The Geometry of Decision-Making

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A central challenge for animals when alone, or when grouping with others, is deciding where to go. Running, swimming, or flying through the world, animals are constantly making decisions while on the move—decisions that allow them to choose where to eat, where to hide, and with whom to associate. Despite this, most studies have considered only on the outcome of, and time taken to make, decisions. Motion is, however, crucial in terms of how space is represented by organisms during spatial decision-making. Employing a range of new technologies, including automated tracking, computational reconstruction of sensory information, and immersive ‘holographic’ virtual reality (VR) for animals, experiments with fruit flies, locusts and zebrafish (representing aerial, terrestrial and aquatic locomotion, respectively), I will demonstrate that this time-varying representation results in the emergence of new and fundamental geometric principles that considerably impact decision-making. Specifically, we find that the brain encodes space in a non-Euclidean manner and spontaneously reduces multi-choice decisions into a series of abrupt (‘critical’) binary decisions in space-time, a process that repeats until only one option—the one ultimately selected by the individual—remains. Due to the critical nature of these transitions (and the corresponding increase in ‘susceptibility’) even noisy brains are extremely sensitive to very small differences between remaining options (e.g., a very small difference in neuronal activity being in “favor” of one option) near these locations in space-time. This mechanism facilitates highly effective decision-making, and is shown to be robust both to the number of options available, and to context, such as whether options are static (e.g. refuges) or mobile (e.g. other animals). In addition, we find evidence that the same geometric principles of decision-making occur across scales of biological organisation, from neural dynamics to animal collectives, suggesting they are fundamental features of spatiotemporal computation.