Inter-Areal competition drives winner-take-all dynamics in a large-scale spiking model of extra-classical receptive fields

S. Madariaga[(1,2)], P. Maldonado[(1,2)], and C. Devia[(1,2)]

[(1)] Universidad de Chile, Department of Neuroscience, Santiago, Chile

[(2)] National Center for Artificial Intelligence (CENIA), Santiago, Chile

Extra-classical receptive field (eCRF) effects, such as surround suppression, demonstrate that local competitive interactions within the primary visual cortex (V1) alone are insufficient for global sensory integration. While hierarchical models incorporating top-down feedback from higher areas (V2) have been proposed, simple feedback architectures often fail to replicate the strong suppression observed physiologically. This study proposes that effective feedback modulation requires analogous lateral competition between cortical columns within higher-order areas to generate "winner-take-all" dynamics driven by differential thalamic activity.

Employing the NEST simulator, we developed a Spiking Neural Network (SNN) based on the canonical cortical microcircuit. The architecture integrates layered circuits representing the biological complexity and connectivity of V1 and V2 cortical columns. To evaluate eCRF emergence, we compared isolated V1 circuits and simple feedback models against a fully hierarchical architecture where V1 interacts with two V2 modules exhibiting lateral competitive dynamics (Fig. 1A).

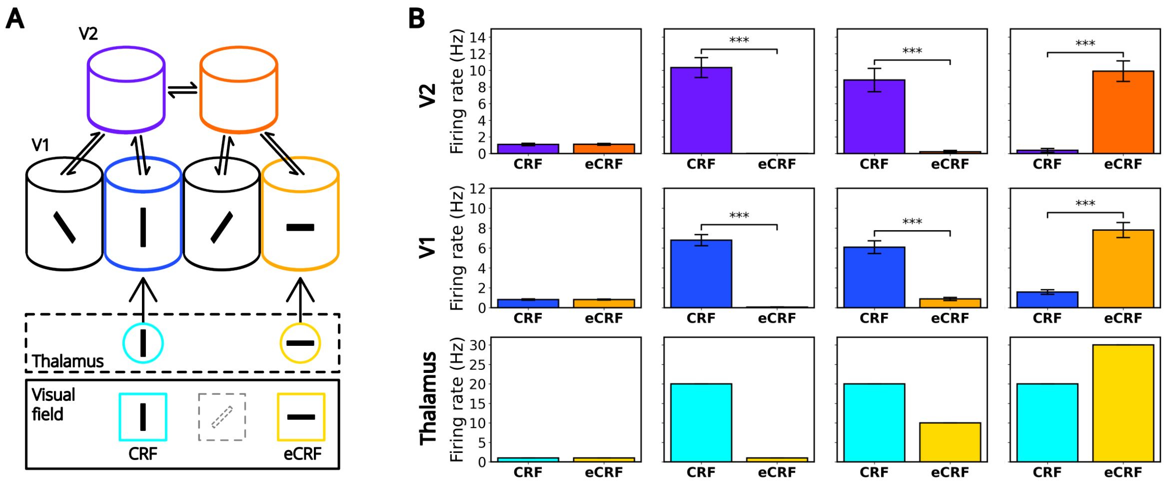

Figure 1: Emergence of winner-take-all dynamics in extra-classical receptive fields. (A) Network architecture showing the interaction between V1 and V2 modules with inter-areal lateral competition. (B) Firing rates of excitatory neuronal groups in supragranular layers, demonstrating how differential thalamic stimulation drives the winner-take-all phenomenon during surround suppression.

Simulations showed that robust surround suppression (75%) was only achieved by integrating vertical feedforward and feedback pathways with lateral spatial competition between cortical columns in V2 (Fig. 1B). This specific architecture dynamically transitions into a nonlinear winner-take-all competition at high stimulation contrasts, successfully reproducing the biological computational principles of visual cortex normalization.

These findings demonstrate that contextual modulation is an emergent product of specific network configurations. By understanding how this competitive dynamic arises from the biological connectivity of cortical columns, these mechanisms can be translated to inform and generate novel biologically-inspired computational algorithms for robust information processing in artificial systems.