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Non-equilibrium physics of neural networks for leaning, memory and decision making: landscape and flux perspectives.

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Cognitive behaviors are determined by underlying neural networks. Many brain functions, such as learning and memory, can be described by attractor dynamics. We developed a theoretical framework for global dynamics by quantifying the landscape associated with the steady state probability distributions and steady state curl flux, measuring the degree of non-equilibrium through detailed balance breaking. We found the dynamics and oscillations in human brains responsible for cognitive processes and physiological rhythm regulations are determined not only by the landscape gradient but also by the flux. We found that the flux is closely related to the degrees of the asymmetric connections in neural networks and is the origin of the neural oscillations. The neural oscillation landscape shows a closed-ring attractor topology. The landscape gradient attracts the network down to the ring. The flux is responsible for coherent oscillations on the ring. We suggest the flux may provide the driving force for associations among memories [1]. Both landscape and flux determine the kinetic paths and speed of decision making. The kinetics and global stability of decision making are explored by quantifying the landscape topography through the barrier heights and the mean first passage time. The theoretical predictions are in agreement with experimental observations: more errors occur under time pressure. We quantitatively explored two mechanisms of the speed-accuracy tradeoff with speed emphasis and further uncovered the tradeoffs among speed, accuracy, and energy cost. Our results show an optimal balance among speed, accuracy, and the energy cost in decision making. We uncovered possible mechanisms of changes of mind and how mind changes improve performance in decision processes. Our landscape approach can help facilitate an understanding of the underlying physical mechanisms of cognitive processes and identify the key elements in neural networks [2]. [1]. H. Yan, L. Zhao, L. Hu, X. Wang, E.K. Wang, J. Wang. Nonequilibrium landscape theory of neural networks. Proc. Natl. Acad. Sci. USA E4185–E4194 (2013). [2]. H. Yan, K. Zhang, J. Wang. Physical mechanism of mind changes and tradeoffs among speed, accuracy, and energy cost in brain decision making- Landscape, flux, and path perspectives. Chin. Phys. B. 25(7), 078702. (2016).