Self-Replication of the J. Byl Replicator in Cellular Automata Space With Permutations of the State Set.

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Abstract

It has been established that heterochiral self-replication of loop structures in cellular automata (CA) spaces cannot be achieved by pooling a state-transition function with its corresponding mirror transition function because some chiral rules specific to right-handed replication are contradicted by chiral rules specific for left-handed replication. A less-strict functional heterochirality of self-reproduction by structures in CA space, notionally achievable by permutation-transformation of structures and transition functions, was hypothesized. Over all possible state-set permutations, it was found that there is no permutation-transformation of the left-handed form of the J. Byl (1989) state-transition function which corresponds to no contradictions with the right-handed (original) transition function. This result demonstrates that the structure's replication is robustly homochiral.

Keywords: Artificial Life, cellular automata, self-reproduction, origin of life, biological homochirality

Introduction

It has been established by analysis of several instances of self-replicating loop-structures in cellular automata (CA) spaces that self-replication in these systems is homochiral [6][7]. In all of these systems [2][3][4][5], a prospective pooling of a state-transition function supporting self-replication with its mirror transition function cannot work to support both right- and left-handed self-replication within a common CA universe because there are some rules in the transition function that are contradicted by rules in the corresponding mirror-function. This conclusion prompts the question of whether heterochirality of self-replication in a CA universe can be supported by a relaxed definition of heterochirality.

The J Byl structure [2] self-replicates in CA space under a state-transition function based on the von Neumann neighbourhood (CNESW) and five possible active cell-states, *i.e.* the set of cell states including the quiescent state 0 is {0, 1, 2, 3, 4, 5}. Assuming strong rotational symmetry, there are 2016 possible von Neumann neighbourhoods of these cell states, so the size-limit of a quiescent plus five active states transition function is 2016 rules, and there are 6^2016 different state-transition functions of maximal size. These calculations indicate the vastness of the transition-function space. The fully-explicit state-transition function under which the J. Byl structure replicates [6] contains 140 state-transition rules, including all state-preserving rules.

Under any permutation of the state set, states within a CA structure and corresponding state-transition function supporting replication can be comprehensively reassigned without altering the replication dynamics, *e.g.* reassigning all active states 1,2,3,4,5 → 2,1,4,5,3 respectively in both a CA structure and its corresponding state-transition function obviously conserves the development of the system. This suggests the possibility of a permutation-reassignment of the states of a mirror (L) self-replicating loop and its state-transition function, corresponding to an absence of contradictions between this transition function and the untransformed state-transition function of the corresponding R-loop. Subject to no contradictions, a pooling of the permutation-transformed L-loop state-transition function with the untransformed R-loop transition function would support both left- and right-handed replication! (though coexisting L-loop and R-loop replicators would now be mutual-mirrors in a functional sense only).

Figure 1 below shows an R-Loop, its corresponding L-loop (mirror of R-loop), and an example state-set permutation-transformed L-loop, at t = 0. Under the state-transition functions specific for the self-replication of each, each one replicates within 27 iterations.

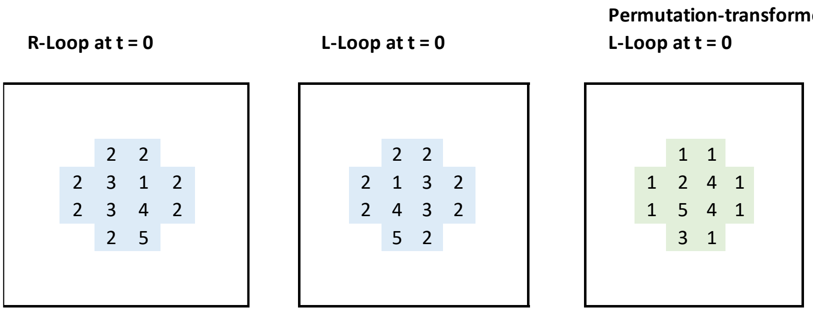

Figure 1. The time = 0 configuration of the original J. Byl self-replicating structure (R-loop) [2], the structure's mirror-form (L-loop), and the time = 0 L-loop structure transformed according to the state-set permutation {1,2,3,4,5} → {2,1,4,5,3}. White space corresponds to the quiescent state 0 common in all cases.

Under the state-transition functions for the self-replication of each of these structures, self-replication of each occurs within 27 iterations. Figure 2 shows the results of the transition functions acting iteratively, at time = 27.

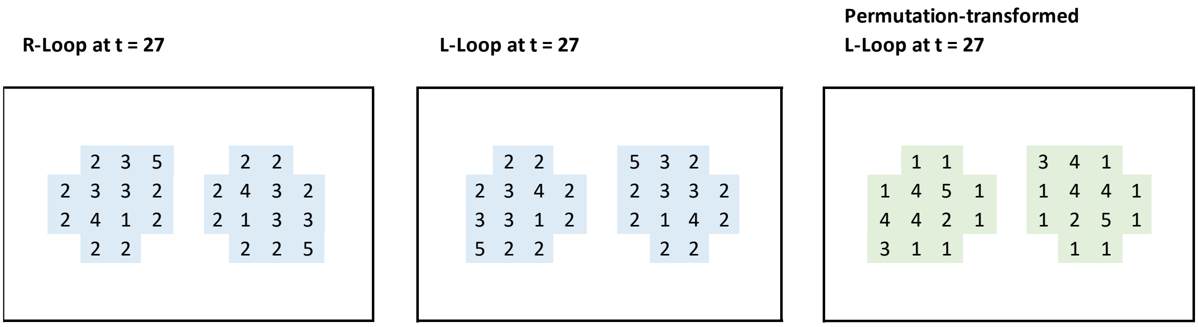

Figure 2. The configurations corresponding to the time = 0 structures shown in Figure 1, after 27 iterations of the respective state-transition functions.

The current work

This work investigates the notion of achieving functional heterochiral self-reproduction of the J. Byl replicator by implementation of state-set permutation-transformations. Always reserving state 0 as the quiescent state, there are 120 permutations of the active state set {1, 2, 3, 4, 5}.

In turn, each of 120 permutation-transformations was applied to the list of rules in the state-transition function for L-loop replication. Contradictions between the transformed L-loop rules and rules in the untransformed transition function for R-loop replication were recognized and counted. The existence of one or more permutation transformations corresponding to no contradictions indicates *functional* heterochiral self-reproduction of the J. Byl replicator. The table below shows the results.

Table 1. Counts of rule-contradictions between the original J. Byl state-transition function (for R-loop replication), and each of 120 permutation-transformations of the corresponding L-loop (mirror) state-transition function. The first 76 permutations listed include one or more states that are not reassigned. All states in the remaining 44 permutations are reassigned. Top of the list is permutation 12345, corresponding to no state-reassignment, so the 20 contradictions-count shown corresponds to the contradictions identified in [6]. The rules shown in the example contradictions indicate the state-transition C → C', in the format CNESW → C'.

State permutation 12345 -->	Count of contradictions	Example contradiction original L-loop rule	Permuted L-loop rule	R-loop rule contradicted
12345	20	00021 --> 0	00021 --> 0	00021 --> 2
12354	24	40212 --> 4	50212 --> 5	50212 --> 4
12435	25	50212 --> 4	50212 --> 3	50212 --> 4
12453	15	40212 --> 4	50212 --> 5	50212 --> 4
12534	15	50212 --> 4	40212 --> 3	40212 --> 4
12543	14	40232 --> 4	40252 --> 4	40252 --> 0
13245	14	20011 --> 2	30011 --> 3	30011 --> 0
13254	18	20011 --> 2	30011 --> 3	30011 --> 0
13425	14	20011 --> 2	30011 --> 3	30011 --> 0
13452	19	20011 --> 2	30011 --> 3	30011 --> 0
13524	12	20011 --> 2	30011 --> 3	30011 --> 0
13542	16	20011 --> 2	30011 --> 3	30011 --> 0
14235	14	30011 --> 0	20011 --> 0	20011 --> 2
14253	12	30011 --> 0	20011 --> 0	20011 --> 2
14325	13	00120 --> 2	00140 --> 4	00140 --> 0
14352	11	00120 --> 2	00140 --> 4	00140 --> 0
14523	9	00120 --> 2	00140 --> 4	00140 --> 0
14532	10	00120 --> 2	00140 --> 4	00140 --> 0
15234	19	30011 --> 0	20011 --> 0	20011 --> 2
15243	16	30011 --> 0	20011 --> 0	20011 --> 2
15324	11	00420 --> 2	00250 --> 5	00250 --> 0
15342	6	31235 --> 5	31532 --> 2	31532 --> 5
15423	10	00420 --> 2	00250 --> 5	00250 --> 0
15432	15	23005 --> 2	54002 --> 5	54002 --> 2
21345	22	10033 --> 0	20033 --> 0	20033 --> 2
21354	22	10033 --> 0	20033 --> 0	20033 --> 2
21435	21	10003 --> 3	20004 --> 4	20004 --> 2
21543	18	30011 --> 0	50022 --> 0	50022 --> 5
23145	14	10033 --> 0	20011 --> 0	20011 --> 2

23415	20	10003 --> 3	20004 --> 4	20004 --> 2
23541	15	30011 --> 0	50022 --> 0	50022 --> 5
24135	15	10033 --> 0	20011 --> 0	20011 --> 2
24315	15	10033 --> 0	20033 --> 0	20033 --> 2
24351	12	10033 --> 0	20033 --> 0	20033 --> 2
25143	12	10033 --> 0	20011 --> 0	20011 --> 2
25314	15	10033 --> 0	20033 --> 0	20033 --> 2
25341	13	10033 --> 0	20033 --> 0	20033 --> 2
31245	14	20011 --> 2	10033 --> 1	10033 --> 0
31425	15	20011 --> 2	10033 --> 1	10033 --> 0
31542	12	20011 --> 2	10033 --> 1	10033 --> 0
32145	30	10003 --> 3	30001 --> 1	30001 --> 0
32154	26	10003 --> 3	30001 --> 1	30001 --> 0
32415	20	00130 --> 1	00340 --> 3	00340 --> 0
32451	16	40252 --> 0	50212 --> 0	50212 --> 4
32514	15	50212 --> 4	40232 --> 1	40232 --> 4
32541	16	40232 --> 4	40252 --> 4	40252 --> 0
34125	17	10003 --> 3	30001 --> 1	30001 --> 0
34215	15	30011 --> 0	20033 --> 0	20033 --> 2
35142	11	10003 --> 3	30001 --> 1	30001 --> 0
35241	16	30011 --> 0	20033 --> 0	20033 --> 2
41235	20	20004 --> 2	10003 --> 1	10003 --> 3
41325	15	20033 --> 2	10033 --> 1	10033 --> 0
41352	15	20033 --> 2	10033 --> 1	10033 --> 0
42135	20	00310 --> 5	00140 --> 5	00140 --> 0
42153	15	40232 --> 4	50212 --> 5	50212 --> 4
42315	25	00310 --> 5	00340 --> 5	00340 --> 0
42351	19	40252 --> 0	50212 --> 0	50212 --> 4
42513	10	00210 --> 0	00024 --> 0	00024 --> 2
42531	13	20252 --> 5	21202 --> 1	21202 --> 2
43125	15	20033 --> 2	30011 --> 3	30011 --> 0
43215	21	20004 --> 2	30001 --> 3	30001 --> 0
45312	11	00310 --> 5	00340 --> 2	00340 --> 0
45321	12	00310 --> 5	00340 --> 1	00340 --> 0
51243	15	10033 --> 0	50022 --> 0	50022 --> 5
51324	12	20033 --> 2	10033 --> 1	10033 --> 0
51342	13	20033 --> 2	10033 --> 1	10033 --> 0
52134	16	50212 --> 4	40252 --> 3	40252 --> 0
52143	16	40212 --> 4	40252 --> 4	40252 --> 0
52314	19	50212 --> 4	40252 --> 1	40252 --> 0
52341	13	40212 --> 4	40252 --> 4	40252 --> 0
52413	13	00120 --> 2	00052 --> 2	00052 --> 5
52431	13	00120 --> 2	00052 --> 2	00052 --> 5
53142	16	20033 --> 2	30011 --> 3	30011 --> 0
53241	18	10033 --> 0	50022 --> 0	50022 --> 5
54312	12	54002 --> 2	21004 --> 4	21004 --> 2
54321	7	00320 --> 3	00340 --> 3	00340 --> 0

21453	17	10003 --> 3	20004 --> 4	20004 --> 2
21534	17	20004 --> 2	10003 --> 1	10003 --> 3
23154	17	10033 --> 0	20011 --> 0	20011 --> 2
23451	15	10003 --> 3	20004 --> 4	20004 --> 2
23514	17	20004 --> 2	30001 --> 3	30001 --> 0
24153	14	10033 --> 0	20011 --> 0	20011 --> 2
24513	9	30011 --> 0	50022 --> 0	50022 --> 5
24531	11	30011 --> 0	50022 --> 0	50022 --> 5
25134	12	10033 --> 0	20011 --> 0	20011 --> 2
25413	13	10003 --> 3	20004 --> 4	20004 --> 2
25431	12	10003 --> 3	20004 --> 4	20004 --> 2
31254	17	20011 --> 2	10033 --> 1	10033 --> 0
31452	12	20011 --> 2	10033 --> 1	10033 --> 0
31524	14	20011 --> 2	10033 --> 1	10033 --> 0
34152	16	10003 --> 3	30001 --> 1	30001 --> 0
34251	12	30011 --> 0	20033 --> 0	20033 --> 2
34512	12	54002 --> 2	21004 --> 4	21004 --> 2
34521	7	00120 --> 2	00340 --> 4	00340 --> 0
35124	16	10003 --> 3	30001 --> 1	30001 --> 0
35214	18	30011 --> 0	20033 --> 0	20033 --> 2
35412	12	23005 --> 2	54002 --> 5	54002 --> 2
35421	11	00420 --> 2	00250 --> 5	00250 --> 0
41253	17	30001 --> 0	20004 --> 0	20004 --> 2
41523	9	50022 --> 5	30011 --> 3	30011 --> 0
41532	13	20004 --> 2	10003 --> 1	10003 --> 3
43152	18	20033 --> 2	30011 --> 3	30011 --> 0
43251	16	30001 --> 0	20004 --> 0	20004 --> 2
43512	12	20004 --> 2	30001 --> 3	30001 --> 0
43521	7	50022 --> 5	10033 --> 1	10033 --> 0
45123	12	00310 --> 5	00140 --> 3	00140 --> 0
45132	12	54002 --> 2	23005 --> 5	23005 --> 2
45213	12	30001 --> 0	20004 --> 0	20004 --> 2
45231	12	30001 --> 0	20004 --> 0	20004 --> 2
51234	15	10033 --> 0	50022 --> 0	50022 --> 5
51423	11	50022 --> 5	30011 --> 3	30011 --> 0
51432	12	20004 --> 2	10003 --> 1	10003 --> 3
53124	12	20033 --> 2	30011 --> 3	30011 --> 0
53214	16	10033 --> 0	50022 --> 0	50022 --> 5
53412	12	20004 --> 2	30001 --> 3	30001 --> 0
53421	8	50022 --> 5	10033 --> 1	10033 --> 0
54123	7	34423 --> 3	12241 --> 1	12241 --> 4
54132	11	00320 --> 3	00140 --> 1	00140 --> 0
54213	7	10033 --> 0	50022 --> 0	50022 --> 5
54231	8	10033 --> 0	50022 --> 0	50022 --> 5

None of the counts of contradictions is zero, so it is immediately clear that functional heterochirality of self-reproduction of the J. Byl structure as defined above is not possible. Within the domain of the state-set {0, 1, 2, 3, 4, 5}, the homochiral self-reproduction of the structure can now be recognized as ***robustly*** homochiral. (It is also notable that rule contradictions are not constrained to chiral rules).

Discussion

Commonly, it is the behaviour of Artificial Life implementations that is studied. This work is part of a line of enquiry into the internal logic of some Artificial Life implementations, and its potential relevance to real biology. The hope is that these kinds of observations about homochirality made from the "bottom up" (simple abstract logic → biology) can complement the longer history of realist inquiry into the ongoing enigmas of biological homochirality, see [1].

By exploring a larger state-transition function rule space by permutation-transformations of rules, it is shown here that replication of the J. Byl structure subject to the state-set {0, 1, 2, 3, 4, 5} remains resolutely homochiral. I conjecture that a similar permutation-transformation exercise applied to the other CA homochiral self-replicating structures [3][4][5] previously studied [7] would deliver the same conclusion.

An extravagant solution for engineering functional heterochirality of self-reproduction is enabled by a doubling of the size of the active state set, *i.e.* for the J. Byl replicator, an expansion from {0, 1, 2, 3, 4, 5} to {0, 1, 2, 3, … , 9, 10}. Mirror (L-loop) self-replication can then be implemented from the state-subset {0, 6, 7, 8, 9, 10}. This allows left- and right-handed self-replication to coexist, but only by pooling together two disjunct transition functions. This solution has been discussed previously [7] for a different system [3].

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