3D Simulations Using Cellular Automata –A Survey

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ABSTRACT

Cellular automata (CA) are used for modelling many physical systems because of its distinct dynamic behaviour. Cellular automata provide an alternative for modelling and solving large-scale complex system in place of partial differential equations which involve complex and computationally exclusive simulations. The purpose of this paper is to explore the use of CA in 3D modelling and parallel simulation where CA model for 3D unsaturated flow simulation is also defined. 3D image processing using CPU alone is very slow and highly time consuming. There is a macroscopic CA approach where local laws with a clear physical meaning govern interactions among automata. This paper includes survey of cellular automata used in 3D simulations.

KEYWORDS

CA, 2D CA, 3D CA, GPGPU, CAMELot, Object-Oriented Language (OOL), OpenGL Shader Language (GLSL), cellular Potts model (CPM).

1. INTRODUCTION

Cellular Automata are called "Systems of Finite Automata," that is defined as deterministic Finite Automata (DFAs) and provides a lattice arrangement [1]. Ulam [2] and Von Neumann [3] primarily announced Cellular automata with the purpose of obtaining models of biological self- reproduction. Now a day's Cellular Automata became very popular because of its diverse function and utility as a discrete modal for many processes [4]. Cellular Automata consists of an array of cells each of which can be in one of a finite number of possible states, updated synchronously in discrete time steps, according to a local identical interaction state transition function .Every state of a cell at the next time step is resolute by the current states of a surrounding neighborhood of cells [5-6]. CAs could be applied to execute a series of computer visualization tasks, such as-

- Calculating distances to features [1];
- Calculating properties of binary regions like as area and perimeter [7];
- Performing medium level processing like as gap filling and template matching [8];
- Performing image enhancement operations like as noise filtering and sharpening [9];
- Performing simple object recognition [10].

1.1. CA:

Here is an array in Cellular Automata that includes an array of cells with a finite number of possible states, updated synchronously in distinct time steps, according to a local identical interaction state transition function .At the next time step the state of a cell is determined by the current states of a surrounding neighbourhood of cells. For example, one dimension CA will consists of a line of cells; a simple two states, each of which can take value 0 and 1to represent binary images [11].

0	**1**	**1**	**0**	**1**	**0**	**1**	**0**

Figure 1. One Dimensional Cellular Automata

At a particular time cells change their states and each cell looks their neighbour states and congregates information from its neighbour's states then cell decides what state should be the next.
An algorithm that is discrete in space, time operates on a lattice of sites used in cellular automaton.
A 2-D cellular automaton (CA) is a triple $A = (S; N; \delta)$,
Where, S = nonempty state set
$N \subseteq \mathbb{Z}^2$, is the neighbourhoods
$\delta : SN \rightarrow S$, is the local transition function (rule)

Where δ provides the information of the state of neighbourhood cells at particular time. In order to give a definition of neighbourhood in a standard way it can use some rules h on $\mathbb{Z}^2$ such as $N = B\,h\,(0, r) \cap \mathbb{Z}^2$ (where B h (0, r) is the ball of radius $r \geq 1$). The most common Neighbourhoods are: [6].

1.2. 3D CA:

Cellular automata (CA) is also provides an efficient computations in the simulation of natural phenomena and physical processes domain [12, 13, 14, 15].Use a detailed CA rules for simulation of composite phenomena or geometric transformations.

CA3D is a three-dimensional continuous valued Cellular Automata simulator. It discovers active models and 3D structures by using 3D Heat rule, 3D Hodge rule and 3D Win free rule [21]. Here is the capability of 3D structures in different angle, level of depth, and viewing perspective in three-dimensional experience used in CA3D where program is consecutively as Java application or applet utilizing JOGL for 3D rendering. It also needs OpenGL software or hardware accelerated video device [16].

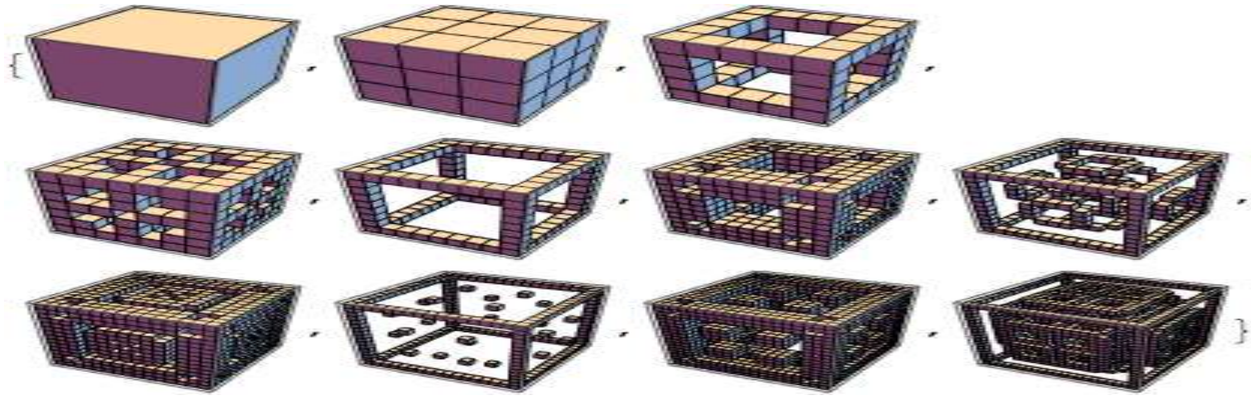

Figure 2. One Dimensional Cellular Automata

It can be simulated the propagation of an electric stimulation with 3 states after selecting an appropriate neighborhood:

- The cell stimulates its neighborhood cells which are in an "inactive" state if cell is in an "activated" state for an amount of predefined time. In this state, this state communicates to cell depolarization.
- With the help of an "activated" cell, It can't be stimulated if a cell is in a "refractory" state for a certain predefined time. This state communicates to cell repolarisation.
- A cell is in an "inactive" state in the remaining of the time.

There is an issue where better accuracy cannot be reached only by a growth in cube size. Each dimension raised by a factor of 10, the total number of cells raised by the factor of 1000 at each time. The cell repolarisation ("refractory") can be subdivided into two parts:

1) A first one called the "absolute refractory state", where the cell can't be reactivated by an incoming impulse.
2) A second, called the "relative refractory state" where it can [16].

1.3. GPGPU Computation for 3d CA:

Graphics processor unit (GPU): When compared to CPUs, GPU performance has increased radically greater than the last four years and up to 900 times improvement was demonstrated more recently[17,18]. To attain 3D CA in efficient manner, the graphics cards classically should use three programs in their pipeline: the Vertex, the Geometric, and the Fragment Shaders (Pixel Shaders).

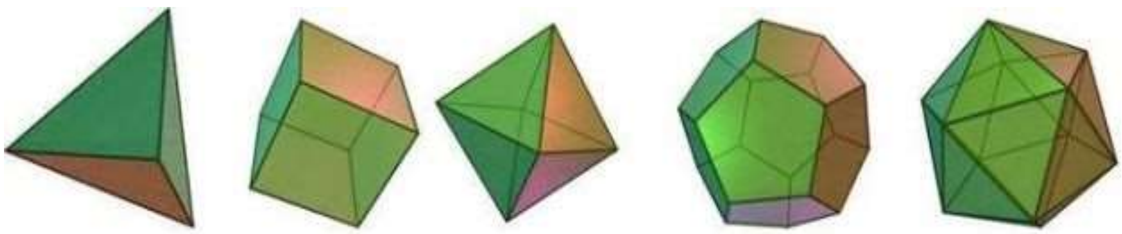

Figure 3. Natural 3D structures, i.e. "close packing," with its cellular 3D shape.

The following structured rule is used to signify them:
Dimension d {State}{Structure} Cellular Automata≡ d DSt {n} CA

Dimension (d)

n, No. of states of a cell

St, Structure

For cube/square use direct neighbors

For the hexagonal grid $N \equiv$ 'h' = 6 in 2D.

For the triangle or tetragonal structure $N \equiv$'t' = 3 in 2D and = 4 in 3D. [19]

Three dimensional structures of neighbourhoods as:

Moore neighbourhood with (26 cells + the cell itself = 27 Blue cells) are adjoining cells of the green cell in the environs of 3D Moore.

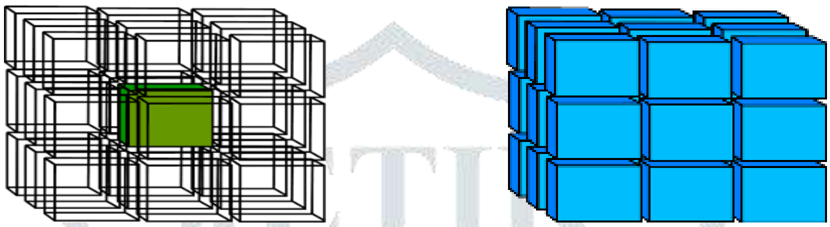

Figure 4. 3D Moore neighbourhood

Von Neumann neighbourhood with (6-cell + the cell itself = 7 Blue cells) are adjoining cells of the green cell in the environs of 3D Von Neuman.

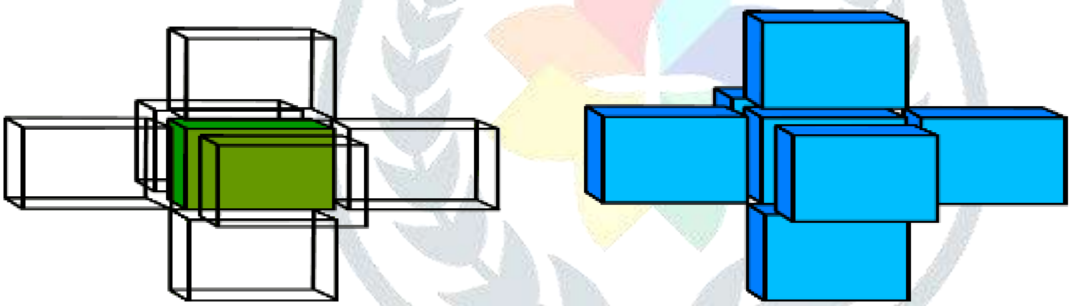

Figure 5. 3D Von Neumann neighbourhood

Cellular Automata in the form of 3D matrices in real time on a common personal computer (such as magnetic resonance imaging (MRI) in biomedical applications) can be developed and envisage their large data sets. To simplify and understanding the CA functions a practical technique using 3D symmetric pattern on an interactive user interface with simultaneous centre and surface visualizations designed a CA model that adheres to the curvature and dispersion properties found experimentally in excitable media [20-21].

There are two approaches with3dCA in GPU:

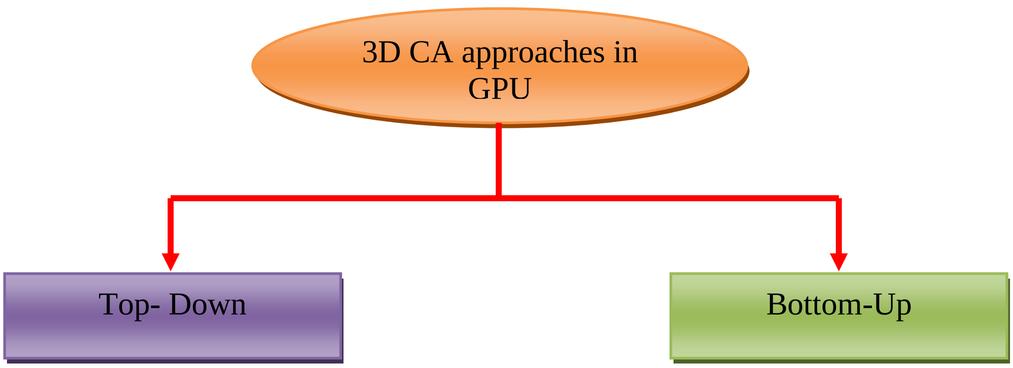

Figure 6. Approaches of 3D CA in GPU

Bottom-up: Approach is used to study the narrow performance for the purpose of finding direct logic-based rules to make simplified models of the original problem.
Top-down: Approach is used to obtain a set of local rules that are based on the specific behaviour of the event.
Top-down approach is used in most of the graphics technique in CA as compared to the large number of 3D graphics applications on GPU on the other hand top-down or bottom-up CA implementations on GPU are still rare and in the literature for generic real-time bottom-up 3D CA none were found [17, 22,18, 21, 23, 24]. Now a day's current GPU implementations use top-down approaches [25, 23, and 24]. There is a top-down implementation on GPU that is relevant [26].

2. CA FOR 3D SIMULATORS IN MEDICAL IMAGE PROCESSING

Computer models are widely used in many disciplines, ranging from physics, chemistry, biology, economics, to hydrology. Computer reality consists of electrons moving through electronic components, their behaviour can be described in terms of electronics, then logic, bits and instructions, algorithms and data structure, languages, software engineering, etc.

2.1. Simulators with CA

Due to the simplicity of cellular automata, it attracts researchers to form biological models or simulators. Cellular Automata like models are simple model along with the complex behaviour. Cellular Automata model populations of source of revenue self-reproducing individuals (cells) that was imaginary to replicate a population of fake self-reproducing folks. There is an Integrative biology which provides a solution to simulate multi-scale models such as: Reaction-Diffusion Equations, Dissipative particle dynamics or Finite component method [27, 29]. Cellular automata used for organ's simulations, depolarization and heart muscles cells' re-polarization with increase rate in improvement [30, 31]. The upcoming state of each cell is calculated concurrently according to the state of the cube cells at the current imitation time but due to evolution in cellular automata there are various solutions in 3d simulators with 3D cellular Automata. There is a very simple model for normal behaviour such as Game of Life [31]. This model was used for 2D toric space that allowed simulating bacteria reproduction where a cell can only have two states: dead or alive. Wire World cellular automata used to build simulators for Electronic circuits [32]. Excitable medium in biology can also be simulated with cellular automata [33]. To process graphics on computer there was GP-GPU (General Purpose Graphic Processing Unit) so there are various factors to speed up the processing [34]. At the time when a cell is in active state for a specified time interval interact with its neighbourhood cells that are in inactive states and That state corresponds to depolarization of cell. A straightforward heart model can be formed with the help of cellular automaton after choosing a suitable neighbourhood basically a Moore cubic-shaped neighbourhood that could be simulated by the propagation of an electric stimulation with 3 states but there is a big issue that affect the accuracy of model like: Number of cells used. Cellular Automata has become popular in computer graphical and playing an active role including Graphics Processing Unit (GPU) [35, 36]. 3D cellular automaton is also provided a solution to the unverified classification (clustering) in textual. The transition function used in our cellular automata evolved to form the group (cluster) similar to a certain threshold fields. There are very proofs that provide encouraging and verify the idea of increasing the dimension of the automat to find the way and make a realistic visual concept [37]. For 3D flow which is unsaturated there are several adjustments and additions of the standard CA in different modelling [38]. There is a CAMELot: A software to simulate CA models.[39].CA is used to make simulator for retina where GPU architecture produces spectacular performances, that used optimized programming using varied algorithm—Object-Oriented Language (OOL) OpenGL Shader Language (GLSL) [40,41].That is based on a CPU-based OPL simulation— that's representation of the retina pipeline is modelized by using a succession of two-dimensional matrices often associated with a cellular automaton (CA) for computation[42, 43, 44.].There are various fields where CA combined with computer graphics and/or image processing to make a great change in the graphics based simulators designing and understanding of image processing phenomena to enhance it in every perspective where cellular Potts model (CPM) is another model which uses lattice dynamics to study interactions of biological cells [45, 46, 47, 48, 49, 50, 51 and 52] with GPU. CA provided a model for early tumor development researchers at the Complex Bios stems Modelling Libratory, Harvard- MIT have presented an ABM to explore these problems where pH of the extracellular environment plays an important role in tumor invasion [53, 54]. In bio mimetic approach (3D cellular automaton) can help solve one of the problems of textual data mining and visualization. Cellular Automata simulations are also used to study different weathering effects like stone erosion, lichen or moss growing or lampblack deposit. We observed that almost any kind of simulation could be obtained in real-time using very large dynamic surface cellular automaton [55, 56].

2.2. CA for Automatic Texturing on Images

To allow visualizing global behaviour of CA texturing comes with the field of computer graphics (CG) where the first one surrounds the surface and the second one drastically changes the 3D topology. In texturing phase to generate a crack-like pattern select a regular colour propagation, [2].Corrosion as well as patina simulation can be interpreted as a kind or propagation subtracting at each time step a potential of each corroded cells and spreading with a random factor proportional to the number of neighbour corroded cells. Cell behaviour depends on the equilibrium of surrounding. In the first case (i.e. life game), we seek a specific number (2) for stability, and its tangent (3) for sudden state change. Rules of the second case are almost identical to the game of life. Surprisingly, the result is completely different: after a few steps, the system converges to a maze-like pattern with sometimes instable areas. Concerning the "regrouping" CA, it belongs to the family of activation/inhibition [57]
.

Figure 7. (a) Life game (b) Maze-like (c) Reaction diffusion.

2.3. Parallel Simulation with CA

Parallel computing with cellular automata is also making complex simulations in many disciplines feasible, increasing the interest in different application fields. In cellular automata we consider a discrete cell system that is characterized by smaller cell sizes where the homogeny proposition is less respected [58, 59].Cellular automata in parallel processing are suitable for developing parallel computing environments [60]. There is a distinct representation for unsaturated flow that was particularly appropriate for use with the CA model in a parallel computing environment with CAMELot environment [61]. For parallel simulation of laser dynamics with dynamic load balancing using cellular automata where deliberated the recital of a parallel discrete model of laser dynamics on a cellular automaton, administration on a mixed non-dedicated cluster using active load balancing [62, 63].

Table 1. 3D Cellular Automata in different 3d model creation.

Approaches	Purpose
Bottom-Up	3D CA in GPU uses Bottom-Up approach to find direct logic-Based rules.
Top-Down	3D CA in GPU uses Top-Down approach to find the set of local rules.
Wire World CA	Used to build simulator for electronic circuits.
Moore cubic-shaped neighbour CA	Used to build Heart Model.
3D CA	Provide a solution for unverified classification in Textual.
CAMELot	Simulate CA models.
OOL,GLSL,3D CA, OPL simulation	Used to build simulators for Retina.
Textual 3D CA	Used to solve the problem of textual data-mining and visualization.
Regrouping CA	It belongs to family of Activation/ Reticence.
For Parallel simulation	Parallel simulation of laser dynamics with dynamics load balancing.

3. CONCLUSIONS

Based on the 3D CA model, 3D parallel simulations have been carried out in the CAMELot environment that was a method to demonstrate the accuracy of the CA model with the help of two major benchmarks. Also, it has been analyzed the scalability of the model using an analytical performance model with 3D cellular automata. There is a report for findings on an extended model for other three-dimensional Boolean CA with indirect neighbours, such as Moore models 3DM1 b CA and 3DM2 b CA (18 and 26 neighbours). There is a melodious structure such as both hexagonal and cubic close packing 3DhCA models are the most talented field of study for the 3D CA using 12 neighbours and the most natural structure [64]. However, there is a strong change in the algorithm due to change in the geometric nature of CA (from cubic to 3D hexagonal). There are many interesting facets still remain for further improving 3D CA.

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