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Interactive Self-Replicating, Self-Incrementing and Self-Decrementing Loops

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Abstract

Self-replicating loops presented to date are usually worlds unto themselves, inaccessible to observer once the replication process is launched. In this paper we present a self-replicating loop which allows for user interaction. Specifically, the user can control the loop's replication as well as the size of the replica. After presenting the design of this novel loop, we delineate its physical implementation in our electronic wall for bio-inspired applications, the *BioWall*.

Introduction: Interactive Self-Replication

All self-replicating loops presented to date (Langton 1984; Byl 1989; Reggia 1993) are usually worlds unto themselves: once the initial loop configuration is embedded within the cellular automaton (CA) universe (at time-step 0), no further user interaction occurs, and the CA chugs along in total oblivion of the observing user.

In previous works we have described the design of self-replicating loops which could be activated by the user (Stauffer 2001; 2002). The user was able to control the loop's replication and induce its destruction. In this paper we present another interactive self-replicating loop which give birth to a daughter loop whose size is identical, incremented by one or decremented by one. The next section explains the corresponding self-replication, self-incrementation and self-decrementation processes. Section III discusses the hardware implementation of the loop in our electronic wall for bio-inspired applications, the *BioWall*. Finally, we present concluding remarks in Section IV.

Loop Design and Operation

Contrary to previous loops, which self-replicate continually, the novel one presented below is idle *unless externally activated*. This $n \times n$ loop, with $n \geq 3$, is therefore an interactive self-replicator.

Defined in a two-dimensional, five-neighbor cellular space, with seven basic states per cell (Figure 1), our minimal 3×3 loop is made up of eight cells. As long as no external input is provided, the loop is inert, continually undergoing an eight-time-step cycle (Figure 2).

0: empty component
1: building component
2: east-moving growth signal
3: north-moving growth signal
4: west-moving growth signal
5: south-moving growth signal
6: left-turn signal
7: east-branching signal (rep),
east data-decrement and cut-off signal (inc)
8: east-branching and cut-off signal (rep),
east data-increment and cut-off signal (dec)
9: north-branching signal (rep),
north data-decrement and cut-off signal (inc)
10: north-branching and cut-off signal (rep),
north data-increment and cut-off signal (dec)
11: west-branching signal (rep),
west data-decrement and cut-off signal (inc)
12: west-branching and cut-off signal (rep),
west data-increment and cut-off signal (dec)
13: south-branching signal (rep),
south data-decrement and cut-off signal (inc)
14: south-branching and cut-off signal (rep),
south data-increment and cut-off signal (dec)
15: cut-off signal (rep),
A: replication-activate variable (rep,inc,dec)
I: data-increment variable (inc)
D: data-decrement variable (dec)

Figure 1: The seven basic cellular states 0 to 6 used for the idle loop and the nine additional states 8 to 15 involved in the self-replication (rep), self-incrementation (inc) or self-decrementation (dec) processes when the control variables A, I or D are activated.

In order to launch the self-replication process, the self-incrementation process or the self-decrementation process, the user activates the idle loop by providing an external input on one of its eight cells (in Section activation occurs by physically touching the BioWall). This external input presets respectively one out of three control variables: the replication-activate variable A, the data-increment variable I or the data-decrement variable D of the cell.

Presetting the replication-activate variable ($A = 1$) leads to the appearance of a shadowed state 6 which corresponds to an activated left-turn signal at time-step 0 (Figure 3). The activated loop is then ready to self-replicate and the process is performed in 48 time-steps.

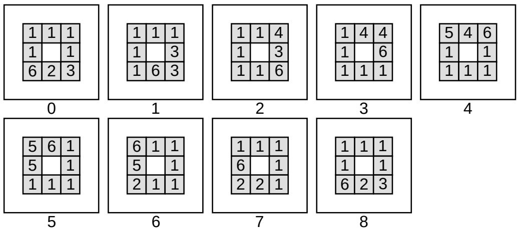

Figure 2: The eight-time-step idle cycle of the inactive loop.

In addition to the seven basic cellular states and to the replication-activate variable, the self-replication process requires the nine extra cellular states defined in Figure 1. The control part of each cell involves the three variables A, I and D as well as the state C of the cell itself. When the left-turn signal $C = 6$ is activated ($A, I, D = 100$), the replication-activate variable A is reset and the self-replication process is launched (see Appendix).

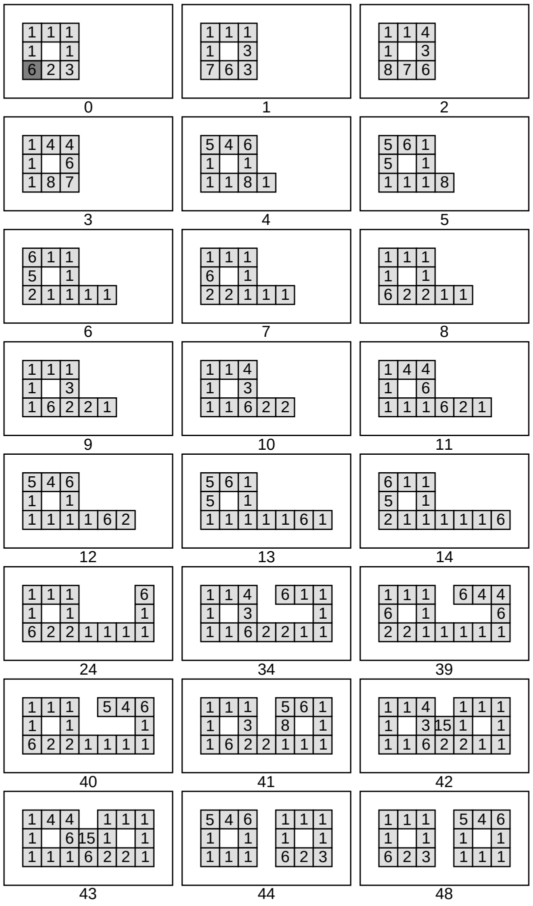

Figure 3: When the lower-left cell is activated after presetting control variable A, the loop self-replicates eastward within 48 time-steps (1 to 7 are the branching steps, 41 to 44 are the cut-off steps).

Presetting the data-increment variable ($I = 1$) results in the extension of the sequence of moving signals in the idle loop and in the appearance of an activated left-turn signal at time-step 2 (Figure 4). The activated loop is then ready to self-increment and the process is performed in 57 time-steps. The self-incrementation process introduces thus the data-increment variable and the five cellular states 7, 9, 11, 13, 15 (Figure 1). These states permit to reduce afterwards the sequence of moving signals in the mother loop at time-step 50 and to detach the daughter loop from the mother loop at time-step 53. At the control variable level, when $A, I, D = 010$, a data-increment signal $C = 15$ is first introduced instead of the usual left-turn signal $C = 6$ (time-step 1). It is then replaced by an activated left-turn signal $C = 6$ when the control variables A, I, D become 100 (time-step 2). During this prodedure, the size of the sequence of moving signals is effectively increased by one and the idle loop activated in order to perform the self-incrementation process.

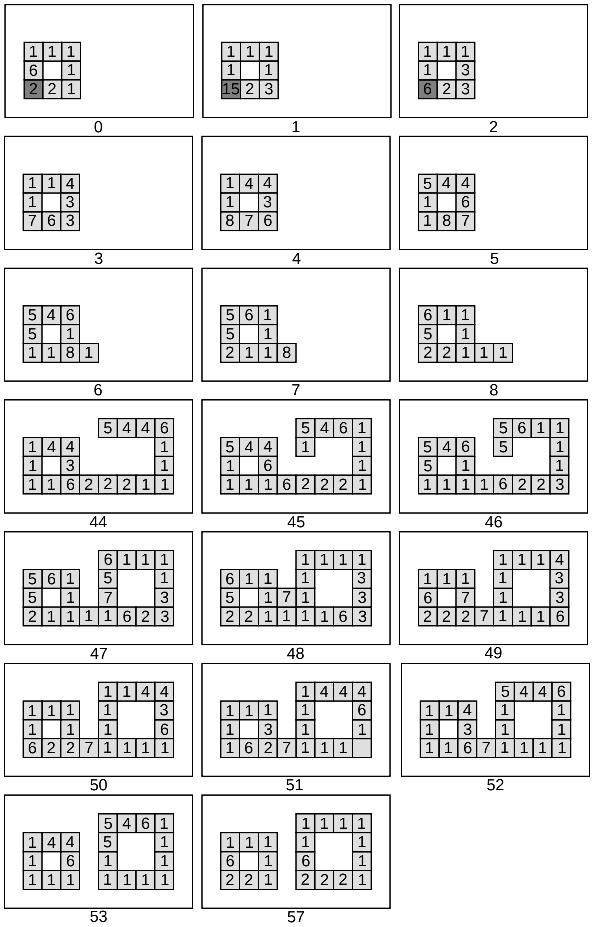

Figure 4: When the lower-left cell is activated after presetting control variable I, the loop self-increments eastward within 57 time-steps (1 to 8 are the sequence extension and branching steps, 44 to 53 are the sequence reduction and cut-off steps).

Presetting the data-decrement variable ($D = 1$) results in the reduction of the sequence of moving signals in the idle loop and in the appearance of an activated left-turn signal at time-step 4 (Figure 5). The activated loop is then ready to self-decrement and the process is performed in 73 time-steps. Figure 1 represents the data-decrement variable and the four cellular states (8, 10, 12, 14) involved in the self-decrementation process. Towards the end of the process, these states allow the extension of the sequence of moving signals in the mother loop at time-step 68 and the separation of the daughter loop at time-step 69. At the control variable level, when $A, I, D = 001$, the first moving signal of the sequence is suppressed (time-step 1). The control variables A, I, D become then 100 and the remaining signals of the sequence are maintained. In the procedure, the size of the sequence of moving signals is decreased by one and the idle loop activated in order to perform the self-decrementation process.

The BioWall Implementation

We have physically implemented the five-neighbor CA described above in a two-dimensional electronic wall for bio-inspired applications, the *BioWall*, which is an undergoing project in our lab (Figure 6). The BioWall is ultimately intended as a self-repairing display medium, capable of interacting "intelligently" with the user and recovering from faults. In our implementation, each CA cell is made up of one unit in the wall. The physical realization of this unit includes: (1) an input device, (2) a digital circuit, and (3) an output display.

The unit's outer surface consists of a touch-sensitive panel which acts like a digital switch, enabling the user to activate the randomly self-replication, the self-incrementation or the self-decrementation process (Figure 7).

The unit's internal digital circuit is a field-programmable gate array (FPGA), configured so as to implement: (1) external (touch) input, (2) execution of the CA state-transition and variable-transition rules necessary for the three loop processes, and (3) control of the output display. This latter is a two color light-emitting diode (LED) display, made up of 128 diodes arranged as an 8 × 8 dot-matrix, each dot containing a green and a red LED. The display allows the user to view a CA cell's current state (of the sixteen possible) and whether this cell is in activated or deactivated mode.

Concluding Remarks

We presented an interactive self-replicating loop wherein the user can control the size of the daughter loop. In addition to the usual self-replication process, the user can therefore induce a self-incrementation process and a self-decrementation process. We then described the loop's physical implementation within our electronic wall for bio-inspired applications, the BioWall.

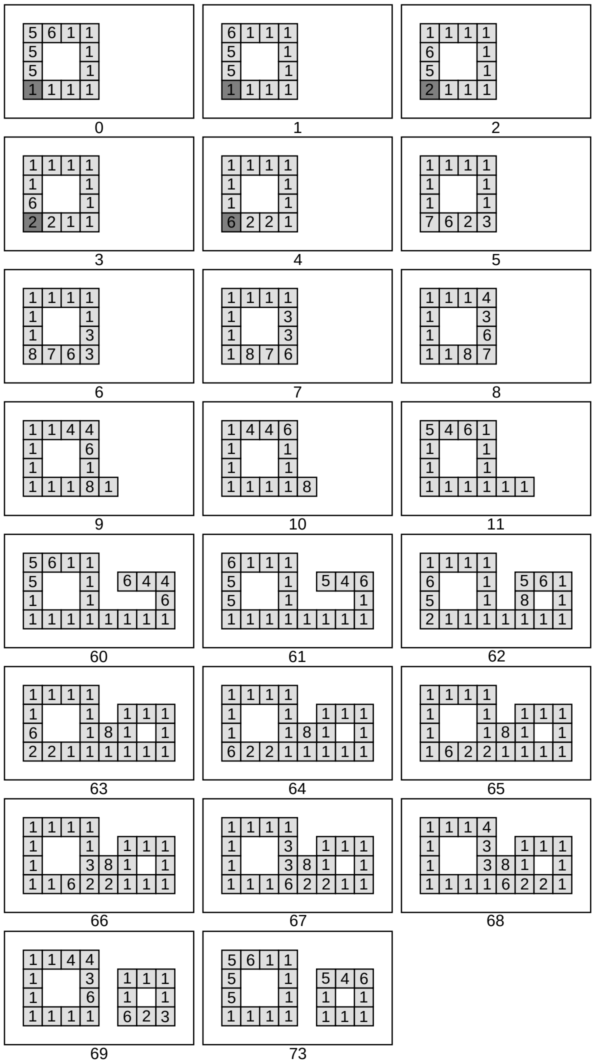

Figure 5: When the lower-left cell is activated after presetting control variable D, the loop self-decrements eastward within 73 time-steps (1 to 11 are the sequence reduction steps and branching steps, 62 to 69 are the sequence extension and cut-off steps).

The ability to interact with a CA universe—a little-studied issue—is of fundamental import where cellular devices are concerned: one must be able to enter input and to view the output if any practical application is envisaged (Sipper 1998). Our work herein is but a first step in the domain of interactive cellular replicators, an issue which we believe will play an important role in the future of such devices.

Acknowledgments

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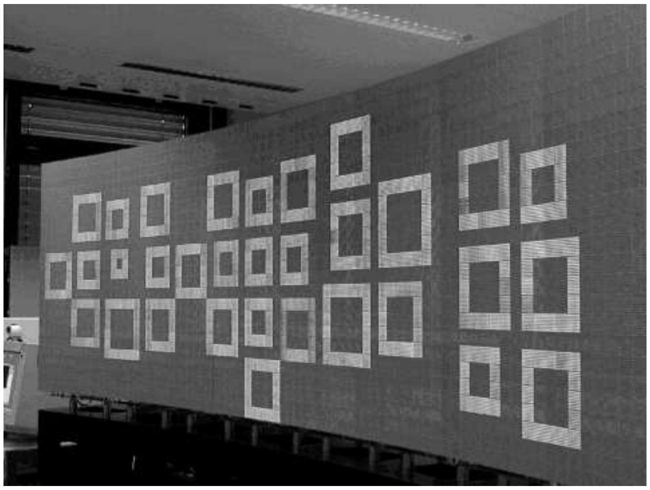

Figure 6: The BioWall used to physically implement our loop (Photograph by A. Badertscher).

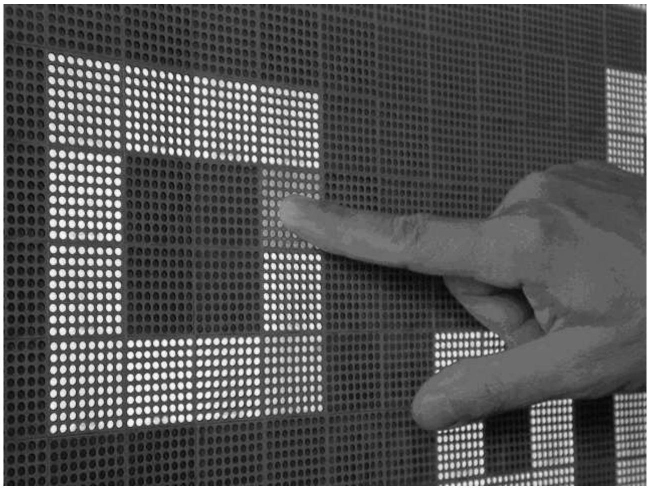

Figure 7: Touching a unit in order to activate the loop (Photograph by A. Badertscher).

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Appendix: Specification of the CA Variable-Transition Rules

The variable-transition rules of the CA appears in Figure 8. In this figure, C, N, E, S, and W correspond to the current states of the cell and of its neighbors to the north, east, south, and west, respectively. A, I, D are the current states of the control variables. Knowing the current state of the cell, of its neighbors and of the control variables, the set of rules defines the state $A+$, $I+$, $D+$ of the control variables at the next time-step.

C,N,E,S,W	A,I,D	->	A+,I+,D+
6,X,X,X,X	1,0,0	->	0,0,0
15,X,X,X,X	0,1,0	->	1,0,0
1,X,X,X,2	0,0,1	->	1,0,0
1,X,X,3,X	0,0,1	->	1,0,0
1,X,4,X,X	0,0,1	->	1,0,0
1,5,X,X,X	0,0,1	->	1,0,0

Figure 8: CA variable-transition rules.