Multisensory Integration in the HBP Neurorobotics Platform

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Abstract—Analyzing and validating neural models of multisensory integration has so far been limited to static datasets or required custom simulations. Based on a probabilistic population code model, we illustrate how this process can be drastically simplified with the Neurorobotics Platform, a cloud-based simulation environment for connecting virtual robots to neural networks that is developed in the Human Brain Project.

Keywords—Multisensory Integration, Sensor Data Fusion, Neurorobotics, Probabilistic Population Codes, Spiking Neural Networks

1 Introduction

The consistent and robust integration of stimuli from different sensory modalities is a key feature of the human brain and an important research question in both neuroscience and engineering. A comprehensive neural model of multisensory integration will not only contribute to a better understanding of the brain but also enable the development of enhanced sensor data fusion methods for applications such as robotics or autonomous driving. With neuromorphic processor architectures becoming more and more widespread and mature, the design of capable neural models will gain even more importance.

It is already known from behavioral experimental studies that the human brain can integrate information from different modalities in a statistically optimal fashion [1] and there is a wealth of literature with different computational and neural models for multisensory integration. However, the systematic analysis and validation of these models under realistic conditions is still an open challenge. Often, it is limited to simple artificially generated stimuli, which are substantially different from sensory input streams in real-word environments that span across multiple correlated modalities and that generate constantly changing input in response to actions and events.

In this paper, we describe a novel approach to analyzing and validating neural models of multisensory integration that is based on the HBP Neurorobotics Platform (NRP), an open source cloud-based simulation environment that enables closed-loop control of virtual robots by simulated neural networks [2]. The NRP includes a comprehensive environment simulation and editors for defining virtual experiments that enable the study neural models under realistic conditions. Data generated in the simulation is naturally correlated and therefore very well suited for studying multisensory integration and, more generally, data fusion. The remainder of this paper is organized as follows: Section 2 provides an overview of the NRP. Section 3 briefly describes a neural model that will be the basis of the neurorobotics experiment for studying multisensory integration discussed in section 4. Finally, section 5 concludes the paper with an outlook to future work.

2 The HBP Neurorobotics Platform

The NRP is based on a state-of-the-art robot simulator with realistic 3D rendering and physics simulation. At its core is the *transfer function framework* that connects the robot model to a spiking neural network simulation running in NEST [3]. Transfer functions specify which sensors and actuators are mapped to which neurons in the neural network and how data is converted from and to spikes.

Users can interact with the NRP via a web-based frontend that covers the complete workflow from the design to the execution of a *neurorobotics experiment*. This workflow starts with the choice of a robot model and the specification of the details of the environment model. After providing the code for the brain model, i.e. the neural network that will be simulated by NEST, the final step is to connect robot and brain by implementing the required transfer functions. All models and functions are programmed in Python. Optionally, the experiment can also include a state machine for defining specific experimental protocols (e.g. time-triggered activation of stimuli). When running the experiment, the backend synchronizes the robot simulation with the neural simulation and exchanges data as specified in the transfer functions.

Since NEST is mainly used in computational neuroscience, the NRP additionally supports Google TensorFlow for machine learning applications. It also contains a *Virtual Coach* that automatically executes series of experiments for tasks such as parameter optimization. Moreover, a *Robot Designer* enables the creation of new robot models. In particular, it supports modeling and simulating muscles, which is especially relevant for experiments with brain models that were designed with a focus on high biological realism.

3 Probabilistic Population Codes

To investigate multisensory integration in the NRP, we implemented a simple neural model for integrating two sensory modalities based on probabilistic population codes (PPCs) [4]. A PPC model is comprised of one or more populations of neurons. The response of each neuron in a population to a stimulus is described by a tuning curve. In the following, we will assume

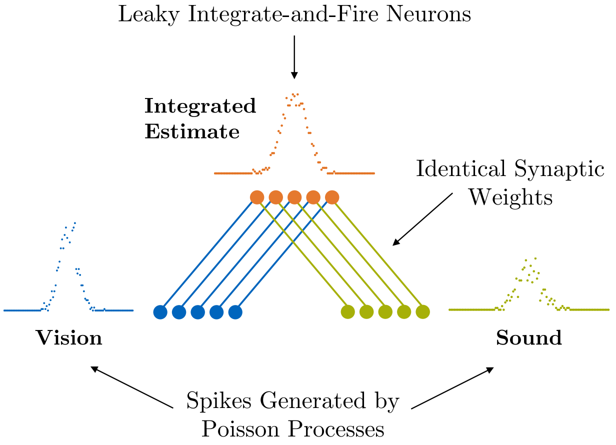

Figure 1: Network architecture of the probabilistic population code model for two sensory modalities.

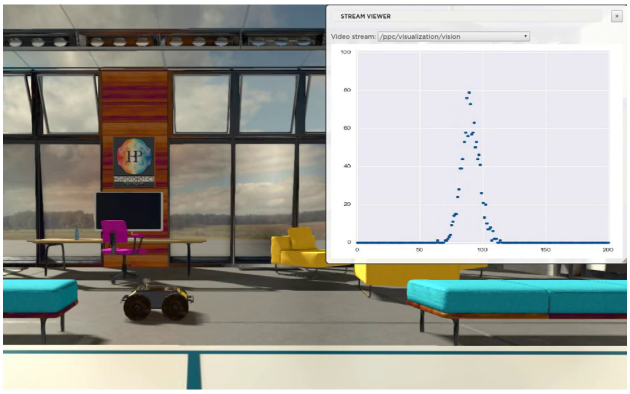

Figure 2: Visualization of the running experiment in the web-based simulation viewer of the NRP. The PPC encoding of the current vision-based position estimate is plotted live in the top right corner.

that the activities of all neurons are described by independent Poisson processes. For a given summed population activity $\mathbf{r_s}$, the resulting probability distribution $p\left(s|\mathbf{r_s}\right)$ for a stimulus s converges to a Gaussian as the number of neurons increases. If all populations in a model have equal size and corresponding neurons from different populations have identical tuning curves, it turns out that computing the optimal Bayesian inference $p\left(s|c_1,c_2\right) \propto p\left(c_1|s\right)p\left(c_2|s\right)p\left(s\right)$ for a stimulus s from two cues c_1 and c_2 is equivalent to computing the sum of the two population activities $\mathbf{r_1}$ and $\mathbf{r_2}$, i.e. $\mathbf{r_s} = \mathbf{r_1} + \mathbf{r_2}$ [4].

The process described above is illustrated in Figure 1. The lower part depicts two populations with position estimates for an object based on a visual and an auditory cue. The horizontal axis of the distributions indicates the neuron ID while the vertical axis indicates the activity level or gain. Larger gains encode higher confidence. The receptive fields of the individual neurons are modeled with Gaussian functions. Projections from the two input populations to a third population for the combined estimate correspond to the summation of population activities according to the description above.

4 Simulation of PPCs in the NRP

We designed an experiment in the NRP to evaluate the model from the last section in a dynamic environment. The overall setup is depicted in Figure 2. A mobile robot is moving back and forth on a straight line. Information about its current position along that line is provided by a camera and a stereo microphone. As long as the robot is fully visible, the confidence of the visual localization is maximum. However, as soon as it is occluded by one of the benches, the confidence decreases and the integrated estimate is dominated by the sound-based localization. Distortions of the sound signal caused by occlusions are neglected.

The neural model from Figure 1 is implemented in NEST. To ensure sufficient activation of the population that encodes the integrated estimate, every receptive field of the input populations is represented by sub-populations of fixed size. Synaptic weights were adjusted to ensure that resulting population activity for the integrated estimate stays within functionally useful bounds. The current location of the robot is provided as ground truth by the robot simulation. It is used to compute receptive field activations and to determine if the robot is currently occluded. When an occlusion is detected, the gain of the population for the vision-based location estimate is adjusted accordingly.

5 Conclusion

We have presented an experimental setup for multisensory integration in the Neurorobotics Platform. While this work is a somewhat simplistic proof of concept, it does demonstrate the potential usefulness of the NRP for studying the functionality of neural systems, as the platform enables analyzing embodied models under realistic conditions with adequate correlations between sensory streams. Future work should include models for visual and auditory localization in order to be able to compute estimates from sensor data instead of accessing internal ground truth information from the simulator. Another interesting line of investigation is to use the integrated estimate for controlling another robot, which will allow analyzing the system in a closed action-perception loop.

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