Modeling Complex Phenomena in Neuronal Circuits

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Although the brain structural architecture has been characterized and studied for over hundred years, the role of brain dynamics has been addressed much less. Models of brain activity can be categorized into a hierarchy of different levels of detail. A detailed model might include specific dependences of the voltage-gated channels to describe neurons and their interactions [1]. A less detailed, but still robust, description would include simple neurons, neural populations or even neural mass models [2]. A whole description of the brain is also possible by using, e.g., the Free Energy Principle for the brain [3].

In this presentation, we opt to use an intermediate approach. Simple models for neurons and synapses are robust enough to qualitative describe experimental observations, while being computationally less demanding. In what follows, we show results of synchronization in coupled neuronal populations and information transmission in a chain of neuronal layers.

In the first example, we study the transition between delayed (DS) to anticipated (AS) synchronization in two unidirectionally coupled neuronal populations. Each neuron in the population is modeled using the Izhikevich equations [4]. Connectivity within the population is sparse (10%) and we assume 80% excitatory and 20% inhibitory neurons coupled via chemical AMPA and $GABA_A$ synapses. Each neuron is subject to an independent Poisson train mimicking the input of other neurons that are not part of the population. By changing the inhibitory conductance or the oscillating frequency in the receiver population, a transition from DS to AS can occur, as shown in figure 1. This transition explains the counterintuitive results observed in experiments with monkeys performing a visual task. A positive Granger Causality (information flow) from the sender to the receiver area was observed to be accompanied by a negative delay in the activation of both areas [6].

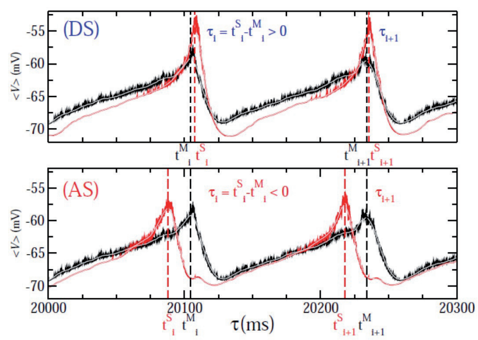

Figure 1: Time evolution of the mean value of the membrane potential of two neuronal populations coupled in a sender-receiver configuration. In the upper (lower) panel we show the case of delayed (anticipated) synchronization between the populations.

In the second example we study the transmission of signals in a chain of 11 mutually-coupled neuronal layers. We find, in the case of symmetric connections, that local perturbations on the dynamics of one layer will propagate in the network, being detected by other nodes, if the node receiving the perturbation has a higher intrinsic frequency. Moreover, we find that high frequency units determine the direction of signal propagation (see Figure 2), and consequently the effective connectivity in such a network.

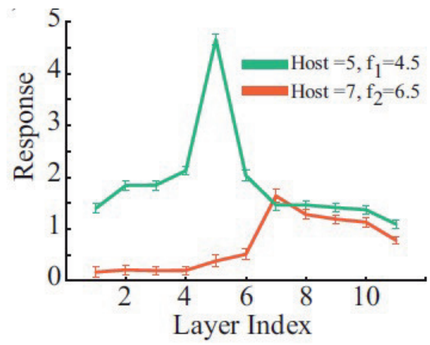

Figure 2: Propagation of signals: one signal with frequency f_1 is injected into the high-frequency layer 5 and another signal with frequency f_2 is injected into another layer with low oscillating frequency (in this case layer 7). It can be seen that the signal injected into layer 5 propagates in both directions while that injected in layer 7 only propagates in the direction oposite to the high frequency node.

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