A new correlation-based measure of spike timing reliability

Susanne Schreiber[1,2], Jean-Marc Fellous[2,3], Diane Whitmer[2], Paul Tiesinga[1,2], and Terrence J. Sejnowski[1,2,3]

[1]Sloan-Swartz Center for Theoretical Neurobiology, [2]Computational Neurobiology Lab, [3]Howard Hughes Medical Institute
The Salk Institute, La Jolla, CA

1. Introduction

Spike timing reliability places limits on the amount of information a neuron can potentially transmit about the stimulus. A multitude of different measures has been used to characterize spike timing reliability. One popular group of measures is based on the histogram of spike times (PSTH) in response to repeated presentation of the same stimulus. These measures characterize reliability faithfully, but rely on at least two independent parameters, which have to be carefully adapted, and require the explicit definition of firing events. Here, we describe a simple correlation-based measure, which only requires one intuitive parameter and does not involve the definition of "a posteriori" events. We test and compare the measure in the context of

1. **A surrogate test data set**
2. **Model neurons with different dynamics**

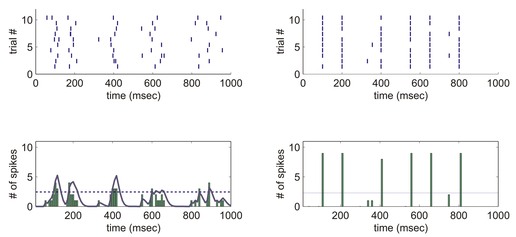
2. Reliability Measures

2.1 Histogram-based measures

- based on spike trains recorded in response to repeated presentation of the same stimulus (N trials)

- PSTH may be smoothed with a filter
- threshold is applied to PSTH to define events
- reliability is characterized as number of spikes within events vs. Total number of spikes (Rhist is in [0;1])

example A **example B**



n_e … number of spikes per bin

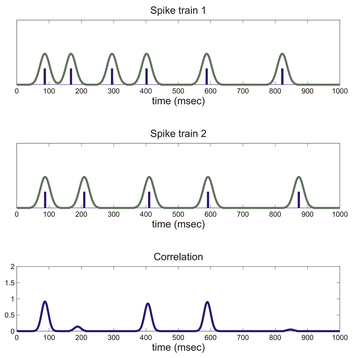
n_{total} … total number of spikes

$$R_{hist} \quad \frac{n_e}{n_{total}} \quad \frac{e\ events}{}$$

Parameters of the measure:

1. **Bin size**,
2. **Smoothing filter width** ,
3. **Threshold value** (absolute, relative to mean firing rate, relative to max. if PSTH, defining event separations (as upper or lower boundary); needs to be adjusted for bin size, number of trials N etc.)

2.2 The correlation measure



- Also based on repeated presentation of the same stimulus (N trials)

- All spike trains are filtered with Gaussian of width $_c$

- Two individual trials are correlated (and normalized)

- Average "correlation" of all pairs of trials defines reliability

(Rcorr is in [0;1])

$\vec{s}_i$ … filtered spike train i (i=1,..N)

N … number of trials

$$R_{corr} \quad \frac{2}{N(N-1)} \sum_{i=1}^{N} \sum_{j=i+1}^{N} \frac{\vec{s}_i \cdot \vec{s}_j}{\left|\vec{s}_i\right| \left|\vec{s}_j\right|}$$

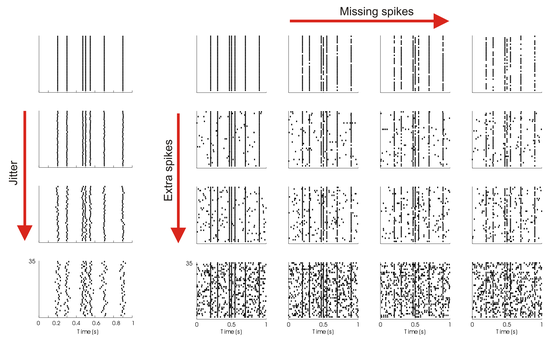
parameters of the measure:

1. **width of the filter** $_c$

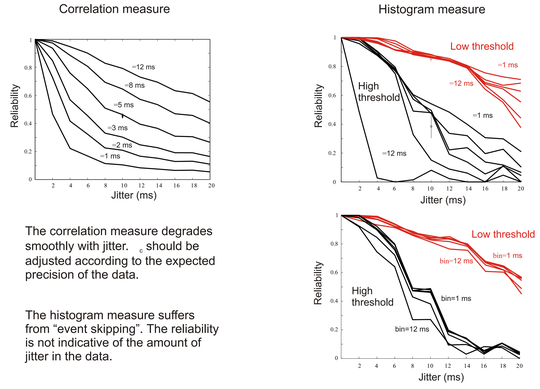
- original bin size (e.g. from a 10 KHz recording) can be used
- filter width directly correlates with the expected temporal precision

3. The surrogate test data set

3.1 The test data set: jitter, additional, and missing spikes



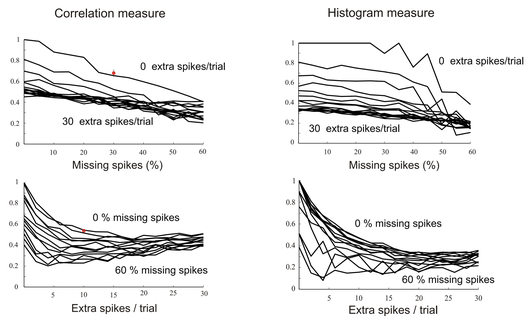
3.2 Reliability with jitter



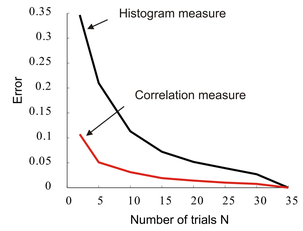
The correlation measure degrades smoothly with jitter. $_c$ should be adjusted according to the expected precision of the data.

The histogram measure suffers from “event skipping”. The reliability is not indicative of the amount of jitter in the data.

3.3 Reliability with extra and missing spikes



3.4 Dependence on the number of trials



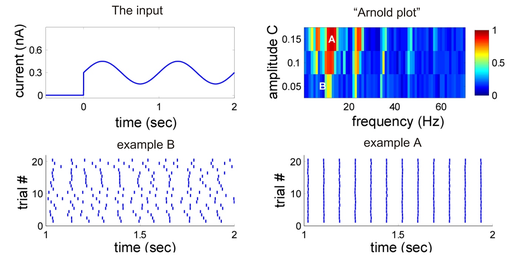
The average error in reliability with only N<35 trials is calculated taking reliability for 35 trials as a reference. (Based on 208 test sets with additional/missing spikes).

The error in the correlation-based reliability estimate is always more than a factor two lower than the error in the histogram-based reliability estimate.

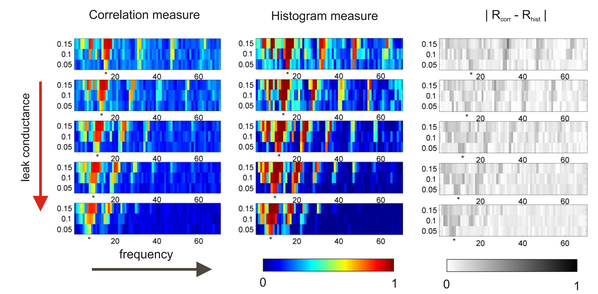
4. Model neurons with different dynamics

4.1 Model neurons and stimulus protocol

- Model neurons implemented in NEURON
- Adapted from a model of a pyramidal neuron
  (five basic conductances: Na^+, K^+, passive, slow K^+, and persistent Na^+)



4.2 “Arnold plots”



5. Summary

- **The correlation measure is reliable in quantifying missing, additional spikes, and spike jitter.**

- In contrast to histogram measures the correlation measure **only relies on one parameter** (related to the precision of spike timing); no assumptions about event structure in the data are made.

- Smooth degradation as a function of missing/additional spikes and jitter.

- The correlation measure is robust in characterizing spike timing reliability independently of the dynamics of the neuron, the mean firing rate, the frequency content of the input; on average fewer trials than for the histogram measure are necessary.

- Well suited to characterize spike timing resonances.

- Computational efficiency (data not shown):
  in most cases it is enough to only average neighboring trials;
  bin size can be traded for filter width.

Supported by the Sloan-Swartz Center for Theoretical Neurobiology, the Daimler-Benz Foundation, and the Howard Hughes Medical Institute.