Real Time On-Chip Implementation of Dynamical Systems with Spiking Neurons

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***Abstract*— Simulation of large-scale networks of spiking neurons has become appealing for understanding the computational principles of the nervous system by producing models based on biological evidence. In particular, networks that can assume a variety of (dynamically) stable states have been proposed as the basis for different behavioural and cognitive functions.**

This work focuses on implementing the Neural Engineering Framework (NEF), a formal method for mapping attractor networks and control-theoretic algorithms to biologically plausible networks of spiking neurons, on the SpiNNaker system, a massive programmable parallel architecture oriented to the simulation of networks of spiking neurons. We describe how to encode and decode analog values to patterns of neural spikes directly on chip. These methods take advantage of the full programmability of the ARM968 cores constituting the processing base of a SpiNNaker node, and exploit the fast Network-on-chip for spike communication.

In this paper we focus on the fundamentals of representing, transforming and implementing dynamics in spiking networks. We show real time simulation results demonstrating the NEF principles and discuss advantages, precision and scalability. More generally, the present approach can be used to state and test hypotheses with large-scale spiking neural network models for a range of different cognitive functions and behaviours.

I. Introduction

Construction of large-scale spiking neural models is possible thanks to the emergence of unified approaches that are able to scale up seamlessly. These models can be simulated taking advantage of recent developments in computational infrastructure that can equally be scaled up. Some models aim to find emerging functions from the structural data known from biology. For example, quantitative descriptions of cortex based on anatomical data [4] can be used to model systems that naturally scale up [19], due to the regularity of the laminar organization of the thalamo-cortical system [35]. Other approaches can be considered more functional, where neural dynamics and quantities act as biological constraints in modelling specific cognitive functions [7]. Some functions can be modelled using attractor networks [1], networks that can represent information by settling to a (dynamically) stable state with their self-sustained, persistent activity. For example functions like memory can be associated to brain areas that are believed to use attractor representation such as the hippocampus [37].

Simulating large scale networks of biologically plausible neurons is a challenging task which require scalable computational and communication resources. Therefore simulations usually take place on supercomputers [2], general purpose hardware as FPGAs [24] or dedicated neuromorphic hardware [28] [36]; every approach has different scalability, programmability, precision and power consumption characteristics.

In this context we describe how to map the principles of the Neural Engineering Framework (NEF) [10], a unified approach for implementing complex neuro-dynamical systems and mapping control-theoretic algorithms with the neural connections between a highly heterogeneous population of spiking neurons, to the SpiNNaker System [13], a massively parallel programmable architecture oriented to the simulation of large scale models of spiking neural networks.

The paper describes the approach taken to encode and decode values directly on-chip, taking advantage of the programmability of the SpiNNaker system and exploiting the fast on-chip spike-based interconnect for communication between neural populations.

We show how a variety of networks can be built using encoding/decoding methods. In short, the approach presents the basis for testing large-scale neural models built with the NEF integrating SpiNNaker as the computational back-end in the existing framework and tools.

The rest of the paper is structured as follows: we introduce the Neural Engineering Framework and the SpiNNaker System in the first two sections. We then present the approach used to port the NEF on SpiNNaker, and present results obtained with the approach in sections IV and V respectively. Finally, discussion about how to expand the work and conclusions are drawn in the last two sections.

II. Neural Engineering Framework

The Neural Engineering Framework [10] describes how biologically relevant variables can be encoded and processed in the dynamic neural activity of recurrently connected networks. This approach can be used to introduce complex control theoretic models into spiking neural networks, including standard attractor network models [8]. The NEF is captured by three principles:

1) **Representation** in neurons is defined by the combination of nonlinear encoding (exemplified by neuron tuning curves) and weighted linear decoding.

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