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Analysis of various spike-trains from a digital spiking neuron

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Abstract. A digital spiking neuron (DSN), a quantized analog spiking neuron (QSN) and a discrete spike position map are introduced, and their relations are discussed. Spike position modulations for various spike-trains of DSN and QSN are considered. In addition, some applications are discussed.

Keywords: Spiking neuron; Spike position modulation; FPGA; Analog-to-digital converter

1. Introduction

We introduce a digital spiking neuron (DSN) which has discrete state and time [1]. The DSN can generate various periodic spike-trains that can be symbolized by digital codes based on a spike position modulation. Using a discrete spike position map [2], we clarify that the DSN can have multiple co-existing periodic spike-trains (for initial state) that can correspond to binary number codes. We also introduce a quantized analog spiking neuron (QSN) [3,4]. As a periodic stabilization signal is applied, an analog state of the QSN is quantized and its dynamics can correspond to the discrete spike position map. We then clarify that the QSN can have multiple co-existing super-stable periodic spike-trains that can correspond to binary number codes. Applications of DSN and QSN are also discussed.

The motivations for considering DSN and QSN include the following points: (a) Considerations of simple spike-train generators are fundamental for developing spike-based engineering systems having interesting properties, e.g., fast computation ability and low-power consumption [5–8]. (b) The spike position modulation may be fundamental for

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considering information codings in artificial pulse-coupled neural networks and/or spike-based communications [5–8]. (c) The DSN is suited for implementing a learning rule in FPGA. The QSN can realize robust operation of analog-to-digital converter (ADC) unlike the conventional ADC [9].

2. Digital spiking neuron

Fig. 1A shows a digital spiking neuron (DSN) [1] having discrete-time $t=0, 1, 2. \ldots$. The DSN has M p-cells with digital states $p_i(t) \in \{0,1\} \equiv \mathbf{B}$ and N x-cells with digital states $x_i(t) \in \mathbf{B}$, where $N>M$. The p-cells are governed by $p_i(t+1)=p_{i(\mathrm{mod}1)+1}(t)$. In this paper, we fix initial states of the p-cells: $p_{\mathrm{Int}((M+1)/2)}(0)=1$ and $p_k(0)=0$ for $k \neq \mathrm{Int}((M+1)/2)$, where $\mathrm{Int}(l)$ is the integer part of l. Then the p-cells oscillate with period M. The connecting terminals have reconfigurable wirings that are represented by an $N \times M$ wiring matrix $\mathbf{A}=[a_{ji}]$ with binary element $a_{ji} \in \mathbf{B}$. In Fig. 1A, $a_{ji}=1$ for $i \in \{1, \ldots, M\}$ and $a_{ji}=0$ for $i \neq j$. The connecting terminals accept a state vector $(p_1(t), \ldots, p_M(t))^t \equiv \mathbf{P}(t)$ of the p-cells, and output a signal vector $(b_1(t), \ldots, b_N(t)) \equiv \mathbf{b}(t)=\mathbf{AP}(t)$ which is called *base signal*. Let $(x_1(t), \ldots, x_N(t))^t \equiv \mathbf{X}(t)$ be a state vector of the x-cells, and let $S((x_1, \ldots, x_N)^t)=(0, x_1, \ldots, x_{N-1})^t$ be a shift operator. Then dynamics of the x-cells is described by $\mathbf{x}(t+1)=S(\mathbf{x}(t))$ if $x_N(t)=0$ and $\mathbf{x}(t+1)=S(\mathbf{x}(t)) \cup \mathbf{b}(t)$ if $x_N(t)=1$. Basic dynamics is shown in Fig. 1B. If

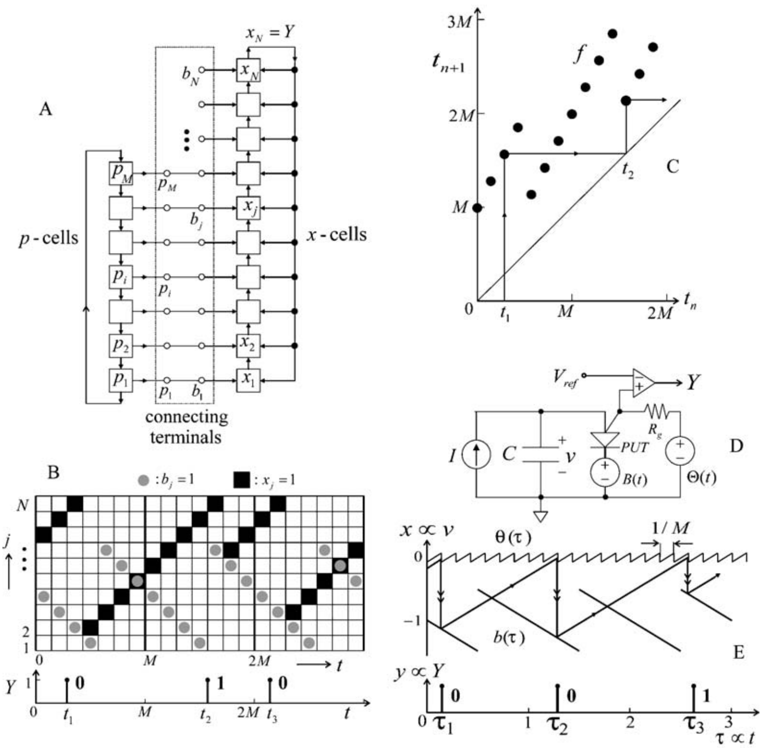

Fig. 1. (A) Digital spiking neuron (DSN). $M=7$ and $N=10$. (B) Basic dynamics of DSN. (C) Discrete spike position map. (D) Quantized analog spiking neuron (QSN). (E) Basic dynamics of QSN. $M=7$.