Image Processing Based on Fuzzy Cellular Automata Model

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***Abstract*—For the task of image segmentation in image processing, we propose an arithmetic of image processing based on fuzzy cellular automata. It combines the theory of cellular automata and fuzzy rule to establish a model of fuzzy cellular automata. Thus, the pixels whose grey level is between object and background can be handled well, and good result of image segmentation can be got. In medical image processing, follicle recognition problem of ultrasonic images of ovaries is important and difficult. And it is well solved by using fuzzy cellular automata.**

Keywords—Cellular Automata, Fuzzy Cellular Automata, Image Segmentation

I. INTRODUCTION

Cellular automata (CA) are dynamical systems in which space and time are discrete . The basic theory of the classical CA was established by Von Neumann[1]. Later, Stephen Wolfram developed the theory [2]. Cellular automata can simulate abundant and complicated process of evolution and can be considered as a dynamics system whose dimension is infinite. CA model is more than an important model of computer theory, and it is applied in the study of nonlinear appearance and fractal structure in mathematics, physics, biology, chemistry, geography and economics.

In the practical application, the questions we study always lack the accurate information and there are many vague factors and data, to solve the problems, we can set up fuzzy cellular automata model by turning cell state of CA into fuzzy cell state, and evolution rules of CA into fuzzy evolution rules. This paper is organized as follows: in section 2, application of cellular automata model in image processing is introduced and a simple example is provided; in section 3, application of fuzzy CA in image segmentation is introduced. The paper ends with some conclusions in section 4.

II. CA AND APPLICATION OF CA IN IMAGE PROCESSING

2.1 About CA model

CA model is composed of cell, state set of cell, neighborhood and local rule. Time advances in discrete steps and the rules of the universe are expressed by a single recipe through which, at each step, each cell computes its new state from that of its close neighbors. Thus, the rules of the system are local and uniform. There are one-dimensional, two-dimensional and three-dimensional CA models. For example, a simple two-state, one-dimensional cellular automaton consists of a line of cells, each of which can take value 0 or 1. Using a local rule (usually deterministic), the values of all cells are updated synchronously in discrete time steps. With a K-state cellular automaton model, each cell can take any of the integer values between 0 and K−1. In general, the rule controls the evolution of the cell automaton which will encompass m sites up to a finite distance r away. We call this cellular automaton is a K-state, m-site neighborhood CA model.

Formal definition of CA is: suppose that L to be a regular lattice (the elements of L being called cells), S a finite set of states, N a finite set (of size $n=|N|$) of neighborhood indices such that $\forall r\in L$, $\forall c\in N$, $r+c\in L$, and suppose f : $S^n\to S$ to be a transition function. Then, we call the 4-tuple（L, S, N, f）a cellular automaton.

Elementary cellular automata, whose state set includes two only elements S={0, 1}, neighbor radius $r = 1$, $n = 3$, is the most simple CA model. It is one-dimensional and its local rule $f : S^3\to S$ can be indicated as follows:

$$S_i(t+1) = f\left(S_{i-1}(t), S_i(t), S_{i+1}(t)\right).$$

There are 256 (2^8=256) kinds of different local rules. Therefore, S. Wolfram numbered for elementary CA by its local rules and studied it deeply. The result shows that even though elementary CA is so simple, their space configuration which it presents is extraordinary complex. Rule 22：00010110 is shown in TABLEI.

TABLE I. TABLEI：RULE 22

111	110	101	100	011	010	001	000
0	0	0	1	0	1	1	0

As the digital image is two dimensions, here we use two-dimensional CA model. In two-dimensional CA model there are three regular lattices, namely triangular, square and hexagonal. In most cases the square lattice is used, only occasionally is the triangular or hexagonal lattice a better choice. In the formal definition of CA, one usually requires the lattice to be infinite in all dimensions. However it is impossible to simulate a truly infinite lattice on a computer. Therefore, we must prescribe some boundary conditions. In many cases the periodic boundary condition is used, because it comes closest to simulating an infinite lattice. For a square lattice, two types of neighborhood are typically used. First, the generalized Von Neumann neighborhood of radius r, is defined as

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$$N_{(i,j)} = \{(k,l) \in L \mid |k-i| + |l-j| \le r\},$$

and the second, the Moore neighborhood of radius r, is defined as

$$N_{(i,j)} = \{(k,l) \in L \mid |k-i| \le r \wedge |l-j| \le r\}.$$

For $r = 1$ and $r = 2$ are shown in Fig.1.

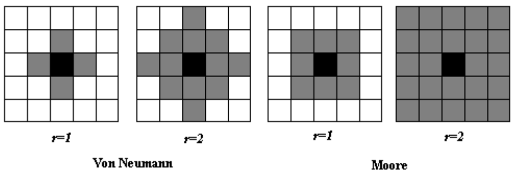


Figure1 Von Neumann and Moore neighborhood of r=1 and r=2

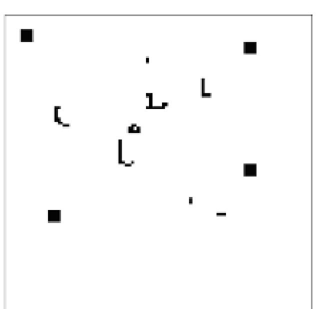
2.2 Application of CA for image segmentation

Image segmentation is one of the main problems of image processing. The so-called image segmentation is to extract the object of the image we are interested in, from the background of the image. Application of CA for image segmentation is composed of at least two phases[3]. In the first phase we allow each pixel in the image to establish a so-called "immune system". The immune system is a kind of protection mechanism, which must be constructed in such a way that it somehow manifests the pixel features at its boundary cells. After all pixels more or less successfully establish their immune systems, they are massively attacked in the second phase of a recognition process. The purpose of the attack is to destroy the cells of all pixels, which have not established fully functional immune system. If everything went right, the pixels that remained untouched in the image would be those we were looking for.

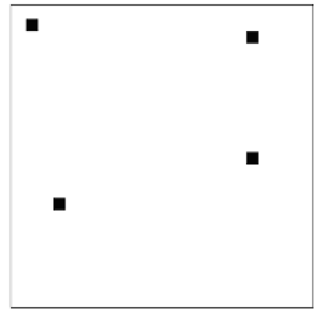
In these two phases, two related CA models evolve by the local rules at discrete time step.

Let us give a simple example: suppose that we have an image containing various different black shapes on a white background among which we would like to locate all black squares of size 4×4 pixels. Here, each pixel of image corresponds to one cell of CA.

Fig. 2 is an example of using CA for recognition. (a) is initial input testing images, (b) is the result of recognition. As we can see, only black squares of size 4×4 pixels have managed to survive, which also our goal.



a



b

Figure2 Example of using CA for recognition

2.3 Application of CA for image edge detection

CA model can be used to solve image edge detection. Fig.3(a) is a 130×104 initial image, Fig.3(b) is the edge extracted by mark matrix, Fig.3(c) is the edge extracted by edge-extract function in MATLAB, Fig.3(d) is the edge got by edge-extract CA model after evolution.

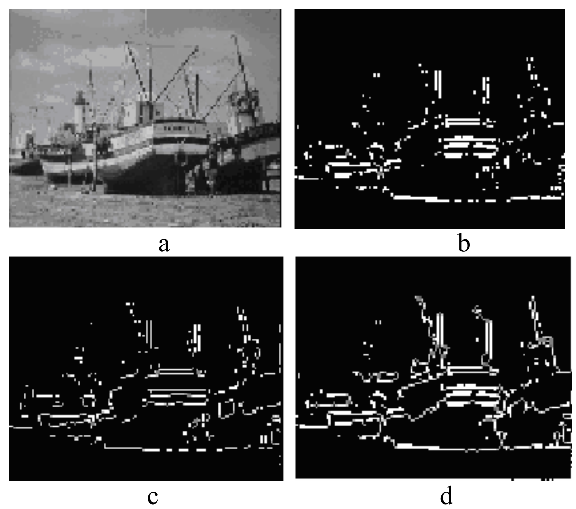


Figure3 Edge detection by CA

III. THEORY OF FUZZY CA AND ITS APPLICATION IN IMAGE SEGMENTATION

When we deal with the real problem, there exist many vague problems because of the complexity of system and the imperfectness of information. In order to solve such problems better, we introduce fuzzy CA models[4,5]. Defining fuzzy rule which is the key problem, is determined according to the specific issues. Fuzzy CA is defined as: $FCA = (L_d, \hat{S}, N, \hat{f})$. Where L_d is uniform grids, d is dimension, the elements of L_d are called as cells, $\hat{S}$ is said the fuzzy state vector of cell, N is the set of all the neighbors, whose size is $|N| = n$, the fuzzy transfer function is

$$\hat{f}: \hat{S}^n \to \hat{S}.$$

Next we will take the following two-dimensional fuzzy CA as an example to illustrate fuzzy rules of the fuzzy CA. As for neighbors, we choose a radius of 1 Moore neighbors. As for the evolution of the rules, the state of CA at *t+1* time step is determined by the following fuzzy rules:

$$\begin{gathered}
\text{IF } \{cell_{i,j}(t) \text{ IS } \mu_f(a_{i,j}{}^t)\} \\
\text{AND } \{cell_{i-1,j-1}(t) \text{ IS } \mu_f(a_{i-1,j-1}{}^t)\} \\
\text{AND } \{cell_{i-1,j}(t) \text{ IS } \mu_f(a_{i-1,j}{}^t)\} \\
\text{AND } \{cell_{i-1,j+1}(t) \text{ IS } \mu_f(a_{i-1,j+1}{}^t)\} \\
\text{AND } \{cell_{i,j-1}(t) \text{ IS } \mu_f(a_{i,j-1}{}^t)\} \\
\text{AND } \{cell_{i,j+1}(t) \text{ IS } \mu_f(a_{i,j+1}{}^t)\} \\
\text{AND } \{cell_{i+1,j-1}(t) \text{ IS } \mu_f(a_{i+1,j-1}{}^t)\} \\
\text{AND } \{cell_{i+1,j}(t) \text{ IS } \mu_f(a_{i+1,j}{}^t)\} \\
\text{AND } \{cell_{i+1,j+1}(t) \text{ IS } \mu_f(a_{i+1,j+1}{}^t)\} \\
\text{THEN } Out \text{ IS } OUT.
\end{gathered}$$

Here, the cell of site (i, j) at time step t is denoted $cell_{i,j}(t)$.$\mu_f(a_{i,j}{}^t)$ is its membership function, $f = 1, 2, \ldots, k$. *Out* is output, while *OUT* is correspond output fuzzy set. Then, *OUT* is defuzzied, and the value of $a_{i,j}^{t+1}$ is got.

In the application of classical CA for image segmentation, getting the packet and processing for the grey level are both "crisp". But in the actual image, pixels of the grey level between the object and background, which should be classified as object or background is uncertain and ambiguous. If we change the cell state of CA into the fuzzy state, the evolution rules into the fuzzy rules, and establish fuzzy CA, the problem can be solved better. Then we get a new image segmentation algorithm.

Now, Let's briefly introduce the images which can be recognized better by this algorithm. In medical image processing, ultrasonic images of ovaries are: follicle region in the image is object, whose grey level is lower than background, while there is not significant grey difference between the edge of follicle and the background. For such images, we can get a better result.

Just the same as the classic CA to deal with the images, we divide the process into two stages. First we establish the immune system, second we attack the immune system. In these two stages, we use two related fuzzy CA models to work respectively. The task of attacking the immune system stage is to change the cells with the low immune degree and the cells whose neighbors have low immune degree into the background. For the algorithm of fuzzy CA, we mainly introduce the fuzzy evolution rules of the first stage (the establishment stage of the immune system) since the second stage is simple.

For a given image, we consider three variables on the eight directions: grey level of neighbor cells, immune state of neighbor cells and state of neighbor cells as input variables of the fuzzy system.

1. Grey level of neighbor cells. It has five values: high, medium-high, medium-medium, medium-low, low. (For brevity, they are denoted respectively: H, MH, MM, ML, L)

2. Immune state of neighbor cells. It has two values: high and low. (For brevity, they are denoted respectively: H, L)

3. State of neighbor cells. It has three values: high degree of immunity, low degree of immunity and generating outer messages. (For brevity, they are denoted respectively: H, L, G)

There is only one variable in output of fuzzy system: state of center cell. It has three values: high degree of immunity, low degree of immunity and generating outer messages. (For brevity, they are denoted respectively: H, L, G)

Fuzzy evolution rules on the base of grey character of image segmentation are defined as follows:

●IF Grey level of center cell at time step t is ML, THEN

If Grey level of neighbor cells is H, then state of center cell at time step (t+1) is H.

If Immune state of neighbor cells is H, then state of center cell at time step (t+1) is H.

If State of neighbor cells is G, then state of center cell at time step (t+1) is H.

●IF Grey level of center cell at time step t is MM, THEN

If The grey level of neighbor cells is H, then the state of center cell at time step (t+1) is H.

If Grey level of neighbor cells is MH or MM, and Immune state of neighbor cells is H, then state of center cell at time step (t+1) is H.

If Grey level of neighbor cells is ML or L, and state of neighbor cells is H, then state of center cell at time step (t+1) is H.

If Grey level of neighbor cells is not L, and state of neighbor cells is G, then state of center cell at time step (t+1) is G.

●IF Grey level of center cell at time step t is MH, THEN

If Grey level of neighbor cells is H, and State of neighbor cells is H, then state of center cell at time step (t+1) is H.

If Grey level of neighbor cells is MH or MM or ML, and Immune state of neighbor cells is H, then state of center cell at time step (t+1) is H.

If Grey level of neighbor cells is ML or L, and State of neighbor cells is G, then state of center cell at time step (t+1) is H.

For the two cases of high and low grey level of center cell at time step t, the pixel classification is clear, so we don't deal with the evolution rules. In addition, if center cell at time step t doesn't satisfy above rules, the output variable of fuzzy system defaults to low degree of immunity. We use fuzzy toolbox in MATLAB to deal with the above evolution rules. The above rules will be embedded in the immune-establishment, and together with the immune-attacking, form a fuzzy CA model of image segmentation. Applying this algorithm to the task of image segmentation we get a better result. Fig. 6 is the ultrasonic image processed by fuzzy CA model. Fig. 4(A), (B), (C) is the results of the ultrasonic images after pre-processing, corresponds to the Fig. 4(a), (b), (c), respectively, is the final images processed by fuzzy CA.

IV. CONCLUSION

In the real world, the information we obtained is often inaccurate, incomplete, or the problem itself is vague and not fully identified. We change the cell state in theory of CA into fuzzy cell state, and the evolution rules into fuzzy rules to establish a fuzzy CA model to deal with the issue of the ambiguity. The result is better and the modified CA model is more intelligent just like the human brain. For image segmentation task in image processing, we introduce a fuzzy CA algorithm, which can make pixels of the grey level between the object and background in the image to be classified better. Consequently, we get a new image segmentation algorithm.

V. REFERENCES

[1] Von Neumann, J. Theory of Self-Reproducing Automata. University of Illinois Press, IL, 1966.

[2] Wolfram S. "Computation theory of cellular automata". Commun. Math. Phys. 96: pp. 15-57, 1984.

[3] B. Viher, A. Dobnikar, D. Zazula. "Cellular Automata and Follicle Recognition Problem and Possibilities of Using Cellular Automata for Image Recognition Purposes". International Journal of Medical Informatics, 49 (1998), pp.231-241.

[4] Fang Zhang, Yongsheng Ding, Zhaofeng Geng. "Production of Complicated Patterns and Texture Based on Fuzzy Cellular Automata." Journal of China Textile University. Vol. 25, No.5, pp.32-34, 1999.

[5] M.Mraz, N.Zimic, I.Lapanja, I.Bajec. "Fuzzy cellular automata: from theory to applications." 12 th IEEE International Conference on Tools with Artificial Intelligence . pp. 13-15,2000.

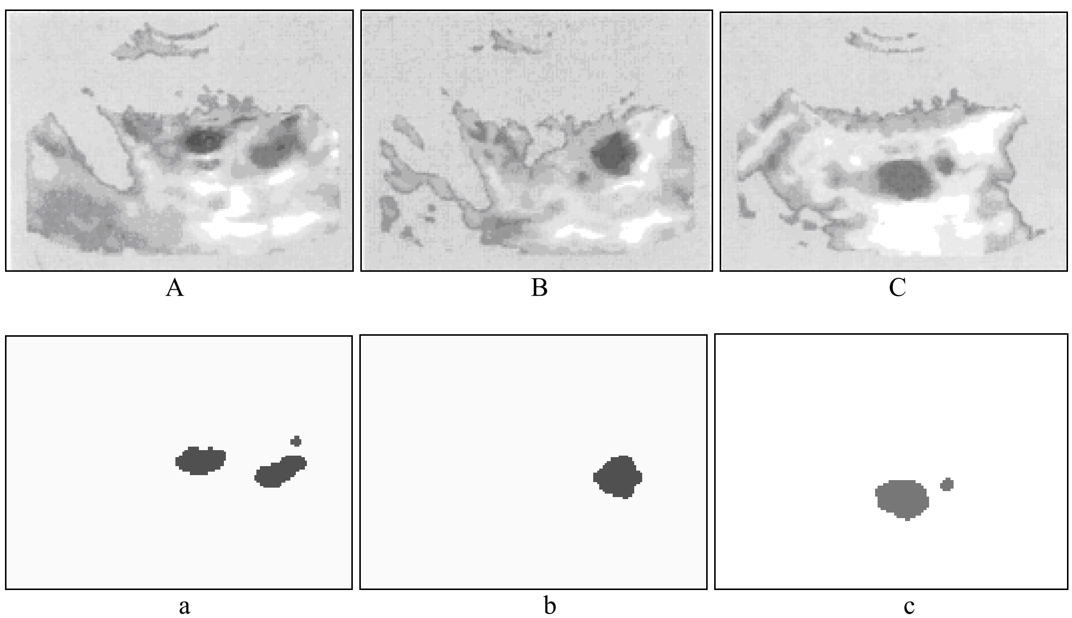


Figure4 Ultrasonic images handled by FCA