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Temporal coding of continuously-varying inputs

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In many neural circuits, precise patterns of spike timing contain information beyond that contained in mean firing rates. Here we illustrate a simple mechanism by which an ensemble of leaky-integrate-and-fire (LIF) neurons can represent continuously-varying input signals in a timing code. Neurons that are post-synaptic to this ensemble can reliably extract these signals (or functions thereof) in the absence of both spike time coincidence and firing rate variations.

Irregular firing is often modelled phenomenologically, for example as a Poisson process with a rate that depends on synaptic input. In contrast, the irregular firing of our LIF neurons is a deterministic consequence of wide variations in applied current over the space of inputs (e.g. Figure 1A). Applied current functions of this kind can arise from weighted output from a previous layer, and we discuss their establishment via Hebbian plasticity. By inclining these functions along a preferred direction, and scaling the peaks, we obtain a continuum between timing and rate codes.

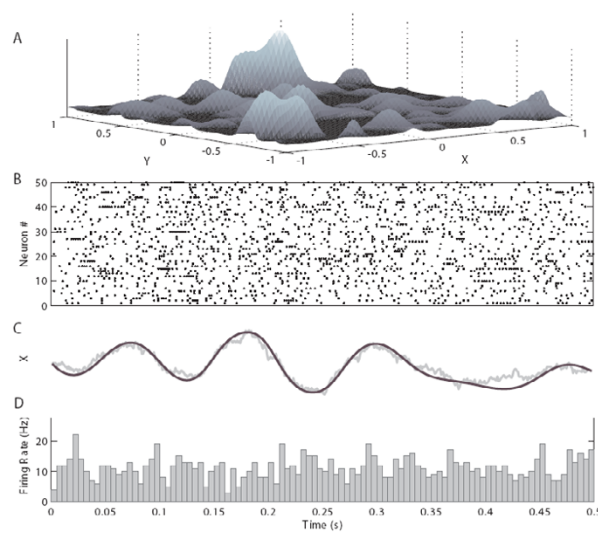

Figure 1

Temporal coding and decoding with LIF neurons. A, Net synaptic current (arbitrary units) experienced by an example LIF neuron, as a function of two inputs (*X* and *Y*). **B**, Irregular firing in 50 different neurons (each with different current functions) as inputs *X* and *Y* vary at low frequency. **C**, Estimate of *X* decoded from activity of an ensemble of 1000 LIF neurons firing as in B. Black line indicates ideal decoding (post-synaptic current dynamics applied to input *X*). Gray line indicates the estimate of *X* by a neuron post-synaptic to the ensemble. This estimate is a weighted sum of post-synaptic currents generated by the firing of the ensemble. **D**, Firing rate histogram showing a lack of mean firing rate dependence of an example neuron on input *X*, over 30 trials. In each trial the input *X* is identical, but *Y* varies randomly.