Low Latency, Closed-Loop, Real-Time Hippocampal 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 **low closed-loop latency** (~2 ms) along with **low overall detection latency** (~35-60 ms) and **accurate *in vivo* detections** (<5 false detections per minute and >0.95 true positive rate). Overall, our system is capable of disrupting more than half of a SWR.

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 and last ~100 ms.[A],[B],[C]

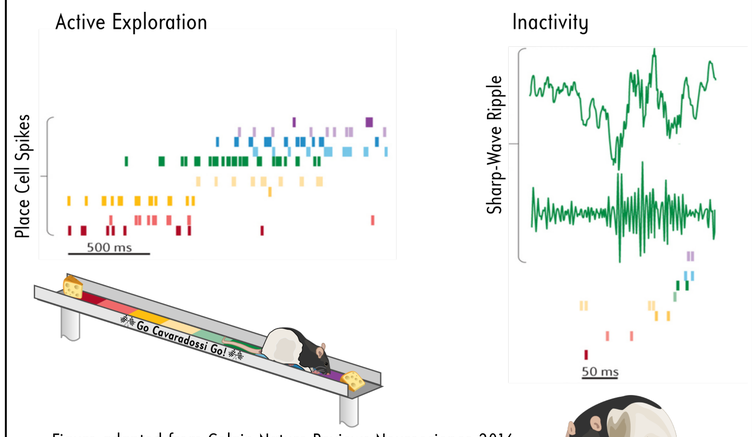


Figure adapted from Colgin Nature Reviews Neuroscience 2016

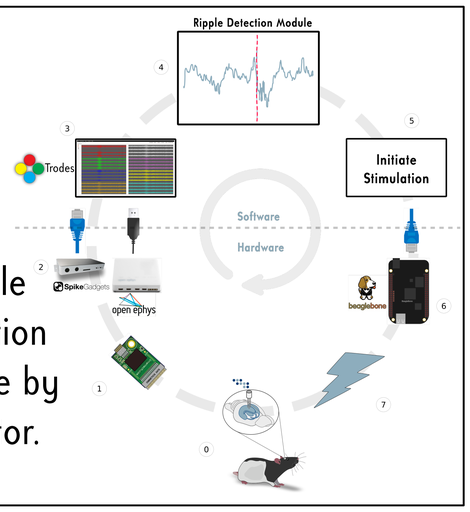
Why do we care about them?

The CA1 neurons active during a SWR can be the same ones active while an animal is going through a sequential task (e.g. spatial navigation). This implies that SWRs atre associated with a subject **replaying a past experience**. This association has been causall linked through online detection and disruption of SWR activity.[D] However, null results have been found by Kovács et al. PLoS One 2016 with ripple disruption indicating that further studies inverstigating selective disruption of SWR complexes are needed.

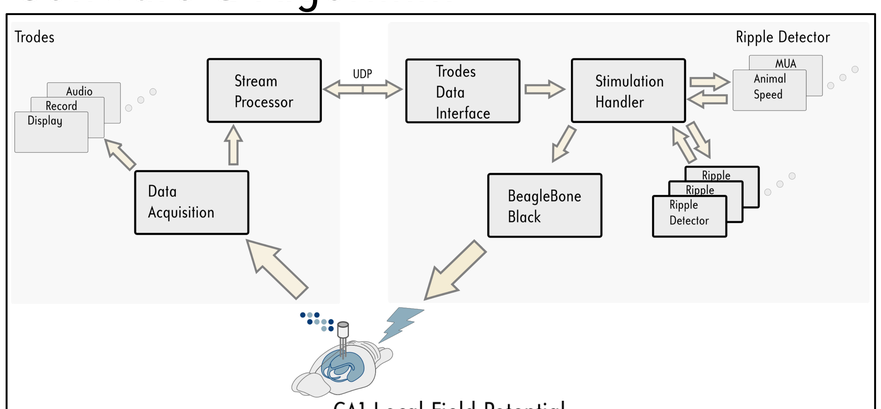
System Architechture

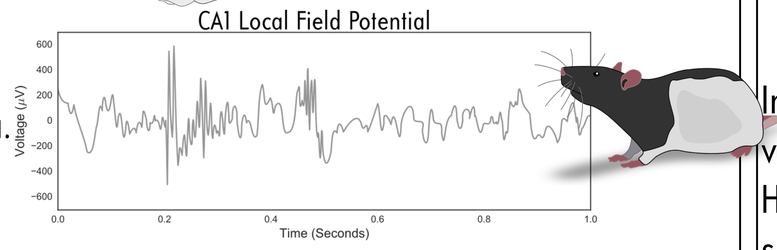
Neurœlectrophysiological recordings from CA1 is sent to a computer. [0-2].

Trodes software is used for data acquisition. Our module detects and initiates disruption pulses for intervention done by microcontroler and stimulator. [4-7].



Software & Algorithm

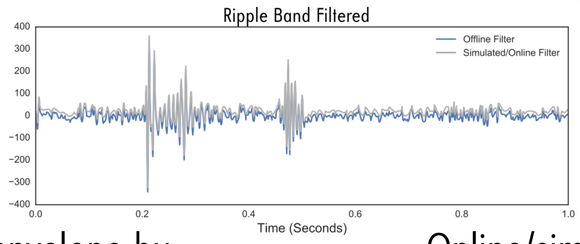




400 Hz LPF data.

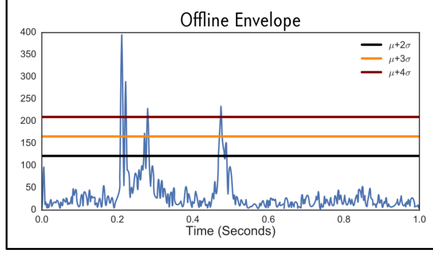
Signal is filtered into ripple band frequencies, 150-250 Hz.

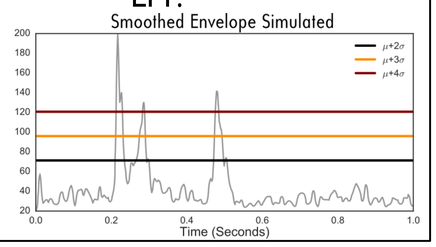
Causal filters in the online and simulated cases cause a delay to the signal.



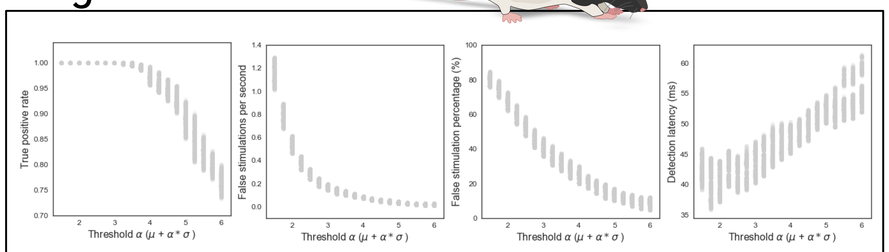
Offline envelope by Hilbert Transform and Gaussian kernel smoothing (4 ms std).

Online/simulated envelope and smoothing by absolute value and LPF.

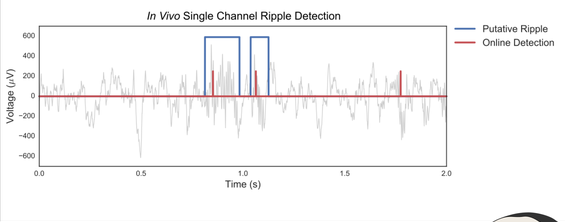


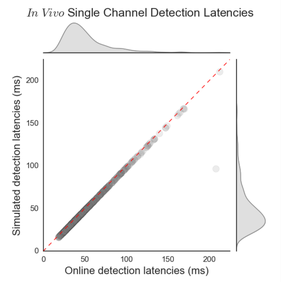


Single Channel *In Vivo*

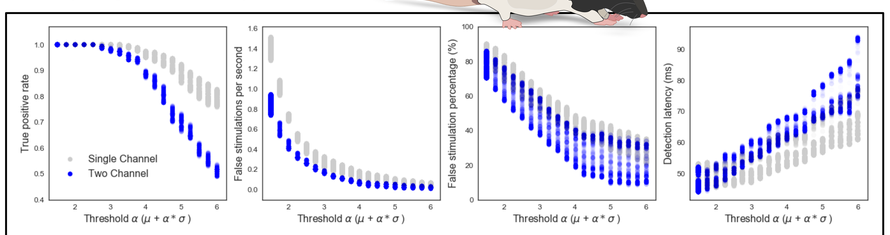


Algorithmic evaluations reveal a threshold of 4 standard deviations above the mean will report ~4.7 false detections per minute while detecting greater than 95% of ripple events.

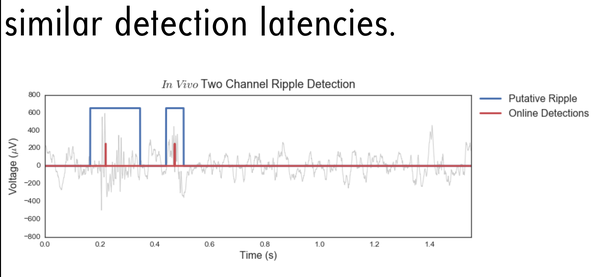


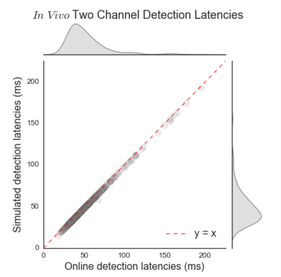


Two Channel *In Vivo*



In the multichannel case, we enable multiple channels to vote on ripple events prior to sending a stimulation pulse. Higher accuracy is achievable at lower thresholds with similar detection latencies.





Conclusion & Future Works

We have built an open-source, closed-loop system for online SWR detection. We have evaluated algorithmic performance and identified tradeoffs that impact efficacy of ripple disruptions. Future works involve lowering false detection counts through algorithmic improvements (e.g. adding a false stimulation detection channel and adding real-time threshold timing requirements).

References

[A] Colgin, Laura Lee. "Rhythms of the hippocampal network." Nature Reviews Neuroscience (2016).
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[D] Jadhav, Shantanu P., et al. "Awake hippocampal sharp-wave ripples support spatial memory." Science 336.6087 (2012): 1454-1458.
[E] Sethi, Ankit, and Caleb Kemere. "Real time algorithms for sharp wave ripple detection." Engineering in Medicine and Biology Society (EMBC).....