**Functional Heterochirality of Replication of the J. Byl Self-Replicating Structure: A Moore Rules State-Transition Function and Cell State-Set Permutations.**

Perry W Swanborough

### Abstract

Heterochiral self-replication of loop structures in cellular automata spaces cannot be achieved by pooling a state-transition function supporting self-replication with its corresponding mirror-transformed transition function because some chiral rules specific to right-handed replication are contradicted by chiral rules specific for left-handed replication. In a subsequent study, a less-strict functional heterochirality of self-replication, notionally achievable by application of state-set permutation-transformation to structures and state-transition functions was investigated. Although this strategy reduces the number of rule contradictions between left-handed and right-handed self-replication, state-set permutations applied to left-handed replication do not enable functional coexistence of left- and right-handed self-replication. This work describes the consequences of rewriting von Neumann state-transition rules as a larger set of corresponding Moore state-transition rules. It was observed that there are less state-transition rule contradictions between left- and right-handed self-replication under the Moore rules state-transition function. The observations that state-set permutation-transformations and Moore state-transition rules independently reduce rule contradictions between left- and right-handed self-replication suggested the hypothesis that both strategies implemented together may reduce rule contradictions between left- and right-handed self-replication to zero, enabling functional coexistence of left- and right-handed self-replication. This work reports success in implementing functional coexistence of left- and right-handed self-replication of the J. Byl structure (1989) by application of a Moore rules state-transition function, and any one of six state-set permutation transformations applied to left-handed self-replication.

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

### Introduction

An important unsolved question in biology is the question of why biology is homochiral. Specifically, the amino acids of life are the L (not D) enantiomers (excepting achiral glycine), and the sugars of life are the right-handed (D) enantiomers. In previous work, I have described the homochirality of self-replication of cellular automata (CA) structures, noting the parallel with homochirality of real biology [2][3][4]. In particular, my previous work focuses mostly on the simple self-replicating structure of J. Byl [1] as a specific example. I describe this structure as originally published in 1989 as an “R-Loop” and describe its self-replication as right-handed replication. As previously described [2][4], the mirror-transformation of an R-Loop is an L-Loop supported in its left-handed replication by a mirror transformation of the state-transition function supporting R-Loop replication.

The previous work has shown that pooling state-transition rules supporting right-handed self-replication with state-transition rules supporting left-handed self-replication (mirror transformations of right-handed rules) to produce a prospective state-transition function for heterochiral self-replication does not work to support heterochiral self-replication, due to rule contradictions within the prospective heterochiral state-transition function [3].

## State-set permutations

Subsequent to this observation, I hypothesized that a state-set permutation applied to the rules and structures of left-handed self-replication might allow a *functional* heterochiral self-replication [4]. An investigation of this hypothesis [4] showed that rule contradictions between L-Loop and R-Loop state-transition functions are reduced in number (but not eliminated) by some state-set permutations applied to L-loop replication. The R-loop state-transition function combined with its mirror-transformed function contains twenty contradictions [2], but if the state-permutation 12345 → 15342 is applied exclusively to the J. Byl mirror structure (L-Loop) and its corresponding (mirror) state-transition function for self-replication, the number of rule contradictions in the prospective pooled state-transition function is reduced from twenty to just six [4].

## Moore rules corresponding to von Neumann rules. A new observation.

Independently of applying state-set permutations to L-Loop self-replication state-transition rules and structures, rule contradictions between L-Loop and R-Loop state-transition functions are also reduced by rewriting von Neumann rules in the state-transition function as corresponding Moore rules. There are four cell-neighbour inputs to a cell-state transition in von Neumann state-transition rules, but eight cell-neighbour state inputs in each Moore rule. The von Neumann neighbourhood of a cell (C, centre of the neighbourhood) includes North (N), East (E), South (S) and West (W) cells, so a von Neumann rule is coded as **CNESW → C'**, where C' is the cell state of C after application of the relevant rule. The Moore neighbourhood of a cell C includes N, NE, E, SE, S, SW, W and NW cells, so a Moore neighbourhood state-transition rule is coded **C, N, NE, E, SE, S, SW, W, NW → C'**.

Applying the Moore-rules transition function corresponding to the original state-transition function of von Neumann rules, with no state-permutation applied to L-loop replication, the twenty contradictions existing under the prospective heterochiral state-transition function of von Neumann rules [4] are reduced to just two (**One** and **Two** below):

**One**: Referring to original R-loop replication of the J. Byl structure [1][2], the von Neumann rule 00012 → 0 is a state-preserving rule (C = 0 to C' = 0) which applies in the transition from time = 3 to 4. It contradicts the L-loop von Neumann rule 01200 → 2 (C = 0 to C' = 2) which applies in the transition from time = 8 to 9. The two respective corresponding Moore rules are 000001320 → 0 applying from time 3 to 4 in R-loop replication, and 013200000 →2 applying from time 8 to 9 in L-loop replication. These two Moore rules conserve the contradiction.

**Two** (mirror contradiction of **One**): The R-loop von Neumann rule 01002 → 2 (C = 0 to C' = 2) applies in the transition from time = 8 to 9. It contradicts the L-loop state-conserving von Neumann rule 00210 → 0 (C = 0 to C' = 0) which applies in the transition from time = 3 to 4. The two respective Moore rules are 010000023 → 2 applying from time 8 to 9 in R-loop replication, and 000231000 → 0 applying from time 3 to 4 in L-loop replication. This is the other instance of a von Neumann rule contradiction preserved in the corresponding Moore rules.

So, rewriting the von Neumann state-transition rules as Moore rules resolves eighteen of the twenty original contradictions. To contrast against the two instances of von Neumann rule contradictions which persist in the corresponding prospective Moore rules state-transition function, the following is an example of a rule contradiction in the prospective heterochiral von Neumann rules state-transition function which is resolved in the corresponding Moore rules transition function:

The von Neumann rule 00310 → 5 applying in L-Loop replication from time 20 to 21 contradicts rule 00031 → 1 applying in R-Loop replication from time 11 to 12. These rules correspond respectively to Moore rules 003341000 → 5 and 000003110 → 1 which do not contradict.

Accepting that either applying a suitable state-set permutation to L-loop replication, ***or*** that applying a Moore-rules state-transition function to L-Loop and R-Loop replicating structures both reduce rule contradictions in prospective heterochiral state-transition functions supporting self-replication, does the combination of a suitable state-set permutation for L-Loop self-replication, **and** a Moore rules state-transition function overall reduce state-transition rule contradictions to none?

The answer is **yes**, when the state-permutation applied to L-Loop replication is one of 12345 →

14325,

14523,

14532,

15423,

15432,

or 21435

With a Moore-rules state-transition function, and any one of the six cell-state permutations listed above applied to L-loop replication, there are no contradictions between state-transition rules supporting state-permutated L-Loop replication and rules supporting R-Loop replication. Under these conditions, a *functional* coexistence of left- and right-handed replication under one consistent and complete state-transition function is supported.

The simplest state-permutation of these is 12345 → 14325, in which states 2 and 4 are swapped. This work demonstrates that functional heterochiral self-replication is achieved with this state-permutation applied to L-loop replication, with a Moore rules state-transition function applied.

**Completing the current work**: **The combination of active state-permutation 12345 → 14325 applied to L-Loop self-replication, and pooling-together of the Moore rules for state-permutated L-Loop and R-Loop self-replication to achieve functional heterochiral self-replication.**

**The size of the new Moore rules state-transition function.**

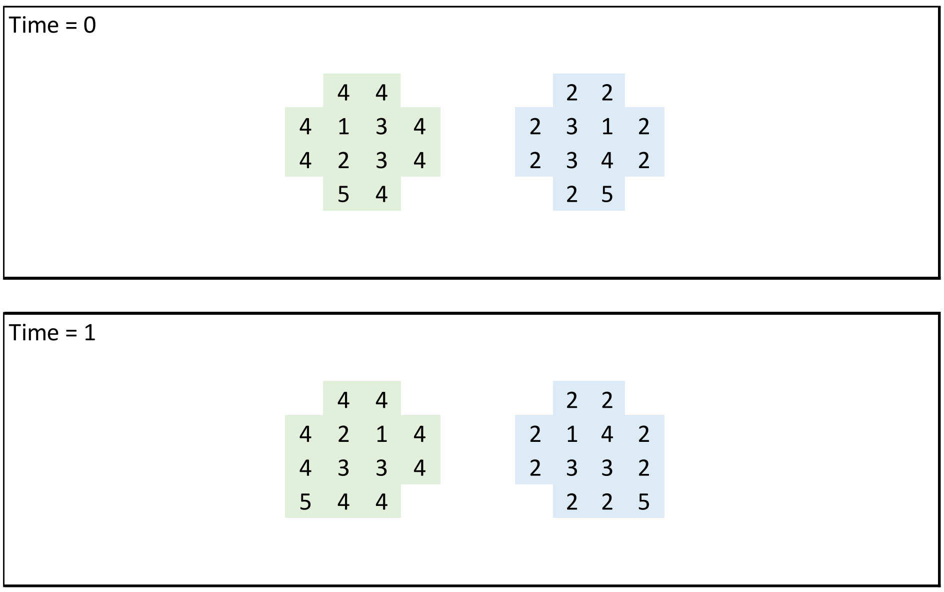
A single von Neumann rule can correspond to several Moore rules, due to different NE, SE, SW, and NW neighbour states across the various locations in space and time where the von Neumann neighbourhood appears, so it follows that the number of rules in a state-transition function will increase with a replacement of von Neumann rules with corresponding Moore rules. To illustrate, the single state-preserving von Neumann rule 43202→4 corresponds to Moore rules:

433200023 → 4
431200023 → 4
433200021 → 4
434200023 → 4
435200021 → 4

The state transition function also expands due to the adding of L-Loop self-replication rules to R-Loop rules allowed by the conditions corresponding to no rule contradictions. Consequently, the 140 explicit von Neumann state-transition rules supporting replication of the J. Byl structure [2] correspond to an expansion of the state-transition function to 564 Moore state-transition rules supporting both L-Loop and R-Loop replication. The **Appendix** of this paper shows the 564 Moore rules of the consistent and comprehensive state-transition function supporting functional heterochiral self-replication.

An additional observation is that of the 564 rules, there are 20 rules shared in R-Loop and L-Loop replication, *i.e.,* there is only a small overlap between the R-Loop state-transition rules subset and the L-Loop rules subset within the state-transition function.

Figure 1 below shows the time-course of initial L-Loop and an R-Loop structures, each self-replicating under a state-transition function of Moore rules incorporating the state-set permutation 12345 → 14325 applied exclusively to the L-loop structure and the rules supporting its self-replication. The state-transition function incorporating these properties contains no contradictions between L-Loop and R-Loop self-replication, which consequently can co-exist in a common CA environment.



Time = 2

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| | | | 4 | 4 | |
| | | 4 | 3 | 2 | 4 |
| | | 3 | 3 | 1 | 4 |
| | | 5 | 4 | 4 | |

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| | 2 | 2 | | | |
| 2 | 4 | 3 | 2 | | |
| 2 | 1 | 3 | 3 | | |
| | 2 | 2 | 5 | | |

Time = 3

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| | | | 4 | 4 | |
| | | 4 | 3 | 3 | 4 |
| | 1 | 3 | 1 | 2 | 4 |
| | | 5 | 4 | 4 | |

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| | 2 | 2 | | | |
| 2 | 3 | 3 | 2 | | |
| 2 | 4 | 1 | 3 | 1 | |
| | 2 | 2 | 5 | | |

Time = 4

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| | | | 4 | 4 | |
| | | 4 | 1 | 3 | 4 |
| | 3 | 1 | 2 | 3 | 4 |
| | 4 | 5 | 4 | 4 | |

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| | 2 | 2 | | | |
| 2 | 3 | 1 | 2 | | |
| 2 | 3 | 4 | 1 | 3 | |
| | 2 | 2 | 5 | 2 | |

Time = 5

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| | | | 4 | 4 | |
| | | 4 | 2 | 1 | 4 |
| 1 | 1 | 3 | 3 | 3 | 4 |
| | 4 | 2 | 4 | 4 | |

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| | 2 | 2 | | | |
| 2 | 1 | 4 | 2 | | |
| 2 | 3 | 3 | 3 | 1 | 1 |
| | 2 | 2 | 4 | 2 | |

Time = 6

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| | | | 4 | 4 | |
| | | 4 | 3 | 2 | 4 |
| | 3 | 3 | 3 | 1 | 4 |
| 4 | 4 | 2 | 4 | 4 | |

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| | 2 | 2 | | | |
| 2 | 4 | 3 | 2 | | |
| 2 | 1 | 3 | 3 | 3 | |
| | 2 | 2 | 4 | 2 | 2 |

Time = 7

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| | | | 4 | 4 | |
| | | 4 | 3 | 3 | 4 |
| 3 | 3 | 3 | 1 | 2 | 4 |
| 4 | 4 | 2 | 4 | 4 | |

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| | 2 | 2 | | | |
| 2 | 3 | 3 | 2 | | |
| 2 | 4 | 1 | 3 | 3 | 3 |
| | 2 | 2 | 4 | 2 | 2 |

Time = 8

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| | | | 1 | | 4 | 1 | 3 | 4 | | 2 | 3 | 1 | 2 | | 1 | | | |
| | | 1 | 3 | 3 | 1 | 2 | 3 | 4 | | 2 | 3 | 4 | 1 | 3 | 3 | 1 | | |
| | | | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | | | |

Time = 9

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| | | | 3 | | 4 | 2 | 1 | 4 | | 2 | 1 | 4 | 2 | | 3 | | | |
| | | 3 | 3 | 1 | 2 | 3 | 3 | 4 | | 2 | 3 | 3 | 4 | 1 | 3 | 3 | | |
| | | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | | |

Time = 10

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| | | | 1 | | | 4 | 4 | | | | 2 | 2 | | | 1 | | | |
| | | | | | 4 | 3 | 2 | 4 | | 2 | 4 | 3 | 2 | | | | | |
| | 1 | 3 | 1 | 2 | 3 | 3 | 1 | 4 | | 2 | 1 | 3 | 3 | 4 | 1 | 3 | 1 | |
| | | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | | |

Time = 11

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| | | 1 | | | 4 | 3 | 3 | 4 | | 2 | 3 | 3 | 2 | | | 1 | | |
| | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 4 | | 2 | 4 | 1 | 3 | 3 | 4 | 1 | 3 | |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 12

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| | 1 | | | | 4 | 1 | 3 | 4 | | 2 | 3 | 1 | 2 | | | | 1 | |
| 1 | 1 | 2 | 3 | 3 | 1 | 2 | 3 | 4 | | 2 | 3 | 4 | 1 | 3 | 3 | 4 | 1 | 1 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 13

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| | | | 1 | | 4 | 2 | 1 | 4 | | 2 | 1 | 4 | 2 | | 1 | | | |
| | 2 | 3 | 3 | 1 | 2 | 3 | 3 | 4 | | 2 | 3 | 3 | 4 | 1 | 3 | 3 | 4 | |
| 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | 2 |

Time = 14

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| | | 1 | 3 | | 4 | 3 | 2 | 4 | | 2 | 4 | 3 | 2 | | 3 | 1 | | |
| 4 | 3 | 3 | 1 | 2 | 3 | 3 | 1 | 4 | | 2 | 1 | 3 | 3 | 4 | 1 | 3 | 3 | 2 |
| 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | 2 |

Time = 15

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| | | | 1 | | | 4 | 4 | | | | 2 | 2 | | | 1 | | | |
| | 1 | | | | 4 | 3 | 3 | 4 | | 2 | 3 | 3 | 2 | | | | 1 | |
| 4 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 4 | | 2 | 4 | 1 | 3 | 3 | 4 | 1 | 3 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 16

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| | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | |
| 4 | 3 | | | | 4 | 1 | 3 | 4 | | 2 | 3 | 1 | 2 | | | | 3 | 2 |
| 4 | 1 | 2 | 3 | 3 | 1 | 2 | 3 | 4 | | 2 | 3 | 4 | 1 | 3 | 3 | 4 | 1 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 17

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| | 1 | | | | | 4 | 4 | | | | 2 | 2 | | | | | 1 | |
| 4 | 1 | | 1 | | 4 | 2 | 1 | 4 | | 2 | 1 | 4 | 2 | | 1 | | 1 | 2 |
| 4 | 2 | 3 | 3 | 1 | 2 | 3 | 3 | 4 | | 2 | 3 | 3 | 4 | 1 | 3 | 3 | 4 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 18

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| 4 | | | | | | 4 | 4 | | | | 2 | 2 | | | | | | 2 |
| 4 | 2 | | 3 | | 4 | 3 | 2 | 4 | | 2 | 4 | 3 | 2 | | 3 | | 4 | 2 |
| 4 | 3 | 3 | 1 | 2 | 3 | 3 | 1 | 4 | | 2 | 1 | 3 | 3 | 4 | 1 | 3 | 3 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 19

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| 4 | 4 | | 1 | | | 4 | 4 | | | | 2 | 2 | | | 1 | | 2 | 2 |
| 4 | 3 | | | | 4 | 3 | 3 | 4 | | 2 | 3 | 3 | 2 | | | | 3 | 2 |
| 4 | 3 | 1 | 2 | 3 | 3 | 1 | 2 | 4 | | 2 | 4 | 1 | 3 | 3 | 4 | 1 | 3 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 20

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| | 4 | | | | | 4 | 4 | | | | 2 | 2 | | | | | 2 | |
| 4 | 3 | 1 | | | 4 | 1 | 3 | 4 | | 2 | 3 | 1 | 2 | | | 1 | 3 | 2 |
| 4 | 1 | 2 | 3 | 3 | 1 | 2 | 3 | 4 | | 2 | 3 | 4 | 1 | 3 | 3 | 4 | 1 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 21

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| | 4 | 4 | | | | 4 | 4 | | | | 2 | 2 | | | | 2 | 2 | |
| 4 | 1 | 1 | 5 | | 4 | 2 | 1 | 4 | | 2 | 1 | 4 | 2 | | 5 | 1 | 1 | 2 |
| 4 | 2 | 3 | 3 | 1 | 2 | 3 | 3 | 4 | | 2 | 3 | 3 | 4 | 1 | 3 | 3 | 4 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 22

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| | 4 | 4 | | | | 4 | 4 | | | | 2 | 2 | | | | 2 | 2 | |
| 4 | 2 | 1 | 4 | | 4 | 3 | 2 | 4 | | 2 | 4 | 3 | 2 | | 2 | 1 | 4 | 2 |
| 4 | 3 | 3 | 5 | 2 | 3 | 3 | 1 | 4 | | 2 | 1 | 3 | 3 | 4 | 5 | 3 | 3 | 2 |
| | 4 | 4 | 4 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 2 | 2 | 2 | |

Time = 23

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 4 | | | | 4 | 4 | | | | 2 | 2 | | | | 2 | 2 | |
| 4 | 3 | 2 | 4 | | 4 | 3 | 3 | 4 | | 2 | 3 | 3 | 2 | | 2 | 4 | 3 | 2 |
| 4 | 3 | 1 | 4 | 5 | 3 | 1 | 2 | 4 | | 2 | 4 | 1 | 3 | 5 | 2 | 1 | 3 | 2 |
| | 4 | 4 | 5 | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | 5 | 2 | 2 | |

Time = 24

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 4 | | | | 4 | 4 | | | | 2 | 2 | | | | 2 | 2 | |
| 4 | 3 | 3 | 4 | | 4 | 1 | 3 | 4 | | 2 | 3 | 1 | 2 | | 2 | 3 | 3 | 2 |
| 4 | 1 | 2 | 4 | | 5 | 2 | 3 | 4 | | 2 | 3 | 4 | 5 | | 2 | 4 | 1 | 2 |
| | 4 | 5 | | 4 | 2 | 4 | 4 | | | | 2 | 2 | 4 | 2 | | 5 | 2 | |

Time = 25

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 4 | | | | 4 | 4 | | | | 2 | 2 | | | | 2 | 2 | |
| 4 | 1 | 3 | 4 | | 5 | 2 | 1 | 4 | | 2 | 1 | 4 | 5 | | 2 | 3 | 1 | 2 |
| 4 | 2 | 3 | 4 | | 4 | 3 | 3 | 4 | | 2 | 3 | 3 | 2 | | 2 | 3 | 4 | 2 |
| | 5 | 4 | | 4 | | 4 | 4 | | | | 2 | 2 | | 2 | | 2 | 5 | |

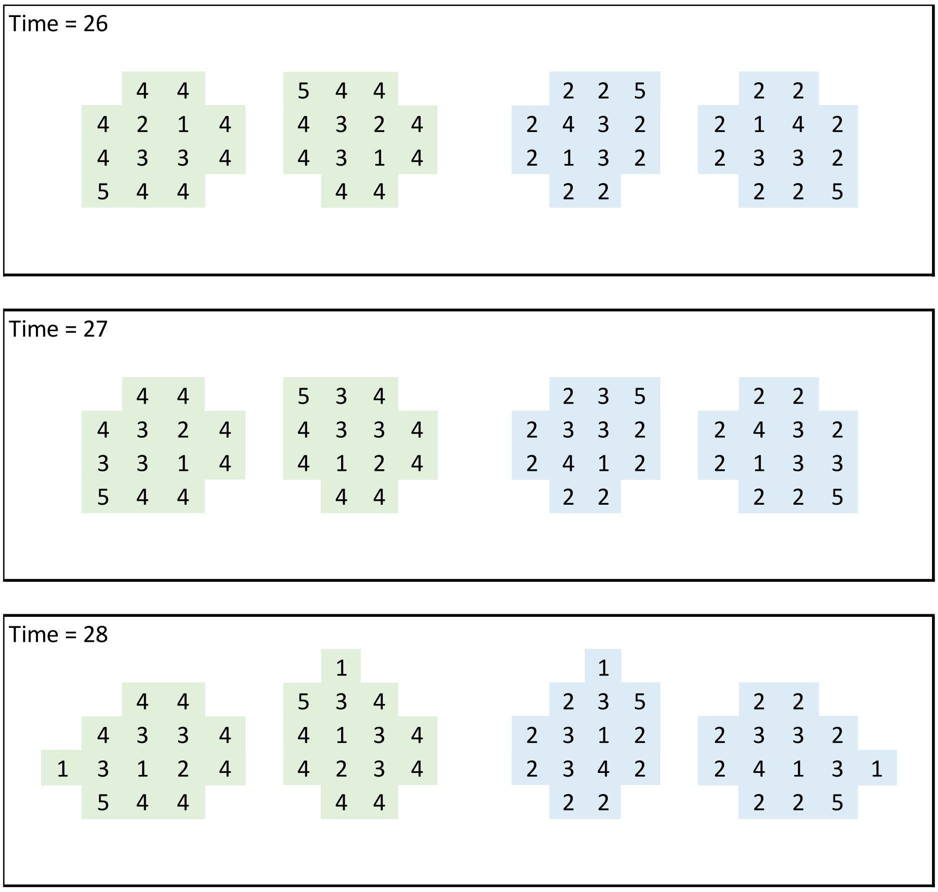


**Figure 1.** At Time = 0, the blue-highlighted structure is the initial structure (R-Loop) which self-replicates under its corresponding state-transition function [1][2]. The neighbouring green-highlighted structure is the corresponding mirror-structure (L-Loop), with the state-permutation 12345 → 14325 applied (states 2 and 4 swapped). The consistent and comprehensive Moore rules state-transition function shown below in the Appendix supports the self-replication of both structures in their common CA environment. Self-replication of both structures is apparent by Time = 26. White space corresponds to quiescent state 0.

## Discussion

Previous work [2][3][4] established the homochiral replication of self-replicating loops in cellular automata environments. This conclusion is of interest because it parallels the homochirality observed in real biology. However, using the example of J. Byl's self-replicating structure [1] the new work described above shows that the replication asymmetry can be "unbroken" by introducing a relaxed notion of what defines mirror replication. Figure 1 shows that with a Moore rules state-transition function and a suitable state-set permutation applied to left-handed (L-Loop) replication, left- and right-handed self-replication can coexist in a common cellular automata environment. The L-Loops in Figure 1 (green highlighted) are not structural mirrors of the corresponding R-Loops, because in L-Loop replication, states 2 and 4 are exchanged. However, the *mechanism* of the state-permutated L-Loop replication exactly mirrors R-Loop replication.

Neither the state-set permutation applied to L-Loop replication, nor the Moore rule state-transition function are independently sufficient to support functional heterochiral self-replication, but the Moore rules state-transition function implements a more complex state-transition algorithm than a corresponding von Neumann rules state-transition function, because under Moore rules, there are more inputs (more neighbours) determining each cell's state transition. With an appropriate state-set permutation applied to left-handed replication, the increased complexity of cell state-transitions (von Neumann rules → Moore rules) is sufficient to support functional heterochiral self-replication.

What relevance, if any, does this work have for understanding the homochirality of biology? Perhaps the homochirality of real biology is an outcome of life's level of complexity, and some conceivable more complex biology could accommodate a larger range of heterochiral structures and functions. Research relevant to understanding biological homochirality is continuing by the efforts of many interested researchers.

## References


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## Appendix

The Tables 1 to 7 below categorize all of the 564 Moore rules in the state-transition function which supports the coexisting L-Loop and R-Loop self-replication shown in Figure 1, given the 12345 → 14325 state set permutation applied to L-Loop self-replication. The format applying to all listed rules is C, N, NE, E, SE, S, SW, W, NW → C'. The state transition is C (cell state at time t) → C' (cell state at time t+1). Strong rotational symmetry applies, so for example:

132342243 → 4,

143323422 → 4,

122433234 → 4,

and 134224332 → 4

are all equivalent rules. The list below (Tables 1 to 7) includes no rotation-symmetry duplications.

**Table 1**. Achiral rules common to L-Loop and R-Loop replication.

| | | | |
|---|---|---|---|
| 000000000 --> 0 | 000000005 --> 0 | 000000400 --> 0 | 000003000 --> 1 |
| 000000001 --> 0 | 000000010 --> 0 | 000001110 --> 0 | 000003330 --> 0 |
| 000000002 --> 0 | 000000300 --> 0 | 000001310 --> 0 | 100000000 --> 0 |

**Table 2**. Achiral rules supporting L-Loop replication only.

| | | | |
|---|---|---|---|
| 000400000 --> 0 | 000424000 --> 0 | 024000004 --> 0 | 404000004 --> 0 |
| 004440000 --> 0 | 000040400 --> 0 | 054000004 --> 0 | 233400043 --> 2 |
| 000414000 --> 0 | 004400044 --> 0 | 400434000 --> 0 | 500434000 --> 5 |
| 000434000 --> 0 | | | |

**Table 3**. Achiral rules supporting R-Loop replication only.

| | | | |
|---|---|---|---|
| 000000020 --> 0 | 000002420 --> 0 | 042000002 --> 0 | 202000002 --> 0 |
| 000000222 --> 0 | 000020200 --> 0 | 052000002 --> 0 | 433200023 --> 4 |
| 000002120 --> 0 | 002200022 --> 0 | 200002320 --> 0 | 500002320 --> 5 |
| 000002320 --> 0 | | | |

**Table 4**. Chiral rule mutual-mirror pairs. Rules in this table are common to L- and R-Loop replication, support L-Loop replication only, or support R-Loop replication only, as indicated.

| **mirror pairs** | **Common to L-Loop and R-Loop replication** | **Supports L-Loop replication only** | **Supports R-Loop replication only** |
|---|---|---|---|
| 000000022 --> 0 | | | 1 |
| 000000220 --> 0 | | | 1 |
| 000000023 --> 0 | | | 1 |
| 000000320 --> 0 | 1 | | |
| 000000522 --> 0 | | | 1 |
| 025000002 --> 0 | | | 1 |
| 000010200 --> 0 | | | 1 |
| 000020100 --> 0 | | | 1 |
| 000020500 --> 0 | | | 1 |
| 000050200 --> 0 | | | 1 |
| 000000052 --> 0 | | | 1 |
| 050000002 --> 0 | | | 1 |
| 025000000 --> 0 | | | 1 |
| 020000005 --> 0 | | | 1 |
| 020200023 --> 0 | | | 1 |
| 023200020 --> 0 | | | 1 |
| 022000004 --> 0 | | | 1 |
| 024000002 --> 0 | | | 1 |

**Table 4 continued:**

| mirror pairs | Common to L-Loop and R-Loop replication | Supports L-Loop replication only | Supports R-Loop replication only |
|---|---|---|---|
| 000000053 --> 0 | | | 1 |
| 003500000 --> 0 | | 1 | |
| 000001100 --> 0 | | | 1 |
| 000011000 --> 0 | | 1 | |
| 000001300 --> 0 | | | 1 |
| 000031000 --> 0 | | 1 | |
| 000004300 --> 0 | 1 | | |
| 003400000 --> 0 | | 1 | |
| 000010010 --> 0 | | | 1 |
| 000100100 --> 0 | | 1 | |
| 000110100 --> 0 | | | 1 |
| 000010110 --> 0 | | 1 | |
| 004400000 --> 0 | | 1 | |
| 000440000 --> 0 | | 1 | |
| 004450000 --> 0 | | 1 | |
| 044000005 --> 0 | | 1 | |
| 000040100 --> 0 | | 1 | |
| 000010400 --> 0 | | 1 | |
| 000050400 --> 0 | | 1 | |
| 000040500 --> 0 | | 1 | |
| 004500000 --> 0 | | 1 | |
| 054000000 --> 0 | | 1 | |
| 040000005 --> 0 | | 1 | |
| 045000000 --> 0 | | 1 | |
| 043400040 --> 0 | | 1 | |
| 040400043 --> 0 | | 1 | |
| 042000004 --> 0 | | 1 | |
| 044000002 --> 0 | | 1 | |
| 000003110 --> 1 | | | 1 |
| 000113000 --> 1 | | 1 | |
| 000003300 --> 1 | | | 1 |
| 000033000 --> 1 | | 1 | |
| 000013000 --> 1 | | | 1 |
| 000003100 --> 1 | | 1 | |
| 000013101 --> 1 | | | 1 |
| 001013100 --> 1 | | 1 | |
| 000023310 --> 1 | | | 1 |
| 000133200 --> 1 | | 1 | |
| 000043310 --> 1 | | | 1 |
| 000133400 --> 1 | | 1 | |
| 100033130 --> 0 | | | 1 |
| 100313300 --> 0 | | 1 | |

**Table 4 continued:**

| mirror pairs | Common to L-Loop and R-Loop replication | Supports L-Loop replication only | Supports R-Loop replication only |
|---|---|---|---|
| 100013300 --> 3 | 1 | | |
| 100033100 --> 3 | 1 | | |
| 200002332 --> 2 | | | 1 |
| 200023320 --> 2 | | | 1 |
| 233200043 --> 2 | | | 1 |
| 233400023 --> 2 | | | 1 |
| 233400041 --> 2 | | 1 | |
| 231400043 --> 2 | | 1 | |
| 300033100 --> 0 | | | 1 |
| 300013300 --> 0 | | 1 | |
| 431200023 --> 4 | | | 1 |
| 433200021 --> 4 | | | 1 |
| 404334000 --> 4 | | 1 | |
| 400433400 --> 4 | | 1 | |
| 433200043 --> 4 | | 1 | |
| 433400023 --> 4 | | 1 | |

**Table 5**. Chiral rules common to L- and R-Loop replication. The complement mirror-transformations of these rules are absent from the state-transition function.

000030200 --> 0
000040300 --> 0
100000211 --> 0
100011400 --> 0

**Table 6**. Chiral rules supporting only R-Loop replication. The complement mirror-transformations of these rules are absent from the state-transition function. (n = 223).

| | | | |
|---|---|---|---|
| 000000230 --> 1 | 103322240 --> 4 | 220002332 --> 2 | 320105213 --> 1 |
| 000000532 --> 1 | 103322442 --> 4 | 220002340 --> 2 | 320124234 --> 3 |
| 000001320 --> 0 | 105322442 --> 4 | 223320200 --> 2 | 320221410 --> 1 |
| 000002110 --> 2 | 110102240 --> 4 | 223450200 --> 2 | 320223142 --> 3 |
| 000002230 --> 3 | 110224300 --> 4 | 224125250 --> 2 | 320231432 --> 1 |
| 000002240 --> 2 | 110322240 --> 4 | 230000023 --> 2 | 320233142 --> 3 |
| 000002310 --> 2 | 120214332 --> 4 | 230000051 --> 2 | 320324213 --> 1 |
| 000003120 --> 0 | 120224312 --> 4 | 230200043 --> 2 | 320324233 --> 3 |
| 000003320 --> 0 | 120224332 --> 4 | 231000021 --> 2 | 320424233 --> 3 |
| 000005420 --> 5 | 120254332 --> 4 | 231000023 --> 2 | 320524213 --> 5 |
| 000011320 --> 0 | 120324241 --> 4 | 232500023 --> 2 | 325223142 --> 3 |

000020250 --> 0
000033120 --> 0
000033320 --> 0
000043300 --> 1
000043320 --> 0
000100200 --> 0
000114300 --> 0
000131401 --> 0
000131420 --> 0
000133120 --> 0
000143300 --> 5
000215000 --> 0
000220225 --> 0
000220250 --> 0
000220520 --> 0
000225320 --> 0
000230010 --> 0
000254320 --> 0
000314300 --> 0
000314320 --> 0
000331420 --> 0
000433130 --> 0
000531420 --> 0
001014320 --> 0
001043320 --> 0
001143310 --> 0
002202025 --> 0
002202452 --> 0
002331401 --> 1
010000053 --> 2
010014300 --> 0
010031400 --> 0
020000004 --> 0
024500020 --> 0
025000004 --> 0
100000210 --> 0
100000230 --> 3
100000231 --> 3
100000532 --> 3
100031400 --> 0
100102432 --> 3
100322240 --> 4
101322240 --> 4
101322442 --> 4
102314300 --> 1
120325241 --> 3
122143350 --> 1
122433520 --> 4
130322240 --> 4
131322240 --> 4
132202240 --> 4
132202241 --> 4
132342243 --> 4
132352243 --> 4
143322522 --> 4
200000023 --> 2
200000024 --> 2
200000231 --> 2
200002130 --> 2
200002132 --> 2
200002230 --> 2
200002342 --> 2
200002411 --> 2
200002412 --> 2
200003332 --> 2
200005412 --> 5
200013132 --> 2
200013342 --> 2
200014342 --> 2
200021120 --> 2
200021320 --> 2
200023420 --> 2
200024120 --> 2
200031412 --> 2
200033132 --> 2
200033332 --> 2
200043332 --> 2
200053132 --> 2
200054120 --> 2
200211500 --> 2
200523420 --> 3
202000045 --> 2
202135400 --> 2
202412500 --> 2
211000043 --> 2
213200024 --> 2
213200044 --> 2
213200052 --> 5
213400024 --> 2
213500024 --> 2
233200021 --> 2
233200025 --> 2
233200041 --> 2
233400021 --> 2
233500021 --> 2
234200023 --> 2
234200043 --> 2
234400023 --> 2
234500002 --> 2
241200023 --> 2
241200043 --> 2
241400023 --> 2
241500023 --> 2
245200043 --> 2
245400023 --> 2
250020234 --> 2
252500043 --> 2
253200024 --> 5
300002211 --> 1
300002230 --> 3
300002233 --> 3
300002512 --> 1
300022432 --> 3
300031400 --> 0
300102210 --> 1
300131400 --> 0
300221400 --> 1
300222231 --> 3
300322412 --> 1
300322432 --> 3
300422230 --> 3
300422231 --> 3
300422432 --> 3
301322412 --> 1
301422230 --> 3
301422231 --> 3
304322213 --> 1
310102230 --> 3
310202210 --> 1
310322210 --> 1
310322213 --> 1
311422235 --> 3
314322022 --> 1
314322252 --> 1
320005233 --> 3
330322210 --> 1
331452022 --> 3
332202210 --> 1
332342214 --> 1
332352214 --> 1
342202230 --> 3
342342231 --> 3
342442231 --> 3
351322210 --> 5
400022230 --> 3
400122230 --> 3
400122432 --> 3
401122230 --> 3
402223300 --> 3
402522432 --> 5
403122230 --> 3
403122432 --> 3
412142233 --> 3
412152233 --> 3
412202230 --> 3
412202231 --> 3
412205233 --> 3
412542233 --> 3
413122230 --> 3
413200024 --> 4
420124234 --> 3
420223312 --> 3
420233312 --> 3
420243312 --> 3
433125022 --> 3
434200023 --> 4
435200021 --> 4
441200023 --> 4
450200024 --> 0
500002342 --> 2
502133100 --> 2
502252432 --> 0
513200024 --> 4
520024241 --> 2
521200025 --> 0
521322240 --> 2
530000023 --> 5
531000021 --> 5
541200002 --> 2

**Table 7**. Chiral rules supporting only L-Loop replication. The complement mirror-transformations of these rules are absent from the state-transition function (n = 223).

| | | | |
|---|---|---|---|
| 000340000 --> 1 | 100244433 --> 2 | 444334000 --> 4 | 343145010 --> 1 |
| 004350000 --> 1 | 104224433 --> 2 | 440234000 --> 4 | 342342410 --> 3 |
| 000431000 --> 0 | 104224435 --> 2 | 440040433 --> 4 | 340121440 --> 1 |
| 000114000 --> 4 | 110244010 --> 2 | 440040523 --> 4 | 344213440 --> 3 |
| 000344000 --> 3 | 110032440 --> 2 | 440545412 --> 4 | 344321340 --> 1 |
| 000244000 --> 4 | 110244430 --> 2 | 433400000 --> 4 | 344213340 --> 3 |
| 000134000 --> 4 | 144332140 --> 2 | 431500000 --> 4 | 343142430 --> 1 |
| 000413000 --> 0 | 144132440 --> 2 | 433200040 --> 4 | 343342430 --> 3 |
| 000433000 --> 0 | 144332440 --> 2 | 431400001 --> 4 | 343342420 --> 3 |
| 000425000 --> 5 | 144332540 --> 2 | 433400001 --> 4 | 343142450 --> 5 |
| 000431100 --> 0 | 141242430 --> 2 | 433400054 --> 4 | 344213445 --> 3 |
| 000540400 --> 0 | 141245430 --> 3 | 431400043 --> 4 | 330144430 --> 1 |
| 000413300 --> 0 | 140533214 --> 1 | 435400043 --> 4 | 334404521 --> 3 |
| 000433300 --> 0 | 140453324 --> 2 | 431200043 --> 4 | 330144044 --> 1 |
| 000033200 --> 1 | 130244430 --> 2 | 431400023 --> 4 | 332144234 --> 1 |
| 000433200 --> 0 | 130244431 --> 2 | 431400053 --> 4 | 332144534 --> 1 |
| 000040010 --> 0 | 130244044 --> 2 | 433400042 --> 4 | 320344044 --> 3 |
| 000032110 --> 0 | 131244044 --> 2 | 433200042 --> 4 | 321344234 --> 3 |
| 001021310 --> 0 | 133244234 --> 2 | 433400022 --> 4 | 321344224 --> 3 |
| 000421310 --> 0 | 133244534 --> 2 | 434000052 --> 4 | 350144431 --> 5 |
| 000413310 --> 0 | 124454433 --> 2 | 423400041 --> 4 | 200344400 --> 3 |
| 000033210 --> 5 | 403400000 --> 4 | 423200041 --> 4 | 200344410 --> 3 |
| 000005140 --> 0 | 402400000 --> 4 | 423400021 --> 4 | 204324410 --> 3 |
| 005440440 --> 0 | 401340000 --> 4 | 423400051 --> 4 | 200344411 --> 3 |
| 000540440 --> 0 | 400314000 --> 4 | 423200045 --> 4 | 200033444 --> 3 |
| 000450440 --> 0 | 404314000 --> 4 | 423400025 --> 4 | 204324454 --> 5 |
| 000435440 --> 0 | 400344000 --> 4 | 452340400 --> 4 | 200344413 --> 3 |
| 000100340 --> 0 | 404234000 --> 4 | 453200054 --> 4 | 204324413 --> 3 |
| 000432540 --> 0 | 401124000 --> 4 | 452400043 --> 5 | 213344214 --> 3 |
| 000032130 --> 0 | 404124000 --> 4 | 301144000 --> 1 | 213344514 --> 3 |
| 000432130 --> 0 | 404333000 --> 4 | 300344000 --> 3 | 210344044 --> 3 |
| 000421330 --> 0 | 404125000 --> 5 | 303344000 --> 3 | 211344044 --> 3 |
| 000313320 --> 0 | 404313100 --> 4 | 304154000 --> 1 | 213345044 --> 3 |
| 000421350 --> 0 | 404233100 --> 4 | 304324400 --> 3 | 213344254 --> 3 |
| 000432101 --> 0 | 404232100 --> 4 | 300021300 --> 0 | 210344413 --> 3 |
| 000433201 --> 0 | 400411400 --> 4 | 300144010 --> 1 | 212400043 --> 2 |
| 000133211 --> 0 | 400431400 --> 4 | 300021310 --> 0 | 242342410 --> 3 |
| 005404044 --> 0 | 400423400 --> 4 | 300021440 --> 1 | 244133440 --> 3 |
| 004524044 --> 0 | 400412400 --> 4 | 301344440 --> 3 | 244133340 --> 3 |
| 001021334 --> 1 | 404121300 --> 4 | 304124430 --> 1 | 244133240 --> 3 |
| 013500000 --> 4 | 404313300 --> 4 | 304324430 --> 3 | 234405413 --> 3 |
| 010032100 --> 0 | 404333300 --> 4 | 300344420 --> 3 | 233400042 --> 2 |
| 010021300 --> 0 | 404333200 --> 4 | 301344420 --> 3 | 231400045 --> 2 |
| 042000000 --> 0 | 404313500 --> 4 | 304324420 --> 3 | 223400041 --> 2 |

040400052 --> 0
042000005 --> 0
100140000 --> 0
100340000 --> 3
101340000 --> 3
104350000 --> 3
100021300 --> 0
104324010 --> 3
100244430 --> 2
100244431 --> 2
104224431 --> 2
100032134 --> 1

400412500 --> 4
400051140 --> 4
400423450 --> 3
405200004 --> 4
400025314 --> 4
400054124 --> 4
413200001 --> 4
412400043 --> 4
412200043 --> 4
414500043 --> 5
412400023 --> 4
412400053 --> 4

304124431 --> 1
300344421 --> 3
301344421 --> 3
303144432 --> 1
310344010 --> 3
310144040 --> 1
310144430 --> 1
313144430 --> 1
315344421 --> 3
314404432 --> 1
314544432 --> 1
343345000 --> 3

252400040 --> 0
504234000 --> 4
500013314 --> 4
504324544 --> 0
512400043 --> 2
541242400 --> 4
545400041 --> 0
540244431 --> 4
533400000 --> 5
531400001 --> 5
524000041 --> 4