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THALAMOCORTICOTHALAMIC CIRCUITS FOR UNIVERSAL LEARNING

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We propose a new canonical microcircuit for thalamus and cortex, based on the idea that the neocortex is a universal learning machine which uses Hebbian synapses to extract high-order statistical regularities from the environment. The basis of our approach is that activity-dependent plasticity cannot be completely synapse-specific (even though adaptations such as spines, glia and synapse spacing clearly promote specificity). We analyzed unsupervised learning models whose “weights” are composed of realistic synapses which are updated slightly nonlocally, the degree of nonlocality measured by an error parameter e. We assumed that “weights” are comprised of many synapses (potential and actual), so that Hebbian “errors” could occur between all possible weights (“error onto all”). Models with n inputs that only learn pairwise statistics, such as the Oja Principal Component model, are error tolerant because they only show learning collapse for $n \sim 1/e$. We propose that this accounts for the extremely accurate wiring found for driving inputs on thalamic relay cells and cerebellar Purkinje neurons. However, models that are sensitive to higher order statistics, such as ICA models, show an “error catastrophe” for $n > -1/\log e$, so it is impossible that a cortical column receiving several hundred input axons could learn anything resembling an independent component (such as an oriented bar), unless additional machinery exists. The simplest way to dramatically lower the error rate would be to increase synapse spacing, but at best one can only add one input for each doubling of synapse spacing. Therefore other machinery must ensure that learning only occurs under favorable conditions (i.e. when the environment is particularly rich in high-order statistics.) In the simplest case, the error rate can be dramatically lowered by independently measuring the correlated firing of the input and output cells contributing to a connection using a special purpose “coincidence-detecting” neuron, and using the output of this neuron to “gate” the plasticity of the connection. We suggest that this is done by layer 6 simple neurons, which are known to receive both thalamic input and input from layer 4 simple cells, and which innervate via special neuromodulatory “drumstick” synapses sets of relay cells and their simple layer 4 targets. We propose that layer 4 thalamocortical synapses are only plastic when their relay cells burst. If the layer 6 coincidence measure is compared to other simple layer 6 cells measuring coincidences across incipient connections, the error catastrophe can be avoided at the expense of slower learning. Similar circuits would apply to complex cells. We therefore make the heretical claim that most cortical circuitry is involved in error-avoidance rather than information processing.