Systems of State Set-Permutated Langton Cellular Automata Replicators Compared with Systems of Byl Replicators

Perry W. Swanborough

Abstract.

Methods applied to the Byl cellular automata (CA) replicator (1989) which demonstrated strict homochirality and functional heterochirality of replication were applied to the earlier Langton CA replicator (1984). Langton replicators varying by state set permutations group into systems of two members each, replicating under a single system-specific cell state transition function. Notably, the Langton systems are smaller than the homochiral Byl replicator systems of three or four members. There are fundamentally two Langton systems distinguishable by the non-existence of permutation transforms which interconvert either one to the other, so in one sense there is non-trivial state-set permutation variation in the set of permutated Langton systems that does not exist in the set of permutated Byl systems.

Keywords: artificial life, biochirality, Byl replicator, cellular automata, Langton replicator, permutation

Introduction

In the absence of direct evidence showing the processes of ancient abiogenesis and immediately subsequent evolution, researchers are compelled to investigate these questions by less direct means. Of the prospective active lines of enquiry, speculation about "life as it could be" (Artificial Life, or Alife) may help to elucidate credible pathways from the pre-biotic to the biotic [10]. Replication is characteristic of life, and as a topic in its own right, replication can be studied with the help of artificial abstractions.

In the field of cellular automata (CA), several replicating structures have been developed, *e.g*. [1, 2, 3, 4] and a feature of these is that they share the property of homochirality with organic life [7]. Identification of commonalities in simple abstractions of life processes may indicate some universal principles of life.

In the 1980s and nineties, a problem of interest in the Alife community was identification of the simplest possible CA structure capable of non-trivial self-replication. The Byl replicator [1] is a substantial simplification of the Langton replicator [2] and as such I accepted the Byl structure as convenient for further study, in particular for consideration of biochirality-related questions [6, 7, 8, 9]. In this study I extend some of my methods of Byl replicator analysis to the 1984 Langton replicator [2].

Recap. of the Byl replicator findings

The Byl structure as originally published [1] replicates under a state transition function of von Neumann neighbourhood rules (*i.e.*, the five-cell neighbourhood of N, S, E, W and centre are inputs to the state transition of the centre cell from time t to time t+1). Both the state transition function and the replicator structure are homochiral: the right-handed (R-) form of the replicator structure cannot be superimposed on its mirror-transformed (L-) form, and additionally a comparison of the mirror transformation of the state transition function with its original (R-) formulation identifies contradictory rules preventing coexistence of left- and right-handed replication under one consistent state transition function [6].

Functional heterochirality of Byl replication

The original von Neumann neighbourhood rules facilitating Byl structure replication can be replaced by functionally-equivalent Moore neighbourhood rules (*i.e.*, all cells in the local nine-cell neighbourhood are inputs to the state transition), which expands the list of explicit rules comprising the state transition function. A combination of an appropriate permutation of the active state set {1, 2, 3, 4, 5} applied to one chirality of the replicator structure (R- or L-), and a corresponding Moore-rules state transition function supporting replication of both R- and L-structures enables *functional* heterochirality of replication [8]. In other words, left- and right-handed replication can coexist, but only with introduction of a different chiral asymmetry: a permutation of the active state set applied to just one of the two chiral forms [8].

Subsequent work established that sets of several state set-permutated structures replicating under one common system-specific state transition function (*systems*) exist [5, 9] and both functionally-heterochiral and homochiral systems were identified. Tables 1 and 2 below list the Byl replicator systems.

Table 1. This Table is reproduced from [5]. The columns show five systems of right-handed (R-) state set-permutated Byl replicators. All members of each system replicate under one system-specific state transition function.

R-12345	**R-12345**	**R-12345**	**R-12345**	**R-12345**
R-25413	**R-12354**	**R-12354**	**R-12354**	**R-12354**
R-25431	**R-41532**	**R-51432**	**R-14523**	**R-15423**
			R-14532	**R-15432**

Table 2. This Table is reproduced from [5]. The four columns show heterochiral systems of state set-permutated Byl replicators. All members of each system replicate under one system-specific state transition function.

R-12345	**R-12345**	**R-12345**	**R-12345**
L-14325	**L-21435**	**R-12354**	**R-12354**
		L-14523	**L-15432**
		L-14532	**L-15423**

This study: functional heterochirality of the Langton replicator

In this study, the methods which identified functional heterochirality of the Byl replicator and identified the system groupings was applied to the Langton replicator [2] from which the Byl replicator was derived as a simplification. Figure 1 shows the Langton replicator at Time = 0 and at Time 151 when a replication cycle has completed.

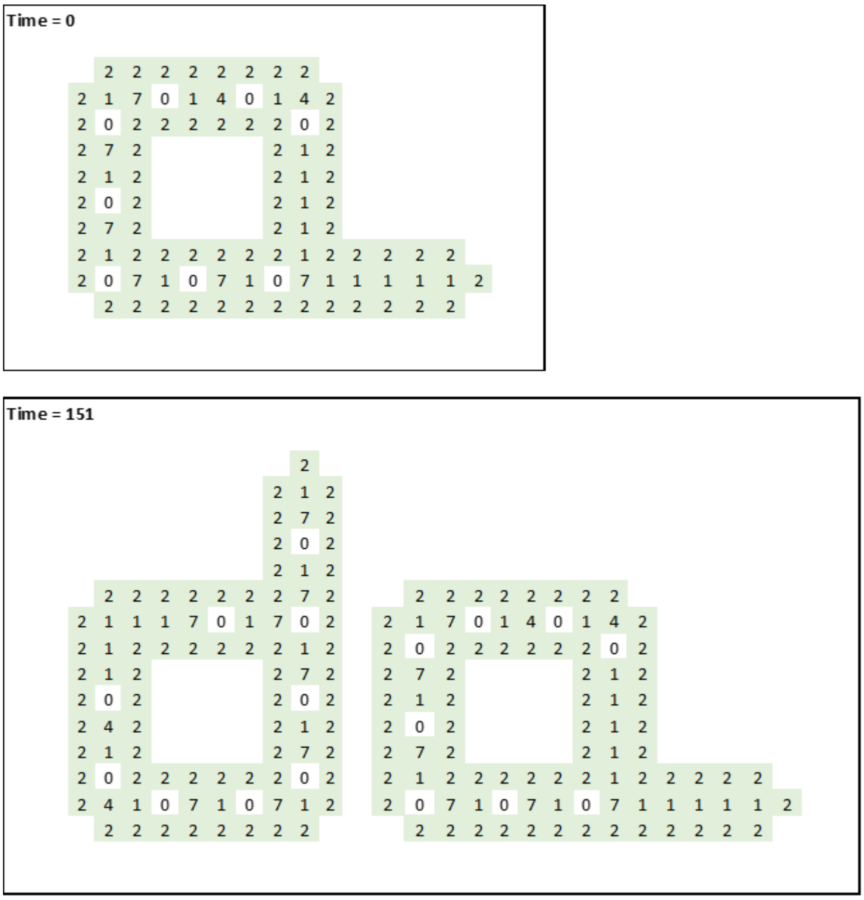

Figure 1. One replication cycle of the Langton replicator [2] is achieved in 151 time-steps. After a child structure is produced to the right of the parent, a further replication cycle by the parent is directed upward ("north"). States 3, 5 and 6 do not appear at times 0 and 151, but do appear during the course of a replication cycle. The quiescent state is state 0 represented as white space background, but also exists as a state of the structure's information loop where it is explicitly labelled. (Applying the nomenclature scheme defined for the Byl replicator and its state set permutated versions in [5], this original form of the Langton replicator is R-1234567.)

Like the original Byl replicator, the Langton replicator state transition function incorporates von Neumann neighbourhood state transition rules, but the active state set for the Langton replicator {1, 2, 3, 4, 5, 6, 7} is larger. There are 7! (5040) permutations of the Langton replicator active state set compared with 120 permutations of the Byl replicator state set, so systematically comparing state transition functions with different applied state set permutations to identify contradictions is a much larger task in the case of the Langton replicator compared with the Byl replicator analysis. However, the task applied to Langton replication is tractable, and the results are reported here.

As for the Byl replicator analyses, the original von Neumann neighbourhood state transition function facilitating Langton loop replication was replaced with the functionally-equivalent Moore neighbourhood state transition function. The state transition function as originally published consists of 219 von Neumann neighbourhood state transition rules, but twelve of these are superfluous [4]. The original state transition function of 207 necessary rules expands to 501 Moore neighbourhood rules required to support functional heterochirality of replication. The search for rule contradictions required 5039 pairwise comparisons of permutated state transition functions to find all of the permutated replicators which coexist with the original form R-1234567, and then further comparisons of these with each other to deliver the results reported below. Two separate rule comparison searches were done to identify both functionally-heterochiral and homochiral system categories.

Results

All systems of state-permutated Langton replicators consist of two members – they are smaller than the Byl homochiral systems of three or four members. There are eight heterochiral systems (Table 3 and Table 4, right column) and four homochiral systems (Table 4, left column).

Table 3. Functionally-heterochiral systems of Langton replicators sharing a common member.

R-1234567 L-5326714	**R-1234567 L-5327614**	**R-1234567 L-6327145**	**R-1234567 L-6327154**

Table 4. Homochiral systems (left column) with corresponding functionally-heterochiral systems (right column). In each pair of systems (rows), one of the members can exist in either R- or L- form while preserving replication of both system members under one consistent system-specific state-transition function.

R-1234567 R-4327615	**R-1234567 L-4327615**
R-1234567 R-4326715	**R-1234567 L-4326715**
R-1234567 R-6321745	**R-1234567 L-6321745**
R-1234567 R-6321754	**R-1234567 L-6321754**

As shown in [9], Byl systems can be walked across permutation space by applying a consistent permutation transformation to all system members per step. If the transformations applied are limited to those which correspond to the minimum possible number of replacements of system members sufficient to drive a walk, the walks are restricted to visiting only a subset of the maximum range of permutation possibilities. This may be relevant to questions of ergodicity in evolution.

Table 5 below shows walks of the state set permutated Langton R-systems listed in the left column of Table 4. Each of the four walks across permutation space shown are driven by application of a single permutation transformation which preserves one state set permutated replicator from time t to time t+1, *i.e.*, minimizing the rate of permutation-driven change. The four walks shown in Table 5 illustrate a dynamic of short loops within permutation space corresponding to a minimum rate of change.

Table 5. Four walks of Langton R-systems across permutation space. The systems shown at iteration 0 (first row) are the homochiral systems listed in the left column of Table 4. Each walk is driven by iterative application of a permutation transformation shown at the top of the table. As the permutation transformations correspond to just one system member change per time step (minimal change), all walks form short-cycle loops as shown with colour-highlighting.

	Permutations applied successively to systems: 1234567 -->			
Iteration	**4326715**	**4327615**	**6321754**	**6321745**
0	R-1234567 R-4326715	R-1234567 R-4327615	R-1234567 R-6321754	R-1234567 R-6321745
1	R-4326715 R-6231547	R-4327615 R-7235146	R-6321754 R-5236471	R-6321745 R-4236517
2	R-6231547 R-1324765	R-7235146 R-5326471	R-5236471 R-7325146	R-4236517 R-1324765
3	R-1324765 R-4236517	R-5326471 R-6231754	R-7325146 R-4237615	R-1324765 R-6231547
4	R-4236517 R-6321745	R-6231754 R-1324567	R-4237615 R-1324567	R-6231547 R-4326715
5	R-6321745 R-1234567	R-1324567 R-4237615	R-1324567 R-6231754	R-4326715 R-1234567
6	R-1234567 R-4326715	R-4237615 R-7325146	R-6231754 R-5326471	R-1234567 R-6321745
7		R-7325146 R-5236471	R-5326471 R-7235146	
8		R-5236471 R-6321754	R-7235146 R-4327615	
9		R-6321754 R-1234567	R-4327615 R-1234567	
10		R-1234567 R-4327615	R-1234567 R-6321754	

Discussion

While there are 5040 permutations of the Langton replicator's seven-element active state set, and just 120 permutations of the Byl replicator's five-element active state set, systems of Langton state set-permutated replicators are all restricted to size two (Tables 3 and 4), but Byl systems include sizes of three or four (Tables 1 and 2).

Three-member homochiral Byl systems and separately, four-member homochiral systems, are comprehensively interconvertible between each other by application of permutation transforms [9], so depending on objectives, we can choose to interpret the complete range of state-set permutated homochiral Byl systems as just one fundamental system representable by any one of a set of cell-state labelling permutations. By contrast, the two-member homochiral Langton systems are not comprehensively interconvertible. The four homochiral systems shown by colour highlighting in Table 5 correspond to two pairs of systems (purple/blue and gold/green). Each of the system pairs are *within*-pair interconvertible by permutation transform, as shown by the colour highlighting in Table 5, but it is clear that there is no possible interconversion by permutation transform *between* system pairs. To illustrate with an example, there is no permutation transform which will convert system R-6321745, R-1234567 (purple highlight) to system R-1234567, R-4327615 (green highlight). The difference between such pairs of systems cannot merely be permutation of state labelling – there is no interpretation other than that they are pairs of systems between which there is system-specific shifting of functions, yet paradoxically, these system pairs as represented in Table 5 share the replicator form R-1234567.

Also noteworthy is that the number of Langton systems sharing a common state set permutated replicator expressed as a proportion of the number of state set permutations (12/5040) is much less than the corresponding Byl replicator proportion (nine systems sharing a common replicator/120 permutations). We see that proportionally less Langton system variation is possible by means of application of state set permutations.

Following these observations, we can pose an open question: Do these observations point to a universal principle about the increasing size of replicators and their variation within the family of CA loop replicators?

Considering each of the rows of Table 4, it can be observed that left-column systems show the same state set permutation identities as the corresponding right-column systems. The consistent difference between the left- and right-column systems is the switching of handedness of one system member between the corresponding row entries. As an example, we might consider system R-1234567 and L-4327615 transforming to homochiral system R-1234567 and R-4327615 (Figure 4, row 1) by some process of L-4327615 switching to its R- form. This might be considered as analogous to a prospective step in the emergence of homochirality in protobiology.

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