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Neocortical Locks and Keys: Coherence Induction Among Complex, Heterogeneous Neuronal Patterns

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Abstract**—** What kind of computer is the mammalian brain? To improve upon simple rate-based neural networks, computational neuroscience research over the past decade focused on more biologically realistic spiking neuron models on the millisecond time scale—but still ascribing a *digital* overtone to brain processing. A more recent development has been to explore the spectral properties of subthreshold membrane potentials, emphasizing an *analog* mode of computing. Together, by modeling the fine temporal structure of neural signals, these research trends have revealed a great diversity of collective *spatiotemporal regimes*: synchronization and phase locking, delayed correlations and traveling waves, rhythms and chaos, etc. Through recurrent (and plastic) synaptic connections, neural cells transiently interact as *dynamical subnetworks* that promise an immense richness of coding expression and computational power, combining the discrete and the continuous. What repertoire of dynamical regimes and phase diagrams can such subnetworks sustain? In the classical feed-forward paradigm, subnetworks (layers, cell assemblies) are initially silent and must be literally activated by external stimuli. However, documentation of pervasive feedback connectivity and the observation of persistent or *ongoing* activity both challenge the traditional view that "lower" areas are necessary to activate "higher" areas. Our modeling work subscribes to this new paradigm by endowing subnetworks with already viable and complex endogenous activity modes, which are only *perturbed* through coupling with an input or with other subnetworks. Local groups of neurons possess spontaneous and preferred modes of ongoing activity that are learned and later *influenced* by stimuli in various ways. These modes are intrinsically *heterogeneous* in nature, i.e., temporally and spatially complex rasters of spikes and/or landscapes of subthreshold membrane potentials. Using spiking neuronal simulations, we describe progress towards building cohesive digital-analog "perturbation" principles based on such subnetworks, which could underlie real-time pattern recognition and response learning to natural environmental stimuli. In a first model, the dynamics of a simplified network of quasi-periodic units is described on a phase circle by the collective coalesce-and-scatter motion of dots. In a second model, we examine the regimes and phase transitions of Recurrent Asynchronous Irregular Networks (RAINs) and their modification by STDP learning. In both cases, we explore "lock and key" principles, proposing that pattern recognition and memory storage are based on a dynamics of *coherence induction* between "key" input stimuli and "lock" patterns. The receiving lock patterns are learned by tuning synaptic efficacies to a point of maximal postsynaptic response. They represent neocortical *pattern formation*, i.e., the emergence of structurally complex, spiking neurodynamic "shapes".