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Driver Mechanisms on Cellular Automata

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Abstract. A driver mechanism is introduced to a cellular automaton by which the state of one or several cells is controlled independently of the other cells. One way of achieving this is to set certain cell values using a separate rule governed by external inputs to the cellular automaton. When such a mechanism is used in the Life rule, one-dimensional waves are generated by the driver cell and are propagated along the cellular automaton. It is hoped that such driving cells may be used to study the effects of disturbances to real-life models.

Introduction

Linear electric circuits may be analyzed in terms of their continuous response to a given input condition or by their response to a given external signal. A cellular automaton with a single rule can be compared to the transient circuit, evolving by some fixed law from a given initial condition.

Here we study the behavior of a Cellular Automata Machine (CAM) whose cell values (zero or one) are displayed as (on or off) pixels on a two-dimensional computer display. At least one pixel in its two-dimensional plane is driven externally rather than solely by the main rule. We call this a *driver mechanism.* It is analogous to an external input to a linear circuit and its effect is analogous to the transient response of a linear electric circuit to a given external input. We have modified a CAM-6 cellular automaton machine (from Systems Concept, Inc.), having a 256 × 256 cell plane, to run with externally controlled cells. We will refer to this machine simply as CAM. All programs we describe here use the terminology of [1], which describes CAM architecture in detail. Here we describe how a driver rule is run on a background plane of cells. A background plane is any plane not used directly by the main rule. Therefore, a driver rule is embedded within the main rule and is used by the CAM to constantly modify the pattern file, which describes the state of the plane. The modified pattern is used as the input to the next step of the main rule. The use of the background plane prevents any influence of the main rule over the driver. However, the

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```
NEW-EXPERIMENT N/MOORE

                                      : 8SUM
                  NORTH SOUTH WEST EAST
             N.WEST N.EAST S.WEST S.EAST
                                 +++++++;

                                      : LIFE
        { 0 0 CENTER 1 0 0 0 0 0 } >PLN0 ;

MAKE-TABLE LIFE
```

Figure 1: The Game of Life.

driver must be linked to the main rule in a manner that enables the driver to execute on the planes used by the main rule. The output of the driver's execution is then provided as the input for the next step in the execution of the main rule.

In this paper we modify (program-driven pixels) three commonly studied cellular automata rules that have been named Life, Fray, and Parity [1]. In each case, we force all 256 cells on a horizontal line to stay ones after 256 steps. This line grew from a single one cell by adding another forced one cell to the right of the line of ones at each of the first 256 steps. We chose this example of a driving mechanism because it has an initial transient phase and a final (after 256 steps) steady-state phase. It is also easy to program. For CAM rules Life and Parity, we start with a standard pattern file (DISK.PAT, see [2]) that produces a solid circle of ones (of diameter 128 cells) on a background of zeros. Results are markedly different from free-running behavior with no externally controlled cells. A driver rule can be merged with a main rule with some predetermined purpose or as a tool for experimentation. In this paper, we illustrate the form and effects of a driver mechanism as an experimental tool. The CAM rule simulating the driver point consists of three parts: the first determines the state of the driver pixels, the second part links the driver with the main rule, and the third part serves to control the frequency of execution of the driver rule.

The modified Game of Life rule

One of the rules that showed an interesting property when influenced by the driver is the Game of Life rule (see [2], pages 20–21, for a detailed explanation of the rule). Figure 1 shows the actual rule of Life, while figure 2 shows the modified rule of Life with a driver mechanism.

In the modified rule, the Forth word `GENERATE-WAVE` is used to generate one-dimensional waves from a point source on planes 2 and 3. `PROPAGATE-WAVE` is responsible for propagating the generated one-dimensional waves on planes 2 and 3. The third line in `PROPAGATE-WAVE (&CENTER CENTER OR`

```
NEW-EXPERIMENT N/MOORE

                                         : 8SUM
                    NORTH SOUTH WEST EAST
              N.WEST N.EAST S.WEST S.EAST
                                 +++++++;

                                         : LIFE
       { 0 0 CENTER 1 0 0 0 0 0 } >PLN0 ;

MAKE-TABLE LIFE

                                         :GENERATE-WAVE
                 WEST CENTER' OR >PLN2
                         CENTER' >PLN3 ;

MAKE-TABLE GENERATE-WAVE

                                         : PROPAGATE-WAVE
                            WEST >AUX2
                         CENTER' >AUX3
               &CENTER CENTER OR >AUX0
                         CENTER' >AUX1 ;

MAKE-TABLE PROPAGATE-WAVE

                                         : SHIFT-CYCLE
           REG-TABS STEP AUX-TABS STEP ;

MAKE-CYCLE SHIFT-CYCLE
```

Figure 2: Modified Life rule with driver mechanism, used to generate figures 3 and 4.

>`AUX0`) makes the connection between plane 0 and plane 2. This is the link that enables the modification of the initial pattern. The next Forth word, `SHIFT-CYCLE`, controls the frequency of the application of the outputs from the regular tables and the auxiliary tables.

The influence of the driver mechanism on the Life rule is illustrated in figure 4. The initial pattern is a circular mask of ones on planes 0 and 1. On the left side of the circular mask is a cell with a one on planes 2 and 3 only. Figure 3 shows two stages of the original Life rule on the initial pattern. It is not an interesting case since after some time there is not much activity, and all the live cells alternate between two fixed states. Figure 4 shows the result of the modified Life rule starting with the same initial pattern file as used in figure 3.

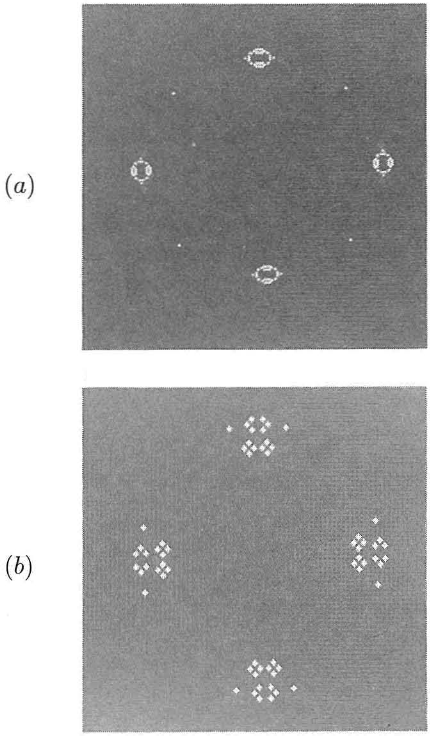

Figure 3: (*a*) State of CAM after six steps with original Life rule. Initial state is a solid circle of ones described in the text. (*b*) State of CAM after 139 steps with original Life rule. Only cells that stay alive or alternate between life and death appear as on pixels. This pattern is periodic with a period of 2 steps.

An interesting result of the modified rule is that cell activity seems to concentrate around the line of ones. A relatively small number of cells away from the line enter an alternating state in which they switch back and forth between two patterns. The activity of the cells continues as time goes on. In the context of life, one can imagine this to be a model for the growth of civilization centered around a river, the river being the supporter of life around it. The farther away the cell is from the essential resources of life, the less the chance of survival. Most cells far away from the driver point cease to exist while a few enter an alternating state, each oscillating between two fixed patterns while the cells close to the waves exhibit a considerable amount of birth-death activity.

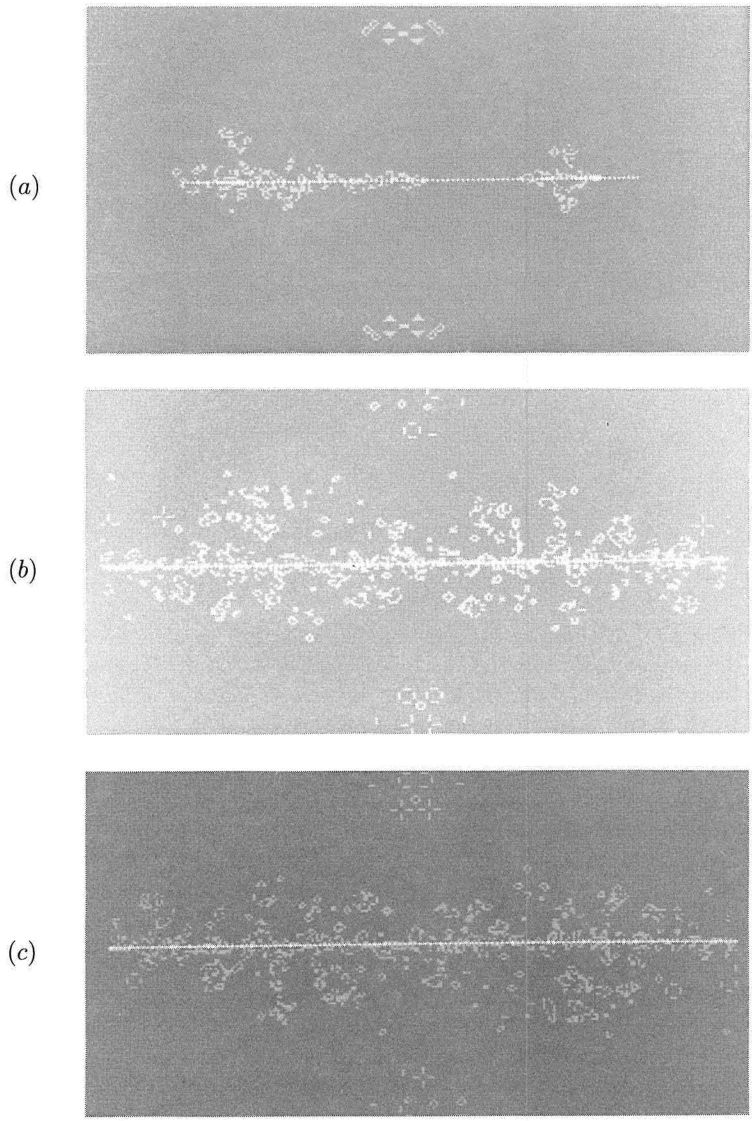

Figure 4: Patterns from the modified Life rule with the same initial pattern as used in figure 3, after (*a*) 184 steps, (*b*) 1000 steps, and (*c*) 10,000 steps.

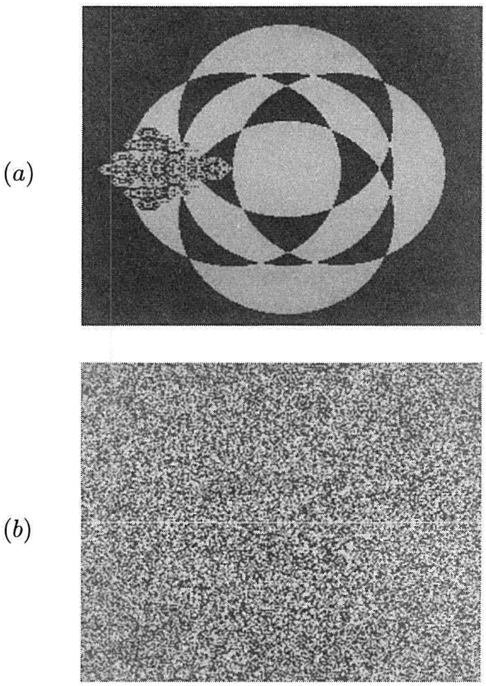

Figure 5: (*a*) Pattern from the modified Parity rule after 64 steps. The initial pattern is the same as in figures 3 and 4. (*b*) Patterns from the modified Parity rule after 500 steps. The line of bright on pixels in the center is the line of ones on plane 2. The other one cells are on plane 0.

The modified Parity rule

Another rule exhibiting interesting properties in the presence of a driver is the Parity rule (see [2], pages 30–33). The same driver rule (as used in modified Life) is merged with the original Parity rule.

Figure 5(*a*) shows the result of the Parity rule on the initial pattern. Figure 5(*b*) shows the effect of the modified Parity with a driver mechanism. The original rule produces repeated symmetric patterns, while the modified rule destroys the symmetry and does not produce any patterns at all. After a few steps, the outcome is just haphazard and asymmetric.

The modified Fray rule

Another rule that shows interesting properties when influenced by the driver mechanism is the Fray rule. Figure 6 shows the modified Fray rule with a driver mechanism. The modified rule consists of a slightly different driver

```
NEW-EXPERIMENT N/MOORE &/CENTERS
                                              : FRAY
  NORTH EAST AND SOUTH WEST AND XOR CENTER' XOR >PLN0
                                         CENTER >PLN1 ;

MAKE-TABLE FRAY

                                              : AND5
   NORTH SOUTH WEST EAST CENTER AND AND AND AND >AUX0
                                         CENTER >AUX1 ;

MAKE-TABLE AND5
TRUE 0 VAL>PL TRUE 1 VAL>PL
TEMP-SEG 2 2 AREA 0 NOT-PL 1 NOT-PL WHOLE-AREA
DECIMAL 83 AND-STEPS
0. STEP-NUMBER 2!

                                              : GENERATE-WAVE
                               CENTER' NOT CENTER NOT
    NORTH SOUTH WEST EAST S.EAST S.WEST N.EAST N.WEST
                   OR OR OR OR OR OR OR AND AND >PLN2
                                        CENTER' >PLN3;

MAKE-TABLE GENERATE-WAVE

                                              : PROPAGATE-WAVE
                              CENTER &CENTER OR >AUX0
                                         CENTER >AUX2
                                        CENTER' >AUX3
                                        CENTER' >AUX1 ;

MAKE-TABLE PROPAGATE-WAVE

                                              : SHIFT-CYCLE
                         REG-TABS STEP AUX-TABS STEP;

MAKE-CYCLE SHIFT-CYCLE
```

Figure 6: The modified Fray rule with a driver mechanism.

than the one used in the modified Life or Parity rules. In this case, a point source generated waves in all directions at alternating steps, contrary to the one-dimensional waves in the previous cases.

Figure 7 shows the initial pattern with a cell in the center of the diamond containing a one in planes 2 and 3.

Figure 8 shows stages of the original Fray rule.

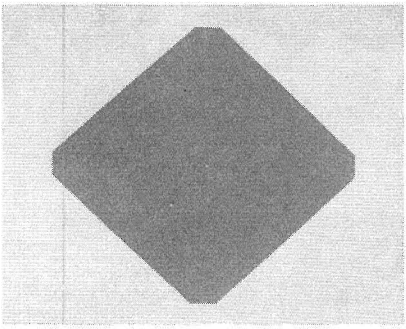

Figure 7: Initial pattern used for original and modified Fray rule. The cell in the center of the diamond contains a one on plane 3. Cells surrounding the diamond have a one on plane 0 and plane 1.

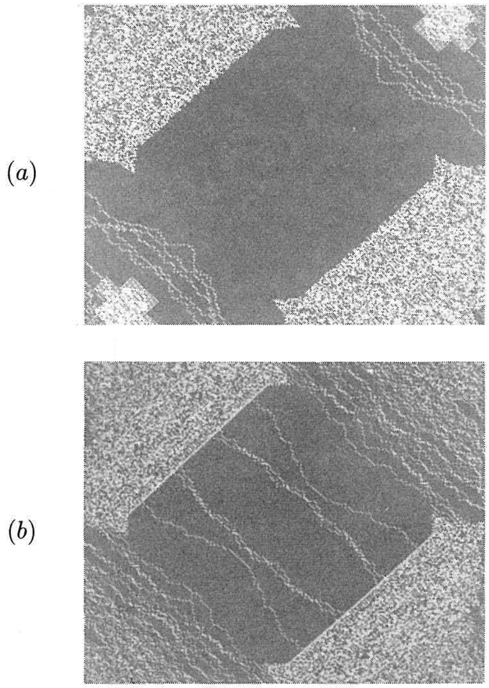

Figure 8: (*a*) Pattern from the original Fray rule after 464 steps. (*b*) Pattern from the original Fray rule after 2953 steps. The fraying lines forming in the "diamond" start with a one on plane 1 and slowly get a one on plane 0 as well.

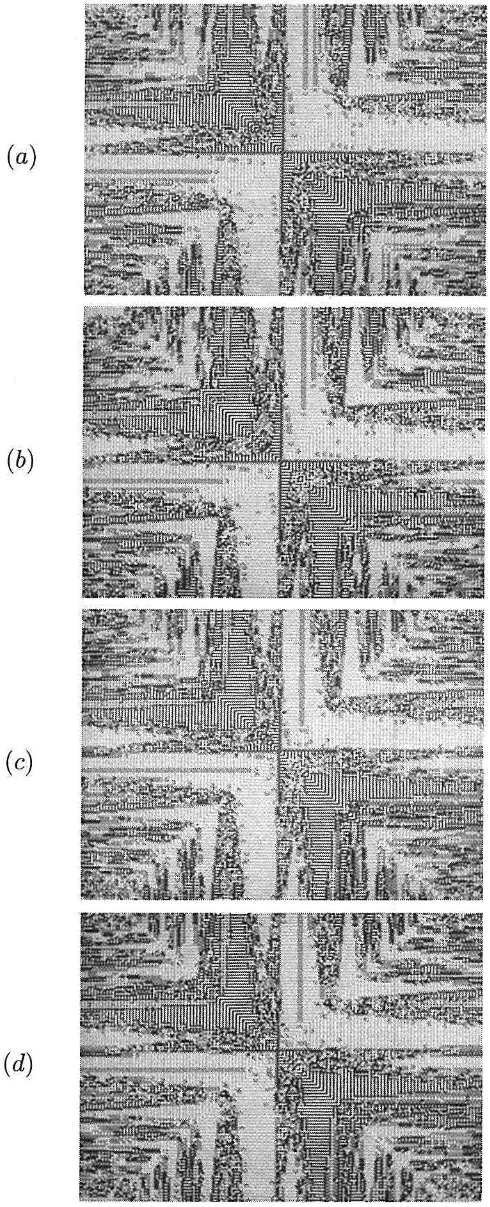

Figure 9: Four consecutive patterns from the modified Fray rule. (*a*) A one cell goes toward the boundary of the two octants in the top right part of the figure. (*b*) The one cell does not encounter a corresponding one cell in the neighboring octant, so it "moves" into that octant. (*c*) It is now moving horizontally right in the new octant. Also shown is a pair of cells at the boundaries of the two octants. (*d*) These two cells collide and go back along their original paths and stay in the

Figure 9 shows three steps of the modified Fray rule on the same initial pattern. The rule divides the screen into four sections. Each quarter is independent of any other. Each quarter is also divided into two subsections, thus forming octants. The interaction between the octants is interesting. A colored cell at the boundary between the two octants interacts in two ways, depending on its neighbor along the border in the neighboring octant in the same quarter. If the neighbor cell is dark, the cells collide and go back along their original paths (middle). However, if the neighbor is light, then the dark cell is absorbed into the neighboring octant in the quarter (right).

We have seen that, in all three rules, the driver mechanism changed the behavior of the original rule on an initial pattern. The driver rule acted as an external input with a certain frequency and influenced the main rule at certain intervals. The observations made in each case were the reactions of the main rule to the influence of the driver rule on the pattern file.

The driver mechanism provides us with a tool for analyzing the reaction of a rule to varying inputs. This can be very useful while modeling complex processes on CAM. In modeling complex processes it is sometimes very useful to implement certain perturbations and observe their effects on the model. A cleverly devised driver mechanism can serve this purpose. This was clearly illustrated in the three rules we discussed.

Acknowledgments

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References

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