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Poster presentation

Theory of neuronal spike densities for synchronous activity in cortical feed-forward networks

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Synchronization of spiking activity in neuronal networks of the cortex has been proposed as a mechanism underlying higher brain functions. This idea is challenged by ongoing cortical activity generating large fluctuations in synaptic input, causing the neurons to operate in a noisy environment. The propagation of synchronized spiking in feed-forward subnetworks ("synfire chains") has been studied to demonstrate the feasibility of precise spike timing [1]. However, the theoretical analysis of even this toy model is impeded by the intricacy of calculating the distribution of spike times in response to time-dependent inputs. Therefore, most quantitative results rely on simulations or semi-numerical methods, and insight into the structure of the dynamics is limited. Recently [2], we showed that for a biophysically plausible integrate-and-fire neuron model the probability of emitting a response spike is concentrated on the rising phase of the membrane potential transient caused by synchronous input and that during this time the instantaneous spiking rate is governed by the derivative of this transient. These observations were confirmed by an ad hoc calculation of the neuron's spike density. A corresponding instantaneous rate model enabled us to investigate the synchronization dynamics analytically. Inherent to the approach, the theory for the spike density breaks down at the peak of the membrane potential transient and during its descent. Meanwhile based on an exact series expression for the first passage time density of differentiable random processes (Wiener-Rice series) new successful approximations have been presented [3]. Here, we use the first term of the series to approximate the spike density of a stochastic integrate-and-fire neuron model receiving time-dependent input.

The figure displays the densities of response spikes for four characteristic input parameters describing synchronous activity in feed-forward subnetworks (vertical: number of input spikes; horizontal: temporal dispersion of the input). Extending [2], the results of the new approximation (blue curves) are valid during the rising and the descending phase of the membrane potential transient and are in excellent agreement with the simulation results (gray curves). While in the earlier theory the relationship between output and input dispersion is independent of the amplitude of the input, the new theory resolves this degeneracy; it also holds in the less synchronized and subthreshold regime. We finally have a theory at hand covering the full dynamical range of synchronized spiking in cortical feed-forward networks. The approximation is valid for a wide range of relative time constants. In conclusion, our work provides a more fundamental theory for the earlier findings. The method has the potential to be applied to other time-dependent problems in computational neuroscience.

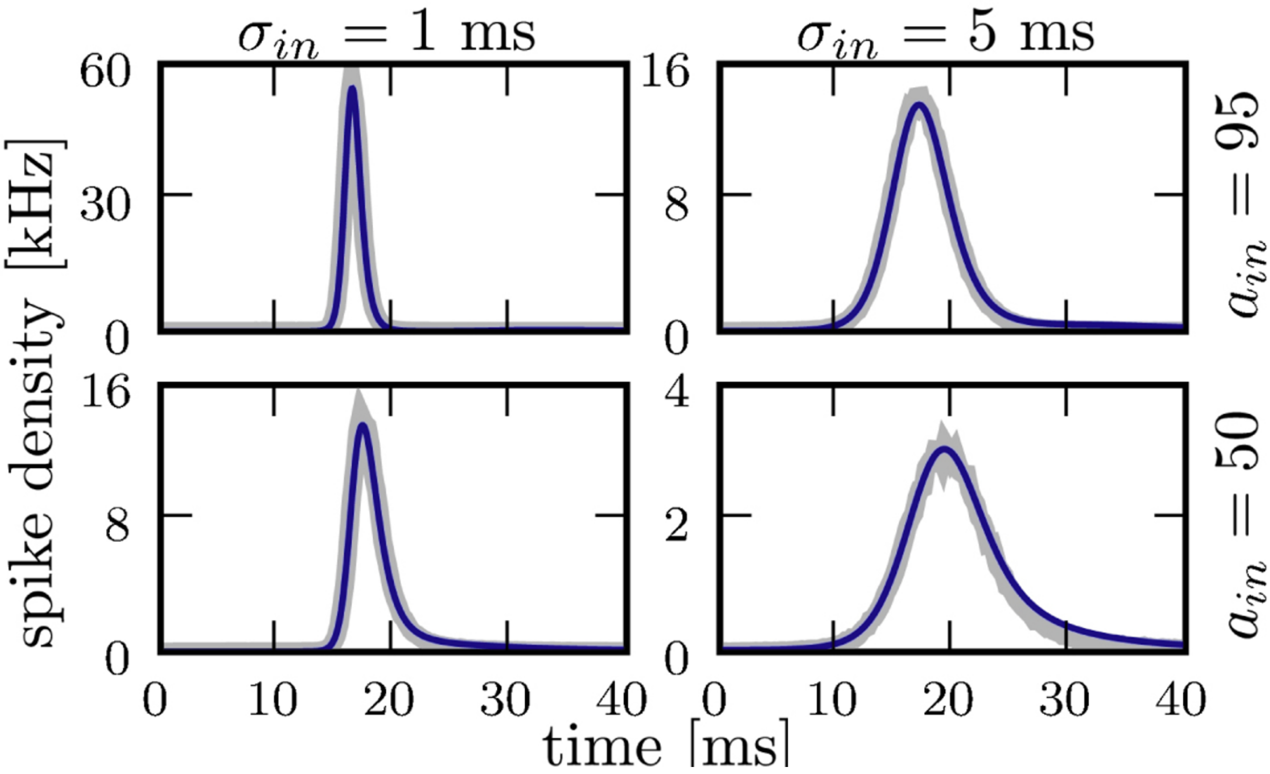

Figure 1
Comparison of theoretical (blue) and simulated (gray) spike density of a population of leaky integrate-and-fire neurons in response to transient excitatory synaptic input caused by synchronous activity of presynaptic neurons. In the four panels, the number of input spikes decreases from top (95) to bottom (50) and their temporal precision from left (1 ms) to right (5 ms). The vertical axes are individually scaled.

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