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Space, Time, Neural Oscillations and Memory

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All animals move in space and keep track of time. Hence, they must have a clear percept of space-time. Unlike many sensory processing, space-time is abstract concepts because they can neither be directly felt nor readily controlled. How does the brain, or the ensemble of neurons, create a perception of space-time? This has puzzled scientists for a long time. Research in the past few decades have revealed that individual neurons in a few key brain regions, especially the hippocampus and entorhinal cortex, fire selectively as a function of the subjects position in space and as a function of elapsed time. In fact, the spatial activity pattern of specific neurons forms a hexagonal lattice. The biophysical mechanisms governing the neural maps of space and time have remained elusive. A primary difficulty has been that when animals walk in the real world, stimuli from various modalities, e.g. sound, light, smell, texture etc., all change at the same time and these changes are difficult to measure, let alone control, precisely. Hence, we have developed a noninvasive, immersive and multisensory virtual reality system where the hardware and software transform the movements of a rat into the evolution of complex stimuli surrounding him to form an audio-visual space. Using this apparatus we have measured the activities of thousands of individual neurons. We then developed analysis techniques to decipher the spatio-temporal activity patterns buried in these neural ensembles, and related the emergent neural dynamics to spatial behavior in the virtual world. Finally we have developed computational models that can capture the emergent neural dynamics to reveal the biophysical mechanisms governing the emergent neural dynamics. This has revealed surprising findings which I will discuss. Specifically, we find that neural oscillations are crucial for perceiving space-time. Further, just as in physical world, spatial representation is relative not absolute. These findings open up unprecedented experimental and theoretical avenues for understanding how neural ensembles perceive space-time and guide complex behavior.