A HIDDEN PARAMETER NETWORK THAT EXPLAINS TOPOLOGICAL PROPERTIES OBSERVED IN NEOCORTEX

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ABSTRACT

The mammalian neocortex is a highly structured network, and has the innate ability to make strong generalizations from sparse, noisy, and ambiguous examples. This dense neural network forms synaptic connections that are determined by features that range from the genetic to the cellular level, spanning up to 6 orders of magnitude. The ongoing advancements in experimental techniques have afforded us access to a rich variety of empirical measurements. Despite the major progress over the past decades, partial observations of the complete wiring diagram have so far defied a generalized mechanistic understanding of connectivity in the brain. Our perspective emphasizes on implementing an artificial network model to explain the global organization of cortical circuits. In this model, pre- and post-synaptic targets (i.e., axonal boutons and dendritic spines) are characterized by independent hidden variables controlling the establishment of synaptic connections between neuron pairs. For simplicity, we assume that a single sequence of hidden variables η defines the spatial distribution of pre- and post-synaptic targets, to avoid incoming and outgoing degrees. Thus, we set η as an approximation of the distribution of axonal boutons. We find that the spatial distribution of η fully explains some structural properties of the neocortex, such as non independence of neuron degrees at the end points of any given synaptic connection.

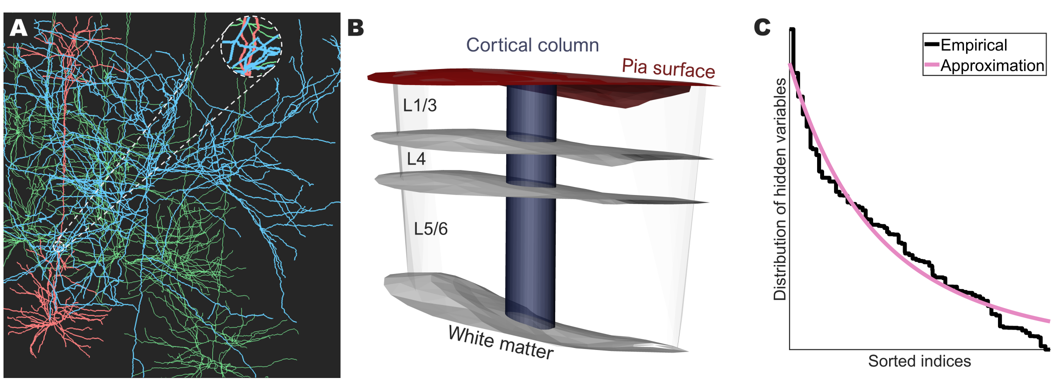

Figure 1: **Schematic of our hidden parameter network model.**
(A) To calculate the connection probability $p(A, B)$ between a pair of neurons (A, B), consider the axon morphology of A (blue), the dendrite morphology of B (red), and the dendrite morphologies belonging to other neurons (green). For each pre- and post-synaptic target pair (i, j) with $i \in \mathcal{A}$ and $j \in \mathcal{B}$, compute the connection probability $p(i, j) = \eta_i \eta_j / \sum_k \eta_k$ in a sphere centered in the axonal bouton i with fixed radius r (insert). Then, the connectivity rule is $p(A, B) = \sum_{i \in \mathcal{A}} \sum_{j \in \mathcal{B}} p(i, j)$.
(B) The analysis is performed in a cortical column using a standardized reference frame with 17 195 excitatory and 2 511 inhibitory neurons, including their respective axon and dendrite morphologies.
(C) The distribution of axonal boutons in a cortical column (black) is approximated by a sequence of hidden variables, $\eta_i \sim i^{-\alpha}$ (pink).