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Neuronal Avalanche Dynamics in Simulated Mouse Motor Cortex (M1): Excitatory-Inhibitory Balance and Sustained Apical Dendritic NMDA Depolarization Effects

Cortical networks display diverse oscillatory patterns, as revealed by Beggs and Plentz's discovery of neuronal avalanches in rat cortex recordings, suggesting self-organized cerebral signal processing. This study investigates such signals in a simulated mouse M1 cortex to determine if avalanches adhere to power-law distributions in size and duration and to characterize their patterns.
Method: In a 10-minute simulation, brief stimulation (100ms; 0.57 nA/cell) on 1.5% of 15 cell types triggered spontaneous, self-sustained avalanches, reflecting power-law patterns seen in both real and experimental data. We categorized simulated spiking activity into 1ms intervals, defining avalanches as sequences of activity-filled bins surrounded by empty bins.
Results: We identified four distinct activity patterns, including some with rhythmic components, showcasing varied avalanche dynamics: Irregular, Beta, Delta+, and Fragment, all sharing a power-law exponent of -1.52. Investigating intervals between avalanches revealed variability, a mean inter-avalanche interval of 1.67ms, with occasional gaps exceeding 10ms, suggesting a complex mechanism governing avalanche timing and frequency. Shorter avalanches typically ended with excitatory cell activity, whereas longer ones concluded with inhibitory cell activity, underscoring inhibitory cells' role in modulating avalanche durations. The initiation of subsequent avalanches was linked to sustained NMDA apical dendritic depolarization in IT5B and IT6 cells, underscoring the critical role of NMDA receptor-mediated processes in excitatory neurons for sparking collective dynamics.
Discussion: Our findings deepen the understanding of the interplay between excitatory and inhibitory influences in neuronal networks and highlight the sophisticated dynamics underpinning neuronal avalanches. This emphasizes the importance of further research into the synaptic inputs and intrinsic properties of neuronal populations.