Computational Physics - Assignment 4

4 a)

In this problem, a one-dimensional cellular automata was implemented. The user can select an N number of sites, whether to implement the finite grids or periodic boundary conditions and the number of cycles for which the process goes on for.

Here, an initial array with randomized 0s and 1s is genereted. Next, the possible neighbour combinations are determined and a specific rule assigns a 0 or a 1 to each combination of neighbours. Considering boundary conditions, the finite grids method assumes an extra 0 at each end of the array to determine the neighbours and the periodic boundary condition assumes that the left neighbour of the first element is the last element of the array and that the right neighbor of the last element is the first element of the array. (each element has only 2 neighbours since this is one-dimensional) Finally, each element of the original array is assigned a new value depending on the neighbours it had and a new array is generated with these new values. This process repeats itself to give us the desired automata.

In my code, as an example, Rule 30 is implemented and an output is generated accordingly using N=25, finite grids and 50 cycles.
The code is explained in detail in the attached python file for this problem (4a.py).
The corresponding output is shown below:

original random data: [1 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 1 0 1 0 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [0 0 0 1 1 1 1 0]
generated array with finite bound:
[1 1 1 1 0 1 1 1 0 1 1 1 1 1 0 1 0 1 1 0 1 1 0 1 0]
[1 0 0 1 1 1 0 1 1 1 0 0 0 1 1 0 1 1 1 1 1 1 1 0 1]
[0 1 0 1 0 1 1 1 0 1 1 0 0 1 1 1 1 0 0 0 0 0 1 1 0]
[0 0 1 0 1 1 0 1 1 1 1 1 1 0 1 0 0 1 1 0 0 0 0 1 1 1]
[0 0 0 1 1 1 1 1 0 0 0 1 1 0 1 0 1 1 1 1 0 0 0 1 0 1]
[0 0 0 1 0 0 0 1 1 0 0 1 1 1 0 1 1 0 1 1 0 0 0 1 0]
[0 0 0 0 1 0 0 1 1 1 0 1 0 1 1 1 1 1 1 1 1 0 0 0 1]
[0 0 0 0 0 1 0 1 0 1 1 0 1 1 0 0 0 0 0 0 0 1 1 0 0 0]

[0 0 0 0 0 0 1 0 1 1 1 1 1 1 1 0 0 0 0 0 1 1 1 0 0]
[0 0 0 0 0 0 0 1 1 0 0 0 0 0 1 1 0 0 0 0 1 0 1 1 0]
[0 0 0 0 0 0 0 1 1 1 0 0 0 0 1 1 1 0 0 0 0 1 1 1 1]
[0 0 0 0 0 0 0 1 0 1 1 0 0 0 1 0 1 1 0 0 0 1 0 0 1]
[0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 0 0 1 0 0]
[0 0 0 0 0 0 0 0 1 0 0 1 1 0 0 1 0 0 1 1 0 0 0 1 0]
[0 0 0 0 0 0 0 0 0 1 0 1 1 1 0 0 1 0 1 1 1 0 0 0 1]
[0 0 0 0 0 0 0 0 0 0 1 1 0 1 1 0 0 1 1 0 1 1 0 0 0]
[0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0 0]
[0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 0 0 0 0 1 1 0]
[0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 1 1 0 0 0 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 1 1 1 0 0 1 0 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0 1 1 0 0 1 0]
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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

4 b)

Rule 150 was implemented with a single seed site.

Using finite grids, N=100 and 50 cycles:

original data: [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [1 0 0 1 0 1 1 0]
generated array with finite bound:

[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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 0 0 0 0 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]
[0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 0 0
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0 0 0 0 0 0 1 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 1]

Using periodic boundary conditions, N=100 and 50 cycles:

original data: [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [1 0 0 1 0 1 1 0]
generated array with periodic bound
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
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 1 0 1 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 1 0 1 0 0 0]

For a clearer result,

Finite grids, N=25 and 50 cycles:

original data: [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [1 0 0 1 0 1 1 0]
generated array with finite bound:
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0]
[0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0 0 1]
[1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0]
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[0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 1]
[1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0 1 0 0 1 0 0]
[1 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1]
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[0 0 1 0 1 0 0 0 1 0 0 0 1 0 1 0 0 0 1 0 1 0 1 0 1]
[1 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 1 0 0 1 0 1 0 1 0]
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[0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 0 1 0 0 0 1 0 1 0 0]

Periodic Boundary conditions, N=25 and 50 cycles:

original data: [1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [1 0 0 1 0 1 1 0]
generated array with periodic bound
[0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0]

[1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]
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[1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
[0 0 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 0]
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[1 0 1 0 0 0 1 0 1 0 1 0 0 0 0 1 0 1 0 1 0 0 0 1 0]
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[1 0 1 0 0 1 0 1 0 1 0 0 0 0 0 0 1 0 1 0 1 0 0 1 0]
[0 1 0 0 0 0 1 0 1 0 0 1 1 1 1 0 0 1 0 1 0 0 0 0 1]
[1 0 0 1 1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 1 1 0 0]
[0 0 0 1 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 1 0 0]
[1 1 0 1 1 0 1 1 0 0 0 1 1 1 1 0 0 0 1 1 0 1 1 0 1]
[0 1 1 1 1 1 1 1 0 1 0 1 0 0 1 0 1 0 1 1 1 1 1 1 1]
[1 1 0 0 0 0 0 1 1 0 1 0 0 0 0 1 0 1 1 0 0 0 0 0 1]
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[1 0 1 1 0 1 1 1 0 1 0 0 1 1 0 0 1 0 1 1 1 0 1 1 0]
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[0 1 0 1 0 1 0 0 1 1 0 1 1 1 1 0 1 1 0 0 1 0 1 0 1]
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[0 1 0 1 0 0 1 0 1 0 0 1 0 0 1 0 0 1 0 1 0 0 1 0 1]
[1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0]
[0 1 0 0 1 1 0 0 0 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1]
[1 0 0 0 1 1 0 1 0 1 0 0 0 0 0 0 1 0 1 0 1 1 0 0 0]

4 c)

A randomized array was used.

Rule 90

Finite grids, N=25 and 50 cycles

original random data: [0 1 1 1 1 1 1 1 1 1 0 0 1 0 0 0 1 1 0 1 0 0 0 0 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [0 1 0 1 1 0 1 0]
generated array with finite bound:
[1 1 0 0 0 0 0 0 0 1 1 1 0 1 0 1 1 1 0 0 1 0 0 0 0]
[1 1 1 0 0 0 0 0 1 1 0 1 0 0 0 1 0 1 1 1 0 1 0 0 0]
[1 0 1 1 0 0 0 1 1 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0]
[0 0 1 1 1 0 1 1 0 1 1 1 0 0 0 1 1 0 0 0 1 1 0 1 0]
[0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 1 1 1 0 1 1 1 0 0 1]
[1 1 1 0 0 0 1 1 0 0 0 1 1 0 1 0 0 1 0 1 0 1 1 1 0]
[1 0 1 1 0 1 1 1 1 0 1 1 1 0 0 1 1 0 0 0 0 1 0 1 1]
[0 0 1 1 0 1 0 0 1 0 1 0 1 1 1 1 1 1 1 0 0 1 0 0 1]
[0 1 1 1 0 0 1 1 0 0 0 0 1 0 0 0 0 1 1 1 0 1 1 1 1]
[1 1 0 1 1 1 1 1 1 0 0 1 0 1 0 0 1 1 0 1 0 1 0 0 1]
[1 1 0 1 0 0 0 0 1 1 1 0 0 0 1 1 1 1 0 0 0 0 1 1 0]
[1 1 0 0 1 0 0 1 1 0 1 1 0 1 1 0 0 1 1 0 0 1 1 1 1]
[1 1 1 1 0 1 1 1 1 0 1 1 0 1 1 1 1 1 1 1 1 1 0 0 1]
[1 0 0 1 0 1 0 0 1 0 1 1 0 1 0 0 0 0 0 0 0 1 1 1 0]
[0 1 1 0 0 0 1 1 0 0 1 1 0 0 1 0 0 0 0 0 1 1 0 1 1]
[1 1 1 1 0 1 1 1 1 1 1 1 1 0 1 0 0 0 1 1 1 0 1 1]
[1 0 0 1 0 1 0 0 0 0 0 0 0 1 0 0 1 0 1 1 0 1 0 1 1]
[0 1 1 0 0 0 1 0 0 0 0 0 1 0 1 1 0 0 1 1 0 0 0 1 1]

[1 1 1 1 0 1 0 1 0 0 0 1 0 0 1 1 1 1 1 1 1 0 1 1 1]
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[0 1 1 0 1 0 0 1 0 0 0 0 1 0 1 1 0 0 0 1 0 0 0 0 0]
[1 1 1 0 0 1 1 0 1 0 0 1 0 0 1 1 1 0 1 0 1 0 0 0 0]
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[1 0 0 0 0 1 1 1 0 1 0 1 0 0 1 1 1 0 1 1 1 0 1 0 1]
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[1 0 1 1 1 1 0 0 1 0 0 1 1 0 1 0 0 0 0 0 0 1 0 0 0]
[0 0 1 0 0 1 1 1 0 1 1 1 1 0 0 1 0 0 0 0 1 0 1 0 0]
[0 1 0 1 1 1 0 1 0 1 0 0 1 1 1 0 1 0 0 1 0 0 0 1 0]
[1 0 0 1 0 1 0 0 0 0 1 1 1 0 1 0 0 1 1 0 1 0 1 0 1]
[0 1 1 0 0 0 1 0 0 1 1 0 1 0 0 1 1 1 1 0 0 0 0 0 0]
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[1 0 0 1 0 0 0 1 0 0 1 1 1 1 0 1 1 1 1 1 1 0 0 0 0]
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[0 0 1 0 1 1 1 1 0 1 1 0 1 0 0 1 0 0 1 1 1 1 1 0 0]
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[0 0 1 1 0 1 1 1 1 0 0 0 0 1 0 0 0 1 1 0 1 0 0 1]
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[1 1 0 1 0 0 1 0 1 1 1 1 1 0 0 0 0 1 0 1 1 1 1 1 1]
[1 1 0 0 1 1 0 0 1 0 0 0 1 1 0 0 1 0 0 1 0 0 0 0 1]
[1 1 1 1 1 1 1 1 0 1 0 1 1 1 1 1 0 1 1 0 1 0 0 1 0]
[1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 1 1 0 0 1 1 0 1]

Periodic Boundary Conditions, N=25 and 50 cycles

original random data: [0 0 0 1 1 1 0 1 0 1 0 1 1 0 1 1 0 1 0 1 1 1 0 1 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [0 1 0 1 1 0 1 0]
generated array with periodic bound

[0 0 1 1 0 1 0 0 0 0 0 1 1 0 1 1 0 0 0 1 0 1 0 0 1]
[1 1 1 1 0 0 1 0 0 0 1 1 1 0 1 1 1 0 1 0 0 0 1 1 0]
[1 0 0 1 1 1 0 1 0 1 1 0 1 0 1 0 1 0 0 1 0 1 1 1 0]
[0 1 1 1 0 1 0 0 0 1 1 0 0 0 0 0 0 1 1 0 0 1 0 1 0]
[1 1 0 1 0 0 1 0 1 1 1 1 0 0 0 0 1 1 1 1 1 0 0 0 1]
[0 1 0 0 1 1 0 0 1 0 0 1 1 0 0 1 1 0 0 0 1 1 0 1 1]
[0 0 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0 1 1 1 0 1 1]
[1 1 1 0 0 0 0 1 0 1 0 0 0 0 0 0 0 1 0 1 0 1 0 1 1]
[0 0 1 1 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0]
[0 1 1 1 1 1 0 1 0 1 0 1 0 0 0 1 0 1 0 0 0 0 1 0 1]
[0 1 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 1 0 0 1 0 0 0]
[1 0 1 0 1 0 1 0 0 0 0 1 0 0 0 1 0 1 0 1 1 0 1 0 0]
[0 0 0 0 0 0 0 1 0 0 1 0 1 0 1 0 0 0 0 1 1 0 0 1 1]
[1 0 0 0 0 0 1 0 1 1 0 0 0 0 0 1 0 0 1 1 1 1 1 1 1]
[1 1 0 0 0 1 0 0 1 1 1 0 0 0 1 0 1 1 1 0 0 0 0 0 0]
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[0 0 1 0 0 0 1 0 1 0 1 1 0 0 1 1 0 0 1 1 1 0 0 1 1]
[1 1 0 1 0 1 0 0 0 0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1]
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[0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 1]
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[1 1 0 0 0 0 0 0 0 0 0 1 1 0 1 1 0 0 1 0 0 0 1 0 0]
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[0 0 1 1 0 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 0 0 1 0]
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[0 1 0 0 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 1 0 1 0 0 0]
[1 0 1 1 1 1 0 1 1 0 1 1 1 1 1 0 1 1 1 0 0 0 1 0 0]
[0 0 1 0 0 1 0 1 1 0 1 0 0 0 1 0 1 0 1 1 0 1 0 1 1]
[1 1 0 1 1 0 0 1 1 0 0 1 0 1 0 0 0 0 1 1 0 0 0 1 1]
[0 1 0 1 1 1 1 1 1 1 1 0 0 0 1 0 0 1 1 1 1 0 1 1 0]
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[1 1 1 0 1 0 0 0 0 1 1 1 0 0 0 1 0 1 1 1 0 0 1 0 0]
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[0 1 1 1 1 0 1 0 0 1 0 1 1 1 1 1 1 1 1 0 0 0 0 0 0]
[1 1 0 0 1 0 0 1 1 0 0 1 0 0 0 0 0 0 1 1 0 0 0 0 0]
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[0 0 0 1 0 1 0 0 0 0 1 0 0 1 0 0 1 1 0 0 1 1 0 1 1]
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[1 0 0 1 1 1 1 1 1 0 0 1 1 0 1 0 0 1 1 0 0 0 1 0 1]
[1 1 1 1 0 0 0 0 1 1 1 1 1 0 0 1 1 1 1 1 1 0 1 0 0 1]
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[1 0 1 1 1 1 1 1 1 1 0 1 1 0 0 1 1 0 1 0 1 1 1 0 1]
[1 0 1 0 0 0 0 0 0 1 0 1 1 1 1 1 1 0 0 0 1 0 1 0 1]

<u>Rule 150</u>

Finite grids, N=25 and 50 cycles

original random data: [1 1 1 0 0 0 0 0 1 1 0 1 1 0 1 1 1 1 0 1 0 1 0 1 0]

combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']

rule applied to each combination in order: [1 0 0 1 0 1 1 0]

generated array with finite bound:

[1 0 1 0 1 1 1 0 1 1 1 1 1 1 1 0 0 1 1 0 1 0 1 0 0]
[0 1 0 1 1 0 1 1 1 0 0 0 0 0 1 0 0 1 1 1 0 1 0 0 1]
[0 0 1 1 1 1 1 0 1 0 1 1 1 0 0 0 0 1 0 1 1 0 0 0 0]
[1 0 1 0 0 0 1 1 0 1 1 0 1 0 1 1 0 0 1 1 1 0 1 1 1]
[0 1 0 0 1 0 1 1 1 1 1 1 0 1 1 1 0 0 1 0 1 1 1 0 1]
[0 0 0 0 0 1 1 0 0 0 0 1 1 1 0 1 0 0 0 1 1 0 1 1 0]
[1 1 1 1 0 1 1 0 1 1 0 1 0 1 1 0 0 1 0 1 1 1 1 1 0]
[1 0 0 1 1 1 1 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 0 1 0]
[0 0 0 1 0 0 0 0 0 0 1 1 1 0 1 0 1 0 1 1 0 1 0 0 0]
[1 1 0 0 0 1 1 1 1 0 1 0 1 1 0 1 0 1 1 1 1 0 0 1 1]
[1 1 0 1 0 1 0 0 1 1 0 1 1 1 1 0 1 1 0 0 1 0 0 1 1]
[1 1 1 0 1 0 0 0 1 1 1 1 0 0 1 1 1 1 0 0 0 0 0 1 1]
[1 0 1 1 0 0 1 0 1 0 0 1 0 0 1 0 0 1 0 1 1 1 0 1 1]
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[0 1 0 1 0 1 0 0 0 1 1 1 1 1 1 1 1 0 1 1 1 1 0 0 1]
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[1 1 1 1 0 1 1 0 1 1 0 0 0 0 1 1 1 0 0 0 1 1 1 1 1]
[1 0 0 1 1 1 1 1 1 1 0 1 1 0 1 0 1 0 1 0 1 0 0 0 1]
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[1 1 0 0 0 1 1 1 0 1 0 0 0 1 1 0 1 0 1 0 0 0 0 0 1]
[1 1 0 1 0 1 0 1 1 0 0 1 0 1 1 1 0 1 0 0 1 1 1 0 0]
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[0 1 1 1 1 1 1 1 0 1 0 1 1 0 0 0 1 1 0 0 0 0 1 0 0]
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[0 0 0 1 1 1 0 1 1 1 1 0 1 1 0 1 1 1 1 1 1 1 0 1 0 0]
[1 1 0 1 0 1 1 1 0 0 1 1 1 1 1 1 0 0 0 0 1 1 0 0 1]
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[0 1 1 1 0 0 0 1 1 1 1 0 0 1 0 1 1 0 1 1 1 0 0 0 0]
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[0 0 1 0 1 0 1 0 0 0 0 0 1 0 1 0 0 0 1 1 0 1 1 0 1]
[1 0 0 1 0 1 0 0 1 1 1 0 0 1 0 0 1 0 1 1 1 1 1 1 0]
[0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 1 1 0 0 0 0 1 0]
[1 1 1 0 0 0 1 0 0 1 0 0 1 1 1 1 0 1 1 0 1 1 0 0 0]
[1 0 1 0 1 0 0 0 0 0 0 0 1 0 0 1 1 1 1 1 1 1 0 1 1]
[0 1 0 1 0 0 1 1 1 1 1 0 0 0 0 1 0 0 0 0 0 1 1 1 1]
[0 0 1 0 0 0 1 0 0 0 1 0 1 1 0 0 0 1 1 1 0 1 0 0 1]
[1 0 0 0 1 0 0 0 1 0 0 1 1 1 0 1 0 1 0 1 1 0 0 0 0]
[0 0 1 0 0 0 1 0 0 0 0 1 0 1 1 0 1 0 1 1 1 0 1 1 1]
[1 0 0 0 1 0 0 0 1 1 0 0 1 1 1 1 0 1 1 0 1 1 1 0 1]
[0 0 1 0 0 0 1 0 1 1 0 0 1 0 0 1 1 1 1 1 1 0 1 1 0]
[1 0 0 0 1 0 0 1 1 1 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0]
[0 0 1 0 0 0 0 1 0 1 0 1 1 1 0 0 0 1 1 0 1 0 0 1 0]
[1 0 0 0 1 1 0 0 1 0 1 1 0 1 0 1 0 1 1 1 0 0 0 0 0]
[0 0 1 0 1 1 0 0 0 1 1 1 1 0 1 0 1 1 0 1 0 1 1 1 1]

Periodic Boundary Conditions, N=25 and 50 cycles

original random data: [0 0 0 0 1 1 0 0 1 1 1 0 0 0 0 0 0 1 1 0 0 1 1 1 1]

combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']

rule applied to each combination in order: [1 0 0 1 0 1 1 0]

generated array with periodic bound

[0 1 1 0 1 1 0 0 1 0 1 0 1 1 1 1 0 1 1 0 0 1 0 0 1]
[1 1 1 1 1 1 0 0 0 1 0 1 1 0 0 1 1 1 1 0 0 0 0 0 0]
[1 0 0 0 0 1 0 1 0 0 1 1 1 0 0 1 0 0 1 0 1 1 1 1 0]
[0 0 1 1 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 1 1 0 0 1 1]

[0 0 1 1 0 0 0 0 1 0 0 1 0 0 1 1 1 1 0 1 1 0 0 1 1]
[0 0 1 1 0 1 1 0 0 0 0 0 0 0 1 0 0 1 1 1 1 0 0 1 1]
[0 0 1 1 1 1 1 1 0 1 1 1 1 1 0 0 0 0 1 0 0 1 0 0 1 1]
[0 0 1 0 0 0 1 1 1 0 0 0 1 0 1 1 0 0 0 0 0 0 0 1 1]
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[0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0]
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[0 1 1 0 0 1 0 0 1 0 1 0 0 0 0 1 0 1 1 1 0 1 1 0 1]
[1 1 1 0 0 0 0 0 0 1 0 0 1 1 0 0 1 1 0 1 1 1 1 1 0]
[1 0 1 0 1 1 1 1 0 0 0 0 1 1 0 0 1 1 1 1 0 0 0 1 1]
[1 1 0 1 1 0 0 1 0 1 1 0 1 1 0 0 1 0 0 1 0 1 0 1 0]
[1 1 1 1 1 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0 1 0 1 0 1]
[0 0 0 0 1 0 1 0 1 0 0 0 0 1 0 1 1 1 1 0 0 1 0 1 1]

[0 1 1 0 0 1 0 1 0 0 1 1 0 0 1 1 0 0 1 0 0 0 1 1 1]
[1 1 1 0 0 0 1 0 0 0 1 1 0 0 1 1 0 0 0 0 1 0 1 0 1]
[0 0 1 0 1 0 0 0 1 0 1 1 0 0 1 1 0 1 1 0 0 1 0 1 1]
[0 0 0 1 0 0 1 0 0 1 1 1 0 0 1 1 1 1 1 0 0 0 1 1 1]
[0 1 0 0 0 0 0 0 0 1 0 1 0 0 1 0 0 0 1 0 1 0 1 0 1]
[1 0 0 1 1 1 1 1 0 0 1 0 0 0 0 0 1 0 0 1 0 1 0 1 0]

Rule 18

Finite grids, N=25 and 50 cycles

original random data: [1 1 1 1 1 0 1 1 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 1 0]

combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']

rule applied to each combination in order: [0 0 0 1 0 0 1 0]

generated array with finite bound:

[1 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

```
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[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

Periodic Boundary Conditions, N=25 and 50 cycles

```
original random data: [1 0 1 1 1 0 0 0 0 0 0 1 0 0 0 1 0 1 1 1 0 0 1 1 1]
combinations possible for input:  ['000', '001', '010', '011', '100', '101', '110',
'111']
rule applied to each combination in order:  [0 0 0 1 0 0 1 0]
generated array with periodic bound
[1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 1 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
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[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

Rule 73

Finite grids, N=25 and 50 cycles

original random data: [0 1 0 0 0 0 1 0 0 1 0 0 1 1 1 0 1 1 0 0 0 1 1 0 0]

combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']

rule applied to each combination in order: [0 1 0 0 1 0 0 1]

generated array with finite bound:

[1 0 1 0 0 1 0 1 1 0 1 1 0 1 0 0 0 0 1 0 1 0 0 1 0]
[0 0 0 1 1 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0 0 1 1 0 1]
[0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 1 1 0 1 0 1 0 0 0 0]
[0 1 0 1 1 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0]
[1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 1 0 1 0 0]
[0 1 0 0 0 0 1 0 1 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0]
[1 0 1 0 0 1 0 0 0 0 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1]
[0 0 0 1 1 0 1 0 0 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0]
[0 0 1 0 0 0 0 1 0 1 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0]
[0 1 0 1 0 0 1 0 0 0 0 0 1 0 1 0 1 1 0 1 0 0 0 0 0]
[1 0 0 0 1 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0]
[0 1 0 1 0 0 0 1 0 1 0 1 0 0 0 0 0 0 1 0 1 0 0 0]
[1 0 0 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0]
[0 1 0 1 0 1 1 0 1 0 0 0 1 0 1 0 0 1 0 1 0 1 0 1 0]
[1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 1 1 0 0 0 0 0 0 0 1]
[0 1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 1 0 0 0 0 0 1 0]
[1 0 1 0 0 0 0 1 0 1 0 1 0 0 0 1 1 0 1 0 0 0 1 0 1]
[0 0 0 1 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 1 0 1 0 0 0]
[0 0 1 0 1 1 0 1 0 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0]
[0 1 0 0 0 0 0 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0]
[1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]
[0 0 0 1 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]
[0 0 1 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1]
[0 1 0 0 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
[1 0 1 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 1 0 0]
[0 0 0 1 1 0 1 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 1 0]
[0 0 1 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0 1 0 1 0 1 0 1]
[0 1 0 1 0 0 1 0 0 0 1 0 1 0 1 0 0 1 0 0 0 0 0 0 0]
[1 0 0 0 1 1 0 1 0 1 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0]
[0 1 0 1 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 0]

[1 0 0 0 1 0 0 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 0 0 0]
[0 1 0 1 0 1 0 0 1 0 0 0 0 0 0 0 1 1 0 0 0 1 0 0 0]
[1 0 0 0 0 0 1 1 0 1 0 0 0 0 0 1 0 0 1 0 1 0 1 0 0]
[0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 1 1 0 0 0 0 0 1 0]
[1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0 0 0 1 0 0 0 1 0 1]
[0 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 1 0 1 0 1 0 0 0]
[0 0 0 0 0 0 1 0 0 1 0 0 0 1 0 1 1 0 0 0 0 0 1 0 0]
[0 0 0 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1 0 0 0 1 0 1 0]
[0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 1 0 1 0 1 0 0 0 1]
[0 0 0 1 0 1 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 1 0 1 0]
[0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 1]
[0 1 0 1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 1 0 1 0 1 0]
[1 0 0 0 0 0 0 0 1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 0 1]
[0 1 0 0 0 0 0 1 0 0 1 0 1 0 0 1 0 0 0 0 0 0 0 1 0]
[1 0 1 0 0 0 1 0 1 1 0 0 0 1 1 0 1 0 0 0 0 0 1 0 1]
[0 0 0 1 0 1 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 1 0 0 0]
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[0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 1 0 0 0 0 0 0 0 1 0]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 1]
[0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0 1 0 0 0]

Periodic Boundary Conditions, N=25 and 50 cycles

original random data: [0 0 1 0 1 1 0 1 1 0 0 0 0 0 0 1 0 0 0 1 0 1 1 1 0]

combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']

rule applied to each combination in order: [0 1 0 0 1 0 0 1]

generated array with periodic bound

[0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 1 0 1 0 0 0 1 0 1]
[0 0 1 0 0 0 0 0 1 0 1 0 0 1 0 0 0 0 0 1 0 1 0 0 0]
[0 1 0 1 0 0 0 1 0 0 0 1 1 0 1 0 0 0 1 0 0 0 1 0 0]
[1 0 0 0 1 0 1 0 1 0 1 0 0 0 0 1 0 1 0 1 0 1 0 1 0]
[0 1 0 1 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0]
[1 0 0 0 1 0 0 0 0 0 1 0 1 1 0 1 0 0 0 0 0 0 0 0 0]
[0 1 0 1 0 1 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1]
[0 0 0 0 0 0 1 0 1 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0]
[0 0 0 0 0 1 0 0 0 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 1]
[1 0 0 0 1 0 1 0 0 0 1 0 1 1 0 1 0 1 0 1 0 1 0 0 0]
[0 1 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 1]
[0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0]
[0 0 0 1 0 0 0 1 0 1 0 1 0 0 0 0 0 0 0 0 1 0 1 0 0]

[0 0 1 0 1 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0]
[0 1 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 1 0 1 0 1 0 1]
[0 0 1 0 0 0 1 0 1 0 1 0 0 0 1 0 0 1 0 0 0 0 0 0 0]
[0 1 0 1 0 1 0 0 0 0 0 1 0 1 0 1 1 0 1 0 0 0 0 0 0]
[1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0]
[0 1 0 0 0 1 0 1 0 1 0 1 0 0 0 0 0 0 1 0 1 0 0 0 1]
[0 0 1 0 1 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 1 0]
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[0 0 1 0 1 0 1 0 0 0 1 0 0 0 1 1 0 0 0 0 0 1 0 1 0]
[0 1 0 0 0 0 0 1 0 1 0 1 0 1 0 0 1 0 0 0 1 0 0 0 1]
[0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 1 0 1 0 1 0 1 0 1 0]
[0 1 0 1 0 1 0 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1]
[0 0 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 0]
[0 0 0 0 0 0 0 1 0 1 0 1 0 0 0 1 0 0 0 0 0 0 1 0 1]
[1 0 0 0 0 0 1 0 0 0 0 0 1 0 1 0 1 0 0 0 0 1 0 0 0]
[0 1 0 0 0 1 0 1 0 0 0 1 0 0 0 0 0 1 0 0 1 0 1 0 1]
[0 0 1 0 1 0 0 0 1 0 1 0 1 0 0 0 1 0 1 1 0 0 0 0 0]
[0 1 0 0 0 1 0 1 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0]
[1 0 1 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 0 0]
[0 0 0 0 0 1 0 1 0 1 0 1 0 1 0 1 0 1 1 0 0 0 1 0 1]
[1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0 0 0]
[0 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 1 0 1]
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[0 0 1 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0]
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[1 0 1 0 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 0]
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[0 0 0 0 1 0 1 0 1 0 1 1 0 1 0 0 0 0 0 0 1 0 1 0]
[0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1]
[1 0 1 0 1 0 0 0 0 0 0 0 1 0 1 0 0 0 1 0 1 0 1 0]
[0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 0]
[0 0 0 0 1 0 1 0 0 0 0 1 0 1 0 1 0 0 0 1 0 0 0 0]

Rule 136

Finite grids, N=25 and 50 cycles

original random data: [0 0 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 1 1 0 1 1 0 0 0]
combinations possible for input: ['000', '001', '010', '011', '100', '101', '110', '111']
rule applied to each combination in order: [1 0 0 0 1 0 0 0]
generated array with finite bound:
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1]
[0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]

```
[1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
```

Periodic Boundary Conditions, N=25 and 50 cycles

```
original random data: [0 1 1 0 0 1 0 1 0 0 0 0 0 1 1 0 1 0 1 1 1 0 1 1 1]
combinations possible for input:  ['000', '001', '010', '011', '100', '101', '110',
'111']
rule applied to each combination in order:  [1 0 0 0 1 0 0 0]
generated array with periodic bound
[0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1]
[0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1]
[1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]
[0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0]
[0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]
[1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0]
[0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0]
[1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1]
[0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0]
[1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1]
[0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0]
[0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1]
[1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0]
[0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0]
```

[1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1]
[0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0]
[1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1]
[0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0]
[1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1]
[0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0]
[1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0]
[1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0]
[1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0]
[1 1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0]
[1 1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1]
[0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0]
[1 1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1]
[0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0]
[1 1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1]
[0 0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0]
[1 1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1]
[0 0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0]
[1 1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1]
[0 0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0]
[1 1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1]
[0 0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0]
[1 1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1]
[0 0 0 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0]
[1 1 1 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1]

The sensitivity to the boundary conditions depend on the rule used. For some rules, there is no major difference between the patterns produced while for others, the pattern changes completely.

Taking this fact into consideration, yes, the nature of patterns depends on the use and non-use of periodic boundary conditions.

4 d)

Rule 184 was implemented with periodic boundary conditions.

First test with 50 cycles:

```
random position where we have 1s: [56, 42, 14, 96, 74, 94, 75, 13, 7, 69, 36,
23]
original random data: [1, 1, 1, 1, 1, 1, 0, 1, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0,
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0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 0]
combinations possible for input:  ['000', '001', '010', '011', '100', '101', '110',
'111']
rule applied to each combination in order:  [1 0 1 1 1 0 0 0]
generated array with periodic bound
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Second test with 50 cycles:

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random position where we have 1s: [97, 20, 72, 23, 15, 48, 35, 31, 42, 50, 83,
36, 33, 69, 37, 81, 63, 29, 27, 57, 56, 98,
13, 52, 96, 58, 43, 89, 70, 44]
original random data: [1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 0, 0, 0, 0, 1, 0,
0, 1, 0, 0, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 1, 1, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0, 1, 0, 1, 0, 1,
0, 0, 0, 1, 1, 1, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 1, 1, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1,
0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0]
combinations possible for input:  ['000', '001', '010', '011', '100', '101', '110',
'111']
rule applied to each combination in order:  [1 0 1 1 1 0 0 0]
generated array with periodic bound
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Third test with 50 cycles:

random position where we have 1s: [45, 38, 77, 88, 92, 61, 82, 25, 81, 84, 42, 95, 54, 35, 26, 55, 80, 73, 22, 79, 72, 78,
47, 53, 44, 57, 8, 27, 87, 86, 23, 68, 74, 83, 59, 7, 91, 41, 6, 37, 70, 11, 65, 69, 63, 29, 34, 14]
original random data: [1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 1, 0, 1, 1, 1, 0, 1, 0, 0, 0, 0, 1, 1, 0, 1, 1, 0, 0, 1, 1, 0, 1, 1, 0, 1, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 0, 1, 1, 1, 0, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 1, 1, 0, 0, 1, 0, 0, 0, 0]
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