Exploring Spatial Cell Dynamics in Spiking Neural Networks Trained on a Navigation Task

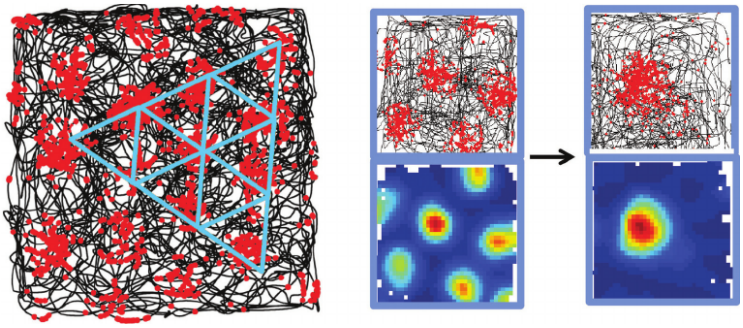

Fig. 1: **Left:** The spikes of a grid cell (red) shown on top of the path (black) that the animal took. They form a hexagonal grid pattern. **Right:** The reponse of a grid cell (left) compared with that of a place cell (right). The bottom images show the firing fields of the respective cells. (Taken from [1])

Background

In the past decades, multiple types of spatially tuned cells have been identified in mammals, such as place cells [2], grid cells [3] or head direction cells [4]. While the specific tuning and activation of individual neurons has been studied quite well, there is still a knowledge gap with regards to the emergence and systemic functionality of these neurons.

One possible way to study positional encoding is by simulating artificial neural network (ANN) models of spatial cells. While numerous models for e.g. grid cells exist [5], [6], they are all manually crafted and hence include a significant bias - with regards to the task and network structure. Recently, some approaches focused on learning grid cells intrinsically with a deep neural network (DNN) trained on a navigation task, such as path integration [7], [8]. Although this successfully demonstrated that grid cells can be helpful in solving navigation tasks, they are not a necessity [9]. It is therefore still unclear how these neurons interact, which structure the networks have and what exact task they are solving.

In order for these spatial cells to constitute an actual benefit for biologically inspired navigation solutions for mobile robots, we need to answer these questions. Within this project we therefore want to explore this paradigm with spiking neural networks (SNNs). These networks work similarly to DNNs but information between neurons is passed by asynchronous, binary spikes instead of floating point numbers. SNNs could reveal new insights into the systemic functionality of spatial cells through their temporal dynamics. To investigate that, we would like to evaluate, whether known spatial patterns occur at all in SNNs and what computational principal is behind an optimal space representation with SNNs.

Task Description

Throughout this project you will be working with an existing evolutionary optimization framework for SNNs from our neuromorphic computing group [10]. You will use this framework to generate grid or place like responses of intermediate neurons in a network of spiking neurons by optimizing the network for a spatial navigation task of your choice. You will then evaluate the result of the optimization and compare it to related approaches based on deep learning.

During this project you will be

- performing a literature research on grid cell models and DNNs for generating them,
- designing suitable spatial navigation experiments for virtual agents,
- optimizing and simulating the agent during the task,
- possibly extending the framework as needed,
- evaluating, analyzing and comparing your results as well as documenting your work.

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Research project:
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Type:
Bachelor Thesis, Guided Research

Research area:
Grid Cells, Spiking Neural Networks, Evolutionary Optimization, Localization, Navigation

Programming language:
Python

Required skills:
Python, (Evolutionary) Optimization, Localization/Navigation

Language:
Englisch/German

Date of submission:
24. November 2022

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Requirements

For a successful completion of the project you should have

- programming experience in Python or C++,
- a background in Artificial Intelligence (Machine/Deep Learning),
- some knowledge in mobile robot localization, mapping and navigation.

Ideally you already know what SNNs are and have some experience with libraries/simulators like Brian, Nest, Nengo or PyNN.

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