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Design of Neuromorphic Cognitive Module based on Hierarchical Temporal Memory and demonstrated on Anomaly Detection

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Abstract

Our presented idea is to integrate artificial neural network (probably of BICA type) with a real biological network (ideally in the future with the human brain) in order to extend or enhance cognitive- and sensory- capabilities (e.g. by associating existing and artificial sensory inputs).

We propose to design such neuro-module using Hierarchical Temporal Memory (HTM) which is a biologically-inspired model of the mammalian neocortex. A complex task of contextual anomaly detection was chosen as our case-study, where we evaluate capabilities of a HTM module on a specifically designed synthetic dataset and propose improvements to the anomaly model.

HTM is framed within other common AI/ML approaches and we conclude that HTM is a plausible and useful model for designing a direct brain-extension module and draft a design of a neuromorphic interface for processing asynchronous inputs.

Outcome of this study is the practical evaluation of HTM's capabilities on the designed synthetic anomaly dataset, a review of problems of the HTM theory and the current implementation, extended with suggested interesting research direction for the future.

Keywords: hierarchical temporal memory, neuromorphic, cognitive module, anomaly detection, BCI, human enhancement

1 Introduction

1.1 Motivation

The conceptual idea of the presented paper is to use an Artificial Neural Network (ANN) as a component/"extension" module in Brain-Computer Interface (BCI) experiments where we wish to integrate an artificial and biological neural network into a single system. Purpose of the artificial module is to provide a novel or improved functionality.

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1.2 Hierarchical Temporal Memory

Hierarchical Temporal Memory (HTM) is a machine learning technique inspired closely by the structural and algorithmic properties of the mammalian neocortex. The observation is that most of the high level cognitive tasks – vision, motor movements, planning or even language processing are performed by the neocortex and, on the contrary to the wide functionality span, all parts of the neocortex exhibit a remarkably uniform neural structure [12], [3], [10]; i.e. organization into vertical columns and horizontal layers with neurons (cells) grouped into (micro)columns[1].

HTM is a memory-based learning system which performs unsupervised on-line learning and continuous predictions; where the role of time is implicit [2] and allows for contextual Anomaly Detection (AD). More details are explained in the section 2.

1.3 Hypothesis

- Is the model *biologically plausible* and exposes sufficient details? We evaluate HTM as the candidate model.
- The model has to provide an extended functionality - *cognitive enhancement*.[3]

2 Materials & Methods

In order to evaluate suitability of the HTM theory for a direct brain-functionality emulation, an as detailed as possible evaluation of the biological plausibility, its limitations, and a practical speed/quality performance of the model is required. In this section, HTM is framed in context with other Machine learning (ML) approaches.

2.1 Comparison of "biological" ML models to HTM

For use-case of this paper, the main focus is on biological models and deep learning.

2.1.1 "Deep" neural networks

Deep Neural Network (DNN) architectures, which gained enermous popularity in recent years, would be the most similar system to HTM, due to the fact that both rely on hierarchies for emergence of stable and more abstract features.

The DNN implementations typically have superior performance optimizations (e.g. GPGPU), as processing "big data" is what gives deep learning its popularity. On the other hand, HTM implementation called Numenta Platform for Intelligent Computing (NuPIC) does not come near the raw speeds of deep learning, but as the model of neurons is much more advanced, HTM requires comparatively smaller number of samples and neurons to successfully learn from data[9], making it effectively fast.

[1] To avoid possible misunderstandings, a cortical "column" in HTM consists of tens of cells, therefore refers to a biological microcolumn. Such column is a main computational unit in HTM (as a neuron in "classical" artificial networks), thus a region consists of columns.

[2] expressed by sequential order, i.e. all inputs are time-series. Typical example in human brains are neural *spike-trains*.

[3] The ANN has to be "useful". Anomaly detection is chosen as the benchmarked task.