A jump-diffusion model of pyramidal neuron membrane noise

Alexandre Melanson[1,2], André Longtin[2,3]

[1]Dép. de physique et astronomie, Université de Moncton [2]Dept. of Physics and [3]Center for Neural Dynamics, University of Ottawa

Université de Moncton Campus de Moncton

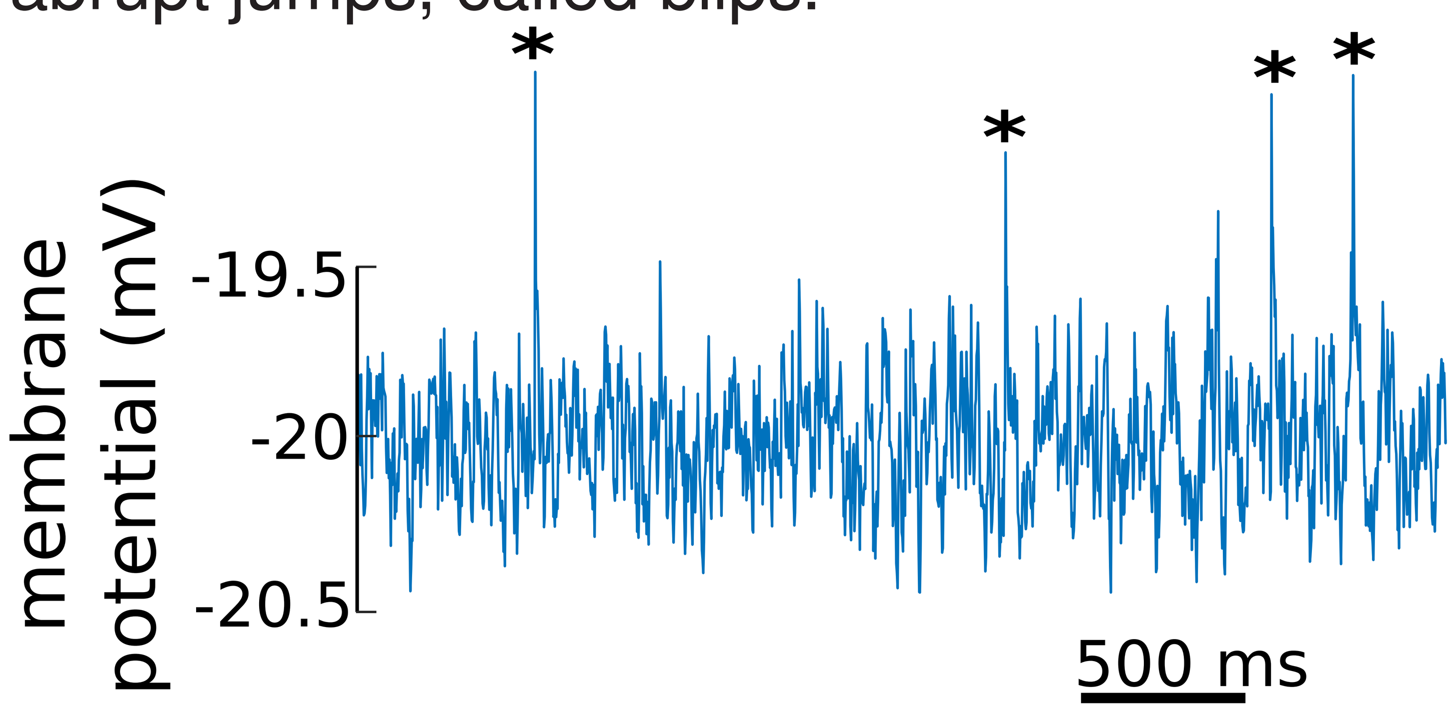
uOttawa

Summary

- A jump-diffusion stochastic differential equation (SDE) can be fitted to electrophysiological recordings of membrane noise in pyramidal neurons.
- This SDE is obtained from a data-driven, semi-parametric inference method.
- Key components of this method are the detection of jumps in the original data by threshold crossing, and the probabilistic calculation associated with diffusive fluctuations falsely identified as jumps (false positives, FP).

Background

- In the absence of synaptic input, pyramidal neurons of the electrosensory lateral line lobe of electric fish displays a combination of diffusive fluctuations and abrupt jumps, called blips.



- Blips occur at random times and briefly depolarize the cell with random amplitudes (0.5 - 1.5 mV).
- No biophysical mechanism has been proposed yet, but it has been hypothesized that blips are involved in weak signal detection.

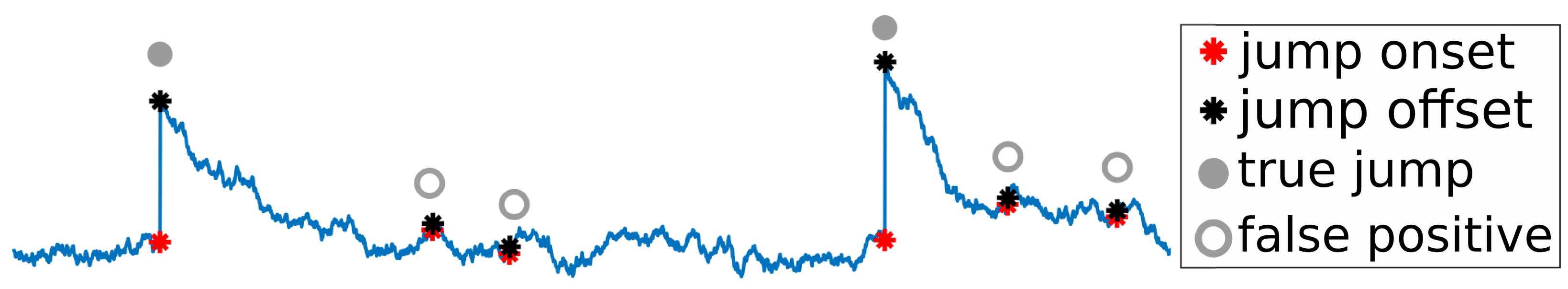
Goal and approach

- Given an experimental time series, $\{X(t)\}$, our goal is to fit an SDE of the form:

$$dY(t) = F(Y(t))dt + \sqrt{2D}\, dW(t) + dJ(t), \qquad (1)$$

where $W(t)$ a Wiener process, and $J(t)$ is a compound Poisson process with rate λ, the increments of which are distributed according to Q_B.

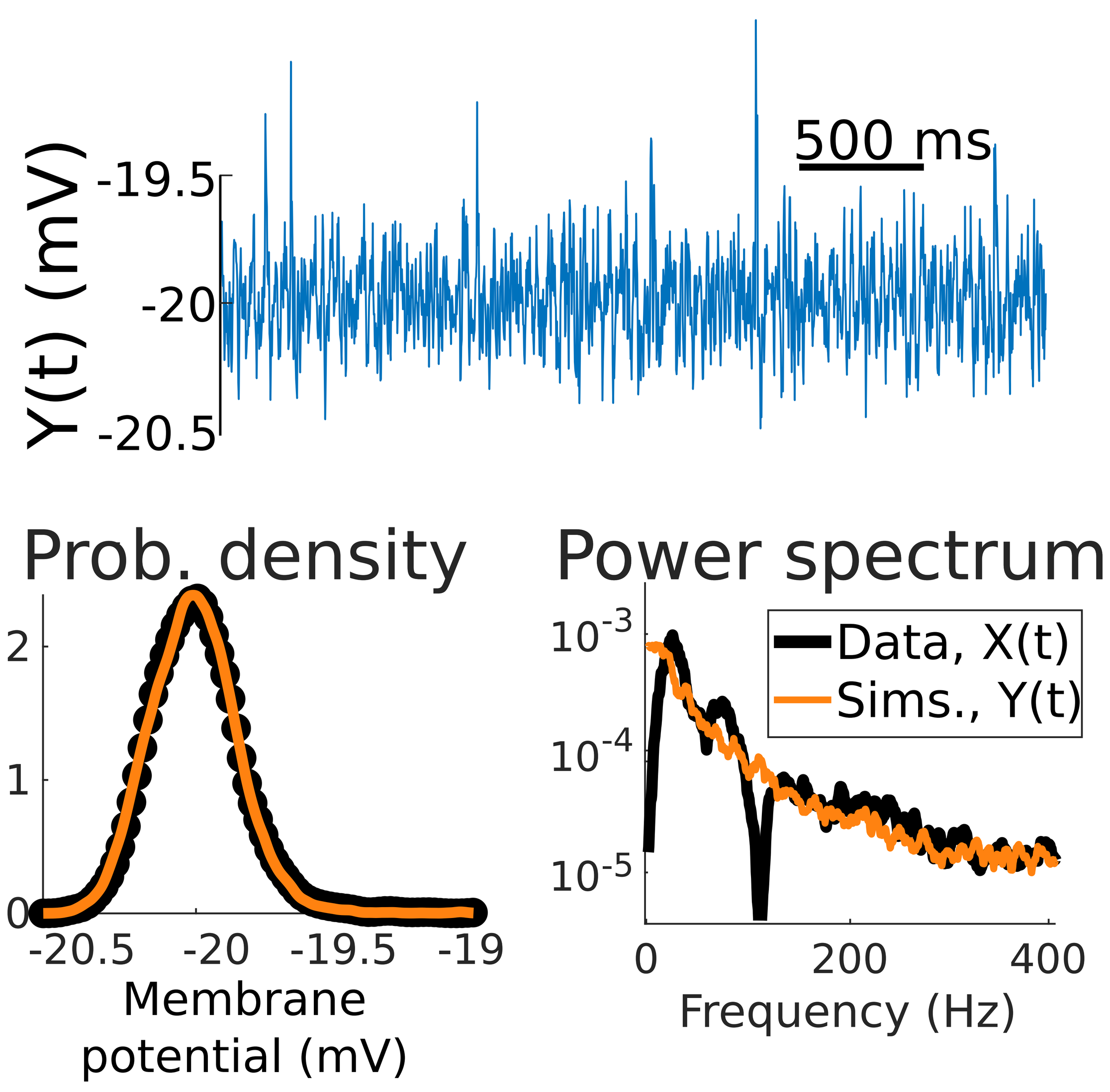
- We first apply a threshold on the increments, $\Delta X(t)$, but FPs are inevitably detected along with true jumps:

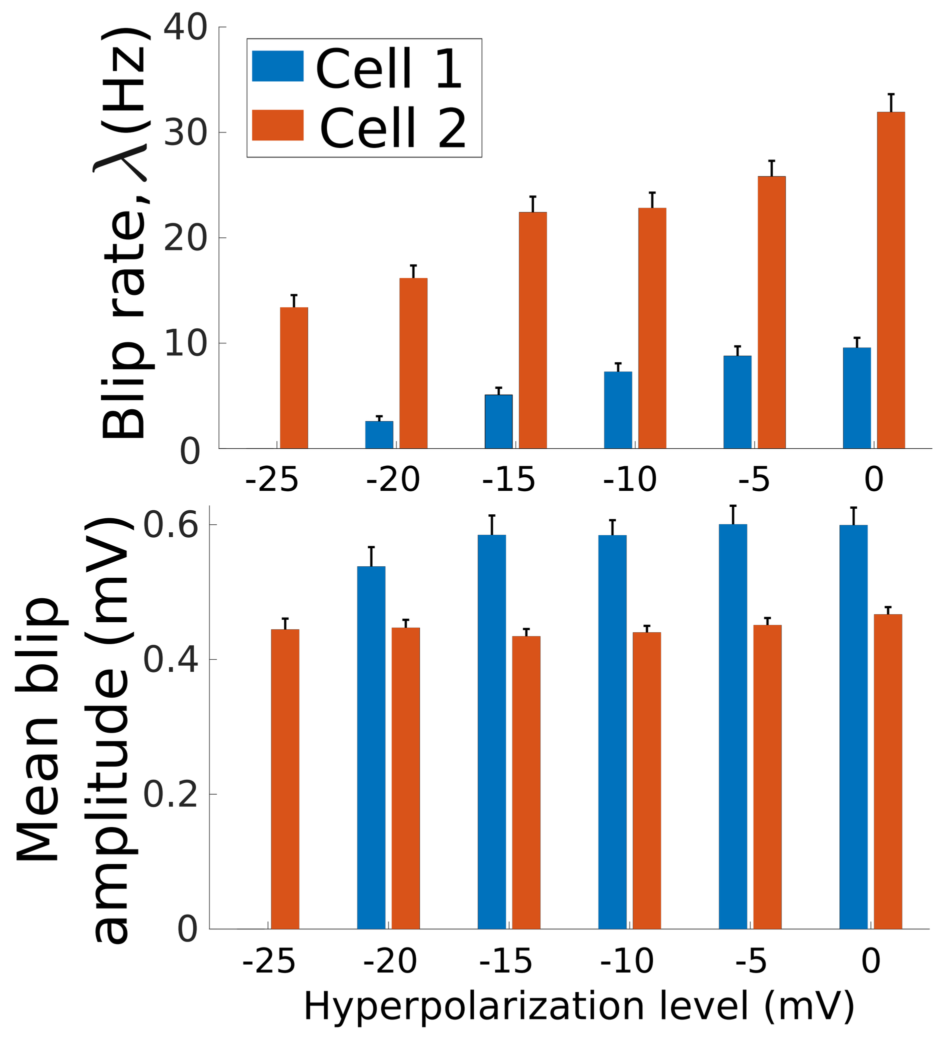


- An SDE fitted to $\{X(t)\}$ is then obtained by estimating all functions and parameters of Eq. (1): D is estimated by evaluating the quadratic variation along jump-free segments, λ and Q_B rely on calculating the rate and amplitude distribution of FPs, and F is obtained from the differential Chapman-Kolmogorov equation.

Results

- Simulations of the fitted SDE represent well the original data, both in terms of the probability density and the power spectrum.
- Different cells, held at various depolarization levels, can be characterized by the parameters of their respective SDEs.
- Blip rate tends to increase with depolarization level, while blip amplitude remains unchanged, but differs across cells.





Outlook

- An effective model of pyramidal neuron membrane noise is obtained, despite the unknown biophysical origin of blips.
- Future work will evaluate the functional role of blips by incorporating the fitted SDE into a neuronal model.
- The SDE inference method is general and can be applied to other time series where jumps occur along diffusive fluctuations.