The brain's map of space: A new discovery about how our brains represent information

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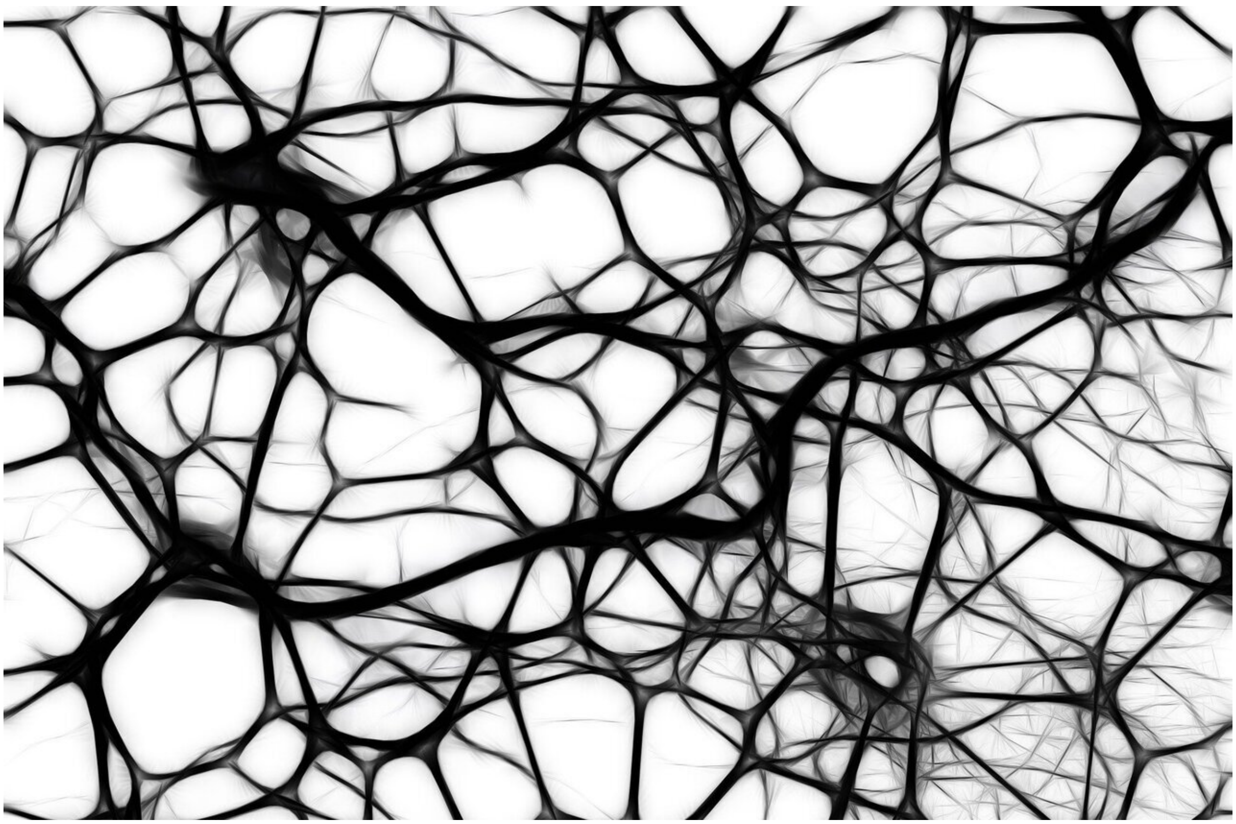

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A new study led by Prof. Yoram Burak of the Edmond and Lily Safra Center for Brain Sciences and the Racah Institute of Physics at the Hebrew University of Jerusalem unveils a unifying mathematical framework to explain how "place cells" in the hippocampus encode spatial information across diverse species and environments.

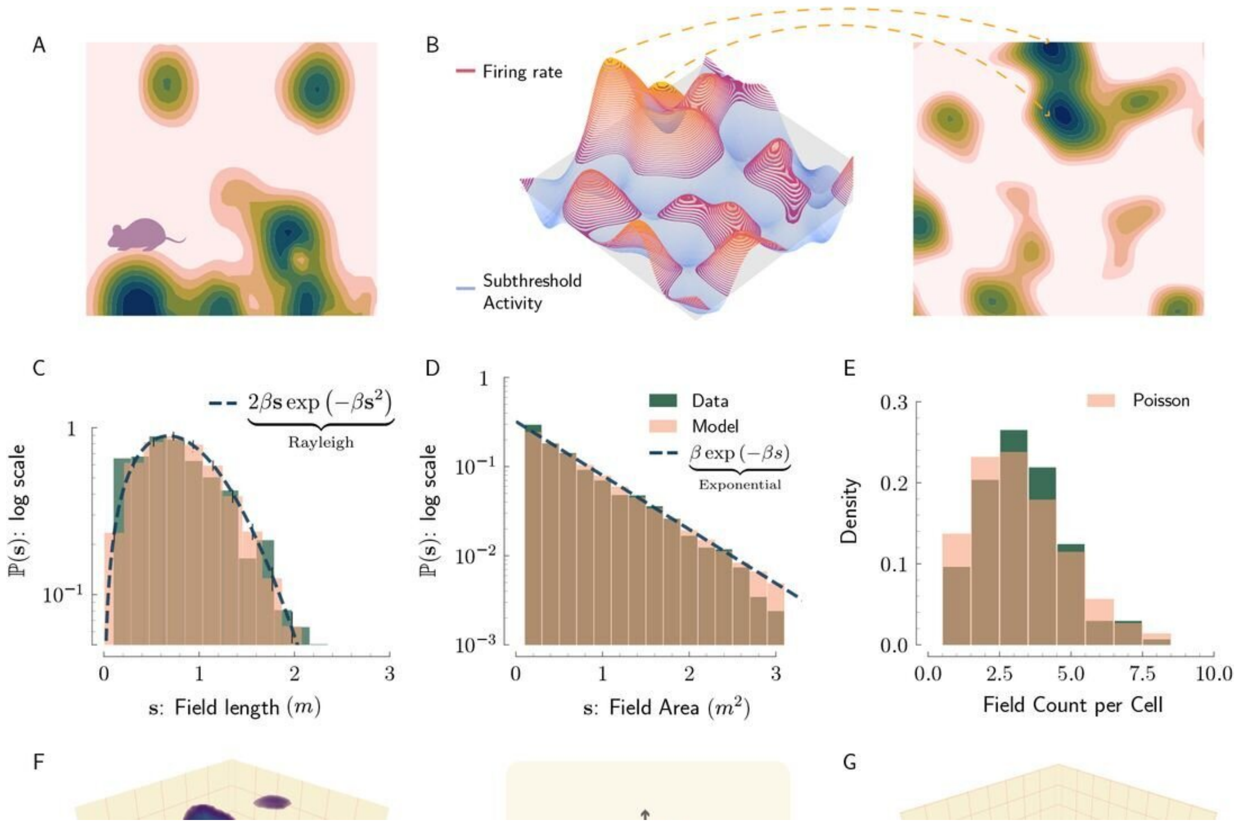
The study is published in the journal *Neuron*.

Place cells are specialized neurons in the hippocampus that help animals navigate by creating firing patterns that encode locations within the animals' surroundings. Traditionally, these cells were thought to fire in single, compact regions of space with a stereotypical symmetric shape.

However, recent research has revealed that in larger environments, these cells display much more complex and irregular patterns of activity, firing in multiple locations with varied shapes and sizes.

Prof. Burak's team has found that a remarkably simple yet powerful mathematical model explains the irregular firing patterns of place cells in large environments. The model is based on the concept of "Gaussian Processes", a class of random functions that play an important role in diverse natural phenomena ranging from cosmology to oceanography.

In the model, firing regions of place cells emerge by marking regions of space in which a random Gaussian process crosses a certain threshold. Using this simple model, the researchers showed that the activity of place cells in bats and rodents across 1D, 2D, and 3D spaces follows universal principles.



Field arrangements of place fields in 2d and 3d spaces are explained by the thresholded Gaussian process model. Credit: Nischal Mainali

These findings imply that these patterns arise from largely random inputs to the hippocampus, challenging the idea that the brain relies on precise organization for its spatial map.

"Our findings suggest that randomness, rather than specific design, governs the synaptic organization of inputs to CA1 neurons in the hippocampus," explains Nischal Mainali, a student at the Hebrew University and one of the authors of the study.

This perspective challenges long-held assumptions about the structure of neural circuits and opens new avenues for understanding spatial cognition.

The model also makes precise testable predictions about the arrangements of place cell firing fields, and their geometry, which were verified by re-examining recordings of place cell activity, collected in previous experiments from bats, mice, and rats that navigated in diverse environments.

These insights not only shed light on the neural mechanisms of spatial navigation but also provide a foundation for exploring how the brain encodes information.

Prof. Burak explains, "The seemingly random firing patterns of place cells in large environments form 'codewords' that are uniquely assigned to different positions in space. We believe that the brain tunes the statistics of these random codewords to create a very efficient representation of positions in large environments".

More information: Nischal Mainali et al, Universal statistics of hippocampal place fields across species and dimensionalities, *Neuron* (2025). DOI: 10.1016/j.neuron.2025.01.017. www.cell.com/neuron/fulltext/S0896-6273(25)00043-1

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