Optimal pattern coding due to firing threshold adaptation near criticality

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The brain encodes information through neuronal populations' output firing rates or spike patterns. However, weak inputs have limited influence on mean output rates, hindering its impact on sensory and memory systems performance. Alternatively, spike patterns can create sparse and combinatorial codes that enhance memory capacity, information transmission, and energy efficiency.

We investigate input-output (I/O) relations in a stochastic recurrent excitatory network with a directed percolation critical point, revealing the influence of single-neuron firing threshold adaptation in both coding capacities. Adaptive networks present a robust synergistic dual-coding scheme, where weak inputs are optimally encoded into patterns and stronger inputs are transduced by mean output rates. Conversely, a similar performance can only be achieved by non-adaptive networks near the critical point. Mutual information is also robustly optimized in adaptive networks together with pattern coding for a recovery timescale of ~ 100 ms.

This timescale aligns with various cells in the brain, including the mammalian cortex, hippocampus, teleost pallial region, and sensory neurons. We thus hypothesize that threshold adaptation – a mechanism of spike frequency modulation – is exploited by neural systems to maintain sensitivity across a wide range of stimuli, from weak to strong, by dynamically switching between pattern and rate coding. This mechanism not only enhances information transmission, feature selectivity, and neural code precision but also ensures robust performance in sensory discrimination and memory tasks, even in the presence of internal noise near critical points.

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