

Cell-intrinsic and stimulus properties that maximize spike-time reliability and stochastic synchronization

Roberto F. Galán^{1,2}, G. Bard Ermentrout^{2,3} and Nathaniel N. Urban^{1,2}

¹*Department of Biological Sciences, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*

²*Center for the Neural Basis of Cognition, Mellon Institute,
Pittsburgh, Pennsylvania 15213, USA*

³*Department of Mathematics, University of Pittsburgh,
Pittsburgh, Pennsylvania 15260, USA*

Implementing temporal codes in the brain requires that neurons are capable of following a stimulus with millisecond precision as well as of responding consistently to it in repetitions of the same stimulus. The biophysical mechanisms that endow neurons with this fundamental property remain unknown. We have explored in simulations, experiments and mathematical models how cell intrinsic as well as extrinsic (stimulus related) properties influence spike-time reliability and more generally, stochastic synchronization. First, using computer simulations and stochastic theory (Fokker-Planck equation), we have shown how reliability depends on the spiking properties of the neuron. In particular we have shown that neurons with type II excitability (resonators) are more reliable and more readily synchronized than neurons with type I excitability (integrator). This kind of excitability typically requires either an outward (hyperpolarizing) current that is activated by brief but properly timed depolarizations, or sodium channels that are partially inactivated by a brief depolarization delivered soon after the spike. Second, combining simulations, dynamical system theory (including calculation of Liapunov exponents) and patch-clamp experiments in the olfactory bulb and the neocortex, we have shown that the autocorrelation time of a fluctuating input (stimulus), influences the level of spike-time reliability. More specifically, we have shown that for neurons firing in the beta/gamma frequency band, spike-time reliability is maximal when the time scale of the input is in the range of a few (2-5) milliseconds and decreases quickly for slower and faster inputs. This suggests that neurons are adapted to optimally respond to their most natural input signal: fast synaptic currents. Moreover, we have demonstrated mathematically and in experiments, that in general the optimal time scale for reliability will be approximately 16% of the average inter-spike interval.

Our findings on spike-time reliability and its optimal time scale are immediately applicable to stochastic synchronization, since both phenomena are closely related. In the former case the timing of the spikes is preserved in repeated trials with the same fluctuating stimulus. In the later case, identical neurons receiving similar (correlated) fluctuating stimuli trigger synchronous spikes. In particular, barrages of spatially correlated synaptic input currents will synchronize postsynaptic neurons quickly. Analogously, in the case of a single neuron, a reproducible barrage of synaptic pulses will trigger highly reliable responses.