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RESEARCH ARTICLE

CHAOTIC RULE APPLIED FOR FRACTAL DIMENSIONAL CLOUDS SIMULATION USING CELLULAR AUTOMATON

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A B S T R A C T

This paper proposes a simple and computationally inexpensive method for simulation of clouds with cellular automata. The cloud evolution is simulated using cellular automaton that simplifies the dynamics of cloud formation. In addition, clouds contain varying degrees of translucence, and their amorphous structure can change with time. Clouds are then generated due to the phase transition from water vapor to water droplets. Realistic cloud simulation would also be an effective tool in the field of meteorology. By using the cellular Automaton, the distribution can be obtained with only a small amount of computation since the dynamics of clouds are expressed by several simple transition rules. The cellular automata are the new style, high performance simulation tool.

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INTRODUCTION

This paper should give a simulation of cloud formation using CA and short overview of what cellular automata are, how we work and what we can be used for, and briefly discusses some of their properties and applications in this field. Clouds are recognized as a major source of Uncertainty in the assessment of climate change and generated due to the phase transition from water vapor to water droplets. Cellular Automata or Cellular Spaces as they were called then were invented by John von Neumann half a century ago. On a quest to figure out where the complexity in nature comes from, Stephen Wolfram encountered cellular automata. Wolfram looked at the simplest possible cellular automata: one dimensional automata with two states and a three cell neighborhood. Since there are eight possible input configurations of three cells with two possible states, there are 256 possible local rules forthese cellular automata. Wolfram refined his classification scheme later into four classes, splitting the class of rules with complex behavior into complex and chaotic rules. The rules with chaotic behavior can be used to generate randomness, while some of the rules with complex behavior are computation universal. Nowadays, CA has been used widely in sociology, biology, ecology, information science, computer science, physics, mathematics and many other scientific research fields. But it is still the underway step to put CA into image processing.

Fractal Dimension

Fractals are of rough or fragmented geometric shape that can be subdivided in parts; each of this is (at least approximately) a reduced copy of the whole. They are crinkly objects that defy conventional measures, such as length and are most often characterized by their fractal dimension. They are mathematical sets with a high degree of geometrical complexity that can model Natural phenomena. Almost all natural objects can be observed as fractals (Coastlines, Trees, Mountains and Clouds). Their fractal dimension strictly exceeds topological dimension. The number, very often non-integer, often the only one measure of fractals. It measures the degree of fractal boundary fragmentation or irregularity over multiple scales. It determines how fractal differs from Euclidean objects (point, line, plane, circle etc.).

The geometry of fractals and the mathematics of fractal dimension provide useful tools for a variety of scientific disciplines in particular study of chaos. Fractals are crinkly objects that defy conventional measures like length and area. Yet fractals are beguilingly far from formless. Clouds, mountains, coastlines, bark and lightning bolts all exhibit non smooth shapes that can be described as fractal.

Related and Basic Work

Kajiya and Herzen proposed a simulation method for cloud by solving the Navier-Stokes equations[1]. However, at that time they could do calculations on a small number of voxels due to the lack of the computational ability. Therefore their method cannot represent a realistic cloud. Voss applied fractal techniques to produce a very realistic looking cloud [2]. Foster and Metaxas proposed a method that can generate realistic motion of turbulent smoke on relatively small number of voxels, but this method is stable only when the time step is very small and costs a lot of time for the calculation[3]. Stam introduced the semi Lagrangian advection scheme to calculate the advection term of the Navier-Stokes equations[4]. By using the semi Lagrangian advection scheme, it is possible to calculate the advection term of the Navier-Stokes equations stably even if the time step is large. Fedkiw et al. provided a technique called vorticity confinement that is applied to Stam's model[5]. The vorticity confinement can represent small scale vortexes lost during the numerical calculation process[6].

Although Suzuki suggested that the model proposed in could be extended to be three dimensional, the computational cost is too expensive[7].

Simulation of Cloud Motion

The exact simulation of cloud motion is complex and computationally expensive. Therefore, we have developed a simple and efficient method. In our method, the cloud motion is simulated using cellular automaton. The method can simulate cloud formation by simple transition rules. The simulation space is divided into voxels. The voxels correspond to cells used in the cellular automaton. At each cell, three logical variables, vapor/humidity (hum), clouds (cld) and phase transition (or activation) factors (act) are assigned. The state of each variable is either 0 or 1. hum=1 means there is enough vapor to form clouds, act=1 means the phase transition from vapor to water (clouds) is ready to occur, and cld=1 means there are clouds. Cloud evolution is simulated by applying simple transition rules at each time step. The transition rules represent formation, extinction, and advection by winds. For the cloud formation, Nagel et al. proposed the following three transition rules[8]. One of the disadvantages of Nagel's method is that cloud extinction never occurs since cld, after it has become 1, remains 1 forever. Therefore, our method simulates the cloud extinction by randomly changing cld to zero.

Although this realizes the cloud extinction, there remains another problem. Clouds are never generated after the extinction at the cell. To solve this, vapor (hum) and phase transition factors (act) are supplied at specified time intervals. Similar to extinction, hum and act, are randomly set to 1.Moreover, to include the wind effect, all the variables are simply shifted toward the wind direction. The state of each variable is either 0 or 1. The growth of clouds is simulated by using simple transition rules.

Since the state is either 0 or 1, the rules can be expressed by the Boolean language. Therefore, the simulation requires only a small amount of computation. These rules can realize the complex motion of clouds.

The simulation output is a binary distribution. What we can obtain is no more than there are clouds (cld = 1) or, there are not clouds (cld = 0) at each grid point. Therefore, realistic images cannot be generated since the density distribution in the real world is a continuous distribution between 0 and 1.First, a new state variable, ext, and its transition rules are introduced to realize cloud extinction. In the real world, however, formation and extinction occur repeatedly. To simulate this hum, act and ext are supplied at every frame using random numbers that obey a user-specified probability distribution. Animators can control the motion of the clouds in their design of the probability function. This achieves simulation of the complicated motion of clouds.

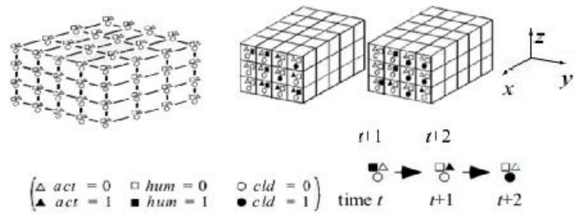

Fig.1 Simulation of dynamic clouds using CA (3d grids and state transitions)

Extend the simulation process to treat continuous values. The other is to calculate the continuous distribution based on the binary distribution obtained by the simulation. In the first approach, we have to develop the new transition rules to take into account continuous values. However, the computation time is increased since the transition rules no longer have simple Boolean expressions using CA. Continuous distribution is calculated in the post process of the simulation. Using the proposed method, to simulate the fractal dimensional cloud and that final result compared with Wolfram CA rule 30.

Past, Present and Future: Some Conclusions Using Cellular Automata

The simulation method developed by Nagel et al. is explained in this section. As mentioned before, the simulation space is represented by 3D grids, and three state variables, hum, act and cld are assigned at each grid point (see Fig. 1). The state of each variable is either 0 or 1. Their grid status (i,j,k) at time t +1 are calculated by the status at time t using the following transition rules.

act (i,j,k,t+1) = NOT. act(i,j,k,t).AND. hum (i,j,k,t) .AND. f act(•)

cld (i,j,k,t+1)= cld(i,j,k,t).OR. act (i,j,k,t)

hum (i,j,k,t+1)= hum (i,j,k,t).AND.NOT.act (i,j,k,t)

Where, fact(•) is a Boolean function and its value is calculated by the status of act around the grid. Fig. (1) Showsthe above transition rules, act becomes 1 at time t +1 if both of the hum and fact(•) are 1 at time t . Then cld becomes 1 at time t +2. In [8], the following function is used for fact(•) by taking into account the fact(•) that clouds grow upward and horizontally.
fact(•)=act(i+1,j,k,t).OR.act(i-1,j,k,t).OR.act(i,j+1,k,t).OR.act(i,j-1,k,t) .OR.act(i,j,k+1,t).OR.act(i,j,k-1,t).OR.act(i+2,j,k,t).OR.act(i-2,j,k,t) .OR.act(i,j+2,k,t).OR.act(i,j-2,k,t).OR.act(i,j,k-2,t) (1)

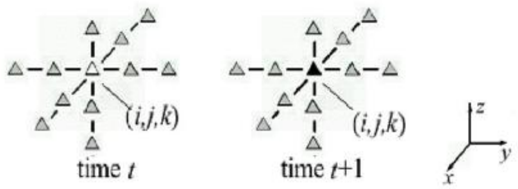

Fig.2 State Transition for act used for growth of Clouds

That is, as shown in Fig. (2), fact (•) returns to 1 if the state of act of one of the shaded grids around the grid (i, j, k) is 1. By changing the rule of fact (•), it is possible to simulate various effects. For example, we found that the following rule is suitable for clouds adverted by winds (see Fig. (3)).

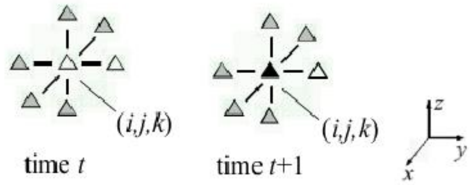

Fig.3 State Transition for act used for Simulating Wind.

In this case, the wind blows toward the plus direction of y axis.

f act(•)= act(i+1,j,k,t).OR.OR. act(i,j,k+1,t).OR.act(i-1,j,k,t).OR.

act(i,j-1,k,t).OR.act(i,j,k-1,t) (2)

Our method of Cloud Simulation based on Cellular Automata with Rule 30.

$a_{i-1}^{(t)} = a_{i-1}^{(t)}$ XOR $[a_{i(t)}$ OR $a_{i+1}^{(t)}]$ (3)

$a_i(t+1) = a_{i-1}(t+1)$ XOR [ai (t+1) OR ai+1 (t+1)] (4)

$a_{i+1}^{(t+2)} = a_{i-1}^{(t+2)}$ XOR $[a_i^{(t+2)}$ OR $a_{i+1}(t+2)]$ (5)

Beginning from initial random status, cloud growth is simulated by updating the state of each variable using Eq. 1 through 5. The initialization is as follows. First, hum is initialized by using uniform random numbers of probability P_{hum}[10]. That is hum set to 1 if a random number between 0 and 1 is less than P_{hum}, otherwise hum is set to 0. Similarly, act is set to either 0 or 1 by using the probability P_{act}, but it cannot be set to 1 when hum is 0. cld is set to zero [10]. In this method, act propagates with changing vapor (hum =1) into clouds (cld=1). The Eq.3,4 and 5 comes based on cellular automata rule 30.

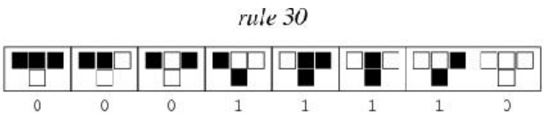

Fig.4 Graphical representation of Chaotic rule 30.

Rule 30 is of special interest because it is chaotic. These rule outcomes are encoded in the binary representation (see Fig. (4)). $30 = 00\ 011\ 110_2$.

CONCLUSIONS

In this paper, a method for simulate clouds using the CA method is presented. The major features of our method are:

A cellular automaton model allows the formulation of a dynamic complex system application in simple rules. Based on standard CA, there are of course many corrective and extended computational models for different applied objectives[9]. According to simple local transition functions, CA are intuitively regarded as a set of interacting elements are updated during a discrete time interval.

Formation and evolution of clouds can be simulated by a small amount of computation. The movement of clouds can be controlled by specifying the probability distributions for hum, act and ext[10]. Simulation of the cloud evolution requires only a small amount of computation since it is executed by Boolean operations. Evolutionary Dynamics are expressed as simple transition rules by using CA. The cellular automata are used to generate small scale clouds based on the global distribution of clouds calculated by the proposed method.

Our cloud simulation method is clearly explained and accepts the cellular automata Rule 30.The cellular automata are the new style, high performance simulation tool. We hope researchers can bring into play well the modeling power of the CA approach in future in variety complex systems.

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