Cellular Automata

Cellular Automata is a program that explores the dynamics of cellular automata. As described in Chapter 9 of Peak and Frame, a cellular automaton is determined by four features:

- The state space
- The number of states per cell
- The neighborhood of a cell
- The evolutionary rule

The state space is the collection of all cells (assumed identical) on which the automation works. Cellular Automata explores binary automata, those that have two states per cell. For binary automata, the two states are often said to be “on” and “off”, or “alive” and “dead”. The neighborhood of a cell is the set of cells in the vicinity of a given cell that can influence the state of that given cell in the next generation. The evolutionary rule determines the state of a cell in the next generation from the states of the cells in its neighborhood in the present generation.

Cellular Automata contains three modes:
1. One Dimensional,
2. Two Dimensional, and
3. Life

Upon execution of Cellular Automata the user is first asked to choose a mode. After that a user can change modes by selecting the appropriate option under the Mode menu. Let’s begin by choosing the One Dimensional mode. In this mode the cells are displayed in the graph window of the screen along a horizontal line with each generation below its predecessor. Upon selecting this mode, you will be asked to select at cell size (in pixels). The choices are 1 x 1 (very small, almost invisible), 2 x 2 (a little larger), and 4 x 4 (even larger). For this example, let’s select the 2 x 2 choice.

Next, you will be asked to select a neighborhood type. There are four choices: (1) “N=3, Full”, (2) “N=3, OT”, (3) “N=5, Full”, and (4) “N=5, OT”. These neighborhood types will be explained a little later, but for now, we will choose the first of these. The “N=3” means that the neighborhood of a cell is itself, the cell to its immediate left, and the cell to its immediate right. Upon selecting the neighborhood type, a window like that of Figure 1. Note that there are eight rows of three boxes, some of which are filled in. Each row is preceded by a check box. The eight rows represent the possible configurations of a cell and its two immediate neighbors – black means live and white means dead. When a box is checked, then if that configuration represents the present state of a cell and its neighbors, that cell will be live in the next generation. For this example, let’s check the second and fifth configurations. Hence a cell will be live in the next generation if it is dead in the current generation, but either of its immediate neighbors is live in the current generation.
Next, you will be asked for a seed choice. There are three options: (1) “Central”, (2) “Random” and “Homemade”. These choices will be explained later, but for now, we will choose the first of these. When this option is selected, the only live cell in the first generation is the one in the middle of the screen. Now press the “Go” button and then “Automate”. Generation after generation is displayed, one below the other. After a few seconds the screen will appear as in Figure 2.

Now let’s look at the modes in more detail. First up is the One Dimensional mode. As stated before the cells are displayed in the graph window of the screen along a horizontal line with each generation below its predecessor. We have already seen neighborhood type “N=3, Full”. The second type is “N=3, OT”, where the “OT” stands for “Outer Totalistic”. The neighborhood of a cell is the same as before, itself, the neighbor to its immediate left and the neighbor to its immediate right. However, an outer totalistic rule is stated in terms of the total of on-neighbors outside of the central cell, not in terms of which of the neighbors is on. When this neighborhood type is selected like that of Figure 3 will appear. Note that there are six check boxes, two each under the numbers 2, 1, and 0. The number represents the number of live cells (not including the cell itself) in the neighborhood. Thus, there are three choices – both the other cells could be live (this corresponds to 2), exactly one of the cells could be live (This corresponds to 1), or neither of the cells could be alive (this corresponds to 0). For each pair of boxes, the left member corresponds to the central cell of the neighborhood being live, the right corresponds to the central cell of the neighborhood being dead. For example, checking the right box under 2 and the left box under 1 gives the following rule: if the central cell is dead and both its neighbors are live, or if the central cell is live and exactly one of its neighbors is alive, then the central cell is live in the next generation.
The third neighborhood type is “N=5, Full”, where the neighborhood of a cell consists of the cell itself and its two immediate left and right neighbors. When this option is chosen a window appears similar to the one that appears when the “N=3, Full” option is chosen, except that there are 32 rather than 8 different possible configurations. The final neighborhood type is “N=5, OT”. This type is like the “N=3, OT”, except that the neighborhood of a cell is itself and its two immediate left and right neighbors. There are five possibilities for the number of live cells (not including the cell itself) in the neighborhood, 0 through 4. When this option is chosen, there are ten check boxes displayed, two each under the numbers 4, 3, 2, 1, and 0. The interpretation of these boxes is exactly the same as in the “N=3, OT” case.
A note about neighborhoods. Ideally, a state space is infinite in extent, but any realization in any computer can contain only a finite number of cells. **Cellular Automata** treats this situation by imposing a “wraparound”, that is, the left-most cell and the right-most cell on the screen are taken to be adjacent.

Once the neighborhood type is determined you are asked to select a seed type. There are three choices: (1) Central, (2) Random, and (3) Homemade. When the Central seed option is selected the initial generation consists of a single live cell which is located in the middle of the viewing rectangle. When you select the Random option you will be asked to specify the percentage of live cells in the initial generation. Once that specification is made, **Cellular Automata** randomly chooses the live cells in the initial generation. When the “Homemade” option is selected, a small cursor appears at the top left of the graph window. This cursor can be moved to the left or right by use of the arrows keys. Initially all cells in the initial generation are considered dead. You can change the dead/live status of any cell by moving the cursor over that cell and then pressing the space bar. Once you have definitely decided on which cells should be live in the initial generation you can press the “Enter” key.

Now that the cell size, neighborhood type, the evolutionary rule, and the initial seed are all specified, a “Go” button appears in the status window. When it is pressed, you have the option to plot the “Next State” (generation) only, or to “Automate” (let **Cellular Automata** plot each succeeding generation without stopping), or to stop. When a generation is plotted, the generation number along with the percentage of live cells is printed at the bottom of the screen. Also when “Automate” is selected, the user has the option to “Pause” the calculations at any time. Figure 4 shows the evolution of generations with 2 x 2 cells, the neighborhood type is “N=5, OT” with evolutionary rule

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\begin{array}{cccc}
4 & 3 & 2 & 1 \ 0 \\
\checkmark & \checkmark & \checkmark & \checkmark & \checkmark \\
\end{array}
\]

and a central single live cell in the initial generation.

After a problem is set up, the cell size, the neighborhood type, the evolutionary rules, and the seed type can all be edited via the status window appearing on the right hand side of the screen.

We next move on to the next mode – Two Dimensional. In this mode the cells are displayed in a 100 x 100 square grid and each successive generation replaces its predecessor as it is calculated. Like the One Dimensional mode, **Cellular Automata** imposes a wraparound so the left-most and right-most edge cells are considered to be neighbors and the top and bottom cells are also considered to be neighbors. Also like the One Dimensional Mode, you will first be asked to select a cell size (in pixels). The choices are 2 x 2 and 4 x 4.
Next, you will be asked to select a neighborhood type. There are three choices: (1) “VN, Full”, (2) “VN, OT”, or “M, OT”. The “VN” stands for von Neumann and such neighborhoods consist of the central cell, its immediate neighbor to the left (its western neighbor), to the right (its eastern neighbor), above (its northern neighbor) and below (its southern neighbor). When the “VN, Full” option is chosen, a window like that of Figure 5 appears. Note there are 32 grids of boxes, of which some of the boxes are filled in. Each grid is preceded by a check box. The 32 grids represent the possible configurations of a cell and its four neighbors – black means live and white means dead. When a box is checked, then if that configuration represents that present state of a cell and its neighbors, that cell will be live in the next generation.
The “OT” in the last two neighborhood types stands for “Outer Totalistic”. When the “VN, OT” option is chosen, there are ten check boxes displayed, two each under the numbers 4, 3, 2, 1, and 0. The number represents the number of live cells (not including the cell itself) in the neighborhood. For each pair of boxes, the left member corresponds to the central cell of the neighborhood being live, the right corresponds to the central cell of the neighborhood being dead. For example, checking the right box under 2 and the left box under 1 gives the following rule: if the central cell is dead and two of its four neighbors are live, or if the central cell is live and exactly one of its neighbors is live, then the central cell is live in the next generation.

The third neighborhood type is “M, OT”. The “M” stands for “Moore” – a Moore neighborhood consists of the von Neumann neighborhood plus the cells at the northeast, northwest, southwest, and southeast corners. Thus, when the “M, OT” option is chosen, there are 18 check boxes displayed, two each under the numbers 8, 7, 6, 5, 4, 3, 2, 1, and 0. The interpretation of these boxes is exactly the same as in the “VN, OT” case.

Once the neighborhood type is determined you are asked to select a seed type. There are three choices: (1) Central, (2) Random, and (3) Homemade. When the Central seed option is selected the initial generation consists of a single live cell which is located in the middle of the viewing rectangle. When you select the Random option you will be asked to specify the percentage of live cells in the initial generation. Once that specification is made, Cellular Automata randomly chooses the live cells in the initial generation. When the “Homemade” option is selected, a small cursor appears in the center of the graph window. This cursor can be moved to the left, right, up, or down by use of the arrows keys. Initially all cells in the initial generation are considered dead. You can change the dead/live status of any cell by moving the cursor over that cell and then pressing the space bar. Once you have definitely decided on which cells should be live in the initial generation you can press the “Enter” key.

Now that the cell size, neighborhood type, the evolutionary rule, and the initial seed are all specified, a “Go” button appears in the status window. When it is pressed, you have the option to plot the “Next State” (generation) only, or to “Automate” (let Cellular Automata plot each succeeding generation without stopping), or to stop. When a generation is plotted, the generation number along with the percentage of live cells is printed at the bottom of the screen. When “Automate” is selected, the user has the option to “Pause” the calculations at any time. Figure 6 shows the fiftieth generation with 4 x 4 cells, the neighborhood type is “M, OT” with evolutionary rule

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   8   7   6   5   4
   3   2   1   0
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and a central single live cell in the initial generation.
As in the One Dimensional mode after a problem is set up, the cell size, the neighborhood type, the evolutionary rules, and the seed type can all be edited via the status window appearing on the right hand side of the screen.

The final mode is “Life” and is a specific two dimensional automaton. When you choose this mode you have the option to select 2 x 2 or 4 x 4 pixel sized cells. The neighborhood type is “M, OT” and uses the evolutionary rule

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\begin{array}{cccc}
8 & 7 & 6 & 5 \\
1 & 3 & 2 & 0 \\
0 & 1 & 3 & 2 \\
\end{array}
\]

That is a cell will be live in the next generation if it is live in the current generation and any three of its eight neighbors are also live, or if it is dead in the current generation and any two of its neighbors are live. After you choose the cell size a window like Figure 7 appears.

Option “A.” is an example of a “glider”. After four generations this glider moves one cell down and one cell right, recovering its original shape and orientation. Option “B.” is called an \textit{r pentimino}. After the first few (hundred) generations it appears that the life/death configuration is hopelessly complicated. But after about 1200 iterations the configuration is cyclical. The “Homemade” option works exactly the same as in “Two Dimensional” mode.

Now that the cell size and the initial seed are both specified, a “Go” button appears in the status window. When it is pressed, you have the option to plot the “Next State”
(generation) only, or to “Automate” (let Cellular Automata plot each succeeding generation without stopping), or to stop. When a generation is plotted, the generation number along with the percentage of live cells is printed at the bottom of the screen. Figure 8 shows the 500th generation when the initial generation is option “B.”

After a problem is set up, the cell size and the seed type can be edited via the status window appearing on the right hand side of the screen.