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Unsupervised Learning of Patterns Using Multilayer Reverberating Configurations of Polychronous Wavefront Computation

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Abstract

Polychronous Wavefront Computation (PWC) is an abstraction of spiking neural networks that has been shown to be capable of basic computational functions and simple pattern recognition through multilayer configurations. The objective of this work is to apply unsupervised learning methods to multilayer PWC configurations to improve performance providing a basis for more advanced applications and deep learning. Previous work on defining multilayer PWC configurations is extended by applying biologically inspired learning methods to dynamically suppress unneeded transponders and improve configuration performance. Simple learning approaches based on concepts from spike-timing-dependent plasticity and potentiation decay models are adapted to PWC transponders and combined with training sequences to optimize the transponder configurations for recognition. Learning is further enhanced by configuring transponders in recurrent structures to activate hidden layer transponders creating reverberations that reinforce learning. A means to classify multiple input patterns into general concepts is also introduced to further enhance the recognition capabilities of the configurations. The concepts are experimentally validated and analyzed through application to a 7-segment display digit recognition problem showing that the approach can improve PWC configuration performance and reduce complexity.

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Keywords: polychronous wavefront computation; pattern recognition; multilayer neural networks; spiking neural networks; unsupervised learning

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1. Introduction

Polychronous Wavefront Computation (PWC)[1] was proposed as an abstraction of the spiking neural network paradigm[2] based on temporal and spatial patterns of wavefront activity in a pulse propagating media and their interaction with transponders. It provides a potentially practical model for implementing neuromorphic computing systems because of its simple design that eliminates the need for direct connections between computational units reducing the complexity of large scale implementation.

PWC consists of a configuration of transponders (or nodes) that may emit wavefronts and sense the wavefronts from other nodes. When a node senses two (or more) wavefronts simultaneously, it emits a new wavefront. Figure 1 shows a simple example of PWC interactions. Two nodes (A and B), activated at different times, emit wavefronts (circles) that trigger a third node (C) at the intersection of those wavefronts. The possible wavefront intersections over time form a hyperbola defined by the radii of the wavefronts generated by the two nodes, which in turn are defined by the positions and relative activation times of the nodes. In this example, node A was activated before node B resulting in a larger diameter wavefront. The possible intersection points for the A and B activation are defined by the solid hyperbola. Other possible intersections, defined by different relative activation times of A and B, are shown as dashed hyperbolae.

Izhikevich and Hoppensteadt[1] have defined small configurations of PWC transponders that can perform signal analysis and logical operations. The mathematical properties of simple PWC configurations have been explored in detail and some conceptual sensor configurations suggested[3]. It has also been suggested that numerical programming methods could be used to configure PWC transponders[4]. In addition, recent work has presented a method to define multilayer configurations to perform pattern recognition with PWC[5] but has not shown how to optimize these configurations and improve their recognition performance. Improved performance would allow exploration of complex PWC properties and provide the basis for researching advanced recognition applications such as deep learning.

The objective of this work is to extend the prior work on multilayer PWC configurations to provide a basis for exploring the application of PWC to more complex problems. The paper presents an approach for improving the performance of multilayer PWC configurations through application of biologically inspired mechanisms. It will first overview the multilayer PWC configuration for pattern recognition as a basis for the discussion. It will then introduce two unsupervised learning methods: Activation Threshold Adjustment, which decays or enhances node activation based on frequency of stimulus, and reverberation within the configuration which enhances the effect of Activation Threshold Adjustment. It will also introduce a design for associating multiple input patterns with a common concept to enhance the recognition capability of the configurations. It then discusses the application of the approach to a 7-segment display digit recognition problem and the results obtained. It concludes with a discussion of the characteristics of the proposed method and suggestions for further research.

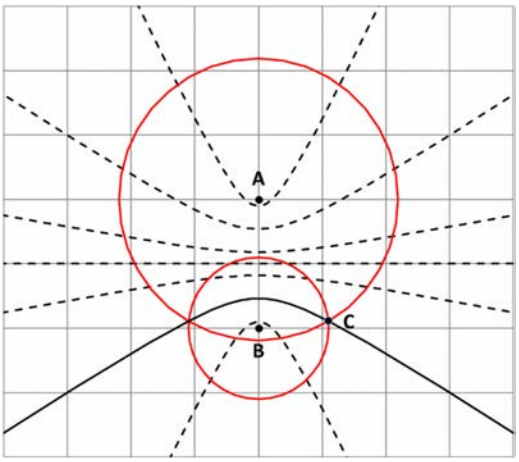

Figure 1 - PWC Two Node/Wavefront Activation

2. Multilayer PWC configurations

A multilayer PWC configuration[5] is an analog of the Multi-Layer Perceptron to perform classification of a set of inputs. It consists of an ensemble of PWC transponders (nodes) divided into a set of input nodes, representing pattern features, hidden nodes that combine subsets of the input features and output nodes to classify sets of features. The input nodes are defined to represent all features and values of the problem and are arranged such that three wavefront intersections for all possible triples of feature values will occur. Hidden nodes are then placed at the wavefront intersections for each feature value triple. Finally, output nodes are selected based on combinations of hidden nodes that cover sets or subsets of input feature values.

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