Paradoxical self-sustained dynamics emerge from orchestrated excitatory and inhibitory leaning rules

Self-sustaining neural activity maintained through local recurrent connections is of fundamental importance to cortical function. Converging theoretical and experimental evidence indicate that self-sustained dynamics in the cortex operate in an inhibition-stabilised regime. This regime contributes to many cortical computations, and is characterised by positive feedback that is held in check by balanced recurrent inhibition. One of the best studied examples of self-sustained inhibition-stabilised network dynamics are Up-states. Here we first show that Up-states emerge in parallel in both excitatory and PV^+ inhibitory neurons across three weeks of cortical *ex vivo* development, pointing to the presence of unsupervised learning rules capable of generating self-sustained dynamics in both types of neurons. Previous computational models have established that four sets of weights ($W_{E\leftarrow E}$, $W_{E\leftarrow I}$, $W_{I\leftarrow E}$, $W_{I\leftarrow I}$) must interact in an orchestrated manner to produce Up-states, but have not addressed how a family of learning rules can operate in parallel at all four weight classes to generate self-sustained inhibition-stabilised dynamics. Using numerical and analytical methods we prove that standard homeostatic rules are unstable in this context, and fail to drive recurrent activity towards a stable self-sustained activity. This is in part due to a signature property of inhibition-stabilised networks: the paradoxical effect. We next show that a family of biologically plausible learning rules based on "cross-homeostatic" plasticity overcomes the paradoxical effect and robustly leads to the emergence of stable Up-states. Our model is the first to capture the emergence of self-sustained activity from a silent network state—as observed in early development—using learning rules that autonomously drive all four synaptic weight classes.