Spatial scale, field stability and dorsoventral organization in a model of grid cells and place cells

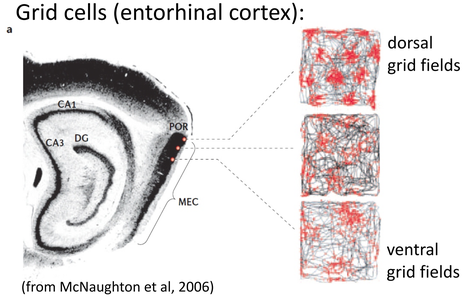
David Lyttle[1], Brian Gereke[2,3], Kevin Lin[1,2] and Jean-Marc Fellous[1,3]

1 Program in Applied Mathematics, University of Arizona, Tucson AZ - **2** Department of Mathematics, University of Arizona, Tucson AZ - **3** Department of Psychology, University of Arizona, Tucson AZ

Background

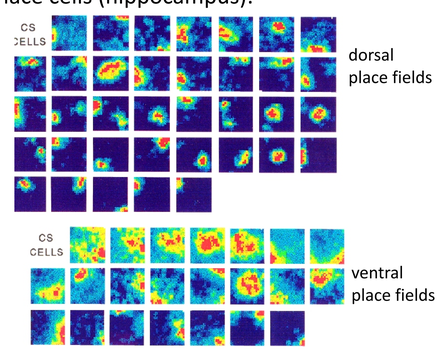
- Entorhinal grid cells and hippocampal place cells have spatially-specific firing patterns, and serve as an important source of experimental data on spatial cognition in rodents
- Both have firing fields that increase in scale along the dorsoventral axes of entorhinal cortex and hippocampus:

Grid cells (entorhinal cortex):



(from McNaughton et al, 2006)

Place cells (hippocampus):



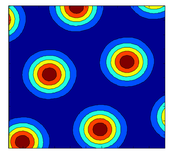
(from Jung, 1994)

Overview & Goals

- Model network contains grid cells, place cells, and nonspatial inputs to place cells
- Goal: determine the relative effects of grid cells and nonspatial inputs on place field properties
- Also assess the effects of grid cell firing rate variability on place fields

Model

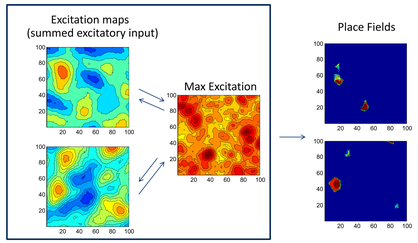
Grid Cells:



$$G(r,\lambda,\theta,c) = g\left(\sum_{k=1}^{3} \cos\left(\frac{4\pi}{\sqrt{3}\lambda} u(\theta_k+\theta)\cdot(r-c)\right)\right)$$

Parameters:
λ = grid scale (30cm – 1m)
θ = grid orientation
c = phase

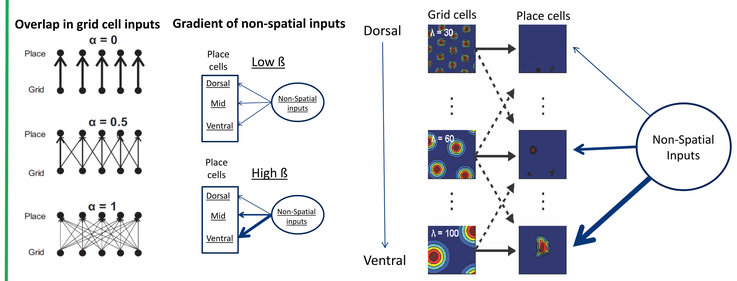
Place Cells:



$$R_i(x,y) = \left[E_i(x,y) - 0.9\, max_j(E_j(x,y))\right]_+$$

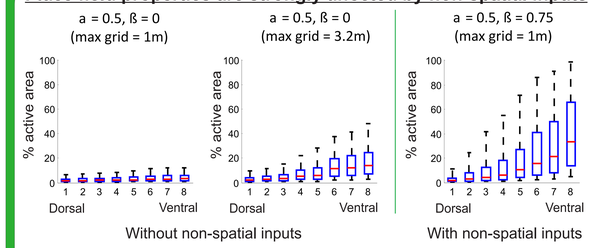
(De Almeida, 2009)

Modularity and Network Structure:

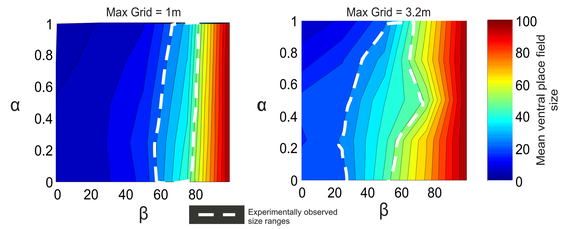


Results

Place field properties are strongly affected by non-spatial inputs



Effect of network parameters on ventral place field size



Model variants - Place field size affected by different mechanisms

Original Model:

$$I_{i,m}(r) = \sum_{j=1}^{N_{grid}} W_{ij}G_j(r) + \sum_{k=1}^{N_{nonspat,m}} W_{ik}B_k$$

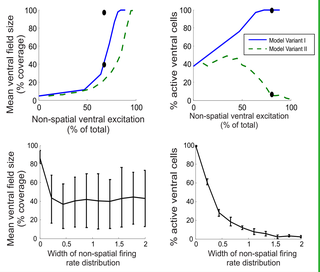
Model Variant I:

$$I_{i,m}(r) = \sum_{j=1}^{N_{grid}} W_{ij}G_j(r) + C_m$$

Model Variant II:

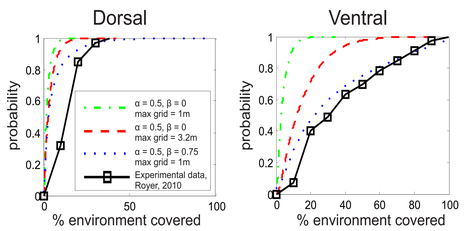
$$I_{i,m}(r) = (1-A_m)\sum_{j=1}^{N_{grid}} W_{ij}G_j(r) + A_m \sum_{k=1}^{N_{nonspat}} W_{ik}B_k$$

$$\left(\sum_{j=1}^{N_{grid}} W_{ij}G_j(r)\right) \approx \left(\sum_{k=1}^{N_{nonspat}} W_{ik}B_k\right)$$



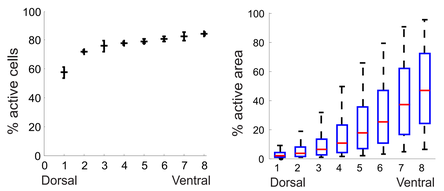
Comparison with experimental data

Place field size distributions



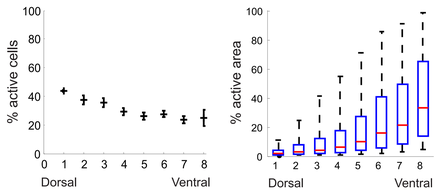
Number of active place cells controlled by nonspatial variance

Low variance in nonspatial inputs



Low non-spatial variance = more active cells

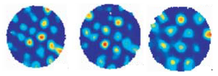
High variance in nonspatial inputs



High spatial variance = fewer active cells

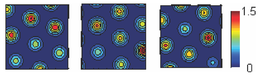
Effects of grid node firing rate variability

Experimental:

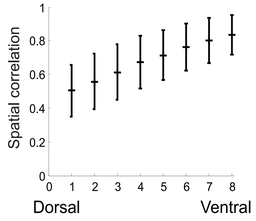


(Hafting 2005)

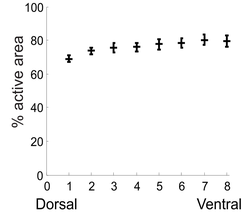
Simulated:



Spatial correlation between original and remapped environments



Mean % of active cells with place fields in both environments



Conclusions

- Gradient in place field size better explained by a change in ratio of spatial to non-spatial inputs
- Possible dorsal/ventral functional differences?
- Non-spatial inputs affect place field size via two distinct mechanisms (increased overall excitation vs. variability in the non-spatial drive). These have different effects on number of active cells
- Variance in non-spatial inputs affects proportion of active cells
- Locations/firing rates of place cells sensitive to fluctuations in firing rates at individual grid nodes
- Model predicts that place field size correlates with amount of non-spatial excitatory inputs

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Acknowledgements

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