Ant World

An 'Ant' is a cellular automaton which wanders over a grid of cells obeying certain rules.

Langton's original ant had 2 cell values (**0** and **1**), two directives (**L** and **R**) and a single state (**A**).

A natural extension of this ant (which we shall continue to call Langton's Ant) allows for multiple cell values and 2, 4 or 6 directives – with the condition that the cell values are updated cyclically. In other words, if a cell has a value of 3, it will be updated to value 4 (or 0 if there are only 4 cell values allowed). In this way, all that is needed to specify a Langton Ant is a string of directives. For example, the string **LNRL** would define an ant with 4 cell values (0, 1, 2 & 3). If this ant landed on a cell with a cell value of 2, it would update it to 3, turn right and move forward one space.

The four direction of a square grid are as follows:

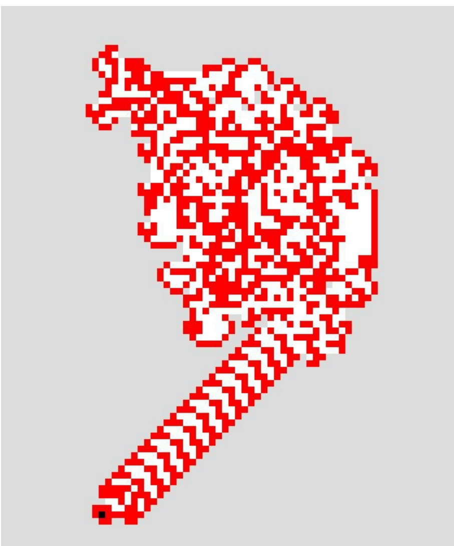
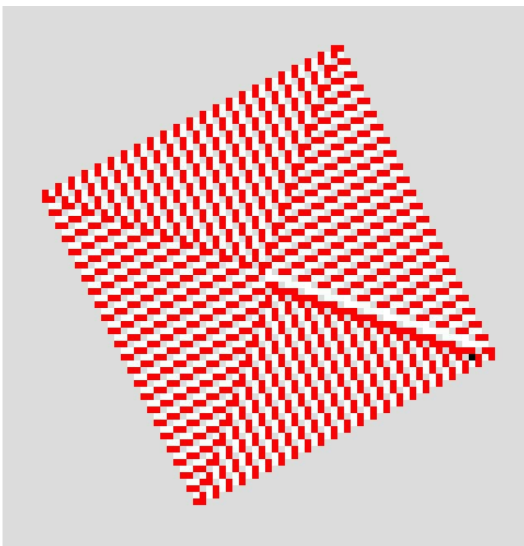
N	No change of heading
L	Turn left 90°
U	Make a U turn
R	Turn right 90°

and the six directions on a hexagonal grid are:

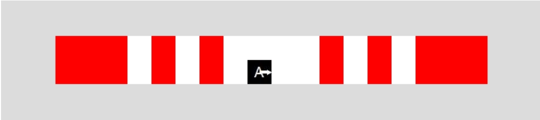
N	No change of heading
L	Turn left 60°
K	Turn left 120°
U	Make a U turn
Q	Turn right 120°
R	Turn right 120°

Whereas Langton's ants move one step at a time, Linton's ants move a number of steps equal to the current cell value plus one. i.e. if the ant moves onto a cell whose value is 3, it will move in the direction specified 4 steps.

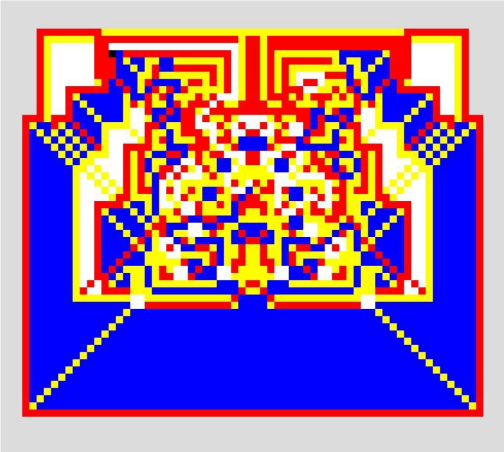
Langton's original ant has the defining string **LR**. After about 10,000 steps or random wanderings it builds a highway down to the SW corner. Linton's ant, with the same defining string does something completely different:

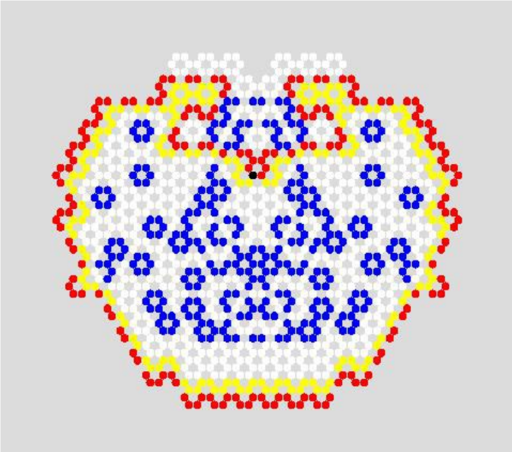
One of the most interesting single state ants is **LN** which builds a horizontal bar and counts in binary.



If the algorithm consists of pairs of left and right turns, the result is always bilaterally symmetric, Here are a couple of Langton examples using the string **RRLL**:



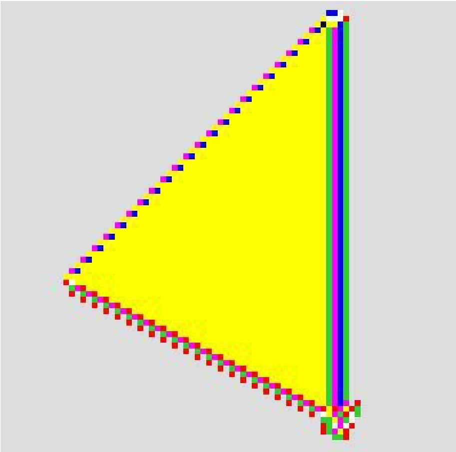
RRLL



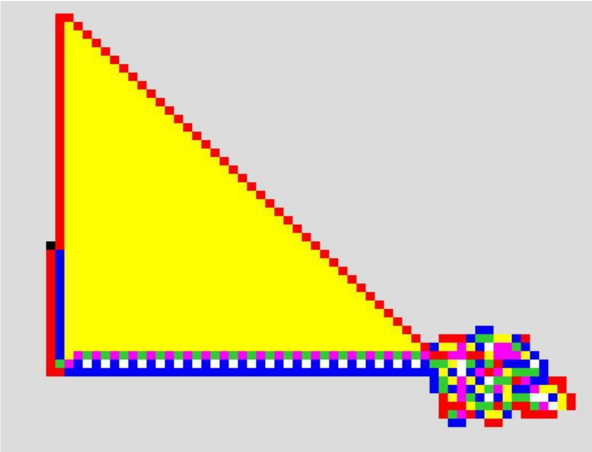
LLRL

All the patterns exhibited here start from an empty grid. Patterns usually only emerge after a short period of chaos. It is perfectly possible that patterns can be 'seeded' with an initial state of cells. For example, it looks as if the ant on the left above could be persuaded to generate a blue red-bordered square with a pair of white diagonals from an appropriate seed.

There are many single state ants which build a highway. Many are only 2 cells wide but some can be quite complex. The two ants illustrated below are rather rare. Both are 6-valued ants. Each builds a highway and an ever expanding sail.

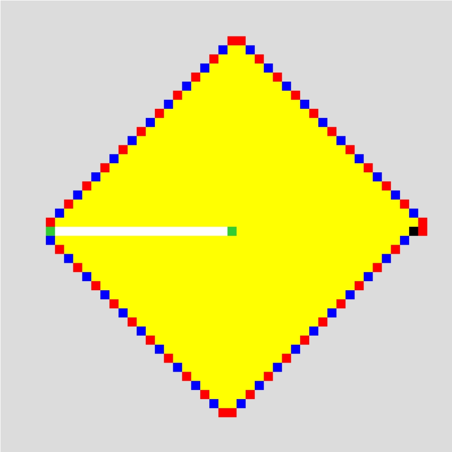


ULRRER

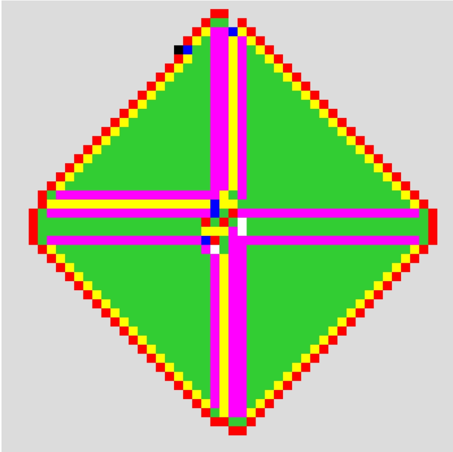


RNLRUR

One common behaviour is the building of a diamond with one or more diagonals. For example:

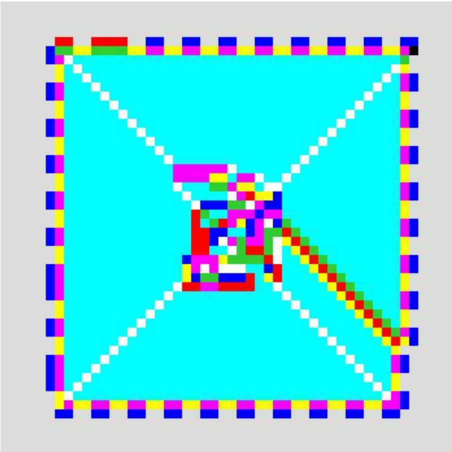


RULNUU

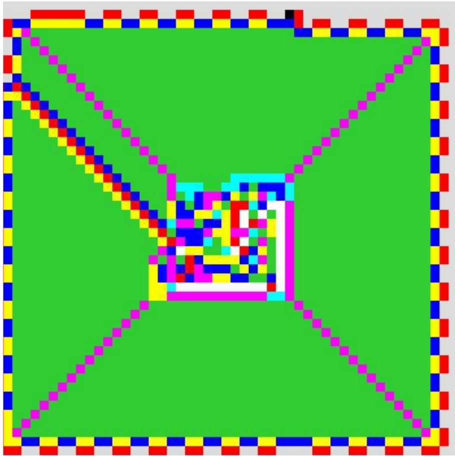


UNRRRN

Slightly less common behaviour is the building of a square. For example:

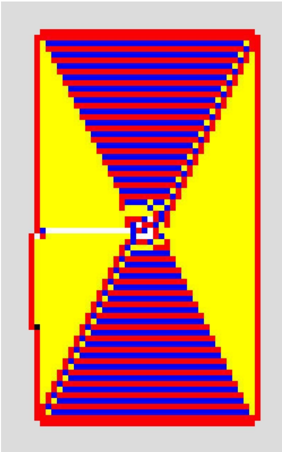


LLRLLL

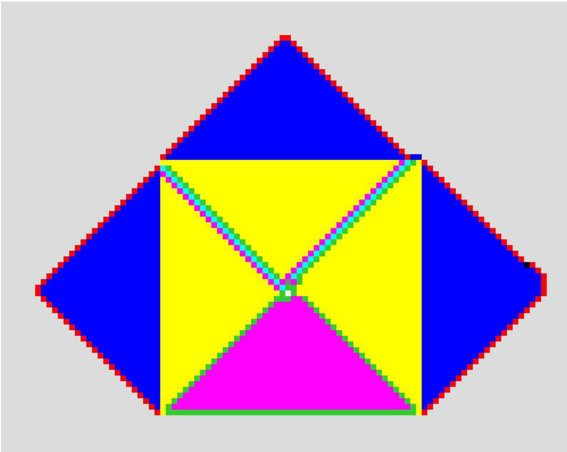


LRLLLL

Finally, here are two rather unique examples:

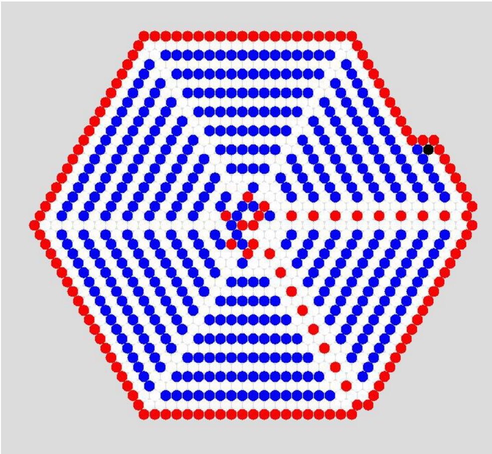


URRR

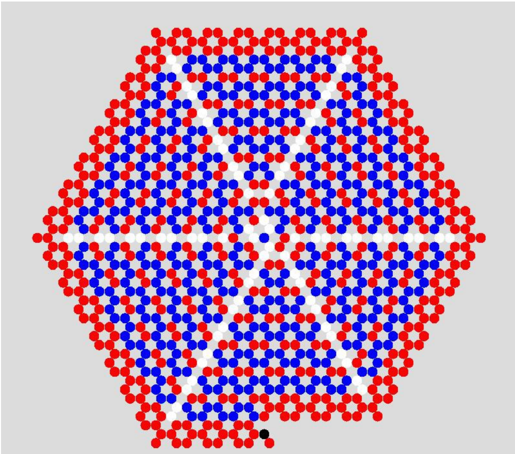


LRNUUNLN

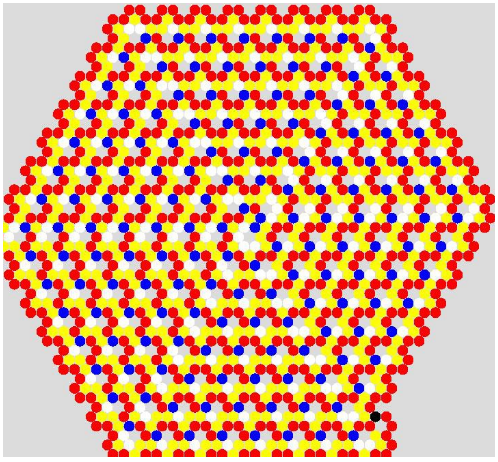
Interesting patterns are more often produced using a hexagonal grid. The most common behaviour is a hexagonal spiral. Here are several examples:



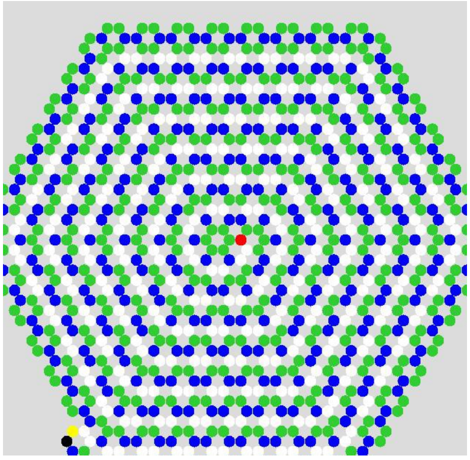
LKK



URR

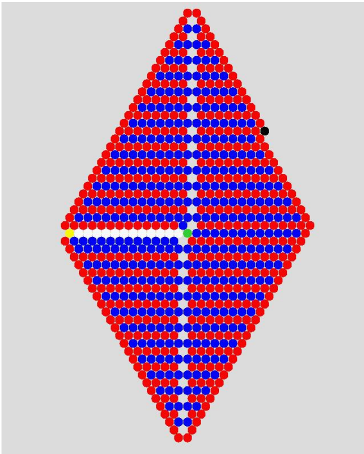


LKUK

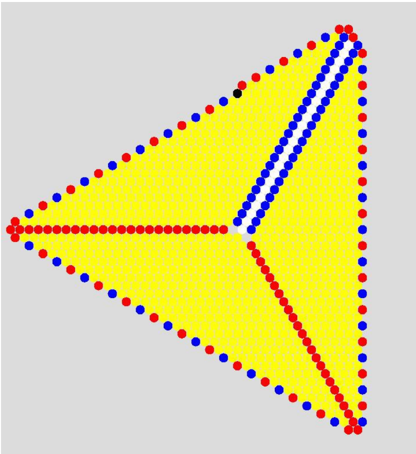


URURR

Here are two rather different and unusual patterns.

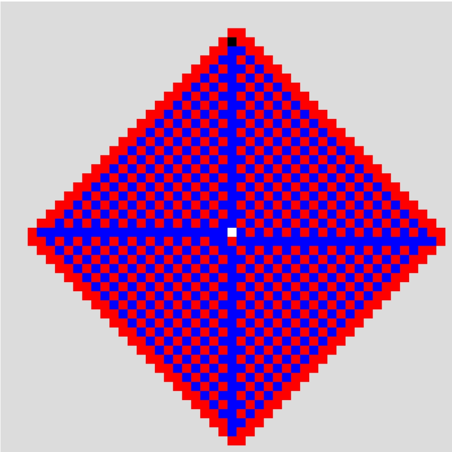


RKRUK

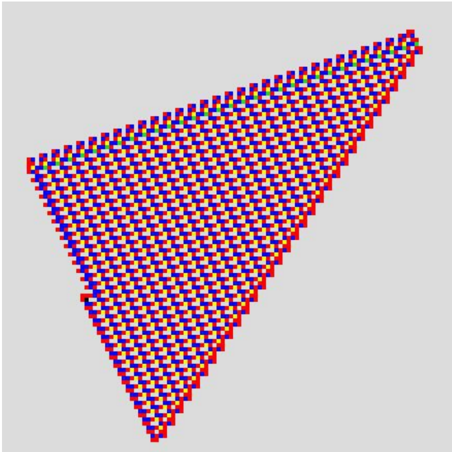


LURK

Here are two patterns generated by Linton's ant.



LUL



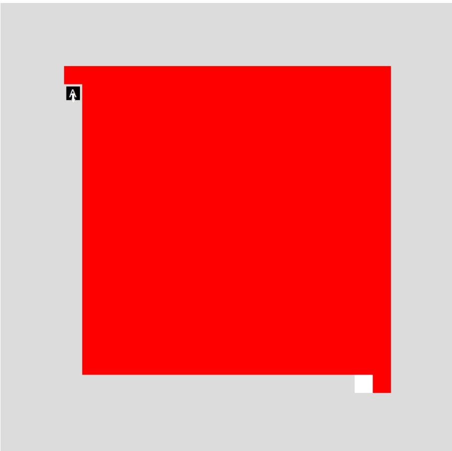
LRUUN

2-state Square Ants

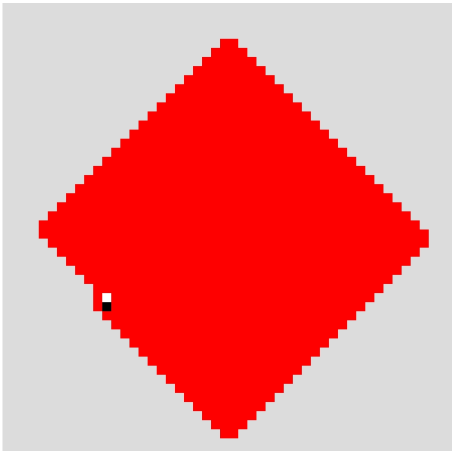
Whereas Langton's and Linton's Ants only have one state, in general an ant may have any number of states. Its behaviour must be specified by a state table which tells what the ant must do given every possible combination of cell values and states. A typical entry is **0RC** which means give the cell the value **0**, turn **R**ight and enter state **C**.

The most interesting ants are those which build regular patterns. In the following examples the captions list first the algorithm used (Langton, Linton, Custom, Busy Beetle), then the kind of board (S2, S4, H2 or H6 where S stands for Square, H for Hexagonal and the number specifies the number of directives). The next two numbers specify the number of states and the number of allowed cell values. Finally the state table is listed in the following order **A0, A1, … ; B0, B1, … ; C0, C1,** … etc.

The simplest patterns are a solid square block or a solid diamond:

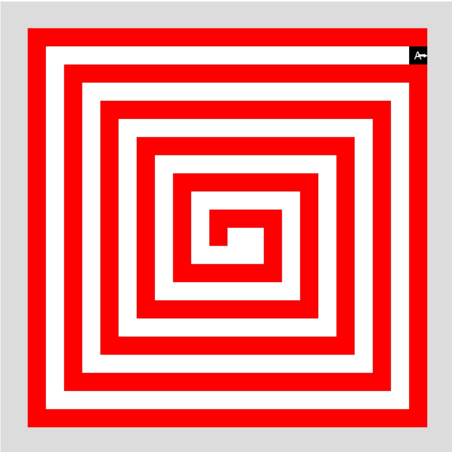


Custom Ant S2 2 2
1LA 1RB ; 0LA 1RA

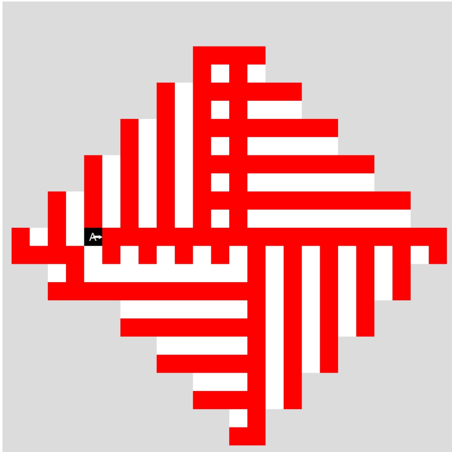


Custom Ant S2 2 2
1LA 0RB ; 1LA 0LA

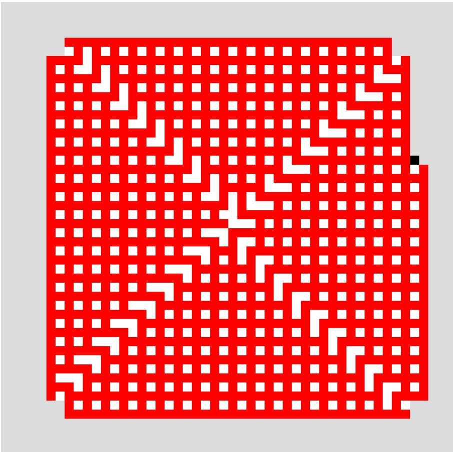
but there are many more interesting designs – e.g.



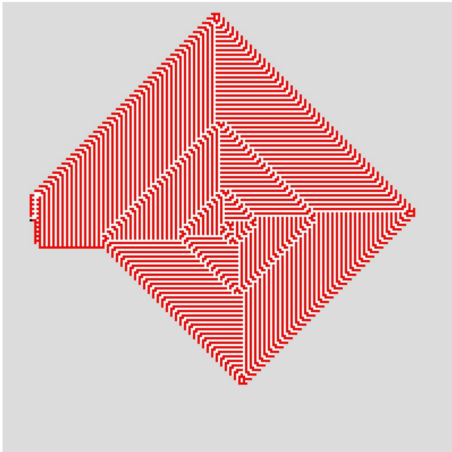
Custom Ant S2 2 2
1LA 0LB ; 0RA 1RB



Custom Ant S2 2 2
0RB 1RB ; 1LB 0RA

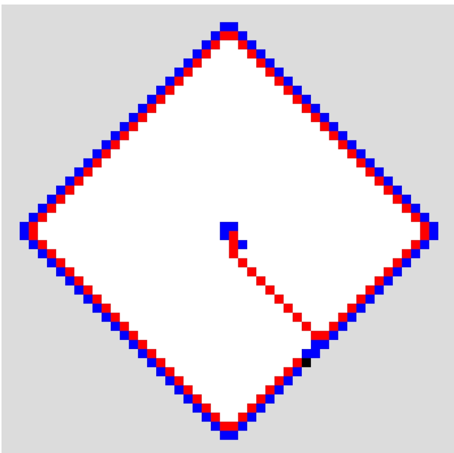


Custom Ant S2 2 2
0LB 1RA 1RB 0LA

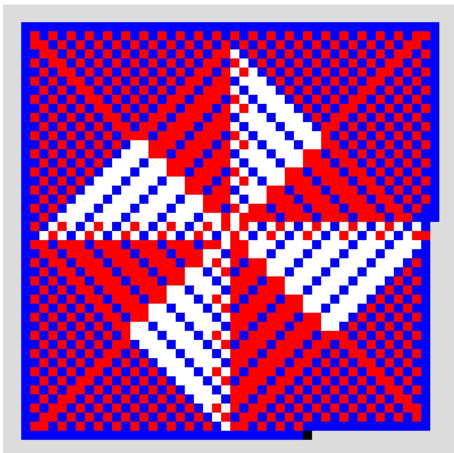


Custom Ant S2 2 2
0LB 0RA 1RB 0LA

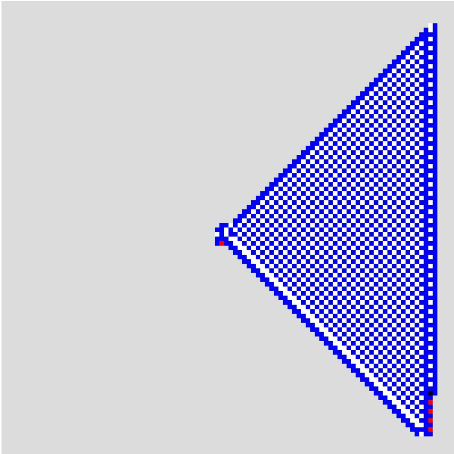
If we allow multiple cell values, the patterns become more colourful but only the octagonal and kite-shaped ones are essentially different .



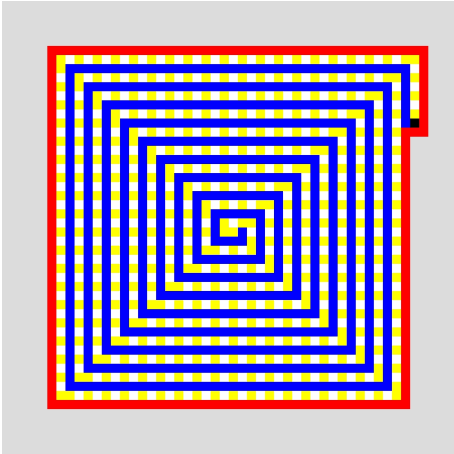
Custom Ant S2 2 3
2LA 0RA 1RB ; 2LA 0RB 2LA



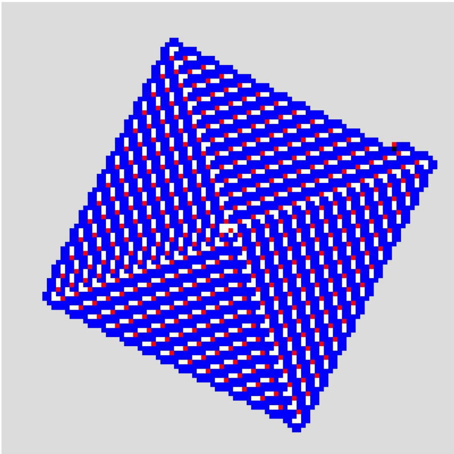
Custom Ant S2 2 3
2LA 1RB 2RB ; 2LA 0RB 1RA



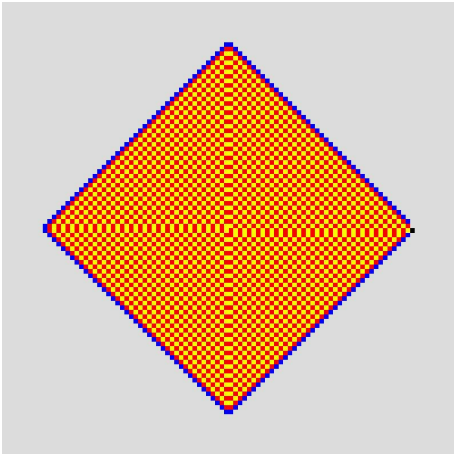
Custom Ant S2 2 3
2RA 0LB 1LB 0RA 0RA 2LA



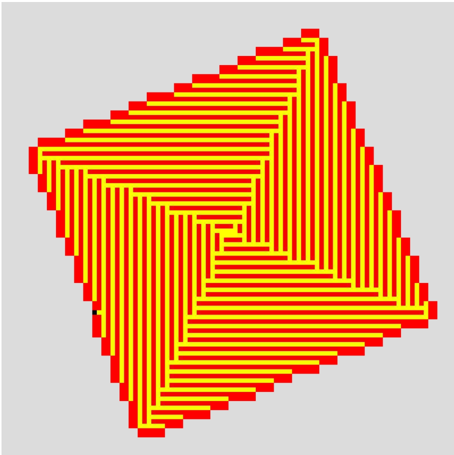
Custom Ant S2 2 4
2RB 0LA 3RA 3LB ; 2LB 3RA 1LB 0RB



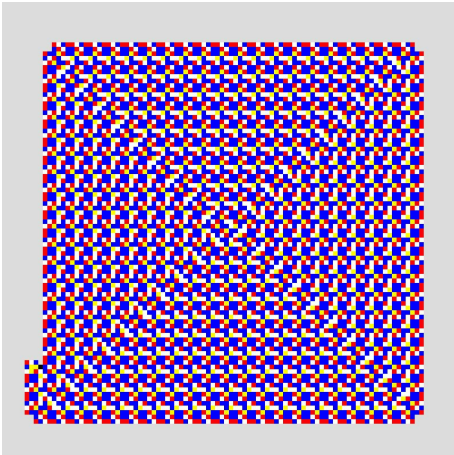
Custom Ant S2 2 4
2RA 0LA 0RB 0RB ; 1RA 0RB 0LB 1RB



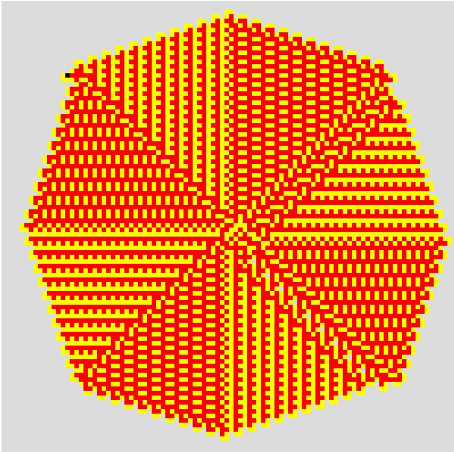
Custom Ant S2 2 4
2LA 1LA 1RB 3LA ; 2LA 2RB 3LA 2RA



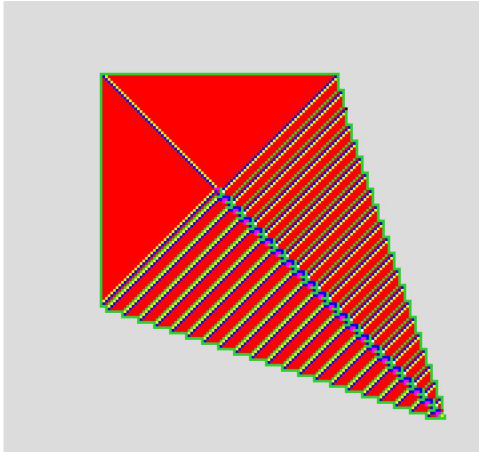
Custom Ant S2 2 4
0RB 3LA 1LA 3LB ; 1LB 1RA 0RB 1LB



Custom Ant S2 2 4
3LA 0RB 2LB 1LA ; 2RA 2RA 2RA 3LA

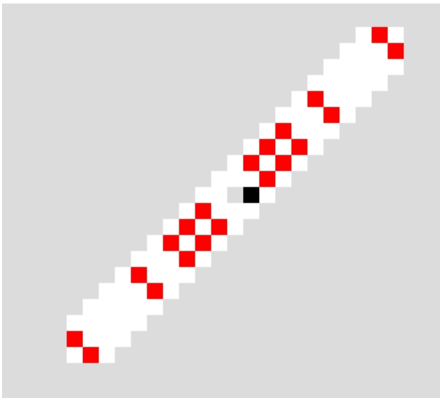


Custom Ant S2 2 4 3LB 3RB 0RB 3LB ; 3RB 1RA 1LB 1RA



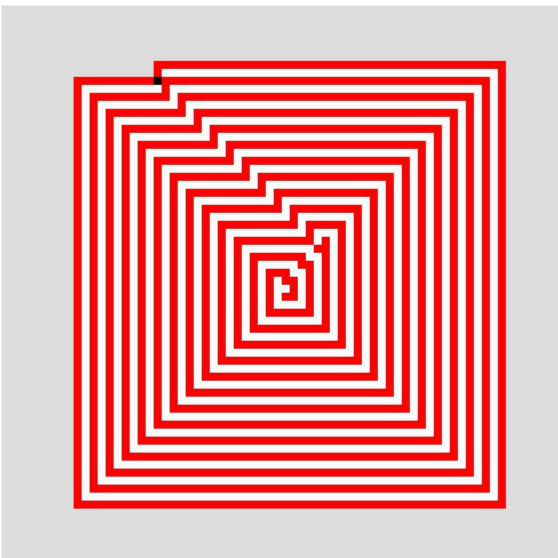
Custom Ant S2 2 6 4RB 2RB 4RB 5RA 3LA 4LB ; 4RB 2LA 3RA 5LB 1LB 0LA

If we allow four directives (**N**, **L**, **U** & **R**) then some new behaviour emerges. One builds a diagonal bar which counts in binary.



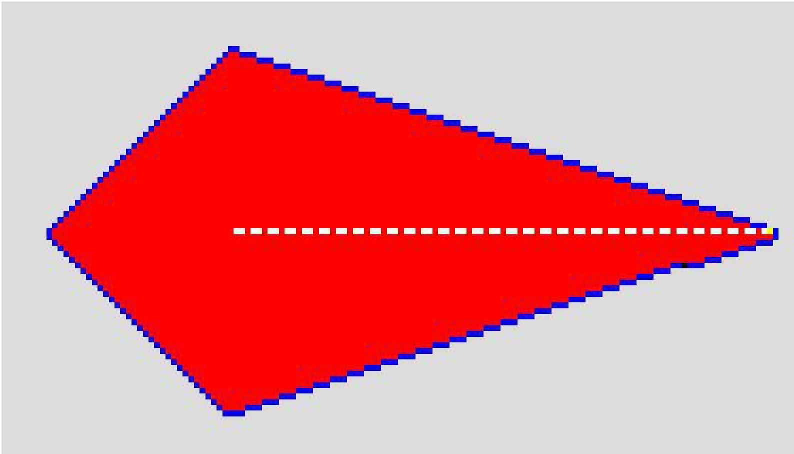
Custom Ant S4 2 2
0LB 1RB ; 1NA 0RA

Another builds a spiral square but not in the way the you might think. It constantly returns to the origin and expands it design from the centre, not the edge!



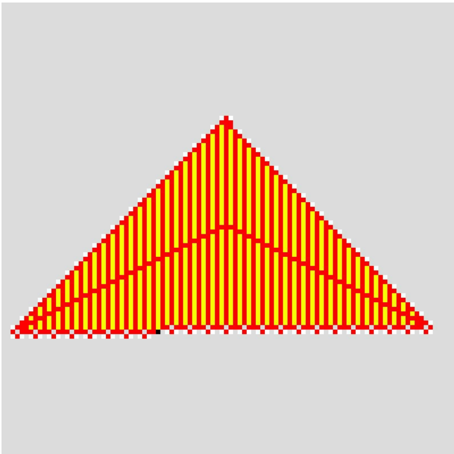
Custom Ant S4 2 2
1RB 0LA ; 1LB 0RA

and one which builds a kite:

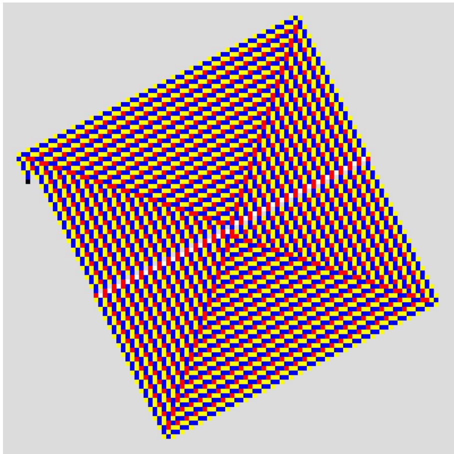


Custom Ant S4 2 4
2RA 1UB 1LA 0LA ; 0NB 3NB 3NA 3RB

These are unusual too:



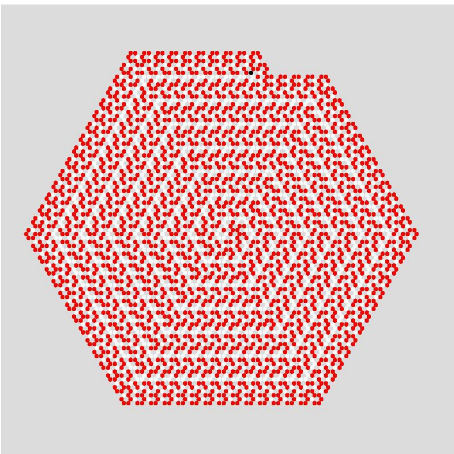
Custom Ant S4 2 4
0LB 3RB 1RA 1RB ; 1NA 1NB 3NB 1UB



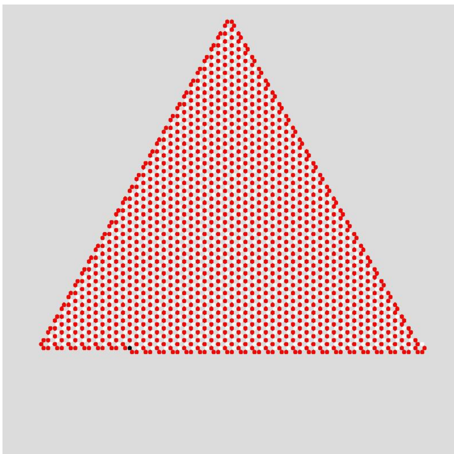
Custom Ant S4 2 4
3LB 1UA 0LB 3UB ; 2NA 0UB 2NB 1LA

2-state Hexagonal Bees

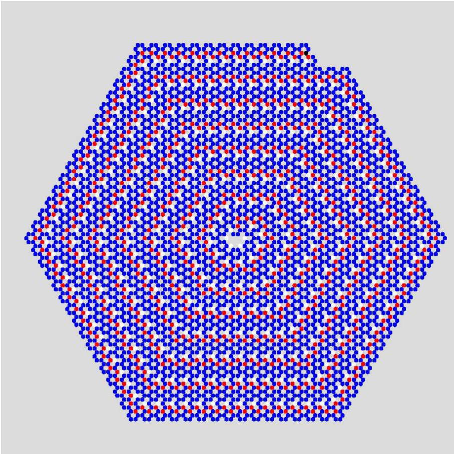
It will not come as a surprise to learn that on a hexagonal grid, most of the patterns generated are either hexagonal or triangular.



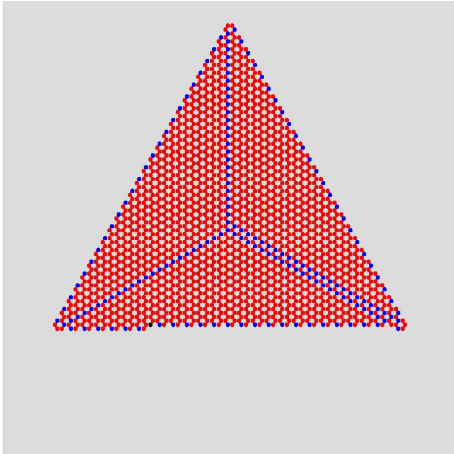
Custom Ant H2 2 2
1RB 1RB ; 1LB 0RA



Custom Ant H2 2 2
0RB 0LB ; 1RB 1LA

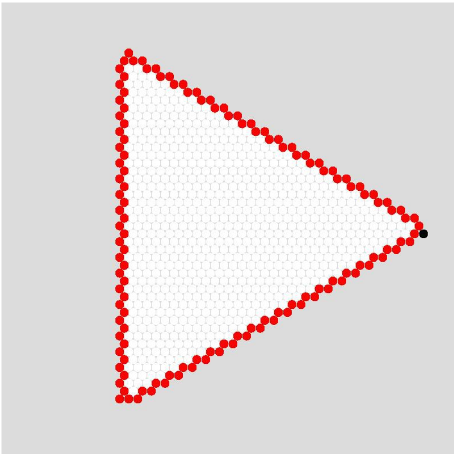


Custom Ant H2 2 3
2LA 2LB 1LB ; 0RA 0LB 2RB

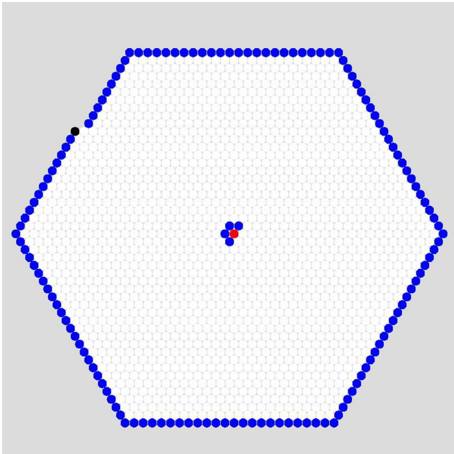


Custom Ant H2 2 3
2LB 1RA 1LA ; 1LB 2RA 1RA

No essentially new behaviour emerges when we increase the number of cell values or directives but I rather like these two patterns:



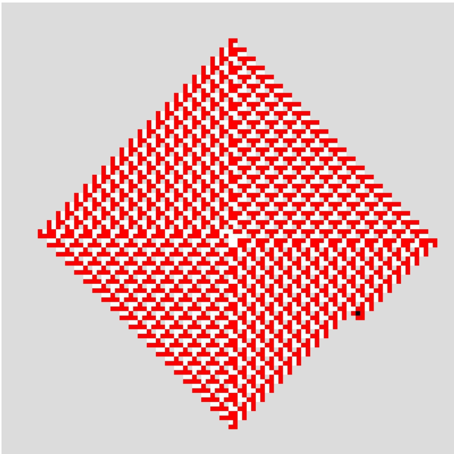
Custom Ant H6 2 2
1KB 1NA ; 1NA 0QA



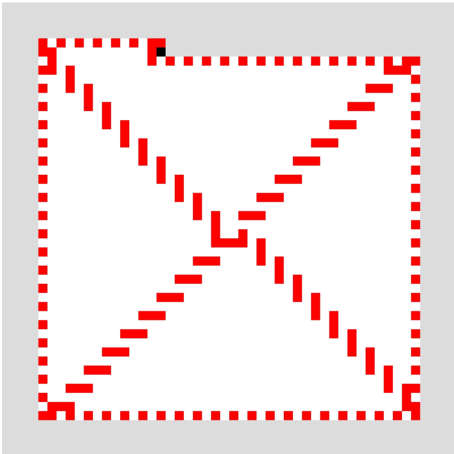
Custom Ant H6 2 3
1RB 0NB 2QB ; 2RB 1QB 0UA

Multiple state Square Ants

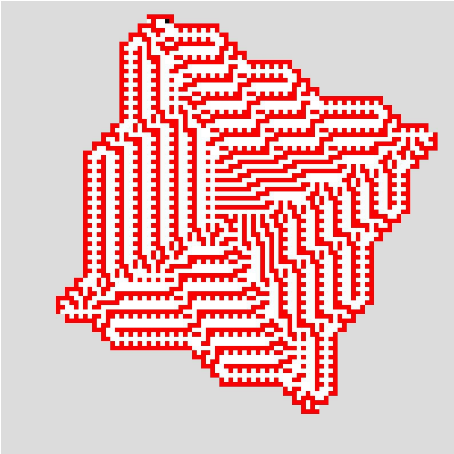
The most common pattern is a square mat. Here are some slightly different designs which I particularly like:



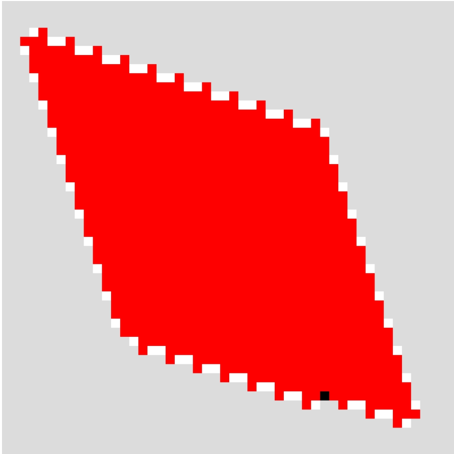
Custom Ant S2 3 2
1LB 0RB ; 0RC 0LA ; 1LC 0RA



Custom Ant S2 3 2
0LB 0RA ; 1LB 0RC ; 0RA 1RB

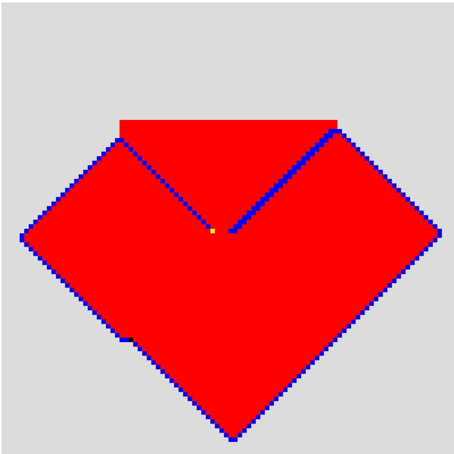


Custom Ant S2 3 2
0LC 0RA ; 1RB 0LA ; 1RB 1LA

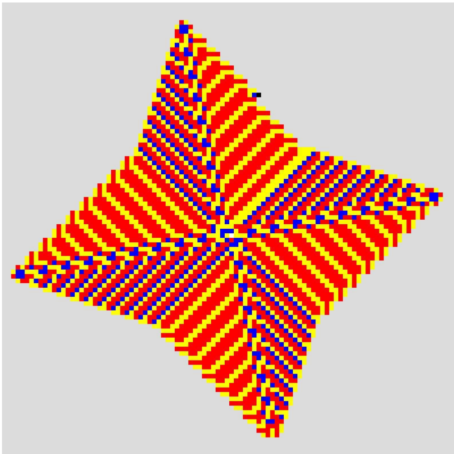


Custom Ant S2 3 2
1LB 1RC ; 0LC 1RC ; 1RA 1RB

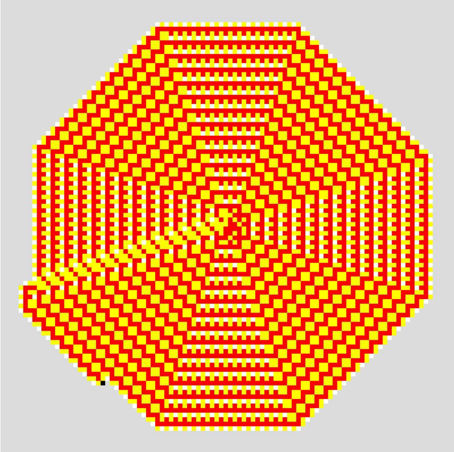
The following patterns were obtained using 4 states, 4 cell values and 2 directives. Each entry in the state table can therefore be one of 4×4×2 = 32 possibilities. Since there are 4×4 = 16 entries in the table, the total number of possibilities is 32^{16} which is approximately the same as the number of molecules in a glass of water and vastly exceeds the number of stars on the observable universe. My search program examined over 100,000 random tables in the space of a few hours and selected over 200 patterns that did not either just shoot of to infinity or wander chaotically round the origin. Of these the great majority were either square of diamond mats. The following ones were the most interesting:



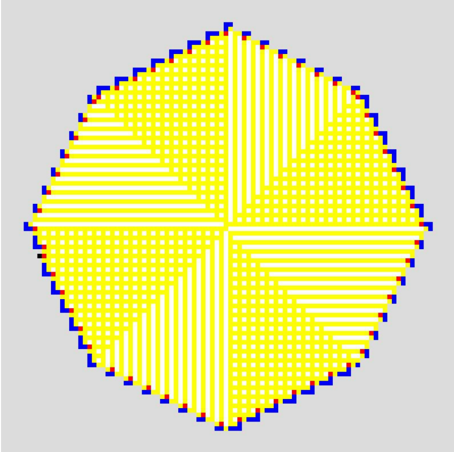
Custom Ant S2 4 4
2LB 2RC 2LC 1RA ; 1LB 1RD 2RC 0RA ;
2RD 2RD 3RD 3LD ; 2RC 1RB 1RA 3RC



Custom Ant S2 4 4
3RC 2LB 2RA 1RD ; 1RC 3LA 1LC 3LA ;
3RD 1LB 2LB 1LB ; 2LB 0RB 3RA 3LB

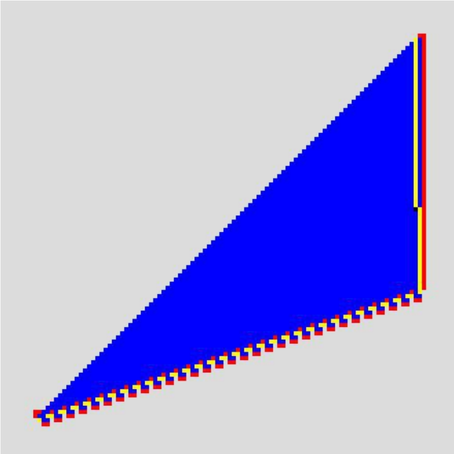


Custom Ant S2 4 4
3RD 3LB 2LA 1RD ; 3RA 3RC 3LB 3RD ;
3LA 2RA 3LC 0RD ; 0RB 3RA 3RB 3LA

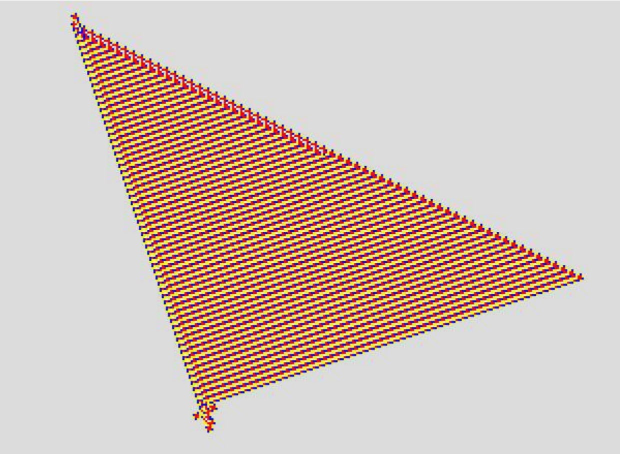


Custom Ant S2 4 4
2LA 2LC 3RC 1RA ; 2LC 0LA 1RB 3RC ;
0RA 0LA 1LC 0LD ; 0LD 3LD 3RD 3LA

Here are a couple of 'sails':

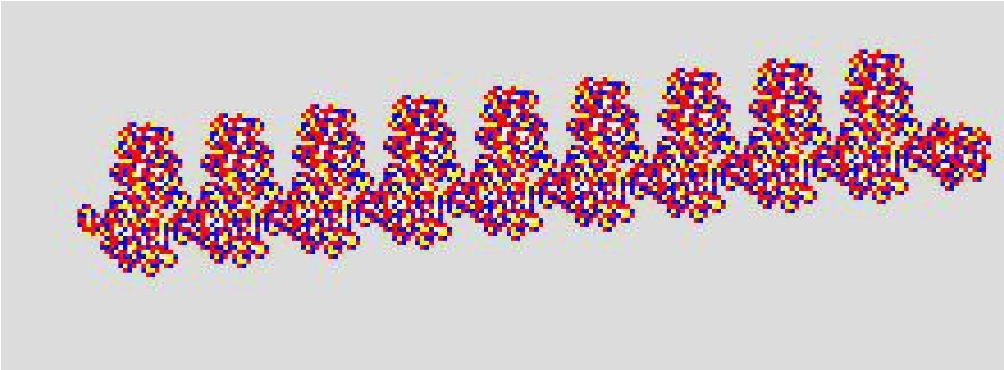


Custom Ant S2 4 4
1RD 1LA 0LB 2LD ; 1LA 3RA 3LB 2RB ;
0LB 0LA 0LA 0LC ; 1RA 2LD 3RB 1LC



Custom Ant S2 4 4
2RB 3LB 0RD 0LD ; 1LC 1LA 3LA 2LC ; 3RA
3RB 0RB 1LC ; 1RB 3RB 3LD 3LB

and this is the most convoluted highway that I have ever seen!



Custom Ant S2 4 4
2LB 2RD 1RA 0RB ; 2RC 3RA 1RB 0LA ;
1RD 0RC 0LD 1RA ; 3LB 1RB 1LA 0RD

Busy Beetles

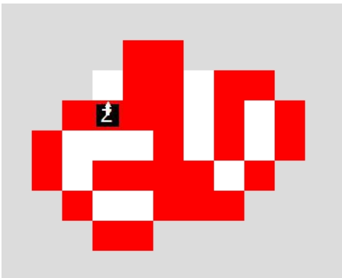
By extension of Turing's concept of a Busy Beaver, I define a Busy Beetle as an Ant with at least one entry with a 'halting state' (**Z**). A *Champion* Busy Beetle is defined as the Ant with a given number of cell values, states and directives, which beetles around for the greatest number of steps before halting (or, sometimes,visits the most number of cells before halting).

Here is a short table of Champion 1-state Busy Beetles:

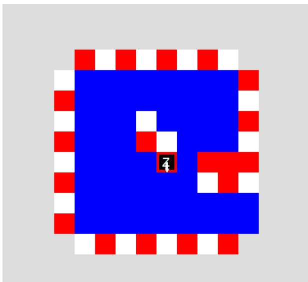
Values	Longevity	Example State Table
2	5	1LA 0LZ
3	9	1LA 2LA 0LZ
4	25	1LA 2RA3RA 0LZ
5	53	1LA 3RA 4RA 2LA 0LZ
6		

cell

The longest lived 2-state Busy Beetles which I have found (with the number of steps and the number of cells visited in brackets) are:

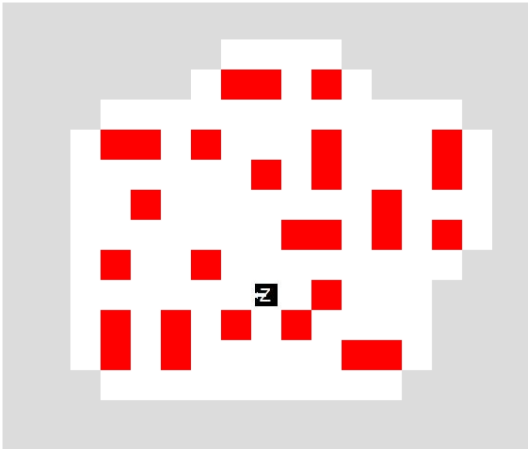


Busy Beetle (121, 41) S2 2 2
1LA 0LB ; 0LZ 1RA



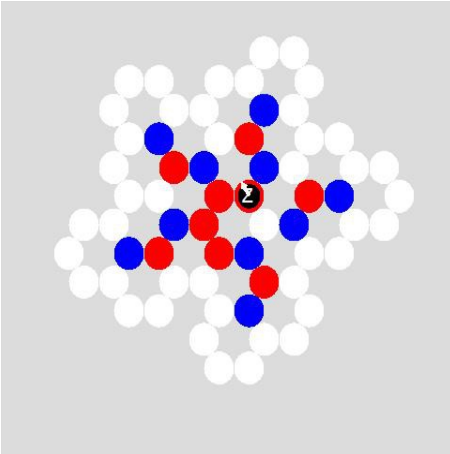
Busy Beetle (485, 96) S2 2 3
2LA 2RA 2LB ; 0LZ 0LB 1LA

and the longest 3-state Busy Beetles which I have found is:

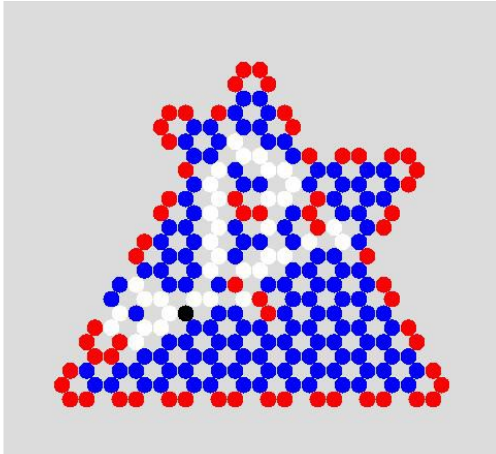


Busy Beetle (878, 137) S2 3 2
1LB 0RA ; 0RC 0LZ ; 0RA 0RB

I shall conclude with a few examples of Busy Beetles on a hexagonal grid. (Should we call them Busy Bees?)



Busy Beetle (188, 63) H2 2 3
2LB 0RA 1LA ; 0RB 0LZ 2LA



Busy Beetle (488, 240) H2 2 3
1LA 2RA 0RB ; 0LZ 0LA 0LA

Carr Bank, February 2024

List of Single State Ants

Algorithm	Square Langton	Hexagonal Langton	Square Linton	Hexagonal Linton
N	Single highway (E)	Single highway (E)	Single highway (E)	Single highway (E)
L	Stable block (4)	Stable ring (6)	Stable block (4)	Stable ring (6)
K	---	Stable triangle (3)	---	Stable triangle (3)
U	Stable block (2)	Stable block (2)	Stable block (2)	Stable block (2)
LN	Binary bar	Chaos	Double highway (E)	Chaotic mesh
LL	Square block (4)	Stable ring (6)	Stable block (9)	Stable blob (53)
LK	---	Chaos	---	Chaos
LU	Square block (4)	Stable ring (6)	Chaos	Broad highway (NNW)
LQ	---	Chaotic mesh	---	Hexagonal mesh
LR	Classic highway	Bilateral doily	Diamond mesh	Hexagonal mesh
KN	---	Double highway (E)	---	Double highway (E)
KL	---	Chaos	---	Hexagonal mesh
KK	---	Stable block (3)	---	Double highway (NNW)
KU	---	Stable block (3)	---	Chaotic mesh
KQ	---	Double highway (SSE)	---	Hexagonal mat
KR	---	Chaotic mesh	---	Hexagonal open mesh
UN	Double highway (E)	Single highway (E)	Single highway (E)	Single highway (E)
UL	Stable block (4)	Stable ring (6)	Diamond mesh	Hexagonal open mesh
UK	---	Stable triangle (3)	---	Hexagonal mesh
UU	Stable block (2)	Stable block (2)	Single highway (W)	Single highway (W)
UQ	---	Stable triangle (3)	---	Hexagonal mesh
UR	Stable block (4)	Stable ring (6)	Diamond mesh	Hexagonal open mesh
LNN	Ternary bar	Chaos	Double highway (E)	Chaos
LNL	Chaos	Chaos	Double highway (E)	Chaos
LNK	---	Chaos	---	Chaos
LNU	Chaos	Chaos	Double highway (E)	Chaos
LNQ	---	Chaos	---	Broad highway (NNW)
LNR	Chaos	Chaos	Double highway (E)	Chaos
LLN	Binary bar	Chaos	Chaos	Chaos

LLL	Square block	Hexagonal ring	Triple highway (E)	Quadruple highway (E)
LLK	---	Chaos	---	Chaos
LLU	Double highway (E)	Chaos	Diagonal highway (NNE)	Chaos
LLQ	---	Triangular chaos	---	Chaos
LLR	Quadruple highway (NW)	Chaos	Chaos	Chaos
LKN	---	Chaos	---	Chaos
LKL	---	Chaos	---	Broad highway (W)
LKK	---	Hexagonal spiral	---	Chaos
LKU	---	Chaos	---	Broad highway (W)
LKQ	---	Chaos	---	Chaos
LKR	---	Chaos	---	Quadruple highway (E)
LUN	Vertical highway	Chaos	Chaos	Chaos
LUL	Horizontal highway	Chaotic mesh	Diamond mat	Hexagonal spiral mesh
LUK	---	Chaos	---	Chaos
LUU	Stable block (4)	Stable ring (6)	Chaos	Chaos
LUQ	---	Chaos	---	Hexagonal spiral mesh
LUR	Chaos	Chaos	Highway (NE)	Chaos
LQN	---	Chaos	---	Chaos
LQL	---	Hexagonal maze	---	Chaos
LQK	---	Chaos	---	Chaos
LQU	---	Chaotic rings	---	Hexagonal spiral mesh
LQQ	---	Chaos	---	Chaos
LQR	---	Chaos	---	Chaos
LRN	Horizontal highway	Chaos	Chaos	Chaos
LRL	Chaos	Hexagonal mesh	Broad highway (NNE)	Chaos
LRK	---	Chaos	---	Chaos
LRU	Stable block (10)	Stable block (24)	Diamond mesh	Chaos
LRQ	---	Chaos	---	Chaos
LRR	Chaos	Hexagonal mesh	Chaos	Chaos
KNN	---	Chaos	---	Double highway (E)
KNL	---	Chaos	---	Double highway (E)
KNK		Double highway		Double highway (E)

KNU	---	Chaos	---	Double highway (E)
KNQ	---	Chaos	---	Double highway (E)
KNR	---	Chaos	---	Double highway (E)
KLN	---	Chaos	---	Chaos
KLL	---	Diagonal highway	---	Chaos
KLK	---	Chaos	---	Chaos
KLU	---	Chaos	---	Chaos
KLQ	---	Chaos	---	Hexagonal mesh
KLR	---	Chaos	---	Chaos
KKN	---	Horizontal highway	---	Double highway (E)
KKL	---	Chaos	---	Double highway (NNW)
KKK	---	Stable block (3)	---	Double highway (NNW)
KKU	---	Stable block (7)	---	Double highway (NNW)
KKQ		Diagonal highway		Double highway (NNW)
KKR	---	Hexagonal mesh	---	Double highway (NNW)
KUN	---	Horizontal highway	---	Chaos
KUL	---	Chaos	---	Broad highway (SSSW)
KUK	---	Stable block (7)	---	Hexagonal mesh
KUU	---	Stable block (3)	---	Chaos
KUQ	---	Diagonal highway	---	Chaos
KUR	---	Chaos	---	Chaos
KQN	---	Chaos	---	Quadruple highway (W)
KQL	---	Chaos	---	Chaos
KQK	---	Diagonal highway	---	Chaos
KQU	---	Stable block (6)	---	Chaos
KQQ	---	Diagonal highway	---	Broad highway (SE)
KQR	---	Chaos	---	Chaos
KRN	---	Chaos	---	Chaos
KRL	---	Diagonal highway	---	Chaos
KRK	---	Chaos	---	Chaos
KRU	---	Horizontal highway	---	Hexagonal open mesh
KRQ	---	Chaos	---	Chaos

KRR	---	Chaos	---	Chaos
UNN	Expanding bar	Expanding bar	Single highway (E)	Single highway (E)
UNL	Chaos	Chaos	Single highway (E) bar	Single highway (E)
UNK	---	Chaos	---	Single highway (E)
UNU	Horizontal highway	Horizontal highway	Single highway (E) bar	Single highway (E)
UNQ	---	Chaos	---	Single highway (E)
UNR	Chaos	Chaos	Single highway (E) bar	Single highway (E)
ULN	Chaos	Chaos	Triple highway (E)	Chaos
ULL	Horizontal highway	Hexagonal mesh	Triple highway (ENE)	Chaos
ULK	---	Horizontal highway	---	Chaos
ULU	Stable block (4)	Stable block (6)	Chaos	Chaos
ULQ	---	Chaos	---	Chaos
ULR	Stable block (10)	Stable block (24)	Chaos	Chaos
UKN	---	Chaos	---	Triple highway (E)
UKL	---	Horizontal highway	---	Chaos
UKK	---	Chaos	---	Chaos
UKU	---	Stable block (3)	---	Chaos
UKQ	---	Stable block (6)	---	Hexagonal mesh
UKR	---	Chaos	---	Chaos
UUN	Horizontal highway	Horizontal highway	Single highway (W)	Single highway (W)
UUL	Stable block (4)	Stable block (6)	Single highway (W)	Single highway (W)
UUK	---	Stable block (3)	---	Single highway (W)
UUU	Horizontal highway	Horizontal highway	Single highway (W)	Single highway (W)
UUQ	---	Stable block (3)	---	Single highway (W)
UUR	Stable block (4)	Stable block (6)	Single highway (W)	Single highway (W)