

Guest Editorial

Learning in Neuromorphic Systems and Cyborg Intelligence

NEUROMORPHIC computing has become an important emerging research area in recent years. By emulating computational principles and architecture found in neural systems, neuromorphic computing has led to the development of neuromorphic sensors, processors, and sensory motor systems for robotic agents. It has also led to rapid progress in related areas covering computational theories of sensory coding, synaptic computing, learning, and signal processing algorithms, circuit designs, and implementations. The work in these areas shows neuromorphic approaches with appealing computational advantages over conventional approaches, but at the same time, neuromorphic systems still pose many research challenges. Neuromorphic computing overlaps with another area called cyborg intelligence which is dedicated to integrating artificial intelligence (AI) with biological intelligence closely and deeply by connecting computer systems and biological beings. Cyborg intelligence aims to compensate for the weaknesses of both systems by combining the computational power of machines with the perceptive and cognitive abilities of biological systems. Recently, many of the advances in cyborg intelligence methods, systems, and applications have demonstrated the trend of the rapid integration of cyborg intelligence with neuromorphic computing in both breadth and depth. These areas pose innumerable interesting and significant questions for AI and could fundamentally change the landscape of AI research.

This Special Issue presents 11 original articles covering topics of brainlike learning in neuromorphic systems and cyborg intelligence, theories, algorithms, modeling, and experiment studies to applications. All the papers have gone through a rigorous review process.

The first paper, entitled Triplet spike time-dependent plasticity in a floating-gate synapse, presents a spike triplet-based learning rule using a single floating-gate (FG) transistor as the synapse for VLSI spiking neural networks (SNNs), and a single pulse and a double pulse drain voltage method to obtain the desired dependence of weight on spike timing. This paper also describes a mathematical procedure to obtain control voltages for the FG device for triplet spike time-dependent plasticity (STDP) and shows measurement results from an FG synapse fabricated in TSMC 0.35- μ m CMOS process to support the theory. Possible hardware implementations

of the drain voltage waveform generator are also proposed and verified through SPICE simulation results. It was shown that the voltage waveform for the double pulse case can be generated more accurately due to its simplistic nature.

The second paper, entitled Bag of events: An efficient probability-based feature extraction method for AER image sensors, presents a feature extraction method for address-event representation (AER) image sensors based on probability theory, namely, bag of events (BOE). The proposed approach represents each object as the joint probability distribution of the concurrent events and each event corresponds to a uniquely activated pixel of the AER sensor. The BOE method is a statistical learning method and has a good interpretability in mathematics. It can significantly reduce the effort to tune parameters for different data sets, because it only has one hyperparameter and is robust to the value of the parameter. BOE is an online learning algorithm which does not require the training data to be collected in advance and can achieve competitive results in real time for feature extraction (>275 frames/s and >120 000 events/s). The implementation complexity of BOE only involves some basic operations, which guarantees the hardware friendliness of our method. The experimental performance shows that the BOE method is remarkably faster than two recently proposed AER categorization systems while preserving a good classification accuracy.

The third paper, entitled A binaural neuromorphic auditory sensor for FPGA: A spike signal processing approach, presents a new architecture, design flow, and FPGA implementation of a neuromorphic binaural auditory sensor, designed completely in the spike domain. The model presented in this paper processes information directly encoded as spikes using pulse frequency modulation and provides a set of frequency-decomposed audio information using an AER interface. In this case, a systematic approach to design led to a generic process for building, tuning, and implementing audio frequency decomposers with different features, facilitating synthesis with custom features. This allows researchers to implement their own parameterized neuromorphic auditory systems on a low cost FPGA platform in order to create models of the audio processing and learning that takes place in the brain. This paper also presents a 64 channel binaural neuromorphic auditory system implemented in a Virtex-5 FPGA using a commercial development board. The performance and features of the system in response to a diverse set of audio signals are analyzed in the work.

The fourth paper, entitled Neuromorphic artificial touch for categorization of naturalistic textures, describes a neuromorphic tactile system that emulates the firing behavior of mechanoreceptors by injecting the raw outputs of a bioinspired tactile sensor into adaptive neuronal models producing spike trains. Through the successful categorization of naturalistic textures in different sensing conditions, this paper shows how the neuromorphic tactile sensors can be used in future real-life neuroprosthetic applications.

The fifth paper, entitled Learning to perceive the world as probabilistic or deterministic via interaction with others: A neuro-robotics experiment, develops a dynamic neural network model, named as stochastic multiple timescale recurrent neural network to develop different behavior generation schemes, such as sensory reflex and intentional proactive behaviors. The model learns to predict subsequent sensory inputs, generating both their means and their uncertainty levels in terms of variance by utilizing its multiple timescale property. The experimental results indicate that two different ways of treating uncertainty about perceptual events in learning, namely, probabilistic modeling and deterministic modeling, contribute to the development of different dynamic neuronal structures governing the two types of behavior generation schemes.

The sixth paper, entitled CONE: Convex Optimized syNaptic Efficacies for temporally precise spike mapping, presents two novel CONE algorithms for estimating the weights of a spiking neuron that maps spatiotemporal input spike patterns to temporally precise output spikes. These algorithms were applied on simulated data and an application involving experimental data for gait-event detection. These techniques provide optimal solutions due to the convex nature of the problem formulation, which also increases memory capacity. The CONE algorithms proposed in this paper enable the user to generate solutions that are robust to specific noise profiles by influencing the weight distribution and membrane voltage trajectory, and is amendable to a variety of pattern recognition applications for complex biological processes.

The seventh paper entitled, Parameter as a switch between dynamical states of a network in population decoding, presents a parameter selection model for population decoding, and successfully uses this method to identify the key conditions for a nonzero continuous attractor. The proposed model uses population codes, identifies the correct parameter, and guarantees the nonzero continuous attractors. The analytical results from this study may benefit many neural computing applications and contribute to a better understanding of population decoding in the neural systems.

The eighth paper, entitled A novel algorithm for learning sparse spatio-spectral patterns for event-related potentials, presents a probabilistic model for trial-by-trial concatenated electroencephalogram, in which the concatenated event-related potentials (ERPs) are expressed as a linear combination of a set of discrete sine and cosine bases. The bases are simply determined by the data length of a single trial. A sparse prior on the rank of the spatiotemporal pattern matrix is introduced into the model to allow the number of components to be automatically determined. A maximum posterior estimation

algorithm based on cyclic descent is then developed to estimate the spatiotemporal patterns. A spatial filter can then be obtained by maximizing the signal-to-noise ratio of the ERP components. The efficacy and efficiency of the algorithm show that the proposed algorithm can estimate ERPs more accurately than several state-of-the-art algorithms. This paper provides a better extraction method for researchers in neural engineering, cognitive neuroscience, and psychology.

The ninth paper, entitled Quantized attention gated kernel reinforcement learning for brain-machine interface decoding, presents a quantized attention gated kernel reinforcement learning (QAGKRL) approach to avoid the local minima adaptation in spatial credit assignment and sparsify the network topology. An animal needs to select its goal among many potential targets in the scene, and the agent without *a priori* knowledge has to infer the subjects goal through trial-and-error. QAGKRL interprets the nonlinear state-action mapping as the linear combination of the inner products in reproducing kernel Hilbert space via kernel adaptive filtering, where the linear operation can be easily applied to reach the global minima. Compared with Attention Gated Reinforcement Learning (AGREL), its higher accuracy and more stable performance indicate its powerful ability for more sophisticated Brain Machine Interfaces (BMI) applications as required in clinical applications.

The paper entitled, Mapping, learning, visualisation, classification and understanding of fMRI data in the NeuCube evolving spatio-temporal data machine of spiking neural networks, presents a new methodology for dynamic learning, visualization, and classification of functional Magnetic Resonance Imaging (fMRI) as spatiotemporal brain data. The method is based on an evolving spatiotemporal data machine of evolving SNNs exemplified by the NeuCube architecture. The proposed methodology allows for the first time to analyze dynamic functional and structural connectivity of a learned SNN model from fMRI data. This can be used for a better understanding of brain activities and also for online generation of appropriate neurofeedback to subjects for improved brain functions. The proposed NeuCube-based methodology offers also a superior classification accuracy when compared with the traditional AI and statistical methods. The created NeuCube-based models of fMRI data are directly and efficiently implementable on high performance and low energy consumption neuromorphic platforms for real-time applications.

The paper entitled, An online unsupervised structural plasticity algorithm for spiking neural networks, presents a new neuroinspired winner-take-all architecture (WTA-NNLD) and an STDP inspired dendrite specific structural plasticity-based learning rule (STDP-NRW) for its training. WTA-NNLD encodes patterns of different classes by either activity of distinct NNLDs or by a distinct sequence of NNLD firings. The experimental results from the proposed network and learning rule conclude that by proper tuning of the inhibitory time constant of the WTA, a tradeoff between specificity and sensitivity of the network can be achieved.

We hope that the ideas of the above-mentioned papers will provide insights into the further development and applications in the fields of neuromorphic systems and cyborg intelligence.

Finally, as the Guest Editors of the Special Issue, we would like to thank all authors for their contributions, the reviewers for their valuable efforts in reviewing these articles and their constructive comments for the authors to improve their work. Most importantly, we are grateful to our Editor-in-Chief, Prof. Derong Liu for his invaluable support and guidance throughout the review and publication process.

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He has been involved in several national and European robotics projects, mainly in the design of artificial visual loops and sensors. He has authored over 100 scientific publications and holds several patents in the area of vision, robotics, event-based sensing, and prosthetics. His current research interests include the understanding of the computation operated along the visual systems areas and establishing a link between computational and biological vision.

Dr. Benosman was awarded with the National Best French Scientific Paper by the Journal La Recherche for his work on neuromorphic retinas and their applications to retina stimulation and prosthetics in 2013.



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