Real-Time Implementation of a Retinal Model

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Abstract

Vision systems in biological entities are one of the most complex sensory inputs in nature. If we want to simulate them, it would require incredible amounts of computing power and, traditionally, several algorithms to perform each individual task. A parallel computation platform is the best way to go while attempting to solve this problem, since neural structures in the brain compute in this way.

SpiNNaker is one of such platforms, a network of low-powered processing units, each of which can simulate several neurons. Given that the SpiNNaker platform resembles this natural neural structures, computer vision algorithms need to be developed in a completely different manner.

The aim of this project is to develop algorithms in the realm of computer vision but using a spiking neural networks approach. In particular we'll study time-based spike codes and how to process them. This algorithms should be able to cooperate and share their interpretation of the input data to gain a more robust understanding of images.

1. Introduction

In recent years neuromorphic (i.e. one that mimics the brain) hardware has risen attention as a different way of computing. One key aspect is the high parallelism found in the infrastructure of the brain. Platforms such as *SpiNNaker* [6] emulate such parallelism; furthermore it does so while maintaining low power consumption. The *SpiNNaker* platform can also give neural simulations the flexibility of software models and keep them running in biological real-time.

Converting conventional images or video into spike based representation is a must-do step for further studies, in section 4 we report on the work done so far towards this goal. From this data we'll develop learning and classification algorithms. Furthermore this algorithms may lead to an implementation of vision tasks such as registration or optical flow.

2. Research Aims and Contribution

This research aims to develop computer vision algorithms using SpiNNaker. This is to be achieved by modelling biological vision, using spiking neural networks, on SpiNNaker. Several stages of vision would need modelling and/or implementation, the latter has been the goal for this year's work. We hypothesize that a better understanding of vision in biology will lead to a unified computer vision framework. Using neural networks should translate in gaining an insight to the meaning of elements in a scene and, thus, a relation between different images of the same scenario.

Bio-inspired vision algorithms using SpiNNaker hardware could be used on robotics, security or transportation applications. The research on learning and classification could lead into a theory of learning and memory in the brain.

3. Previous Work

In order to process visual input from frame based imaging devices on a spiking neural network (SNN) a transformation is needed. The most common way is to simply encode using Poisson spiking with a

rate that is proportional to pixel intensity. This is not entirely accurate as cells in the retina react to changes in intensity[2]. One of the most accurate retinal models was developed by Wohrer and Kornprobst in [9]. A special category is hardware based bio-inspired retinas. First reported on [5]. New devices have been developed and reported in [3, 4], this are splendid real-time, low-powered, high-dynamic-range event-based cameras; though they have limited availability.

4. Project Progress to Date

The literature review is about 60%, though further reading might prove that this number might change. Our objective this year is to generate a video-to-spike train encoder. For this, the first approach was to use a biologically plausible functional model [7] that results in images being transformed into rank-ordered spikes [8].

The retina is a thin layer of neural cells located in the eye, it is responsable for the sensing, processing and transmissiting visual input[2]. At its deepest layer, the retina has a millions of cells known as photoreceptors, they are in charge of transforming light into electrical signals. After this step there are, mainly, three layers of neurons that perform different computations such as lateral inhibition or on/off centre-off/on surround behaviour[1]. A small area at the centre of the retina has very few obstacles to obtain light and has high resolution, this area is known as the *foveal pit*.

This algorithm models the foveal pit, first we perform a two-dimensional *convolution* of the current frame with four different *kernels* which represent four types of ganglion cells. After this step, a correction is needed due to redundancy of information in the convolved images. This last step is carried in the retina via lateral inhibition prior to any ganglion cell activity. This project is near completion and we can encode video at 12 frames-per-second, though we believe some coding optimizations could lead to an increase in performance.

A second way of encoding is to simulate the early stages of the retina, which sense changes in intensity on the photoreceptors. This is quite similar to what DVS do [3, 4], but with limited dynamic range and lower temporal resolution. The main advantage is that no specialized hardware is needed and the operation is so fast that any recent computer should be able to do it. For this type of encoding procedure we hypothesize that the bigger the change, the sooner a cell would spike and, thus, we can obtain a spike timings given the difference of two video frames. This project is also on its final stages, though more testing is required.

5. Thesis Outline

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- **Chapter 1**. Introduction.
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- **Chapter 3**. Methodology.
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  - Hierarchical networks for robust classification.
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- **Chapter 4**. Results.
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- **Chapter 5**. Conclusions and Further Work.
  - Conclusions.
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6. Conclusions and further work

We obtained further knowledge about the anatomy of the eye from both a detailed and a functional approach. We also have come to appreciate the importance of inhibition circuits to enable high-efficiency, low-redundancy computing in the brain and how this brings robustness to neural structure.

Real-time spike encoding, although with low temporal resolution, is achievable with common GPU and the right combination of mathematics and engineering. Memory reads and writes in a GPU are extremely important, it is one of the biggest bottlenecks of the presented algorithms.

We propose timing mechanisms to emit spikes from a rank-ordered source. Possible solutions for a faster mutual inhibition algorithm might be to do it in-line as we send spikes to neuromorphic hardware; or let the neural simulation deal with mutual inhibition.

To reduce the power consumption/hardware requirements for mobile applications the best way to go might be change the resolution so not all image is perceived in high resolution.

7. Publications

Part of the work carried during this year will be published as a paper on a **Frontiers in Neuroscience** journal special issue *Benchmarks and Challenges for Neuromorphic Engineering*. The article will present the MNIST database encoded using different types of spike codes and propose it as a standard way of testing learning and recognition tasks.

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A. Project Plan