Why grid-cell lattices are hexagonal

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Specialized brain cells provide an internal coordinate system that enables mammals to orient in space. Scientists at LMU and Harvard University have now shown mathematically why these cells generate hexagonal lattices.

Neuronal grid cells play a crucial role in mammalian spatial navigation. As the animal moves through its environment, distinct sets of these cells are sequentially activated. Although each individual grid cell responds to multiple positions in space, the overall activation patterns have been found to form virtual hexagonal lattices. These lattices effectively serve as a set of coordinates, on to which the environment is mapped, thus allowing the animal to determine its precise position and navigate in real space. The biologists who characterized this fascinating biological system in rats received the Nobel Prize in Physiology in 2014 for their discoveries.

Andreas Herz (Professor of Computational Neuroscience at LMU) and his Munich colleague Dr. Martin Stemmler, in collaboration with Dr. Alexander Mathis at Harvard University, have now provided a mathematical rationale for the hexagonal symmetry of grid-cell activation patterns. Their work is described in the online journal *eLife*.

Advantages of a hexagonal code

The three neurobiologists have used a mathematical approach to explore the reasons for the lattice-like distribution of spatial codes. Their analyses demonstrate that the hexagonal symmetry characteristic of grid-cell activation patterns (and of more familiar structures such as the honeycomb) affords the highest possible spatial resolution. Furthermore, their work suggests how grid cells should be arranged in mammals other than rodents, such as bats and whales.

"It turns out that, for the purposes of navigating on a horizontal plane, the best coordinate system is indeed the hexagonal lattice that has been experimentally observed for the grid cells of rats," says Herz. "The analysis of the case for three-dimensional space is more complex," adds Martin Stemmler. "Here the optimal configuration resembles that of the pyramidal packing of stacks of oranges." Preliminary experimental evidence is compatible with this theoretical prediction. Recent studies carried out by researchers led by Professor Nachum Ulanovsky at the Weizmann Institute in Israel indeed suggest the existence of such a grid-cell lattice in bats flying through three-dimensional space

"Our findings indicate that the brain may well be capable of utilizing highly efficient grid-like coding schemes for the representation of diverse types of information. And lattice-like configurations provide enormous advantages when it comes to encoding complex objects, which require the registration of a plethora of features for their unambiguous characterization," says Alexander Mathis. Indeed, the researchers believe

that, just as the discovery and investigation of grid cells has revolutionized our understanding of spatial coding in the brain, lattice-like patterns of neuronal activity are also likely to play an important role in other areas of neuroscience.

More information: "Probable nature of higher-dimensional symmetries underlying mammalian grid-cell activity patterns" *eLife* 2015;10.7554/eLife.05979 DOI: dx.doi.org/10.7554/eLife.05979

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