Irregular transients and synchronization in stable neural networks

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- Model: dilute inhibitory network of integrate-and-fire neurons
- Two phases: periodic (weak coupling), desynchronized (strong coupling)
- *Stable Chaos*: negative Lyapunov exponent | irregular long transients
- Synchronization of subset by external signals
- Delay: size dependence of transient behavior

Pulse-coupled integrate-and-fire neurons

System of N identical pulse-coupled neurons with reset:

$$\dot{v}_i = I - v_i - (v_i + E) \sum_{j=1}^{N} \sum_{k} G_{ij} \delta(t - t_j^{(k)}) \ , \quad v_i \in [0,1)$$

- suprathreshold current $I > 1$
- inhibitory coupling, $E > 0$
- **quenched disorder**: random cut of directed links (5%)
- normalization with number of incoming links: $G_{ij} = G/\ell_i$

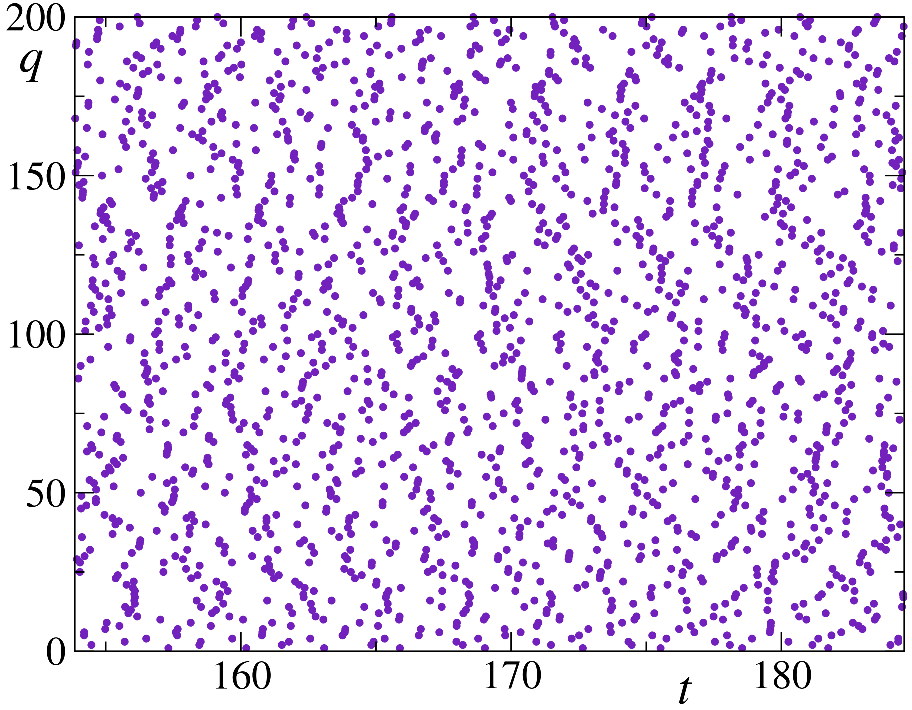
Emergence of desynchronized phase

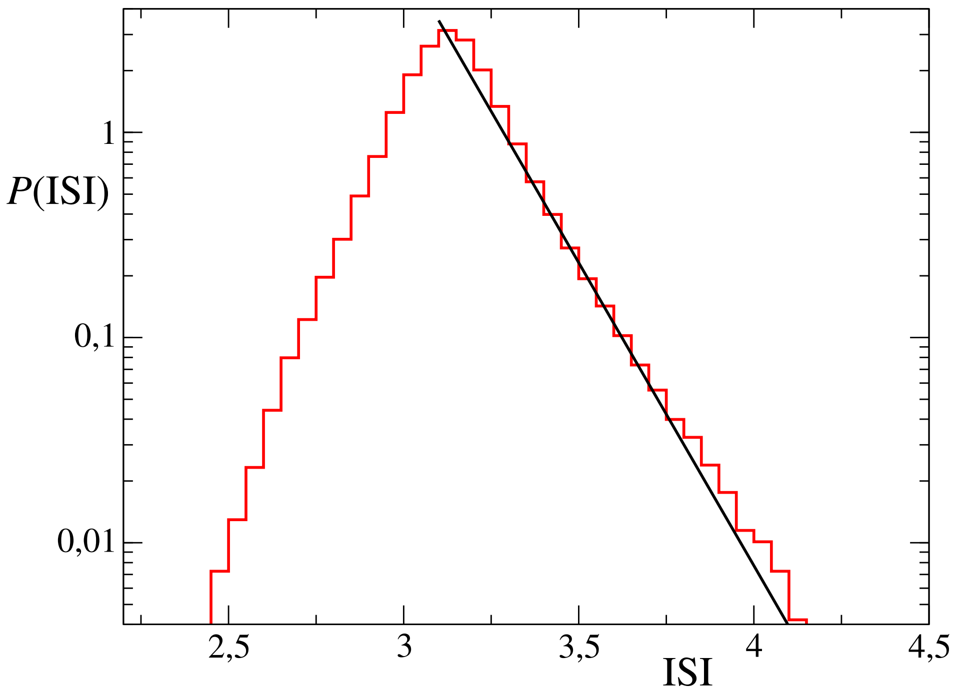
• $G \lesssim 1$: Rapid convergence onto periodic attractors

$\Rightarrow$ all neurons fire with same pace, $\mathrm{ISI} = const.$

• $G \gtrsim 1$: Desynchronized aperiodic evolution

$\Rightarrow$ irregular firing pattern Poisson-like distribution of ISI's



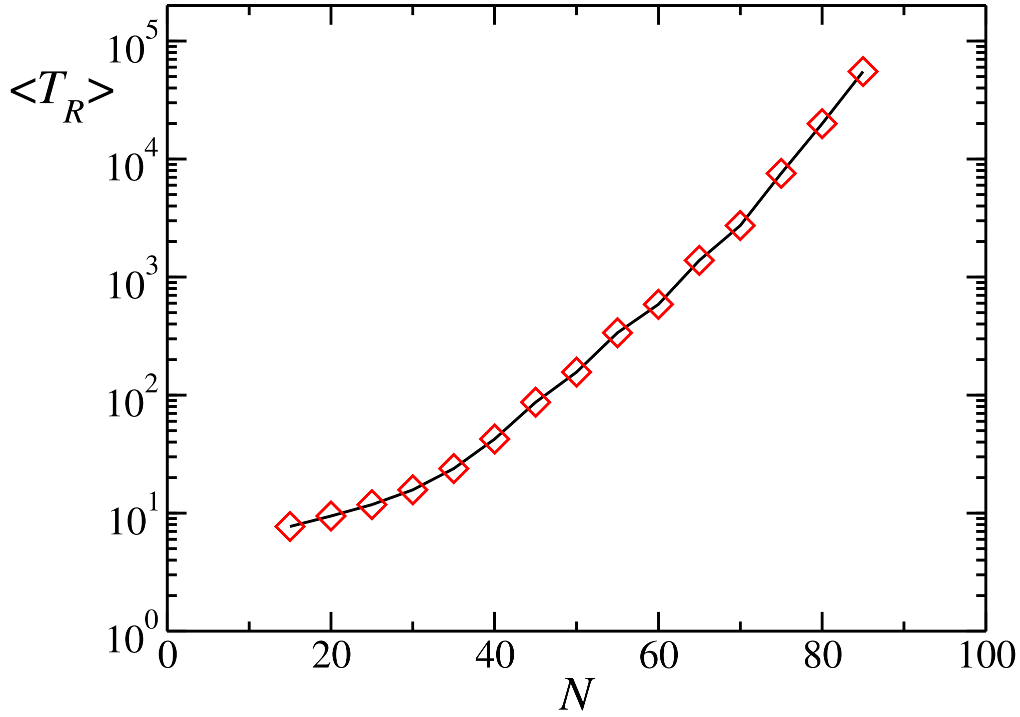


Stable Chaos for $G \gtrsim 1$

- Negative Lyapunov exponent: $\Lambda \approx -G/[I(I-1)\ln(I/(I-1))]$

- Periodic orbit is reached after **exponentially long transient** T_R

$$\langle T_R \rangle \sim \exp(\alpha N)$$



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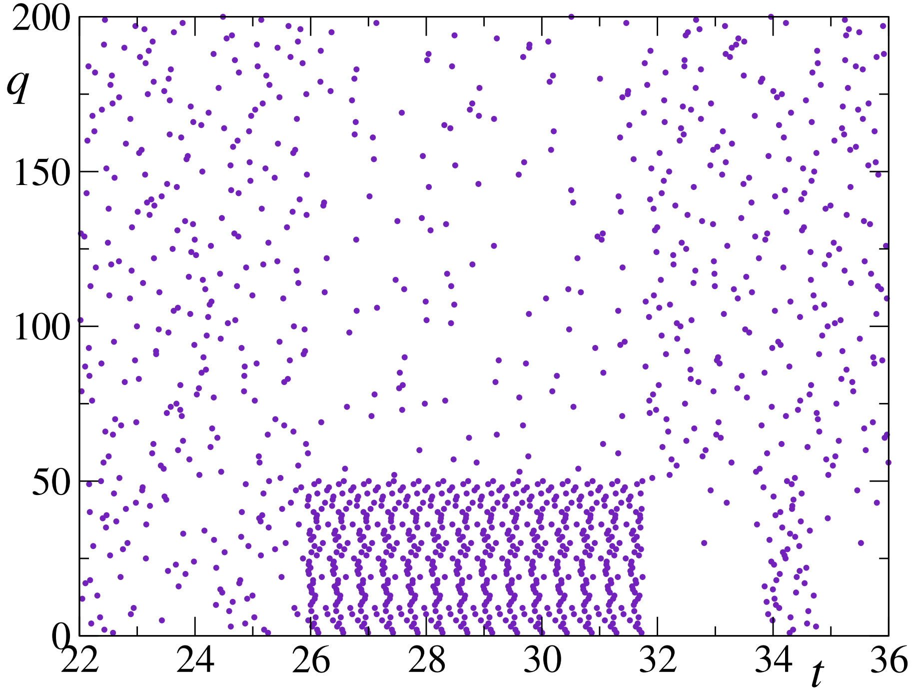
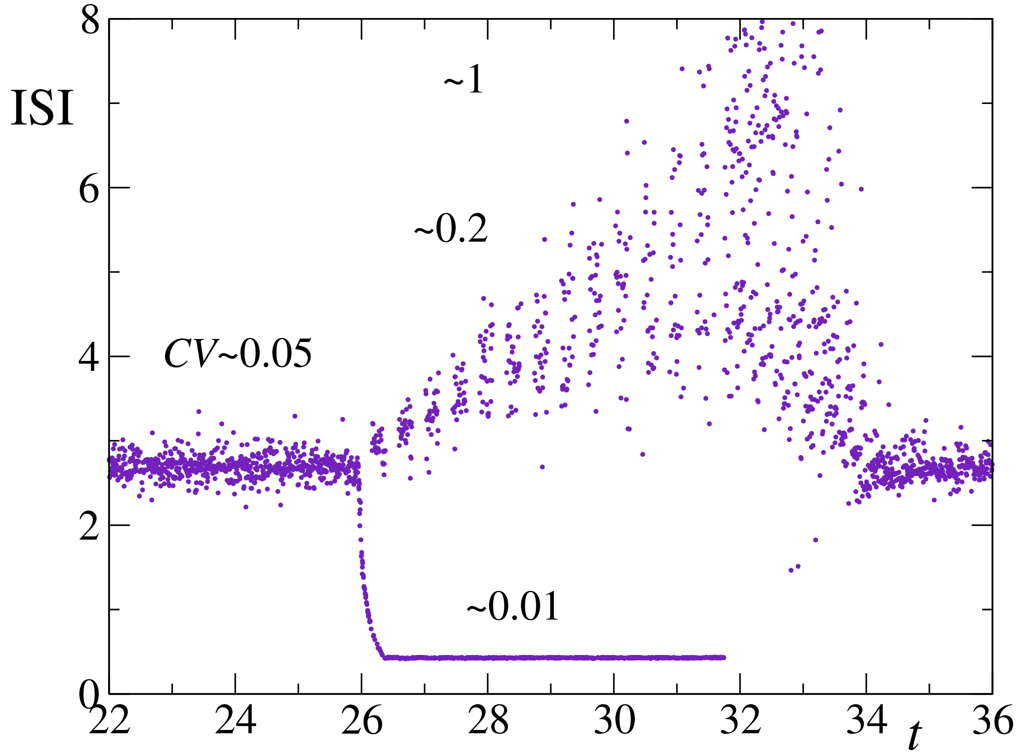
Response to external signal

Signal: Equispaced spike-train with **excitatory** action applied to subpopulation (10%)

$\Rightarrow$ subpopulation almost periodic | irregularity of "background" enhanced

$$CV := \langle \mathrm{ISI} \rangle / \sqrt{\left\langle \mathrm{ISI}^2 \right\rangle - \langle \mathrm{ISI} \rangle^2}$$





Effect of delayed spike transmission

- Neurons tend to fire in **clusters** [U. Ernst et. al. 1995]

  delay τ_d, system size N: average number of neurons per cluster $\sim \tau_\mathrm{d} N$

1) average separation between clusters independent of N
2) for large N self-averaging of clustered input

$\Rightarrow$ Transient length, $T_R(N)$, has maximum: