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Rudolf Kaehr

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Claviatures for morphic and indicational Sound and Graphic CAs
Applications of the sub-rules approach to cellular automata

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Abstract

Claviatures gives a glimpse into the usefulness of the sub-rule approach for all kind of cellular automata. The merits of the sub-rule approach becomes evident for highly complex automata where it is practically not achievable to manipulate all single rules of the automaton explicitly.

Even for a quite simple example of a CA based on the indicational rules *indRCI*, the complexity is not to handle by classical approaches. The sub-rule approach offers a *claviature* of the rule set so that all individual possibilities of the rule space of size $4^{20}=1'099'511'627'776$ are manually accessible.

The complexity of claviatures remains in a finite range of small sets of rules measured by the sum of the Sterling Numbers of the Second Kind.

Hence the rule space of *ruleDM* of the first example of the *Claviatures* is defined by the 15 morphograms distributed

over 15 places generating the combination of $2 \times 3 \times 3 \times 3 \times 4 = 216$ single morphogrammatic compounds of *ruleDM*[{k,l,m,n,o}] with k={1,6}, l={2,7,11}, m={3,8,12}, n={4,9,13} and o={5,10,14,15}.

Therefore the claviature of *ruleDM* with its 15 keys defines all 216 different potential realizations of the automaton *morphoDM*. Because the number of functions for this morphoCA is small and manageable there is no barrier to define the functions explicitly.

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Claviatures for morphic and indicational Sound and Graphic CAs

Applications of the sub-rules approach to cellular automata

Dr. phil Rudolf Kaehr

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Complexity Reduction by Claviatures

Conceptual background

Claviatures gives a glimpse into the usefulness of the sub-rule approach for all kind of cellular automata. The merits of the sub-rule approach becomes evident for highly complex automata where it is practically not achievable to manipulate all single rules of the automaton explicitly.

Even for a quite simple example of a CA based on the indicational rules *indRCI*, the complexity is not to handle by classical approaches. The sub-rule approach offers a *claviature* of the rule set so that all individual possibilities of the rule space of size $4^{20}=1'099'511'627'776$ are manually accessible.

The complexity of claviatures remains in a finite range of small sets of rules measured by the sum of the Sterling Numbers of the Second Kind.

Hence the rule space of *ruleDM* of the first example of the *Claviatures* is defined by the 15 morphograms distributed over 15 places generating the combination of $2 \times 3 \times 3 \times 3 \times 4 = 216$ single morphogrammatic compounds of *ruleD-M*[{k,l,m,n,o}] with k={1,6}, l={2,7,11}, m={3,8,12}, n={4,9,13} and o={5,10,14,15}.

Therefore the claviature of *ruleDM* with its 15 keys defines all 216 different potential realizations of the automaton *morphoDM*. Because the number of functions for this morphoCA is small and manageable there is no barrier to define the functions explicitly.

But the rule space for *ruleDCKV* of morphoCA^(5,5) is $2 \times 3^7 \times 4^6 \times 5 = 89'579'520$. There is certainly no realistic chance to define this amount of rules and to handle it explicitly.

The case for the indicational automaton *indRCI* with its *ruleRCI*[{a,b,c,d,e, f,g,h,i, j,k,l,m,n,o,p,q,r,s,t}], where all components have 4 mutually excluding different indicational rules, the rule space is intriguingly less accessible without the sub-rule approach proposed in this paper.

The 20 positions of the automaton *indRCI* are defining $4^{20}=1'099'511'627'776$ different potential realizations of the indicational rule space of *indRCI*. In contrast, the rule space of ECA is $2^8 = 256$.

Rule space table

Rule space table		
DCKV	89 579 520	$2 \times 3^7 \times 4^6 \times 5$
DM	216	$2 \times 3^3 \times 4$
DMN	486	2×3^5
CIR	59 049	3^{10}
RCI	1 099 511 627 776	3^{20}

The current presentation of Claviatures for 1D automata is not restricting its application to 1D CAs, all higher order cellular automata of arbitrary dimensions are included to the application of claviatures.

Epistemologically, there is a paradigm change involved which turns the definition of classical CAs from an '*algebraic*' to a '*co-algebraic*' understanding of generalized CAs.

The co-algebraic approach emphasizes the '*stream*' of computational events, and configurations are selected out of the stream by selectors like the proposed claviatures. Therefore there is no need to construct all the possible constellations step by step by CA rules.

Instead of developing *reduction* techniques to reduce the complexity of CAs, the claviatures approach plays on a meta-level with CAs that are accessible by selection. This leads to the well known automata theoretic concept of *experiments with automata*.

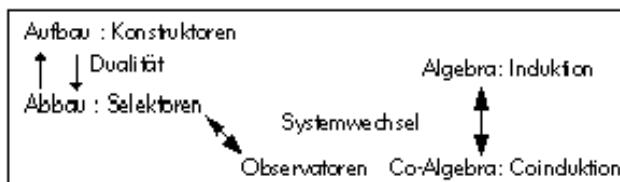
Algebraic structures have to be constructed, co-algebraic structurations have to be selected by interaction.

There is not just a duality between algebras and co-algebras in respect of constructors and destructors but also a not well recognized *asymmetry* between the pair "constructors/destructors" and the new deconstructors. A chiastic system change happens from the *selectors* of the destruction to the *observators* of co-algebras under the interaction of experiments.

Duality of algebras and co-algebras

Algebra	Ko-Algebra
induction	coinduction
initial	final object
constructor	destructor
total	partial functions
algebra	coalgebra
visible	hidden
structure	behavior
well founded	non well founded sets
Turing Machine	Persistent TM
Horn clauses	liveness axioms

Asymmetric shift from internal to external descriptions of selectors and observators



The organon of the claviatures

The claviature approach is exemplified with the morphogrammatic CAs for *ruleDM*, *ruleDMN*, *ruleDMNP* and *ruleDCKV*. Also for the indicational CAs for *ruleCI*, *ruleCIR* and *ruleRCI*. All are applied to the categories of graphics, sound, transition graphs and fixedpoint determination. The case for ECA is exemplified for all categories too.

The method of sub-rules for CAs is an *abstraction* and *parametrization* of the components of the rule schemes that allows a micro-analysis of the CAs. The CA sub-rule manipulator manages explicitly all CA rules of a 1D CA. The sub-rule manipulators enables a *micro-analysis* of the behavior of all CA rules.

Further reading

Peter Wegner, *Why Interaction is more Powerful than Algorithms*, 1997

http://wit.tuwien.ac.at/events/wegner/cacm_may97_p80-wegner.pdf

Dina Goldin, Peter Wegner, *The Interactive Nature of Computing: Refuting the Strong Church-Turing Thesis*

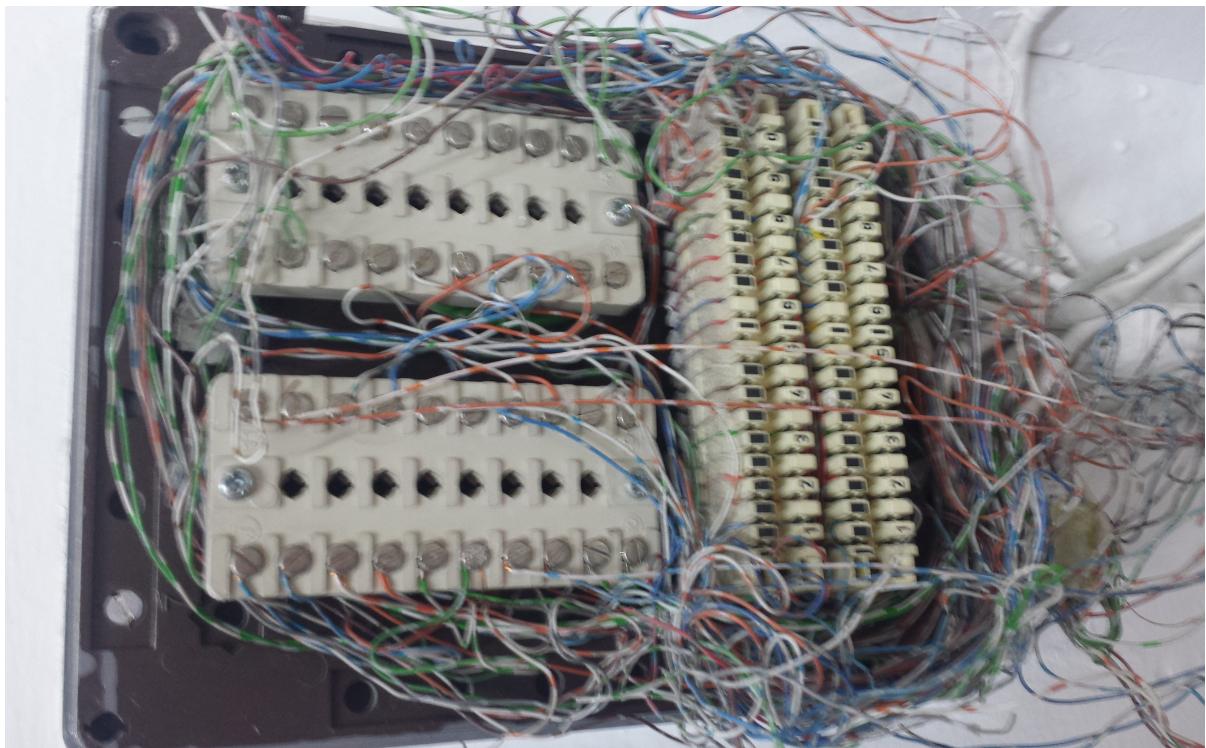
<http://cs.brown.edu/people/pw/strong-cct.pdf>

Rudolf Kaehr, STRUKTURATIONEN DER INTERAKTIVITÄT,
Skizze eines Gewebes rechnender Räume in denkender Leere (2004)

<http://www.thinkartlab.com/pkl/media/SKIZZE-0.9.5-medium.pdf>

<http://www.thinkartlab.com/pkl/lola/Interactivity.pdf>

Initialization





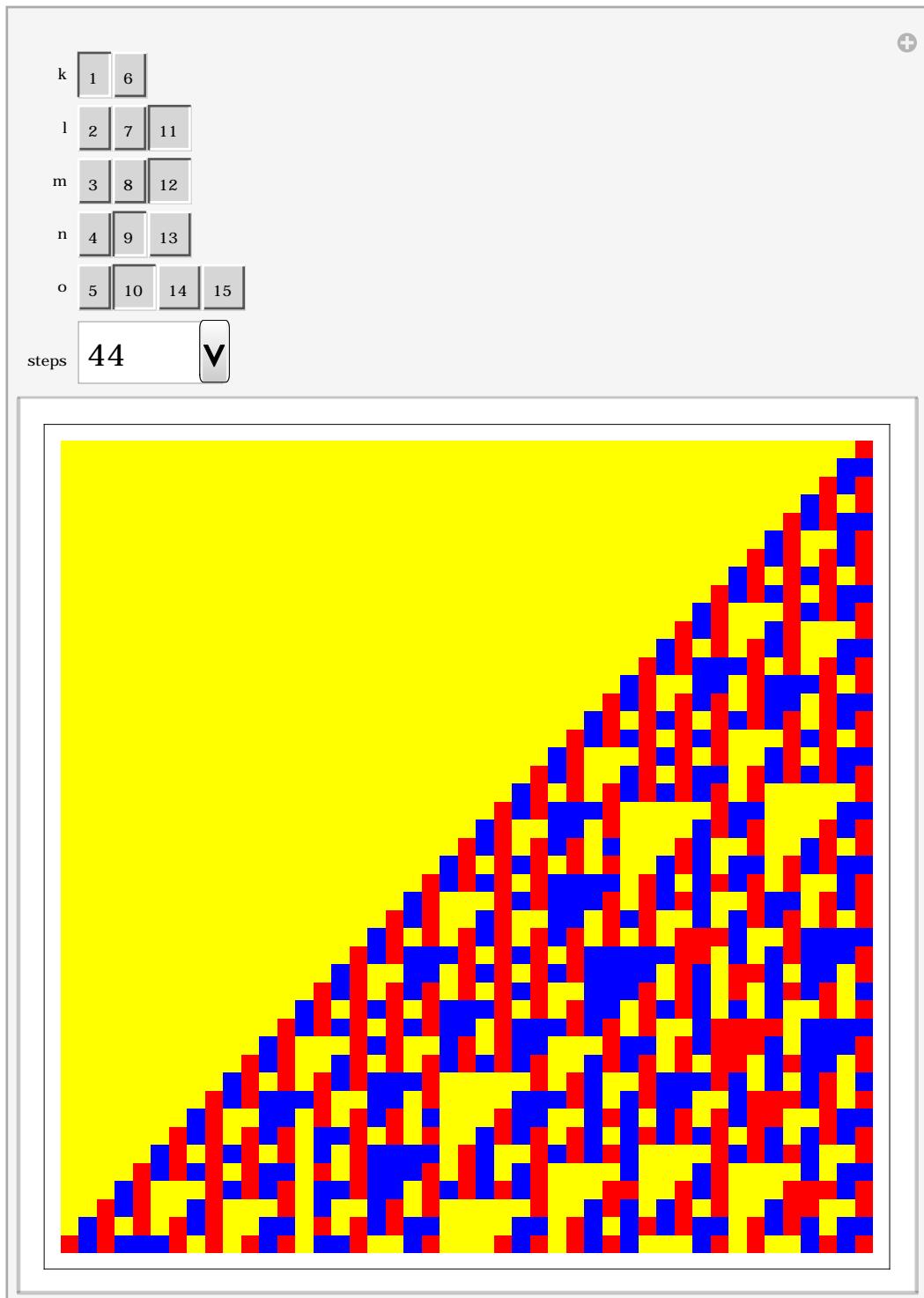
Rosemarie Swan, Degree Show Glasgow School of Art 2015

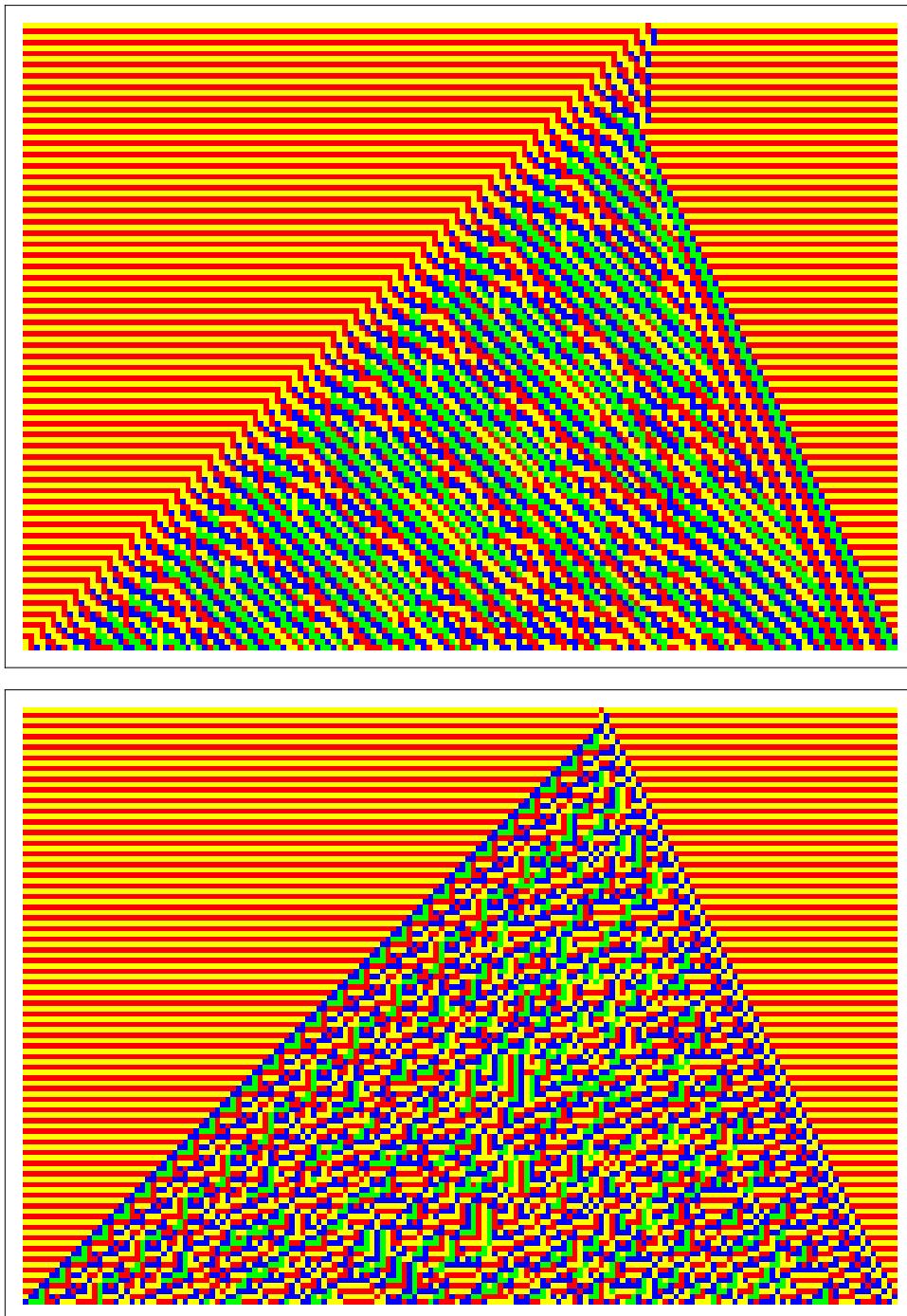
Morphogram: ruleDM-DMN-DMNP

Morphogram: morphoCA^(5,3,4)-DCKV

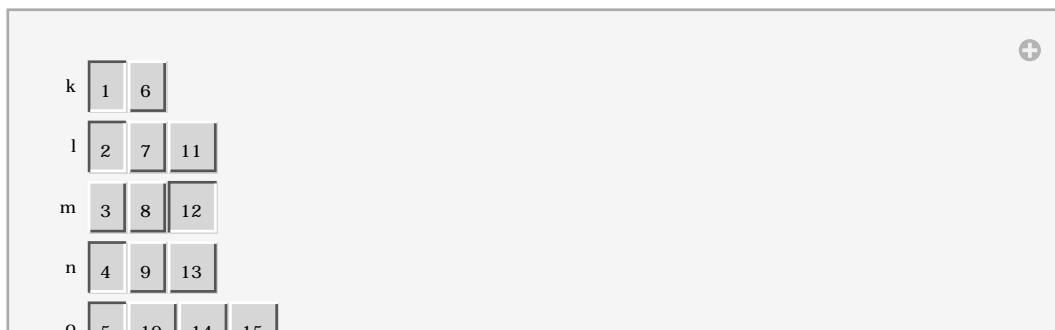
Graphics

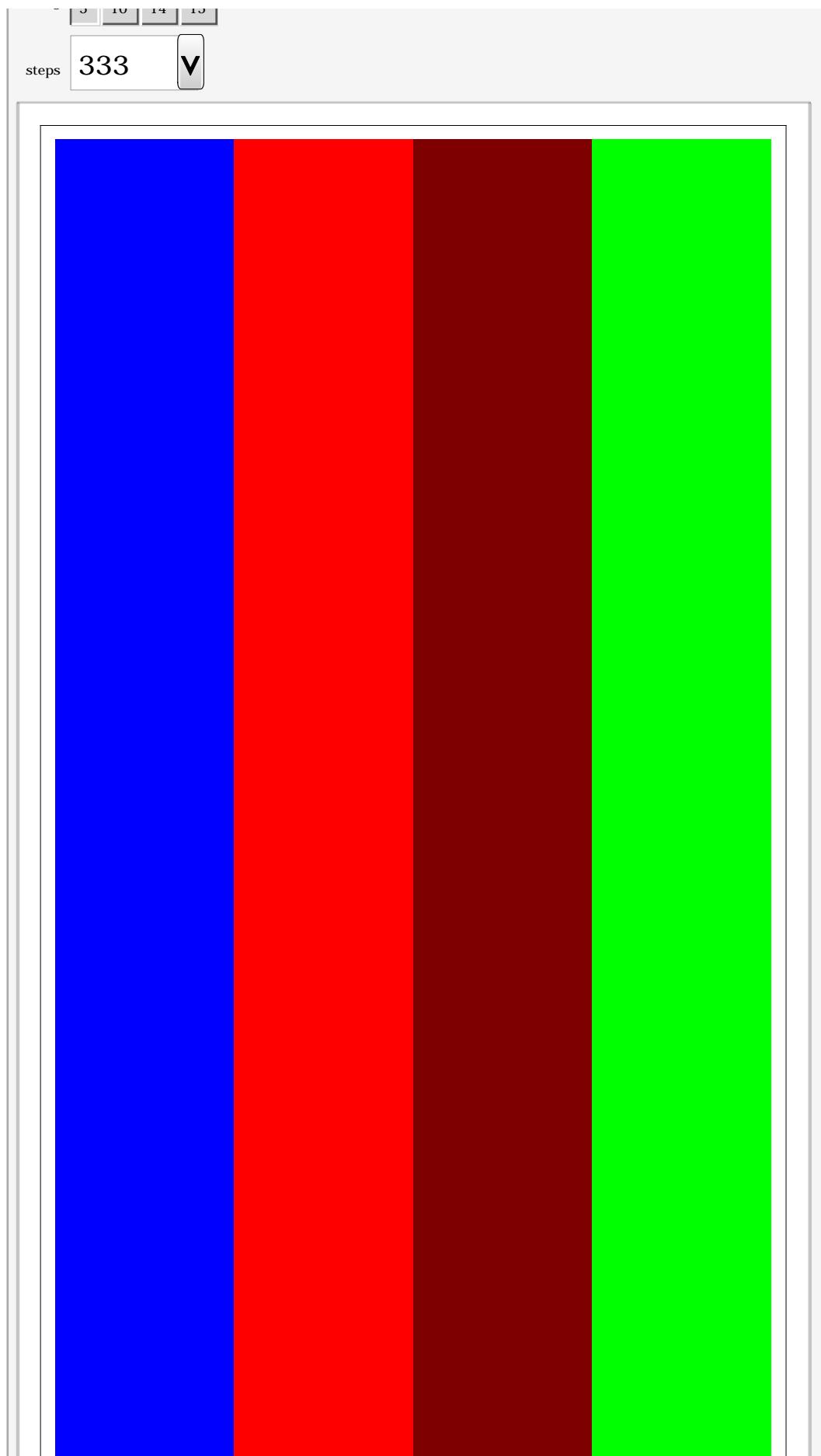
Morphogram: ruleDM

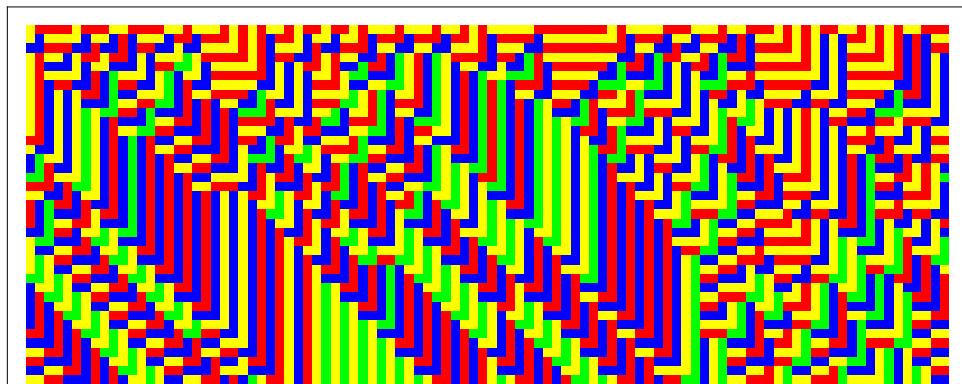
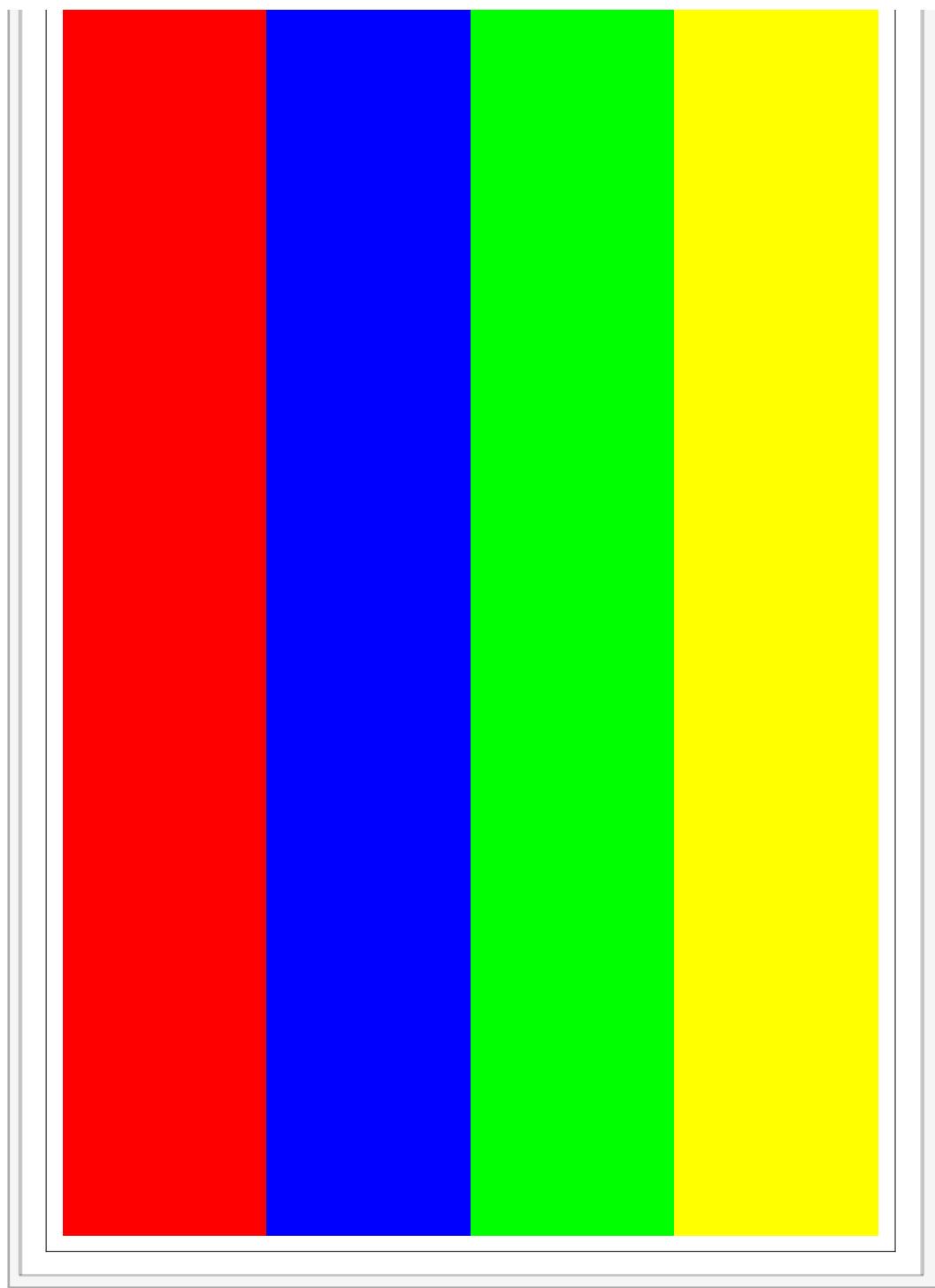


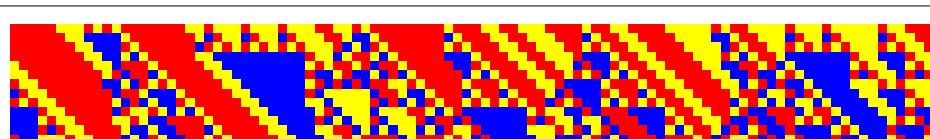
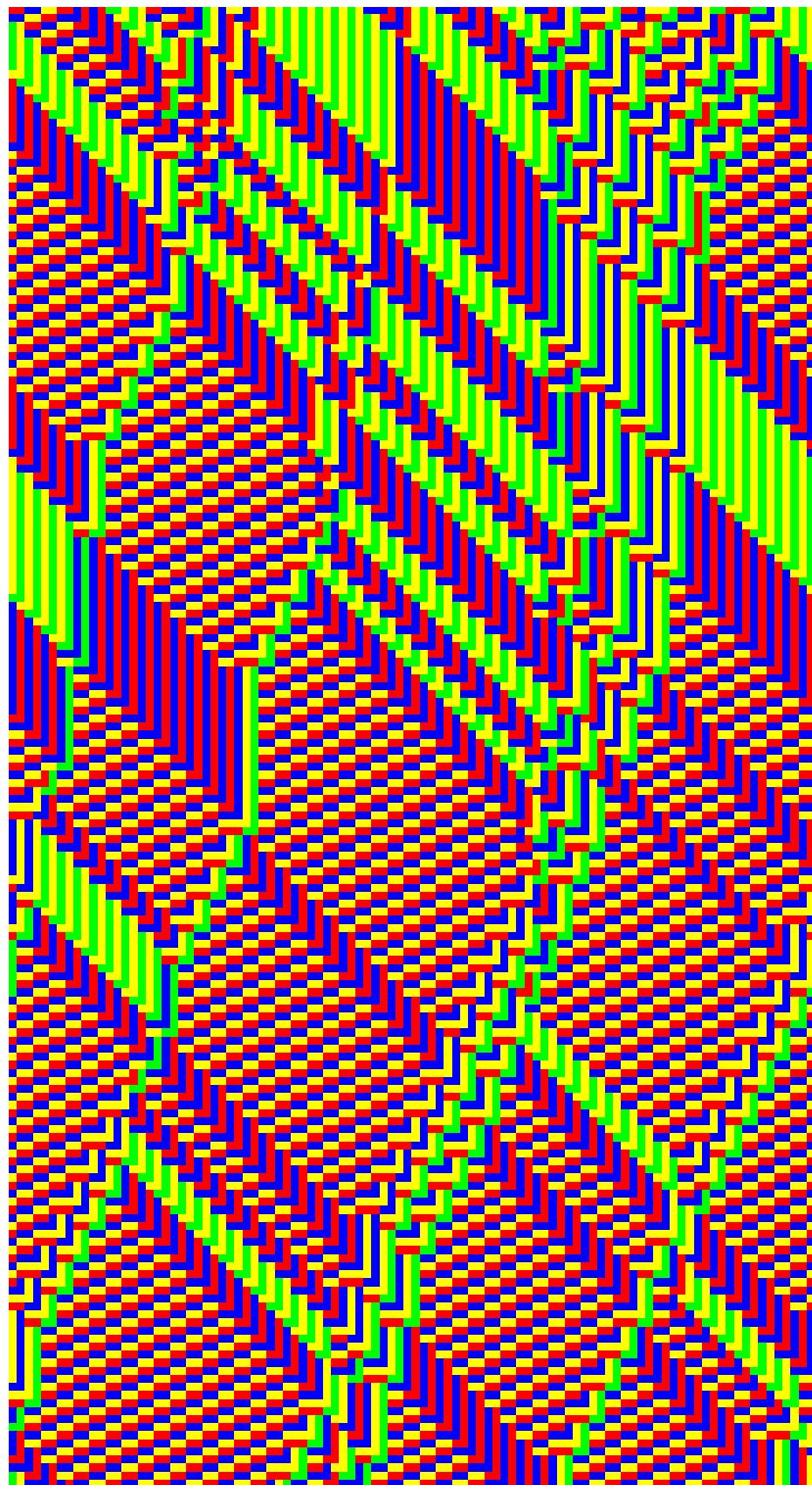


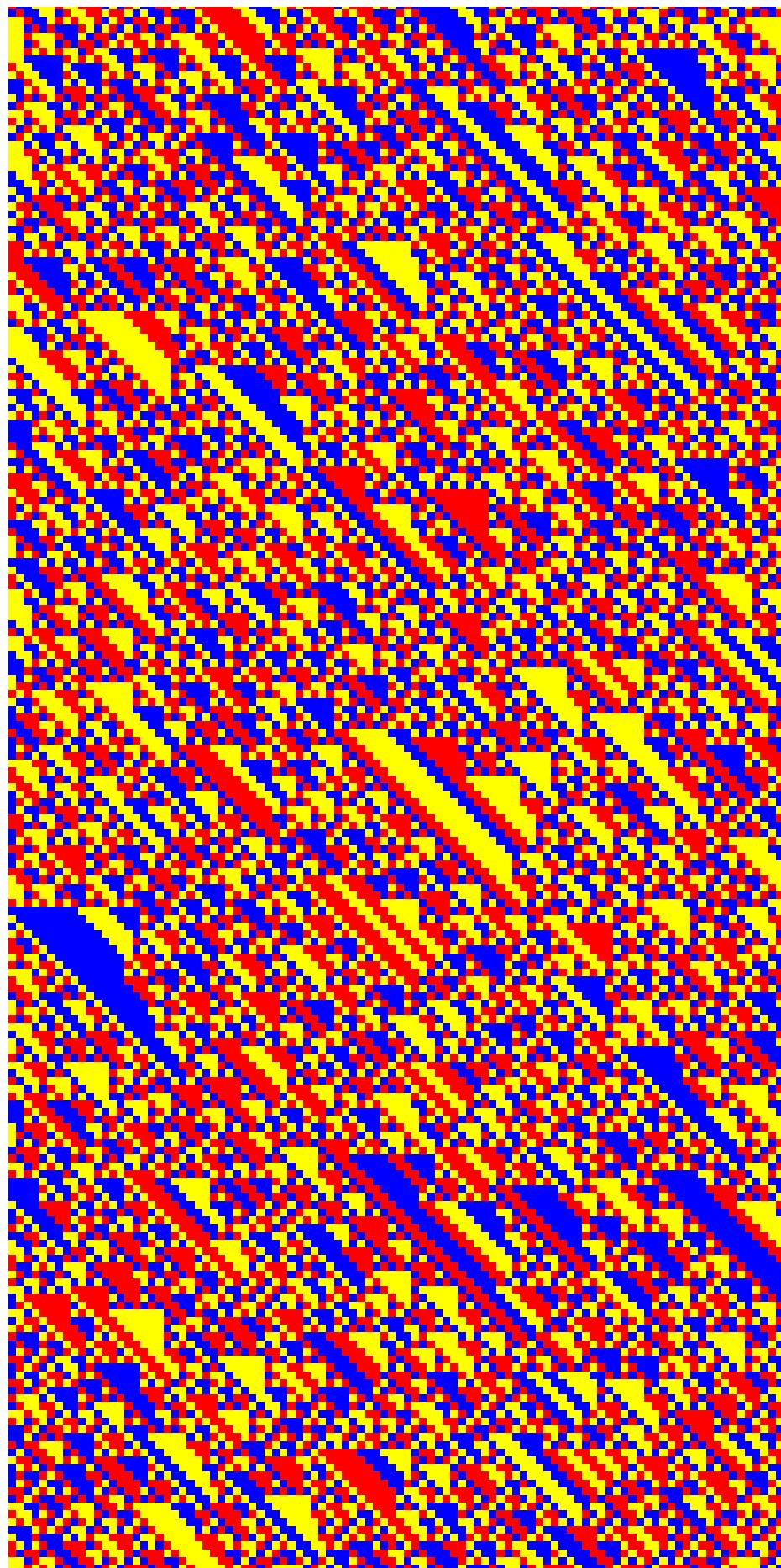
Morphogram: Random ruleDM

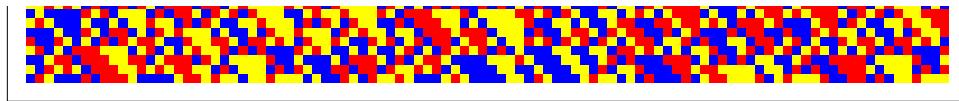






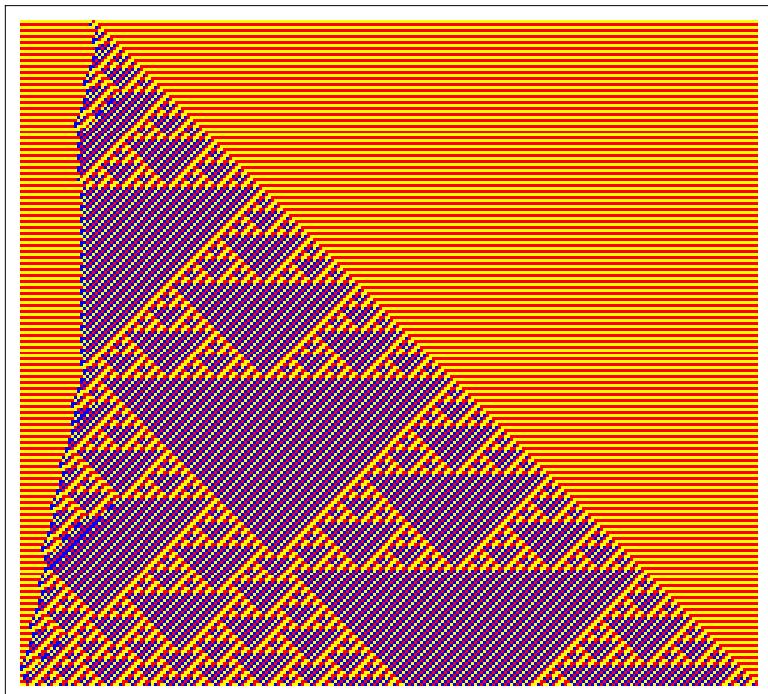


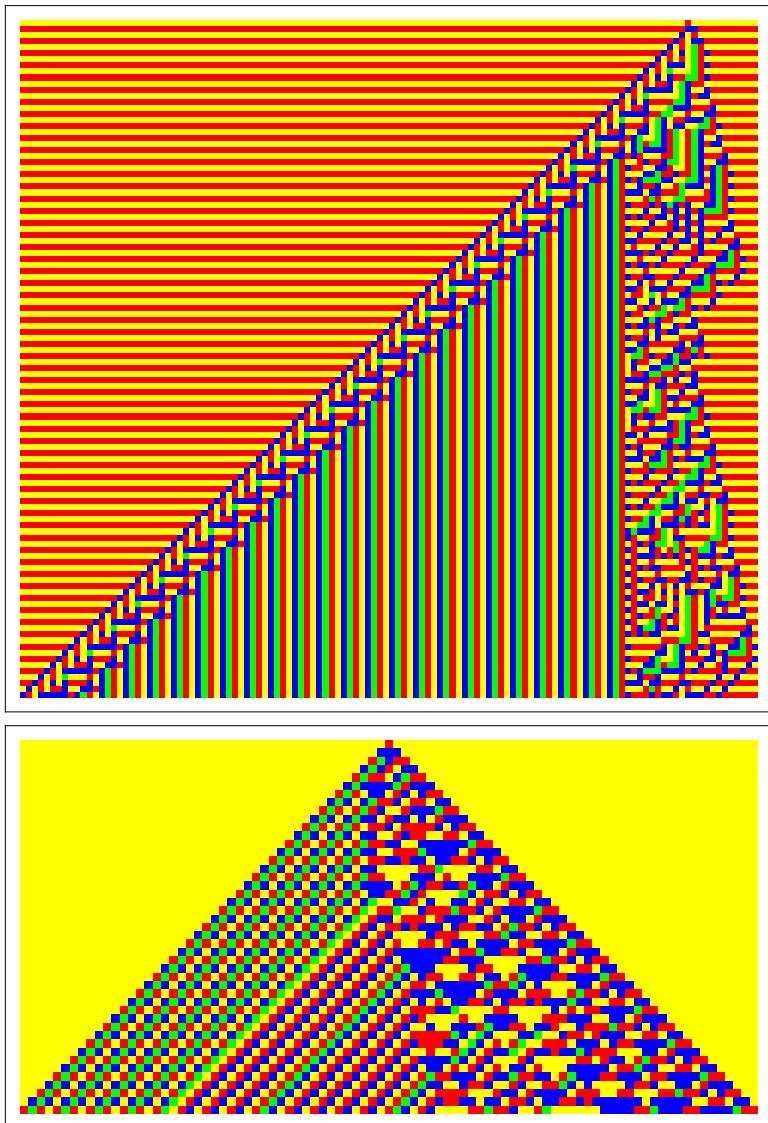




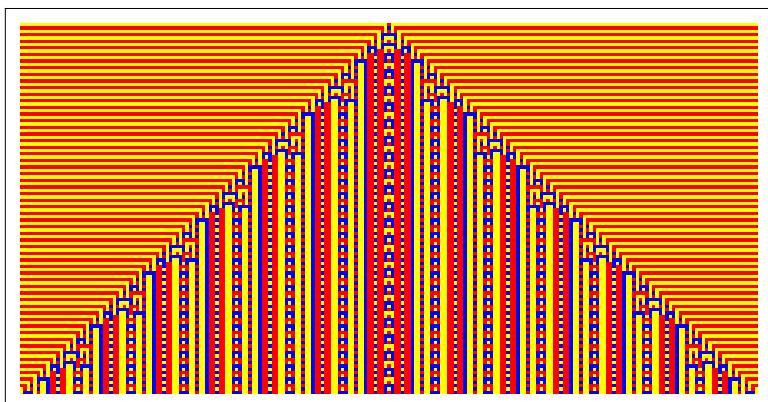
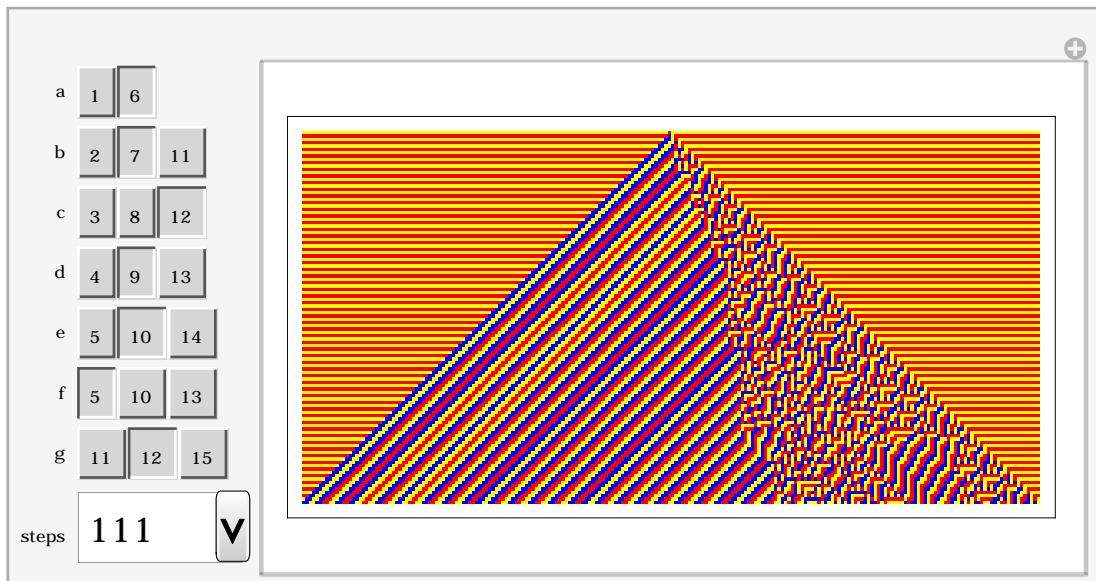
Morphogram: ruleDMN

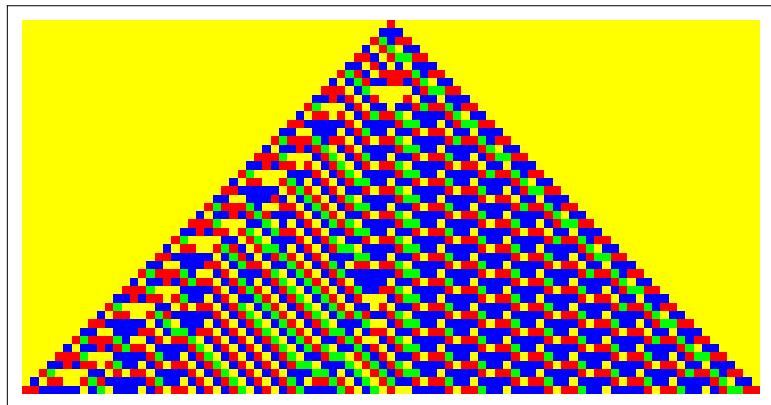
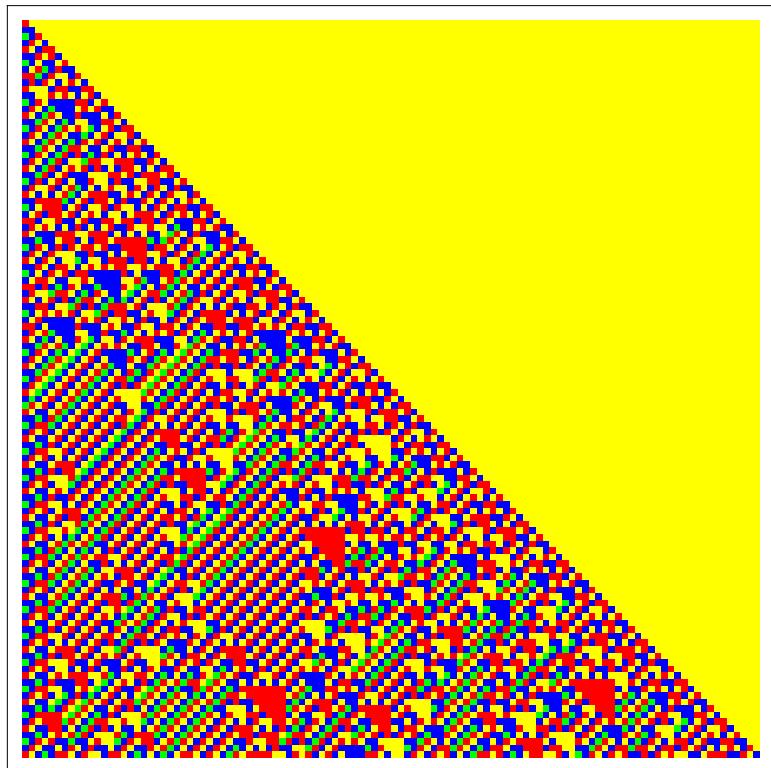




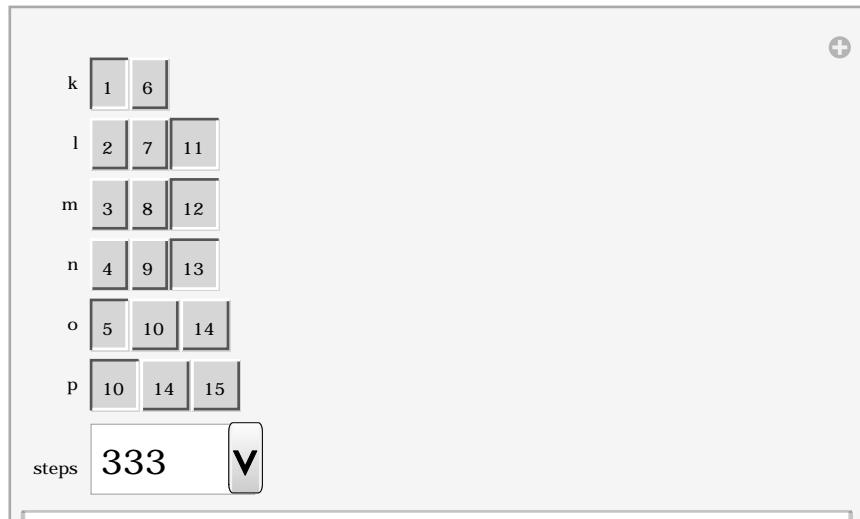


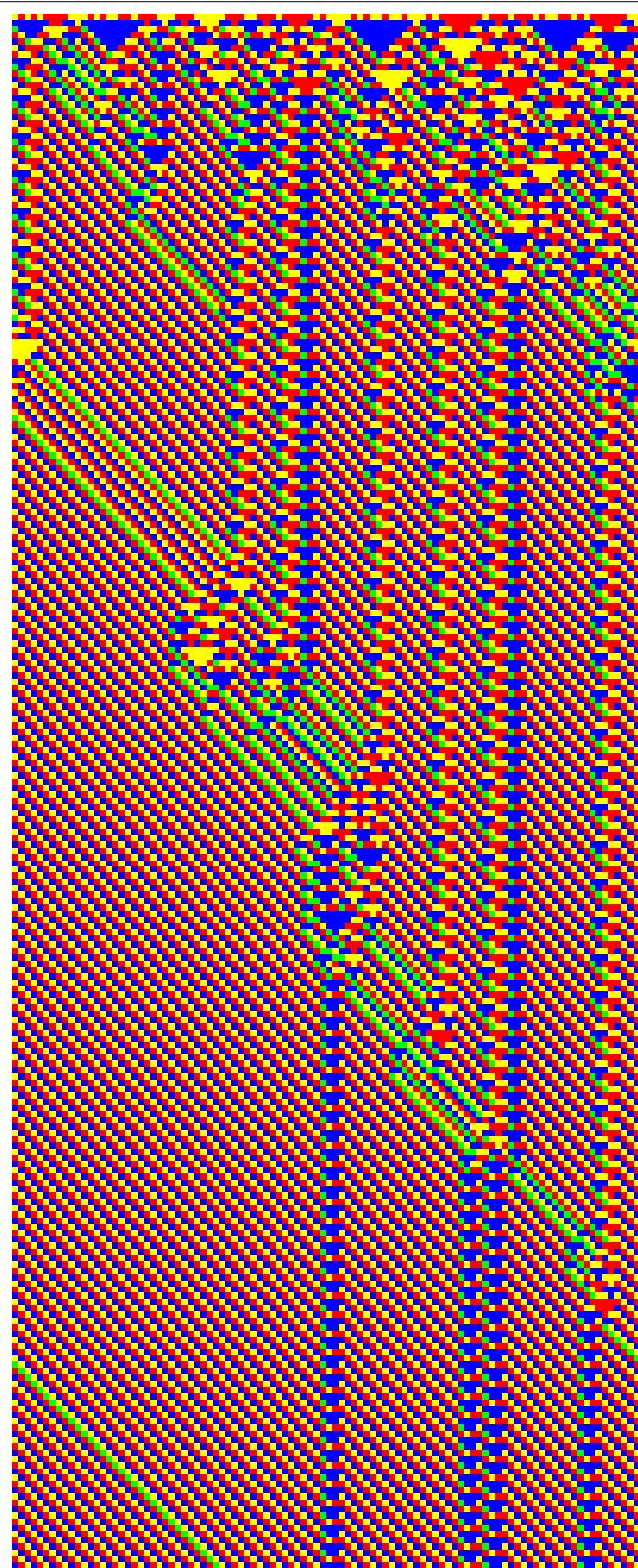
Morphogram: ruleMNP

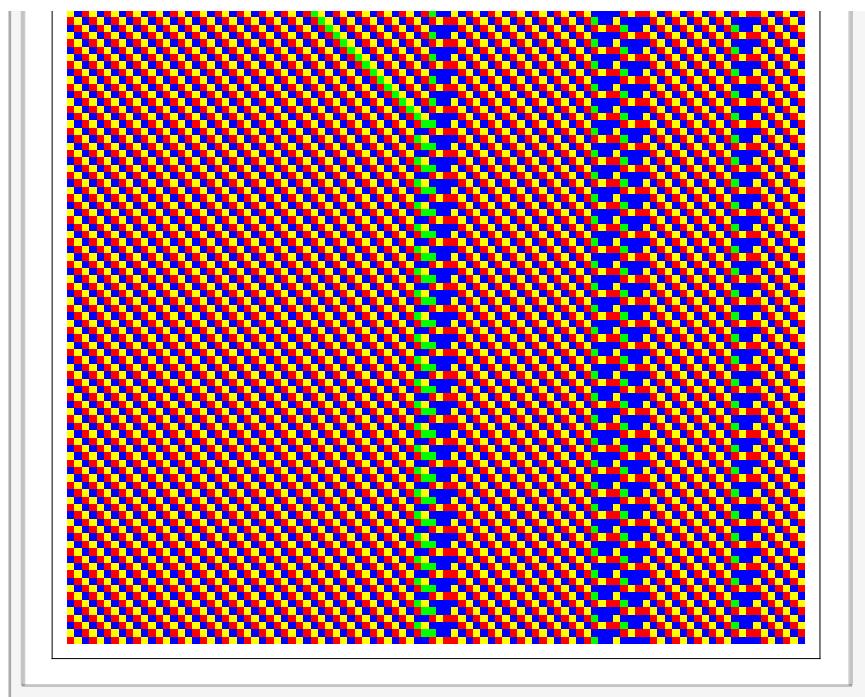


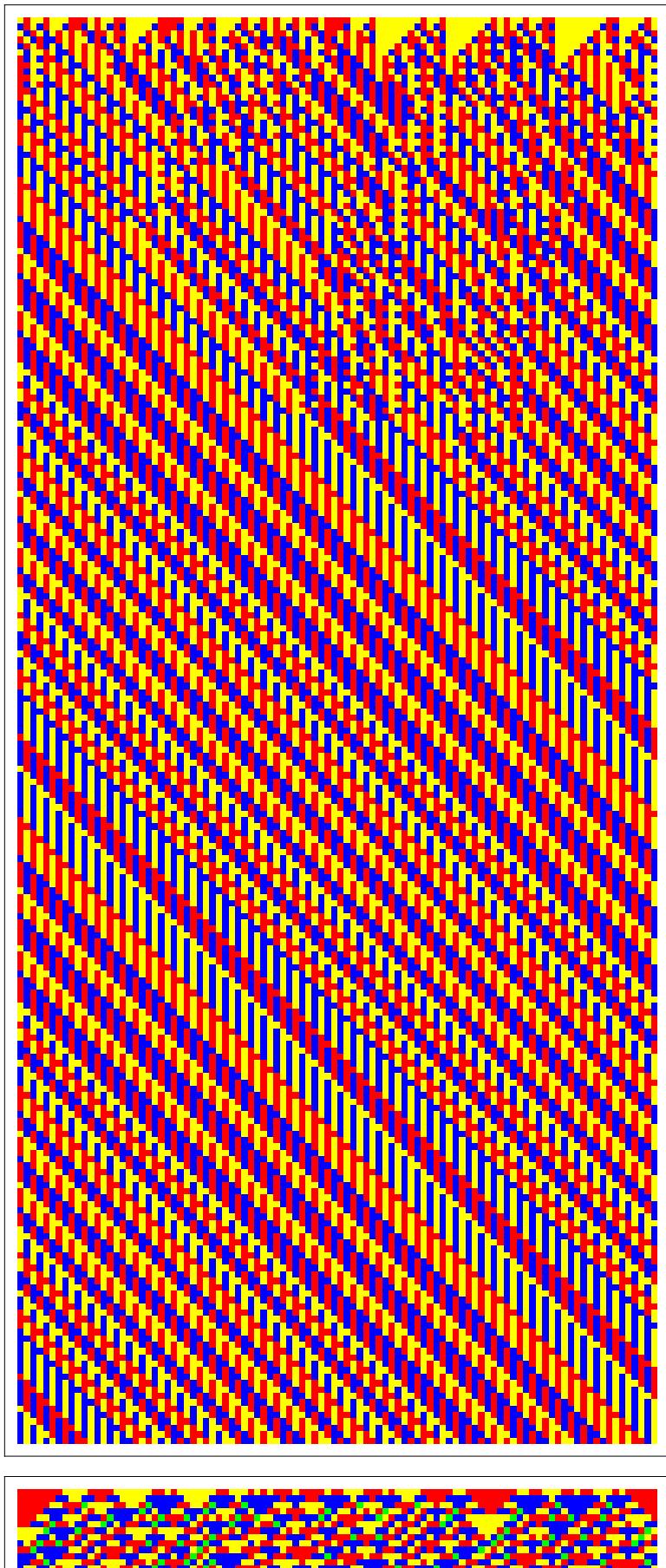


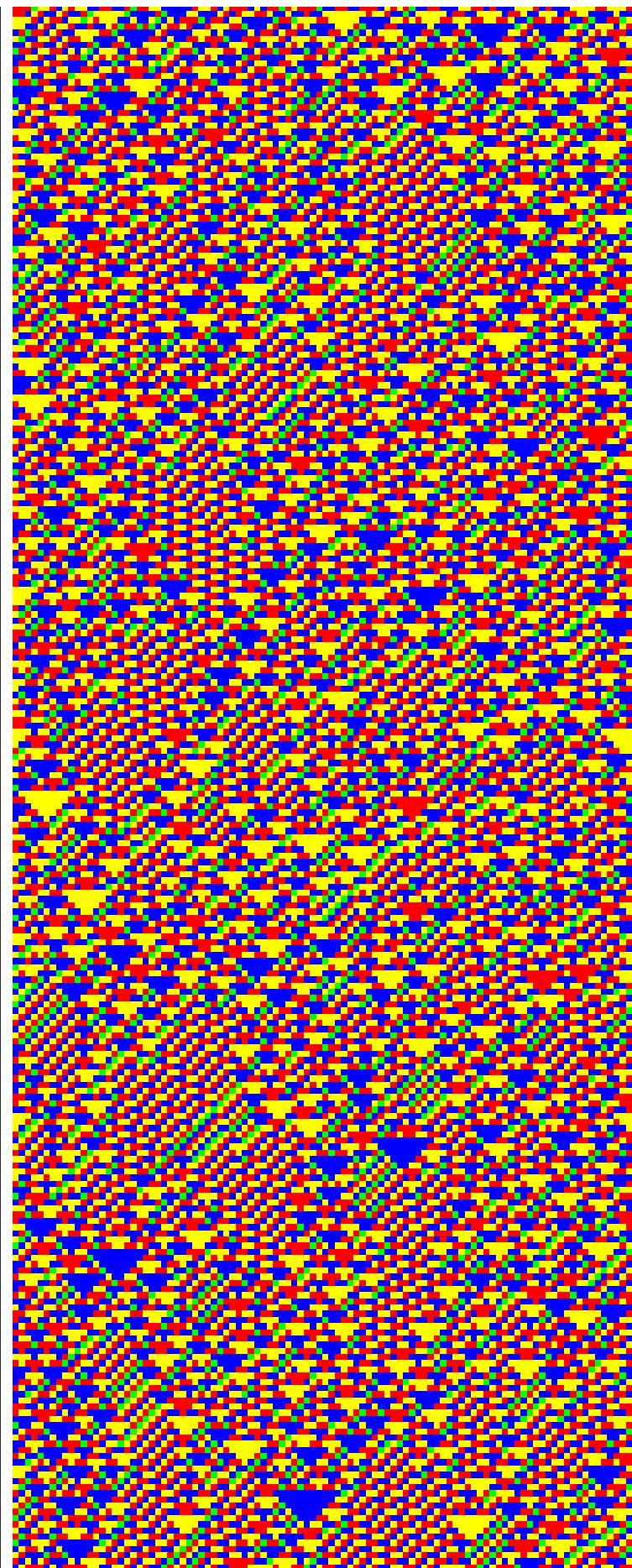
Morphogram: Random ruleDMN

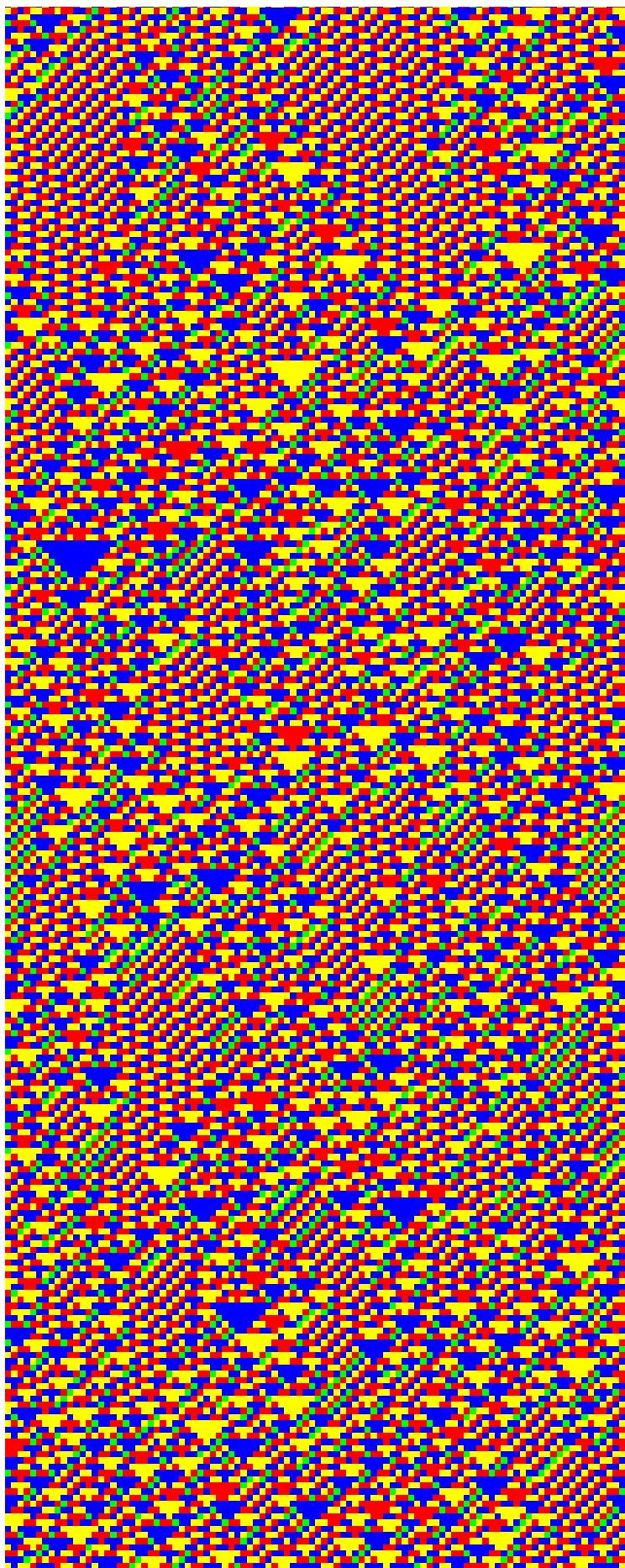


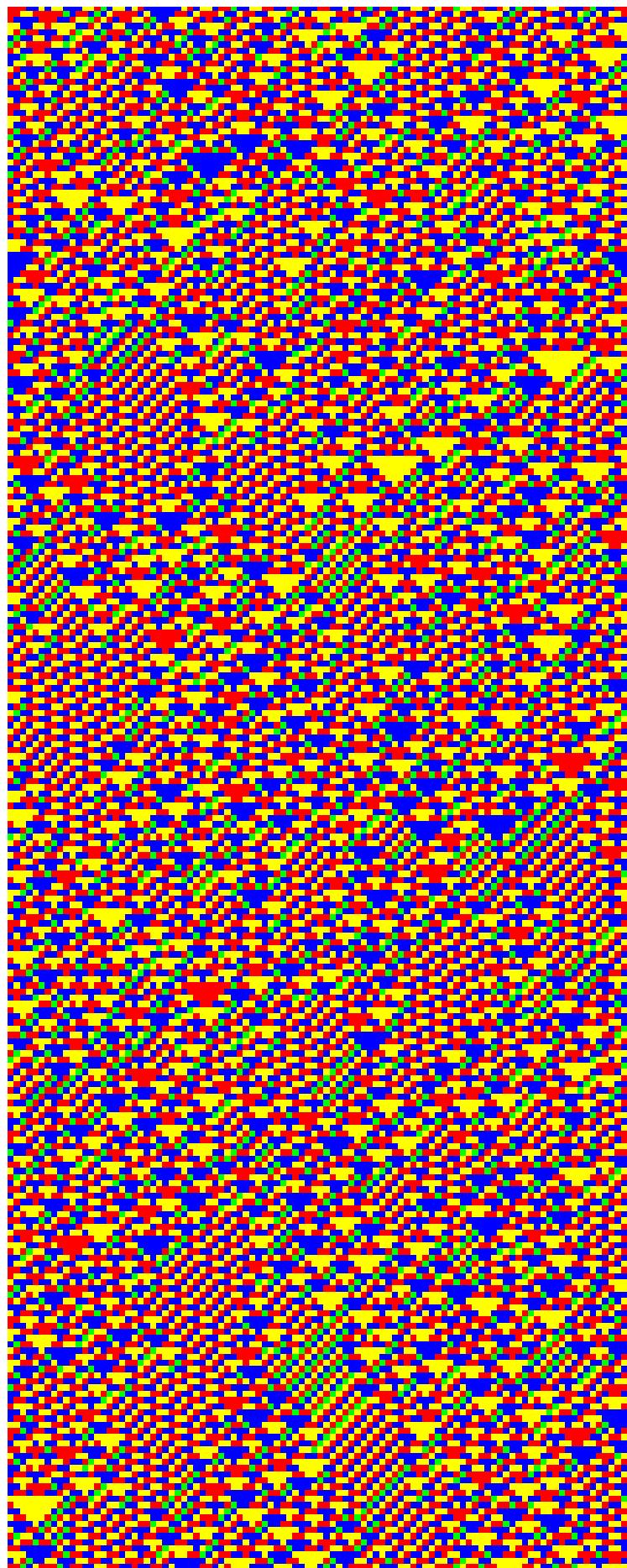


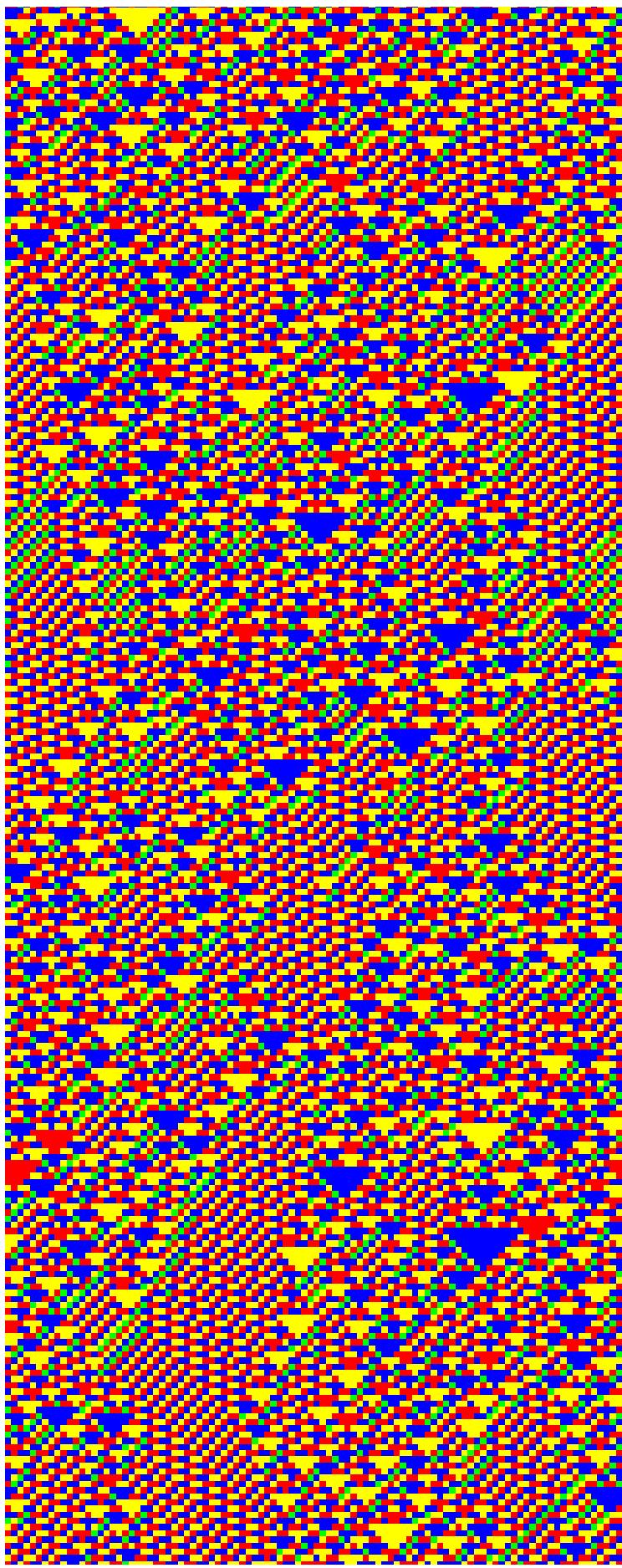


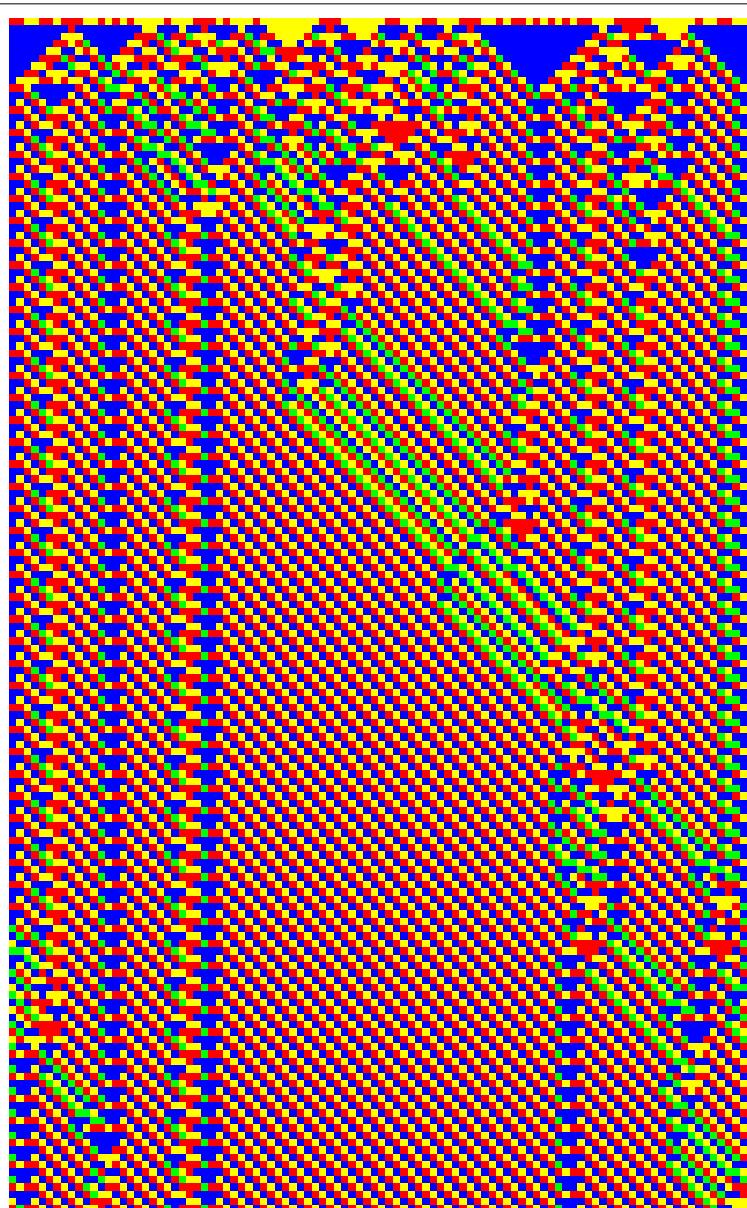
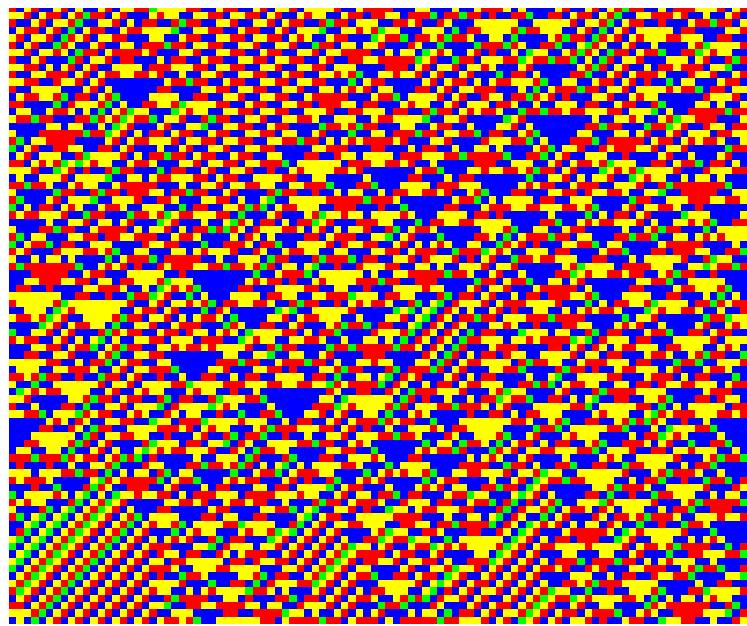


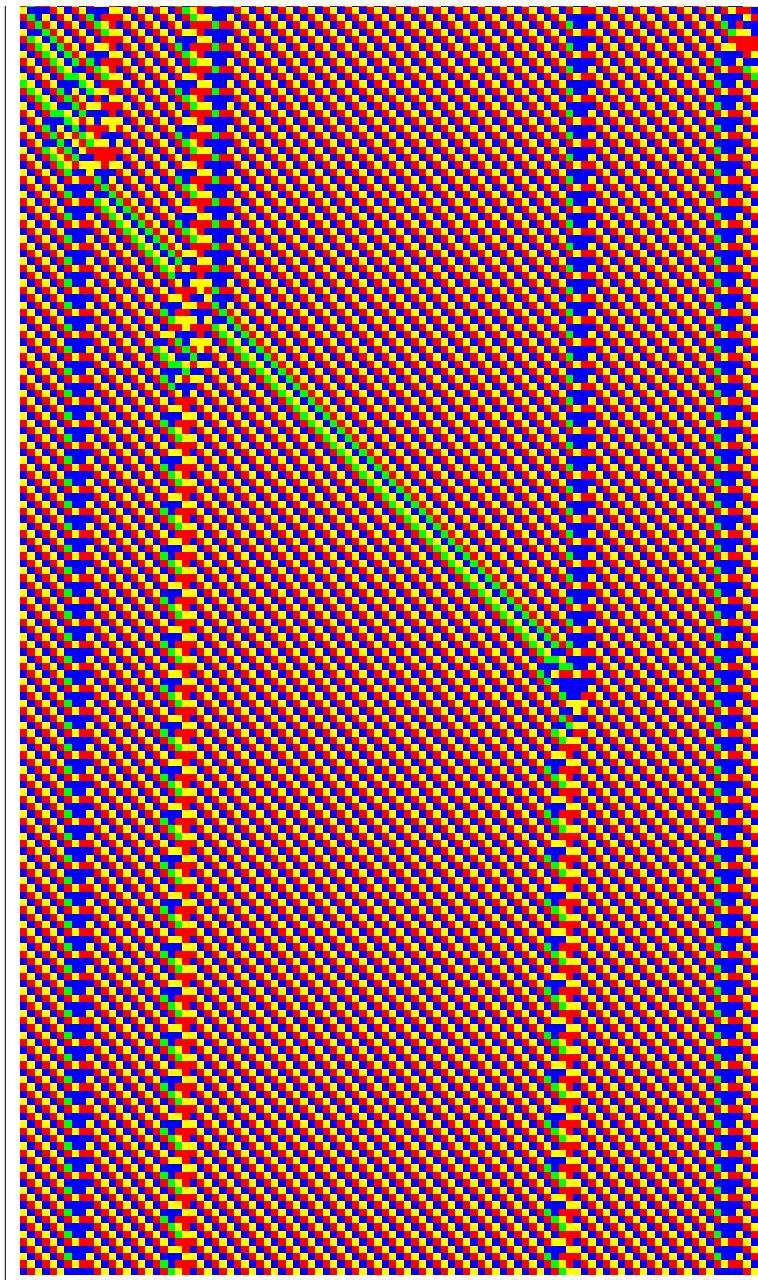




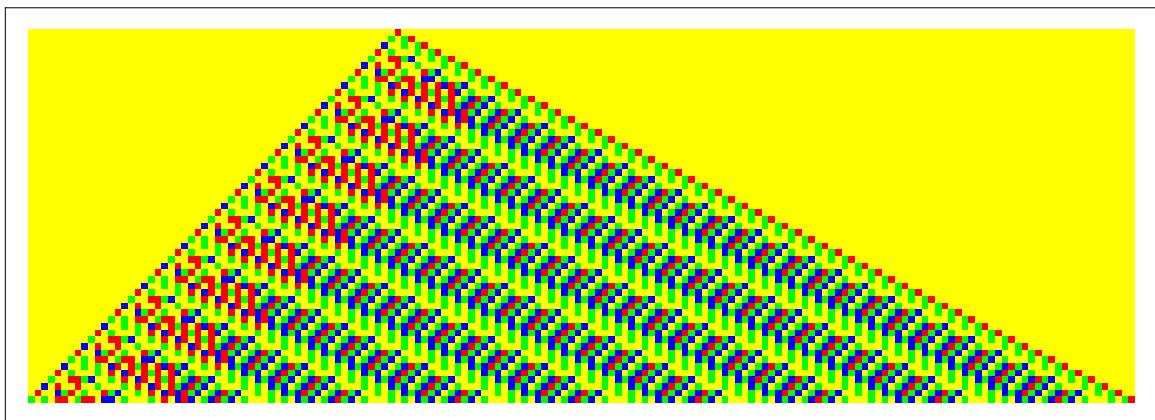
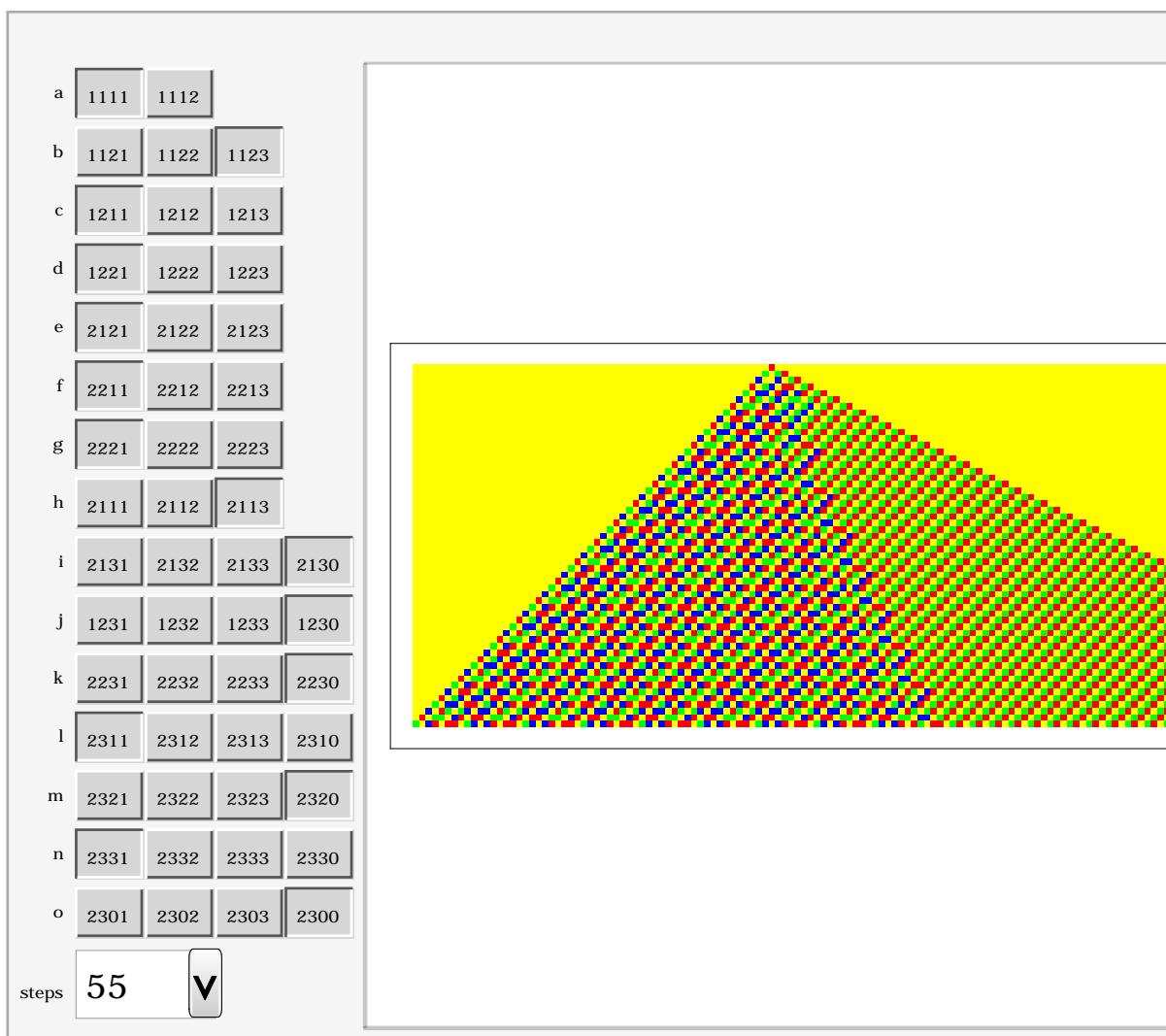


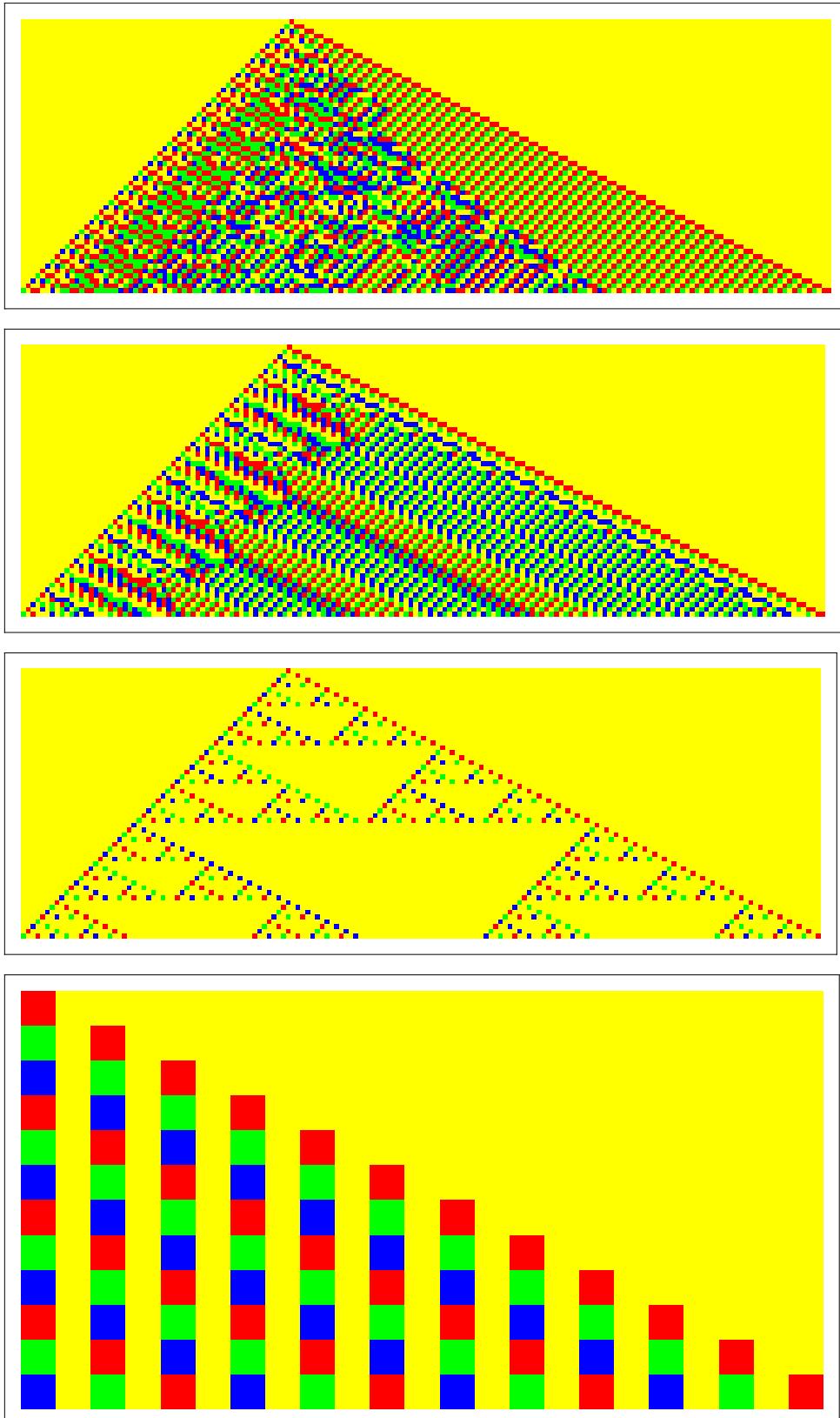


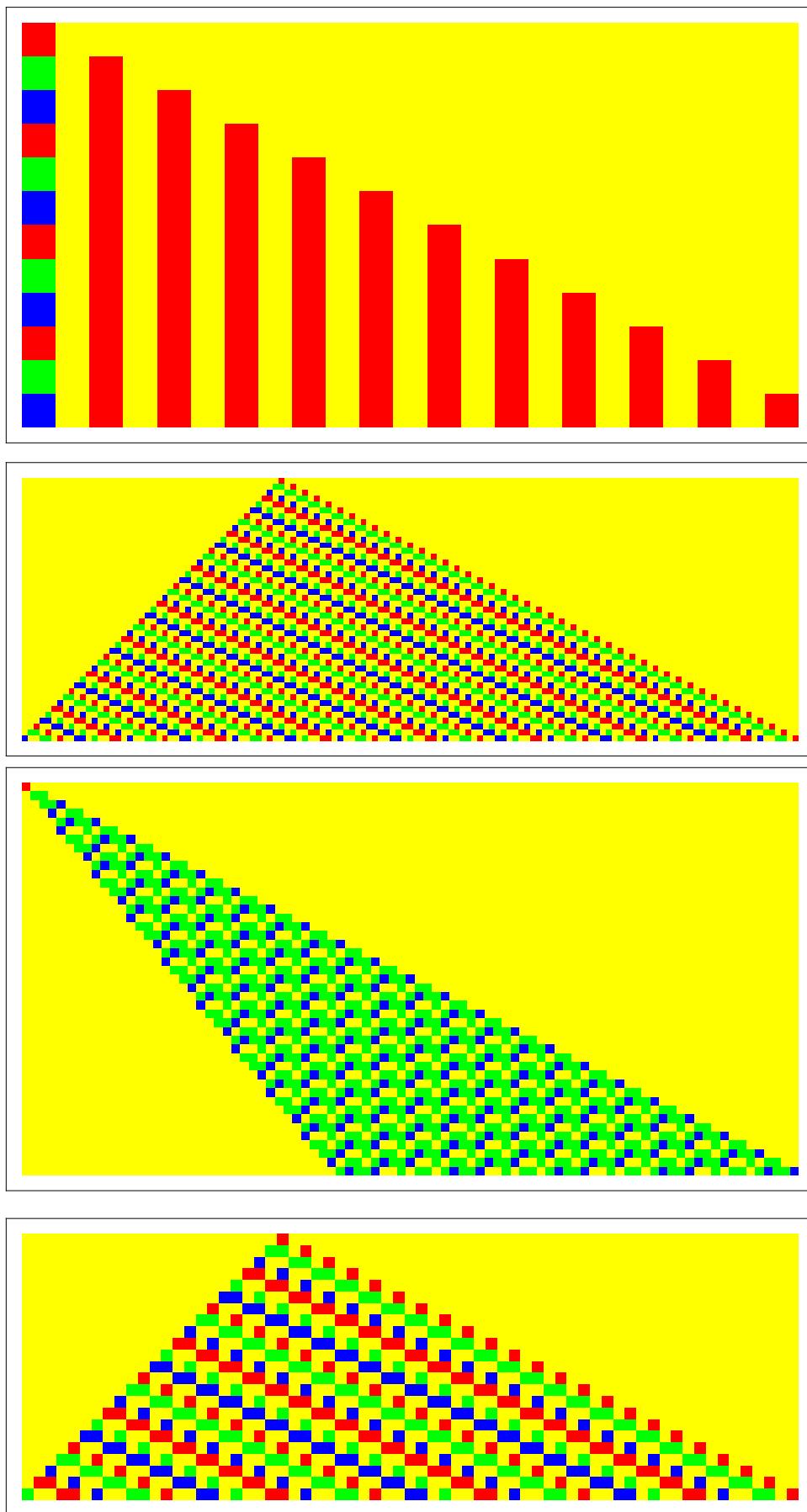


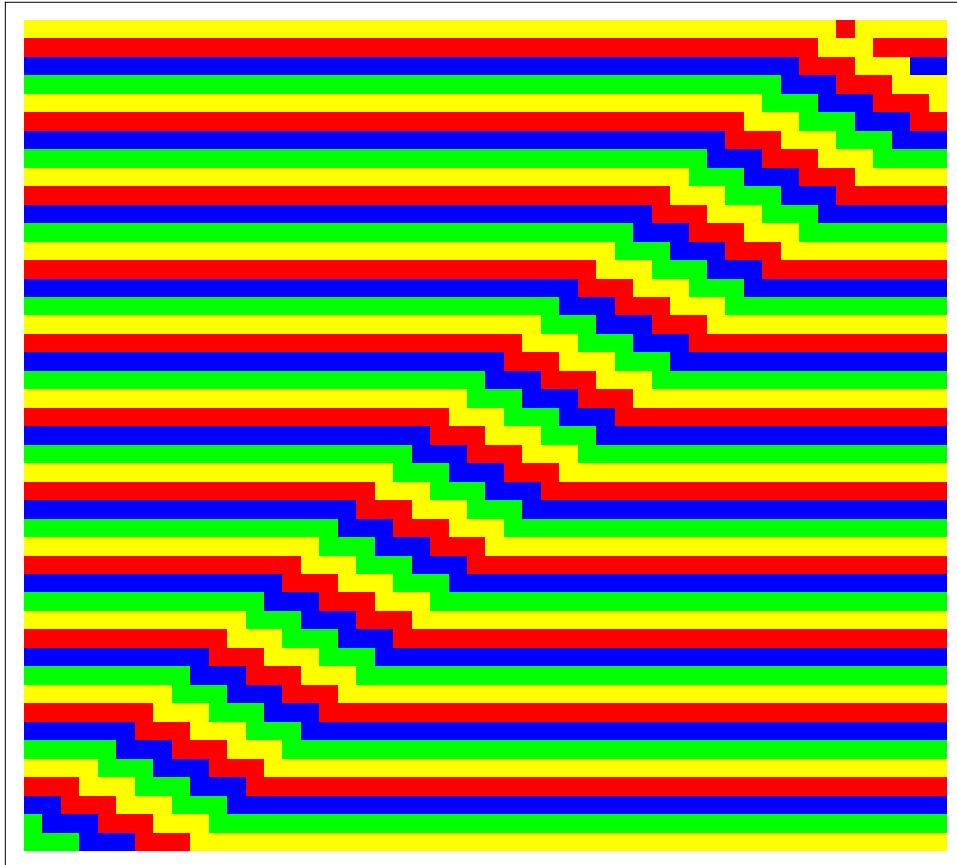
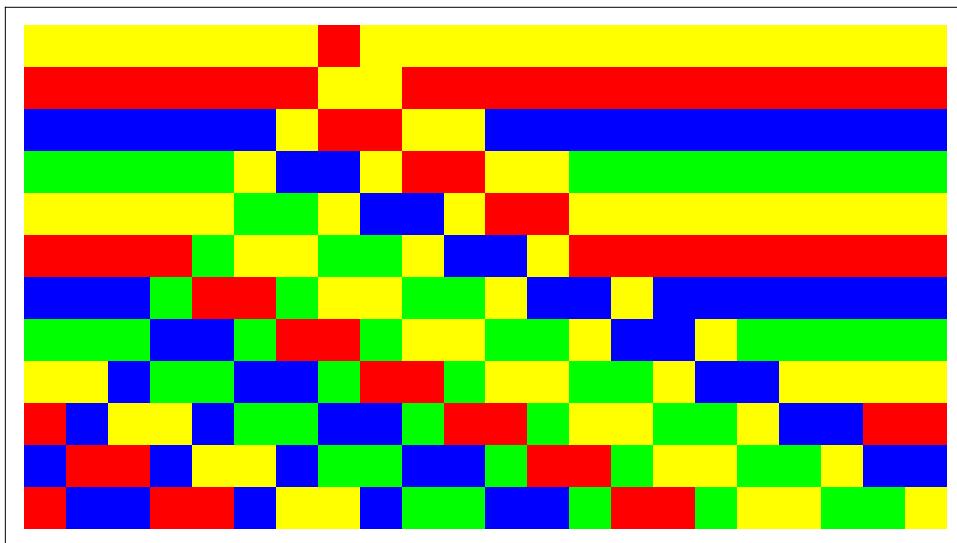
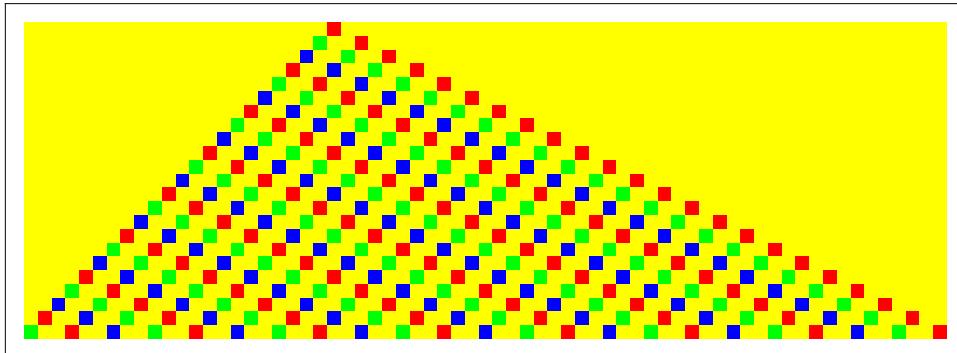


Morphogram: ruleDCKV

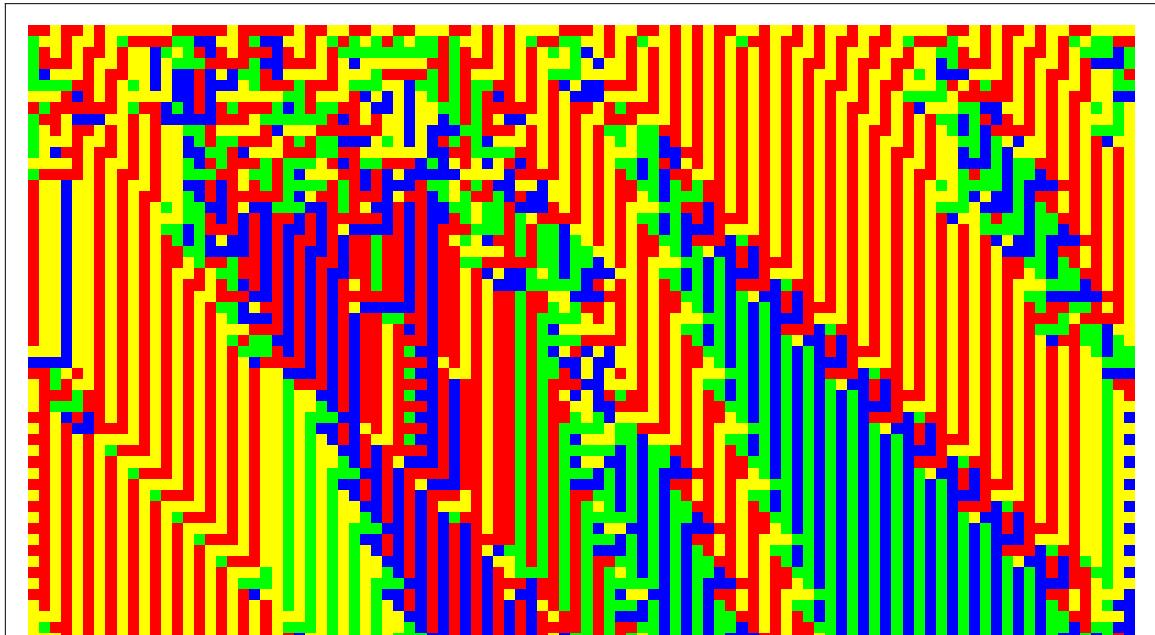
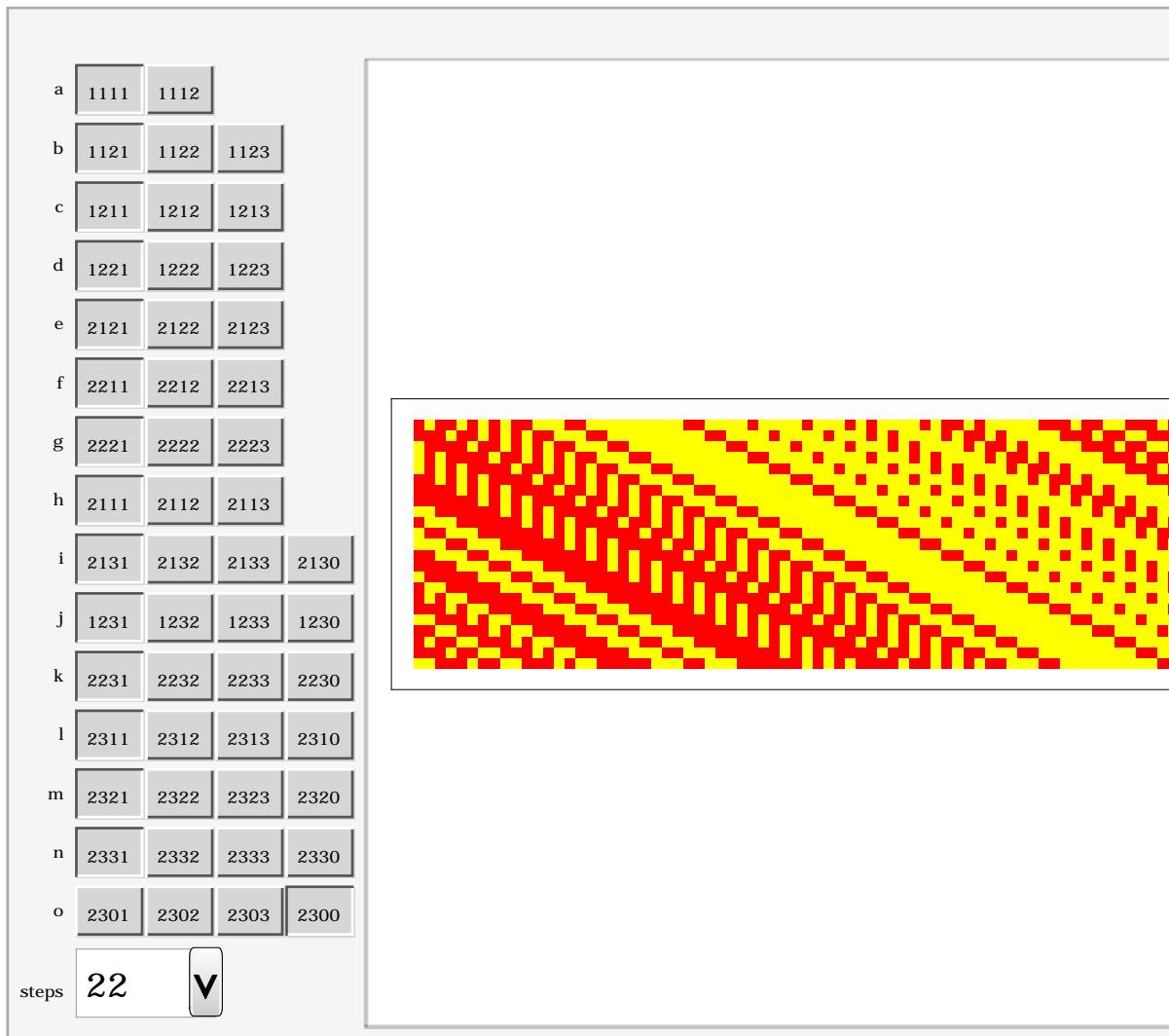




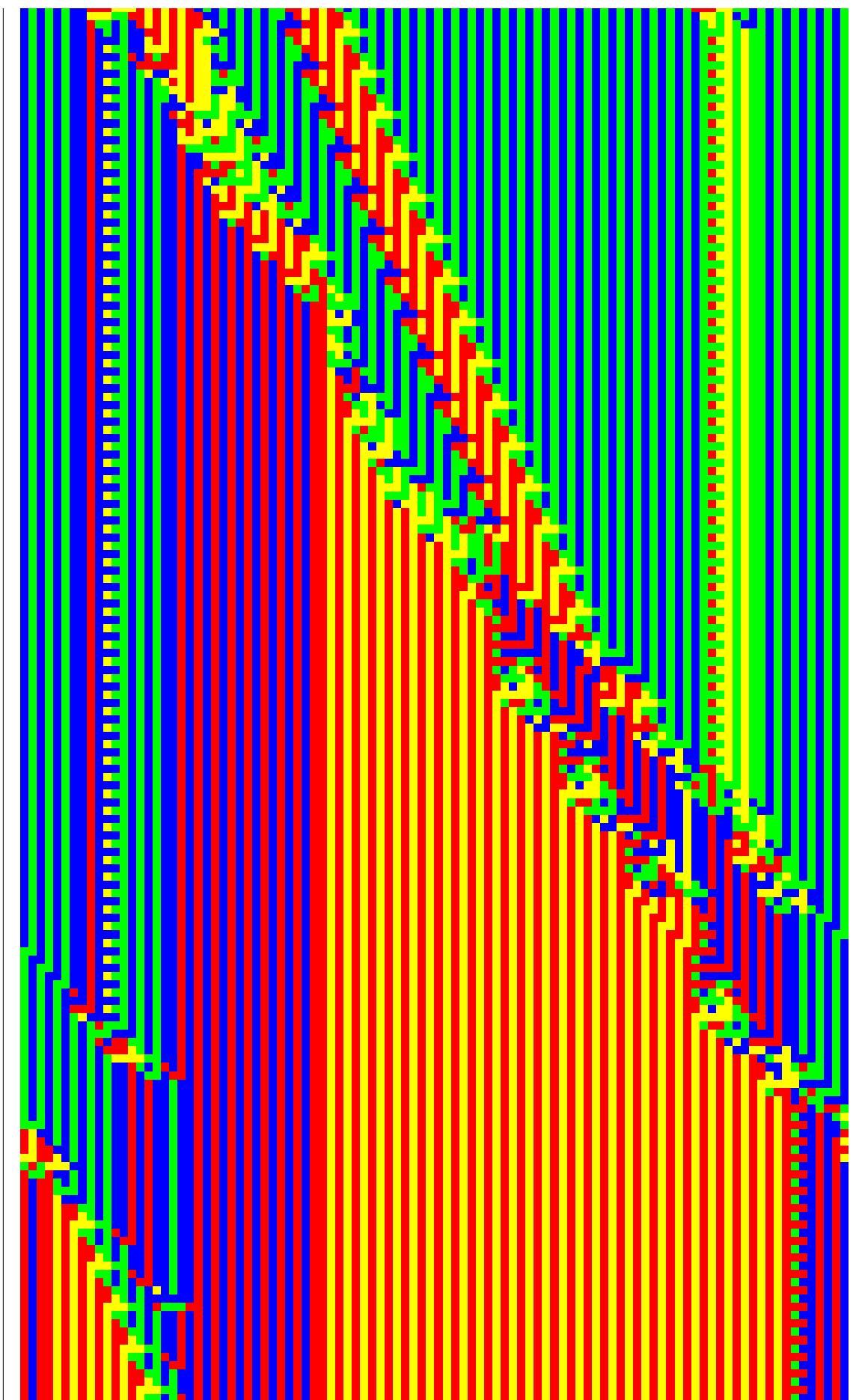


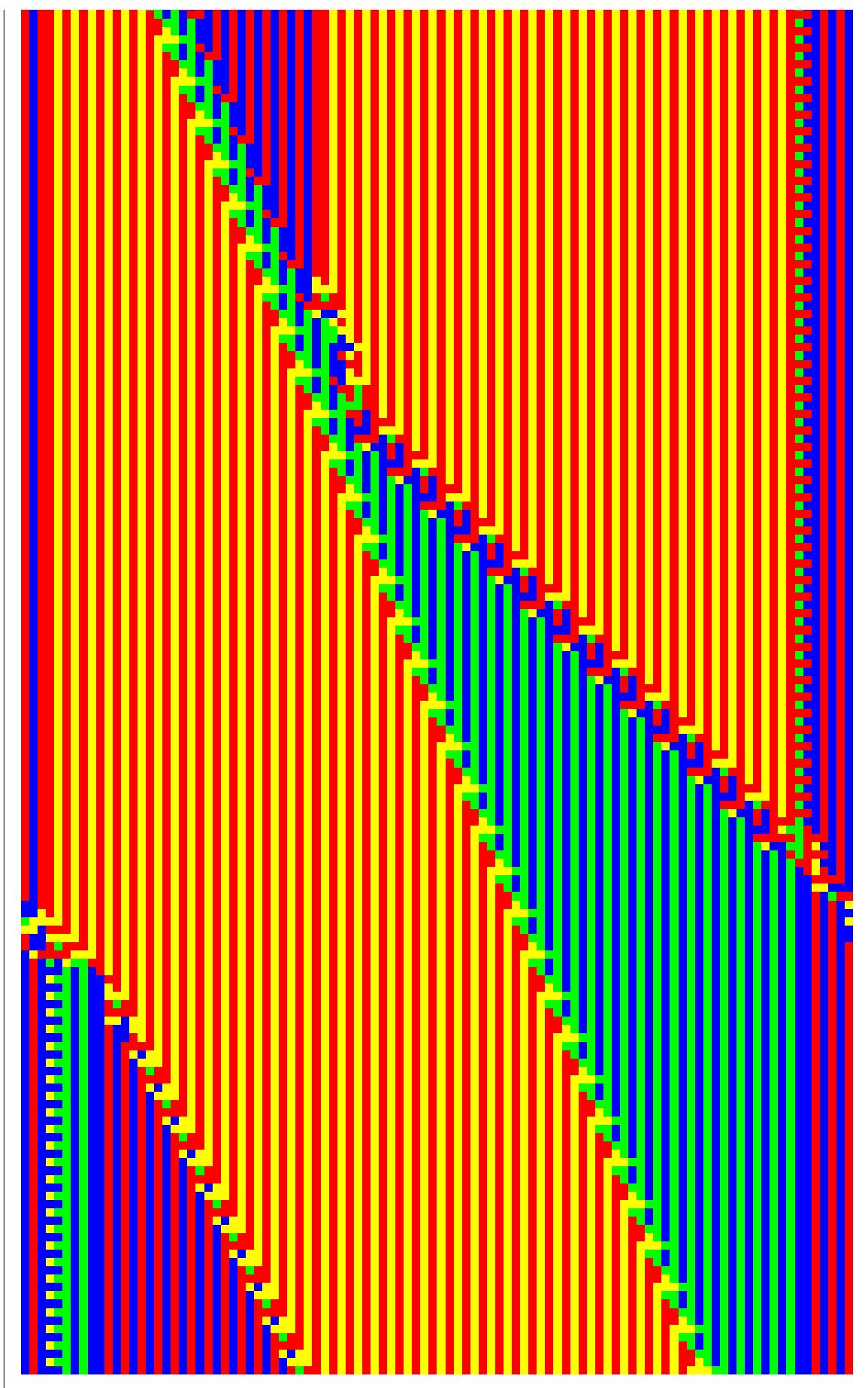


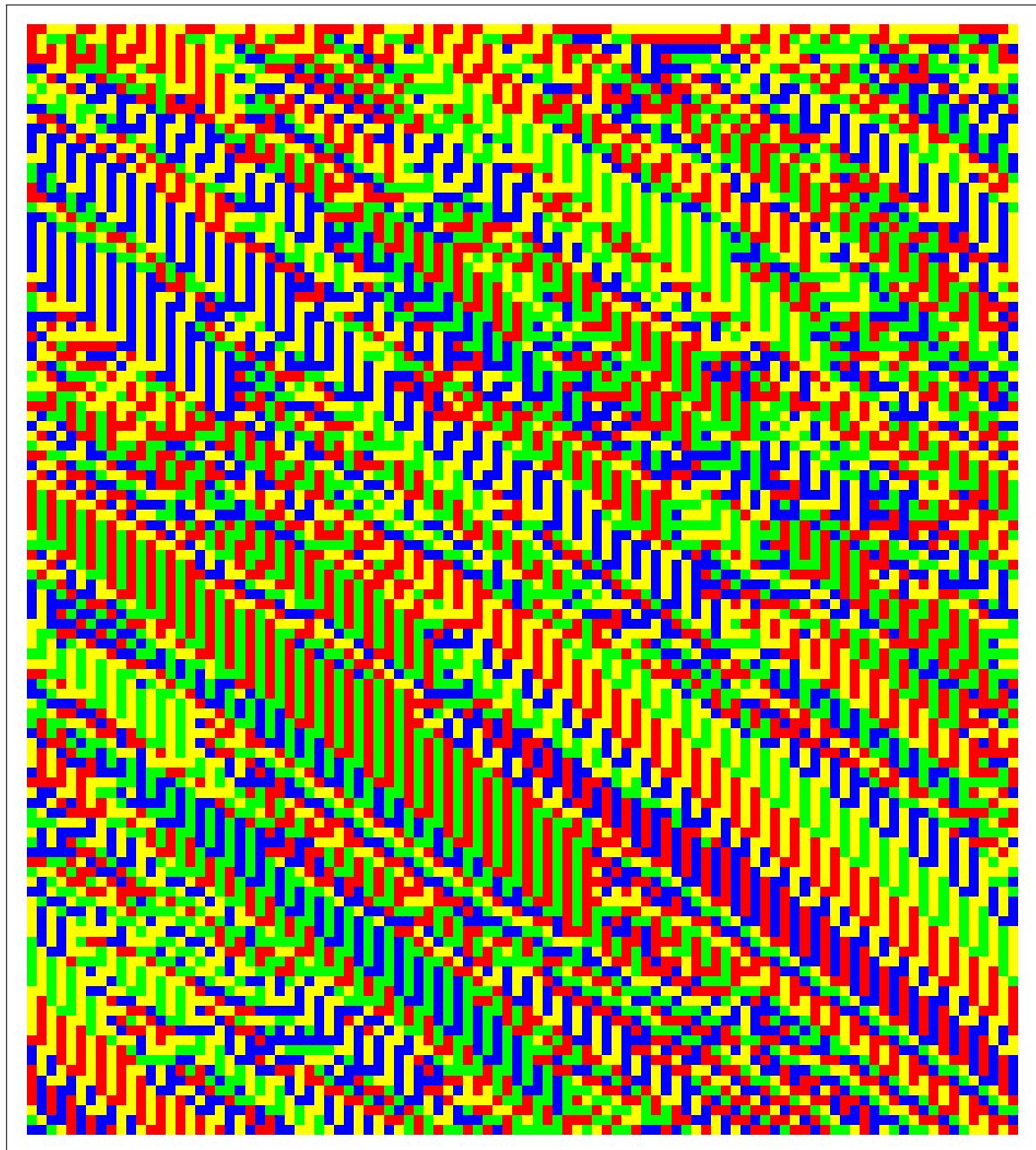
Morphogram: ruleDCKV random



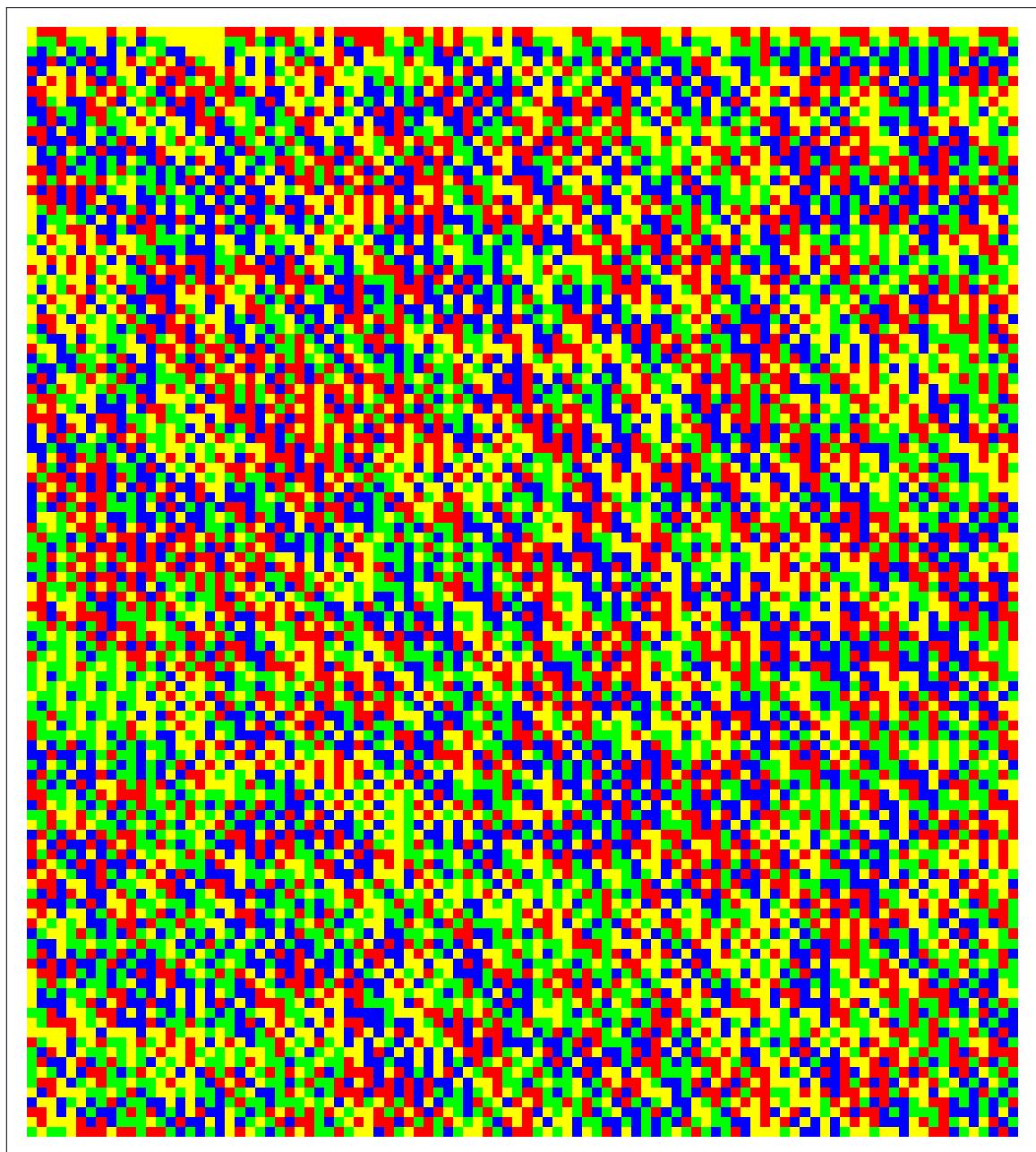




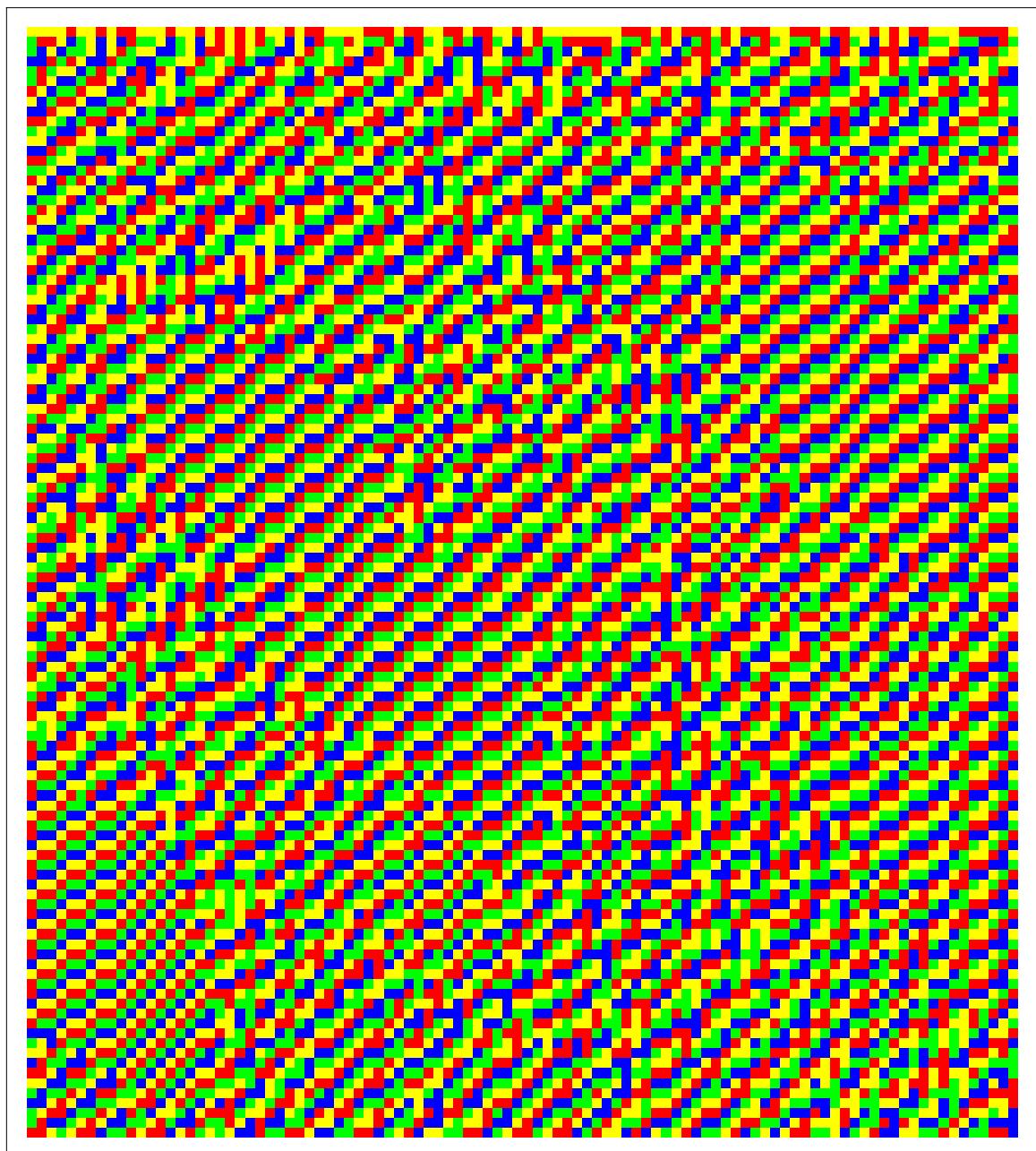


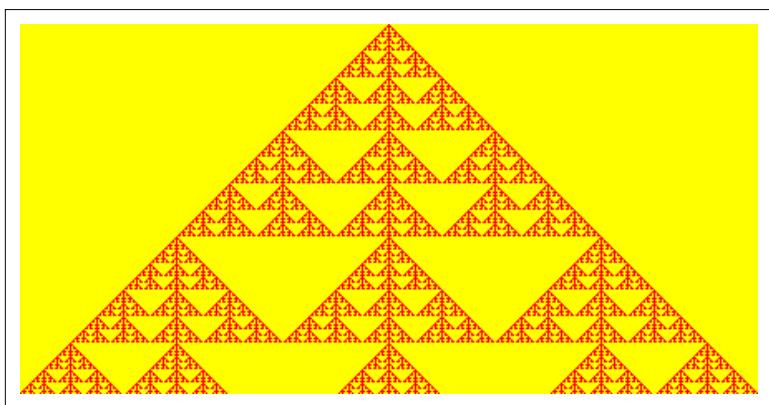
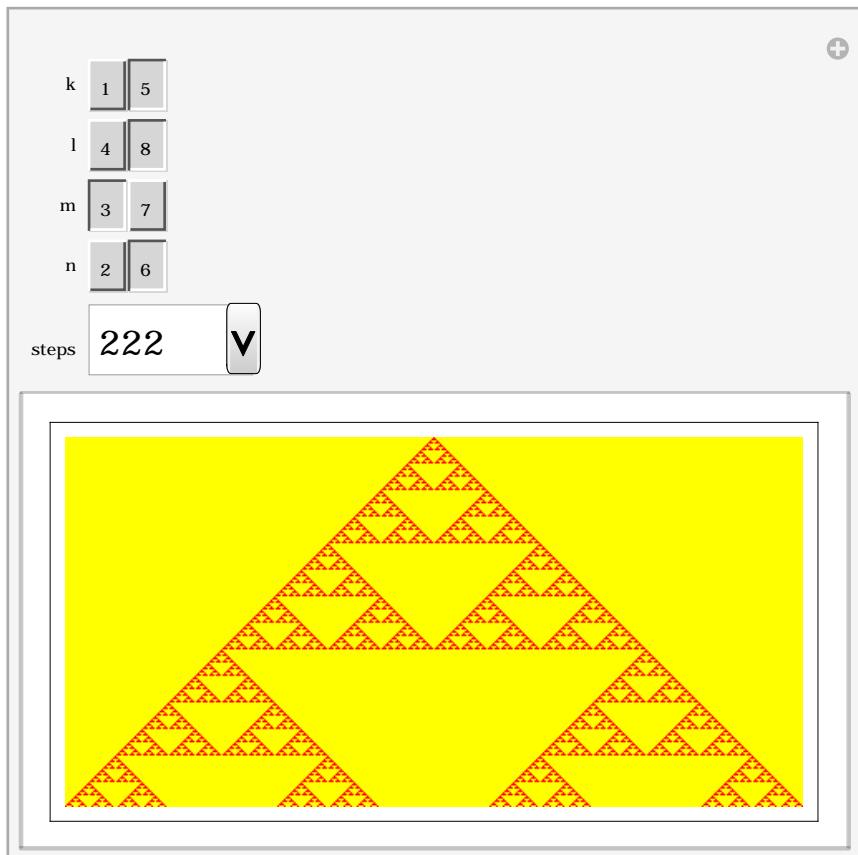


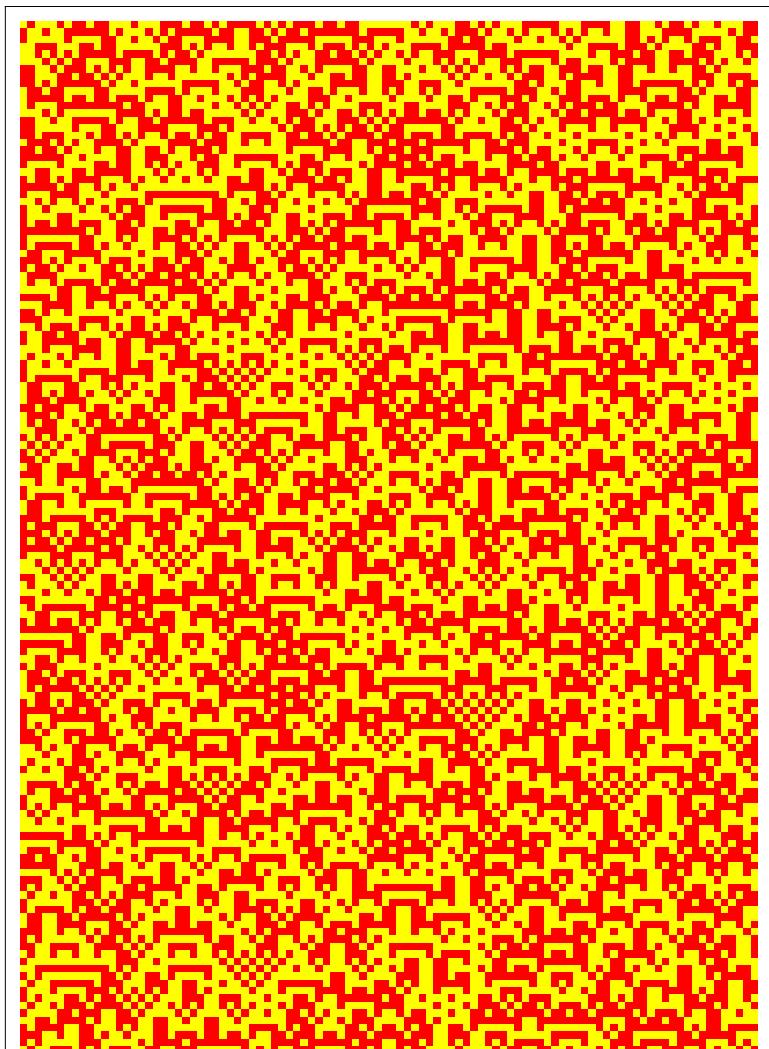
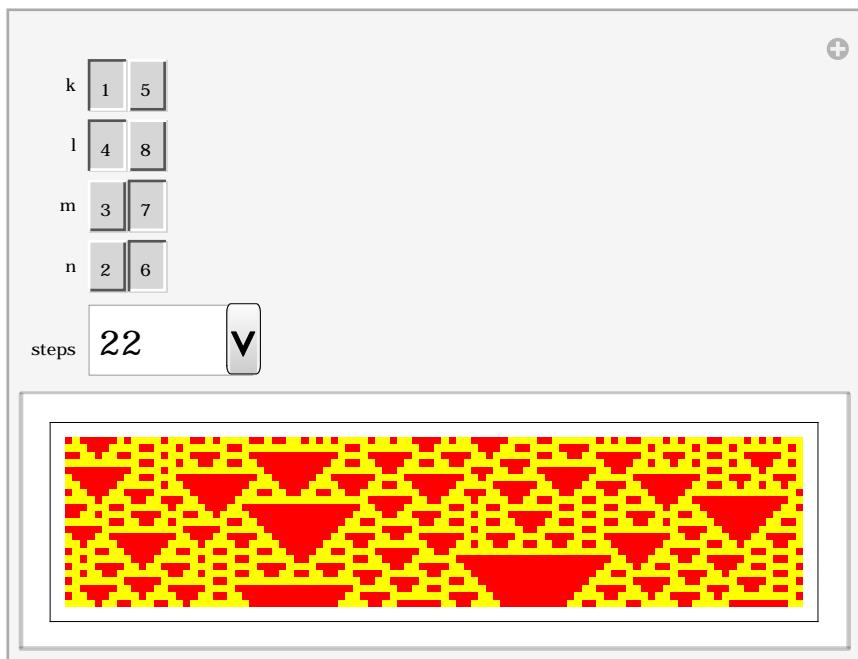


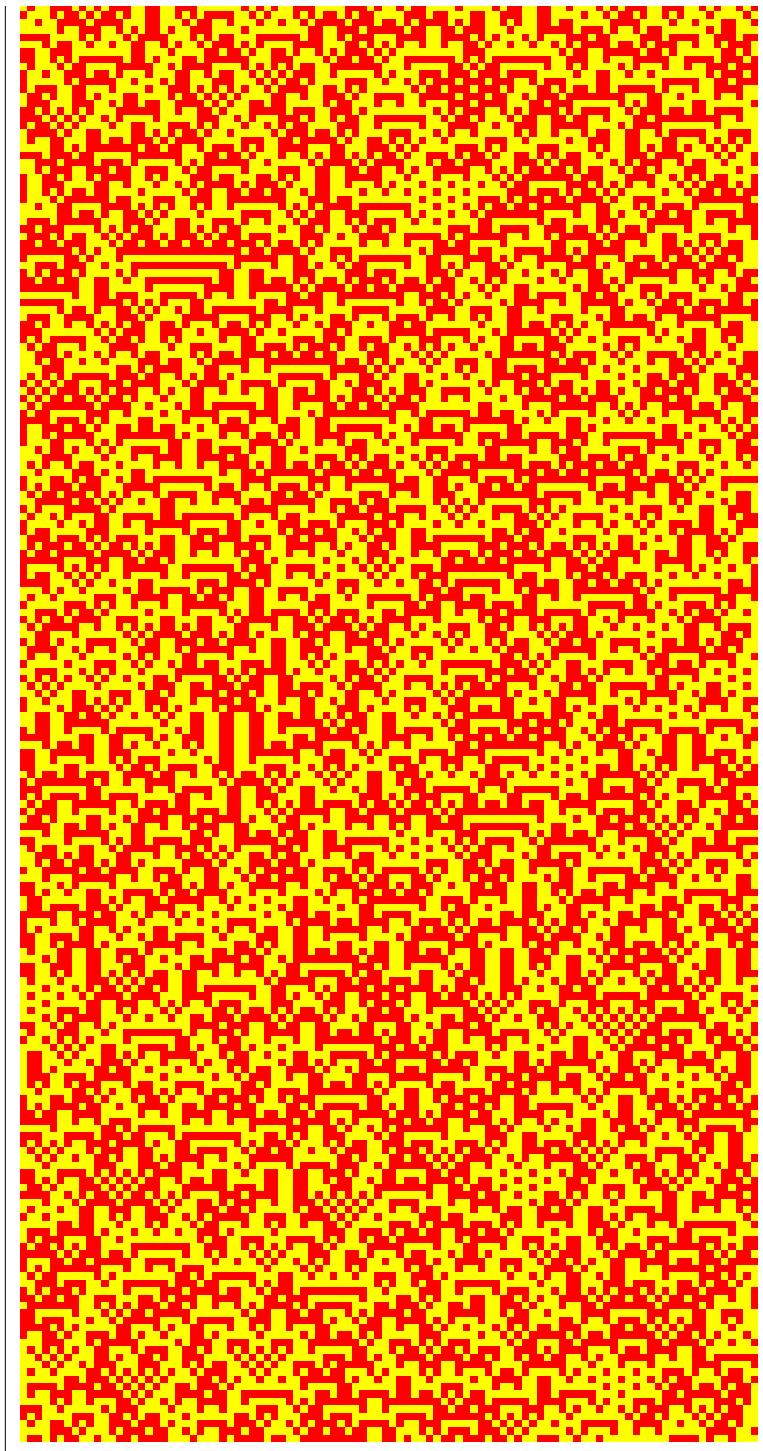




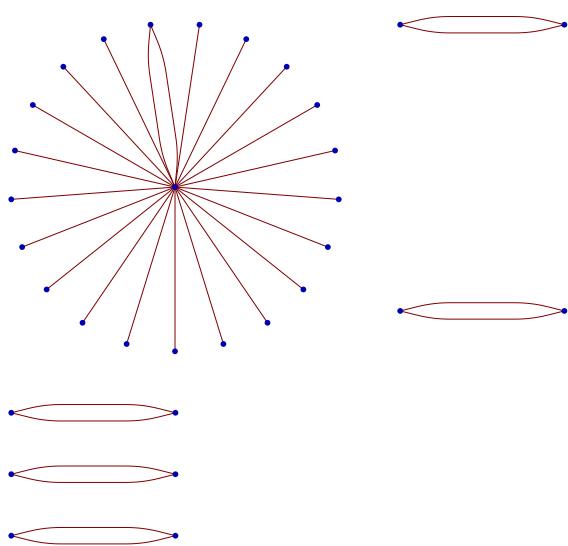
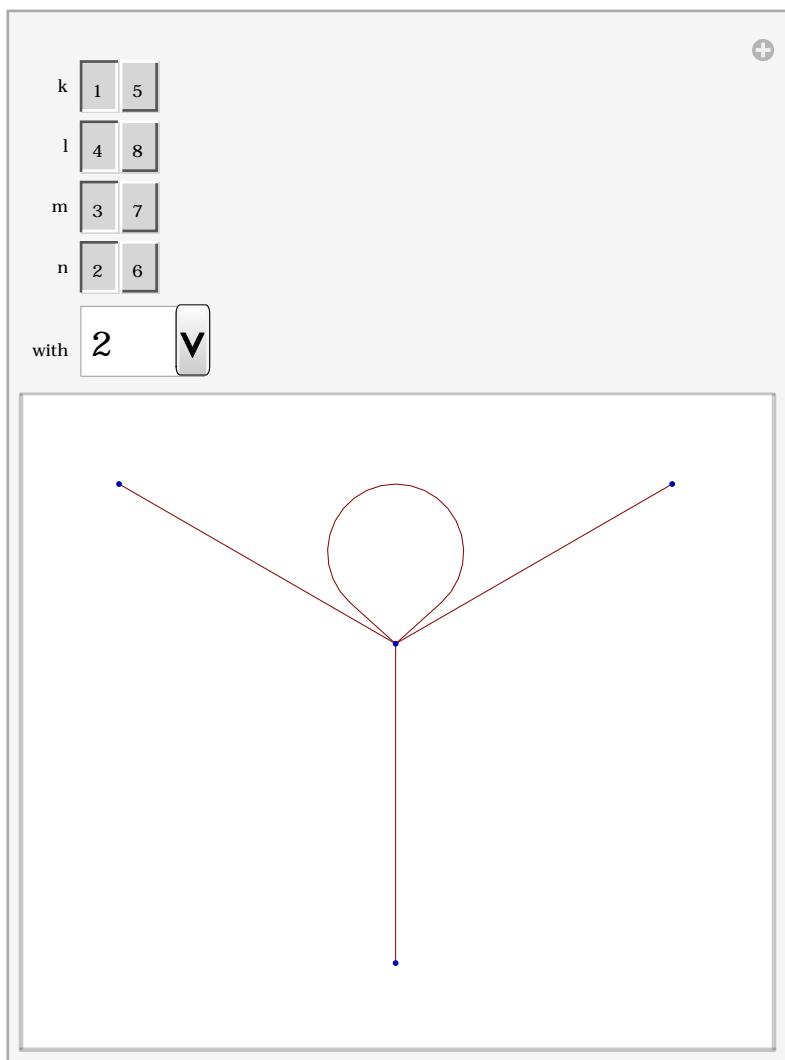


Indication: ruleCI

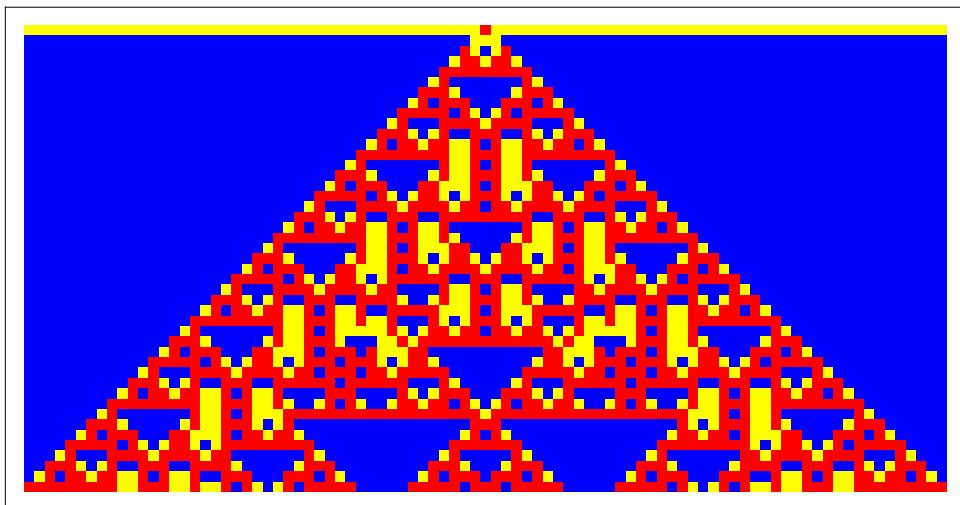
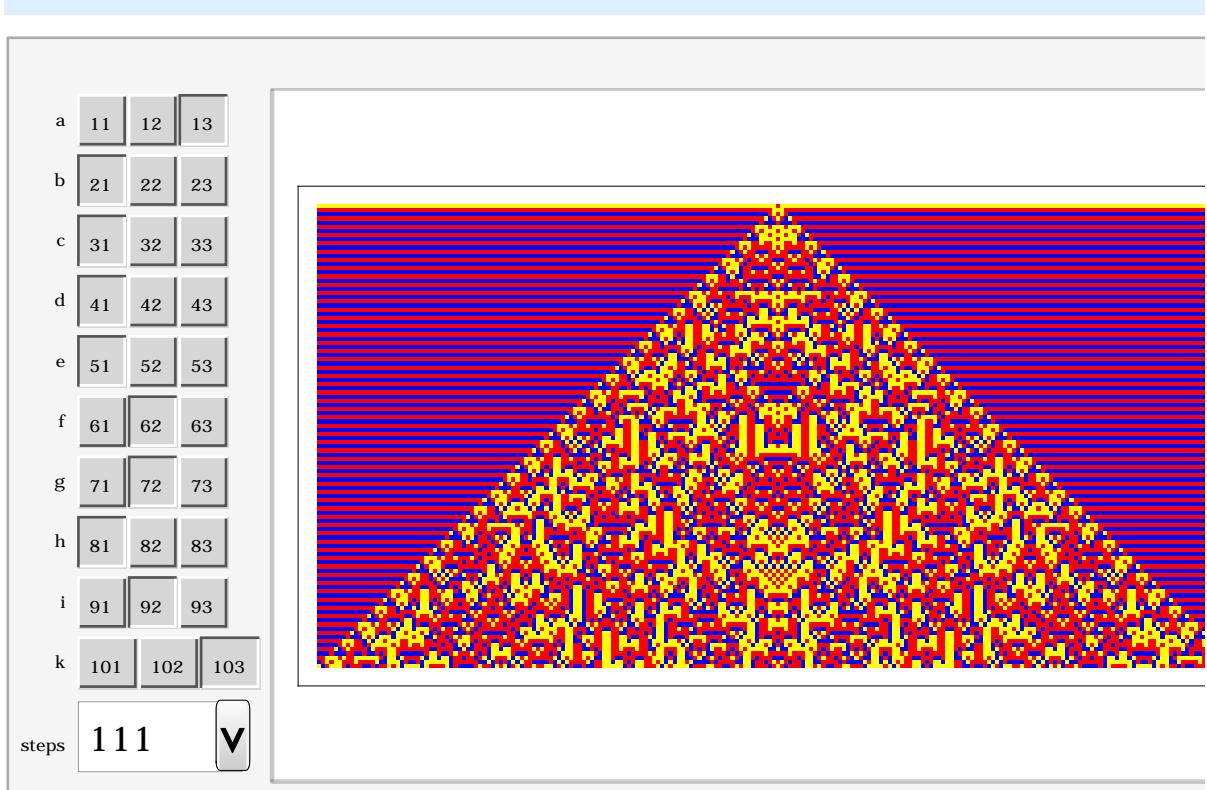
Indication: ruleCI random

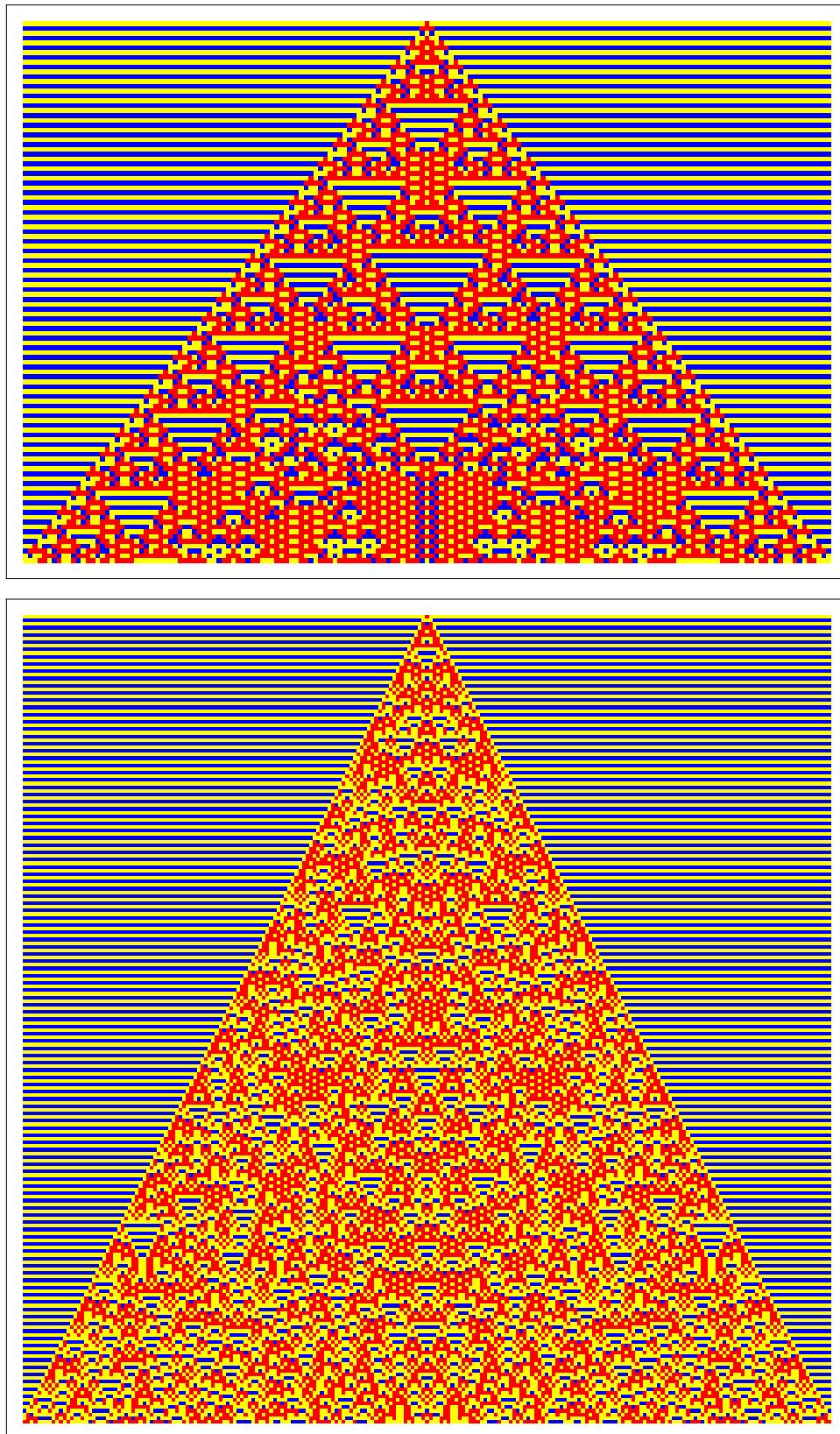


Indication: ruleCI transitions

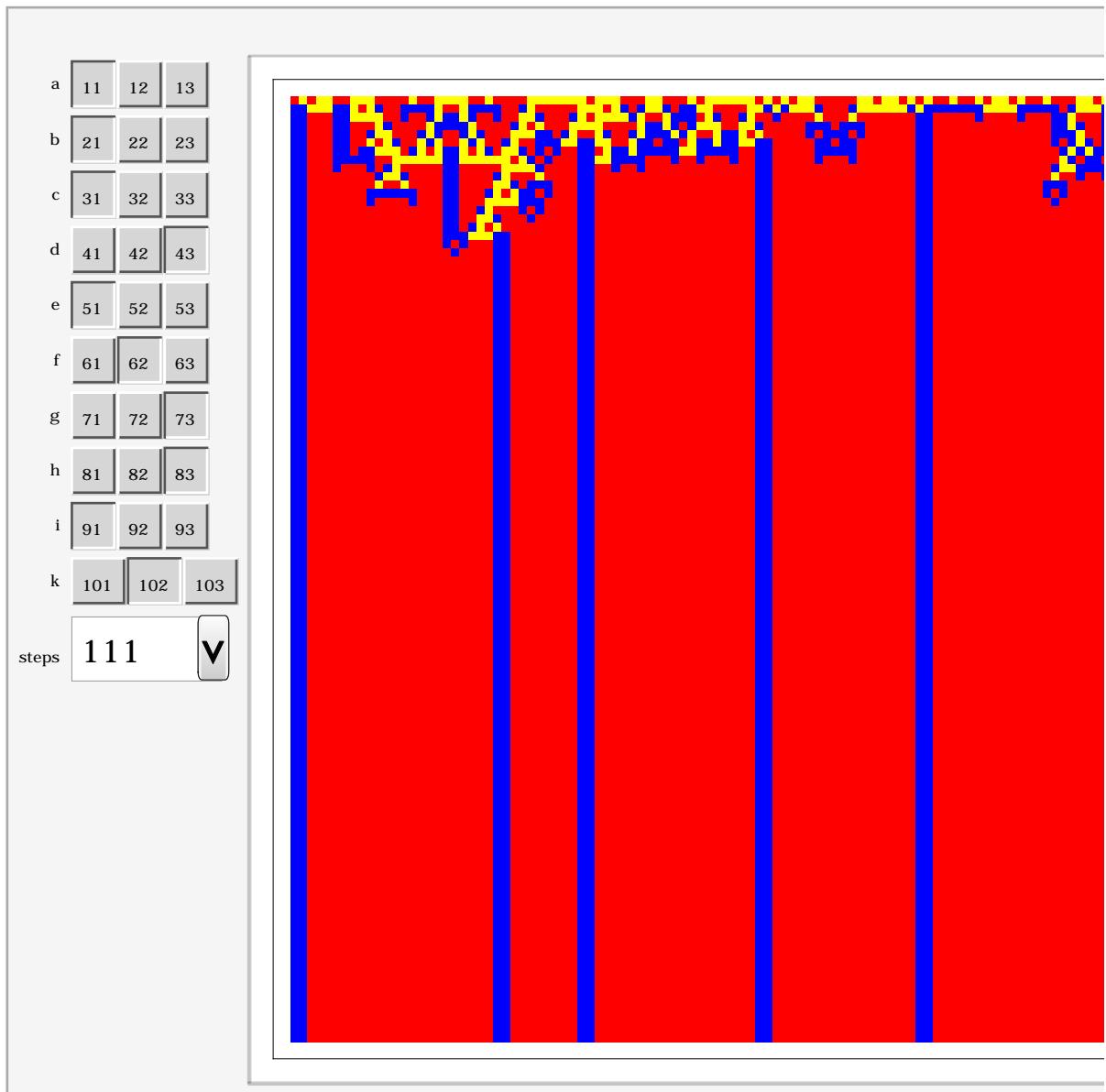


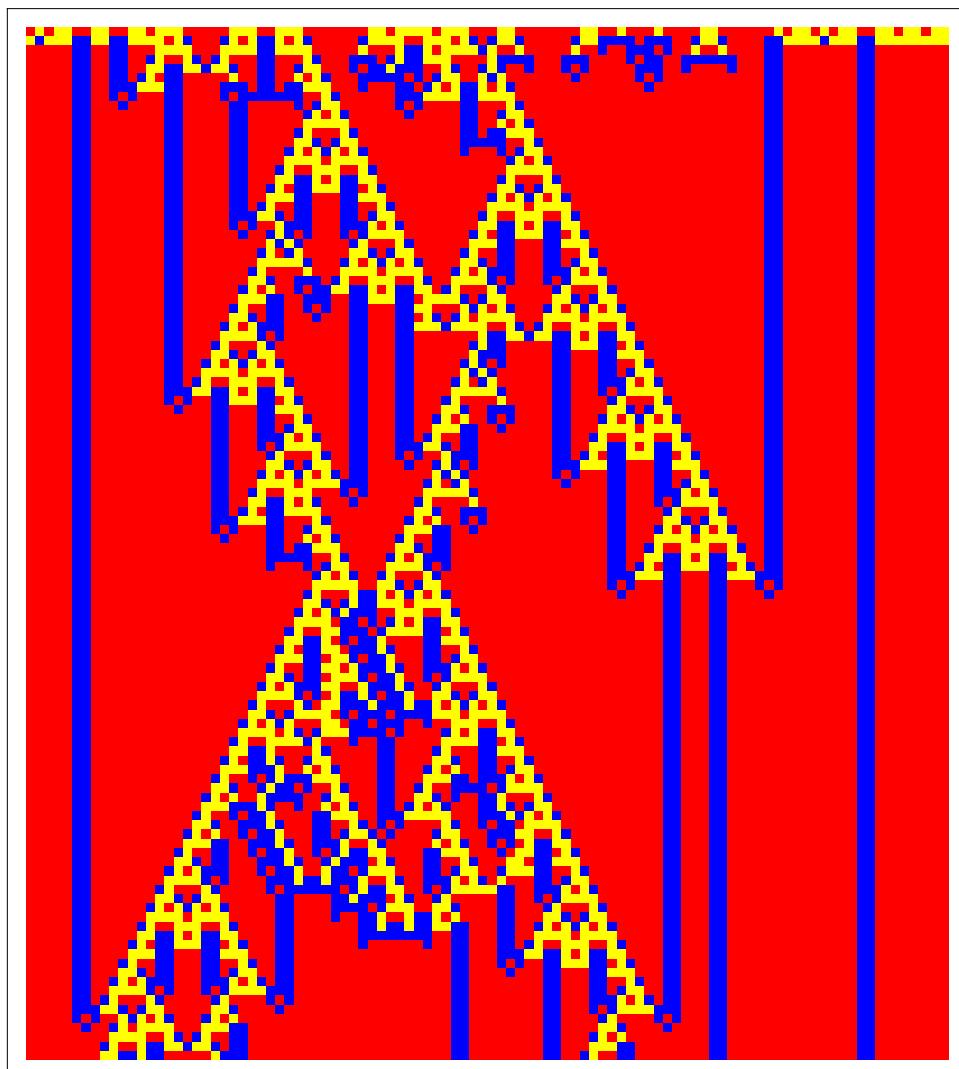
Indication: ruleCIR

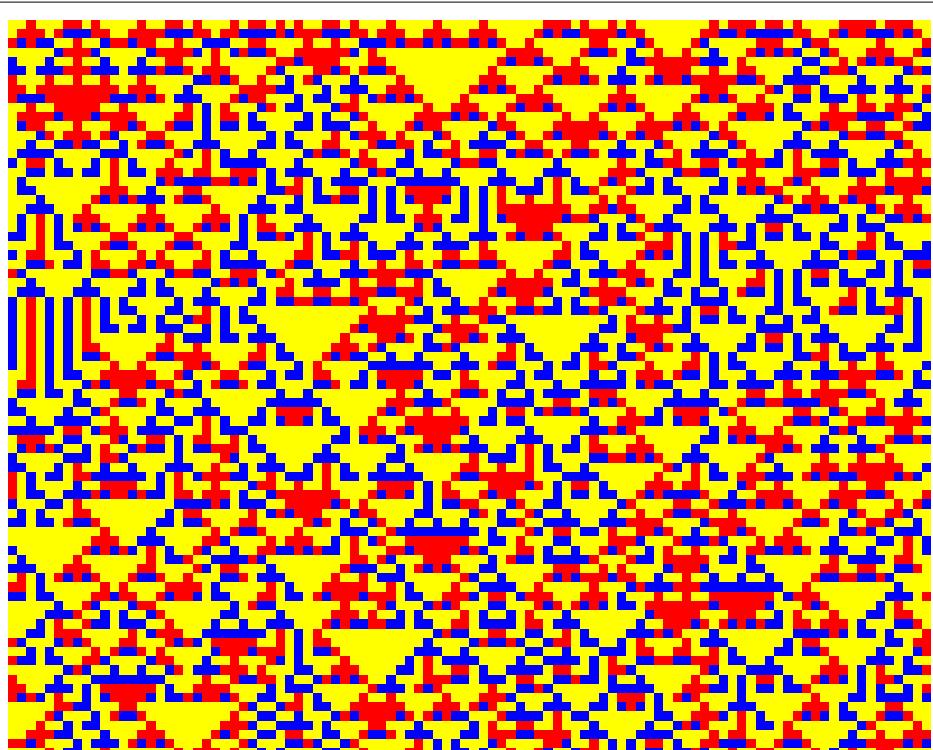
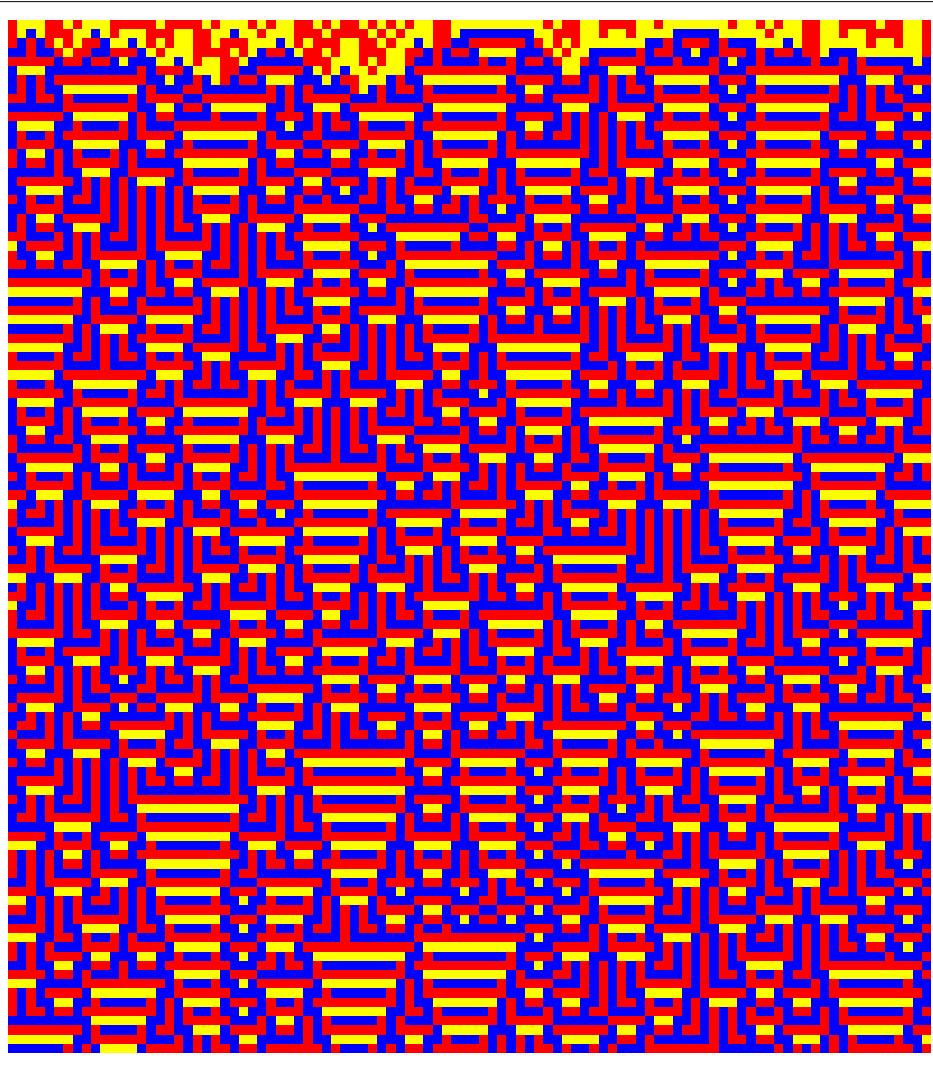


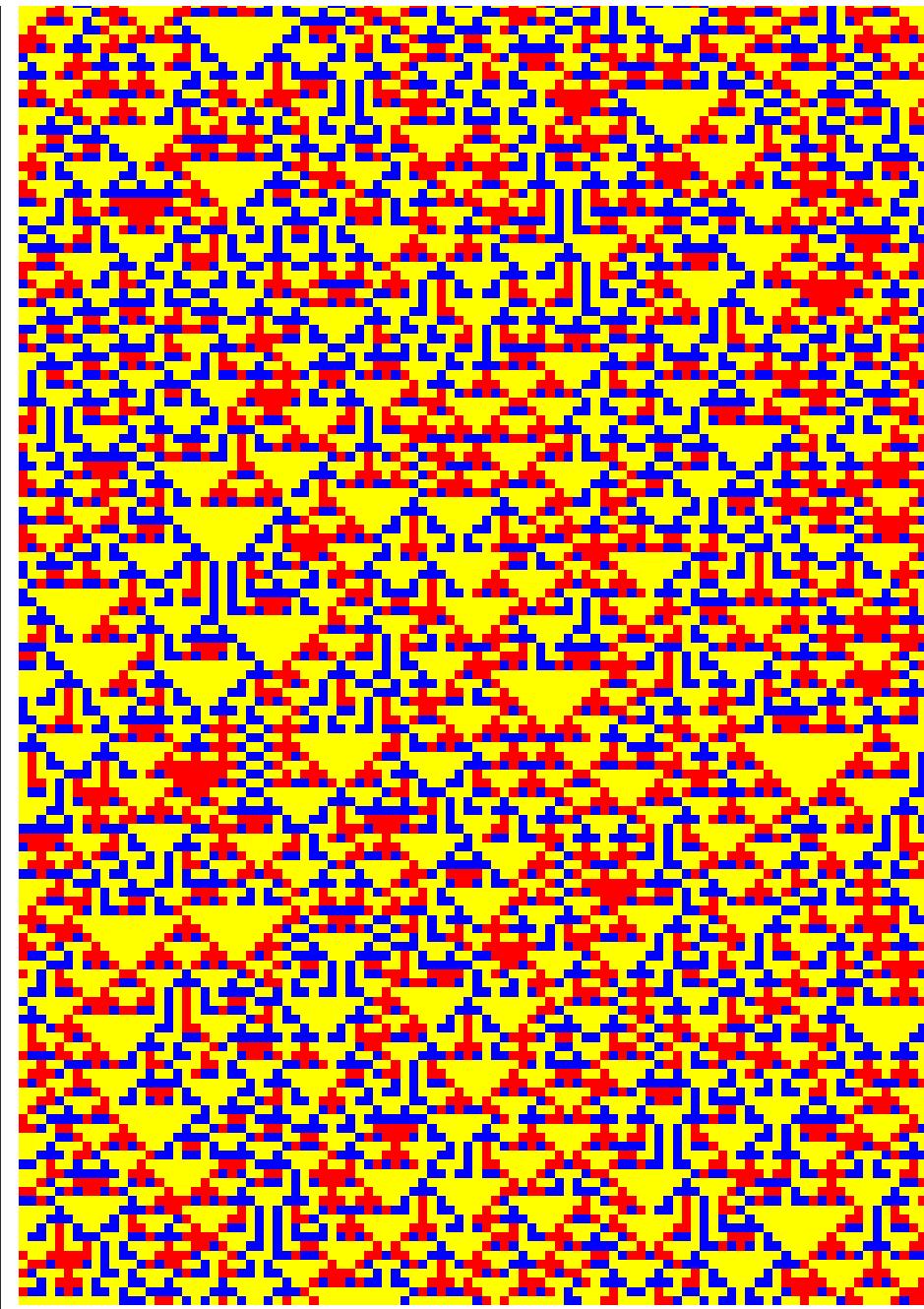


Indication: ruleCIR Random

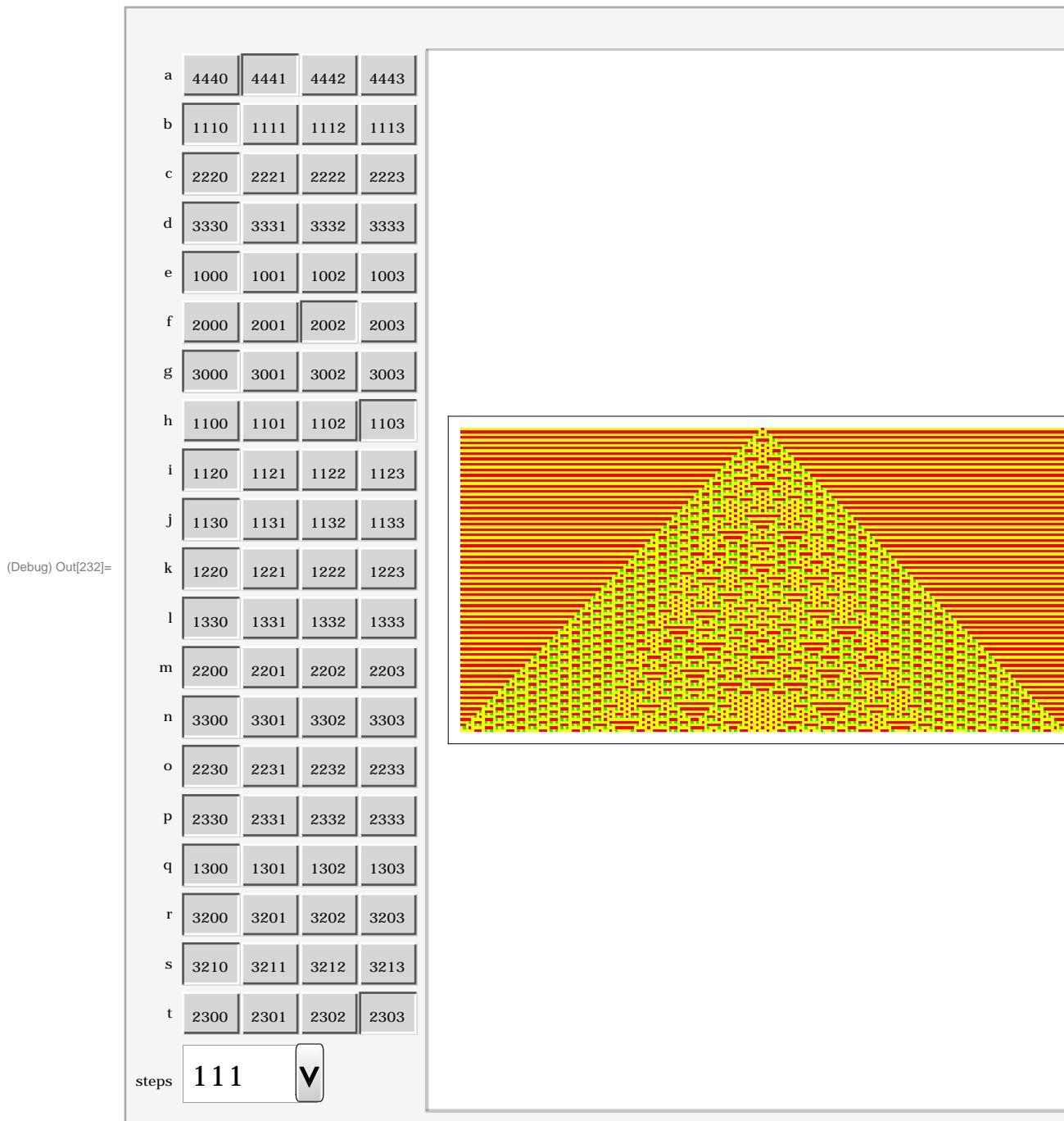


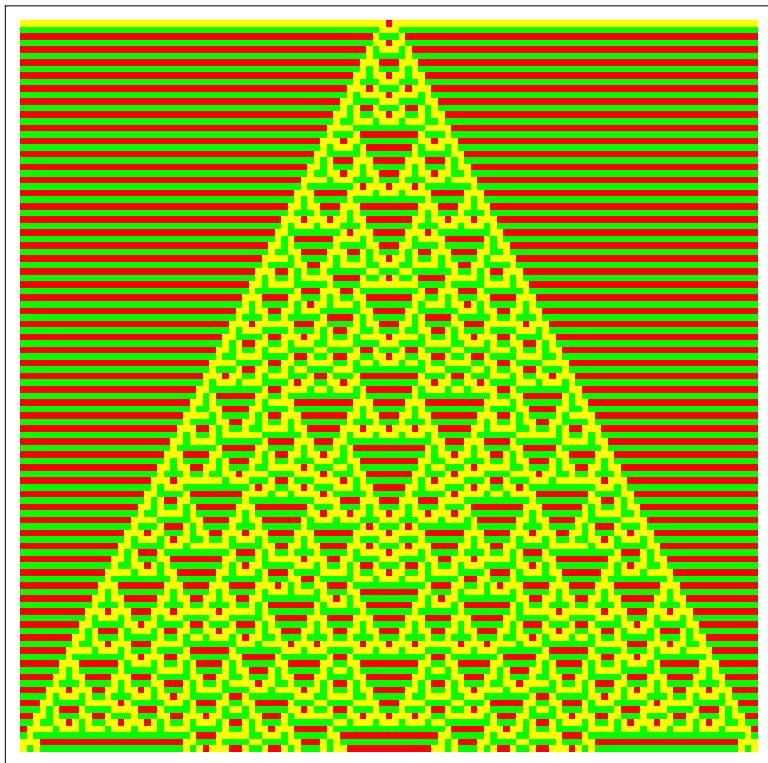
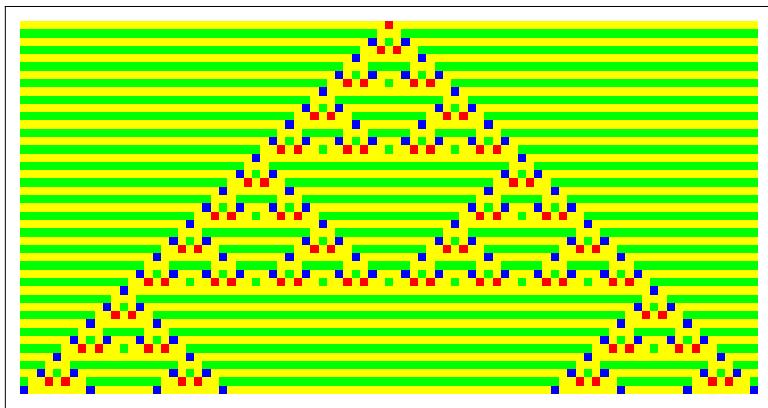


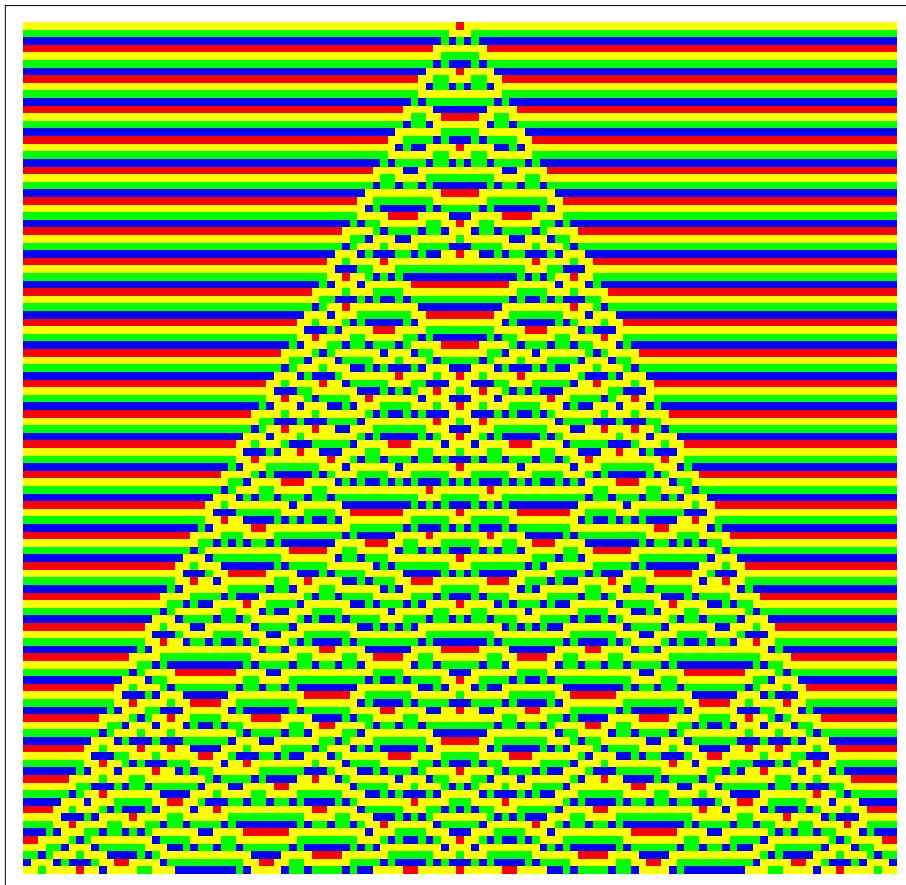
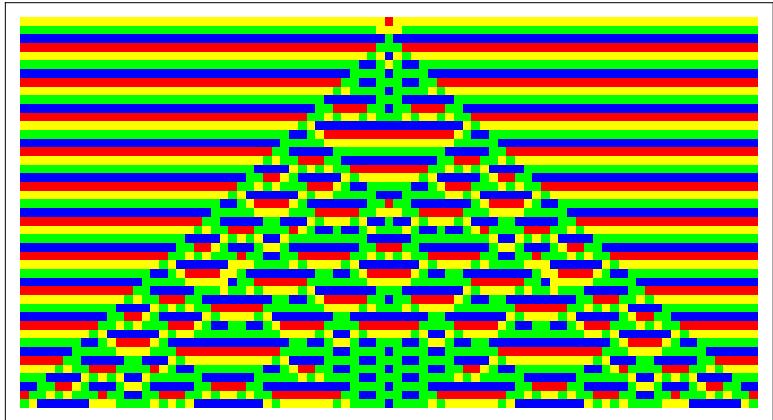


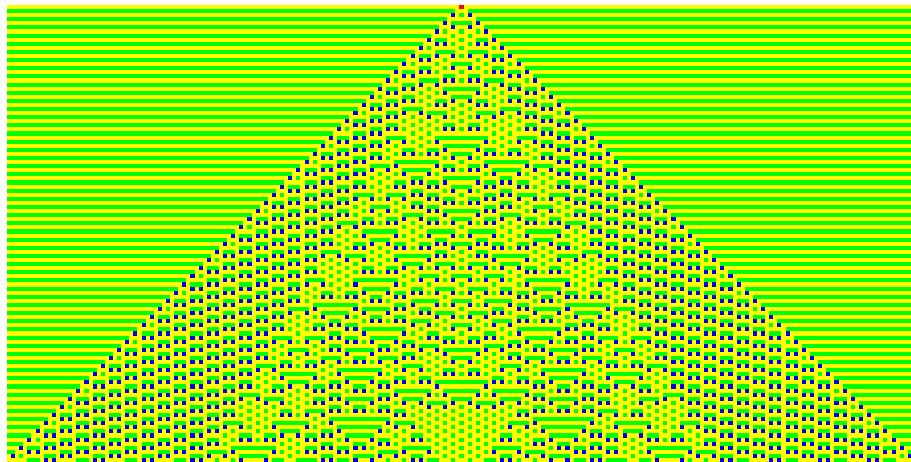


Indication: ruleRCI



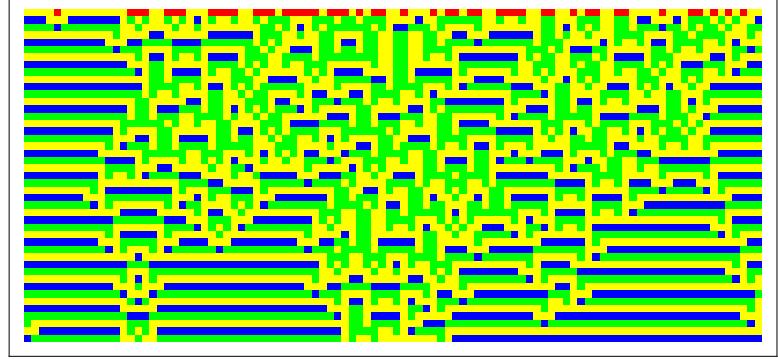


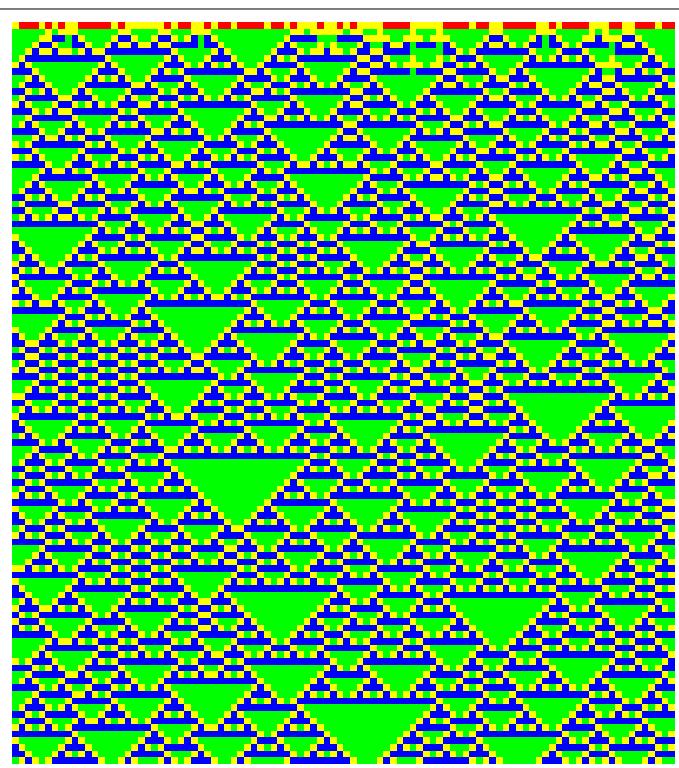
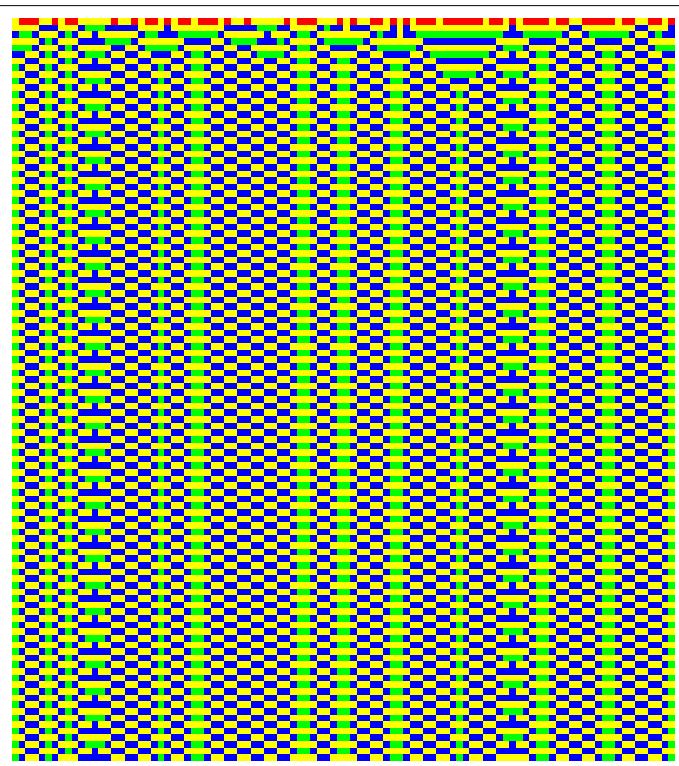


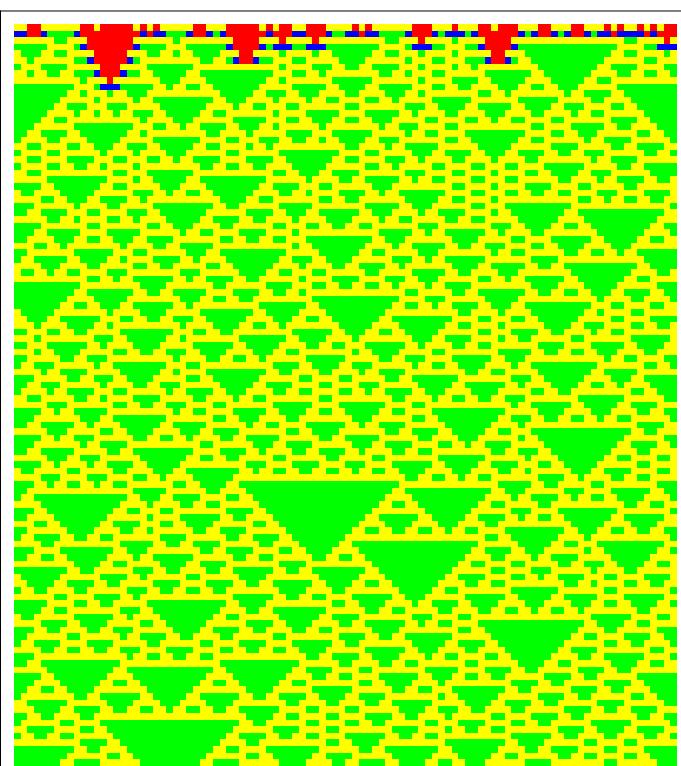
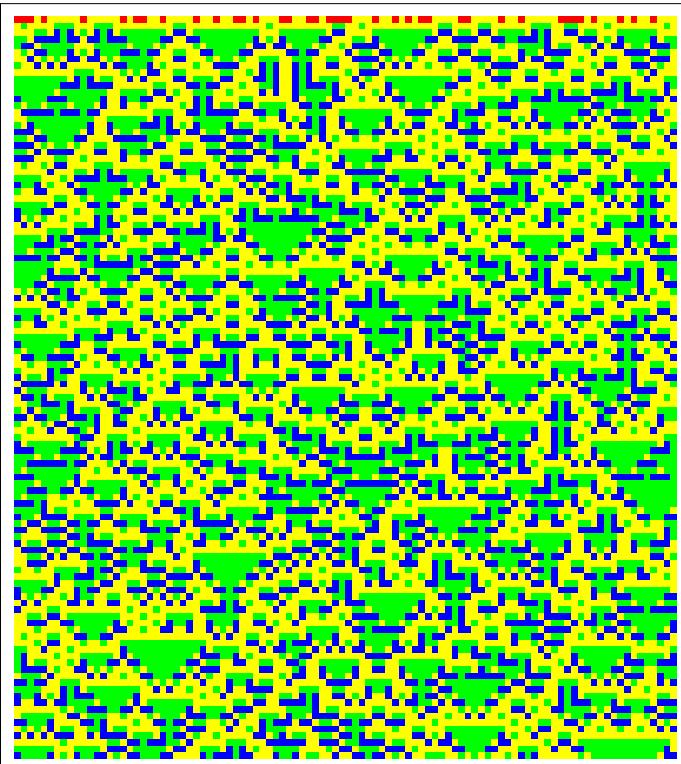


Indication: Random ruleRCI

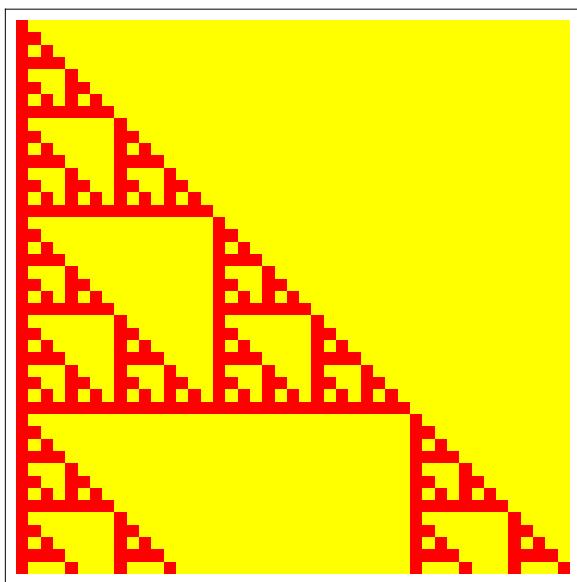
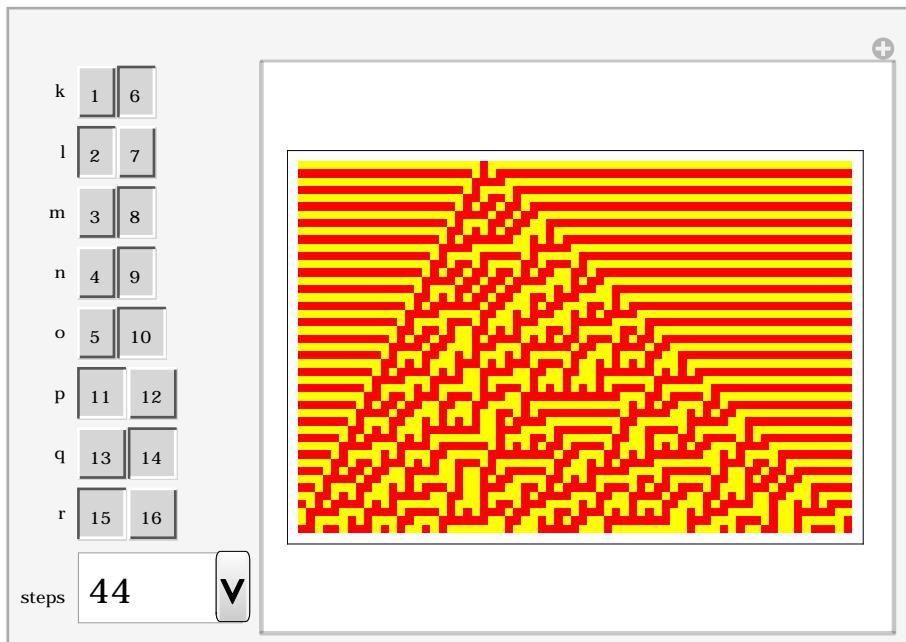
a	4440	4441	4442	4443
b	1110	1111	1112	1113
c	2220	2221	2222	2223
d	3330	3331	3332	3333
e	1000	1001	1002	1003
f	2000	2001	2002	2003
g	3000	3001	3002	3003
h	1100	1101	1102	1103
i	1120	1121	1122	1123
j	1130	1131	1132	1133
k	1220	1221	1222	1223
l	1330	1331	1332	1333
m	2200	2201	2202	2203
n	3300	3301	3302	3303
o	2230	2231	2232	2233
p	2330	2331	2332	2333
q	1300	1301	1302	1303
r	3200	3201	3202	3203
s	3210	3211	3212	3213
t	2300	2301	2302	2303
	steps 44 			

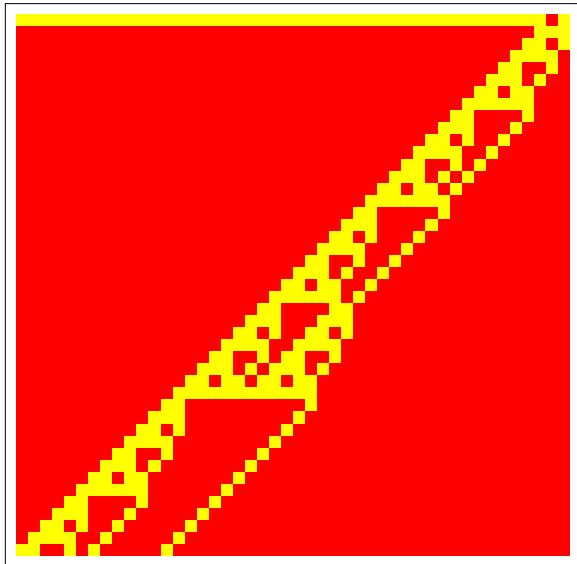






ECA



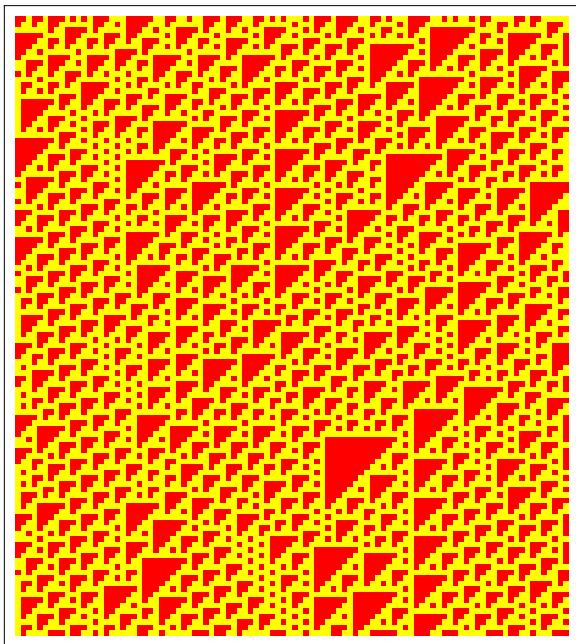


ECA Random

The screenshot shows a software interface for simulating Elementary Cellular Automata (ECA). On the left, there is a control panel with a list of rules labeled k through r, each associated with a 2x2 grid of numbers. Below this is a 'steps' input field containing the value '111' and a downward-pointing arrow button. On the right, there is a large simulation window displaying a 16x16 grid of yellow and red pixels, showing a complex, fractal-like pattern of diagonal stripes.

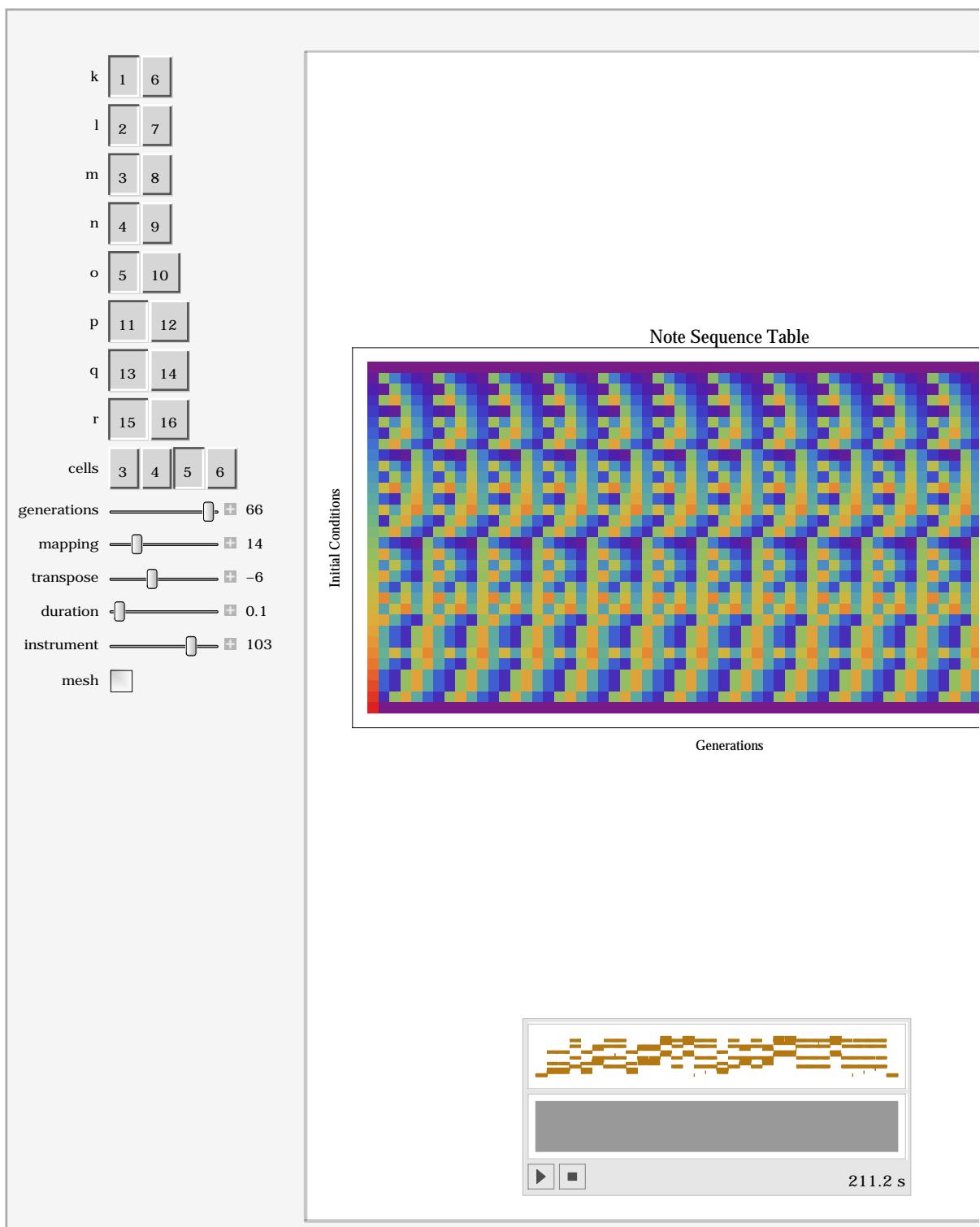
k	1	6
l	2	7
m	3	8
n	4	9
o	5	10
p	11	12
q	13	14
r	15	16

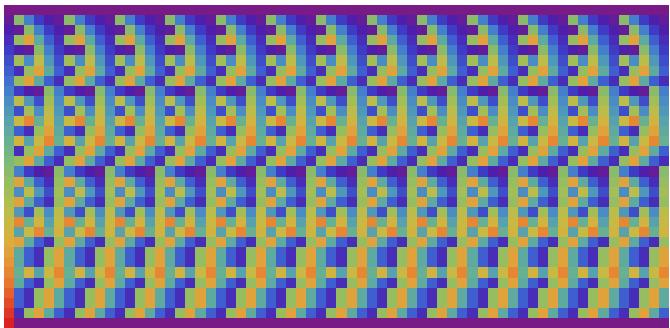
steps 1 1 1 ▼



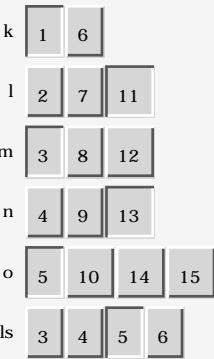
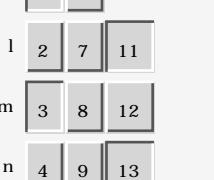
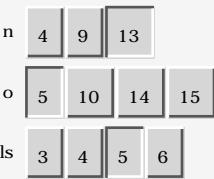
Sound

ECA





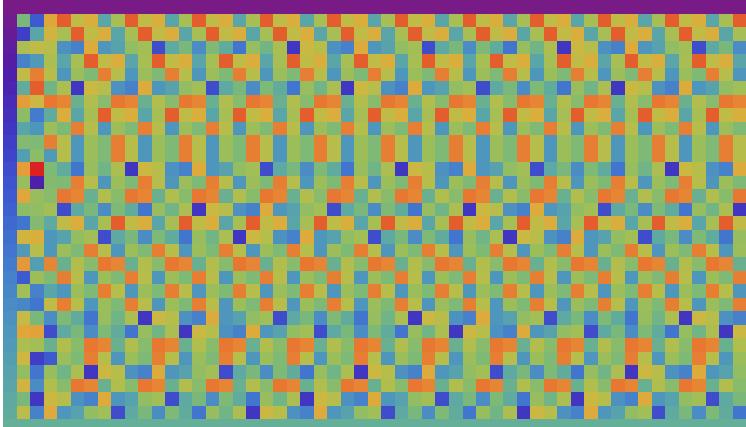
Morphogram: ruleDM

k 
 l 
 m 
 n 
 o 
 cells 

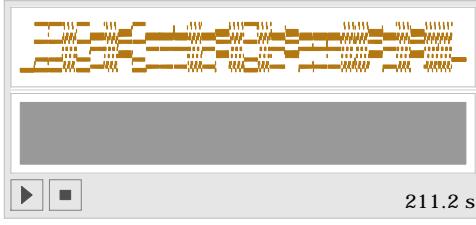
generations 66
 mapping 14
 transpose -6
 duration 0.1
 instrument 103
 mesh

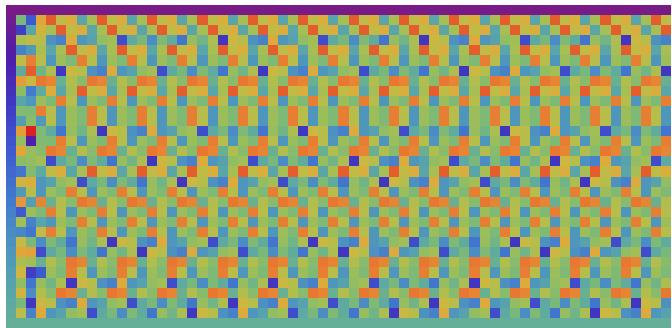
Note Sequence Table

Initial Conditions

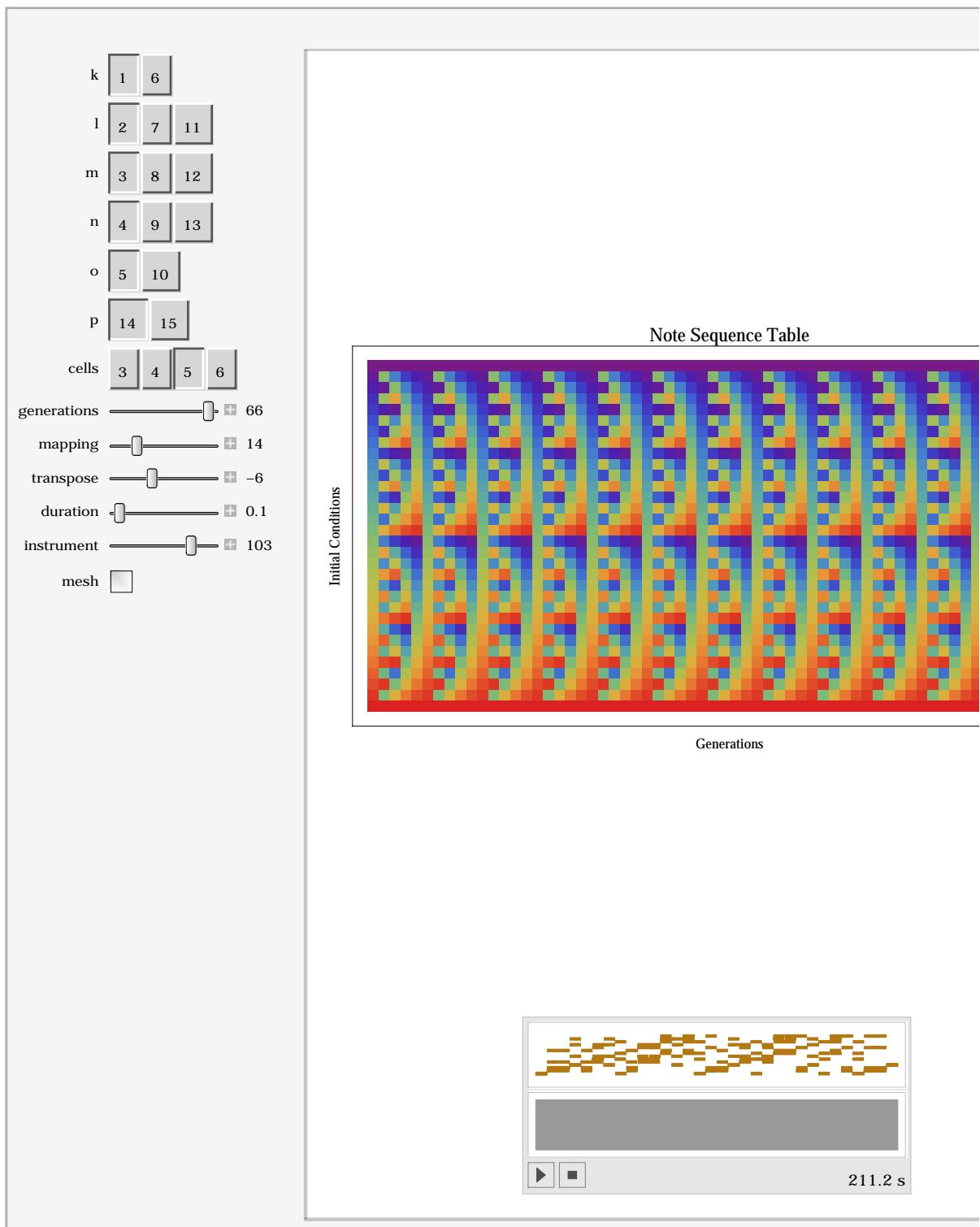


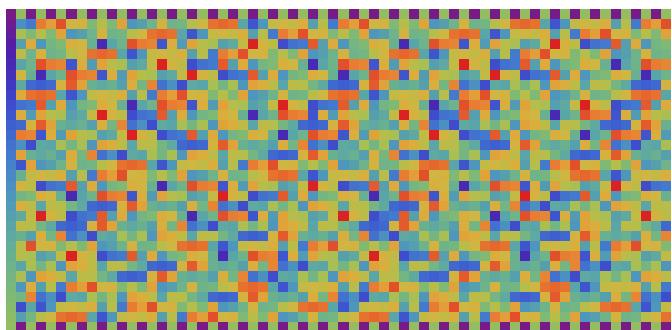
Generations


211.2 s

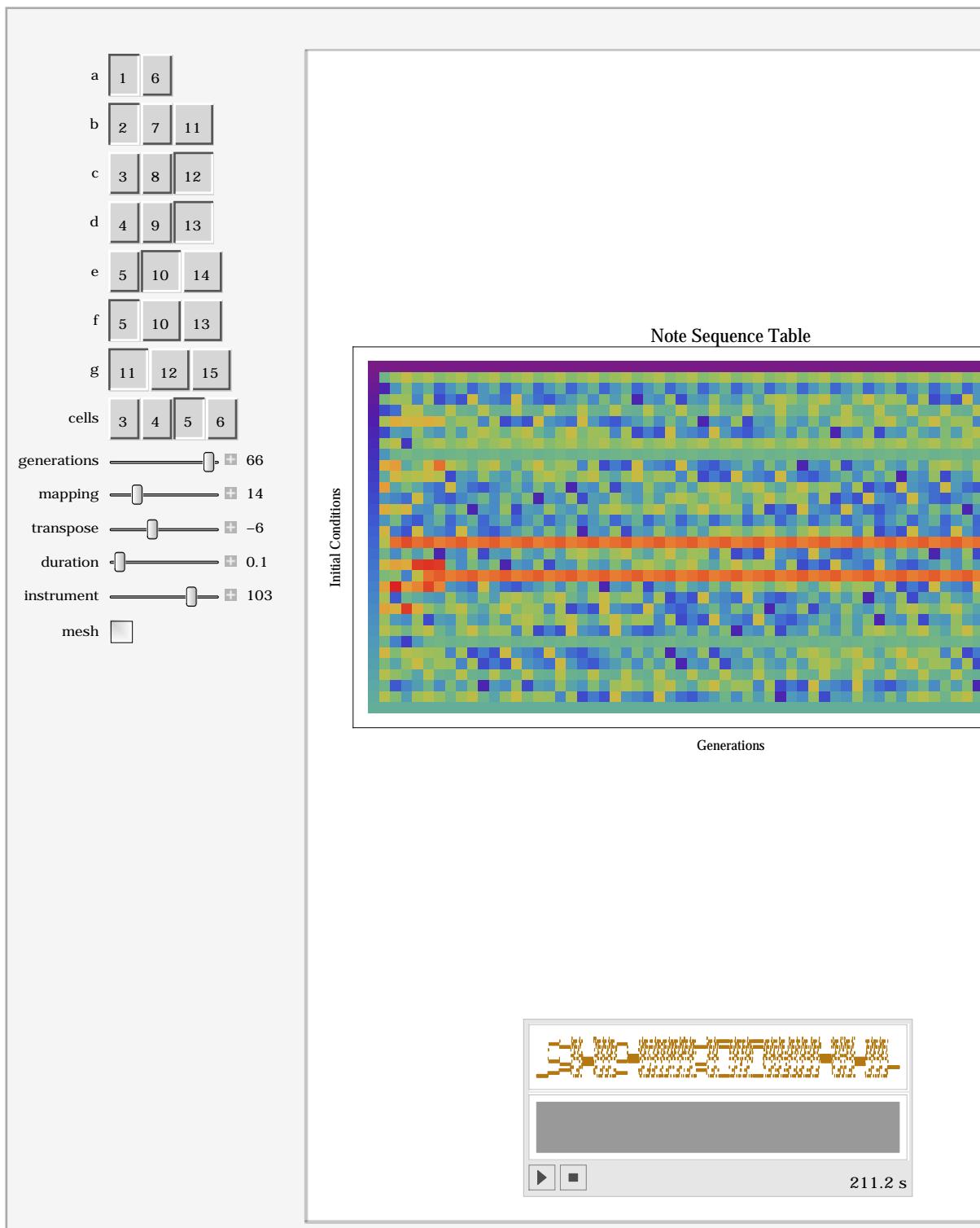


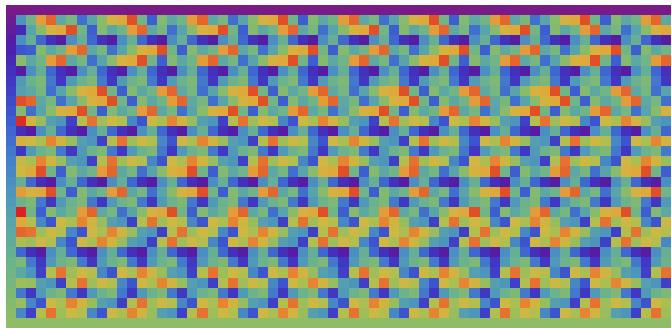
Morphogram: ruleDMN





Morphogram: ruleMNP





Morphogram: ruleDCKV

a	1111	1112		
b	1121	1122	1123	
c	1211	1212	1213	
d	1221	1222	1223	
e	2121	2122	2123	
f	2211	2212	2213	
g	2221	2222	2223	
h	2111	2112	2113	
i	2131	2132	2133	2130
j	1231	1232	1233	1230
k	2231	2232	2233	2230
l	2311	2312	2313	2310
m	2321	2322	2323	2320
n	2331	2332	2333	2330
o	2301	2302	2303	2300
cells	3	4	5	6

generations 66

mapping 14

transpose -6

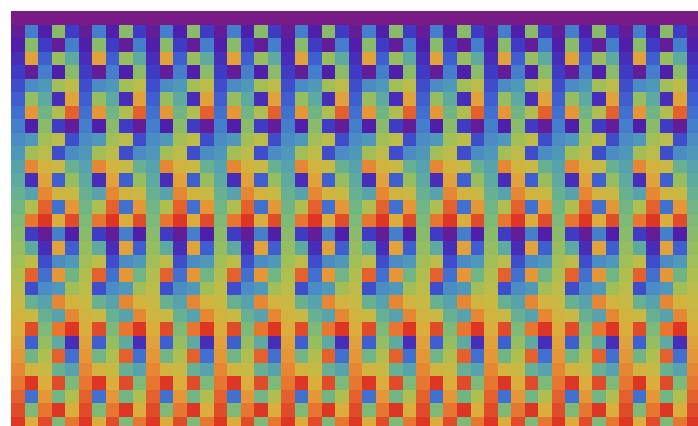
duration 0.1

instrument 103

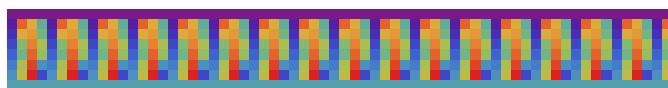
mesh

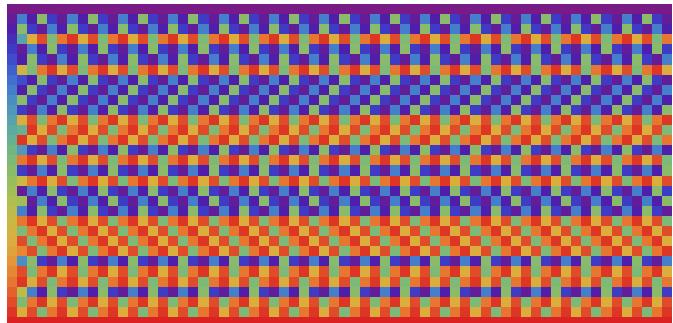
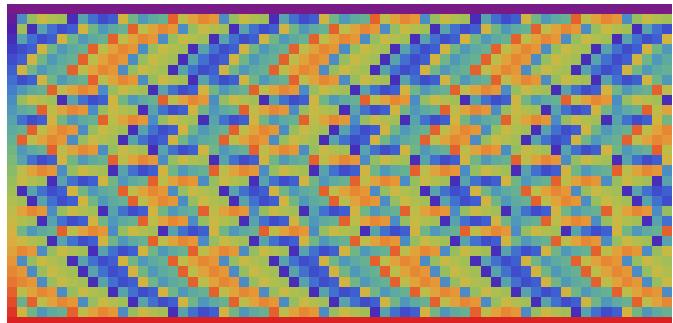
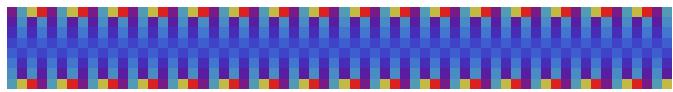
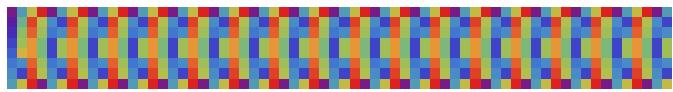
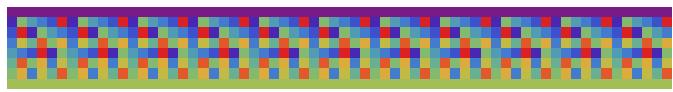
Note Sequence Table

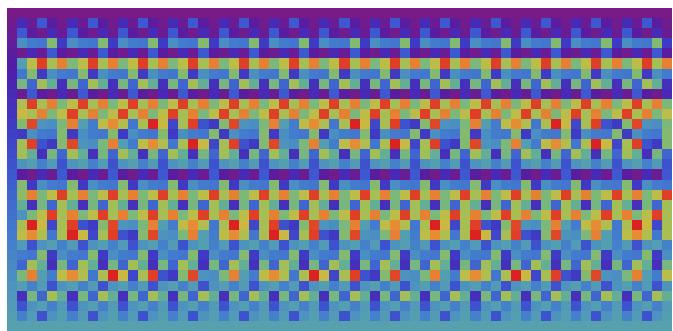
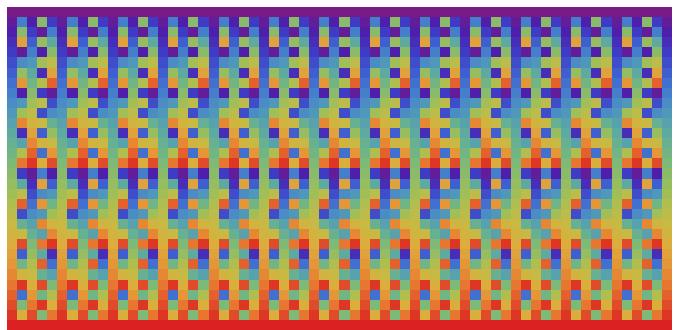
Initial Conditions															Generations



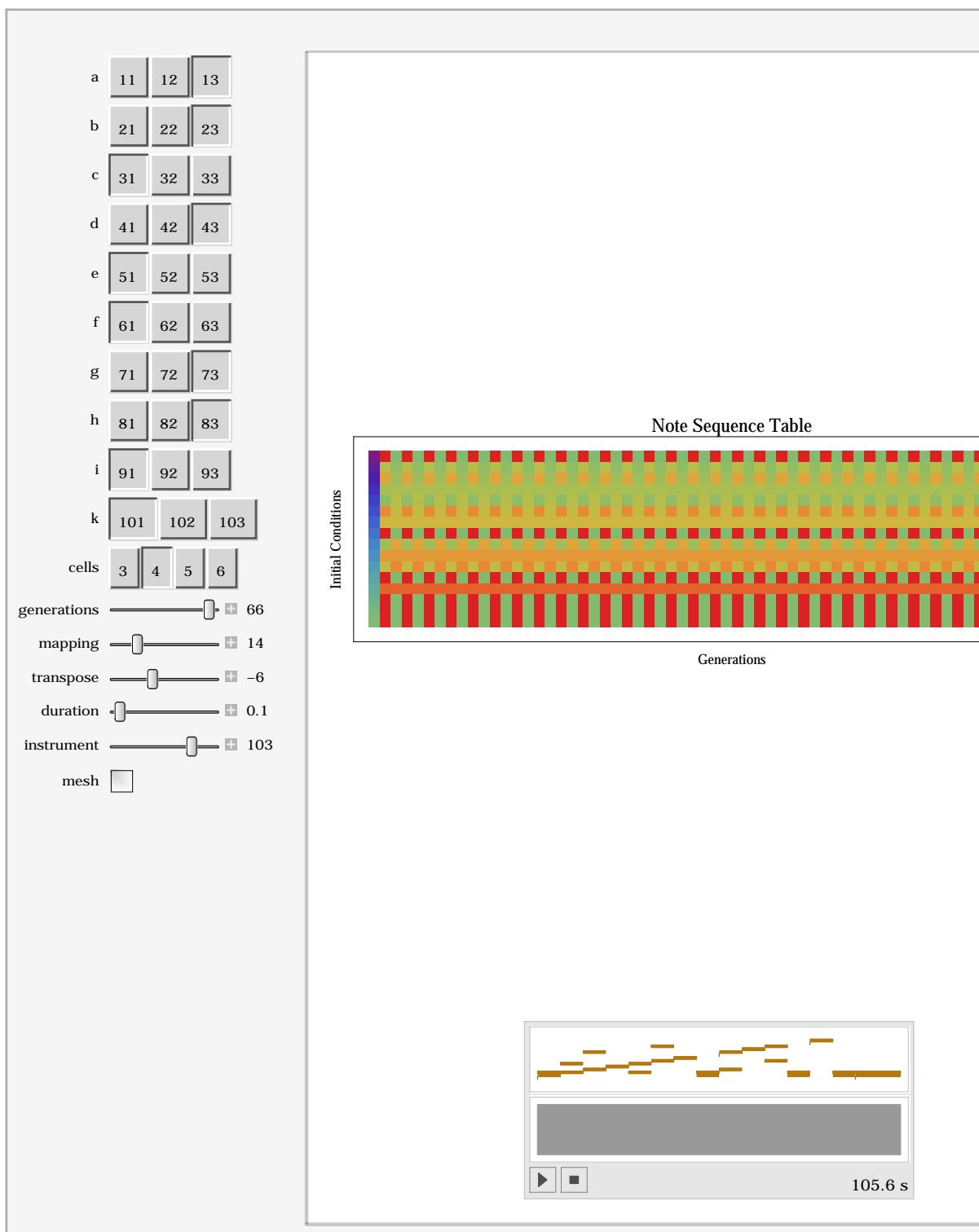
211.2 s

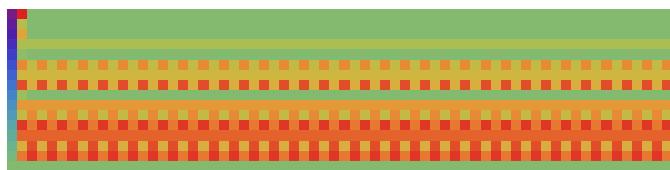






Indication: ruleCIR





Indication: ruleRCI

a	4440	4441	4442	4443
b	1110	1111	1112	1113
c	2220	2221	2222	2223
d	3330	3331	3332	3333
e	1000	1001	1002	1003
f	2000	2001	2002	2003
g	3000	3001	3002	3003
h	1100	1101	1102	1103
i	1120	1121	1122	1123
j	1130	1131	1132	1133
k	1220	1221	1222	1223
l	1330	1331	1332	1333
m	2200	2201	2202	2203
n	3300	3301	3302	3303
o	2230	2231	2232	2233
p	2330	2331	2332	2333
q	1300	1301	1302	1303
r	3200	3201	3202	3203
s	3210	3211	3212	3213
t	2300	2301	2302	2303
cells	3	4	5	6

generations 66

mapping 14

transpose -6

duration 0.1

instrument 103

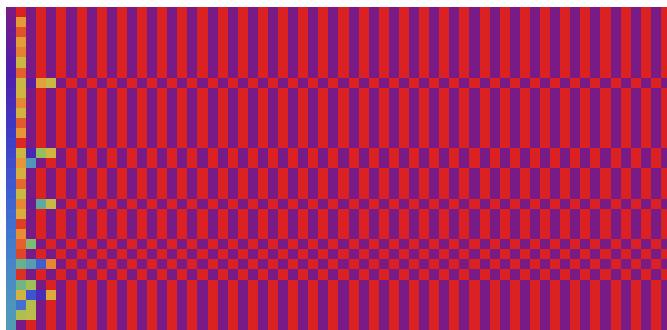
mesh

Note Sequence Table

Initial Conditions

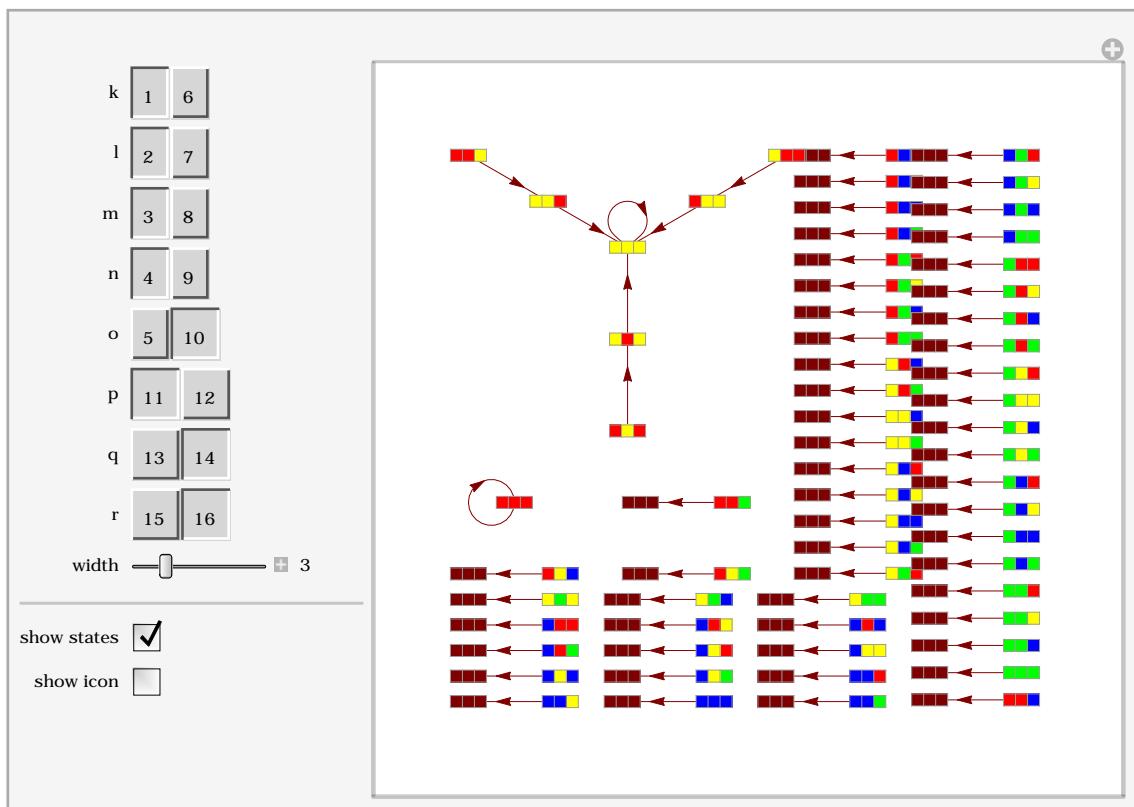
Generations

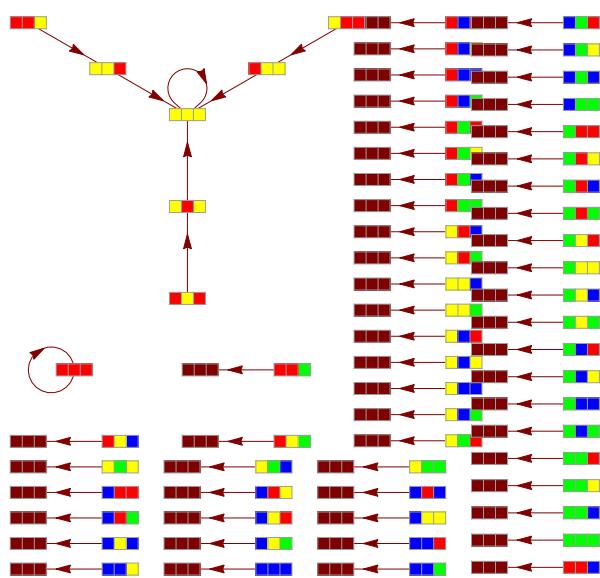
211.2 s



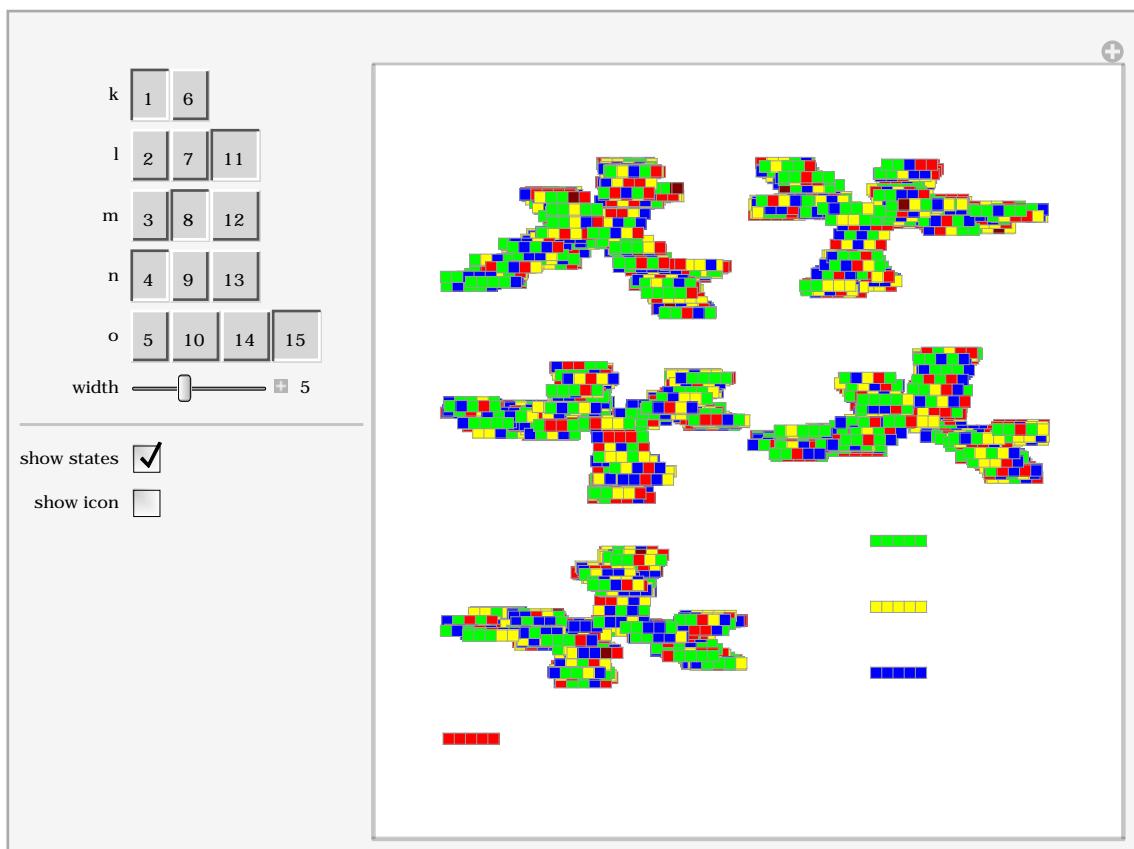
Structures: Transition Graphs

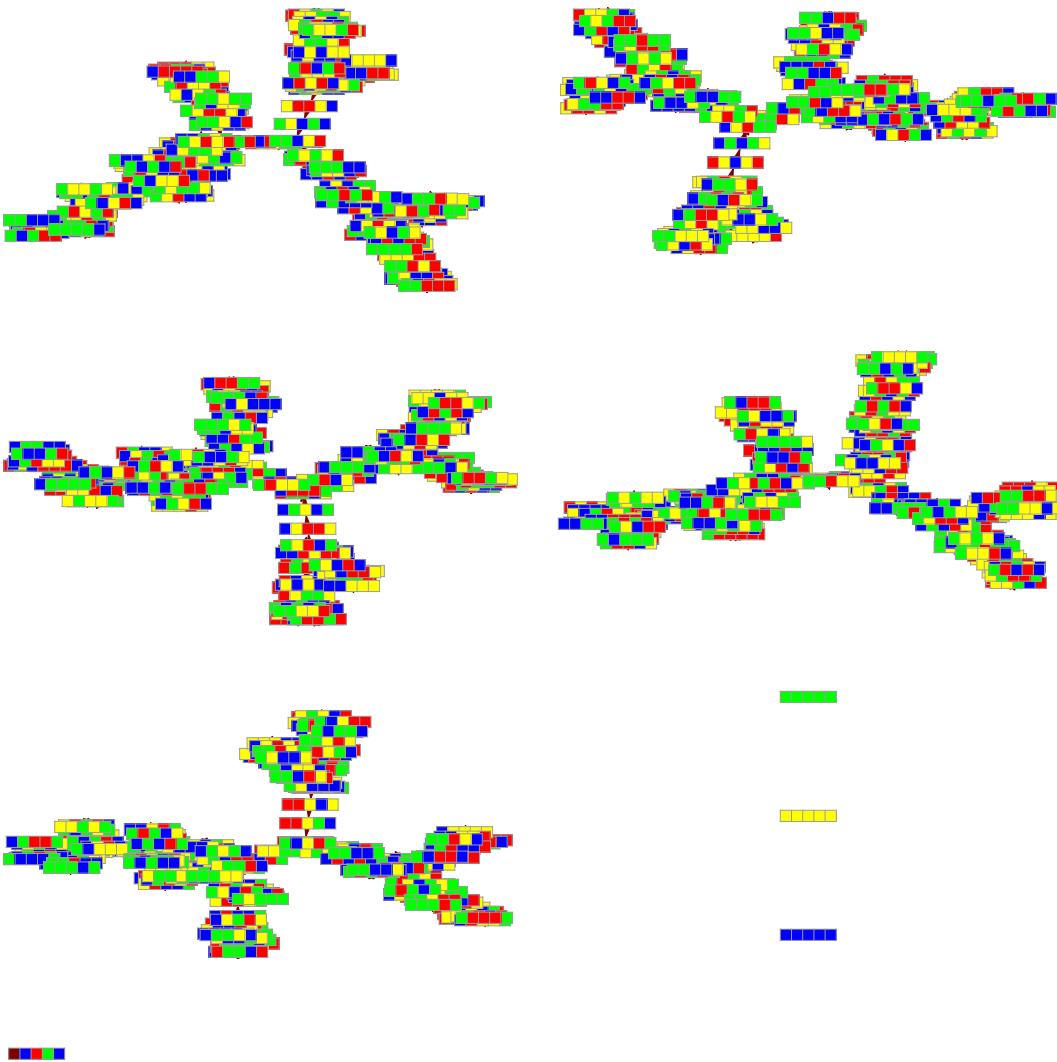
ECA

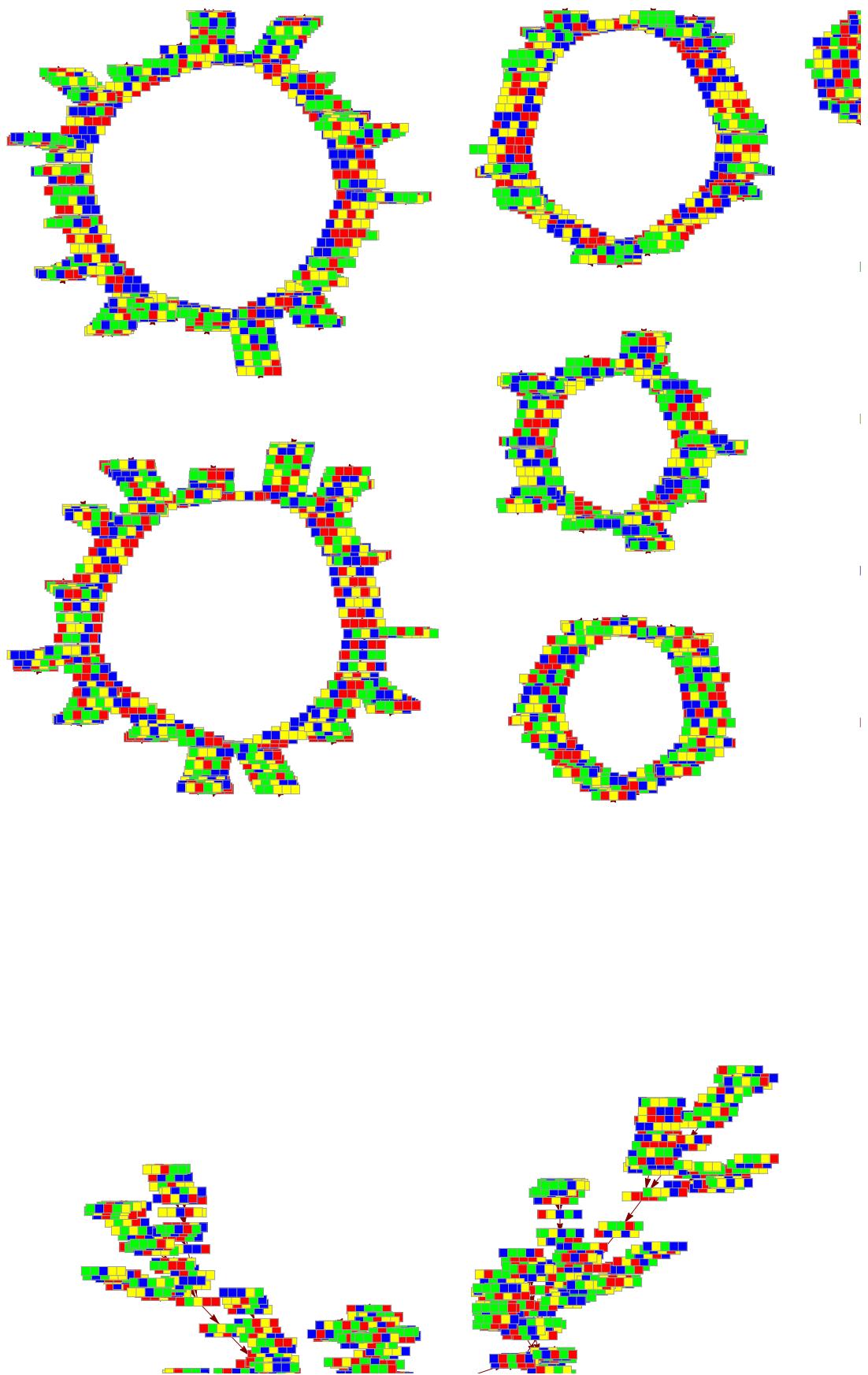


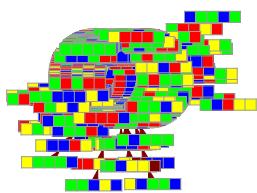
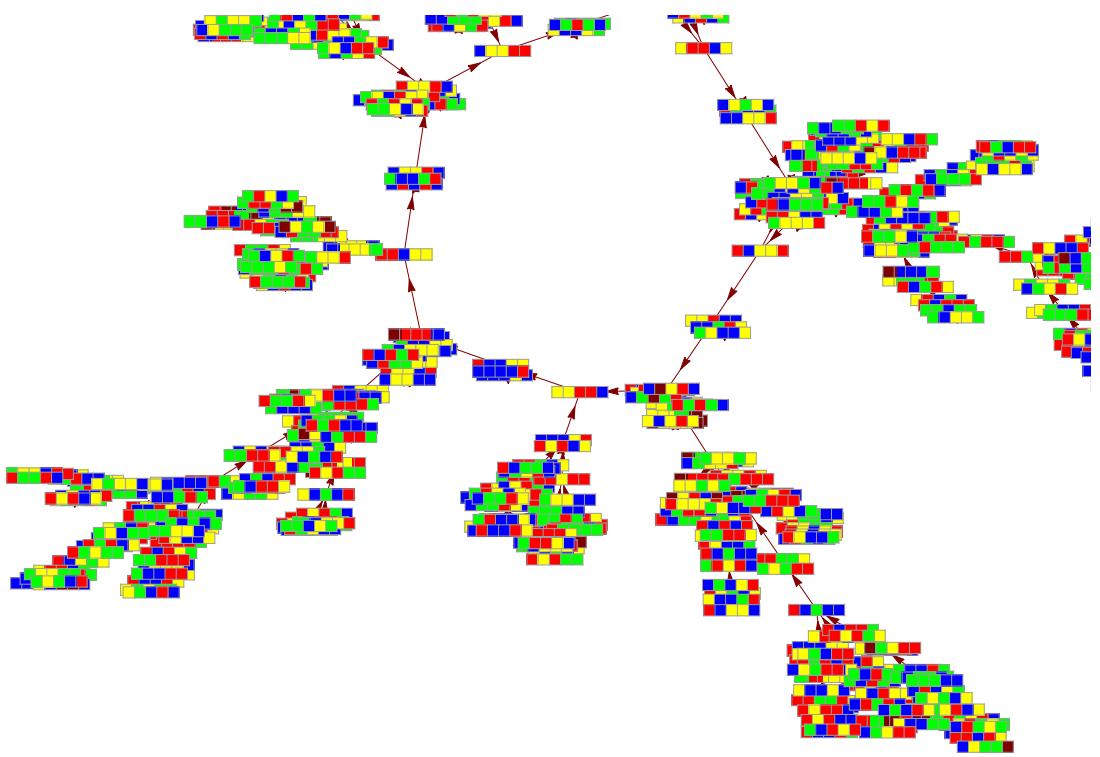


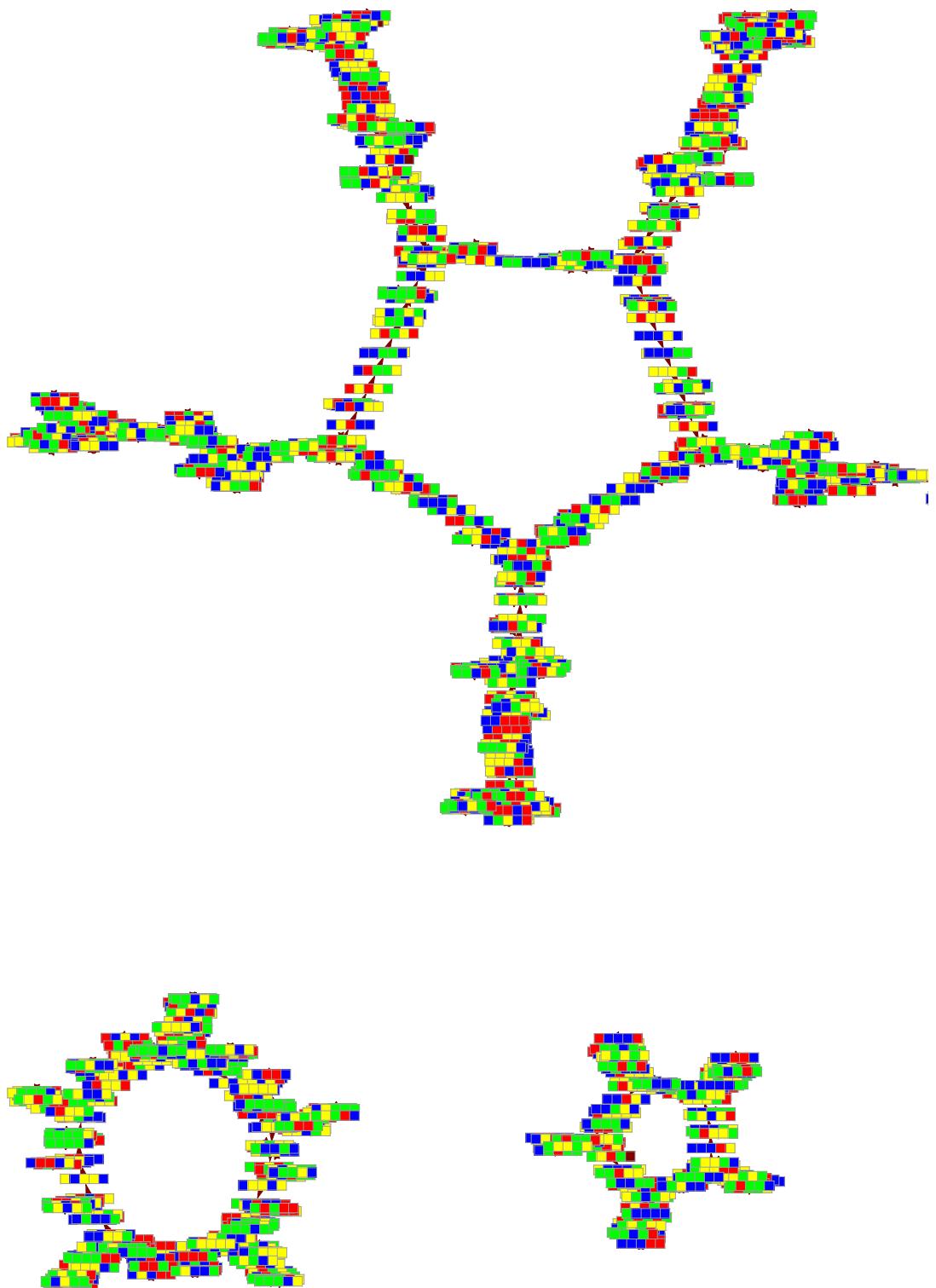
Morphograms: ruleDM

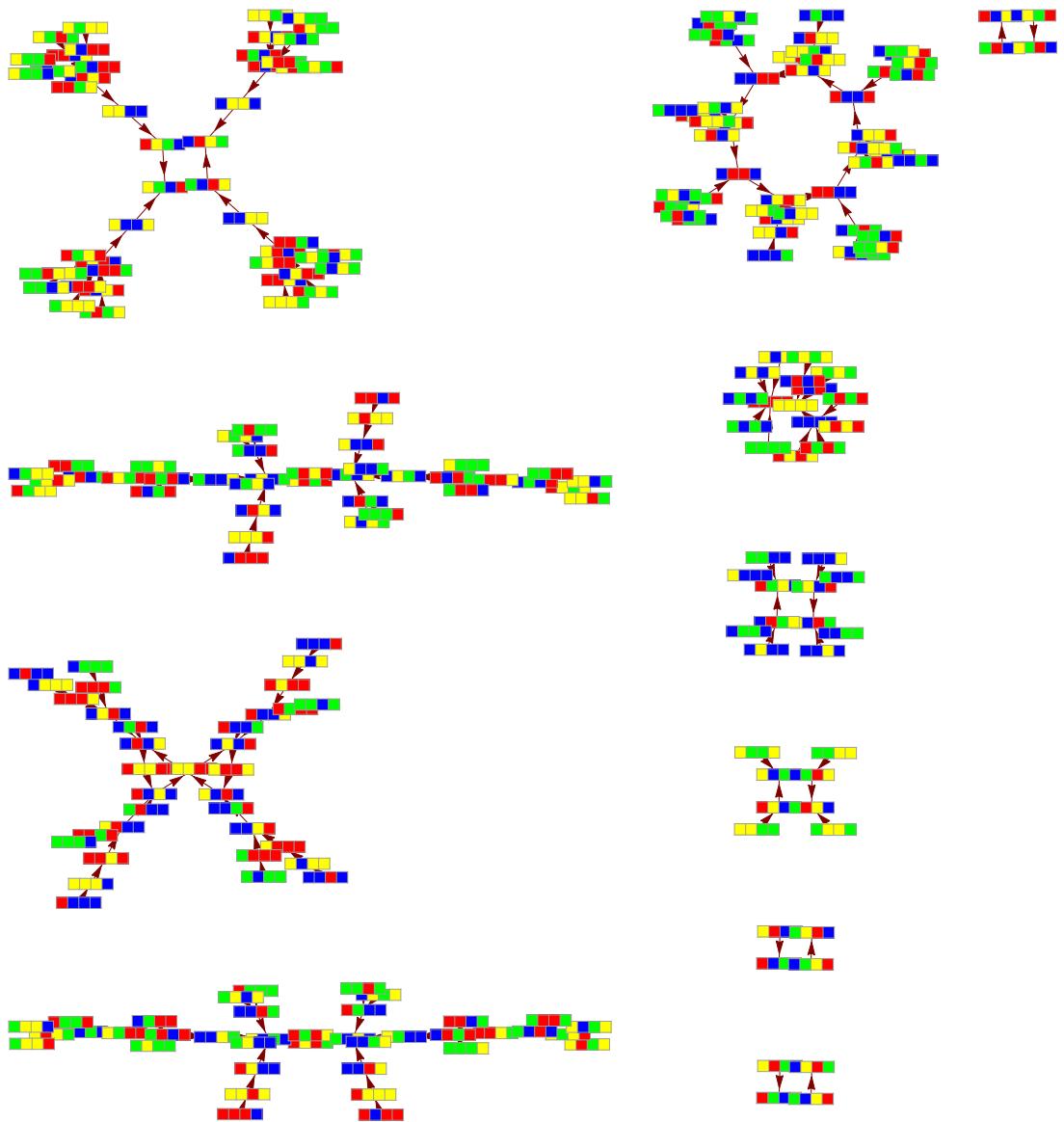


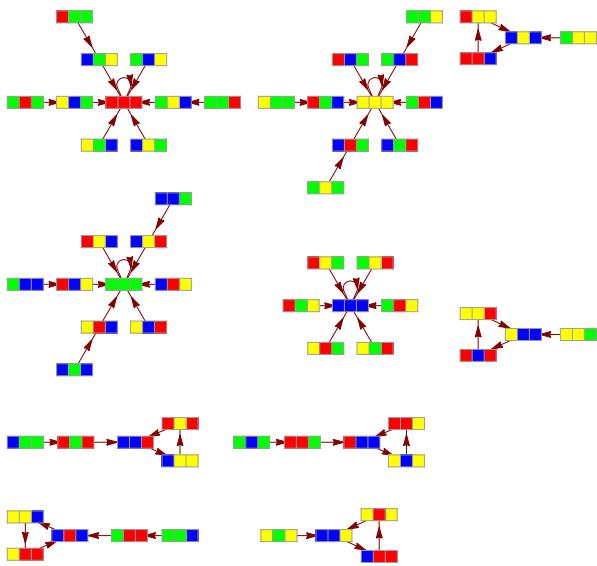












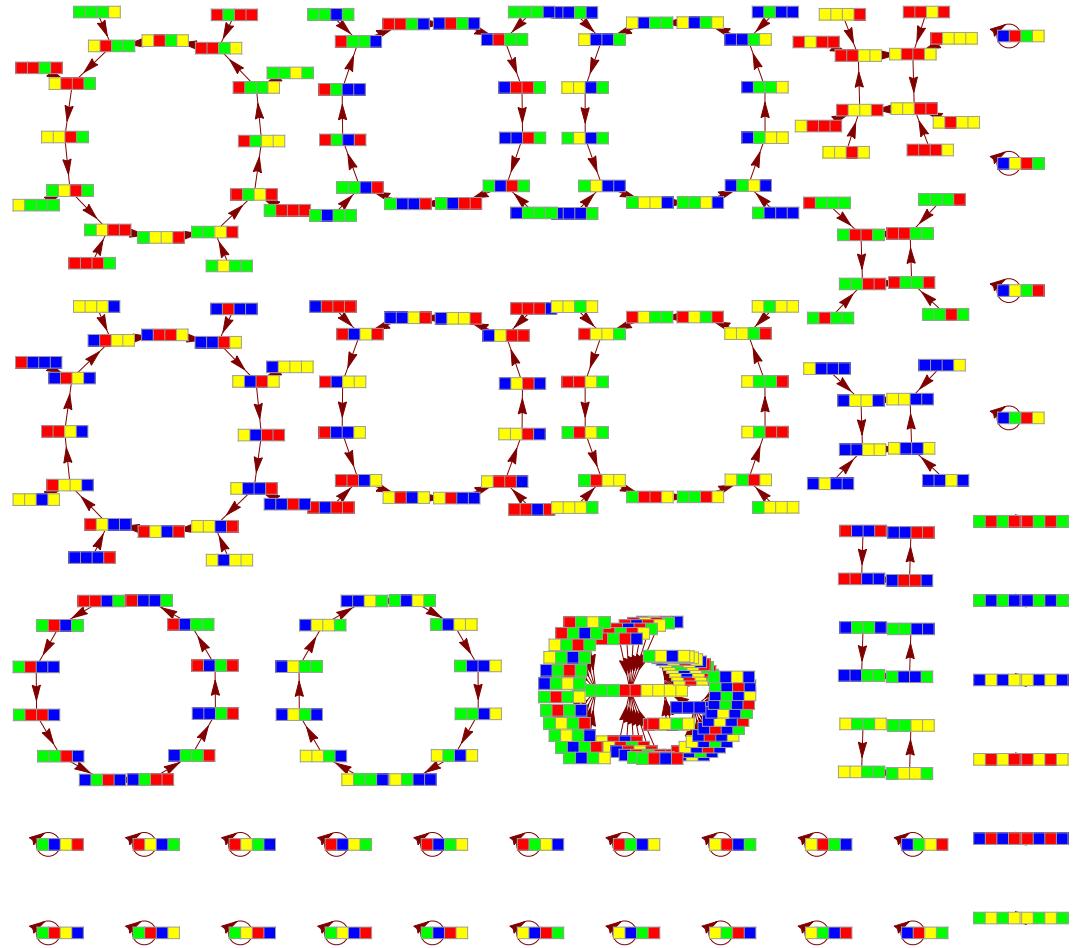
Morphograms: ruleDMN

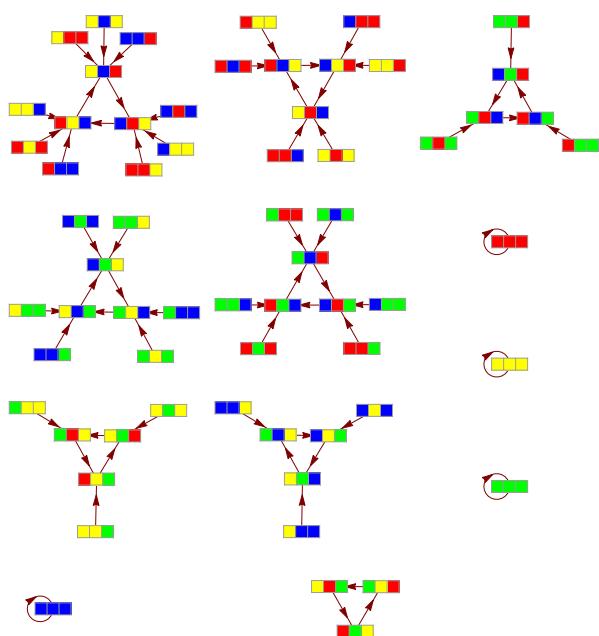
k	1	6	
l	2	7	11
m	3	8	12
n	4	9	13
o	5	10	14
p	10	14	15

width 4

show states

show icon





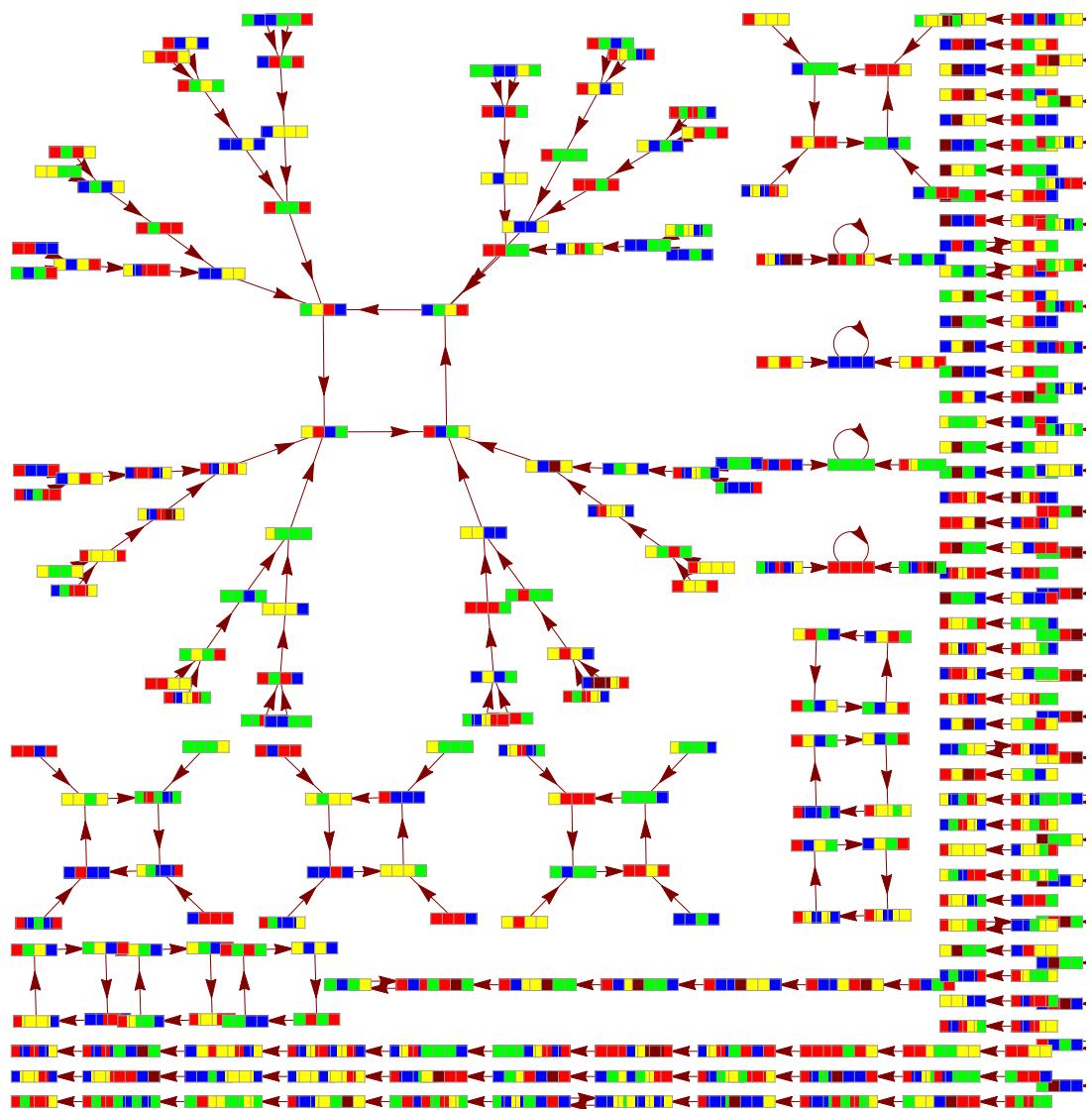
Morphograms: ruleDCKV

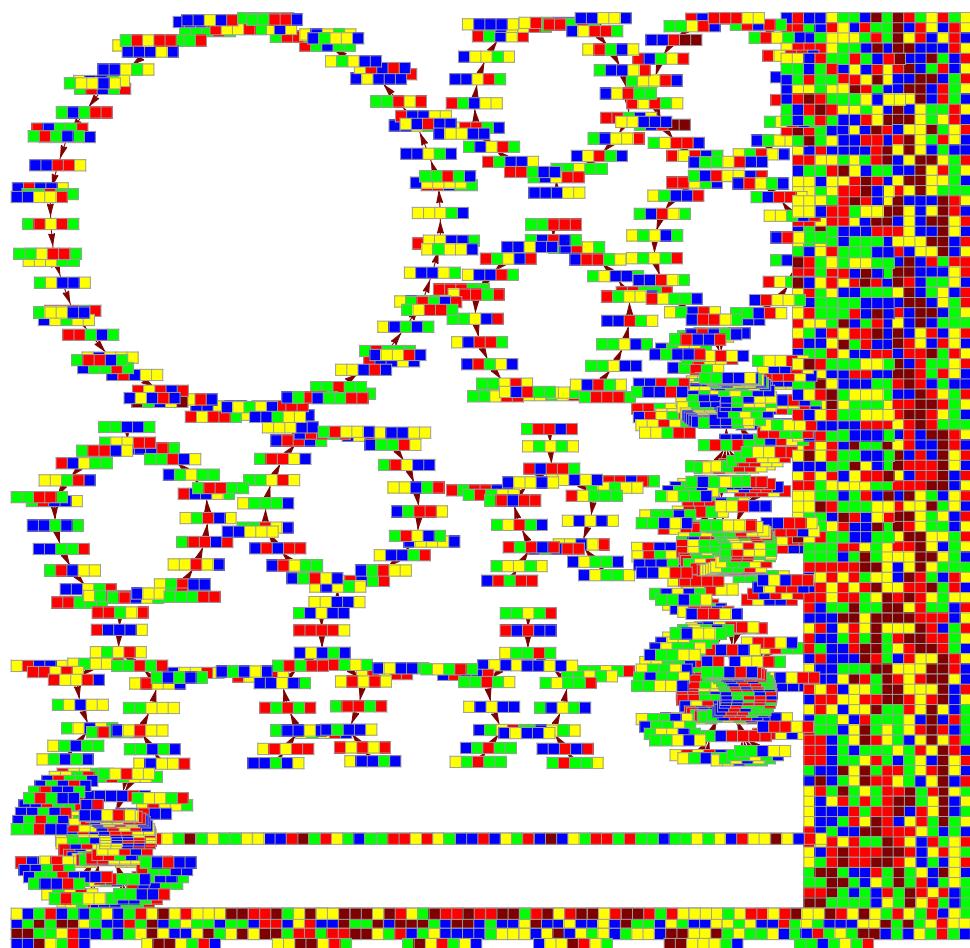
a	1111	1112		
b	1121	1122	1123	
c	1211	1212	1213	
d	1221	1222	1223	
e	2121	2122	2123	
f	2211	2212	2213	
g	2221	2222	2223	
h	2111	2112	2113	
i	2131	2132	2133	2130
j	1231	1232	1233	1230
k	2231	2232	2233	2230
l	2311	2312	2313	2310
m	2321	2322	2323	2320
n	2331	2332	2333	2330
o	2301	2302	2303	2300

width 4

show states

show icon

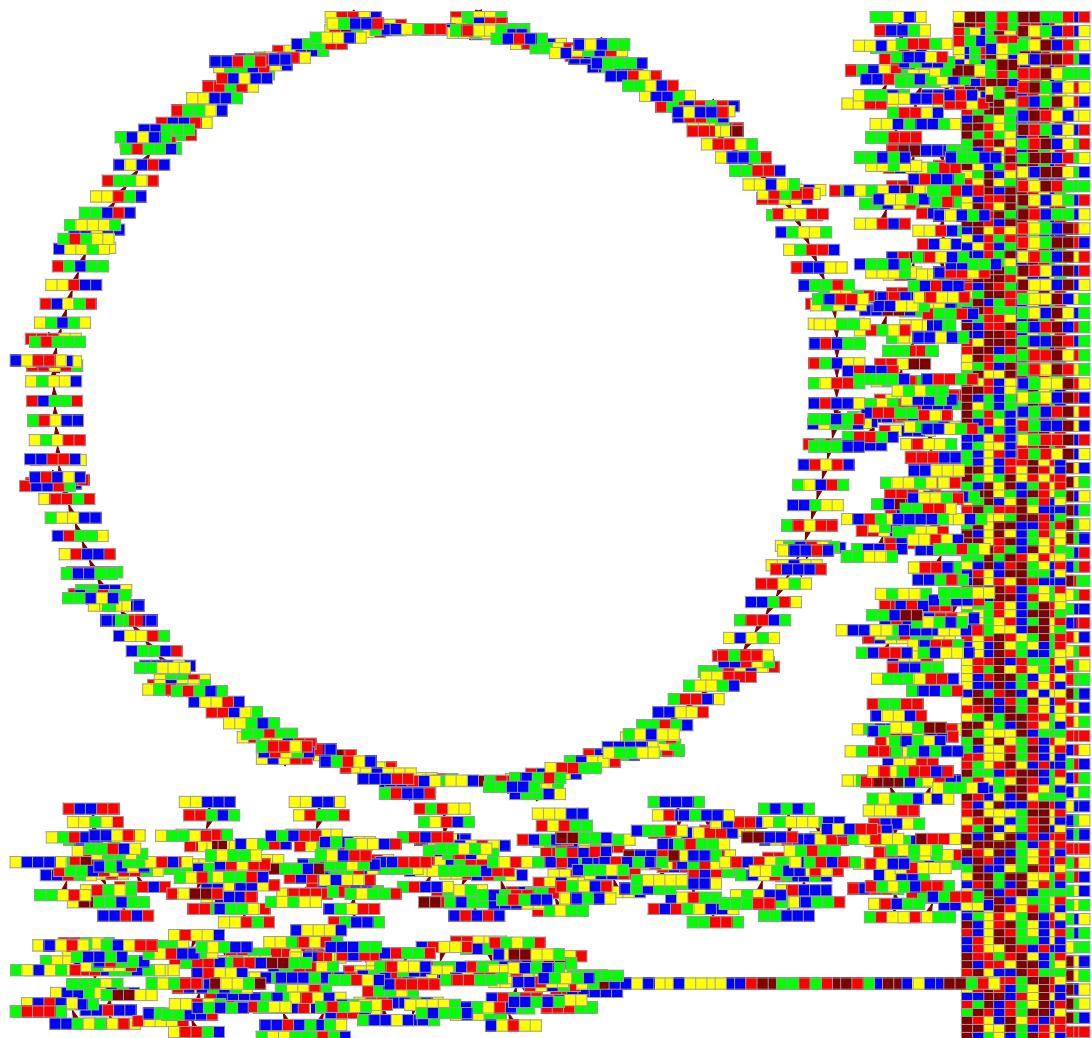


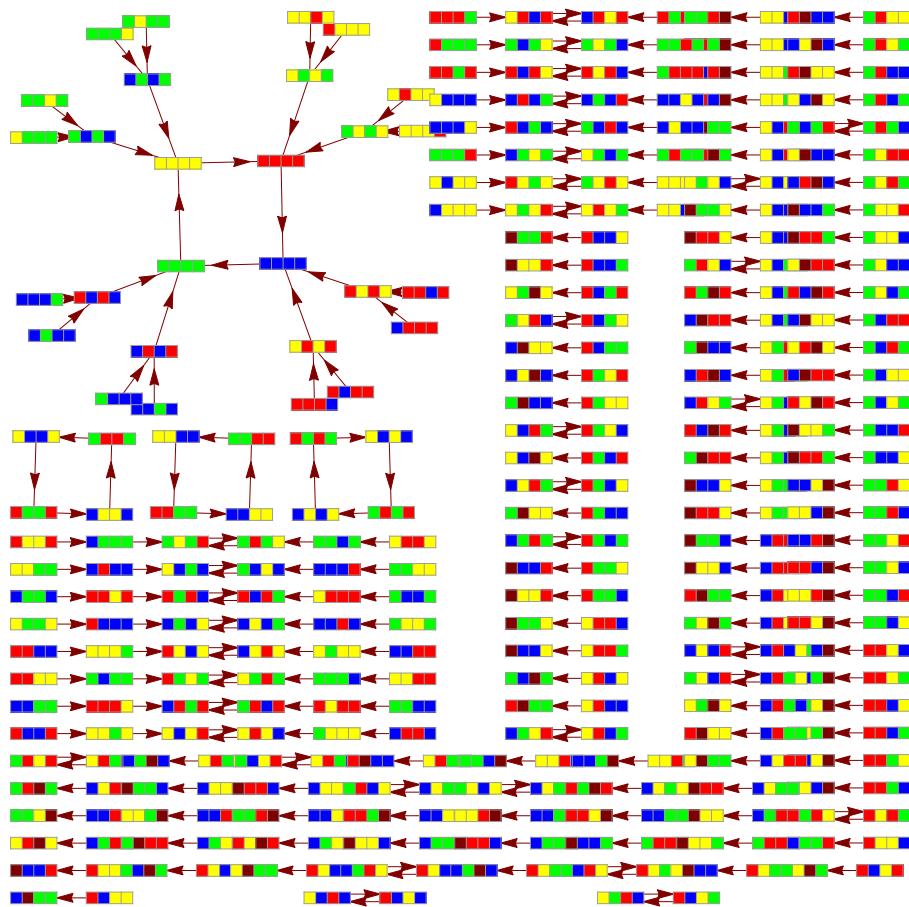


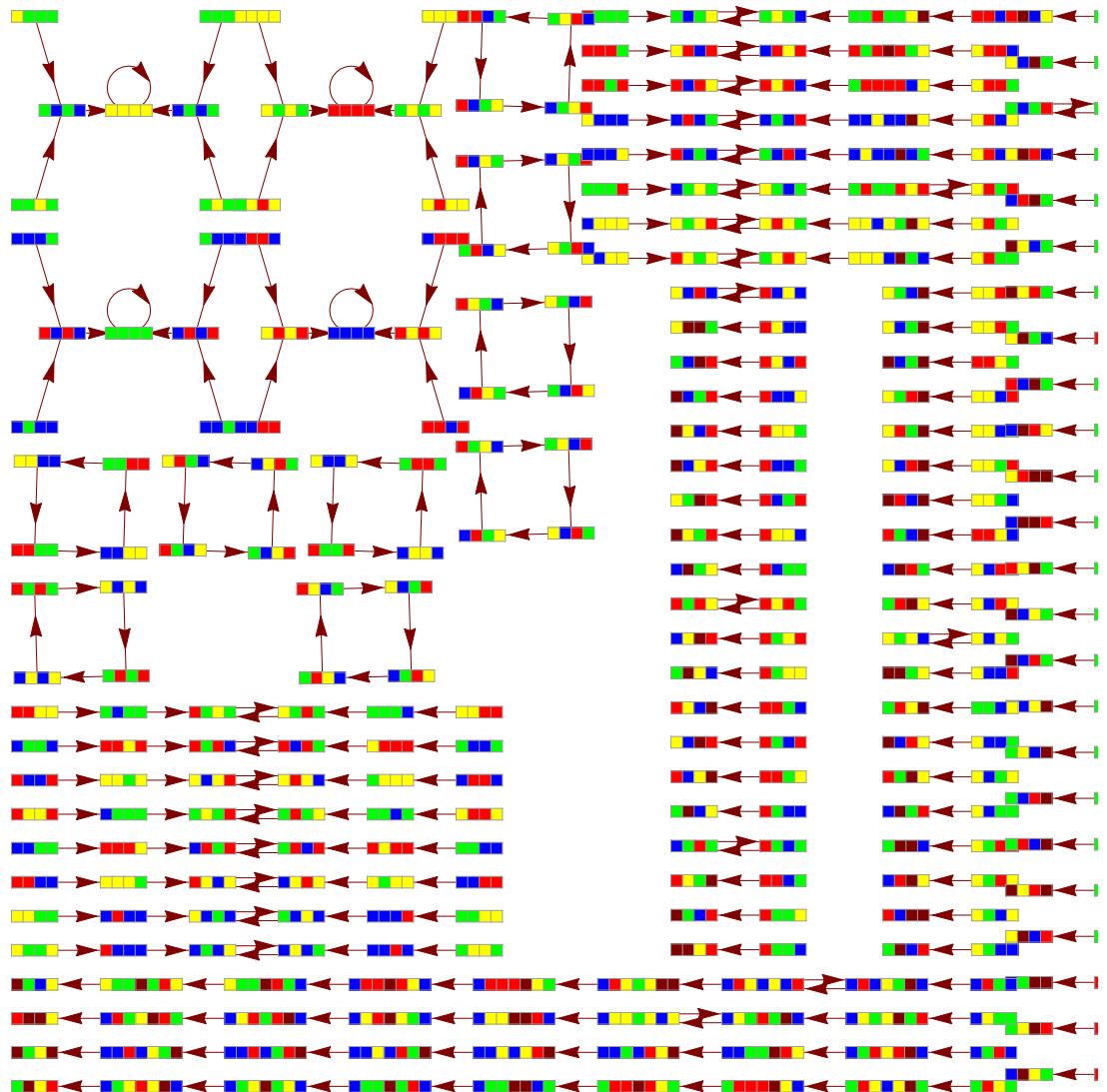


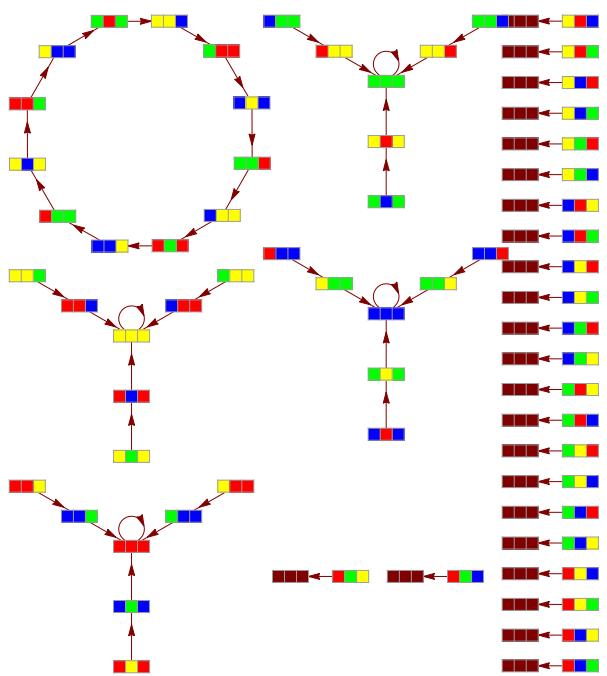


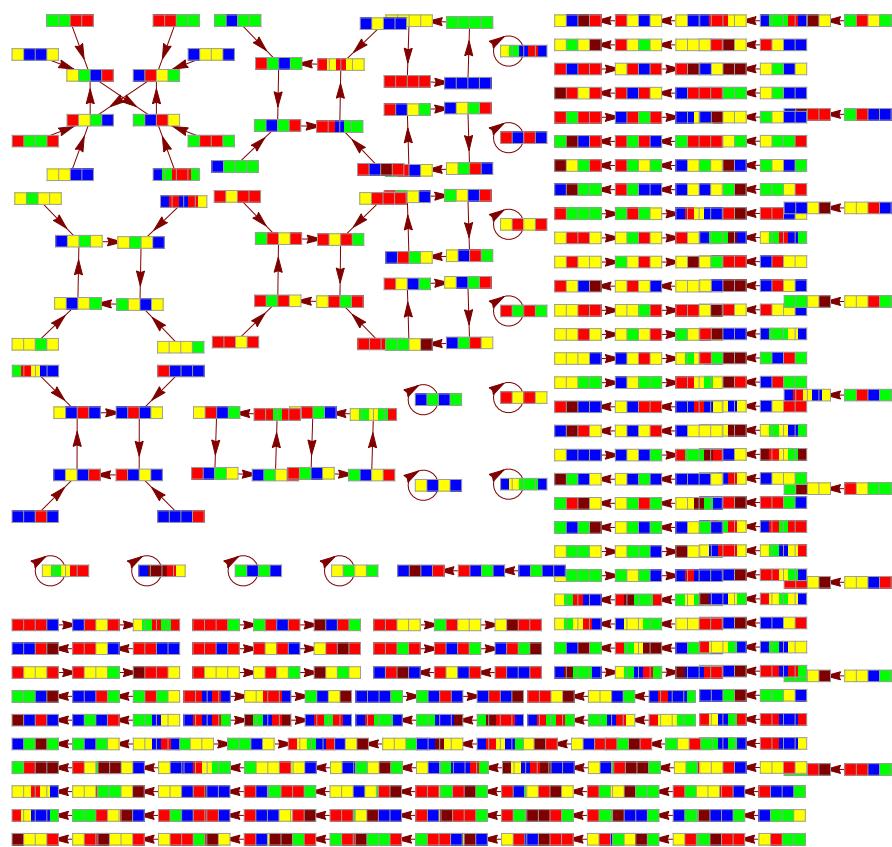


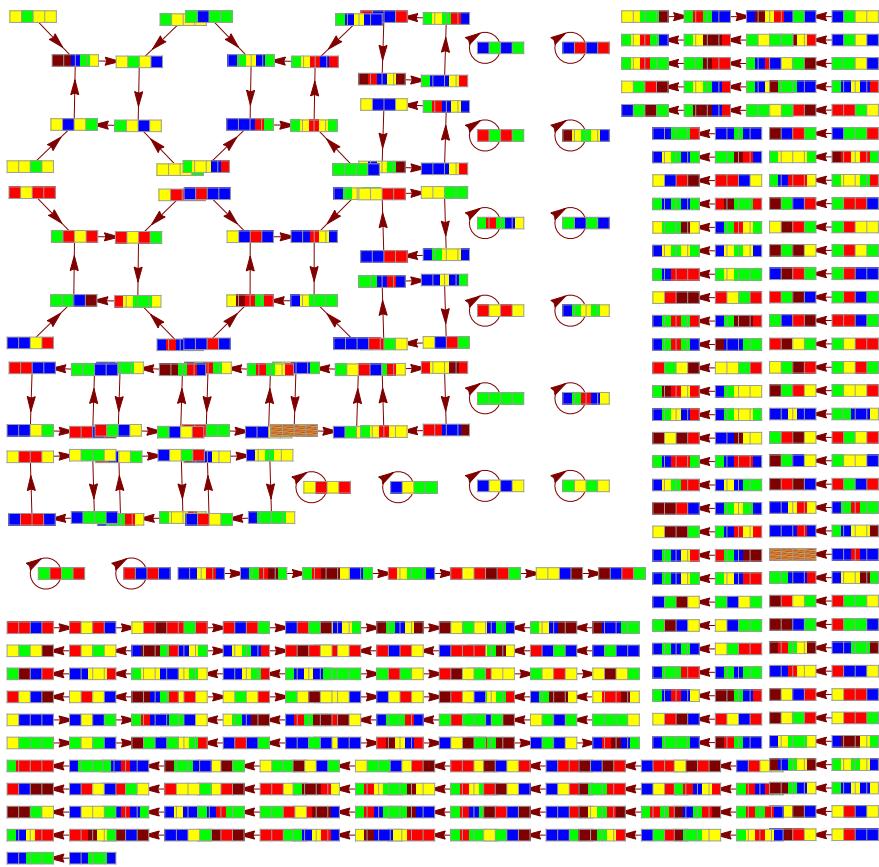


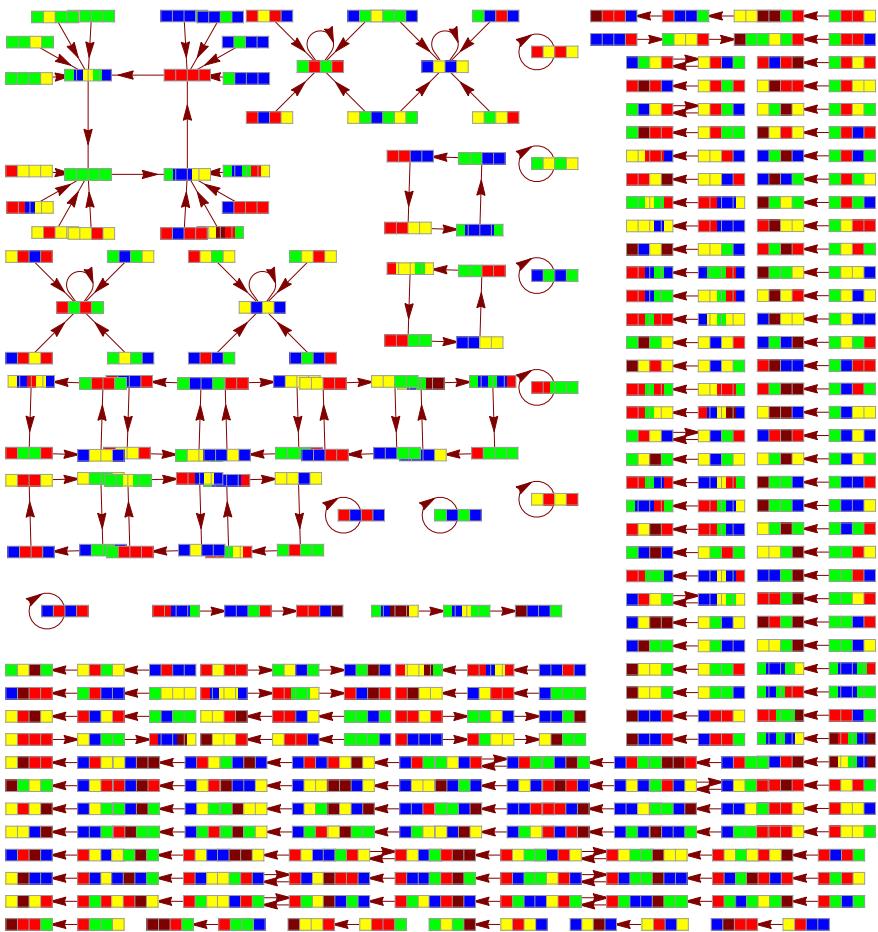


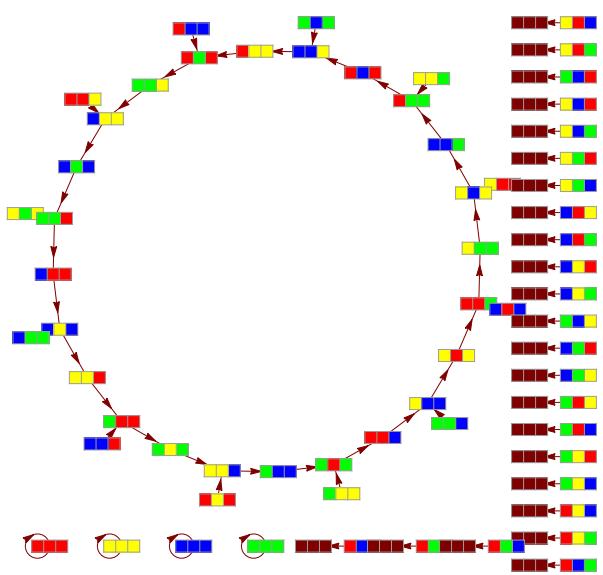
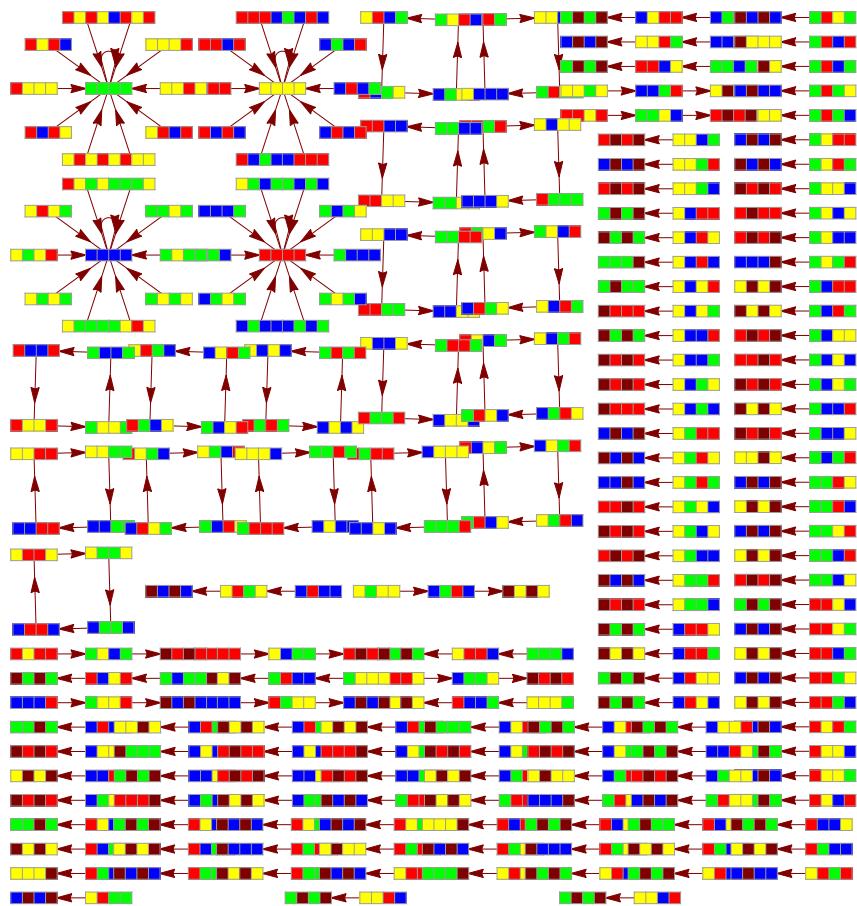


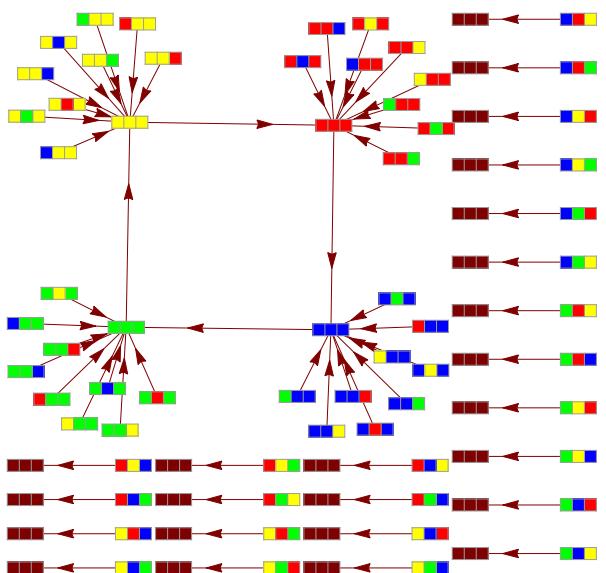
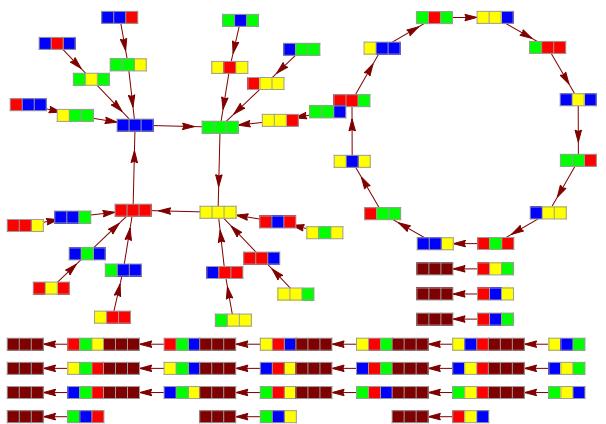




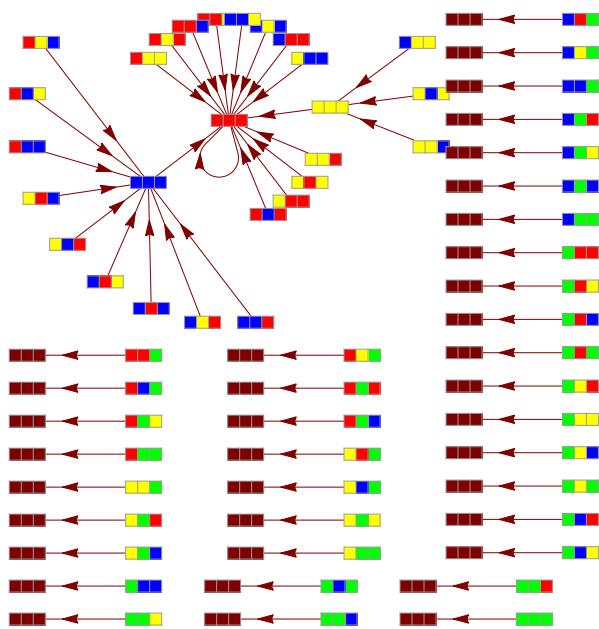
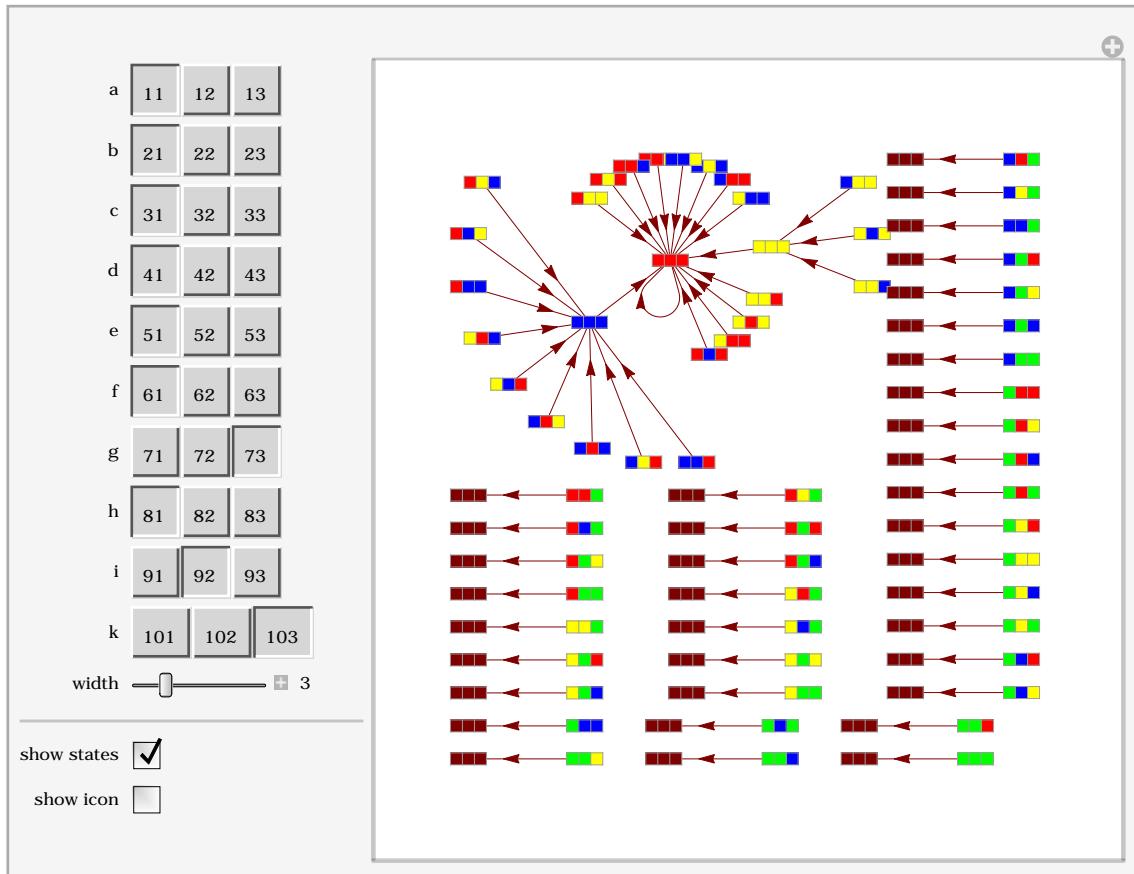




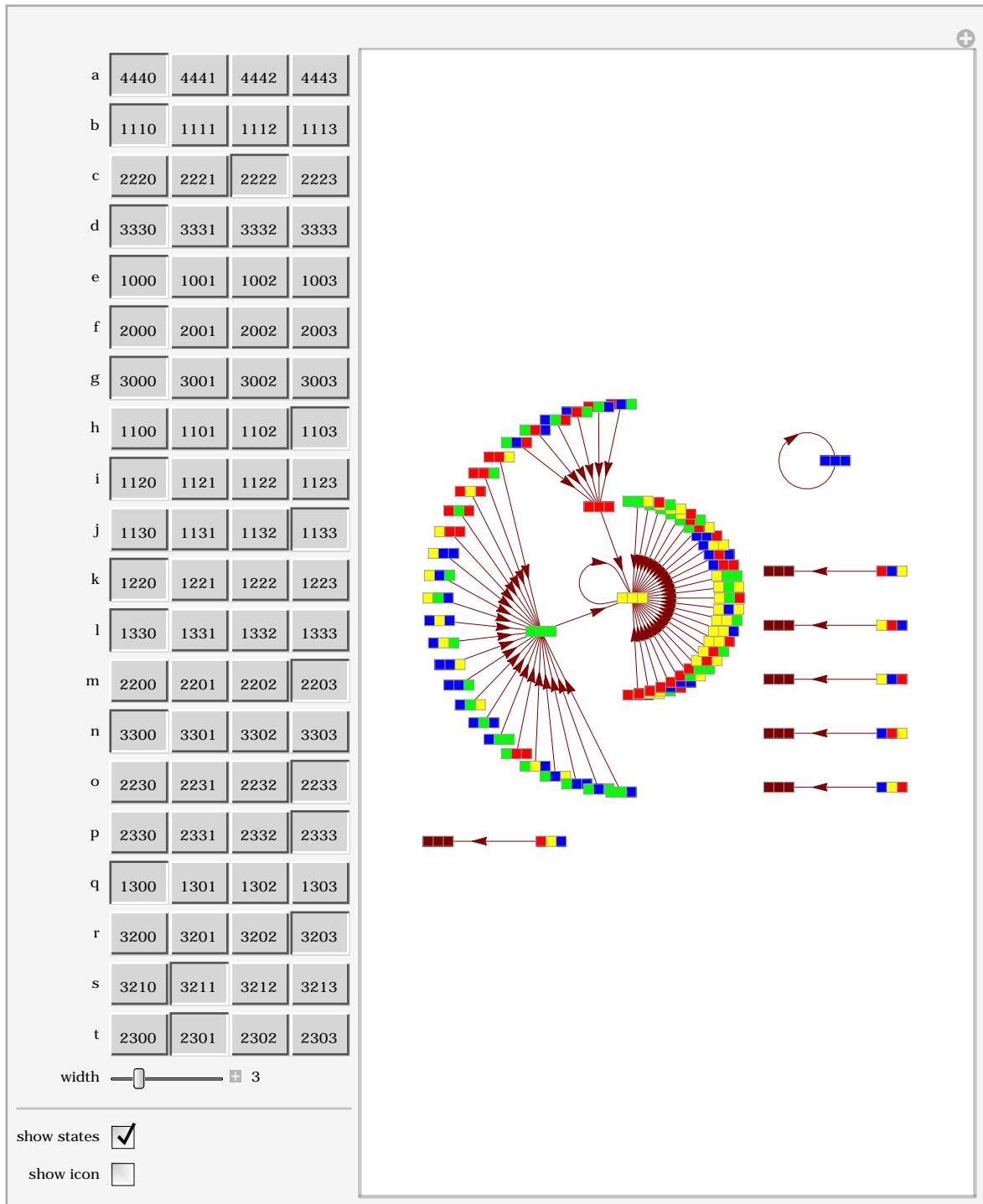


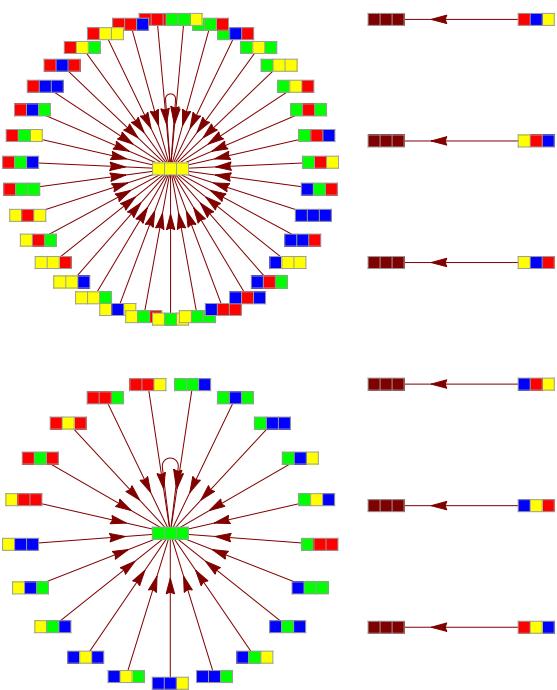


Indication: ruleCIR



Indication: ruleRCI

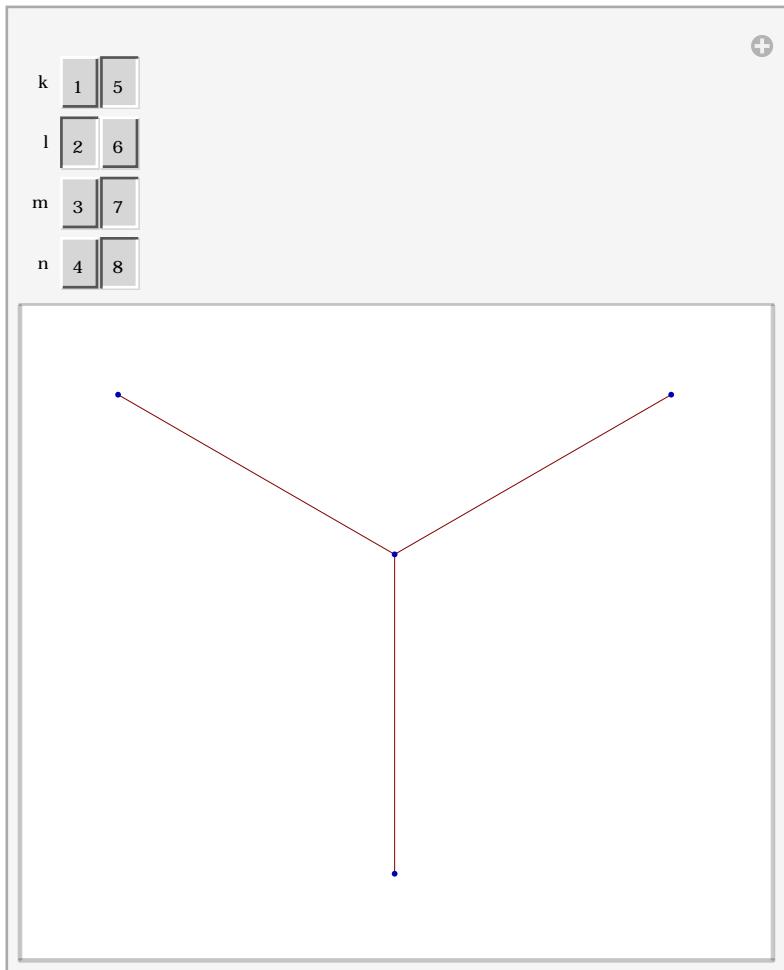




FixedPoints

FixedPoints: indCI

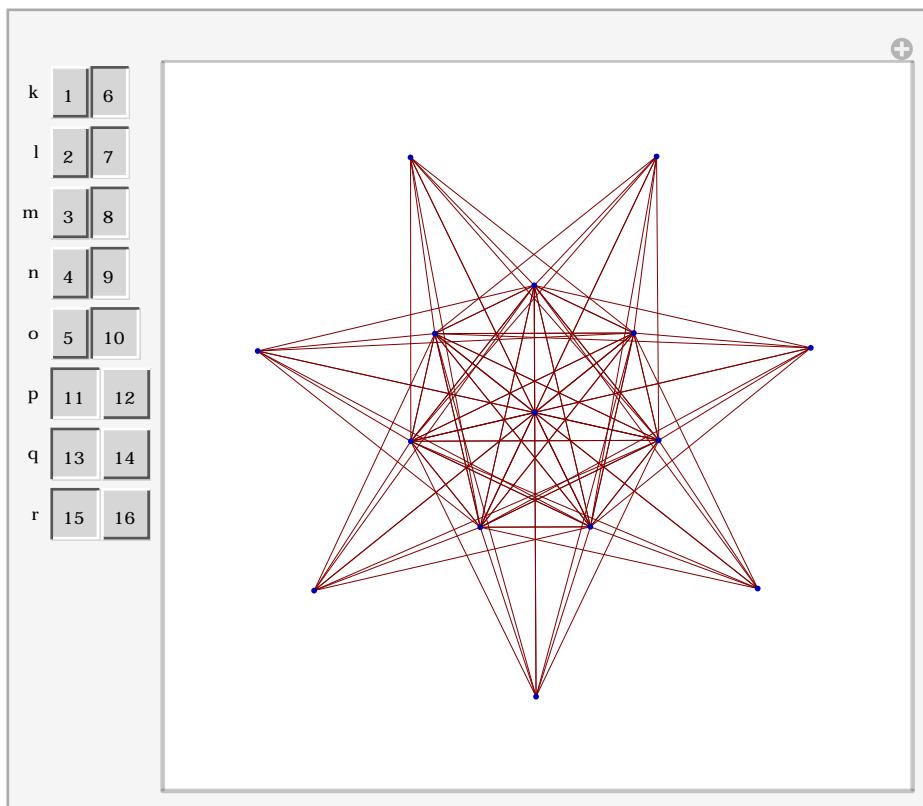
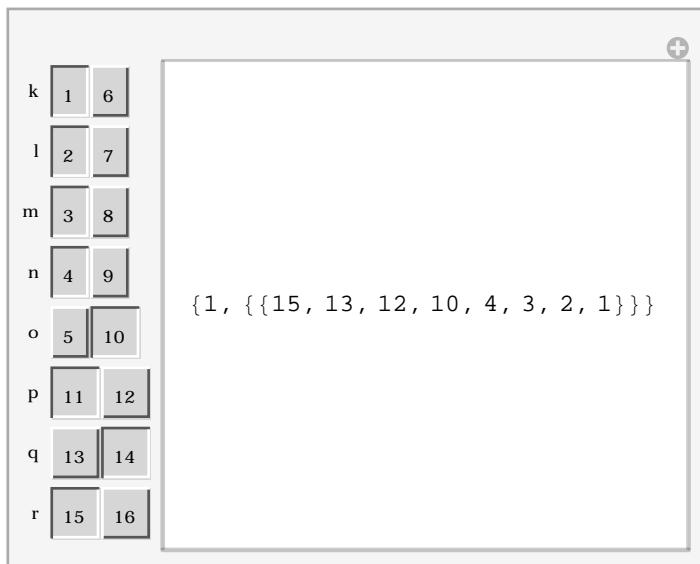
Structure of self - modification for the indicational calculus CI



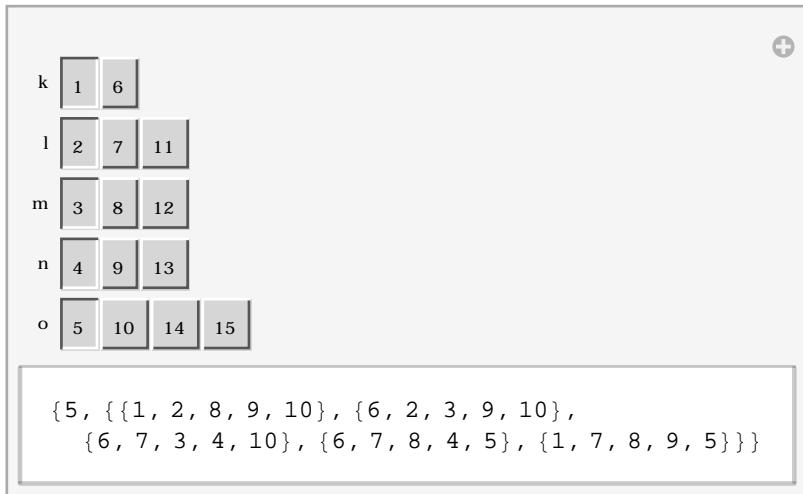
FixedPoints: ECA

The interface includes a toolbar with a slider, a play button, and other controls. Below the toolbar is a code editor window containing the following Mathematica-like code:

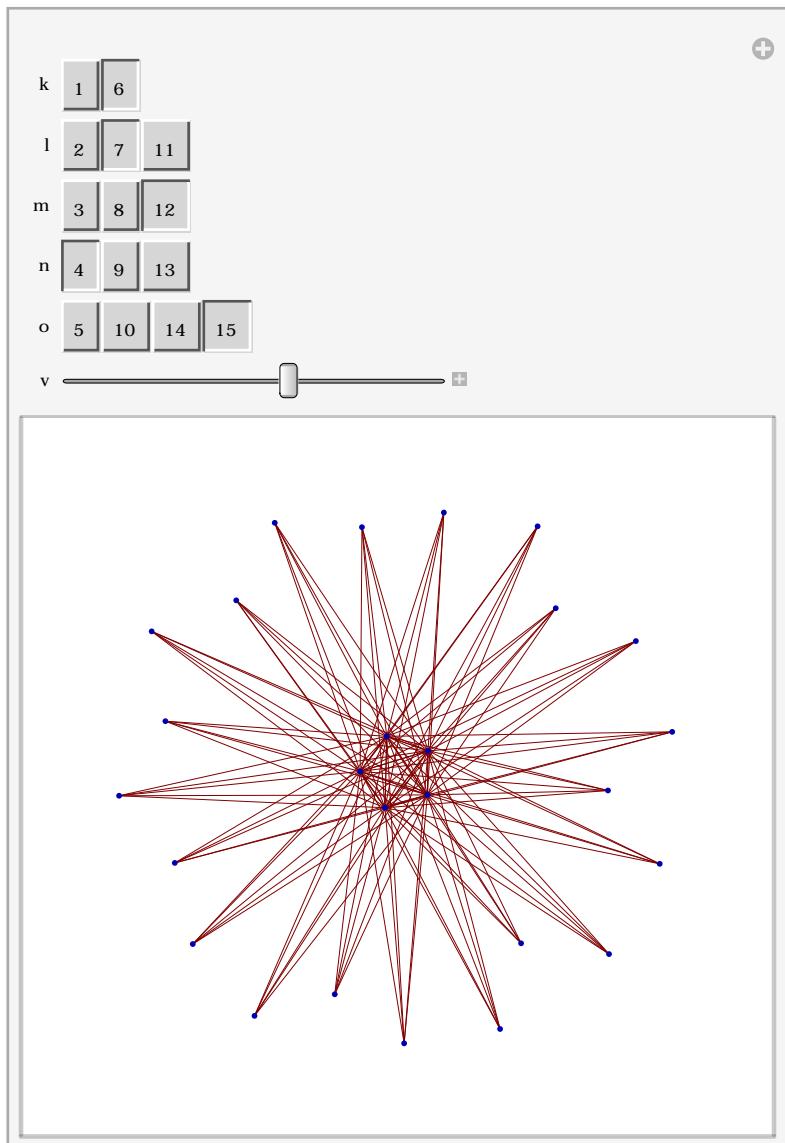
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{ {1, 188, {16, 13, 11, 5, 9, 8, 2, 1}},  
{2, 250, {16, 14, 11, 5, 9, 3, 7, 1}},  
{3, 253, {16, 14, 11, 5, 9, 8, 2, 6}},  
{4, 255, {16, 14, 11, 5, 9, 8, 7, 6}},  
{5, 255, {16, 14, 11, 5, 9, 8, 7, 6}}}
```



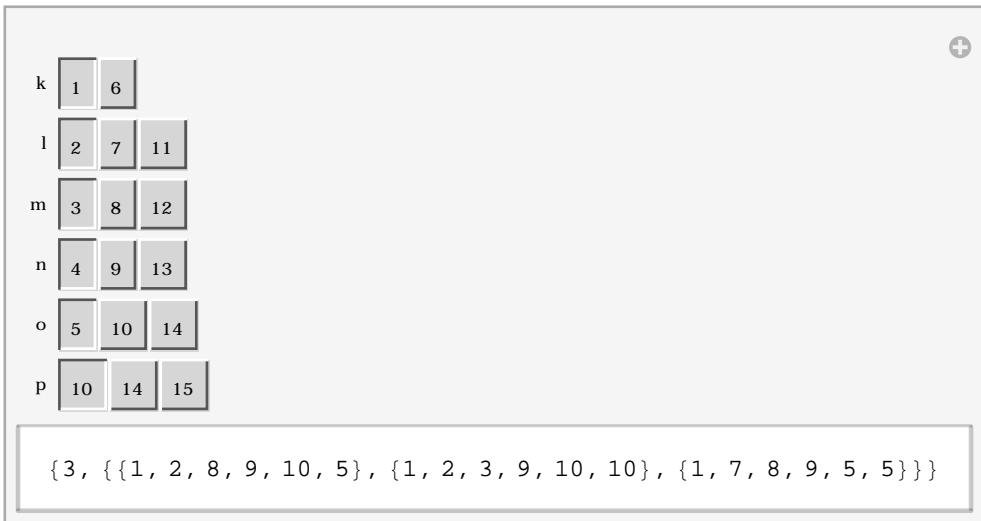
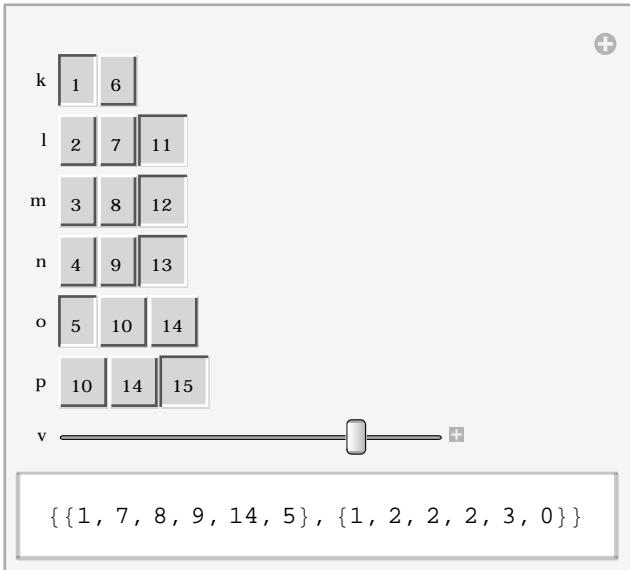
FixedPoints: ruleM



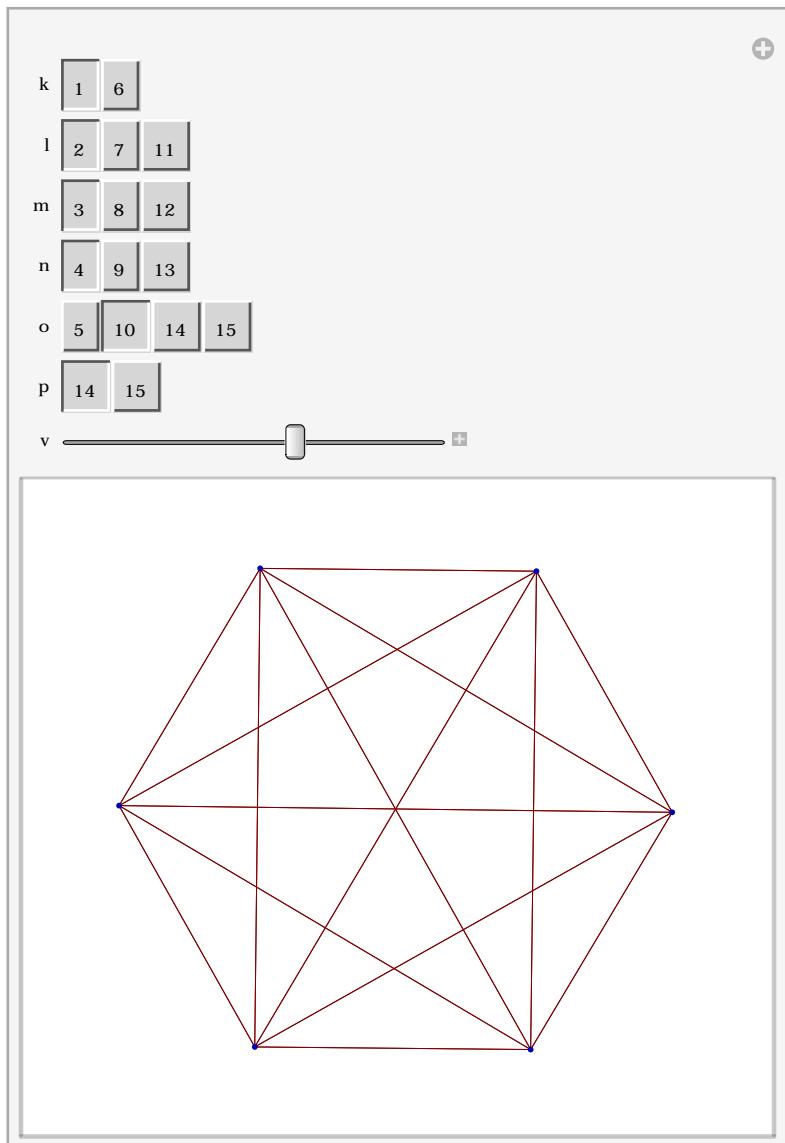
Structure of self - modifications for the morphogrammatic calculus morphoCA DM



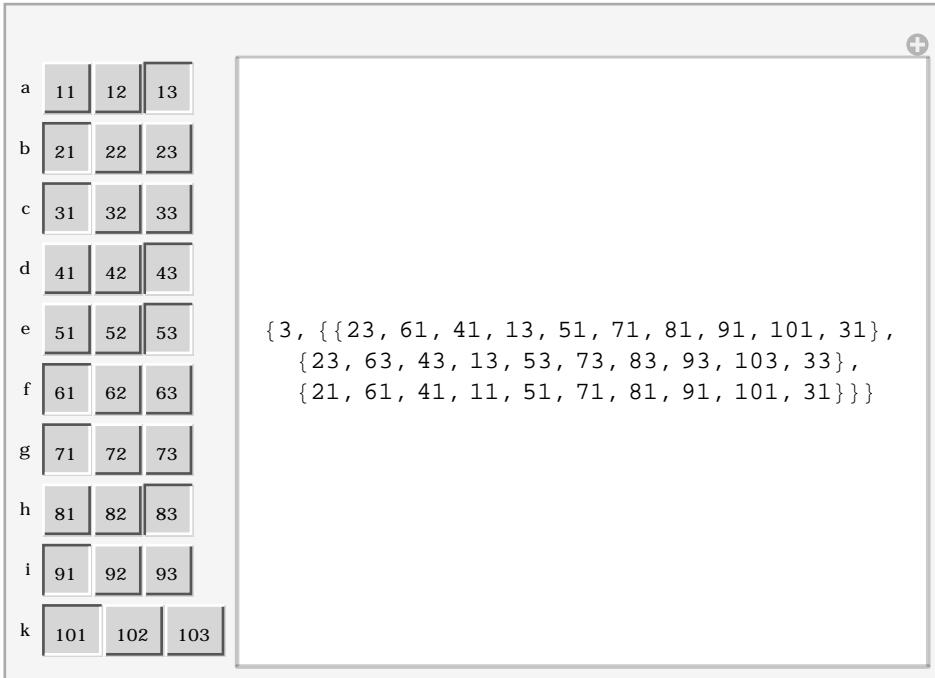
FixedPoints: ruleMN



Structure of self - modifications for the morphogrammatic calculus morphoCA DMN



FixedPoints: ruleCIR



FixedPoints: ruleRCI

FixedPoints: ruleDCKV

a	1111	1112		
b	1121	1122	1123	
c	1211	1212	1213	
d	1221	1222	1223	
e	2121	2122	2123	
f	2211	2212	2213	
g	2221	2222	2223	
h	2111	2112	2113	
i	2131	2132	2133	2130
j	1231	1232	1233	1230
k	2231	2232	2233	2230
l	2311	2312	2313	2310
m	2321	2322	2323	2320
n	2331	2332	2333	2330
o	2301	2302	2303	2300

```
{17, {{1111, 1122, 1213, 1221, 2121, 2113, 2211, 2223,
1233, 2131, 2232, 2312, 2322, 2332, 2303},
{1111, 1122, 1213, 1221, 2122, 2113, 2213, 2222,
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{1111, 1122, 1213, 1221, 2122, 2113, 2211, 2222,
1232, 2131, 2232, 2311, 2321, 2332, 2303},
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1232, 2133, 2231, 2312, 2322, 2331, 2302},
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1233, 2131, 2232, 2313, 2321, 2332, 2302},
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