Guest Editorial
Special Issue on Temporal Coding for Neural Information Processing

LARGELY motivated by neurobiological discoveries, neural network research is witnessing a significant shift of emphasis towards temporal coding, which uses time as an essential dimension in neural representations. Temporal coding is passionately debated in neuroscience and related fields, but in the last few years a large volume of physiological and behavioral data has emerged that supports a key role for temporal coding in the brain. In neural networks, extensive research is undertaken under the topics of nonlinear dynamics, oscillatory and chaotic networks, spiking neurons, and pulse-coupled networks. Various information processing tasks have been investigated using temporal coding, including scene analysis, figure-ground separation, classification, associative learning, inference, and motor control. Progress has been made that substantially advances the state-of-the-art of neural computing. In many instances, however, neural models incorporating temporal coding are driven merely by the fact that real neurons use impulses. It is often unclear whether, and to what extent, the temporal aspects of the models contribute to information processing capabilities. This Special Issue was conceived in part to assess the role and potential of temporal coding in terms of information processing by providing a comprehensive view of the current approaches and issues to the neural network community. The Special Issue intends to present, in a collective way, research that makes a clear contribution to addressing information processing tasks using temporal coding. The issue serves not only to highlight successful use of temporal coding in neural computation but also clarify outstanding issues for future progress.

The Special Issue Call for Papers received a very strong response from the community. A total of 64 manuscripts were submitted for consideration. They represent a broad spectrum of research in temporal coding, ranging from the study of the synchronization phenomenon to spatiotemporal processing. Of these submissions, 33 papers were accepted following a rigorous review process, coordinated by the guest editors.

The accepted papers are organized into the following eight topics.

Coincidence detection. Mikula and Niebur study an ideal coincidence detector and give a solution for its steady-state output in response to an arbitrary number of excitatory and inhibitory spike trains. Beroule surveys temporal processing networks and explicitly discusses the time dimension and temporal coding with implications in perception, learning, and memory. Watanabe and Aihara propose an iterative model with time delay for temporal spike coding. By changing local parameters in their neuron model, they can induce changes in the network dynamics, ranging from periodic oscillations to chaotic behavior.

Dynamics. The paper by Paulin *et al.* aims at deriving a computational state estimation from real sensorimotor neuron measurements using the Kalman filter and fractional-order dynamical encoding. Schmitt addresses the theoretical issue of generalization in networks of spiking neurons, deriving bounds on the number of training samples needed for a wide class of feedforward networks. Horn *et al.* study a proximity measure of spatiotemporal sequences by calculating correlations of synaptic weight matrices that generate such sequences. Kanamaru and Sekine analyze oscillatory phenomena in globally connected active rotators with excitatory and inhibitory connections and different time constants. The paper by Nakano and Saito is a study of an arrangement of spiking chaotic oscillators interacting with each other by signaling with outgoing impulses and synchronizing on the incoming ones. Campbell *et al.* deal with oscillators coupled in chain and lattice networks and analyze synchronization rates in these networks depending on the coupling type and strength.

Neural modeling. Eckhorn *et al.* discuss different coupling mechanisms in the visual cortex and their implications for object representation by neural synchronization, and suggest more general forms of signal coupling and associative learning. D. Xu and Principe conduct a theoretical and numerical analysis of the dynamics of the KII model, which is the building block of Freeman's K-set approach. They derive conditions for the existence and uniqueness of fixed point and limit cycle oscillations in the reduced KII model. Izhikevich reviews various models of cortical spiking neurons, analyzes and their features and computational efficiencies. Complex chaotic dynamics appears to be an important feature both at the level of individual neurons and collective brain dynamics. Choe's paper presents a model for the integration of cortical maps using a framework based on analogy, showing how spatiotemporally organized activity in the thalamocortical loop can facilitate such integrative functions as analogical completion and filtering. The paper by Kenyon *et al.* identifies key factors responsible for oscillatory behavior of the retina, namely the long-range inhibition and short-range coupling, which lead to phase encoded responses to visual objects. Lengyel and Erdi propose a model of the entorhinal cortex and the hippocampus in order to describe place-specific activity patterns. Model calculations show the emergence of theta rhythm in the rate- and phase-coded oscillations generated by interacting pyramidal cell populations.

Auditory processing. Cariani gives a general discussion of various types of temporal codes for sensory representations and perceptual analysis, and the discussion covers different sensory modalities. Khurshid and Denham present a pitch estimation al-

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gorithm that performs in noisy conditions. Their algorithm is compared with a number of representative pitch tracking systems. Smith and Fraser present a biologically motivated technique for detecting sound onsets. This technique works with a spike code and performs onset detection by leaky integrate-and-fire neurons. Hu and Wang present a model for monaural segregation of voiced speech by dealing with resolved and unresolved harmonics separately. Wrigley and Brown present a conceptual framework and a computational model for auditory selective attention. The model consists of a network of neural oscillators, and is capable of attending to an auditory stream.

Visual processing. Perrinet *et al.* discuss how a group of spiking neurons can use spike timing to encode analog features of retinal images. Zhao *et al.* propose a network of coupled chaotic maps to perform multiscale color image segmentation. The paper introduces a pixel motion mechanism to improve the performance of pixel clustering. Yu and L. Zhang apply three-dimensional pulse-coupled networks to the problem of motion detection and segmentation in images. X. Zhang and Minai present an approach for motion-based image segmentation in locally coupled oscillator networks, which uses a two-pathway system, pixel-level pathway and region-level pathway, to address the problems of noise sensitivity and texture insufficiency.

Associative networks. Miyoshi and Okada analyze the interacting effects of pruning and synaptic delays on the storage capacity of an associative memory. The paper by Lee describes an autoassociative network using chaotic oscillator units, and compares its behavior with networks constructed from other oscillator types. Barreto and Arazjo introduce the Vector Quantized Temporal Associative Memory for time series prediction, and system identification and control. Their method is based on self-organizing maps and can achieve similar performance as alternative neural network approaches.

Temporal processing. Manette and Maier perform experimental studies using recordings from motoneurons and from muscle tissues in monkeys. Their result suggests that rate coding determines large-amplitude variations, while temporal coding accounts for fine variations in EMG signals. Lozowski *et al.* study temporal information processing in the olfactory system. They propose a model based on inverse Frobenius-Perron filter approach. In their model, temporal bulbar sequences are fit to the interspike distributions of temporally modulated receptor signals. The paper by L. Xu provides an overview of several adaptive techniques useful in stochastic analysis of temporal processes including identification of the state–space and its dimension, hidden variables and memory.

Hardware implementation. Bofill-i-Petit and Murray present a development in analog VLSI circuitry that implements learning by spike-timing dependent synaptic plasticity, which is a biologically plausible adaptation mechanism. Liu and Douglas demonstrate nearest-neighbor coupling and global inhibition implemented in VLSI as a network of spiking units and the resulting synchronization and signal propagation by means of cross-correlation diagrams. Cosp *et al.* discuss theoretical studies on coupled oscillators, in particular their synchronization properties. The paper also presents electronic oscillators for massive parallel implementation.

In closing, much information about the world is embedded in time, and recent advances in neuroscience have revealed major significance of temporal coding in the brain. As neural network research matures the power of temporal coding is increasingly recognized. This Special Issue is brought to you with the hope of facilitating our understanding of temporal coding and its indispensable role in neural information processing.

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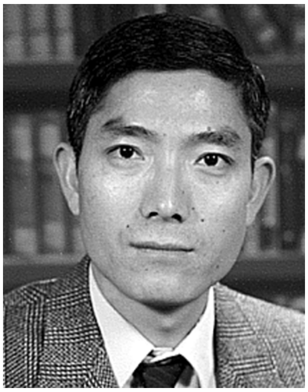

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