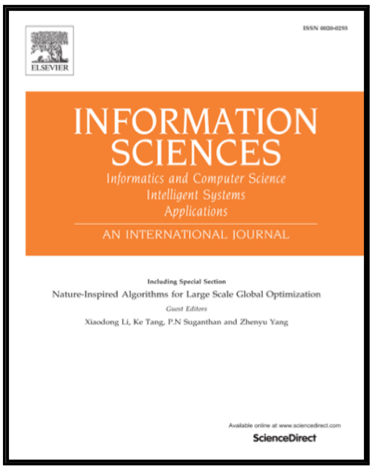


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Nooraini Yusoff , Mohammed Fadhil-Ibrahim

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# Spatio-temporal Event Association using Reward-Modulated Spike-Time-Dependent Plasticity

Nooraini Yusoff[a] and Mohammed Fadhil-Ibrahim[b]

[a] *School of Computing, UUM College of Arts and Sciences, Universiti Utara Malaysia, 06010 UUM Sintok, Kedah, Malaysia*
*nooraini@uum.edu.my*

[b] *Technical College of Management- Baghdad, Middle Technical University (MTU), 10047 Bab Al Muadham, Baghdad, Iraq*
*mfi@mtu.edu.iq*

Corresponding author. Tel.: +6-04-9284 5186; Fax: +6-04-928 5067
*E-mail address:* nooraini@uum.edu.my

**Abstract**

For goal-directed learning in spiking neural networks, target spike templates are usually required. Optimal performance is achieved by minimising the error between the desired and output spike timings. However, in some dynamic environments, a set of learning targets with precise encoding is not always available. For this study, we associate a pair of spatio-temporal events with a target response using a reinforcement learning approach. The learning is implemented in a recurrent spiking neural network using reward-modulated spike-time-dependent plasticity. The learning protocol is simple and inspired by a behavioural experiment from a neuropsychology study. For a goal-directed application, learning does not require a target spike template. In this study, convergence is measured by synchronicity of activities in associated neuronal groups. As a result of learning, a network is able to associate a pair of events with a temporal delay in a dynamic setting. The results demonstrate that the algorithm can also learn temporal sequence detection. Learning has also been tested in face-voice association using real biometric data. The loose dependency between the model's anatomical properties and functionalities could offer a wide range of applications, especially in complex learning environments.

*Keywords:* spiking neural networks, associative learning, spike-time-dependent plasticity, reward-based learning, spatio-temporal events

## 1. Introduction

Spiking neural networks (SNNs) have many advantages over the Mcculloch Pitts neural network models for biologically reasonable values of their function parameters, and provide fast and efficient computation. Unlike the traditional models, which focus on the joint activation of the presynaptic and postsynaptic neurons for plasticity, SNNs regard the timing of presynaptic and postsynaptic neurons as carrying important information [1] [18].

In practice, learning in an SNN can be implemented using either an unsupervised or a supervised approach. For unsupervised learning, spike-time-dependent plasticity (STDP) may be the most biologically plausible approach [1] [6]. In STDP-based learning, the increment or decrement of weights is dependent on the order of pre-and postsynaptic spikes. If the postsynaptic (presynaptic) spike arrives after its presynaptic (postsynaptic) spike within some time interval, the weight is increased (decreased). For unsupervised problems in SNNs, inputs are imposed during training and the network evolves to a state in which its dynamics determine the output using the current values of the weights. The designed learning algorithms must uncover patterns and synchronicity in the network activity to create causal relationship between triggering input and an interpretable, desired network state, i.e., the desired output [10]. However, the unsupervised approach is not directly applicable for goal-oriented applications.

For supervised learning, STDP needs to be coupled with an appropriate encoding scheme, e.g., [19] [36]. For goal-directed learning (i.e., supervised) in SNNs, synaptic changes are dependent on the direction of the gradient of the timing difference between currently produced output and target spike trains. Hence, most proposed algorithms (e.g., [28] [39] require a spike template (i.e., target spike trains) as the learning target. The objective of learning is to minimise the error between the desired and output spike timings. However, practically, in some stochastic environments, it is not easy to provide a set of learning targets