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How chaotic is the balanced state?

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Local cortical circuits often exhibit highly irregular spiking dynamics that appears to be random. Such irregular dynamics are commonly considered as a "ground state" of cortical circuits. In a fundamental work, van Vreeswijk and Sompolinsky [1] suggested that a "chaotic balanced state" underlies this irregular cortical activity. In such a state, strong inhibitory and excitatory inputs to each neuron balance on average and only the fluctuations generate spikes. Moreover, the original high-dimensional network dynamics and a slightly perturbed version of it rapidly diverge from each other, suggesting that chaos is the dynamical mechanism that induces irregularity. Here we show analytically and numerically that irregular balanced activity may equally well be generated by collective dynamics that is not chaotic but stable almost everywhere in state space. This dynamics has the same coarse statistical features as its chaotic counterpart (see figure 1). Our results reveal that chaos is not necessary to generate irregular balanced activity in an entire class of deterministic spiking neural networks. Most importantly, the results also indicate that not chaos or stochasticity, but some other dynamical mechanism may actually underlie the irregularity observed in cortical activity.

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References

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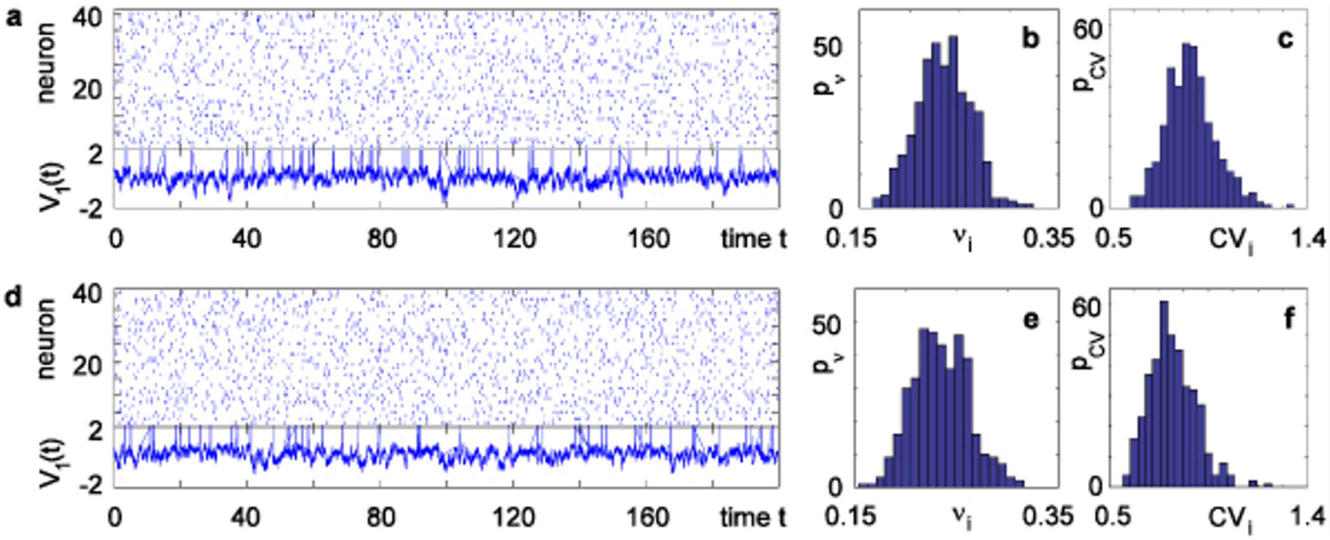

Figure 1

Irregular dynamics in purely inhibitory (a-c) and inhibitory and excitatory (d-f) coupled random networks of identical leaky integrate-and-fire neurons (N = 400). Starting with a network where all connections are inhibitory, we consecutively replace inhibitory connections by excitatory ones. We reduce the external current to keep the average input to a single cell constant. Whereas the spiking activity is similar and highly irregular in both regimes, we demonstrate that the first one is stable while the second one is chaotic. (a, d) The upper panel displays the spiking times (blue lines) of a subset of 40 neurons. The lower panel displays the membrane potential trajectory of one single neuron. (b, e) Histogram of mean firing rates, ν_i. (c, f) Histogram of the coefficients of variation, CV_i, averaged over time.