Low Latency, Open-Source, Closed-Loop System for Sharp-Wave Ripple Detection System

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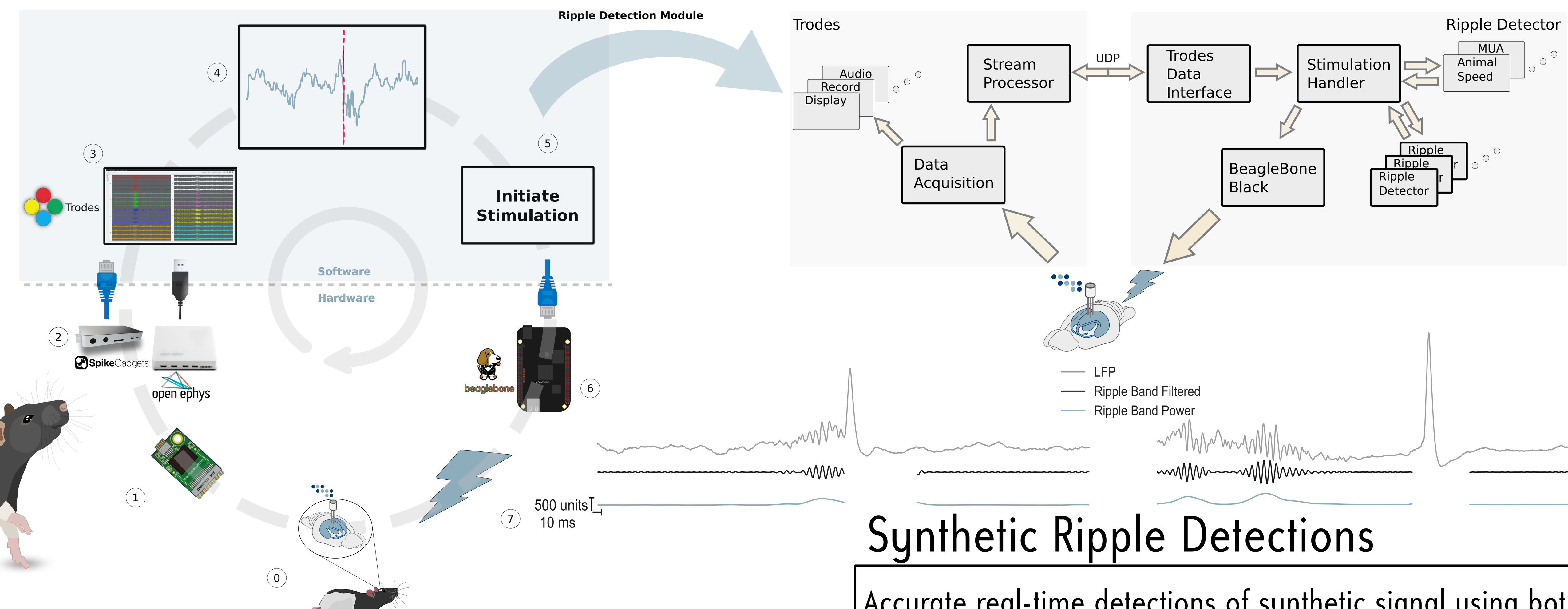
Abstract

We demonstrate an open-source, cross-platform solution for **online sharp-wave ripple (SWR) detection.**

Specifically, we show a two-pronged approach in analyzing a real-time detection system (1) synthetic and *in vivo* offline analysis for parameter space exploration (2) real-time synthetic and *in vivo* validation. Finally we show **low closed-loop latency** (~2 ms) along with **low overall detection latency** (~35-60 ms) and **accurate *in vivo* detections** (<10 false detections per minute and >0.95 true positive rate). Overall, our system is capable of disrupting more than half of each SWR event.



Background & Motivation

*What are **sharp-wave ripples (SWRs)**?*

Coordinated bursts of neural activity in the hippocampus that stem from the CA3 region causing oscillations in the CA1 region. These events are ~150-250 Hz, last ~100 ms, and co-occur with epochs of high multi-unit activity.[A],[B],[C]

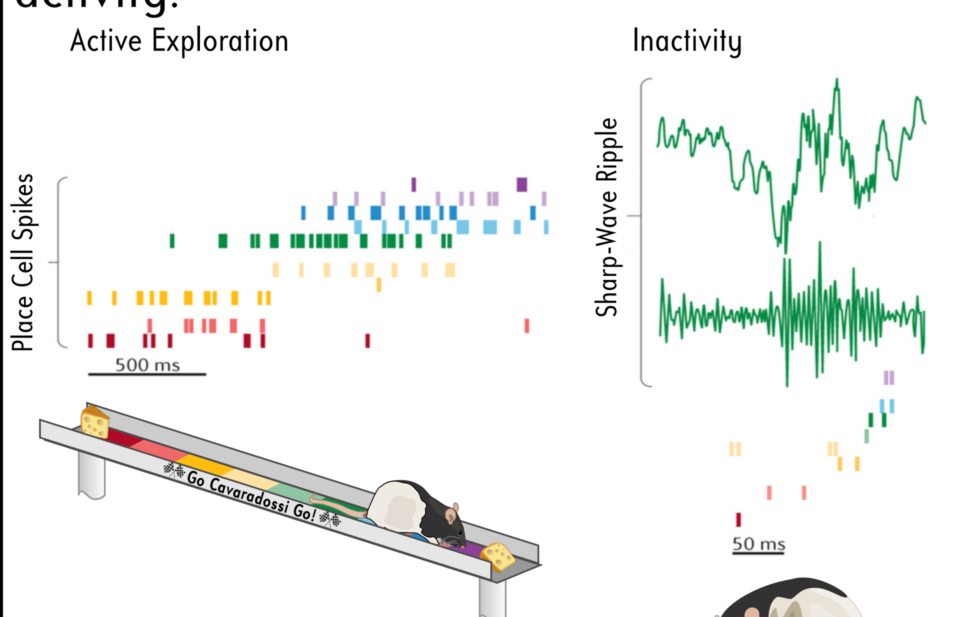
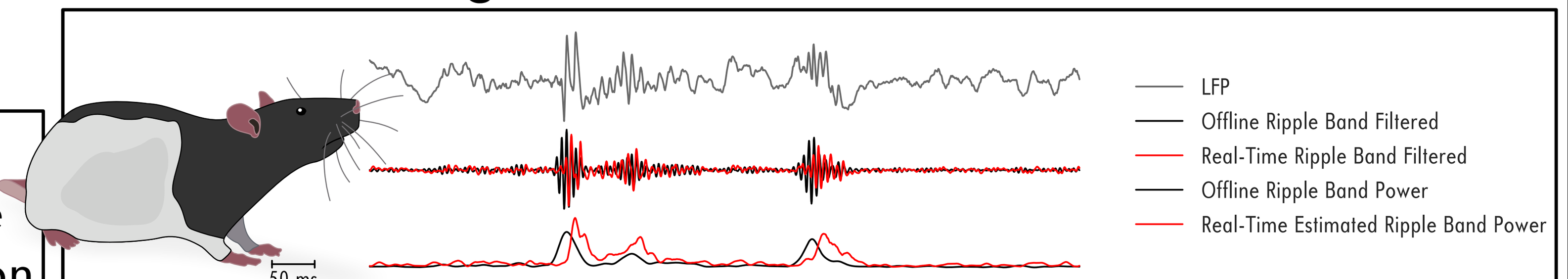


Figure adapted from Colgin Nature Reviews Neuroscience 2016

Why do we care about them?

The CA1 neurons active during a SWR can be the same ones active while an animal is going through a sequential, hippocampal task (e.g. spatial navigation). This implies that SWRs are associated with a subject **replaying a past experience**. This association has been causally linked through online detection and disruption of SWR activity.[D] However, temporal importance and null results of ripple contingent disruptions have been shown by Maingret et al. Nature Neuroscience 2016, Kovács et al. PLoS One 2016, etc. indicating selective disruption efficacy quantifications and a widely accessible systems are needed for the dissemination of real-time neural perturbations of SWRs.

Detection Algorithm



Offline

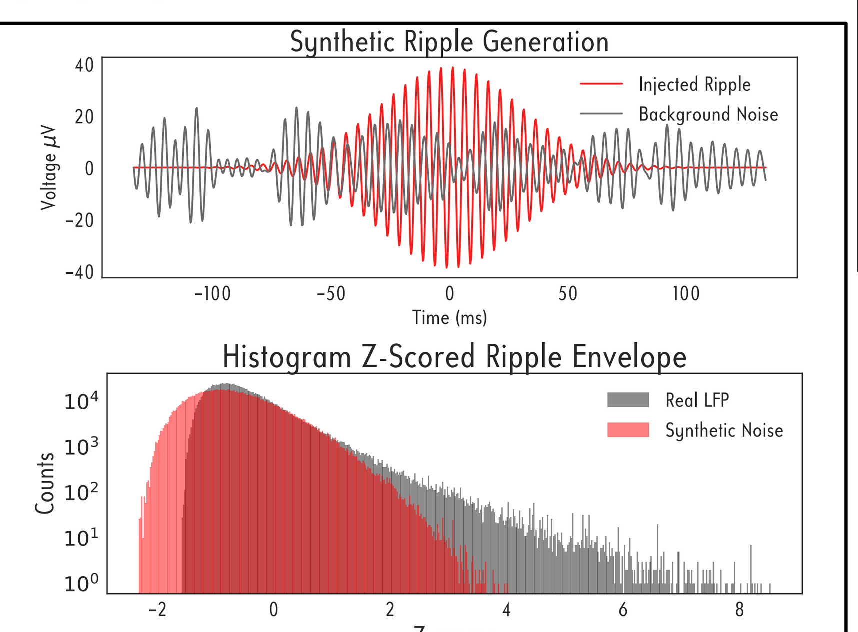
- Raw signal is 400 Hz low pass filtered and decimated
- Ripple band filtering with with forward backward filtering
- Envelope and smooth with Hilbert Transform and Gaussian Kernel (4 ms std)

Online

- Raw signal is 400 Hz low pass filtered and decimated
- Ripple band filtering with causal FIR filter
- Enevelope and smooth with absolute value and low pass FIR filter

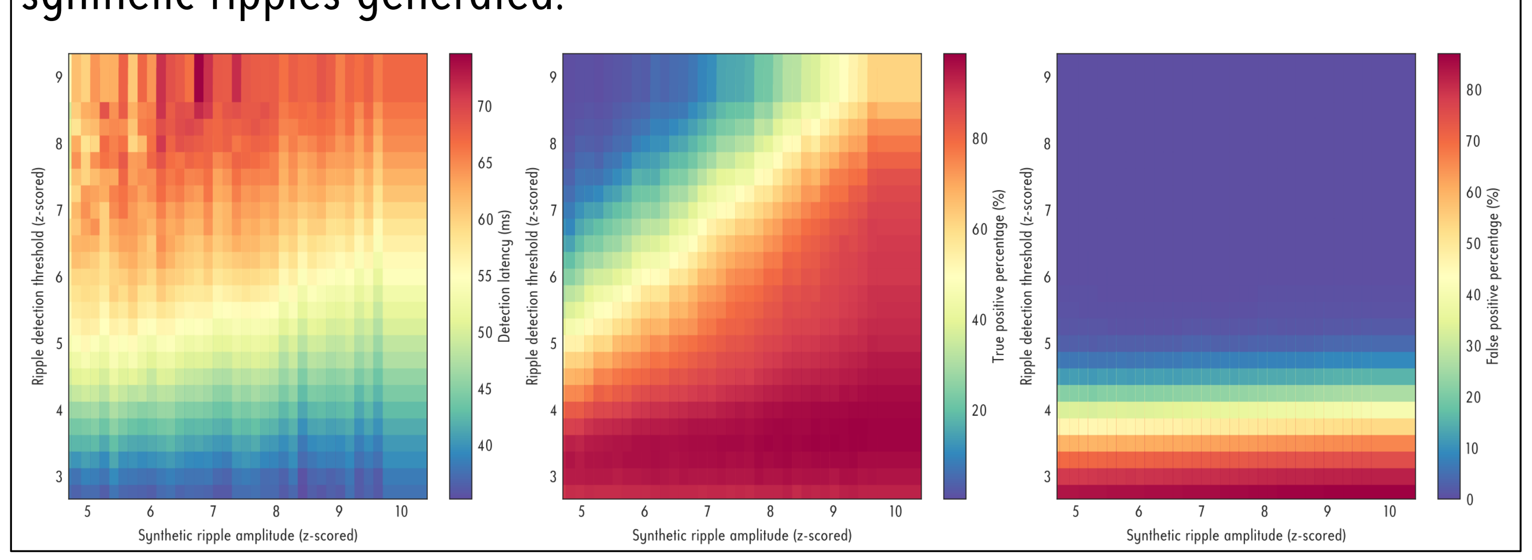
Synthetic Ripple Generation

Synthetic ripple generation:
- Filtering a white noise process into the ripple band
- Normalizing by noise std
- Scaling by ripple band filtered LFP signal std
- Injecting ripple events (sinusoid multiplied by Gaussian pdf multiplied to noise)



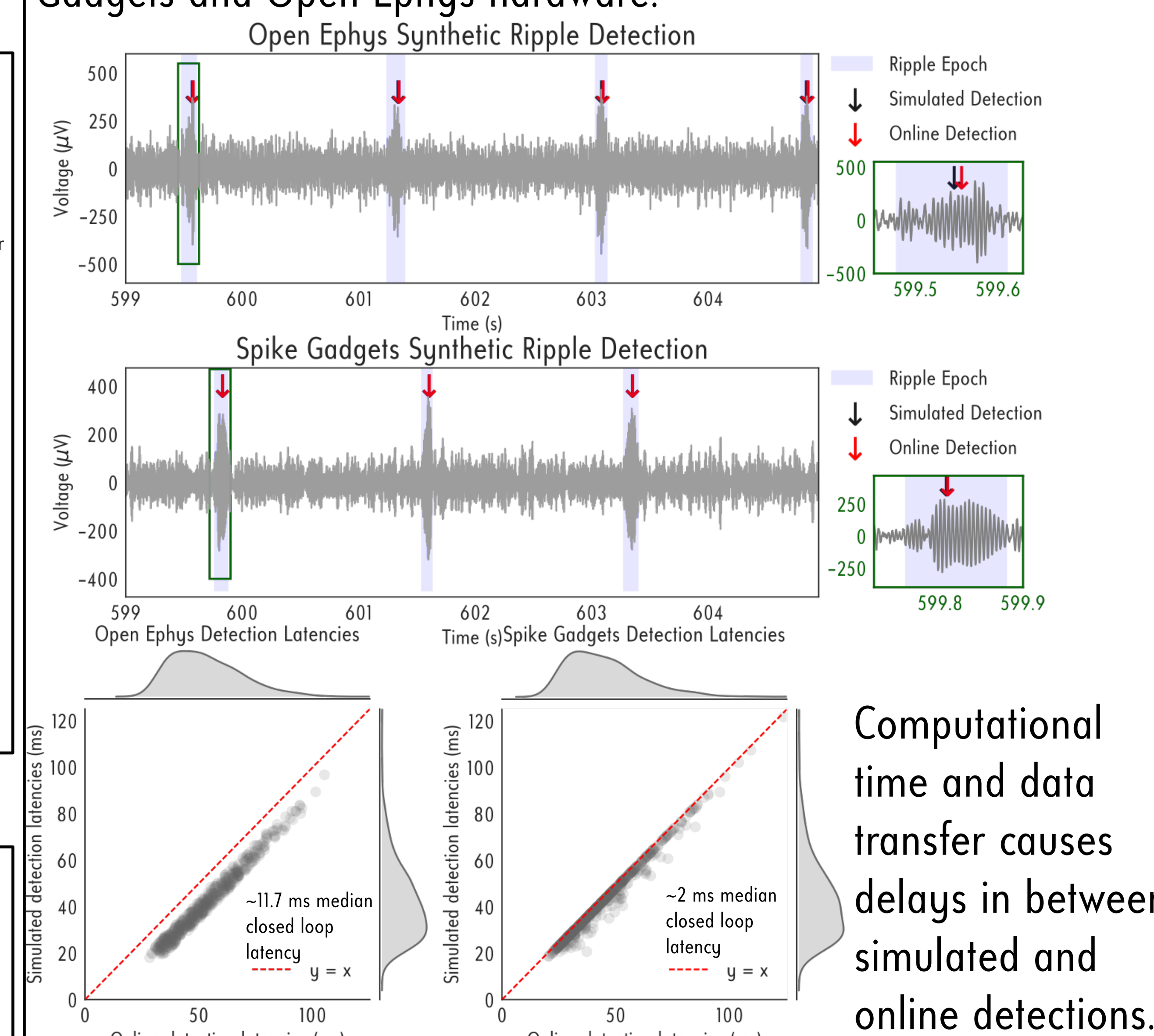
Synthetic Ripple Analysis

Trade-offs between detection latency, true positives, and false positives revealed when varying ripple detection threshold and amplitude of synthetic ripples generated.



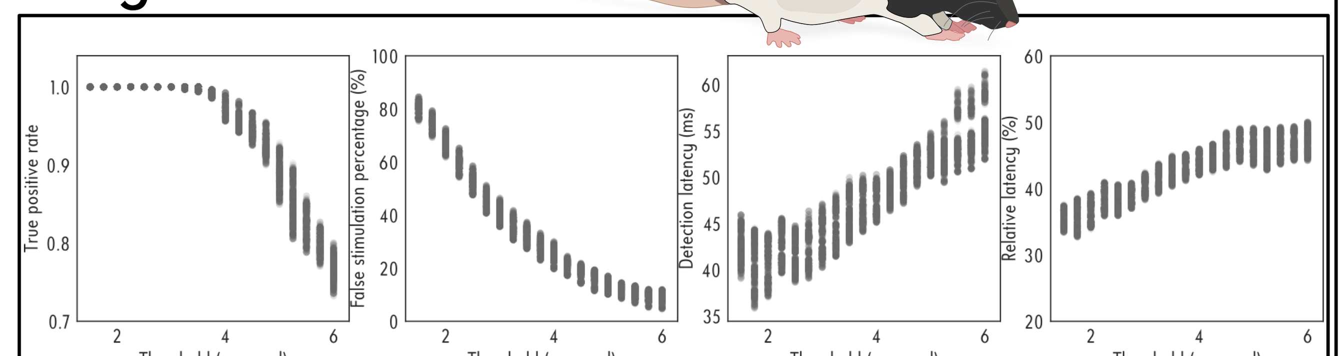
Synthetic Ripple Detections

Accurate real-time detections of synthetic signal using both Spike Gadgets and Open Ephys hardware.

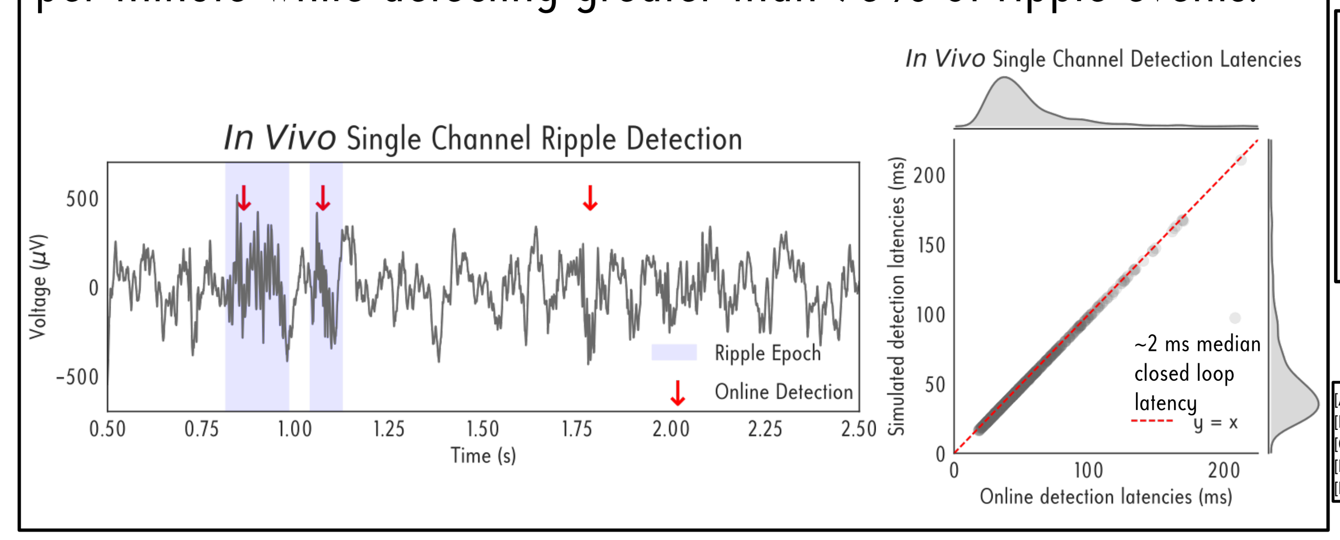


Computational time and data transfer causes delays in between simulated and online detections.

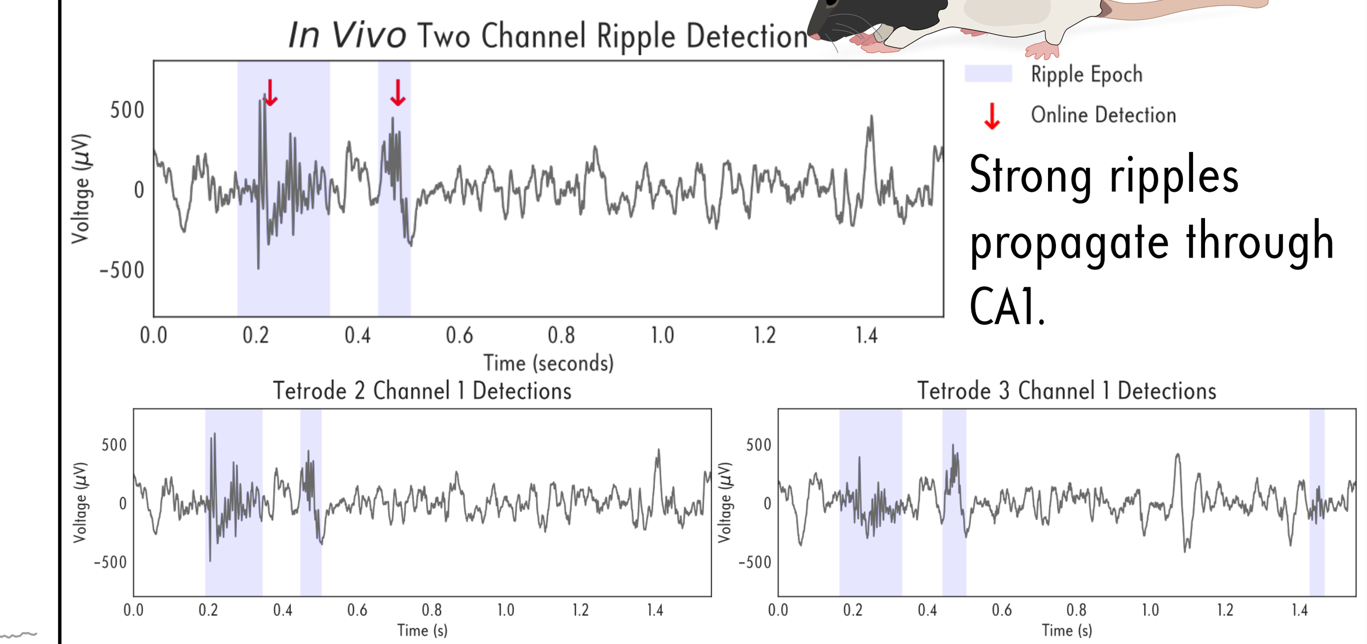
Single Channel *In Vivo*



Algorithmic evaluations reveal a threshold of 4 standard deviations above the mean will report ~4.7 false detections per minute while detecting greater than 95% of ripple events.



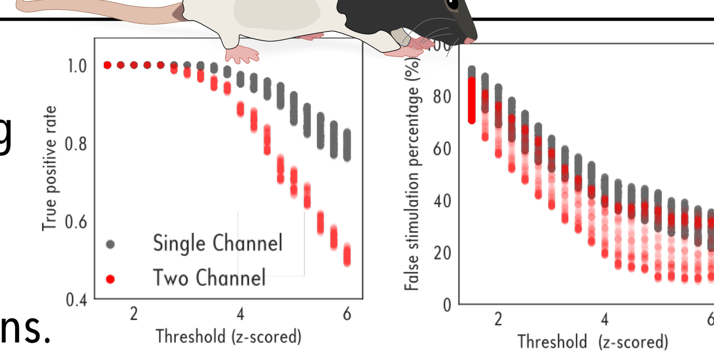
Mutlichannel Algorithm

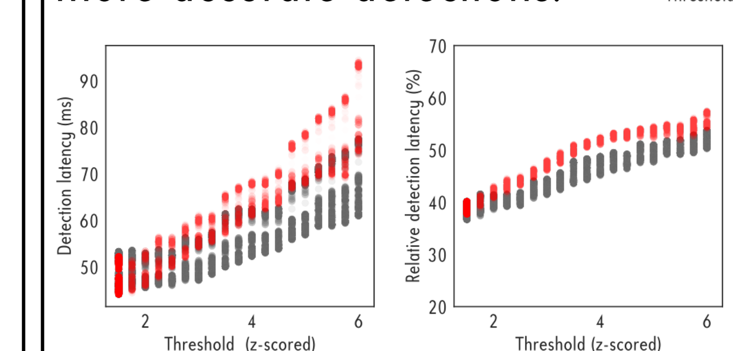


Canonical definition redefined to be ripple epoch overlaps. Real-time algorithm requires multiple channels to cross threshold.

Multichannel *In Vivo*

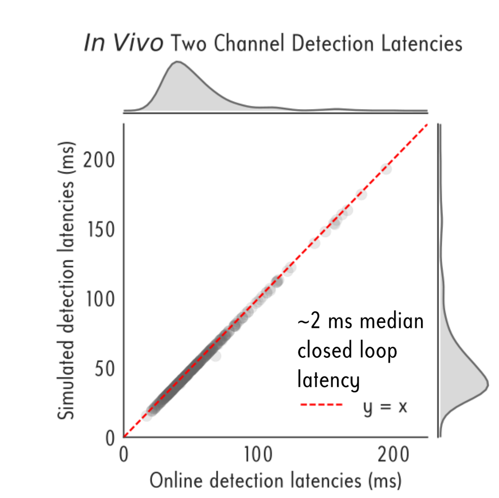
True and false positive rates reveal that adding a second channel to detection can acheive more accurate detections.





However, latency variance and overall value increase with an added channel. Relative latencies remain clustered.

Overall, a second channelimproves acheives more selective (~10 false detections per minute) yet specific detections (>98% TPR) at lower thresholds (3) while maintaining latency and not adding significant software processing time.



Discussions and Conclusions

- Threshold parameter space revealed tradeoffs and enabled algorithmic improvements.
- Intrinsic latencies with LFP event detection isolated.
- Further algorithmic modifications (e.g. false detection) channel can improve accuracy.
- Faster data transfer hardware can get sub-millisecond closed-loop latency
- Relative latency and unit content of ripples may contribute to behavioral alterations after neural perturbations.

Future Works

Future workes involve integrating system with existent spike detector within Trodes software suite. Additionally, we aim to integrate the detection module on-board a wireless for embedded closed-loop neural interactions.

References

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