Modeling cyclic-sequential brain activity via biologically plausible dynamics | Virginia Bolelli

This study develops a biologically plausible model for cyclic-sequential brain activity, characterized by distinct neuronal populations activating in a defined, repetitive order. We tackle this problem by leveraging tools from dynamical systems theory, such as heteroclinic cycles, and by incorporating machine learning techniques. On one hand, heteroclinic cycles typically occur in Lotka-Volterra-type equations, but these do not adequately reflect the biological mechanisms underlying neural activity. On the other hand, we show that mean-field models, such as Wilson-Cowan equations, although better suited to describe neural dynamics, cannot exhibit heteroclinic cycles, especially when equilibria are confined to coordinate axes. To bridge this gap, we exploit the Universal Approximation Theorem to approximate Lotka-Volterra dynamics with Wilson-Cowan-type equations. Our neural network implementation successfully reproduces oscillatory dynamics while overcoming a key limitation of heteroclinic cycles, where residence times in each state grow indefinitely. Indeed, in our case, residence times stay constant, aligning more closely with biological mechanisms. Finally, we apply this model to investigate the cognitive processes underlying Focused Attention Meditation, showcasing its ability to capture sequential transitions and oscillatory dynamics within a biologically realistic framework.

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