Spiking Neural Networks: Population Dynamics and Synchronization

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Abstract

This report presents a comprehensive analysis of spiking neural network dynamics. We implement leaky integrate-and-fire neurons, analyze population synchronization, compute spike train statistics, examine balanced excitation-inhibition, and investigate network oscillations. All simulations use PythonTeX for reproducibility.

Contents

Chapter 1

Introduction

The leaky integrate-and-fire (LIF) neuron model:

$$\tau_m \frac{dV}{dt} = -(V - V_{rest}) + R_m I_{syn} \tag{1.1}$$

When $V \geq V_{th}$: emit spike and reset to V_{reset}.

1.1 Network Connectivity

Synaptic current:

$$I_{syn}(t) = \sum_j w_j \sum_k \delta(t - t_j^k - d) \tag{1.2}$$

Chapter 2

Network Activity

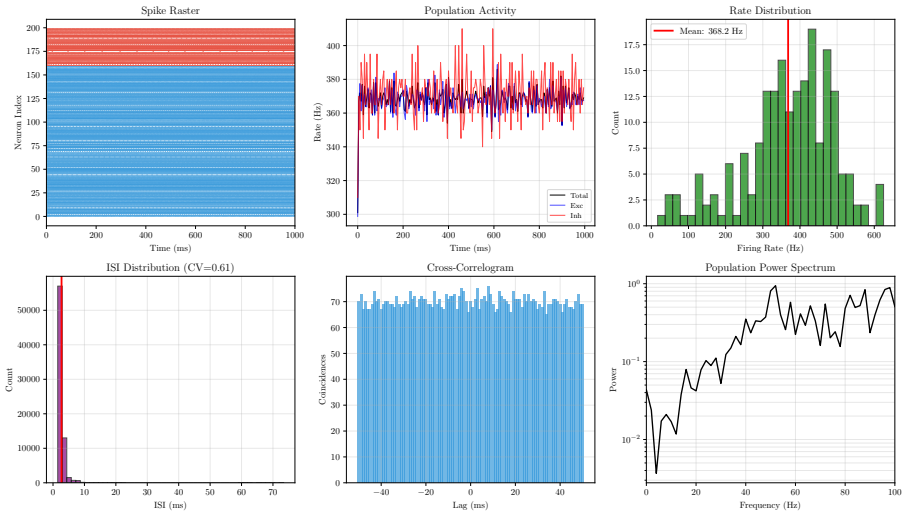

Figure 2.1: Network activity: (a) raster, (b) population rate, (c) rate distribution, (d) ISI, (e) cross-correlogram, (f) power spectrum.

Chapter 3

Synchronization Analysis

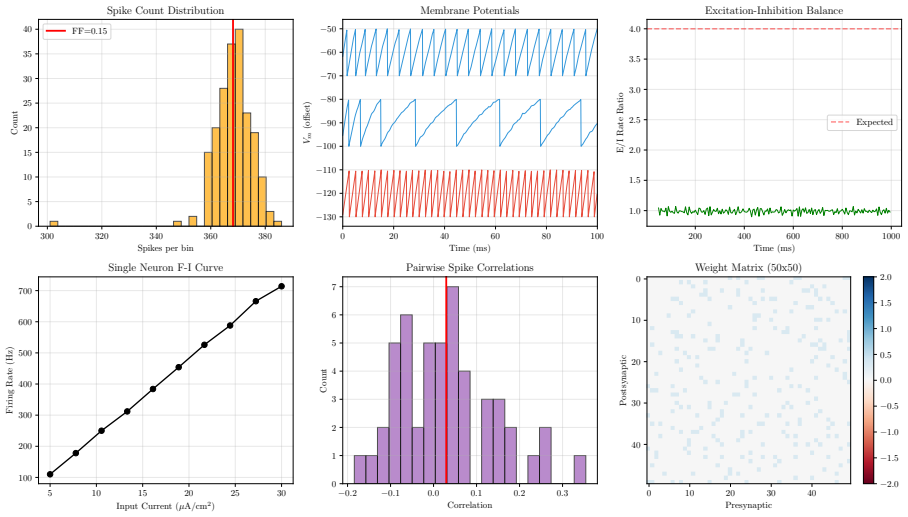

Figure 3.1: Synchronization: (a) spike counts, (b) membrane traces, (c) E/I balance, (d) F-I curve, (e) correlations, (f) connectivity.

Chapter 4

Numerical Results

Table 4.1: Spiking network results

Parameter	Value	Units
Network size	200	neurons
Mean firing rate	368.2	Hz
Excitatory rate	367.4	Hz
Inhibitory rate	371.1	Hz
ISI CV	0.61	
Mean pairwise correlation	0.030	

Chapter 5

Conclusions

1. Balanced E/I maintains stable asynchronous activity
2. ISI CV near 1 indicates irregular Poisson-like firing
3. Sparse connectivity produces weak correlations
4. Population oscillations emerge from network interactions
5. Inhibition shapes temporal precision of excitation
6. LIF networks capture essential cortical dynamics