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Towards the Visualization of Spiking Neurons in Virtual Reality

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Abstract. This paper presents a prototype that addresses the visualization of the microscopic activity structure in the mammalian brain. Our approach displays the spiking behaviour of neurons in multiple layers based on large-scale simulations of the cortical microcircuit. We will apply this visualization to the activity of brain-scale simulations by coupling the microscopic structure with the macroscopic level. Thereby, we hope to convey an intuitive understanding of the concise interaction and the activity flow of pairs of distant brain areas.

Keywords. Spiking neurons, virtual reality, data visualization

1. Introduction

The relationship between structure and function of the human brain is still not understood completely. On the microscopic level the information processing units are neurons that communicate by means of electrical pulses (so-called spikes). A single neuron integrates the information of around 10,000 other neurons, partly located within the local micro-circuit and partly from multiple distant areas. Large-scale simulations link the structure of cortical networks to the neuronal activity. However, the complexity of these networks forms an obstacle for the visualization of the simulated data.

Previous approaches on the visualization of spiking neuronal network simulations focus on single-scale networks [1]. Neuronal network simulations, however, are currently making a qualitative leap to focus on the multi-scale nature of the brain [2]. Here, we present our approach to accompany these developments with appropriate visualization tools that capture the activity of brain-scale simulations.

2. Method

In a first step, we address the visualization of a layered cortical network model that represents the local microcircuit below 1 mm^2 of cortical surface [3]. The model includes

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eight cell types, four excitatory and four inhibitory, distributed in the cortical layers 2/3, 4, 5 and 6. Overall, the model consists of 80,000 neurons and 0.3 billion synapses. Based on the cell-type specific connectivity, the spontaneous and evoked activity of the model reflects *in vivo* recordings. In a second step, we extend our considerations to multi-scale networks that consist of multiple microcircuits, each representing a cortical area, with in total several million neurons.

2.1. Requirements

For an interactive visualization of multi-scale spiking neuronal networks we formulate three conceptual requirements. (1) The visualization must reflect the neuronal activity, including e.g. the membrane potential and spike events of the neurons over time. (2) The system should allow to adjust the level of detail ranging from the representation of a single cell up to the whole neuronal population. (3) The visualization should convey the influence of the macroscopic communication (between different brain areas) on the interaction at a microscopic level (between individual neurons).

2.2. Initial Approach

Excitatory cells are represented as pyramids and inhibitory cells as spheres (Figure 1 left) to distinguish both neuron types from each other. The layers are outlined and an alternate coloring scheme is used for neurons in consecutive layers (Figure 1). Over time spiking neurons are highlighted and a global overview is provided by activating different layout types (Figure 2). Our system is built on top of a virtual reality application in order to provide direct interaction metaphors and increase the depth perception (Figure 3). See [4].

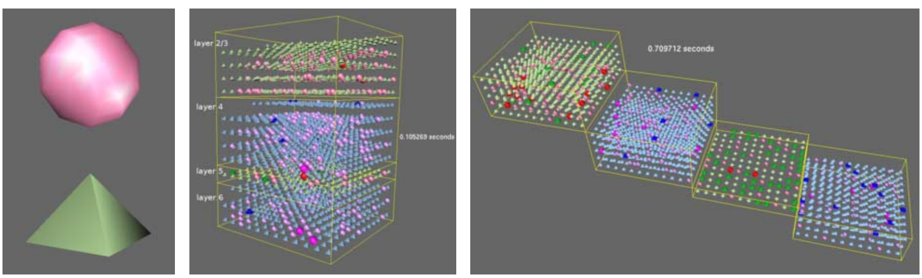

Figure 1. Left: Inhibitory (sphere) and excitatory cell (pyramid). Middle: Layers are organized above each other. Right: Layers are fanned out.

2.3. Extensions

Future extensions integrate statistical information, such as the population firing rates, the irregularity and synchrony of the activity and the cross correlation patterns, to quantify the spiking behavior of the different cell types. Additionally, we visualize connections between firing neurons to understand the propagation of the electric impulses. For the overall pattern of spiking neurons it would be necessary to visualize a larger amount of cells thereby concentrating on the membrane potential.

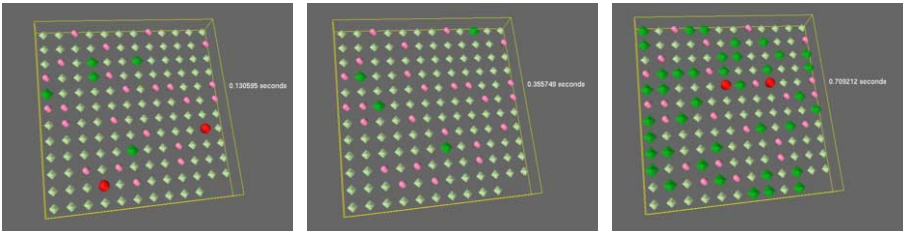

Figure 2. Spiking behavior in layer 5 over time. Spiking neurons are drawn larger and in a more intense color.

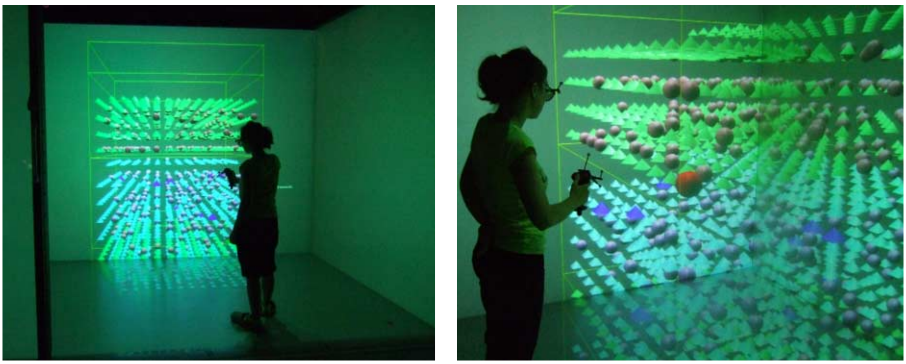

Figure 3. Visualization in the CAVE virtual environment.

Our approach unfolds its potential when we combine the visualization with the activity of multi-scale simulations where an intuitive understanding of the activity patterns is hard to accomplish. Therefore, we couple a macroscopic visualization to the microscopic one. The user may choose pairs of areas for a detailed visualization to shed light on the concise interaction and the activity flow.

3. Conclusion

Our interactive visualization of brain-scale neuronal networks does not only provide a measure to cope with the increasing amout of neuron simulation data but furthermore enables the development of an intuitive understanding of the spiking pattern of neurons.

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