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Reaction-Diffusion Neuro Chips: Analog CMOS Implementation of Locally Coupled Wilson-Cowan Oscillators

Hiromu KATO, Tetsuya ASAI, and Yoshihito AMEMIYA

Department of Electrical Engineering, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, 060-8628, Japan.

E-mail: kato@sapiens-ei.eng.hokudai.ac.jp

We propose analog CMOS circuits that implement Wilson-Cowan (WC) oscillators. The oscillator imitates the group activities of cortical neurons[1]. A large-scale network of locally-coupled WC oscillators can be easily implemented on silicon chips, using the proposed WC circuit. The WC circuits collectively produce various dissipative patterns (e.g., Turing patterns and spiral ones) on the chip. These dissipative patterns are of the same kind as observed in reaction diffusion systems[2]. Since the chip consists of neural oscillators and its construction is similar to typical reaction-diffusion systems, we call the chip "reaction-diffusion (RD) neuro chips".

The RD chip consists of i) reaction circuits that emulate elementary interactions between neurons (or chemical substances) and ii) diffusion devices that imitate synapses (or chemical diffusion of the substances). Figure 1(a) shows a schematic image of self- and mutual-interactions (reactions) between two neurons (chemical substances). The reaction circuit is arranged on a hexagonal grid [Fig. 1(b)] and is connected with its neighboring circuits through the diffusion devices.

Figure 2 shows the reaction circuit (hereafter called the WC circuit) that consists of excitatory- and inhibitory-neuron circuits. Both neuron circuits have the same structure except for the polarity of synaptic connections. The sigmoidal response (f) of the neuron circuit is obtained by a CMOS differential pair consisting of floating-gate transistors. The differential pair also acts as excitatory and inhibitory synapses. It accepts an excitatory input (u) and inhibitory inputs (v) through "+" and "-" terminals, respectively.

The stability of a WC circuit can be controlled by the magnitude of the external inputs (θ_u and θ_v), as predicted in the WC models. Figure 3 shows three types of responses of the WC circuit, i.e., two fixed-points [Fig. 3(a) and 3(b)] and a limit-cycle attractor [Fig. 3(c)].

To construct the RD chip, a number of WC circuits are arranged on a silicon chip and the status nodes (u and v) of each WC circuit is connected with synaptic terminals of the neighboring circuit. The stability of each WC circuit is thus determined by its neighbors, as in typical dissipative systems. Utilizing the dissipative properties of the RD chip, we tried to develop image processing systems. Figure 4 shows a simulated result of fingerprint image processing. The RD chip was configured to generate stable stripe patterns (Turing patterns). When a real fingerprint image was given to the chip as initial states (Fig. 4 left), the chip successfully produced a stable fingerprint pattern without noises and unnatural discontinuities of wrinkles (Fig. 4 right). This example implies future potentialities of RD chips in engineering applications.

References

[1] H.R. Wilson and J.D. Cowan, Excitatory and inhibitory interactions in localized populations of model neurons, *Biophys. J.*, Vol. 12, pp. 1-24, 1972.

[2] G. Nicolis and I. Prigogine, *Self-organization in Nonequilibrium Systems — From Dissipative Structures to Order through Fluctuations.* John Wiley & Sons, Inc., 1977.

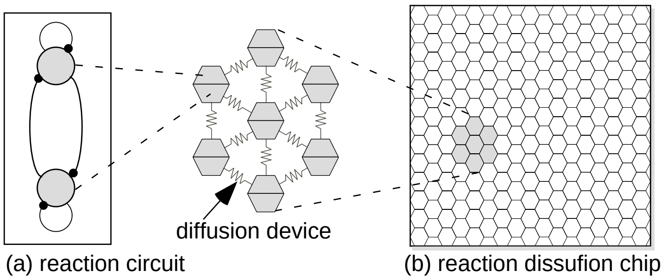

Fig. 1 Construction of the RD chip

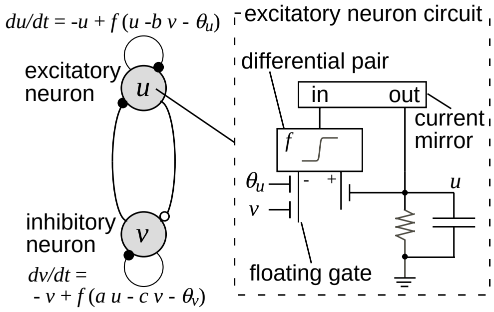

Fig. 2 The WC Circuit

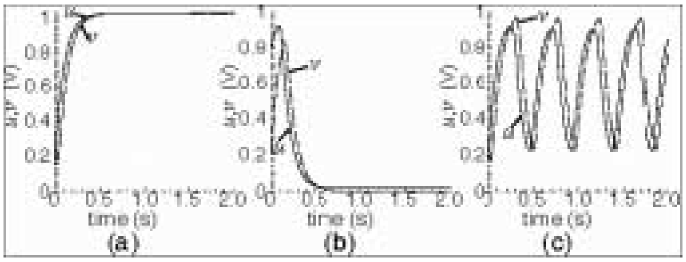

Fig.3 Three types of attractors of the WC circuit

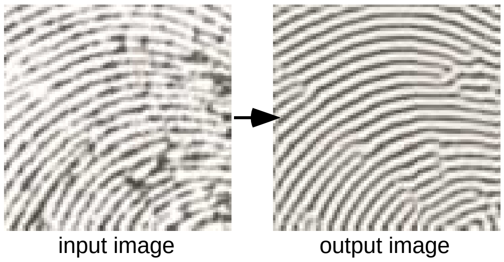

Fig.4 Example operation of the RD neuro chip