3D Printing and Simulation of Naturally-Randomized Cellular-Automata

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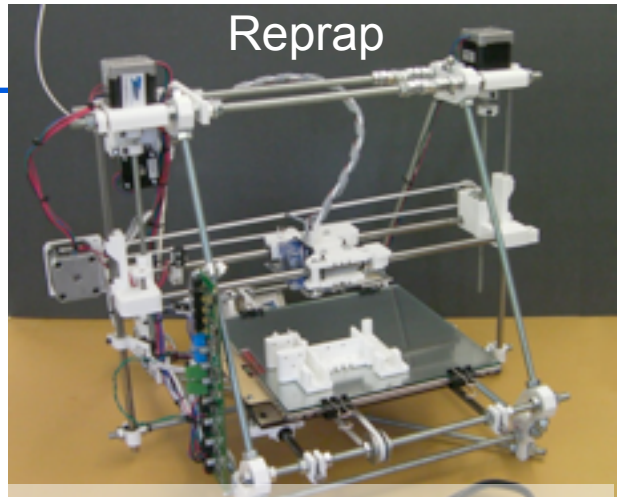
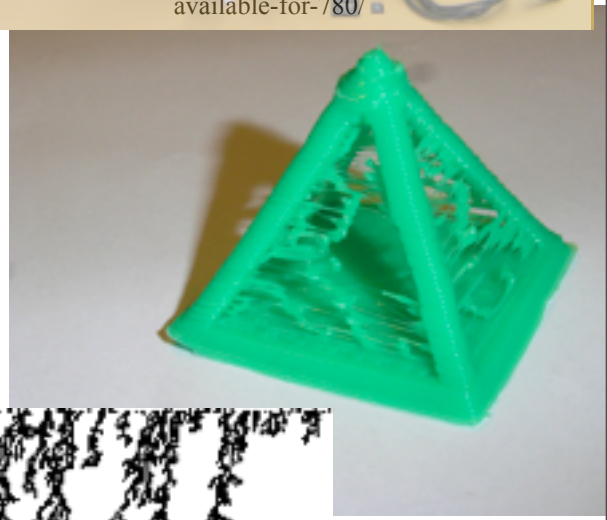
Introduction

- **3D printing** (or Additive manufacturing)
  - 3D objects are generated layer by layer.
  - Cheap FDM 3D printers are widely used. (FDM means fused deposition modeling)
- **3D printers can generate fluctuated, emergent, and stochastic patterns.**
  - Printing conditions and process including nozzle temperature, extrusion process, air motion, etc., are fluctuated.
  - Printing processes contains bifurcations.
- **3D printing can be interpreted as asynchronous CA** (cellular automata).
  - A printing head generates 1D on/off patterns.
  - Fluctuated patterns are similar to patterns generated by stochastic CA.

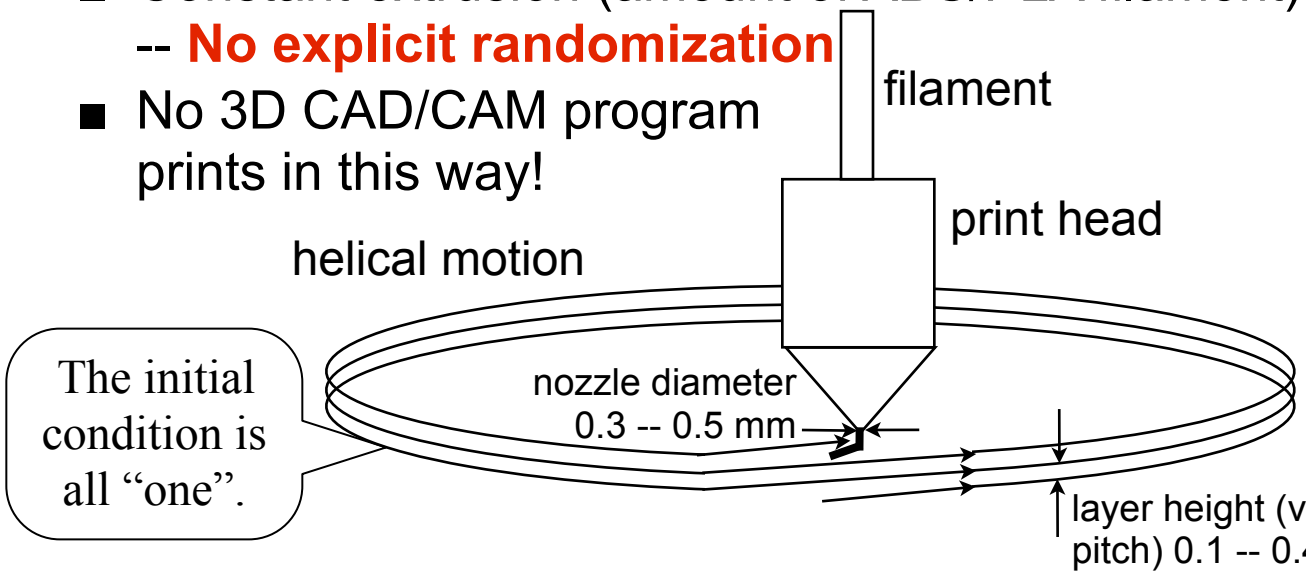


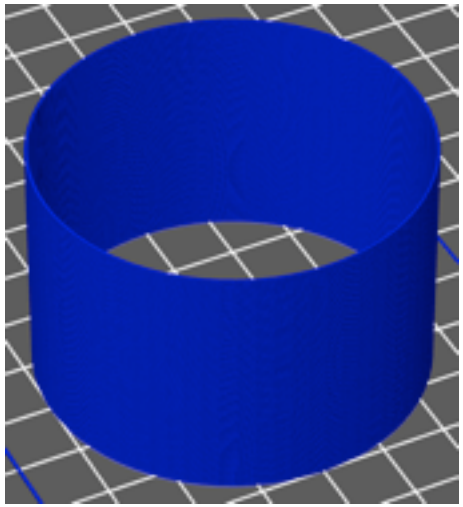
http://www.3dfuture.com.au/2012/04/reprap-full-kit-available-for-780/



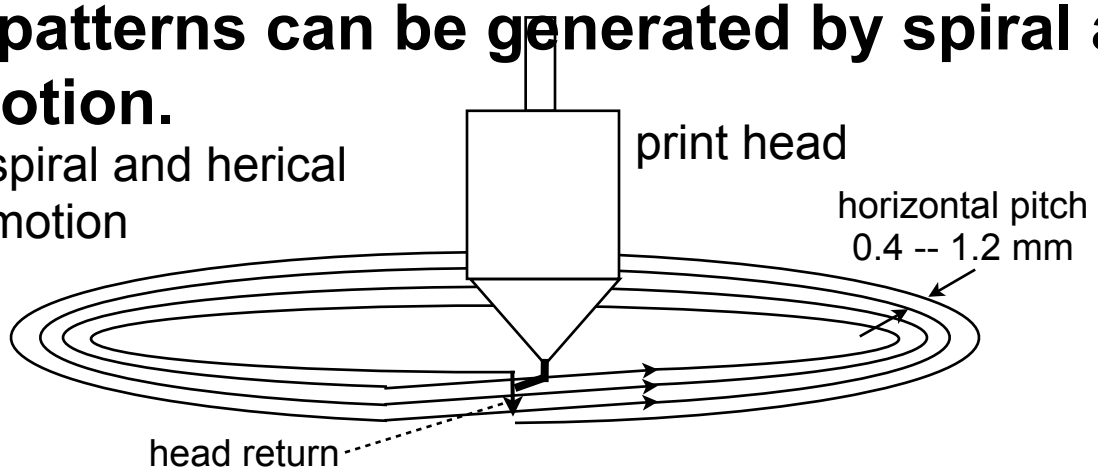
Methods for 1D and 2D CA pattern generation

- **A 1D CA pattern is generated by a helical head motion.**
  - Constant extrusion (amount of ABS/PLA filament) -- **No explicit randomization**
  - No 3D CAD/CAM program prints in this way!

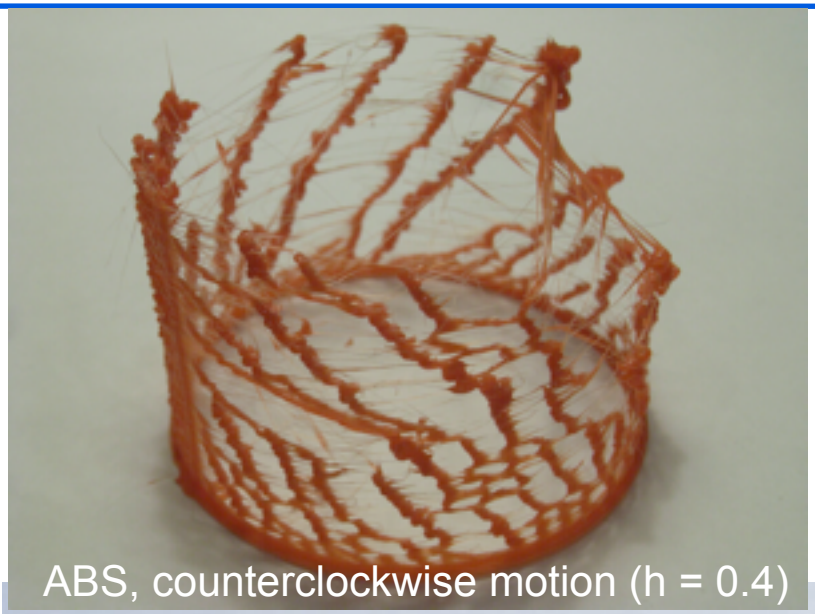



Visualized G-code

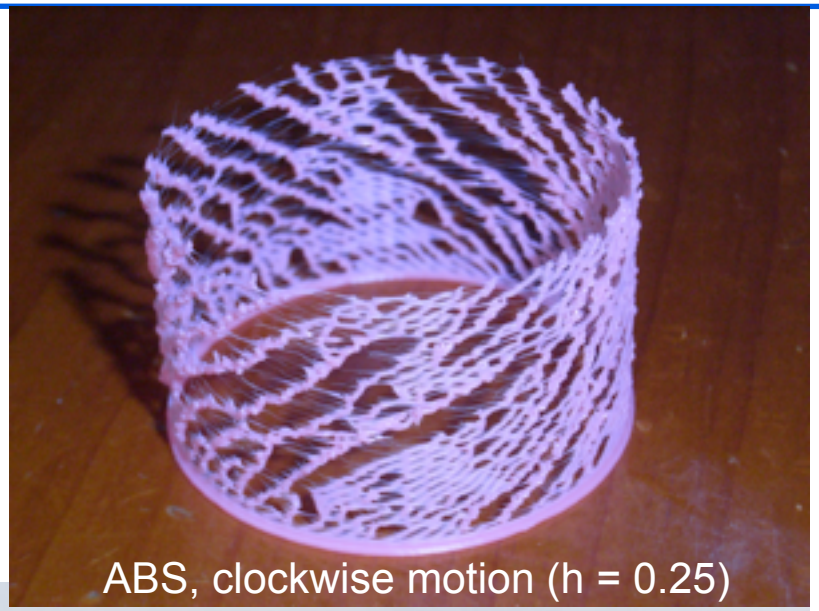
- **A 2D CA patterns can be generated by spiral and helical motion.**



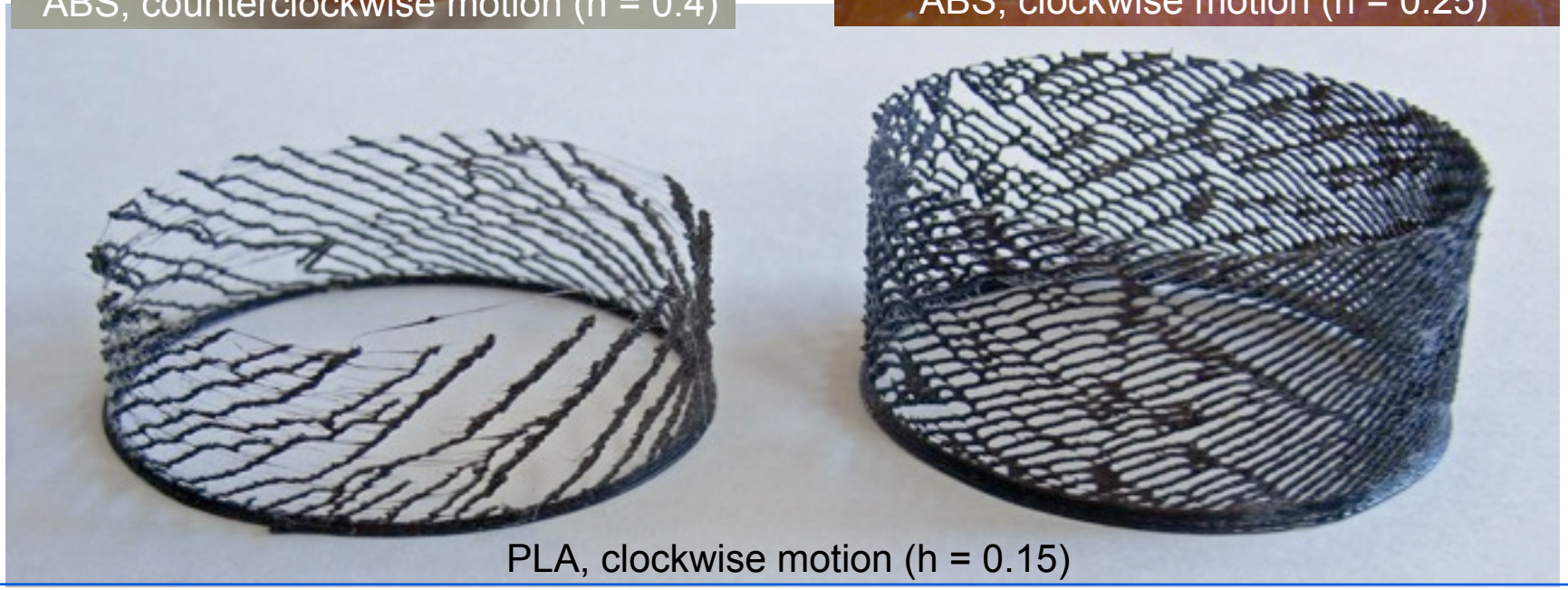
Examples of 1D printed patterns



ABS, counterclockwise motion (h = 0.4)

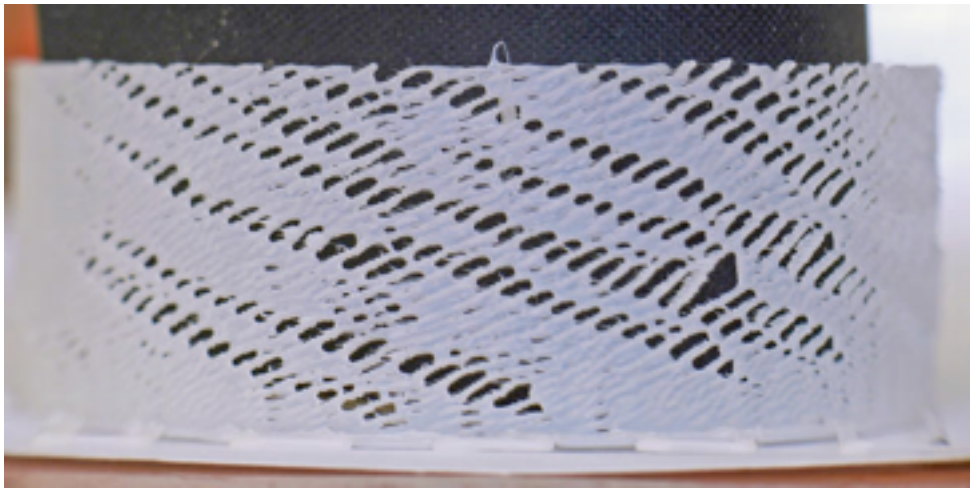


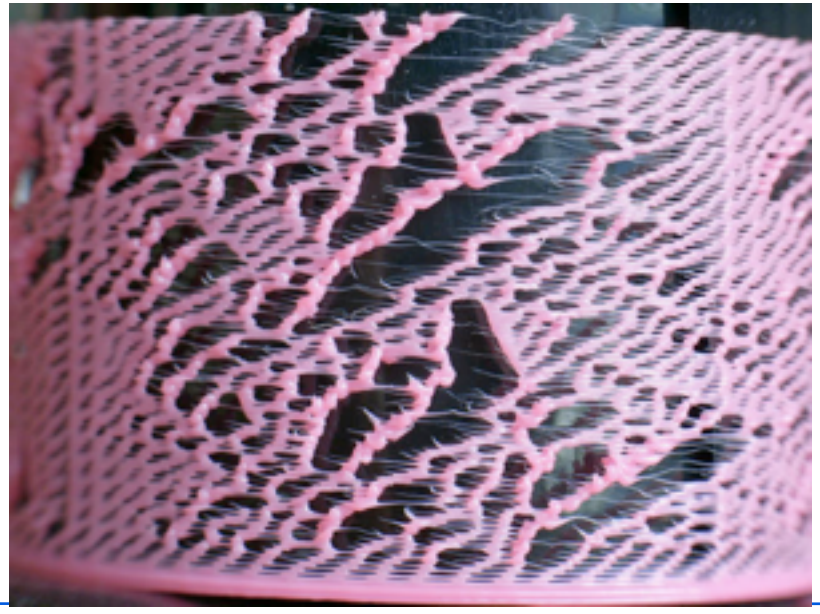
ABS, clockwise motion (h = 0.25)

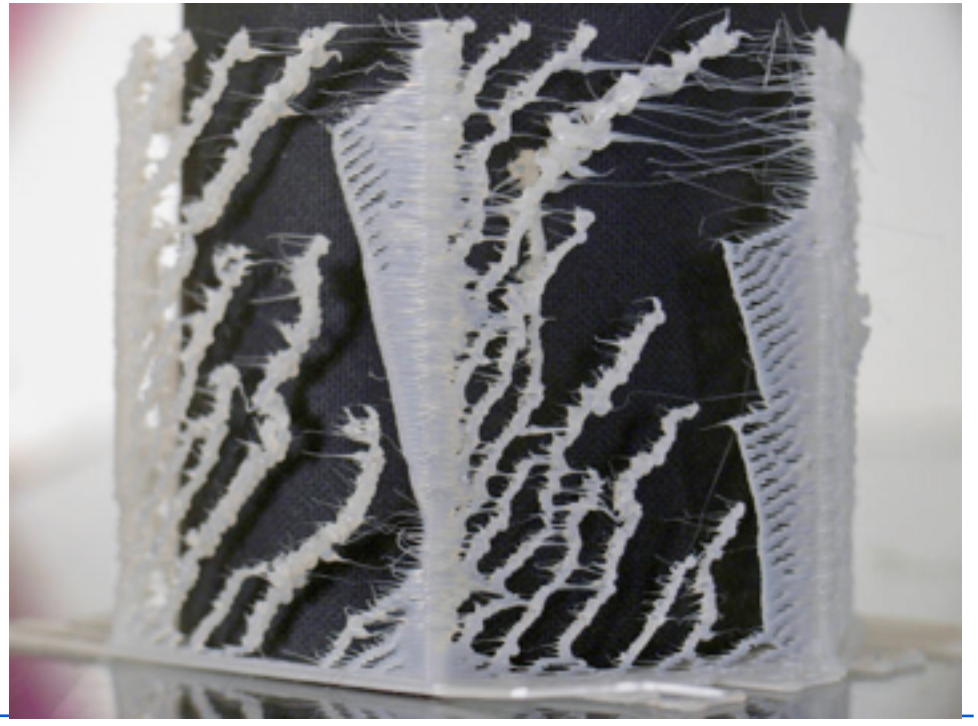


PLA, clockwise motion (h = 0.15)

More 1D patterns





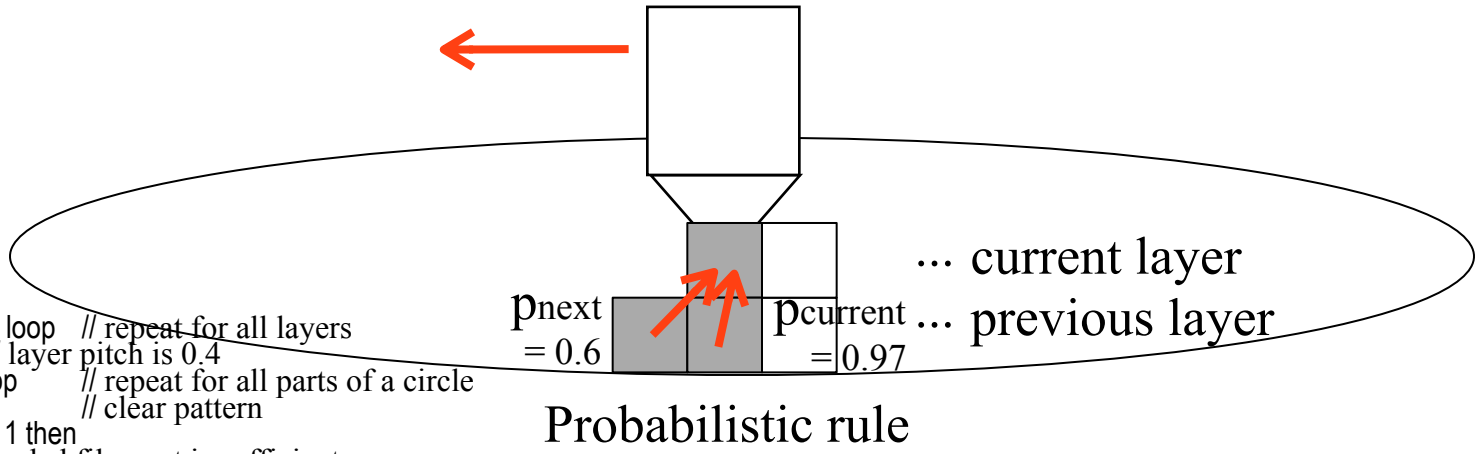


Printing process

Examples of 2D CA patterns

Simulation

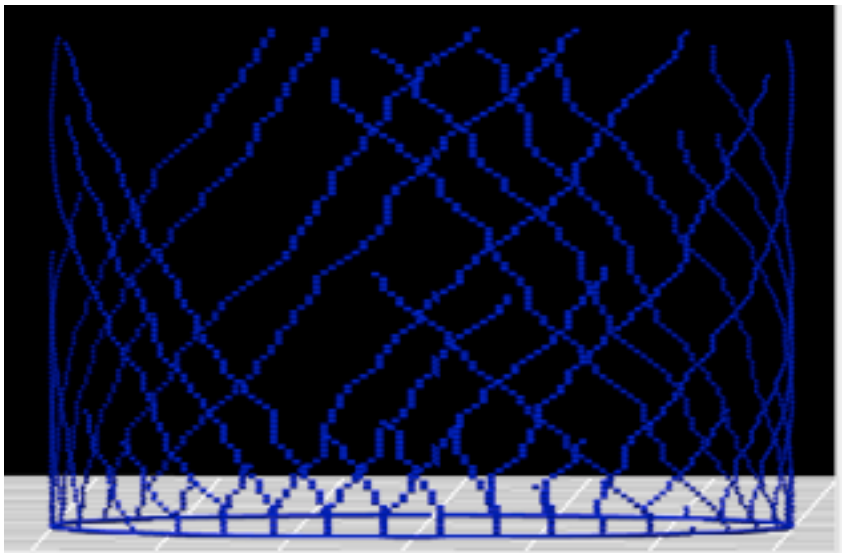
- **A computational model that simulates printed 1D patterns was developed.**
  - A pattern is generated by using a probabilistic rule.
  - **Explicit randomization** was (random numbers were) introduced.

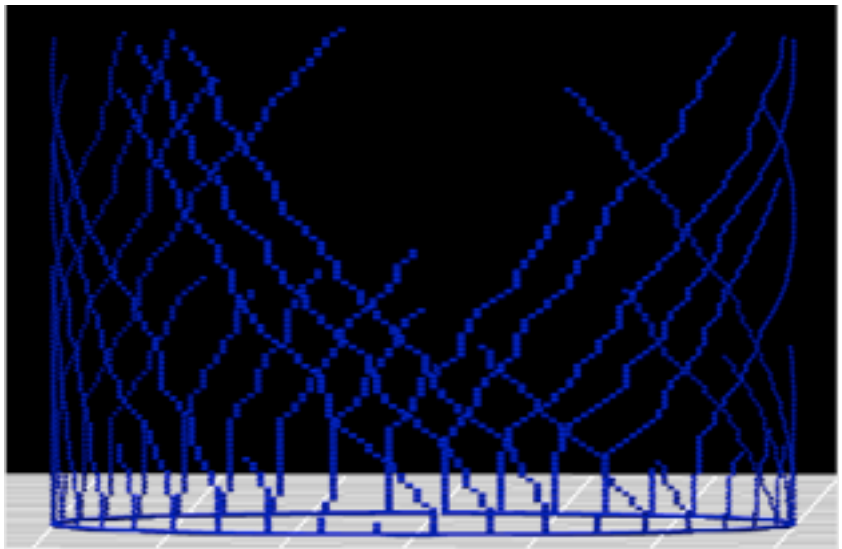



```
extrudedFilament = 0;
for layer in 1, 2, …, layers loop   // repeat for all layers
  z = 0.4 * layer;          // layer pitch is 0.4
  for i in 0, 1, …, 4 * 72 loop       // repeat for all parts of a circle
    pattern[layer][i] = 0;            // clear pattern
    if extrudedFilament >= 1 then
          // Amount of extruded filament is sufficient.
      if pattern[layer–1][i] > 0 and random() <= p_current or
        // The pattern at the same location of previous layer
        // is filled and the filament is successfully sticked.
        pattern[layer–1][i+1] > 0 and random() <= p_next then
        // The pattern at the next location of previous layer
        // is filled and the filament is successfully sticked.
          pattern[layer][i] = 1;                  // fill pattern
          extrudedFilament = 0.0;    // clear filament
          drawNextArc(pattern[layer][i]);
          extrudedFilament += extrudedFilament1;
            // newly extruded filament
      end if
    end if
  end loop
  pattern[layer][steps] = pattern[layer][0];
end loop
```

Simulation results

- The printed patterns were roughly simulated.
- Simulation of detailed structures has not yet been succeeded.





Conclusion

▶ Proposals

- A method for printing patterns of 1D (and 2D) CA using FDM was proposed.
- A computational model of these automata was also proposed.

▶ Results

- Various printing results were shown.
- The basic structure was simulated, but simulation of detailed structures has not yet been succeeded.