................
.........................................
....OOO..................................
....OO...................................
.........................................
...OOO...................................
..O..O...................................
.OOO.OO..................................
....OOO..................................
.........................................
....O....................................
....OOO.....O............................
...........O..O..........O...............
....OOO...OO...O..OO....OO...............
```

```
....0.....00...0..00..00000.000.......0.0
.....00.00........00.0........0.0...0..0.
.....00....0..0.0000.0.0..00....0.0.0..00
...........0..00......0....0..000........
......0.....00.0............0............
......0.0................................
......0.0................................
.......0.................................
```

The last 19 columns of this spaceship are the same as the back component of the weaving wicktrailer shown in article 3 that connects to the “turtle” spaceship. So the tail of this spaceship can be made arbitrarily long by inserting more components of that wicktrailer before the end.

Unfortunately, the completion crosses the line between the two rows of 3 cells at the front. So the bottom part of this spaceship cannot be used to terminate itself symmetrically, or be placed at the edges of the dense c/3 spaceship. But if an extension component from one of the previously shown spaceships is inserted between the two rows of 3 cells, then there is room to do these things. For example:

Period 3 spaceship with parts connected by extension component (speed c/3):

```
........0.................................
.......0.0................................
......00..................................
........0....00.0...............0.........
......00....0.....00...0...000..000.......
......000..0...0.00.0.0....00..0.0..0...00
.....0.00.0.0...00....0......0.0..0.0.00..
.....0..0...0.....0....00..0..000.......0.
.....00......0.00..00.........0...........
...........000...........00...............
.....00...................................
.....0....................................
.....0....................................
...000.0..................................
..000.....................................
..........................................
..0.000...................................
.0..0.....................................
..0.0.....................................
...0..00..................................
......00..................................
.....00...................................
....0.0...................................
...0......................................
....0.0...................................
.....00...................................
......00..................................
...0..00..................................
..0.0.....................................
.0..0.....................................
```

```
..O.OOO...................................
..........................................
..OOO.....................................
...OOO.O..................................
.....O....................................
.....O....................................
.....OO...................................
...........OOO...........OO...............
.....OO......O.OO..OO.........O...........
.....O..O...O.....O....OO..O..OOO.......O.
.....O.OO.O.O...OO....O......O.O..O.O.OO..
......OOO..O...O.OO.O.O....OO..O.O..O...OO
......OO....O.....OO...O...OOO..OOO.......
........O....OO.O...............O.........
......OO..................................
.......O.O................................
........O.................................
```

That ends the summary of new results for period 3 c/3 spaceships. Now I will go on to period 4 spaceship results. Firstly, I will give the new results for the slow period 4 spaceships which travel at c/4.

In September 1992 Hartmut Holzwart found a c/4 spaceship with a new type of front end. This is shown below.

Spaceship with required tagalong (speed c/4):

```
.O..OO............O.....OO..............
O..O....O.....O..O.O....OO..............
.O.....OO....O.OOO...O..OO..OO..........
..OO....O.O....O......OO...OO.OO.O......
..O........OO...O.O.....O..OOOOO........
.OO.O....O.......O...OOOO..O..OOOOOO....
..O.O........O...O......O..OO....O.O..OO
...O.O....OOOOOO.OO..................O..
........................................
...O.O....OOOOOO.OO..................O..
..O.O........O...O......O..OO....O.O..OO
.OO.O....O.......O...OOOO..O..OOOOOO....
..O........OO...O.O.....O..OOOOO........
..OO....O.O....O......OO...OO.OO.O......
.O.....OO....O.OOO...O..OO..OO..........
O..O....O.....O..O.O....OO..............
.O..OO............O.....OO..............
```

The last 20 columns of this spaceship are very similar to a tagalong that appeared in a previously known spaceship. The difference in the tagalongs is in the spacing between the halves, and the position of the cells in the last 3 columns. In the spaceship shown here, this isn't a tagalong since the spaceship requires the tagalong to survive.

The last 3 columns of the tagalong shown above can be reversed and the tagalong will still work. This same rearrangement works on several other tagalongs that have the same end. The rearrangement is shown below.

Possible rearrangement of last few columns of above spaceship:

```
0.0......
0.....0..
00000..00
..0.0....
.........
.........
.........
..0.0....
00000..00
0.....0..
0.0......
```

Hartmut later found a second known tagalong that also can be used to support the new front end. This is shown below.

Spaceship with alternative required tagalong (speed c/4):

```
.0..00............0............0.
0..0....0.....0..0.0...00..0.0000
.0.....00....0.000....0..00.....0
..00....0.0....0......0.00......0
..0........00...0.0..........0000
.00.0....0.......0....00.0.....0.
..0.0........0...0...00..........
...0.0....000000.00....0000......
.................................
...0.0....000000.00....0000......
..0.0........0...0...00..........
.00.0....0.......0....00.0.....0.
..0........00...0.0..........0000
..00....0.0....0......0.00......0
.0.....00....0.000....0..00.....0
0..0....0.....0..0.0...00..0.0000
.0..00............0............0.
```

Hartmut also found some new tagalongs for previously known c/4 front ends. Several of these are shown below.

Several different front ends for old period 4 spaceship (speed c/4):

```
...........0......................0................
.........0..00...00.....00.......0000..........000.
.......000......0000...0........00.0...............
```

```
.O..O...O.......O...O.OO...O.O.........OO...OO..OO.
.O..O.O.OO......OOOO..OO...OO...O.....OO.O.O.OOOO..
OO........O.OO..O..O...O.....O.............O.O.....
.O.OO.OOOO.OO.O..OO.....OO....OO......OO....OOO..O.
.O..........OO........................O....O.OO.O.O
.O.OO.OOOO.OO.O..OO.....OO....OO......OO....OOO..O.
OO........O.OO..O..O...O.....O.............O.O.....
.O..O.O.OO......OOOO..OO...OO...O.....OO.O.O.OOOO..
.O..O...O.......O...O.OO...O.O.........OO...OO..OO.
.......OOO......OOOO...O........OO.O...............
.........O..OO...OO.....OO.......OOOO..........OOO.
...........O......................O................

.........O..OO...OO.....OO.......OOOO..........OOO.
.......OOO......OOOO...O........OO.O...............
.O..O...O.......O...O.OO...O.O.........OO...OO..OO.
.O..O.O.OO......OOOO..OO...OO...O.....OO.O.O.OOOO..
OO........O.OO..O..O...O.....O.............O.O.....
.O.OO.OOOO.OO.O..OO.....OO....OO......OO....OOO..O.
.O..........OO........................O....O.OO.O.O
.O.OO.OOOO.OO.O..OO.....OO....OO......OO....OOO..O.
OO........O.OO..O..O...O.....O.............O.O.....
.O..O.O.OO......OOOO..OO...OO...O.....OO.O.O.OOOO..
.O..O...O.......O...O.OO...O.O.........OO...OO..OO.
.......OOO......OOOO...O........OO.O...............
.........O..OO...OO.....OO.......OOOO..........OOO.
...........O......................O................

...........O.............................O............
.........O..OO...OO.....OO..........OO..O.O...........
.......OOO......OOOO...O.......O.O.OOOO.OOOO..........
.O..O...O.......O...O.OO...O.OOO....OO.OO..OOO....O.O.
.O..O.O.OO......OOOO..OO...OO.O.......O........O.OO..O
OO........O.OO..O..O...O.....O..........O.....OOO....O
.O.OO.OOOO.OO.O..OO.....OO............OO......OO......
.O..........OO.......................O................
.O.OO.OOOO.OO.O..OO.....OO............OO......OO......
OO........O.OO..O..O...O.....O..........O.....OOO....O
.O..O.O.OO......OOOO..OO...OO.O.......O........O.OO..O
.O..O...O.......O...O.OO...O.OOO....OO.OO..OOO....O.O.
.......OOO......OOOO...O.......O.O.OOOO.OOOO..........
.........O..OO...OO.....OO..........OO..O.O...........
...........O.............................O............

...........O.............................O........
.........O..OO...OO.....OO..........OO..O.O.......
.......OOO......OOOO...O.......O.O.OOOO.OOOO......
.O..O...O.......O...O.OO...O.OOO....OO.OO..OOO....
.O..O.O.OO......OOOO..OO...OO.O.......O........OOO
OO........O.OO..O..O...O.....O..........O.....OO.O
.O.OO.OOOO.OO.O..OO.....OO............OO......OOO.
.O..........OO.......................O............
.O.OO.OOOO.OO.O..OO.....OO............OO......OOO.
```

```
OO........O.OO..O..O...O.....O..........O.....OO.O
.O..O.O.OO......OOOO..OO...OO.O.......O........OOO
.O..O...O.......O...O.OO...O.OOO....OO.OO..OOO....
.......OOO......OOOO...O.......O.O.OOOO.OOOO......
.........O..OO...OO.....OO..........OO..O.O.......
...........O.............................O........
```

The last 16 columns of this spaceship are the same as the back of a spaceship that was shown near the end of article 4. But here the back end connects to the rest of the spaceship in a different way.

```
...........O..............................O............
.........O..OO...OO.....OO..........OO..OO.............
.......OOO......OOOO...O.......O.O.OOOOO..O............
.O..O...O.......O...O.OO...O.OOO....OOOOO.O..OOO.O.O...
.O..O.O.OO......OOOO..OO...OO.O.........O.OO..OOOO...O.
OO........O.OO..O..O...O.....O...........OO...........O
.O.OO.OOOO.OO.O..OO.....OO................OOOOOOOOOOO.O
.O..........OO.........................................
.O.OO.OOOO.OO.O..OO.....OO................OOOOOOOOOOO.O
OO........O.OO..O..O...O.....O...........OO...........O
.O..O.O.OO......OOOO..OO...OO.O.........O.OO..OOOO...O.
.O..O...O.......O...O.OO...O.OOO....OOOOO.O..OOO.O.O...
.......OOO......OOOO...O.......O.O.OOOOO..O............
.........O..OO...OO.....OO..........OO..OO.............
...........O..............................O............
```

All of the base slow spaceships shown so far have had odd symmetry. In October 1992, Hartmut Holzwart found the first base c/4 spaceship that had even symmetry. This is shown below.

First slow period 4 spaceship with even symmetry (speed c/4):

```
............................
..........O...OO.OO.........
........OOO........O........
..O...OO.O..O.OO............
OO...OOO..OOOO..O...O..OOO..
..O...OOO...O...O...OOO...OO
..........OO....OOO...O...OO
......OO.OO....O.....OO.O...
......OO.OO....O.....OO.O...
..........OO....OOO...O...OO
..O...OOO...O...O...OOO...OO
OO...OOO..OOOO..O...O..OOO..
..O...OO.O..O.OO............
........OOO........O........
..........O...OO.OO.........
```

Hartmut has found several other c/4 spaceships with even symmetry. They show a range of separations between the front pair of traffic lights predecessors. These spaceships are shown below.

Other slow period 4 spaceships with even symmetry (speed c/4):

```
..................O....
..O.OO.........OO..O...
OO...O.........OO.O....
..O.O..........OOOO....
......OOO..OOOOO.......
......OO..O.O.O.O...OO.
........OOOOO.O.O...O.O
.........OO...OOOO..O.O
..........O.O.O.OOO.O..
..........O.O.O.OOO.O..
.........OO...OOOO..O.O
........OOOOO.O.O...O.O
......OO..O.O.O.O...OO.
......OOO..OOOOO.......
..O.O..........OOOO....
OO...O.........OO.O....
..O.OO.........OO..O...
..................O....
```

```
...........O......OO...
...........OO.OO..OOO.O
...........O....O...O.O
..............OO..OOO.O
..O...OOO.........OO...
OO...OOO..O.O..........
..O...OOOOOO.O.........
.............O.........
......OO...............
......OO...............
.............O.........
..O...OOOOOO.O.........
OO...OOO..O.O..........
..O...OOO.........OO...
..............OO..OOO.O
...........O....O...O.O
...........OO.OO..OOO.O
...........O......OO...
```

```
..........O.................
........OO..................
.....O.O.O.O.........OOO..OO
..O..O....O....O...OO.OOOO..
OO...OO....O...O...O.....O.O
..O..OO.......O.OO.OOOOO.OO.
....O..O....OOO.OO.......O..
.....OO......OO.O...OO.O....
....................OO..OO..
....................OO..OO..
```

```
.....OO......OO.O...OO.O....
....O..O....OOO.OO.......O..
..O..OO.......O.OO.OOOOO.OO.
OO...OO....O...O...O.....O.O
..O..O....O....O...OO.OOOO..
.....O.O.O.O.........OOO..OO
........OO..................
..........O.................
```

Hartmut found very few tagalongs for these even symmetrical spaceships. Tagalongs are only known for the last spaceship shown above. The two known tagalongs are shown below.

Two tagalongs for slow period 4 spaceship with even symmetry (speed c/4):

```
..........O..............................
........OO...............................
.....O.O.O.O.........OOO..OO...........O.
..O..O....O....O...OO.OOOO.......OO..OO..
OO...OO....O...O...O.....O.O..O.OO.O.O.O.
..O..OO.......O.OO.OOOOO.OO..OO.OOOO.O.O.
....O..O....OOO.OO.......O.........OO...O
.....OO......OO.O...OO.O.............O..O
....................OO..OO...............
....................OO..OO...............
.....OO......OO.O...OO.O.............O..O
....O..O....OOO.OO.......O.........OO...O
..O..OO.......O.OO.OOOOO.OO..OO.OOOO.O.O.
OO...OO....O...O...O.....O.O..O.OO.O.O.O.
..O..O....O....O...OO.OOOO.......OO..OO..
.....O.O.O.O.........OOO..OO...........O.
........OO...............................
..........O..............................
```

```
..........O................................
........OO.................................
.....O.O.O.O.........OOO..OO...............
..O..O....O....O...OO.OOOO..........O......
OO...OO....O...O...O.....O.O.......OO....OO
..O..OO.......O.OO.OOOOO.OO......O...O.OOOO
....O..O....OOO.OO.......O...O..O......O...
.....OO......OO.O...OO.O......O..O.O...O...
....................OO..OO..O..O...........
....................OO..OO..O..O...........
.....OO......OO.O...OO.O......O..O.O...O...
....O..O....OOO.OO.......O...O..O......O...
..O..OO.......O.OO.OOOOO.OO......O...O.OOOO
OO...OO....O...O...O.....O.O.......OO....OO
..O..O....O....O...OO.OOOO..........O......
.....O.O.O.O.........OOO..OO...............
........OO.................................
..........O................................
```

No wide and short c/4 spaceships have been found yet, nor has a base c/4 spaceship which is non-symmetrical been found yet.

Near the end of October 1992, the first example of a new type of Life object was found by Hartmut Holzwart and Dean Hickerson. This new type of object is now called a "wickstretcher," for reasons that will become obvious.

The first wickstretcher found is shown below. At the left is a period 4 c/4 spaceship component that was found by Hartmut Holzwart. As it moves leftwards it leaves behind a thin wick which has period 5 (but which appears to move at the speed of light). Without a terminating component at the back of the wick, the wick decays at the speed of light and ends up destroying the spaceship component. No moving termination component is known for the wick to finish making a c/4 spaceship. But Dean Hickerson found a period 5 stationary termination component for the wick which stabilizes it, which is seen at the right. In the generation shown here, the wick itself is almost nonexistent, but quickly becomes apparent as the object is run.

First example of a "wickstretcher" known:

```
...................................00..........00........
...................0................0...00.0..0.0........
.............0.00.00...............0...0.0.0000.0.00.....
.............0...0.00..........0...00..0.0......0..0.....
..0...000....00000.0.0.0......0.0....0.0..000000.0.......
00...000..0.00.....0.0.0.......0.....0.0.......0.00......
..0...000000..........0.....0.....00.0...0..00.....0.00.0
.................0......0.......0..0.00..0..0.0..000.0.00
......00.......00......0.00.000.......0.......0.....0....
......00.......00......0.00...0000.0..0.0.0...0.0.00.....
.................0......0...00.....0.00.00.0...00.0......
..0...000000..........0......0..00.0...0...0........0....
00...000..0.00.....0.0.0...0....00.000.0...00......00....
..0...000....00000.0.0.0...00.........0..................
.............0...0.00................0...................
.............0.00.00.................00..................
...................0.....................................
```

A month later Dean Hickerson found a smaller version of the termination component, which is shown below. Like the previous terminator, this one is unsymmetrical. (Dean had looked for symmetrical terminators, but none were found.)

Smallest version of "wickstretcher:"

```
.................00..............................
.............00....0.............................
............000.0................................
0.00..00...0...0000.0.0....00.......00...........
0....00..0........0.000....0....00.0..0.00.0.....
0.00....00.00....0...........0...0.0.00.0.00.....
......0.......0.............00.....0..0.0...00...
.....0.........0.0....000...0....0..0.0.000...0..
.....0.........0.0....000.00.0..00.0.0...0..00.0.
```

```
......0.......0.............00.0...00....00....0.
0.00....00.00....0..........0........00.0.0.00.00
0....00..0........0.000........0...0...00.0..0.0.
0.00..00...0...0000.0.0.......0.0...00....0..0.0.
............000.0..............0.....0.000....0..
.............00....0.................0.0.........
.................00...................0..........
```

These two wickstretchers are the only known use of the orthogonal non- standard speed spaceships to create objects which grow arbitrarily large. The search for true puffers for non-standard speed spaceships is still unsuccessful.

New period 4 Spaceships

As this article was being prepared, Hartmut Holzwart found another reasonably small slow period 4 spaceship. This is shown below. The front end of this spaceship is the same as in some previous spaceships shown in article 4, but the back end is much smaller.

Newest slow period 4 spaceship (speed c/4):

```
.......0..................
.....00...................
.......0...00.....00......
.....000...00....0.....0..
....00..........00.000..00
..0....0...0.0.0.000.0....
00....0..0.0.00.00........
..0..000..................
..........................
..0..000..................
00....0..0.0.00.00........
..0....0...0.0.0.000.0....
....00..........00.000..00
.....000...00....0.....0..
.......0...00.....00......
.....00...................
.......0..................
```

That ends the discussion of the new results for slow period 4 spaceships. Now I will go on to the new results for the period 4 spaceships which move at the standard speed of c/2. Most of these new spaceships are tagalongs of a convoy of standard spaceships, or almost-spaceships.

Hartmut found some new tagalongs for pairs of almost-spaceships with several different separations, all of which are symmetrical. The spaceships below have a separation of one cell between the almost-spaceships.

Two period 4 spaceships (speed c/2):

```
....................0.0......
...........00.....00....0....
..........0000....00.....00..
.0.......0.0.00.0....000.0000
0.....0.00.....0..000.00.....
0.....000....0......00.0.0.0.
00000.0.0..00....0....00.....
........0.0.0...0......0.0...
........0.0..................
........0.0.0...0......0.0...
00000.0.0..00....0....00.....
0.....000....0......00.0.0.0.
0.....0.00.....0..000.00.....
.0.......0.0.00.0....000.0000
..........0000....00.....00..
...........00.....00....0....
....................0.0......
```

```
.....................0..0.0.0..........
.....................0....0.0..........
..............00.00..0.....0...........
.0........000...00.0..0...0.......0000.
0.....0..00...........0...0.......0...0
0.....000.0.0..0.......00.0......0.....
00000.0.0.0.0..0..........00..0.0000..0
........0.0...0............0000.00.....
........0.0............................
........0.0...0............0000.00.....
00000.0.0.0.0..0..........00..0.0000..0
0.....000.0.0..0.......00.0......0.....
0.....0..00...........0...0.......0...0
.0........000...00.0..0...0.......0000.
..............00.00..0.....0...........
.....................0....0.0..........
.....................0..0.0.0..........
```

In the above spaceship, the last seven columns are actually a tagalong and can be removed. The tagalong is made of two standard spaceships pushing ahead little bits of "dirt."

The following is a tagalong to four standard spaceships. The separation of one cell for the front two spaceships is the same as that used for the Schick engine.

Four standard spaceships with period 4 tagalong (speed c/2):

```
..........0000....
.........000000...
........00.0000...
.........00.......
..................
..............0...
............0.....
```

```
0000.......0...0..
0...0.....00....0.
0.......0..0......
.0..0..000.0..0...
......00..00..0..0
.0..0..000.0..0...
0.......0..0......
0...0.....00....0.
0000.......0...0..
............0.....
..............0...
..................
.........00.......
........00.0000...
.........000000...
..........0000....
```

For a separation of seven cells, Hartmut Holzwart found that two LWSSs can support a particularly small tagalong. This one could possibly have been found manually.

Small period 4 tagalong for two LWSSs (speed c/2):

```
0000.....
0...0....
0........
.0..0....
.........
.....0000
....0..0.
....0..0.
....0..0.
.....0000
.........
.0..0....
0........
0...0....
0000.....
```

The same two LWSSs also can support a larger tagalong, as shown below. This tagalong has a nice set of sparks at the back.

Two LWSSs supporting a larger tagalong (speed c/2):

```
0000..............
0...0.......000...
0.......000..000..
.0..0..0000..000..
......000.....00..
....00....00..000.
...0.00.0.00..0.00
```

```
..O......O..O.O.O.
..O..O.....O..O.OO
..O......O..O.O.O.
...O.OO.O.OO..O.OO
....OO....OO..OOO.
......OOO.....OO..
.O..O..OOOO..OOO..
O.......OOO..OOO..
O...O.......OOO...
OOOO..............
```

The sparks from the above tagalong can support a number of other tagalongs. Some of these are shown below. In the phases shown here, some of the connections appear very tenuous.

Various tagalongs to a tagalong of two LWSSs (speed c/2):

```
OOOO..................
O...O.......OOO.......
O.......OOO..OOO......
.O..O..OOOO..OOO......
......OOO.....OO......
....OO....OO..OOO.....
...O.OO.O.OO..O.OO....
..O......O..O.O.O..O.O
..O..O.....O..O.OO....
..O......O..O.O.O..O.O
...O.OO.O.OO..O.OO....
....OO....OO..OOO.....
......OOO.....OO......
.O..O..OOOO..OOO......
O.......OOO..OOO......
O...O.......OOO.......
OOOO..................
```

```
...................O.O...................O.O...
OOOO..............O.....................O..O.O.
O...O.......OOO...O..O....OOO..........OO.....O
O.......OOO..OOO..OOO.OO.O.OO.OO......O....O..O
.O..O..OOOO..OOO......OO.O.O.OO...OO.OOOOO.O.O.
......OOO.....OO.....O...O.O...................
....OO....OO..OOO.....OO.OOOOOOOOO...OOO.OOO..O
...O.OO.O.OO..O.OO.....OO................OOO..O
..O......O..O.O.O.......OOOOOOOOOOOO..O.......
..O..O.....O..O.OO.....................OO......
..O......O..O.O.O.......OOOOOOOOOOOO..O.......
...O.OO.O.OO..O.OO.....OO................OOO..O
....OO....OO..OOO.....OO.OOOOOOOOO...OOO.OOO..O
......OOO.....OO.....O...O.O...................
.O..O..OOOO..OOO......OO.O.O.OO...OO.OOOOO.O.O.
O.......OOO..OOO..OOO.OO.O.OO.OO......O....O..O
O...O.......OOO...O..O....OOO..........OO.....O
```

```
0000..............0.....................0..0.0.
...................0.0...................0.0...
```

In the following spaceship, the final tagalong is supported by a set of two close sparks from the first tagalong. Those sparks could be provided by two LWSSs instead, but that turns out not to work because the sparks from the LWSSs two generations later destroy the MWSSs. So you need this large spaceship (or ones with similar sparks) in order to support the last tagalong.

Period 4 spaceship with simple tagalong to a tagalong (speed c/2):

```
0000................00....
0...0.......000....00.000.
0.......000..000....00000.
.0..0..0000..000.....000..
......000.....00..........
....00....00..000.........
...0.00.0.00..0.00...00.00
..0......0..0.0.0....0....
..0..0.....0..0.00...0....
..0......0..0.0.0....0....
...0.00.0.00..0.00...00.00
....00....00..000.........
......000.....00..........
.0..0..0000..000.....000..
0.......000..000....00000.
0...0.......000....00.000.
0000................00....
```

In the following two tagalongs in the series, the only difference is in the last few columns. In the first spaceship, the tail is actually of period 2. But in the second spaceship, the last few columns revert back to period 4.

Two period 4 spaceships with interesting tagalongs (speed c/2):

```
...................0.0.......0.0............
0000..............0.........0.00............
0...0.......000...0..0....0..............0.0
0.......000..000..000.00.0.0.0..........0..0
.0..0..0000..000......00.0.0.00........00...
......000.....00.....0...0.0.00..000..0...0.
....00....00..000.....00.0...00.0....000.0..
...0.00.0.00..0.00.....00.....0.0...0.......
..0......0..0.0.0........00000...000000000..
..0..0.....0..0.00..........................
..0......0..0.0.0........00000...000000000..
...0.00.0.00..0.00.....00.....0.0...0.......
....00....00..000.....00.0...00.0....000.0..
......000.....00.....0...0.0.00..000..0...0.
.0..0..0000..000......00.0.0.00........00...
0.......000..000..000.00.0.0.0..........0..0
```

```
O...O.......OOO...O..O....O..............O.O
OOOO..............O.........O.OO............
...................O.O.......O.O............

...................O.O.......O.O...........O.O..
OOOO..............O.........O.OO..........O..O..
O...O.......OOO...O..O....O..............OO.....
O.......OOO..OOO..OOO.OO.O.O.O..........O...O...
.O..O..OOOO..OOO......OO.O.O.OO........OOO.O....
......OOO.....OO.....O...O.O.OO..OOO..O.........
....OO....OO..OOO.....OO.O...OO.O....OOOOOOO....
...O.OO.O.OO..O.OO.....OO.....O.O...O........O.O
..O......O..O.O.O........OOOOO...OOOOOOOOOOOOOOO
..O..O.....O..O.OO..............................
..O......O..O.O.O........OOOOO...OOOOOOOOOOOOOOO
...O.OO.O.OO..O.OO.....OO.....O.O...O........O.O
....OO....OO..OOO.....OO.O...OO.O....OOOOOOO....
......OOO.....OO.....O...O.O.OO..OOO..O.........
.O..O..OOOO..OOO......OO.O.O.OO........OOO.O....
O.......OOO..OOO..OOO.OO.O.O.O..........O...O...
O...O.......OOO...O..O....O..............OO.....
OOOO..............O.........O.OO..........O..O..
...................O.O.......O.O...........O.O..
```

Hartmut Holzwart found another series of spaceships which are tagalongs to four standard spaceships, and which are no longer symmetrical, but which are glide-reflective. Some of these are shown below.

Four LWSSs with various large tagalongs (speed c/2):

```
........O..O.....................................
.......O.........................................
.O..O..O...O...........................O.........
O......OOOO.......................O...O....O.O...
O...O...............O....OO.O..OOOOO.OO..OO...OO.
OOOO..........O..OOOOO.OO.....OO.....OOOO....O...
.......O..O...O.OO......OOO..O.O..OOO..O....O....
......OO.OO.OO...OOOO.O.OO.OO..O..O.OOO.....O....
.....O.O.O........OOO.O..OOO...OO......O...OO....
.....O...OO.OOO...........OOO..OO........O.O.OO.O
.....OO.OO....OOO........OO.O..OO......OO.....OO.
.....OO.O.O.OO.OO...OO.........OO.O..O.....O...O.
............OOO..OO...O.O....O..O..OOO..O.....O..
.O..O..OO...OO.O...O...O...O..O.OO.OO.OO.OO......
O..............O...O....OOO.O.O.........O..OO....
O...O...O..O.....O.O..OO.O.....OOO...OOO...OOO..O
OOOO...O.........................O....OOOO.OO..O.
.......O...O...........................O.........
.......OOOO......................................

........O..O..................................
```

```
.......O........................O.OO....OO.OO.
.O..O..O...O.................OOOO.OO....OO....
O......OOOO.......OO........OO...O..OOOOO..OO.
O...O...........OOOO.......OOO..O...O..O......
OOOO..........O.O...O..OOO..O..OO...O...O.....
.......O..O...O......O.O.OO.............O.....
......OO.OO.OO.....O.OOO.O.OO........OO.O....O
.....O.O.O.........O.OO...............OOOO.O.O
.....O...OO.OOO..OOO.O.O.O...............O....
.....OO.OO....OOO..OO..O.O............OOO.....
.....OO.O.O.OO.OO......O.O.O..........OO..OO..
............OOO.O..........OO........O..OO.OO.
.O..O..OO...OO.OO...OOO.O..OOOO.......O..OO...
O..............O.OO.OO.OOO..OOO...O..O..OOO...
O...O...O..O....OOOO.OO.OO.OO.OO....OO.OOO....
OOOO...O....................O......O...O......
.......O...O.................OOO.O.....OOO.O..
.......OOOO....................O.OO.......O...
..........................................O...
```

In the last spaceship of this series, the tagalong breaks apart into two components which do not react with each other. Each one of these components becomes symmetrical, which is unusual.

Four LWSSs with tagalong which splits and becomes symmetrical (speed c/2):

```
........O..O...................................
.......O................OO.........OO.OO...OO..
.O..O..O...O..........O........OOO.OOO..O..O..O
O......OOOO.........OOO...O..O..O..O.....O....O
O...O...........O...O.O....OOOO.OO....O..O.O...
OOOO..........O.OOOO....OO.O.O..O..O.....O....O
.......O..O...O.........OO.....OOO.OOO..O..O..O
......OO.OO.OO....O.O.....O........OO.OO...OO..
.....O.O.O.......O....OOO......................
.....O...OO.OOO..O..O.O........................
.....OO.OO....OOO..............................
.....OO.O.O.OO.O..OO..OOO......................
............OOO.O..O....O.......OO.O..O..O.O..O
.O..O..OO...OO.OOOOO....OOO.....OOO.O.O....O..O
O..............O...OO..O..O..O.O.....OO.....OO.
O...O...O..O....OO.O.O....O.O.OO..OOO...O..O...
OOOO...O............O........O.O.....OO.....OO.
.......O...O..........OOOO......OOO.O.O....O..O
.......OOOO.....................OO.O..O..O.O..O
```

Here is another spaceship in a series started in article 5, where a known front end connects to several large components. Like those other spaceships, this spaceship is glide-reflective.

Period 4 spaceship with large components (speed c/2):

```
...................................................................O.O
..OOO.................................................OO..........OO.O
.OOOO....................O..O........................OO.OO.O.....O....
OO.....................OOO..O............O..O.........O.OO.....OO.OO..
.O.OO.................O.....O.......O....O...O......O.O....O.O.O.O....
..OO.OO.O...OOO.....OO.OOO.O.......OO....O.........OO.O.OO..O.O.OO....
......O..OO.OO.O...O.O..OO.O.....OOOOOOO.O.O......O.O.O..OO..OO......
....OOO.OO...OO..O...OO....O.........OO.O.O.O..OOO.O.O.O..O..O.O......
....OOO.....O...O.O...O.OO...OO..O........O.O...OO.O.O.O...O.OO.......
......O.OO.O.O...............O.OO..O.OOO.O.O....O.O.O.O....O..OO......
....OO.......OOO..OO.O..O......OO.OOO...OO.O.OO..O..O.O.OO....OO......
...OO.OOO.....O...O.O....O....O...OO.....O.O.....O..O.O....O.OO.......
..O...OO....OOOO.....OO..OO...O....O....O...O......OO..O.OO...........
.OO.O.O......OO......OO.............O...OO.O........OO.O...O.O.O......
OO..O.O................OOOO...O...........O..........O.OOO...O.OOOO...
.OO.......................OO.O........................O....O....OOO...
....OO................................................OOOOO..........O
.......................................................OO..........OO.
```

Finally, Hartmut Holzwart found another small symmetrical period 4 spaceship. This produces sparks on the outside edge like a HWSS.

Small period 4 symmetrical spaceship (speed c/2):

```
..OO.OOOOOO.
.OOOO......O
OO..........
.O.........O
..OOO.O.....
....O.......
....O.......
.....O......
....O.......
....O.......
..OOO.O.....
.O.........O
OO..........
.OOOO......O
..OO.OOOOOO.
```

The length of the tails in the above spaceship cannot be shortened to produce the MWSS or LWSS style of sparks. But the tails can be lengthened if they are supported by standard spaceships. This is shown below.

Longer period 4 spaceship supported by two standard spaceships (speed c/2):

```
......OO......
.....OO.OOO...
......OOOOO...
.......OOO....
```

```
..............
..............
..............
..OO.OOOOOOO..
.OOOO.......O.
OO............
.O..........O.
..OOO.O...O...
....O.........
....O.........
.....O........
....O.........
....O.........
..OOO.O...OO..
.O...........O
OO............
.OOOO........O
..OO.OOOOOOOO.
..............
..............
..............
.......OOOO...
......OOOOOO..
.....OO.OOOO..
......OO......
```

That ends the discussion of new period 4 spaceships. Now I will go on to the single new result for period 5 spaceships. On December 5, 1992, Hartmut Holzwart found a period 5 spaceship which travels at 2c/5. This is only the second such base spaceship known. Unlike the first spaceship which was found by Dean Hickerson, this one has even symmetry.

Second known period 5 spaceship (speed 2c/5):

```
...O............
.O.O....O.......
OO.OOO...O....O.
.OO.O........O.O
......OO...OOO..
.....O...O......
......OO....OOOO
......OO.OOOO.OO
................
................
......OO.OOOO.OO
......OO....OOOO
.....O...O......
......OO...OOO..
.OO.O........O.O
OO.OOO...O....O.
.O.O....O.......
...O............
```

No period 5 spaceship has been found which travels at c/5.

That ends the discussion on period 5 spaceships. Now I will move on to the period 96 c/12 Cordership. In article 1 of my series, I showed Dean Hickerson's Cordership which travels diagonally at c/12. I neglected to give a few useful pieces of information about it.

Firstly, the back four switch engines can be moved backwards by any multiple of eight cells, if extra blocks are also inserted on the sides to continue the obvious pattern. This is because the only use of the back four switch engines is to delete the blocks left by the other switch engines. So this allows an arbitrarily large spaceship to be constructed which moves diagonally at c/12. And where there is room, the phase of the back switch engines can be adjusted with respect to the other switch engines.

Secondly, the Cordership will still work if the back four switch engines are moved backwards by one or two cells. (In fact, any combination of the four back switch engines can be moved backwards by two cells.)

Thirdly, a Cordership can be made larger by inserting more switch engines into each row of switch engines. This lets you make a Cordership which is as wide as you want.

Lastly, if one switch engine is moved one cell backwards with respect to an adjacent one, then a block will be produced behind the two switch engines. By adjusting the positions of the back switch engines, from 1 to 3 blocks can be produced. These blocks can be used to support other rows of switch engines to produce very large compound Corderships.

Below is a compound Cordership which illustrates an extra row of switch engines connecting two Corderships which each leave behind single blocks. Since this is a large object, the picture has been compressed. Each dollar sign represents ten periods. Simply use an editor to replace each dollar sign by ten periods to reconstruct the full picture.

Two period 96 Corderships connected by switch engines (speed c/12):

```
$$$.....OO$$$$$$$$$$$$$...
$$$.....O...OO$$$$$$$$$$$$.........
$$$....O......O.......OOO$$$$$$$$$$$........
$$$..OOOOO...O.....OOO$$$$$$$$$$$$.
$$$.....O...O......OOO$$$$$$$$$$$$.
$$$..O..O$.O$$$$$$$$$$$$..
$$....OO.......OO$$$$$$$$$$$$$.....
$$....OO$$$$$$$$$$$$$$....
$$$$$$$$$$$$$$$$$
$$$$$........O$$$$$$$$$$$.
$$$$$........O$$$$$$$$$$$.
$$$$$........O$$$$$$$$$$$.
$$$$$......OO$$$$$$$$$$$..
$$$$$.....OOO$$$$$$$$$$$..
$......OO$$$........OO$$$$$$$$$$$..
$......OO$$$$$$$$$$$$$$$..
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$........O$$$$$$$$$$$.
```

```
$$$$$.......0$$$$$$$$$$$..
$$$$$........0$$$$$$$$$$$.
........00$$$$$$$$$$$$$$$$
........00$$$......0$$$$$$$$$$$$...
$$$$.....0.0$$$$$$$$$$$$..
$$$$....00.00$$$$$$$$$$$$.
$$$$.......00$$$$$$$$$$$$.
$$$$.00$$$$$$$$$$$$.......
$$$$...0..000$......0.0.......000$$$$$$$$$..
$$$$.00.0$$.0.....000$$$$$$$$$.....
00$$$$.0..0$$.....000$$$$$$$$$.....
00$$$$.0$$.........0$$$$$$$$$......
....0.......0$$$.00$$$$$$$$$$$$....
...0.0.....000$$$$$$$$$$$$$$$......
..0..0..0000.00$$$0$$$$$$$$$$$$....
........0..000$$.........00.00$$$......0$$$$$$$$.....
.....0..00..0$$$.0$$$.........0$$$$$$$$.....
...0.0.00$$$........0$$$......0$$$$$$$$.....
....0$$$$0$..0.00$$00$$$$$$$$......
$$$$.........0.0......0.000$........000$$$$$$$$......
$$$$$.0....0.0....0$........00$$$$$$$$......
$$$$........0...0.0......00$$$$$$$$$$.......
$$$$$00..0..0...0$$$$$$$$$$........
$$$$$.0...00.0$$$$$$$$$$$.
$$$$$.......0.0$$$$$$$$$$$
$$$$$.......0.0$$....0$$$$$$$$.....
$$......0$$$$$......0.0$$$$$$$$....
$$.....000$$$$$....0..0$$$$$$$$....
$$....00.00$$$$$$$$$$$$$$.
$$.....000$$$$$$$$$$$$$$..
$$......0$$$$$......0..0$$$$$$$$...
$$....0.0$$$$$....000.00$$$$$$$$...
$$...0000$$$$$...0..00$$$$$$$$.....
$$...0$$$$$......0..0$$$$$$$$......
$$$$$$$$.0.0$$$$$$$$......
$$...00.00$$$$$$$$$$$$$$..
$$..0.....0$$$$$$$$$$$$$$.
$$...0...0$$$$$$$$$$$$$$..
$$......0...0.......0$$$$$$$$$$$$$.
$$.........0.0.....000$$$$$$$$$$$$$
$$........0..0..0000.00$$$$$$$$$$$$.........
$$$....0..000$$$.........00$$$$$$$$.........
$$$.0..00..0$$$$00$$$$$$$$.........
$$.........0.0.00$$$$$$$$$$$$$.....
$$$0$$$$$$$$$$$$$.........
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$.00$$$$$$$$$.......
$$$$$$$.00$$$$$$$$$.......
$$$$$...0$$$$$$$$$$$......
$$$$$..000$$$$$$$$$$$.....
$$$$$.00.00$$$$$$$$$$$....
```

```
$$$.........00$.000$$$$$$$$$$$.....
$$$.........00$..0$$$$$$$$$$$......
$$$$$.0.0$$$$$$$$$$$......
$$$$$0000.........00$$$$$$$$$$.....
$$$$$0$..00$$$$$$$$$$.....
$$$$$$$$$$$$$$$$$
$$$$$00.00$$$$$$$$$$$.....
$$$$.........0.....0$$$$$$$$$$$....
$$$.00$.......0...0$$$$$$$$$$$.....
$$$.00...0.......0........0$$$$$$....00$$$$$
$$$.....0.0.....000$$$$$$$..0...00$$$$......
$$$....0..0..0000.00........00$$$$$$0......0.......000$$$.....
$$$$0..000.........00$$$$$........00000...0.....000$$$........
$$$.......0..00..0$$$$$$$...0...0......000$$$........
$$$.....0.0.00$$$$$$$....0..0$.0$$$.........
$$$......0$$$$$$$00.......00$$$$$..
$$$$$$$$$$.......00$$$$$$.
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$.0$$........
$$$$$$$$$$$$$$.0$$........
$$$$$$$$$$$$$$.0$$........
$$$$$$$$$$$$$.........00$$.........
$$$$$$$$$$$$$........000$$.........
$$$$$........0$$$$00$$$........00$$.........
$$$$$.......000$$$.........00$$$$$$.........
$$$$$......00.00$$$$$$$$$$.........
$$$$$.......000$$$$$$$$$$$
$$$$$........0$$$$$$$$$$$.
$$$$$......0.0$$$$$$$$..0$$........
$$$$$.....0000$$$$$$$$.0$$.........
$$$$$.....0$$$$$$$$.....0$$........
$$$$$$$$$.00$$$$$$$.......
$$$$$.....00.00$$$.00$$$......0$$$$
$$$$$....0.....0$$$$$$.......0.0$$$.........
$$$$$.....0...0$$$$$$.......00.00$$$........
$$$$$........0...0.......0$$$$$.........00$$$........
$$$$$$.0.0.....000$$$$$..00$$$$....
$$$$$$0..0..0000.00$$$$$...0..000$......0.0.......000.........
$$$$$$......0..000$$$$$..00.0$$.0.....000$..
$$$$$$...0..00..0$..00$$$$.0..0$$.....000$..
$$$$$$.0.0.00$......00...0.......0$$.........0$$.........0$...
$$$$$$..0$$....0.0.....000$$.........00$$$$.
$$$$$$$$......0..0..0000.00$$$$$$$.
$$$$$$$$$..0..000$$$0$$$$.
$$$$$$$$.........0..00..0$$.........00.00$$$......0..
$$$$$$$$.......0.0.00$$$....0$$$.........0..
$$$$$$$$........0$$$$.0$$$......0..
$$$$$$$$$$$$........0$..0.00$$00...
$$$$$$$$$$$$$..0.0......0.000$........000...
$$$$$$$$....0$$$$.........0....0.0....0$........00...
$$$$$$$$...000$$$$.....0...0.0......00$$....
$$$$$$$$..00.00$$$$......00..0..0...0$$.....
$$$$$$$$...000$$$$........0...00.0$$........
$$$$$$$$....0$$$$$.....0.0$$.......
```

```
$$$$$$$$..O.O$$$$$.....O.O$$....O..
$$$$$$$$.OOOO.........OO$...O$$$$$......O.O.
$$$$$$$$.O$..OO$..OOO$$$$$....O..O.
$$$$$$$$$$.......OO.OO$$$$$........
$$$$$$$$.OO.OO$$..OOO$$$$$.........
$$$$$$$$O.....O$$..O$$$$$......O..O
$$$$$$$$.O...O$$.O.O$$$$$....OOO.OO
$$$$$$$$....O$$.OOOO$$$$$...O..OO..
$$$$$$$$$$......O$$$$$......O..O...
$$$$$$$$......OO$$$$$$$......O.O...
$$$$$$$$......OO$........OO.OO$$$$$.........
$$$$$$$$$$.....O.....O$$$$$........
$$$$$$$$$$......O...O$$$$$.........
$$$$$$$$$$.........O...O.......O$$$$........
$$$$$$$$$$$..O.O.....OOO$$$$.......
$$$$$$$$$$$.O..O..OOOO.OO$$$$......
$$$$$$$$$$$.......O..OOO$$$.........OO......
$$$$$$$$$$$....O..OO..O$$$$OO......
$$$$$$$$$$$..O.O.OO$$$$$..
$$$$$$$$$$$...O$$$$$......
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$$$....OO$....
$$$$$$$$$$$$$$$....OO$....
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$.....O$$$....
$$$$$$$$$$$$$....OOO$$$...
$$$$$$$$$$$$$...OO.OO$$$..
$$$$$$$$$$$$$....OOO$$$...
$$$$$$$$$$$$$.....O$$$....
$$$$$$$$$$$$$...O.O$OO$$..
$$$$$$$$$$$$$..OOOO$OO$$..
$$$$$$$$$$$$$..O$$$.......
$$$$$$$$$$$$$$$$$
$$$$$$$$$$$$$..OO.OO$$$...
$$$$$$$$$$$$$.O.....O$$$..
$$$$$$$$$$$$$..O...O$$$...
$$$$$$$$$$$$$.....O$$$....
$$$$$$$$$$$$$........OO$$$
$$$$$$$$$$$$$........OO$$$
```

By combining the techniques for modifying Corderships, very large and complicated spaceships can be constructed which travel diagonally at c/12.

That ends the discussion of the Cordership. Now I will summarize the new developments for large period spaceships and puffers. The new results found here are by me.

Firstly, it is possible to fill in some of the gaps in large period puffers. These gaps are the periods below about 1100, above which the glider-turning methods can produce any period which is a multiple of 4.

The pattern below is a puffer with a period of 360. It produces several pairs of blocks, and a small pile of random debris. It is constructed from two period 120 backwards rakes and a blinker puffer. The first pair of gliders from the rakes ignite the blinker fuse, and the rake's period is high enough so that further gliders from the rakes miss the fuse and just form blocks. That is, until the fuse burns out and a new row of blinkers is created to begin the process again.

Period 360 puffer (speed c/2):

```
.................................OO...............................
..O..O.....OO...................OO.OOO............................
.O........OOOO...................OOOOO............................
.O...O...OO.OO....................OOO.............................
.OOOO.....OO......................................................
.........................OO...................................OO..
........................O....O..............................O....O
........................OO...O.............................O......
.....OO........OO......O.OOO..O............................O.....O
...OO.OO.......OO.....OOO....OO............................OOOOOO.
...O..O..........O.....O.OO.O.....................................
...O..O.........O.......OOO.......................................
....OO...................OO.......................................
..................................................................
..................................................................
..O..O............................................................
.O.........OO...............OO.................O..................
.O...O...OO.OOO...........OO.OO..............OOO..................
.OOOO......OOOOO............OOOO...O.....OOO......................
............OOO..............OO...O.OO...OOO...OO.................
.................................O...O........OO..................
.............................OO...O.OO...OOO......................
............................OOOO...O.....OOO......................
...........................OO.OO..................................
............................OO....................................
..................................................................
..................................................................
....................................................O.............
..................................................O...O...........
.................................................O................
.................................................O....O...........
.................................................OOOOO............
..................................................................
..................................................................
..................................................................
..................................................OO..............
.................................................OO.OOO.O.........
..................................................OOOOOOO.........
...................................................OOOOO..........
..................................................................
......................................................OO..........
....................................................O....O........
...................................................O..............
...................................................O.....O........
...................................................OOOOOO.........
```

```
..................................................................
..................................................................
..................................................................
..................................................................
..................................................................
............................OO....................................
...........................OO.OO..................................
............................OOOO...O.....OOO......................
.............................OO...O.OO...OOO......................
.................................O...O........OO..................
............OOO..............OO...O.OO...OOO...OO.................
.OOOO......OOOOO............OOOO...O.....OOO......................
.O...O....OO.OOO...........OO.OO..............OOO.................
.O.........OO...............OO.................O..................
..O..O............................................................
..................................................................
..................................................................
....OO...................OO.......................................
...O..O.........O.......OOO.......................................
...O..O..........O.....O.OO.O.....................................
...OO.OO.......OO.....OOO....OO............................OOOOOO.
.....OO........OO......O.OOO..O............................O.....O
........................OO...O.............................O......
........................O....O..............................O....O
.........................OO...................................OO..
.OOOO.....OO......................................................
.O...O...OO.OO....................OOO.............................
.O........OOOO...................OOOOO............................
..O..O.....OO...................OO.OOO............................
.................................OO...............................
```

The particular pattern above can be squeezed down thinner than is shown, but I left it spread out so that you can easily play with it as described below.

By moving the blinker puffer forwards (leftwards) by 12 cells (and adding 6 produced blinkers), a puffer is created with a period which is 480, which is 120 more than the original. This process can be repeated as desired to create a puffer of any period which is 360 + 120 * N.

By using other period rakes, some more of the missing puffer periods can probably be constructed in the "large period gap." But this method can obviously only produce puffers which are multiples of the rake's periods. The period has to be large enough so that the second pair of gliders can clear the burning fuse (the period 120 shown here seems just large enough).

In article 6 of my series, I described how to construct large period spaceships which use pairs of gliders to ignite a blinker trail. I have since discovered that a single glider will suffice for the ignition, if the collision is perturbed by an accompanying spaceship. So the large period puffers do not have to be symmetrical, they can instead be one-sided.

Below is a puffer with period 1340 which illustrates how the one-sided ignition works. Because the puffer is long, it is given in compressed form. Use an editor to replace each dollar sign by ten periods to reconstruct the full picture.

```
$$$.0000$$$$$$$$$$$$$$..
$$$.0...0$$$$$$$$$$$$$$.
$$$.0$$$$$$$$$$$$$$.....
$$$..0..0$$$$$$$$$$$$$$.
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$....0$$$$$$$$$$$$$$$$..
$..0...0$$$$$$$$$$$$$$$$
$.0$$$$$$$$$$$$$$$$.....
$.0....0$$$$$$$$$$$$$$$$
$.00000$$$$$$$$$$$$$$$$.
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$0$$$$$$$$$$$$$$$$......
.00.0...00.00$$$$$$$$$$$$$$$$....
0..00000.0$$$$$$$$$$$$$$$$.......
0..0.00.00$....0$$$$$$$$$$$$$$$..
00...000.00......00.0..0.0$$$$$$$$$$$$$$$.
..0......00.....0.0.0000.0$$$$$$$$$$$$$$$.
.........00.000.0$$$$$$$$$$$$$$$$
..0......00.....0.0.0000.0$$$$$$$$$$$$$$$.
00...000.00......00.0..0.0$$$$$$$$$$$$$$$.
0..0.00.00$....0$$$$$$$$$$$$$$$..
0..00000.0$$$$$$$$$$$$$$$$.......
.00.0...00.00$$$$$$$$$$$$$$$$....
$0$$$$.....0$$$$$$$$$$$$
$$$$$....0...0$$$$$$$$$$$........
$$$$$...0$$$$$$$$$$$.........0..0
$.00000$$$.......0....0$$$$$$$$$$$...0....
$.0....0$$$......00000$$$$$$$$$$$....0...0
$.0$$$$$$$$$$$$$$$$0000.
$..0...0$$$$$$$$$$$$$$$$
$....0$$$$$$$$$$$$$$$$..
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$....000000$$$.......
$$$$$$$$$$$$$....0.....0$$$......
$$$$$$$$$$$$$....0$$$$..
$$$$$$$$$$$$$.....0....0$$$......
$$$$$$$$$$$$$.......00$$$........
$$$$.00$$$$$$$$$$$$$....
$$$$00.00$$$$$$$$$$$$$..
$$$$.0000$$$$$$$$$$$$$..
```

```
$$$$..OO$$$$$$$$$$$$$...
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$$$$$$.......
$$$$$$$$$$$$......OOOOOO$$$$.....
$$$$$$$$$$$$......O.....O$$$$....
$$$$$$$$$$$$......O$$$$$
$$$$$$$$$$$$.......O....O$$$$....
$$$$$$$$$$$$.........OO$$$$......
```

Moving the back two HWSS backwards and outwards by 6N cells, and also moving the back LWSS backwards by 12N cells, will produce a puffer whose period is increased by 120N, and which attempts to leave 3N more blinkers.

If the top LWSS is removed, and replaced with a LWSS in the symmetrical position to the one at the bottom, then the puffer will also produce a backwards traveling glider.

This concludes my addendum to the Spaceships in Conway's Life series. I would like to thank *Harold McIntosh*, *Hartmut Holzwart*, and especially *Dean Hickerson* for reviewing this article.

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