Accurate position estimation in grid cells through continuous corrections

Erdi Kararmaz[1,2], Sven Krausse[1,2], Emre Neftci[1,2], Johannes Leugering[1], Alpha Renner[1]

[1] Forschungszentrum Jülich, [2] RWTH Aachen University

Grid cells in the mammalian brain encode one's position in the world, serving as a fundamental component of spatial navigation. Within a given environment, these representations remain stable over long periods. Typically, grid cells are assumed to function as a movement integrator, keeping track of an animal's position [1]; however, noisy integration inevitably leads to the accumulation of error [2]. Therefore, maintaining an accurate grid code requires either the integration of a highly precise internal movement signal or the utilization of external corrections generated from sensory modalities.

Previous studies investigating the accuracy of the movement signal in the medial entorhinal cortex (MEC) have shown that the directional signal is tuned more strongly to the animal's head direction (HD) than its movement direction (MD) [4]. Using a recently available dataset [3] alongside our own refined statistical analyses, we validated these findings (Fig 1.a). Our results confirm that the movement signal present in MEC is not particularly precise and systematically biased towards the animal's HD. Thus, an external mechanism is needed to explain the accurate position tracking observed in grid cells.

This strong HD tuning provides a framework to test the nature of this external correction. If the grid cell code were corrected only weakly, or sporadically at specific events, then we should observe a systematic decoding error in the integrated grid-cell state when HD and MD are not aligned. A statistical analysis of this hypothesis showed no significant evidence of such an effect (Fig 1.b).

Our findings indicate that grid cells are continuously and strongly anchored to the external environment to produce a stable and accurate position estimation. We hypothesize that in addition to well-established border-cell anchoring, which would only account for sporadic anchoring events, there is continuous environmental information serving as a dynamic anchor for the grid cell population. This information may be provided by object-vector cells in the MEC and continuous feedback from place cells in the hippocampus.

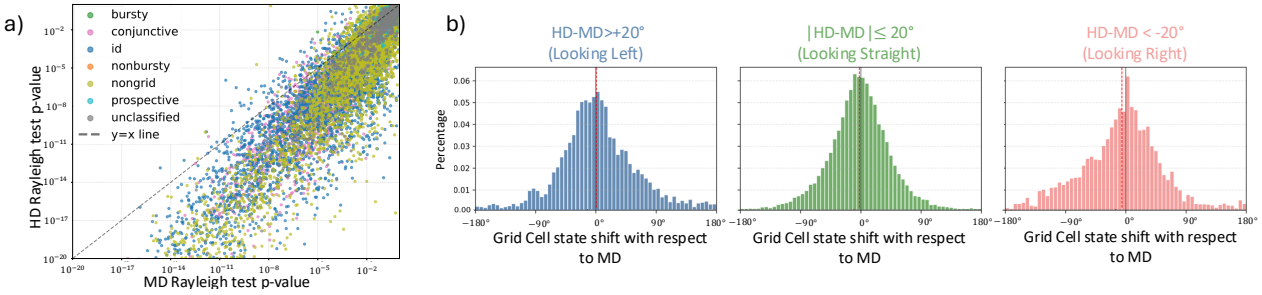

Figure 1: (a) Comparison of Rayleigh test p-values for Head Direction (HD) versus Movement Direction (MD) tuning across recorded cells. (b) Distributions of the angular difference between the decoded Grid Cell (GC) trajectory and the true MD, partitioned into three conditions based on the animal's looking behavior. Across all, the distributions remain centered at zero, demonstrating a lack of systematic bias towards HD.

[1] McNaughton, B. et al., Nat Rev Neurosci, 7, 663–678, 2006

[2] Burak Y, Fiete IR, PLoS Comput Biol, 5(2), e1000291, 2009.

[3] Vollan, A.Z. et al., Nature, 639, 995–1005, 2025

[4] Raudies, Florian et al., Brain Res., 1621, 355–367, 2015