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Cellular Neural Network: Template Switching using Bistable-like Memristors

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1. Introduction

The Cellular Neural Network (CNN) is a network of simple analog cells that have local interactions with each other in a defined neighborhood. These interactions are defined by templates which control input, output, as well as a threshold value. The behavior of the network as a whole depends largely on the propagation phenomenon and the value of these templates. Results differ greatly with the neighborhood size: the 5x5 neighborhood brings noise to the output while the 3x3 neighborhood lacks in precision. Past researches investigated methods to bring the best of two neighborhood sizes by allowing each cell of the CNN to switch between 3x3 and 5x5 templates, using its output voltage to decide if it should switch. In this study, we propose a new switching method using the Memristor CNN (M-CNN) and switching depending on the value of the memristance state.

2. Proposed Method

We use the M-CNN which behavior is described by the following set of co-dependent Ordinary Differential Equations (ODE):

$$C_{x(ij)}\frac{dv_{x(ij)}(t)}{dt} = -\frac{v_{x(i,j)}(t)}{x_{m(i,j)}} + \frac{v_{x(i,j)}(t)}{x_{m(i,j)}(t)} + \sum_{Cell(k,l)\in N_r(i,j)} A(i,j;k,l) * v_{y(k,l)} + \sum_{Cell(k,l)\in N_r(i,j)} B(i,j;k,l) * v_{u(k,l)} + I * z \quad (1)$$

$$\frac{dx_{m(i,j)}(t)}{dt} = k(v_{x(i,j)}(t)) * 1 - (\frac{x_{m(i,j)}(t) - x_{on}}{x_{off} - x_{on}} - step(v_{x(i,j)}(t)))^{2p} \quad (2)$$

with

$$k(v_{x(i,j)}(t)) = -\beta * v_{x(i,j)}(t) + \frac{\beta - \alpha}{2} * (|v_{x(i,j)}(t) + Vt| - |v_{x(i,j)}(t) - Vt|) \quad (3)$$

We set the α and β parameters so that $\beta/\alpha > 10^{15}$, resulting in bistable-like memristors with fast, step-function-like switching characteristics between their low memristance state x_{on} and their high memristance state x_{off} [1]. Inspired by the center-cell method investigated in previous researches [2], we define a 7x7 neighborhood around a cell and follow the next steps:

Step 1: In the neighborhood, find the average memristance state x_{avg} (either x_{on} or x_{off}).

Step 2: Determine the center cell memristance state x_m

Step 3: If $x_m = x_{avg}$, then switch to the 3x3 template. In the other case, switch to the 5x5 template.

We apply these steps for every cell of the M-CNN and repeat them every 0.005τ.

3. Simulation Result

In this study, we tried to assess the result precision of the new M-CNN template switching compared to the original center cell switching method, and to the original 5x5 neighborhood methods, on the field of edge detection. As can be seen on Fig. 1, the new method brings more detail compared to all previous methods.

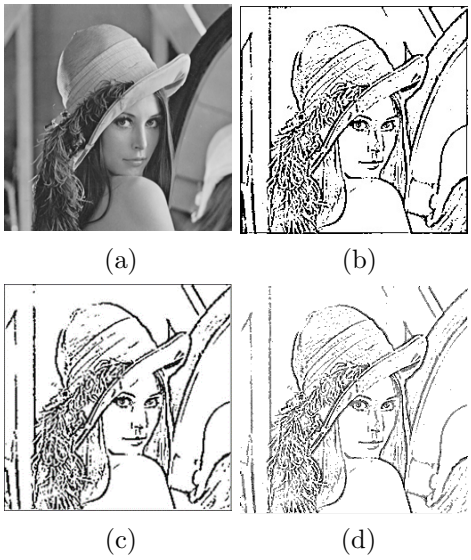

Figure 1: Simulation results. (a) Input image. (b) Simple 5x5 Edge detection template. (c) Edge detection using the original center cell method. (d) Voltage output simulation result of the proposed method.

4. Conclusion

In this study we have proposed and demonstrated the abilities of a new method for template switching inside the CNN, using the sharp switching characteristics of the bistable-like Memristor to bring more details to the output. Future works include focusing on different image analysis templates, as well as understanding the impact of other Memristor parameters to the output result.

References

[1] R. Tetzlaff, A. Ascoli, I. Messaris and L. O. Chua, "Theoretical Foundations of Memristor Cellular Nonlinear Networks: Memcomputing With Bistable-Like Memristors," in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 67, no. 2, pp. 502-515, Feb. 2020, doi: 10.1109/TCSI.2019.2940909.

[2] T. Ando, Y. Uwate and Y. Nishio, "Image processing by cellular neural networks with switching two templates," 2017 IEEE Asia Pacific Conference on Postgraduate Research in Microelectronics and Electronics (PrimeAsia), Kuala Lumpur, 2017, pp. 41-44, doi: 10.1109/PRIMEASIA.2017.8280359.