Grid cells: Oscillations and boundaries

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Grid cells in the medial entorhinal cortex fire at a regularly spaced hexagonal pattern throughout an animal's environment. They are considered essential for coding tasks and spatial navigation. Yet, the mechanistic origin of grid fields remains unresolved. Feed-forward models rely on a spatial weight update rule with Mexican-hat shape: Weights from strongly overlapping place cells get potentiated, weights from place cells with little overlap get depressed. We propose the Mexican-hat shape to be already encoded in the input population of hippocampal place cells, and not in the synaptic learning rule.

We support this claim by considering the precise spike-timing relationship of place cells, which are strongly modulated by the underlying theta rhythm (consistent with phase precession). In summary, and supported by CA1 open field recordings, place cells with high overlap are seen to be positively correlated, in the sense that their pair-wise cross-correlation presents a positive phase in the theta range. In contrast, cells with little overlap exhibit a negative correlation phase. Under Hebbian learning, this effect translates into an effective Mexican-hat relationship inducing the formation of grid fields.

Our model is set apart in that it uniquely relates a classical Turing instability to the underlying theta rhythm strongly modulating place cell activity. As a result, we show that most experimental links between theta oscillations and grid cells' properties are explained within the model, a unique feature within the feed-forward and continuous attractor models of grid cell activity.

In addition, we show how observed boundary effects and population properties are the result of MEC's internal inhibitory connectivity. The reported alignment of the pattern in polarized environmental geometries comes out naturally in the model, as well as the distortions observed in less symmetric enclosures.

All of our results are derived analytically within a neural field theory framework building up from the work discussed as a talk in last years' ICMNS conference.