Cellular Automata

Art or innovation ?
Private Link to YouTube Video

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Definition

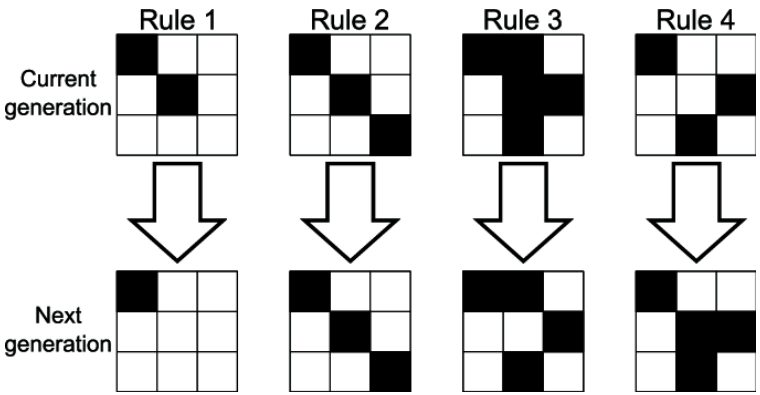


Figure: Conways Game of life [1]

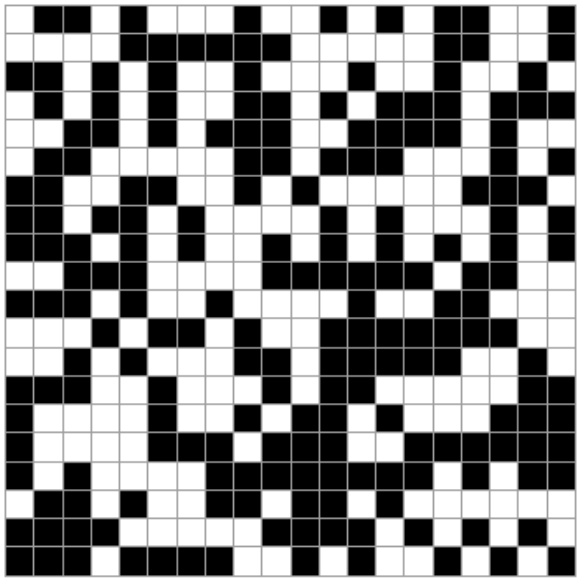


Figure: Game Of Life running [2]

What is Cellular Automata

It is a collection of cells arranged in a grid of specified shape with the form of a two-dimensional array, such that cells "evolve" step-by-step according to the state of neighbouring cells and certain rules.[3]

Where you may have seen Cellular Automata?

Minecraft [4]

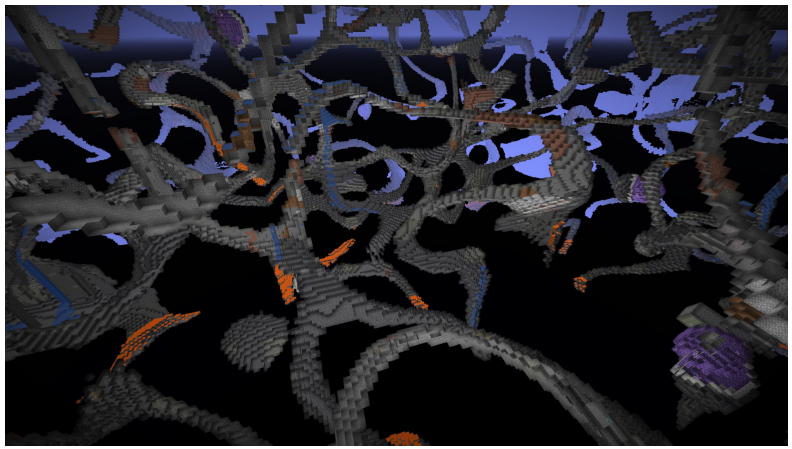


Figure: Minecraft Caves [4]

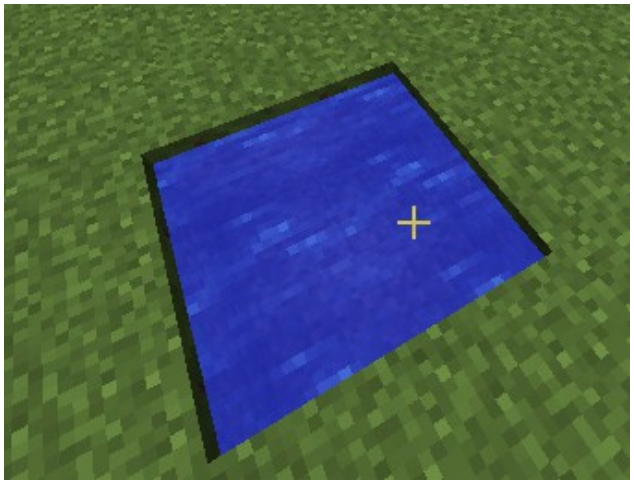


Figure: Minecraft Infinite Water [4]

How are caves generated in Minecraft? A simple rule example would be:

- Walls will stay walls even if more cells are born nearby.
- Isolated or near-isolated cells will often be removed.

- Minecraft water is based on cellular automata.
- Blocks of water determine the states of other water blocks based on how full they are.

Applications

Common CA Application Scenario

An approach to stimulate geomorphic forms and processes.

Some examples:

- Modelling traffic flow [5]
- Route optimization for urban flooding [6]
- Lightweight encryption [7]
- Simulating forest fire spread and fire fighting [8]
- Level generation In video games [9]

Challenge

Our Decision

Effectiveness of modelling with cellular automata

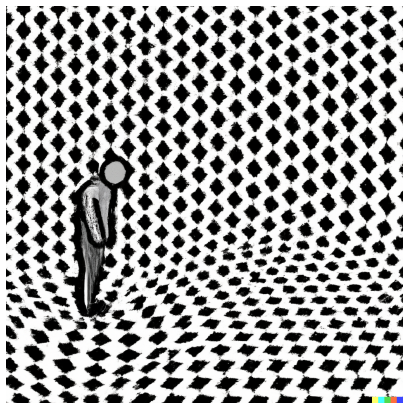


Figure: Challenge within Cellular Automata[10]

Cellular automata use in modelling has been extensive since its initial development. Many models exist covering a plethora of areas. Including (but not limited to):

Changes in land use, urban growth, and pedestrian movement

Why?

Cellular automata offer simple and easy-to-implement modelling solutions that can include relationships and behaviours which are difficult to formulate as continuous equations.

CA model for flood simulation 15x faster computational speed than existing 2D urban inundation model (UIM) [11]

Better prepared us for:

- Population growth
- Impact of climate change
- Impact of Corona Virus

Figure: Question [12]

Why not ?

Unfortunately, not all sunshine and rainbows!

Model Calibration issue [13]

- The common process of trial and error (less effective)
- Theoretically enumerating and evaluating all possible solutions (extremely time-consuming)

CA modelling needs new robust methods to estimate optimal parameters!

Further Issues

- Artificial constraints of a grid
- Difficulty in interpreting simulation outcomes

Urban Growth Experiment

Develop a cellular automata model for exploring the complexities of vertical urban growth.[14]. The model is implemented using Python and Arcpy[15].

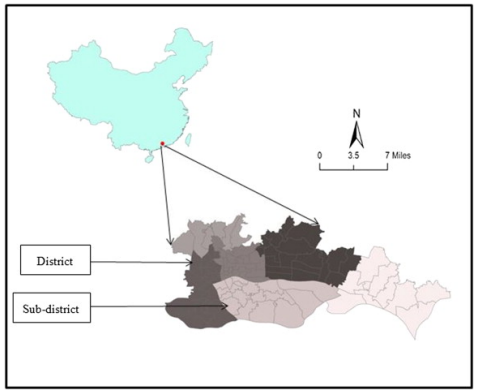


Figure: Map of the case study area-GZ[16]

- Collecting building and transportation data.
- Transition rules denote the logical connections between all driving forces that are adjusted using different weights and orders, which takes an "IF-THEN" form.
- Consider factors accessibility, population density, building density and height.
- Validate the model by comparing it with newly authorized construction buildings.

Viruses

Interactions between cells allow for the modelling of viruses and how they spread. This has been used to model the spread of SARS, COVID-19 and many other viruses/diseases.

Figure: Neighbourhood of infected Cells [17]

- Blue Cells: Not infected
- Red Cells: Infected
- Yellow Cells: Recovered

Using Probability, we can estimate whether a cell becomes infected using defined values and the states of those cells around it.

$$P_{X(i,j),X(m,n)}(t) = \sqrt{r_{X(i,j),X(m,n)} \times (1 - A(i,j))}$$

Figure: Probability Formula of infection [18]

Although this equation looks horrible, there is some sense to it!

The formula essentially calculates the probability of one cell infecting another cell.

Forest Fires

Forest fires can be modelled using CA by modelling the forest area as a large 2-D grid. Cells can be in the following four states: fuel, burning, empty, or burnt.

- A fuel cell next to a burning cell may catch fire with a specific probability.
- Apply the model to a forest fire in Dumai, Indonesia, March 2014

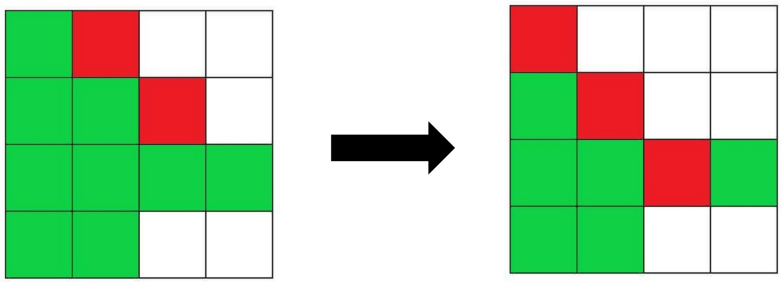


Figure: Fuel cells (Green) adjacent to burning cells (Red) may catch fire with probability P_{burn} [19]

$$P_{burn} = P_h \left(1 + P_{den}\right) \left(1 + P_{veg}\right) P_w$$

Figure: Formula for the probability of fuel cell adjacent to burning cell catching fire [8]

Urban Growth Results

- Urban vertical is important in:
  - The transformation of urban landscapes and city skylines
  - Urban economies development
- Urban vertical growth presents the following pattern:
  - low-rise buildings tend to “spread outward”
  - high-rise buildings exhibit a trend of “compact development”
- Future improvements:
  - Flexibility
  - Applicability

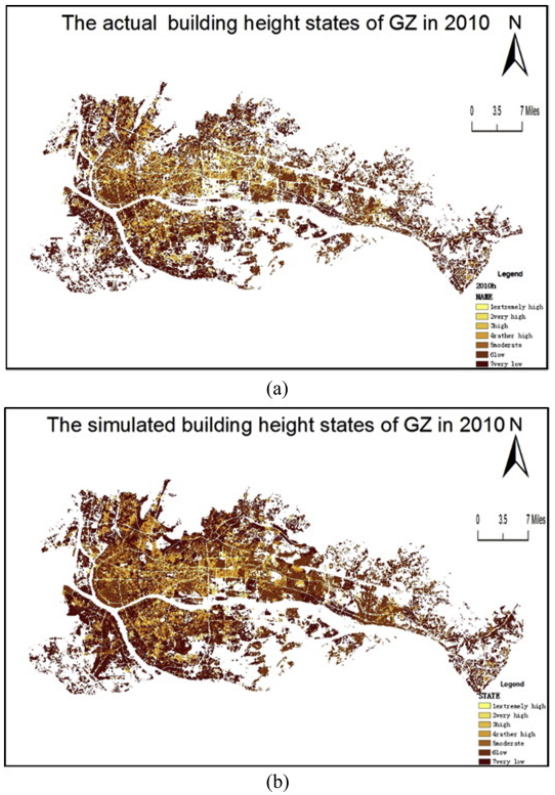
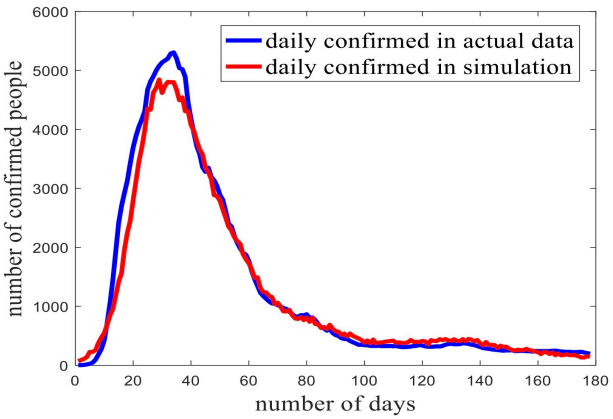
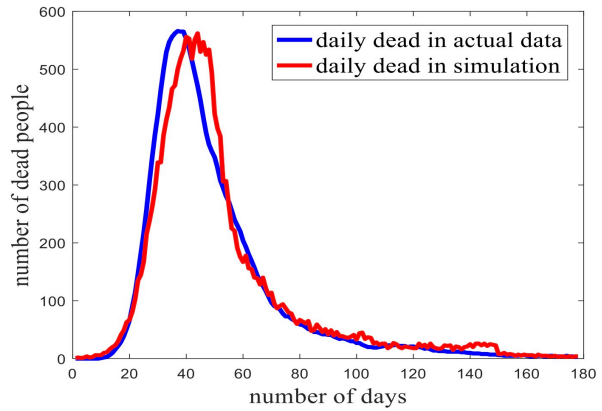


Figure: Spatial distribution of building height states[20]

Viruses Results



(a)



(c)

Figure: The comparison result of New York City [18]

The figure shows COVID-19 data compared to simulated data.

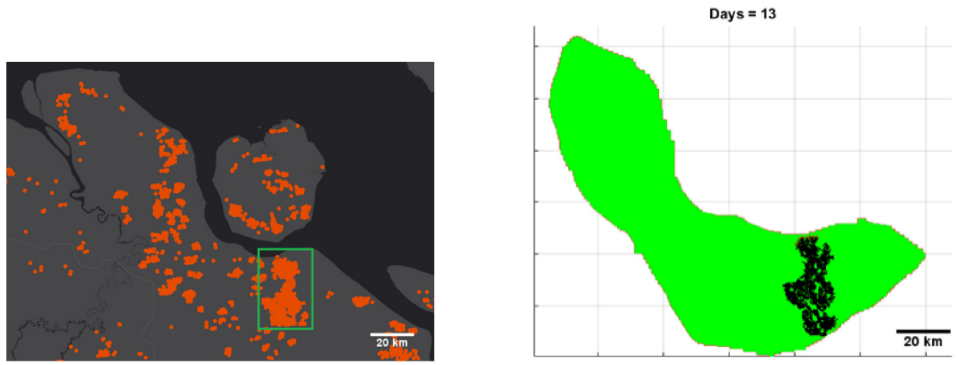
- In both figures, the simulated data is very similar to the actual data. It is realistic!
- With more data, we could achieve a higher degree of accuracy to estimate the effects of a virus better.

What does this allow us to achieve?

- Better prepare for a pandemic.
- Learn what factors affect the chances of a virus infecting successfully.
- Manage active pandemics, but only if the data is available.

Forest Fire Results

- Results of simulation are very similar to observed data
- Remaining differences can be attributed to:
  - Fuel material being transported long distances by wind
  - Farming parties using slash-and-burn in separate locations
- Both of these factors cannot be modelled accurately



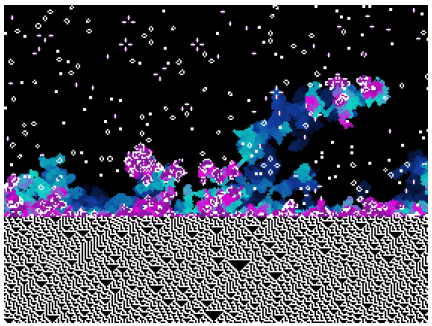
(a) (b)

Figure: The actual observed hotspots in Dumai compared with the results of the CA simulation [8]

Conclusion

From the present to the future

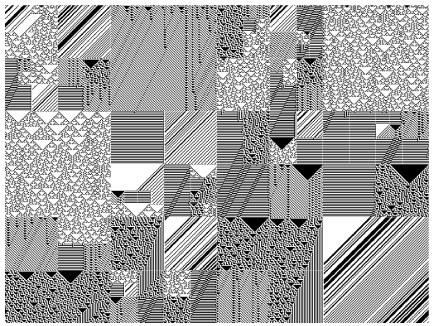
We have discussed what CA is and how its current progress of it.



(a) Game of life [21]

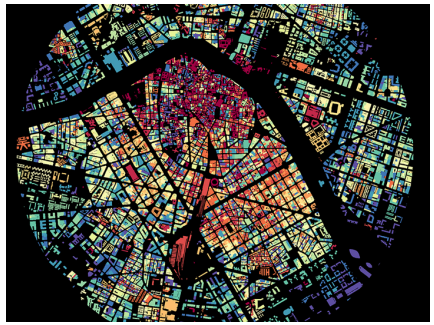
(b) CA in Minecraft [22]

(c) Application [23]

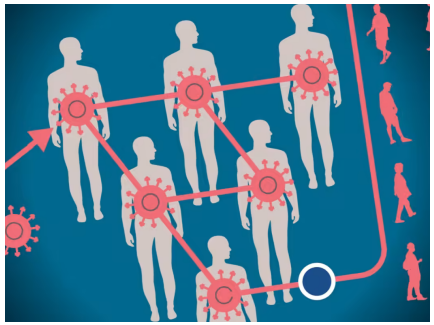


(d) Features [24]

(e) Challenges [25]



(f) Urban Growth [26]



(g) Viruses Spread [27]

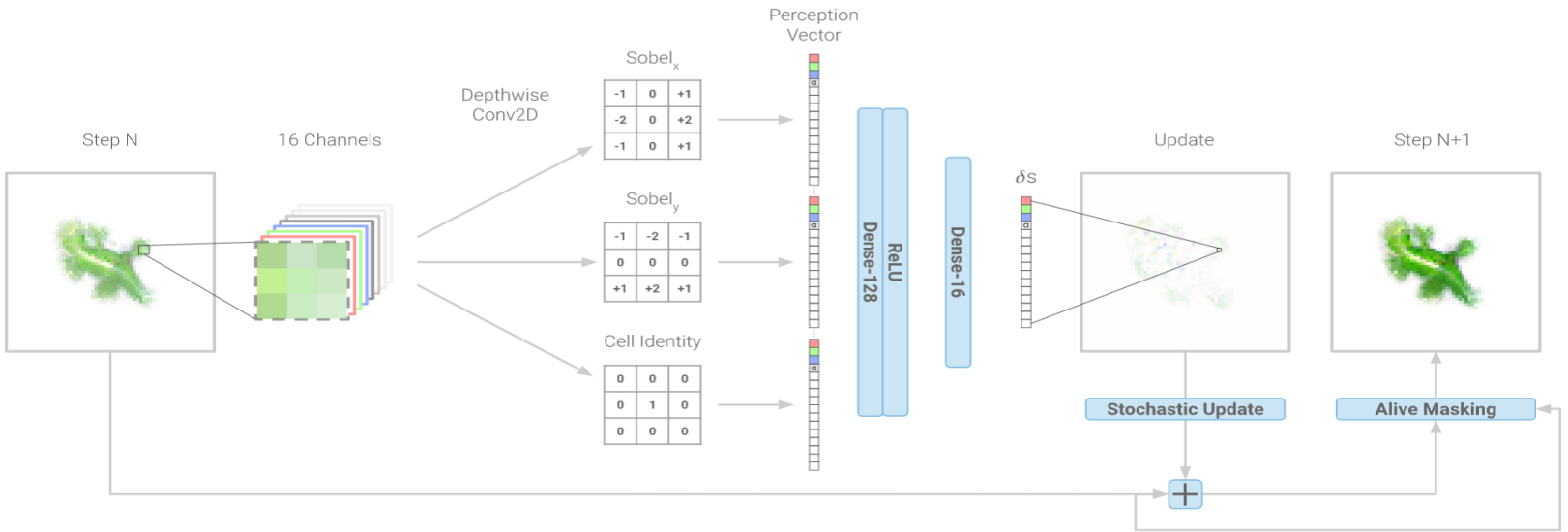
(h) Forest Fire [28]

However... What about the future?

The Future

Form Art to Cell Regeneration

Neural Cellular Automata (NCAs) can simulate the continuous construction of complex structures from very few starting cells. [29]



(a) A single update step of the model [30]

Recent developments in 2D domain [30]:

- Embryogenetic Modeling
- Swarm Robotics

May be extended to the 3D realm [29]:

- Regrow of functional machines parts
- Simulated morphogenetic systems

The Future

Solution of Quantum Computing

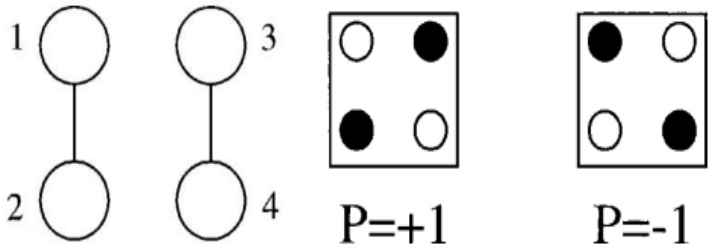
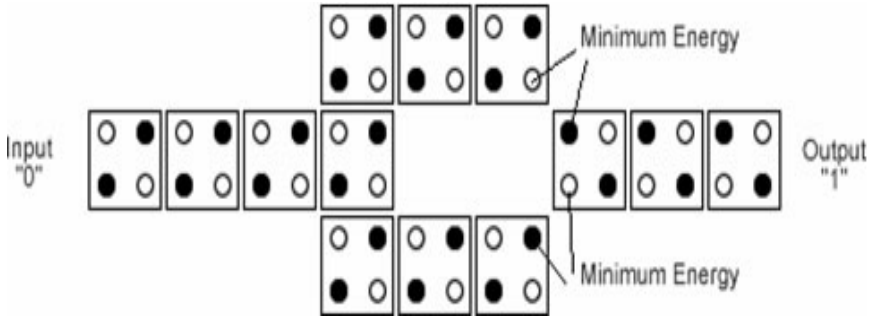
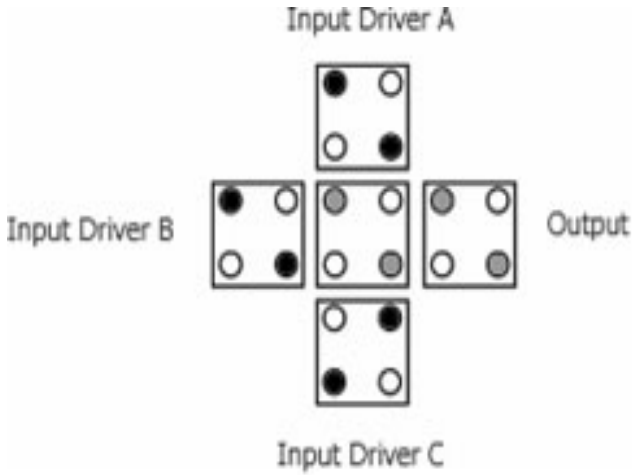


Figure: Principle of QCA cell [31]



(a) Standard Implementation of a NOT gate [32]



(b) QCA Majority Gate [32]

Quantum dot cellular automaton: [31]

- Possible solution for quantum computing
- Proposed improvement on conventional computer design (CMOS)

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