Abstract

The hippocampus has a crucial role in memory formation. Furthermore, it has a remarkable anatomical structure and based on physiological properties it can be divided into in the Cornu Ammonis (CA) regions CA1, CA2 and CA3, and the dentate gyrus (DG). In the last decades a standard model regarding the function of the hippocampus in memory formation has been established and tested computationally. It has been argued that the CA3 region works as an auto-associative memory and that its recurrent fibers are the actual storing place of the memories. Furthermore, to work properly CA3 requires memory patterns that are mutually uncorrelated. It has been suggested that the DG orthogonalizes the patterns before storage, a process known as pattern separation. In this thesis we review the model when random input patterns are presented for storage and investigate whether it is capable of storing patterns of more realistic entorhinal grid cell input. Surprisingly, we find that an auto-associative CA3 network is redundant for random inputs up to moderate noise levels and is only beneficial at high noise levels. When grid cell input is presented, auto-association is even harmful for memory performance at all levels. Furthermore, we find that Hebbian learning in the dentate gyrus does not support its function as a pattern separator. These findings challenge the standard framework.

We suggest the alternative view where a simpler EC-CA1-EC model is
sufficient for memory storage. We find that given biological plausible input this network outperforms the standard model in pattern completion despite its simplicity.

Furthermore, cells in the hippocampus and its input structure, the medial entorhinal cortex (MEC) are highly spatially selective. While grid cells in the MEC have multiple, regularly arranged firing fields, place cells in the CA regions mostly have single spatial firing fields. In this thesis, we investigate the formation of spatial representation in the hippocampus. Since there are extensive projections from MEC to the CA regions, many models have suggested that a feedforward network can transform grid cell into robust place cell firing, however experimental evidence is ambiguous. Here we point out that all current models suffer from another issue that has received little attention so far: unrealistically small place field sizes compared to those in experiments.

In the present work we use a general feedforward model and machine learning algorithms to show that it is implausible that a purely feedforward network can generate realistically sized place fields based on grid cell input alone because of the grid cells’ structured autocorrelation. These results suggest that additional mechanisms are needed for the formation of place cells. We propose that weakly spatially modulated cells, which are abundant throughout EC, provide input to downstream place cells along with grid cells. We test this hypothesis on the EC-CA1-EC model. We find that despite their lack of spatial information and temporal stability weakly spatially modulated cells are able to reproduce robust place cells with realistic field sizes. Moreover, lesion studies in the model reproduce not only many puzzling experimental findings, but also make some strong and testable predictions. These results provide strong support for our hypothesis.
To conclude, with the help of a computational model that accounts for both, hippocampal memory function as well as the formation of spatial representations in the hippocampus we challenge current opinions in the hippocampal research field and provide alternative and testable suggestions.