A Zoo of *Life* Forms

Harold V. McIntosh
Departamento de Aplicación de Microcomputadoras,
Instituto de Ciencias, Universidad Autónoma de Puebla,
Apartado postal 461, 72000 Puebla, Puebla, México.
E-mail:mcintosh@servidor.unam.mx

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Abstract

A catalog is presented, of those *Life* forms on strips of widths up to six whose translational behavior during a single generation can be inferred from two stages of de Bruijn diagrams.

1 Introduction

A previous booklet, *Life*'s Still Lifes, presented an algorithm capable of revealing all *Life* forms of the type (m,n,t), which move uniformly m cells in the x-direction and n cells in the y-direction after t generations. Strictly speaking, the algorithm only yields those forms which can be found in strips of finite width or, which are spatially periodic. Although finding all the forms which could fill the whole plane without periodicity is an undecidable proposition, with ingenuity many other interesting forms can nevertheless be found. However, that is another story.

Life possesses the characteristic that many of its forms are surrounded by arbitrarily long quiescent stretches, which makes them freestanding. The same algorithm yields all isolated forms of this nature. In either event the amount of computation required to obtain forms of even modest extent is quite considerable. Forms of long period, likewise all those of period two, are inaccessible to present computer power. Consequently this presentation is limited to forms whose characteristics can be ascertained within a single generation.

Still lifes, creepers and crawlers can be determined; the latter are not gliders because they are not freestanding; rather many are fuses whose quiescent surroundings extend infinitely in only one direction. Nor do they move by reflection and translation. Still, the word "glider" has acquired a generic connotation referring to any moving configuration and is often used where it is not strictly appropriate.

The algorithm involves two stages of de Bruijn diagrams. The first stage diagrams have a maximum of 64 nodes, typically with four links each, except those which do not belong to the ergodic set of the diagram; those often have none, or participate in chains leading to end nodes which have no continuation. In any event it is awkward to present the de Bruijn diagram in its preferred form as a set of chords of a circle, so a matrix form is used instead.

Even the matrix presentation is unwieldy, so the style actually adopted consists of listing the nodes of the ergodic set on a line together with the nodes to which they are linked. Each line will have a maximum length determined by the number of outgoing links in the full de Bruijn diagram, which in turn will be a fraction of the length of the rows of the full connectivity diagram.

Having formed the first stage de Bruijn diagram, the second stage can be constructed. All the loops in the first stage with a chosen length are candidates to be links in the second stage diagram, that length now becoming the width of a periodic strip. Again, links will be discarded for not joining nodes within the ergodic set.

The following sections are laid out according to the behavior that can be discerned after a single generation of evolution, that is, still lifes, followed by longitudinal, transversal, and diagonal gliders. Only one instance of each symmetry class is presented, meaning that further patterns can be gotten by planar rotations or reflections of the ones shown. The list could also be extended by exhibiting the precursors of a completely quiescent field, or of a completely live field; but all such results have been omitted for reasons of space.

Likewise six is the maximum width of the periodic strips shown; diagrams for wider strips would not fit on a single page without some change in the style of presentation. Since the strips are periodic, they are subject to further reflective and rotational symmetries; the tables have been further compressed by showing only symmetry classes. Link superscripts such as L, R, rot, or F imply that the next node is to be rotated to the left, right, arbitrarily, or reflected, before continuing. Only one node of any given symmetry class is shown.

2 (0,0,1) – still lifes

2.1 First stage de Bruijn matrix

	0	1	2	3	4	5	6	7		0	1	2	3	4	5	6	7
00	00	01	02	03	04	05	06	.	40	00	01	02	.	04	.	.	07
01	10	11	12	.	14	.	.	17	41	10	.	.	13	.	.	16	17
02	20	21	22	.	24	.	.	.	42	20	.	.	.	.	.	.	.
03	30	.	.	.	.	.	.	.	43	.	.	.	33	.	.	.	.
04	40	.	.	43	.	45	46	47	44	40	.	.	43	.	45	46	47
05	50	.	.	53	.	55	56	57	45	.	51	52	53	54	55	56	57
06	.	.	.	.	.	.	60	.	46	.	.	.	63	.	.	.	.
07	.	.	.	.	.	.	.	.	47	.	.	72	.	.	.	.	.
10	00	01	02	.	04	.	.	07	50	00	.	.	03	.	05	06	07
11	10	.	.	13	.	15	16	17	51	.	51	52	53	54	55	56	57
12	20	.	.	.	.	.	.	.	52	.	.	.	.	.	55	.	.
13	.	.	.	13	.	.	.	.	53	.	31	32	.	34	.	.	.
14	40	.	.	43	.	45	46	47	54	.	41	42	43	44	45	46	47
15	.	51	52	53	54	55	56	57	55	50	51	52	53	54	55	56	57
16	.	.	.	.	.	.	66	.	56	.	61	62	.	64	.	.	.
17	.	.	72	.	.	.	.	.	57	70	.	72	.	.	.	.	.
20	00	.	.	.	.	05	06	.	60	.	01	02	.	04	.	.	.
21	.	01	02	.	04	.	.	.	61	10	.	.	.	.	.	.	.
22	.	21	22	23	24	25	26	.	62	20	21	.	.	.	.	.	.
23	30	31	32	.	34	.	.	.	63	30	.	.	.	.	.	.	.
24	.	41	42	.	44	.	.	.	64	40	.	.	.	.	.	.	.
25	50	.	.	.	.	.	.	.	65	.	.	.	.	.	.	.	.
26	20	21	22	.	24	.	.	.	66	60	.	.	.	.	.	.	.
27	70	.	.	.	.	.	.	.	67	.	.	.	.	.	.	.	.
30	.	01	02	.	04	.	.	.	70	00	.	.	.	.	.	.	.
31	10	.	.	.	.	.	.	.	71	.	.	.	.	.	.	.	.
32	20	.	.	.	24	.	.	.	72	20	.	.	.	.	.	.	.
33	30	.	.	.	.	.	.	.	73	.	.	.	.	.	.	.	.
34	40	.	.	.	.	.	.	.	74	.	.	.	.	.	.	.	.
35	.	.	.	.	.	.	.	.	75	.	.	.	.	.	.	.	.
36	60	.	.	.	.	.	.	.	76	.	.	.	.	.	.	.	.
37	.	.	.	.	.	.	.	.	77	.	.	.	.	.	.	.	.

2.2 Powers of the still life de Bruijn matrix

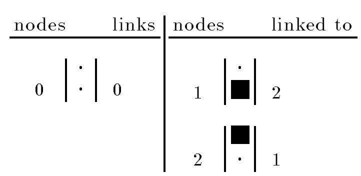
The matrix elements of powers of the first stage matrix tell how many paths there are from the row index node to the column index node. Diagonal elements count loops. The trace counts all possible loops, once for each node which they contain, while specific diagonal elements identify the loops through that particular node.

	(0,0) element					trace				
	initial		final			initial		final		
width	nodes	links	nodes	links	gens	nodes	links	nodes	links	gens
1	1	1	1	1	1	3	3	3	3	1
2	1	1	1	1	1	11	23	7	9	3
3	1	4	1	1	2	57	156	57	156	1
4	10	24	10	16	2	139	499	127	309	3
5	48	103	40	73	3	583	2613	583	2233	2
6	161	455	149	341	4	2519	12320	2515	10986	3

Not all the possible loops will participate in the second stage matrix because they may not overlap correctly. The columns labelled "initial" contain the raw data, including transients as well as the ergodic set. Dropping all those nodes and links which lack predecessors, successors, or both, refines the data. In the process a new set of nodes and links may be exposed, which in turn ought to be dropped for a lack of continuation. Eventually, after "gen" cycles of iteration, zero, one, or more ergodic sets will be reached, in which there are no dead ends.

The "final" columns display the numbers of nodes and links in the second stage de Bruijn diagram, a separate line for each width. To a certain extent, these numbers can be divided by the width to get the number of symmetry classes. If very many of the patterns lack reflective symmetry, twice the width is an appropriate divisor; in any event the internal symmetry of the classes has to be taken into account.

2.2.1 still life, width 1



2.2.2 still life, width 2

nodes		links	nodes		linked to	nodes		linked to
0	· · · ·	0	3	· ■ · ■	3, 6	9	■ · · ■	3
5	· · ■ ■	A	6	· ■ ■ ·	C			
A	■ ■ · ·	5	C	■ · ■ ·	C, 9			

2.2.3 still life, width 3

Width 3 presents certain peculiar features due to a number theoretic property of *Life*'s rule of evolution. On a 3×3 torus, the still lifes are those configurations which contain exactly four live cells. If the central cell is live, it has three live neighbors and thus survives; otherwise the four live neighbors prevent a live cell from forming and again the arrangement is stable.

For a $3 \times N$ torus, the same principle applies, but the arrangement of the live cells in a cross section can vary as one moves along the long dimension of the torus. A constant sum of 4 can be realized in the forms $3+1+0$, $2+2+0$, and $2+1+1$, and their permutations.

There is no way of breaking out of the sequence $2+1+1$, but the presence of zeroes in the other two allows them to terminate in quiescent regions. Moreover, the sequence $0+3+0+3+\cdots$ can be judiciously interspersed in the latter two sequences to produce still further variation.

Connected component of 00

nodes		linked to	nodes		linked to
00	· · · · · ·	00, 40^{rot}, 50^{rot}	50	· · · ■ ■ ·	F0, A1, E1
40 D1	· · · ■ · · ■ ■ ■	A2	F0	■ ■ · ■ ■ ·	A0
A2	■ ■ ■ · · ·	40^{rot}, 51	A0	■ ■ · · · ·	00, 50^{rot}, 51
51	· · · ■ ■ ■	A2, $E2^{\text{rot}}$	A1	■ ■ · · ■ ■	$A0^{R}$
E2 80	■ ■ ■ ■ · · · · ·	00, 40, 51	E0	■ ■ · ■ · ■	$A0^{L}$

Connected component of C0

node		linked to	node		linked to	node		linked to
C0	■ · · ■ · ·	D0, C1, 91	50	· ■ · ■ · ·	D0, C1, 91	42	· · ■ ■ · ·	D0, C1, 91
D0	■ · · ■ ■ ·	E0, $C2^{L}$, 62^{R}	C1	■ · · ■ · ■	$E0^{L}$, C2, 62^{R}	91	■ · · · ■ ■	$E0^{R}$, $C2^{L}$, 62
E0	■ ■ · ■ · ·	C0, 50^{L}, 42^{R}	C2	■ · ■ ■ · ·	C0, 50, 42	62	· ■ ■ ■ · ·	C0, 50^{L}, 42^{R}

2.2.4 freestanding still life, width 4

nodes		links	nodes		links
00	· · · · · · · ·	00, 50	50	· · · · ■ ■ · ·	E0, $E0^{F}$, F0
E0 90 70	■ ■ · · ■ · · · · ■ · · ■ ■ · ·	E0, A0	F0	■ ■ · · ■ ■ · ·	A0
			A0	■ ■ · · · · · ·	00, 50

2.2.5 still life, width 4

nodes		links
00	· · · · · · · ·	00, 01^{rot}, 50^{rot}
01 46	· · · · · · · ■ ■ · ■ ·	89, CC
89	■ · ■ · · · · ■	02
CC	■ · ■ · ■ · ■ ·	CC, 99, 89, 89^{2L}
02	· · · ■ · · · ·	00, 01^{rot}
99	■ · ■ · · ■ · ■	32, 23
23	· ■ · ■ · · · ■	03, 13, 43, 56, 07
F0	■ ■ · · ■ ■ · ·	A0
50	· · · · ■ ■ · ·	B0, $B0^{\mathrm{F}}$, F0
B0	■ ■ · · ■ · · ·	60, 31
60	· ■ · · ■ · · ·	D0, 60^{L}
D0	■ · · · ■ ■ · ·	A0, B0
03	· · · ■ · · · ■	17

nodes		links
56	· · · ■ ■ ■ ■ ·	A0, E8, A9
A0	■ ■ · · · · · ·	00, 50
17	· · · ■ · ■ ■ ■	6A
E8	■ ■ ■ · ■ · · ·	C0, 94, 85
13	· · · ■ · ■ · ■	31
A9	■ ■ ■ · · · · ■	12, 52, 13, 16
AE 84	■ ■ ■ ■ · · ■ · ■ · · ·	59, 5D
94	■ · · · · ■ ■ ·	69
5D	· · ■ · ■ ■ ■ ■	AA
A5	■ ■ · · · · ■ ■	4A, 5A
AA	■ ■ ■ ■ · · · ·	50, 41^{rot}
4A	· · ■ ■ ■ · · ·	94, 95, D4, C5
55	· · · · ■ ■ ■ ■	AA

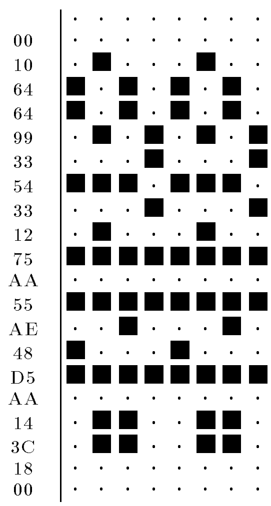
2.2.6 freestanding still life, width 5

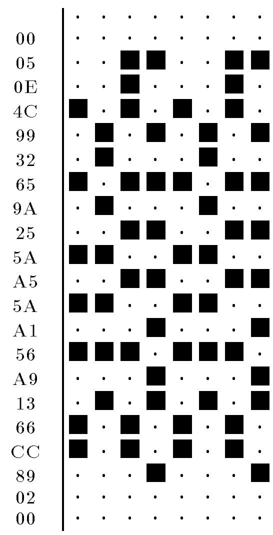
nodes		links
000	· · · · · · · · · ·	000, 010, 500, 500^F
 100 640	· · · · · · ■ · · · ■ · ■ · ·	980, 9C0, $9C0^F$, CC0
CC0	■ · ■ · · ■ · ■ · ·	980
980 200	■ · ■ · · · ■ · · · · · · · ·	000, 100
500	· · · · · ■ ■ · · ·	B00, E00, E40, F00
E00	■ ■ · · · ■ · · · ·	840, 900
840	■ · · · · · · ■ · ·	1C0
900	■ · · · · · ■ · · ·	240, 700
1C0	· · ■ · · · ■ ■ · ·	280, 380, 680
240	· ■ · · · · · ■ · ·	1C0, 4C0

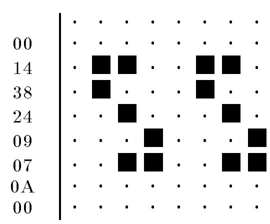
nodes		links
700	· ■ · · · ■ ■ · · ·	A00, E00
280	· ■ ■ · · · · · · ·	000, 140
380	· ■ ■ · · · ■ · · ·	240
680	· ■ ■ · · ■ · · · ·	940, C00
4C0	· · ■ · · ■ · ■ · ·	D80
940	■ · · · · · ■ ■ · ·	2C0
C00	■ · · · · ■ · · · ·	940
D80	■ · ■ · · ■ ■ · · ·	A00
E40	■ ■ · · · ■ · ■ · ·	8C0, 980, 9C0
F00	■ ■ · · · ■ ■ · · ·	A00

2.3 Sample still life strips

Except for very narrow strips it is not easy to display a comprehensive sample of still lifes. Since there are 28 symmetry classes for a strip of width 4, one would need a strip at least 28 lines long; but there are at least twice as many links so it takes an even longer strip to show every possibility of branching at least once. Typical cycles are even harder to portray in full generality.







3 (0,1,1) – longitudinal creepers

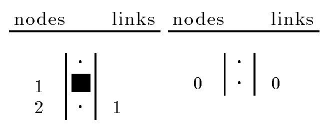
3.1 First stage de Bruijn matrix

	0	1	2	3	4	5	6	7		0	1	2	3	4	5	6	7
00	00	01	02	03	04	05	06	.	40	00	01	02	.	04	.	.	07
01	10	11	12	.	14	.	.	17	41	10	.	.	13	.	.	16	17
02	20	21	22	.	24	.	.	.	42	20	.	.	.	.	.	.	.
03	30	.	.	.	.	.	.	.	43	.	.	.	33	.	.	.	.
04	40	.	.	43	.	45	46	47	44	40	.	.	43	.	45	46	47
05	50	.	.	53	.	55	56	57	45	.	51	52	53	54	55	56	57
06	.	.	.	.	.	.	60	.	46	.	.	.	63	.	.	.	.
07	.	.	.	.	.	.	.	.	47	.	.	72	.	.	.	.	.
10	00	01	02	.	04	.	.	07	50	00	.	.	03	.	05	06	07
11	10	.	.	13	.	15	16	17	51	.	51	52	53	54	55	56	57
12	20	.	.	.	.	.	.	.	52	.	.	.	.	.	55	.	.
13	.	.	.	13	.	.	.	.	53	.	31	32	.	34	.	.	.
14	40	.	.	43	.	45	46	47	54	.	41	42	43	44	45	46	47
15	.	51	52	53	54	55	56	57	55	50	51	52	53	54	55	56	57
16	.	.	.	.	.	.	66	.	56	.	61	62	.	64	.	.	.
17	.	.	72	.	.	.	.	.	57	70	.	72	.	.	.	.	.
20	00	.	.	.	.	05	06	.	60	.	01	02	.	04	.	.	.
21	.	01	02	.	04	.	.	.	61	10	.	.	.	.	.	.	.
22	.	21	22	23	24	25	26	.	62	20	21	.	.	.	.	.	.
23	30	31	32	.	34	.	.	.	63	30	.	.	.	.	.	.	.
24	.	41	42	.	44	.	.	.	64	40	.	.	.	.	.	.	.
25	50	.	.	.	.	.	.	.	65	.	.	.	.	.	.	.	.
26	20	21	22	.	24	.	.	.	66	60	.	.	.	.	.	.	.
27	70	.	.	.	.	.	.	.	67	.	.	.	.	.	.	.	.
30	.	01	02	.	04	.	.	.	70	00	.	.	.	.	.	.	.
31	10	.	.	.	.	.	.	.	71	.	.	.	.	.	.	.	.
32	20	.	.	.	24	.	.	.	72	20	.	.	.	.	.	.	.
33	30	.	.	.	.	.	.	.	73	.	.	.	.	.	.	.	.
34	40	.	.	.	.	.	.	.	74	.	.	.	.	.	.	.	.
35	.	.	.	.	.	.	.	.	75	.	.	.	.	.	.	.	.
36	60	.	.	.	.	.	.	.	76	.	.	.	.	.	.	.	.
37	.	.	.	.	.	.	.	.	77	.	.	.	.	.	.	.	.

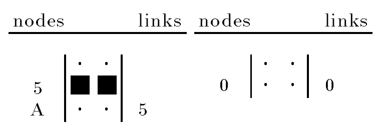
3.2 Powers of the longitudinal de Bruijn matrix

	(0,0) element					trace				
	initial		final			initial		final		
width	nodes	links	nodes	links	gens	nodes	links	nodes	links	gens
1	1	1	1	1	1	3	3	3	3	1
2	1	1	1	1	1	3	13	3	3	2
3	1	4	1	1	2	3	51	3	3	2
4	1	13	1	1	2	35	137	3	3	4
5	8	45	1	1	3	143	533	58	93	5
6	25	148	1	1	3	349	1909	99	135	6

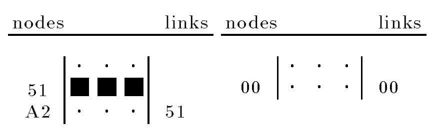
3.2.1 longitudinal, width 1



3.2.2 longitudinal, width 2



3.2.3 longitudinal, width 3



3.2.4 longitudinal, width 4

nodes		links
 55 AA	· · · · ■ ■ ■ ■ · · · ·	 55
00	· · · · · · · ·	00

3.2.5 longitudinal, width 5

There is a fivefold symmetry, according to which the first eleven nodes shown below can be rotated by an arbitrary amount, giving 55 nodes altogether. The last three nodes are invariant to rotation, completing the total of 58 nodes shown in the table.

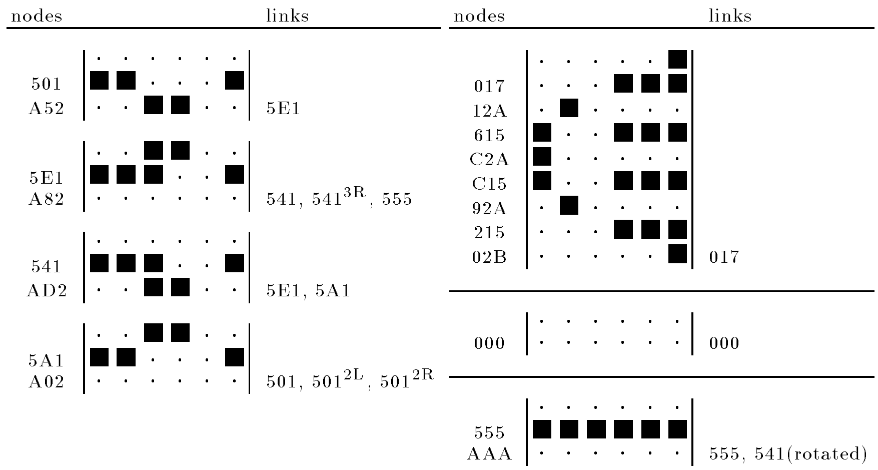
It is convenient to show only one member from each symmetry class, so the links between nodes need to indicate the amount of rotation or reflection implicit in the link.

nodes		links
 5A0 A00	· · ■ ■ · ■ ■ · · · · · · · ·	 000, 500
000	· · · · · · · · · ·	000, 500 (rotated)
 500 A50	· · · · · ■ ■ · · · · · ■ ■ ·	 0F0, 5E0
0F0	· · ■ ■ · · · ■ ■ ·	5A0

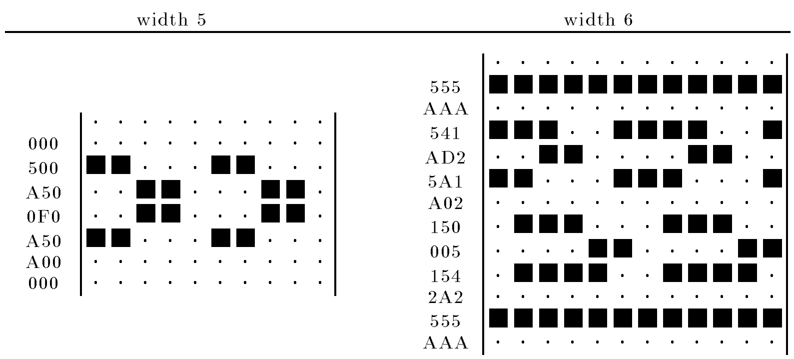
nodes		links
 5E0 A80	· · ■ ■ · ■ ■ ■ · · · · · · ·	 551, 540
 551 AA2	· · · · · ■ ■ ■ ■ ■ · · · · ·	 551, 540 (rotated)
 540 AD0	· · · · · ■ ■ ■ · · · · ■ ■ ·	 5A0, 5E0, 0B0
 0B0 070	· · ■ ■ · · · · ■ · · · ■ ■ ·	 5E0

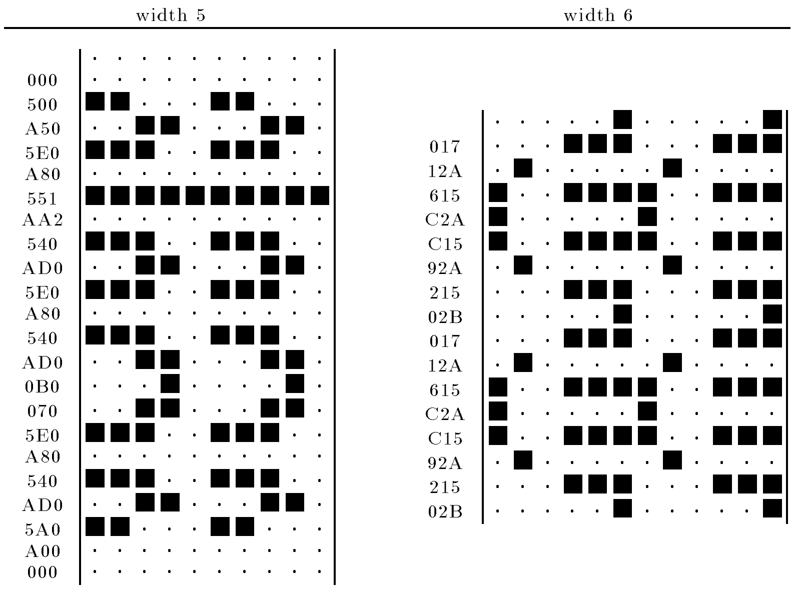
The simplest figure which can be constructed uses the lines of the first column above, just filling a 5×5 square. It is ubiquitous; it might be named an ant. Although not self-propelled, it can be led by any live cell placed in front of it, or by a pair of live cells flanking it. Such cells can even be the hind feet of the ant in front, or of a pair of ants straddling it. Ants can even be staggered, although there is not enough room in a strip of width 5 for them to do anything but march in parallel. Nevertheless, space allowing, they frequently trail behind other configurations, sometimes leading still smaller processions.

3.2.6 longitudinal, width 6



3.3 Sample strips with longitudinal movement





A variety of structural elements can be discerned in these patterns. The simplest is the ant, encased in its 5×5 square, which is almost freestanding. Except for the guiding bit or bits which is required to lead it, it can exist in isolation, or it can be stacked with other ants either in a single file or staggered in various ways. Wider strips are required to display the full variability possible.

Figures flow along channels according to the next most restrictive format. The channel boundaries can be stabilized with castellations, supporting blocks, and various other ways which are not evident when translational symmetry is restricted to a single cell of displacement. Some figures can be packed side by side within their channels, and sometimes they can be packed with relative displacements.

Finally there are figures which cannot be interrupted at all, preserving their integrity only when they fill the entire infinite strip or form a periodic pattern on a torus of appropriate length.

4 (1,0,1) – transversal creepers

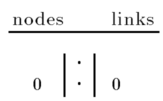
4.1 First stage de Bruijn matrix

	0	1	2	3	4	5	6	7		0	1	2	3	4	5	6	7
00	00	01	02	03	04	05	06	.	40	00	01	02	.	04	.	.	07
01	.	.	.	13	.	15	16	.	41	.	11	12	.	14	.	.	.
02	20	21	22	.	24	.	.	.	42	20	.	.	.	.	.	.	.
03	.	31	32	33	34	.	36	.	43	30	31	32	33	.	.	.	.
04	40	41	42	.	44	.	.	47	44	40	.	.	43	.	.	.	.
05	.	51	52	54	.	.	.	.	45	50	.	.	.	.	.	.	.
06	60	.	.	.	.	.	.	.	46	.	.	.	63	.	.	.	.
07	70	.	72	74	.	.	.	.	47	70	.	.	.	.	.	.	.
10	00	01	02	.	04	.	.	07	50	00	.	.	03	.	05	06	07
11	.	11	12	.	14	.	.	.	51	10	.	.	.	.	.	.	.
12	20	.	.	.	.	.	.	27	52	.	.	.	23	.	25	.	.
13	30	31	32	.	34	.	.	.	53	.	.	.	.	.	.	.	.
14	40	.	.	43	.	45	46	47	54	.	41	42	43	.	.	.	.
15	50	.	.	.	.	.	.	.	55	.	.	.	.	.	.	.	.
16	.	.	.	63	.	.	66	.	56	.	.	.	.	.	.	.	.
17	.	.	72	.	.	.	.	.	57	.	.	.	.	.	.	.	.
20	00	01	02	.	04	.	.	07	60	00	.	.	03	.	05	06	07
21	11	.	12	.	14	.	.	.	61	10	.	.	.	.	.	.	.
22	20	.	.	.	.	.	.	.	62	.	.	.	.	.	.	.	.
23	30	31	.	.	34	.	.	.	63	30	.	.	.	.	.	.	.
24	40	.	.	43	.	45	46	47	64	.	41	42	43	.	.	46	47
25	50	.	.	.	.	.	.	.	65	.	.	.	.	.	.	.	.
26	.	.	.	.	.	.	.	.	66	.	61	.	.	.	.	.	.
27	70	.	.	.	.	.	.	.	67	.	.	.	.	.	.	.	.
30	00	.	.	03	.	05	06	07	70	.	01	02	03	04	05	06	07
31	10	.	.	.	.	.	.	.	71	.	.	.	.	.	.	.	.
32	.	.	.	23	.	25	.	.	72	.	21	.	.	.	.	.	.
33	30	.	.	.	.	.	.	.	73	.	.	.	.	.	.	.	.
34	.	41	42	43	44	45	46	47	74	40	41	42	43	.	.	46	47
35	.	.	.	.	.	.	.	.	75	.	.	.	.	.	.	.	.
36	.	61	.	63	64	.	.	.	76	.	.	.	.	.	.	.	.
37	.	.	.	.	.	.	.	.	77	.	.	.	.	.	.	.	.

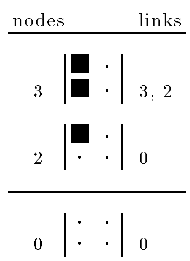
4.2 Powers of the transversal de Bruijn matrix

	(0,0) element					trace				
	initial		final			initial		final		
width	nodes	links	nodes	links	gens	nodes	links	nodes	links	gens
1	1	1	1	1	1	1	3	1	1	2
2	1	1	1	1	1	6	15	5	7	3
3	2	4	1	1	3	10	42	1	1	4
4	5	16	1	1	5	80	227	37	59	6
5	25	57	1	1	11	241	633	41	66	10
6	64	187	11	15	10	617	2367	133	243	8

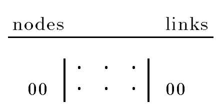
4.2.1 transversal, width 1



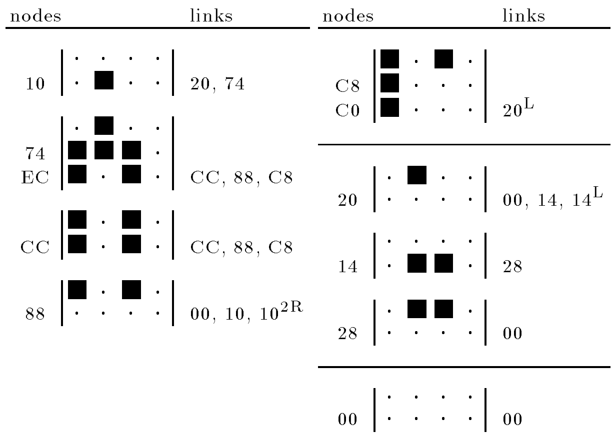
4.2.2 transversal, width 2



4.2.3 transversal, width 3

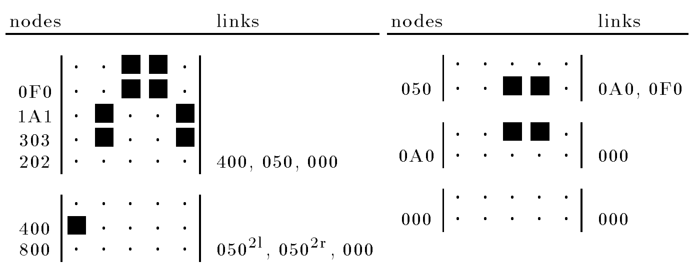


4.2.4 transversal, width 4



The transversal patterns are quite similar to the longitudinal patterns, except for the fact that the width 4 pattern can be stretched out to an arbitrary length and can acquire tail fins, which are capable of supporting a trailing plume. The longer of two tail fins must project an additional two cells, but a single cell projection is capable of generating interesting structures of period two which are outside the present analysis.

4.2.5 transversal, width 5



By turning the ant sideways, a strip of width 5 supports a trailing spark which in turn can lead another ant or a small plume consisting of a pair of cells.

4.2.6 transversal, width 6

nodes		links
 150 7B4 E2C	· · · · · · · ■ ■ ■ · · ■ ■ · ■ ■ · ■ · · · ■ ·	C0C, C4C
C4C	■ · · · ■ · ■ · ■ · ■ ·	C8C
C8C	■ · ■ · ■ · ■ · · · ■ ·	C0C
COC	■ · · · ■ · ■ · · · ■ ·	808
808	■ · · · ■ · · · · · · ·	150, $8A2^{R}$, 001, 000
001	· · · · · · · · · · · ■	002
002	· · · · · ■ · · · · · ·	005, 005^{R}, 000
005	· · · · · · · · · · ■ ■	00A, 00F
00A	· · · · ■ ■ · · · · · ·	000
 00F 41A	· · · · ■ ■ · · · · ■ ■ ■ · · ■ · ·	C30
 C30 820	■ · · ■ · · ■ · · ■ · · · · · · · ·	005^{rot}, 000

nodes		links
223	· ■ · ■ · ■ · · · · · ■	043, 003
003	· · · · · ■ · · · · · ■	002
043	· · · · · ■ · · ■ · · ■	082, 1D3
1D3	· · ■ · · ■ · ■ ■ ■ · ■	3B3
3B3	· ■ ■ ■ · ■ · ■ · ■ · ■	333, $C8C^{3R}$
3B2	· ■ ■ ■ · ■ · ■ · ■ · ·	$C0C^{2R}$
333	· ■ · ■ · ■ · ■ · ■ · ■	333, 222, 223^{P}, 233^{P}
111	· · · · · · · ■ · ■ · ■	222
222	· ■ · ■ · ■ · · · · · ·	001^{L}, 001^{3L}, 001^{R}, 000
451	· · · · · · ■ · ■ ■ · ■	8A2
8A2	■ · ■ ■ · ■ · · · · · ·	111, 111^{R}, 000
000	· · · · · ·	000

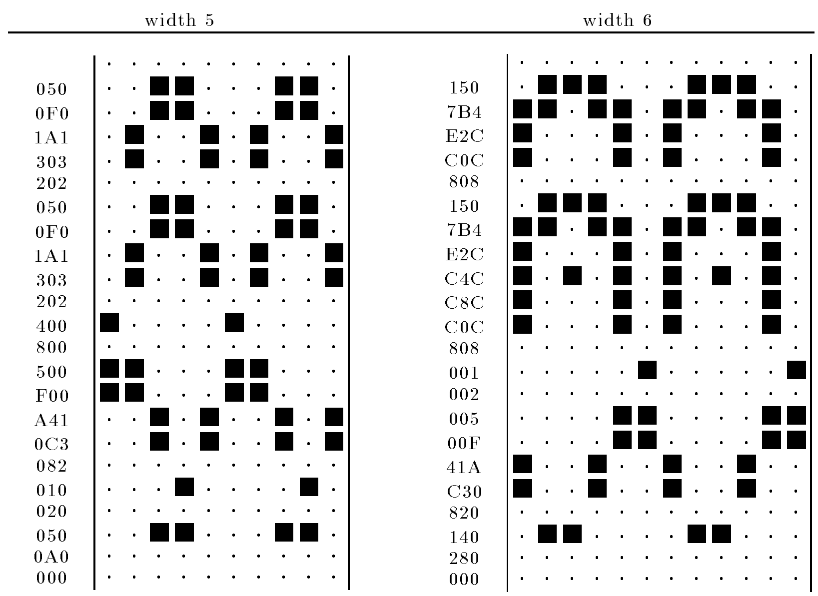
(The superscript P signifies any rotation by two cells)

4.3 Sample strips with transversal movement

A width of 6 allows the width 4 patterns to be separated by a channel and to stretch to arbitrary lengths. Certain interruptions allow channel switching, as indicated by the alternative (pmut) at the node 333. Any permutation of the node 223 is allowed in continuation, which is to say, any rotation by two cells.

With a width of 6, ants have still more freedom of movement; even a wide bodied ant is possible, which can lead ordinary ants in its wake. Unlike an ordinary ant, the wide one requires lateral support for strips of width greater than 6.

Thus there are four basic configurations which may lead from one to another, finally trailing off into a shower of small sparks. The ants themselves can be free-standing, in the sense that parallel columns of marching ants may be separated by arbitrary quiescent regions, even though each individual column extends upward to infinity.



5 (1,1,1) – diagonal creepers

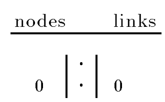
5.1 First stage de Bruijn matrix

	0	1	2	3	4	5	6	7		0	1	2	3	4	5	6	7
00	00	01	02	03	04	05	06	.	40	00	01	02	.	04	.	.	07
01	10	11	12	.	14	.	.	17	41	10	.	.	13	.	15	16	17
02	20	21	22	.	24	.	.	.	42	20	.	.	.	.	.	.	27
03	30	.	.	.	.	.	.	.	43	.	.	.	33	.	.	36	.
04	40	41	42	.	44	.	.	47	44	40	.	.	43	.	45	46	47
05	50	.	.	53	.	.	56	.	45	.	51	52	53	54	.	56	.
06	.	.	.	.	.	.	60	67	46	.	.	.	63	.	65	66	67
07	.	.	.	.	.	.	.	.	47	.	.	72	.	.	.	.	.
10	.	.	.	03	.	.	06	.	50	.	01	02	.	04	.	.	.
11	.	11	12	.	14	.	.	.	51	10	.	.	.	.	.	.	.
12	.	21	22	23	24	25	26	.	52	20	21	22	.	24	.	.	.
13	30	31	32	.	34	.	.	.	53	30	.	.	.	.	.	.	.
14	.	41	42	.	44	.	.	.	54	40	.	.	.	.	.	.	.
15	50	.	.	.	.	.	.	.	55	.	.	.	.	.	.	.	.
16	60	61	62	.	64	.	.	.	56	60	.	.	.	.	.	.	.
17	70	.	.	.	.	.	.	.	57	.	.	.	.	.	.	.	.
20	00	01	02	04	.	.	.	07	60	00	.	.	03	.	05	.	.
21	10	.	.	13	.	15	16	17	61	.	11	12	13	14	15	.	.
22	20	.	.	.	.	.	.	.	62	.	.	.	.	.	.	.	.
23	.	.	.	33	.	.	.	.	63	.	31	.	.	.	.	.	.
24	40	.	.	43	.	45	46	47	64	.	41	42	43	44	45	.	.
25	.	51	52	53	54	.	56	.	65	50	51	52	53	54	.	.	.
26	.	.	.	63	.	65	.	.	66	.	61	.	.	.	.	.	.
27	.	.	72	.	.	.	.	.	67	70	.	.	.	.	.	.	.
30	.	01	02	.	04	.	.	.	70	00	.	.	.	.	.	.	.
31	10	.	.	.	.	.	.	.	71	.	.	.	.	.	.	.	.
32	20	21	22	.	24	.	.	.	72	20	.	.	.	.	.	.	.
33	30	.	.	.	.	.	.	.	73	.	.	.	.	.	.	.	.
34	40	.	.	.	.	.	.	.	74	.	.	.	.	.	.	.	.
35	.	.	.	.	.	.	.	.	75	.	.	.	.	.	.	.	.
36	60	.	.	.	.	.	.	.	76	.	.	.	.	.	.	.	.
37	.	.	.	.	.	.	.	.	77	.	.	.	.	.	.	.	.

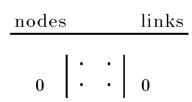
5.2 Powers of the diagonal de Bruijn matrix

	(0,0) element					trace				
	initial		final			initial		final		
width	nodes	links	nodes	links	gens	nodes	links	nodes	links	gens
1	1	1	1	1	1	1	3	1	1	1
2	1	1	1	1	1	3	11	1	1	3
3	2	4	1	1	3	10	42	1	1	4
4	6	14	1	1	5	37	131	25	41	3
5	14	44	1	1	6	141	463	56	96	8
6	39	151	1	1	7	350	1556	97	163	10

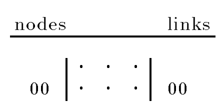
5.2.1 diagonal, width 1



5.2.2 diagonal, width 2



5.2.3 diagonal, width 3



5.2.4 diagonal, width 4

nodes		links
01 02	· · · · · · · ■ · · · ·	00, 11
11 22	· · · · · ■ · ■ · · · ·	00, 05, 05^{2R}

nodes		links
05 0A	· · · · · · ■ ■ · · · ·	00, 01^{2R}
06	· · · ■ · · ■ ·	01^{2L}, 06^{2L}
00	· · · · · · · ·	00

5.2.5 diagonal, width 5

nodes		links
041 082	· · · · · · · ■ · ■ · · · · ·	041^{L}, 111, 040, 000
111 222	· · · · · · ■ · ■ ■ · · · · ·	000
040 080	· · · · · · · ■ · · · · · · ·	000
012	· · · · ■ · · · ■ ·	012^{L}, 020
020	· · · ■ · · · · · ·	000
000	· · · · · · · · · ·	000

nodes		links
003	· · · · ■ · · · · ■	042, 002
002	· · · · ■ · · · · ·	000
042	· · · · ■ · · ■ · ·	003^{2L}, 080
080	· · ■ · ■ · · · · ·	000
802	■ · · · ■ · · ■ · ·	010, 050
010	· · · · · · · · ■ ·	000
050	· · · · ■ · · ■ ■ ·	802^{2L}

5.2.6 diagonal, width 6

nodes		links
	· · · · · ·	
011	· · · ■ · ■	032, 202^{2L}
	· · · ■ · ■	
032	· · · ■ · ·	
121	· ■ · · · ■	202
	· ■ · · · ■	
202	· · · · · ·	011, 514, 000
	· · · · · ·	
514	■ ■ · ■ ■ ·	
A28	· · · · · ·	000
	· · · · · ·	
001	· · · · · ■	002
	· · · · · ■	
002	· · · · · ·	000
	· · · · · ■	
006	· · · · ■ ·	006^{L}, 002^{L}
	· · · · · ·	
000	· · · · · ·	000

nodes		links
	· · · · · ■	
003	· · · · · ■	012, 002
	· · · · · ■	
012	· · · ■ · ·	003^{2L}, 002^{2L}, 130
	· · · · ■ ·	
130	· · ■ · ■ ·	981^{R}
	· · · · ■ ■	
00A	· · · · · ·	050, 001^{2L}, 000
	· · · · · ·	
050	· · ■ ■ · ·	$00A^{2L}$, 1A0
	· · ■ ■ · ·	
1A0	· ■ · · · ·	
640	■ · ■ · · ·	981
	■ · ■ · · ·	
981	· ■ · · · ■	981^{2L}

5.3 Sample strips with diagonal movement

For clarity, only one strand of the three diagonal strings is shown, as though they were embedded in a strip of width 12 rather than 6.