A Comprehensive Identification of Coexisting Cellular Automata Replicators Varying by State-Set Permutations.

Perry W. Swanborough

Abstract

A study to determine state-set permutated replicators of opposite handedness coexisting with John Byl's 1989 replicator subsequently suggested the task of identifying the comprehensive set of all left- and right-handed state-set permutated replicators coexisting with the Byl replicator. This work reports the lists of both left- and right-handed state-set permutated replicators coexisting with replication of the original Byl structure replicating under Moore state-transition rules, and as such supplements previous work described in viXra:2101.0075 and viXra:2107.0172.

Keywords: abiogenesis**,** artificial life, astrobiology, cellular automata, homochirality, origin of life, replicator

Introduction

A persisting question in origin-of-life studies is whether metabolism developed before the appearance of replicators (Oparin-Haldane hypothesis), or whether replicators preceded metabolic chemistry. Separate from the question of whether or not metabolic pathways historically preceded replicators, the identity of the hypothetical ancestral replicator is unknown. Ribonucleic acid (RNA) has been proposed as the ancestral replicator ("RNA world" [3]), but alternatively the ancestral replicator may have been an unknown structure displaced by later replicators, leaving no subsequent evidence. To explore the question of what an ancestral replicator could have been (or could be within the broad astrobiology perspective), researchers can consider replication from an abstract information-processing perspective [2]. This may suggest avenues of research further assisting progress in identifying credible chemical and biophysical models.

Replication has been studied with cellular automata (CA) which are systems supporting structures encoded in grids of spatially-discrete cells and which develop in discrete time steps by iterative application of cell state transition rules. A comprehensive collection of state transition rules is the state transition function of a CA system. Structures in CA space which replicate under application of an appropriate state transition function have been developed to study the minimal complexity and information requirements of replication, *e.g.*, [4], simplified in [1].

Replication of a CA structure described by John Byl in 1989 [1] is facilitated by a state transition function consisting of rules incorporating the von Neumann neighbourhood, *i.e.*, the states of the N, S, E, and W neighbours of a cell are the neighbour inputs which determine the change of a cell's state to its new state at each iteration. Replication of the Byl structure is chiral in the sense that there is no single state transition function which facilitates replication of both the right- and left-handed forms of the replicator [7]. However, it has been observed that with an appropriate state transition function consisting of Moore neighbourhood rules (all eight immediate neighbour states are inputs), and particular permutations of the active state set {1, 2, 3, 4, 5} applied to one chiral form, *functional* heterochiral replication can be achieved [5][6].

This work

In consideration of the question of how heterochiral replication could be possible, the focus of the work described in [5] was to find oppositely-handed replicators coexisting with the Byl replicator under one state transition function (functional heterochiral replication). The success of finding some left-handed replicators coexisting with the right-handed Byl replicator by the application of state-set permutations led to the finding that there are cases of *two* left-handed replicators coexisting with the original right-handed replicator and with each other [6].

These results have suggested the more-general question of the comprehensive range of replicator variation by means of chiral application of state-set permutations, *i.e.*, are there also cell state-permuted replicators of the same chirality as the original replicator which coexist with it? These can be considered with the previously-discovered instances of functional heterochiral replication to establish a comprehensive identification of replicator variation by means of applying state-set permutations.

A simple scheme of nomenclature including handedness and cell state-set permutation is helpful in the current work. First, if we designate the original published replicator ([1], and illustrated in Figure 1 below, blue highlight) as right-handed (R), and the specific assignment of state labels to its cells as 12345 (unchanged permutation 12345 → 12345), the original replicator can be referred to as R-12345. A variant of the original replicator can be described by reference to the label R-12345 by specifying its chirality (R- or L-) followed by the permutation applied to the state set. To illustrate, a left-handed replicator (mirror of the right-handed form) with states 2 and 4 exchanged (12345 → 14325) is described as L-14325. In Figure 1 below, L-14325 is shown in green to the left of the R-12345 structure shown in blue. As reported in [6], replication of each coexists in one CA space under one common Moore rules cell state transition function.

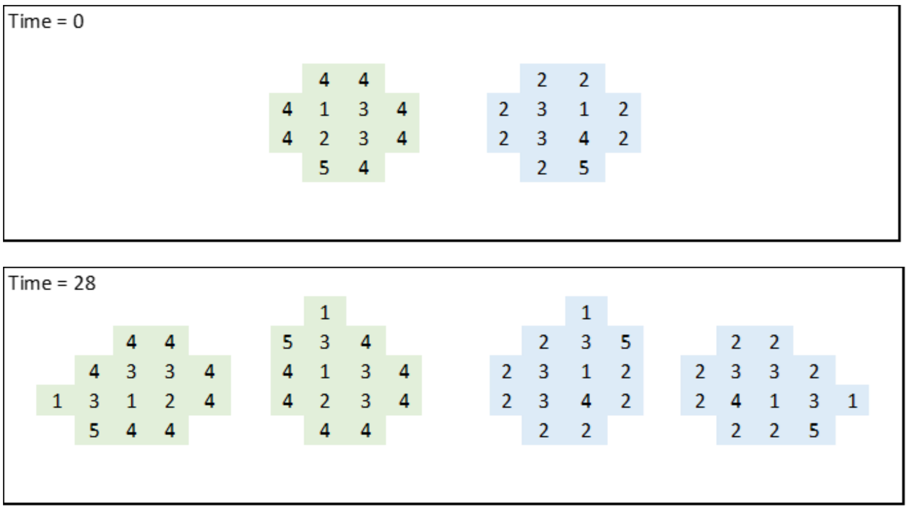

Figure 1. Applying the 12345 → 14325 cell state-set permutation only to L-loop replication, and the corresponding comprehensive and consistent (*i.e.*, no internal contradictions) Moore rules state transition function to both L-loop (L-14325, green structure) and R-loop (R-12345, blue structure) replication, functional heterochirality of self-replication is achieved. This figure is reproduced from [6]. White space corresponds to the quiescent state 0.

Method and Results

The R-12345 transition function consisting of the Moore state transition rules sufficient for one cycle of replication was transformed by application of the other 119 permutations of the active state set {1, 2, 3, 4, 5}. Each of the 119 permutated transition functions was compared with the R-12345 transition function to identify the contradictory rules, *i.e.*, rules applying to common cell-state neighbourhoods but specifying different state transitions. Absence of rule contradictions identified the coexistence of replication of R-12345 and replication of some of the permutated structures. The resulting groupings of structures which coexist as replicators shown in Tables 1 and 2 below were deduced by further comparisons between each other of the permuted transition functions consistent with replication of R-12345.

Table 1. Five sets (columns) of coexisting R-replicators, each including R-12345. A single state transition function of Moore neighbourhood state-transition rules specific to each column facilitates replication of all members of each column. Replication in each of these five CA "universes" is absolutely homochiral – no left-handed (L-) replication coexists with replication in any of these.

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. Four sets (columns) of coexisting replication of R- and L-replicators, each including the original structure R-12345. A single state transition function of Moore neighbourhood rules specific to each column facilitates replication of all members of each column. The left-most columns 1 and 2 correspond respectively to Figures 1 and 2 in [6], with Figure 1 reproduced as Figure 1 in this paper. The right-most columns (3 and 4) both include R-12354 which was not included in corresponding Figures 3 and 4 in [6]. (The focus of work described in [6] was restricted to finding the L-replicators co-replicating with R-12345.)

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

Figures 2 and 3 below illustrate coexistence of replication of the four structures listed in columns 3 and 4 respectively of Table 2 above. The colour-coding of the columns 3 and 4 entries of Table 2 above corresponds to the colour-coding shown in the Figures.

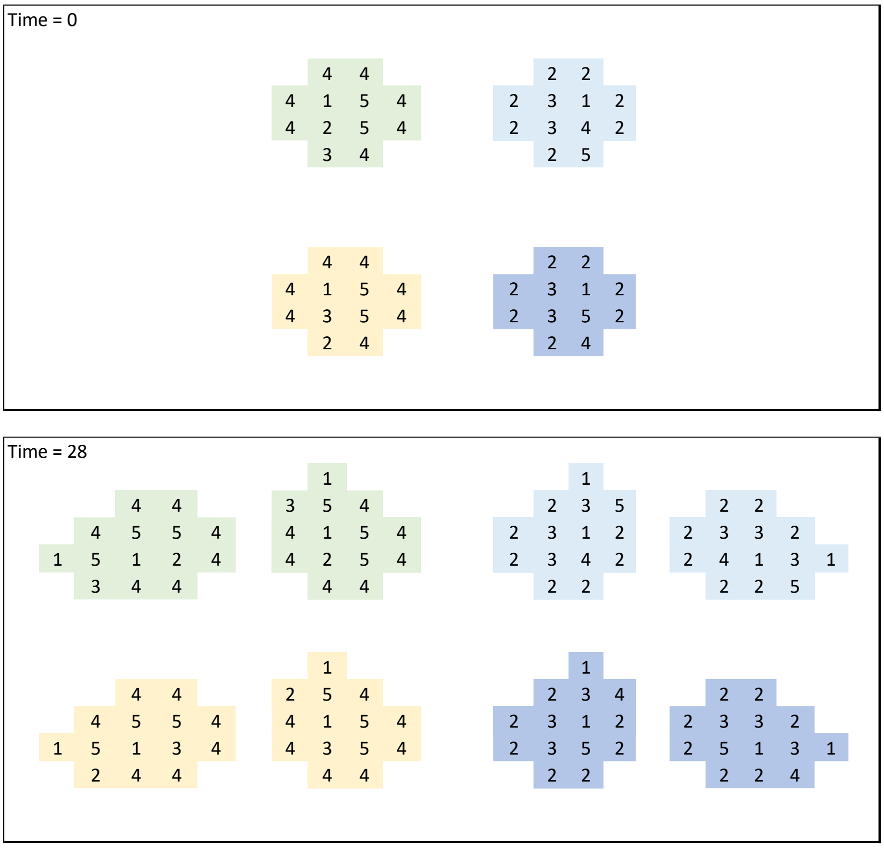

Figure 2. The Moore rules state-transition functions supporting L-loop replication under state-set permutations 12345 → 14523 (L-14523, green), 12345 → 14532 (L-14532, gold) and the state transition functions supporting replication of R-12354 (deep blue) and R-12345 (pale blue) together incorporate no contradictory rules, so a pooling of the R-12345 replication state transition function with the other three state-transition functions delivers one comprehensive, consistent transition function which supports replication of all four structures within a common CA universe. This Figure is Figure 3 from [6] supplemented with the addition of structure R-12354.

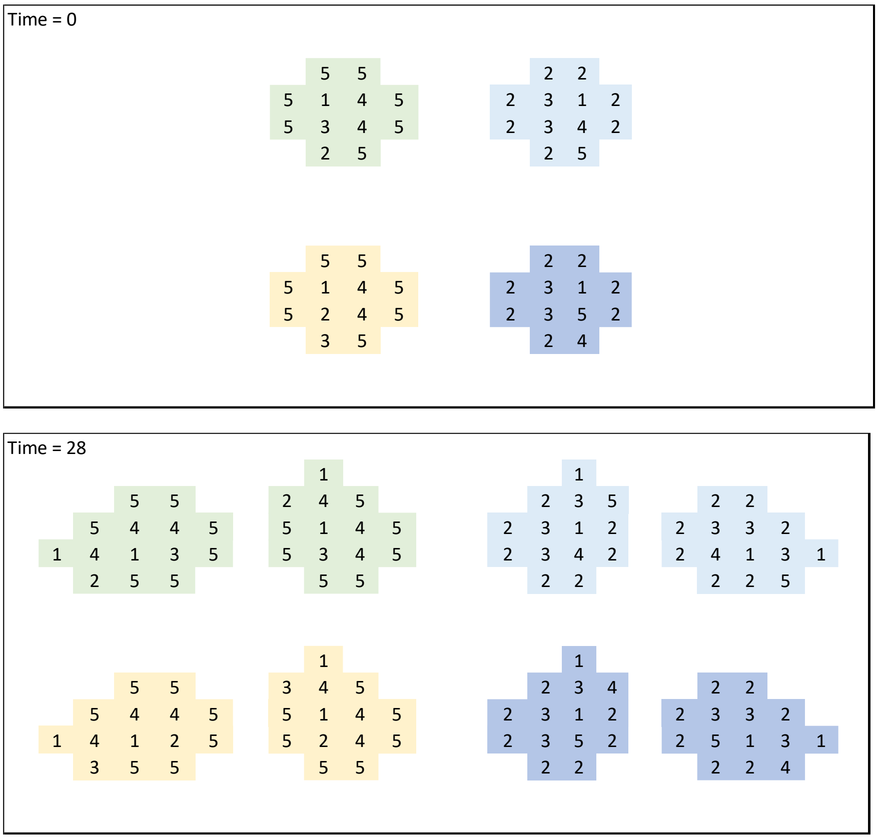

Figure 3. The Moore rules state-transition functions supporting L-loop replication under state-set permutations 12345 → 15432 (L-15432, green), 12345 → 15423 (L-15423, gold) and the state transition functions supporting replication of R-12354 (deep blue) and R-12345 (pale blue) together incorporate no contradictory rules, so a pooling of the R-12345 replication state transition function with the other three state-transition functions delivers one comprehensive, consistent transition function which supports replication of all four structures within a common CA universe. This Figure is Figure 4 from [6] supplemented with the addition of structure R-12354.

Discussion

R-12345 replicating under its original von Neumann neighbourhood state transition function [1] does not coexist with L-loops or R-loops incorporating any permutation of the state-set [7]. Each of the L- or R-loops replicating under a state transition function of von Neumann rules can only exist by itself in a CA environment, so all of the R-loops and, separately, all of the L-loops are identical because permutations of the state set are merely state labelling variations.

By contrast, the coexistence of multiple state-set permutated structures replicating under a common transition function of Moore state-transition rules corresponds to reassignments of cell state roles. To illustrate, R-12345 and L-14325 structures coexist as replicators (Figure 1) so with reference to R-12345, component 4 swaps its role with boundary component 2 in the coexisting left-handed form of the replicator.

Figure 4 below illustrates that three of the five states in the active state set {1, 2, 3, 4, 5} form a 2x2 cell array (1,3,3,4) in the structure which serves as an *information loop*. The 2x2 cell information loop functions simultaneously as instructions directing the replication of the structure, and as data which are replicated into a descendant structure. The four-cell information loop is therefore a very simple analogy of a biological genome which is the recipe for construction of descendants while also being copied as data into next-generation descendants.

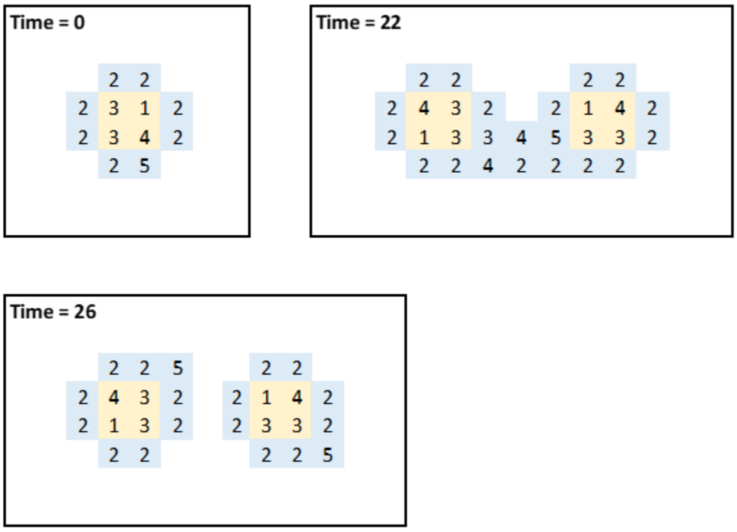

Figure 4. The highlighted 2x2 cell structure of states 1,3,3,4 within R-12345 shown at Time = 0 can be interpreted as the information loop which directs the replication of the John Byl structure. At Time = 22, a replication cycle is not yet completed, but the four-cell information loop has already been replicated. By Time = 26, a replication cycle has completed and each of the separated instances of the replicator continues its own replication cycle under the direction of its own copy of the information loop.

The 120 (5x4x3x2x1) permutations of the active state set {1, 2, 3, 4, 5} can be organized into sixty pairs with a common four-cell information loop each (*e.g.*, permutation 12345 shares the information loop 1,3,3,4 only with permutation 15342 which swaps states 2 and 5). No pair of structures corresponding to any of the sixty common information loop pairs coexist as replicators and all of the sixty pairs are essentially the same pair - the only difference is state-labelling variation. We can see that state-set permutation variation of structures which preserves information loops does not support coexistence of replication. Conversely, no coexisting replicators (the replicators comprehensively listed and grouped in Tables 1 and 2) share any common information loop. We see that coexisting replication corresponds specifically to information loop (genome) variation but genome variation does not guarantee coexistence of replication, given that there are also many subsets of structures over ranges of state-set permutations that neither share information loops **or** coexist as replicators.

References

[1] J Byl, Self-reproduction in small cellular automata, *Physica D* **34** (1989) 295-299.

[2] P Davies, *The Demon in the Machine*, Allen Lane (Penguin Random House), 2019.

[3] W Gilbert, The RNA World, *Nature* **319** (1986), 618.

[4] CG Langton, Self -reproduction in cellular automata, *Physica D* **10** (1984) 135-144.

[5] PW Swanborough, Functional Heterochirality of Replication of the J. Byl Self-Replicating structure: A Moore Rules State-Transition Function and Cell State-Set Permutations, *viXra:2101.0075* (2021).

[6] PW Swanborough, Instances of Functional Heterochiral Replication of the J. Byl Structure Supported by Two State-Set Permutations, *viXra:2107.0172* (2021).

[7] PW Swanborough, Self-Replication of the J. Byl Replicator in Cellular Automata Space With Permutations of the State Set, *viXra:2004.0070* (2020).