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** (<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]

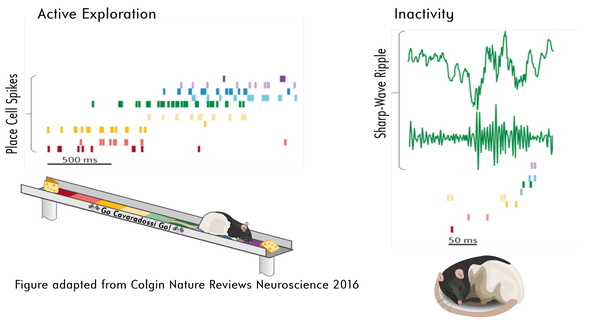
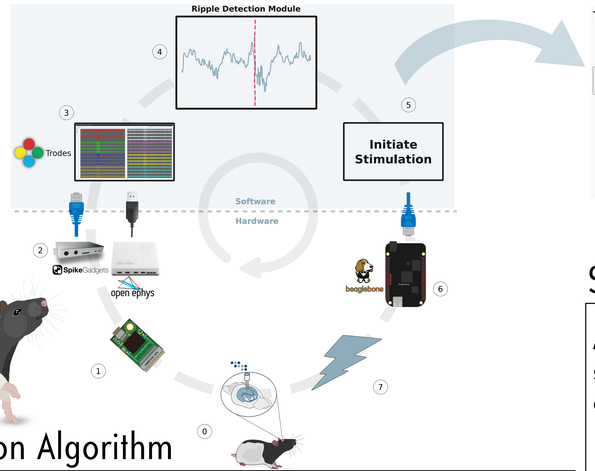


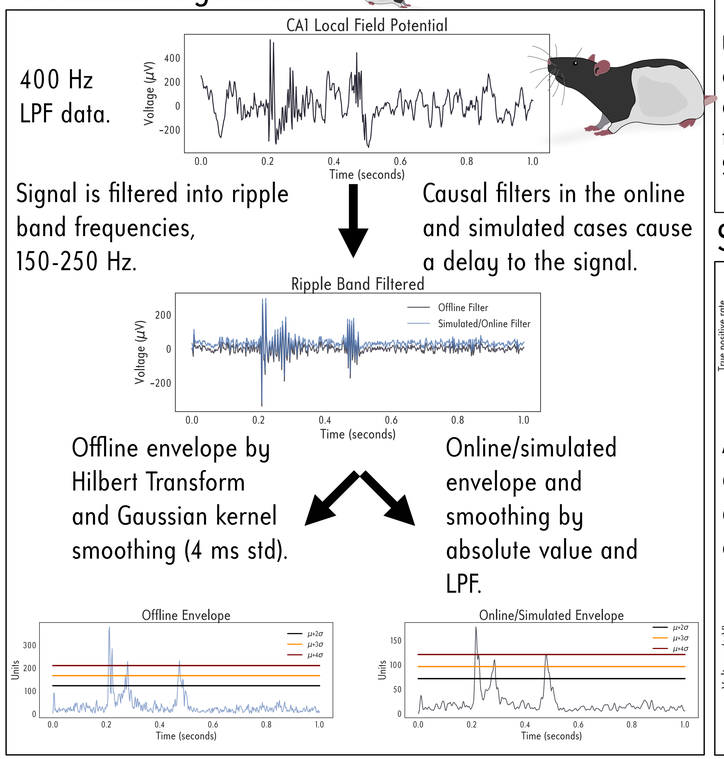
Figure adapted from Colgin Nature Reviews Neuroscience 2016

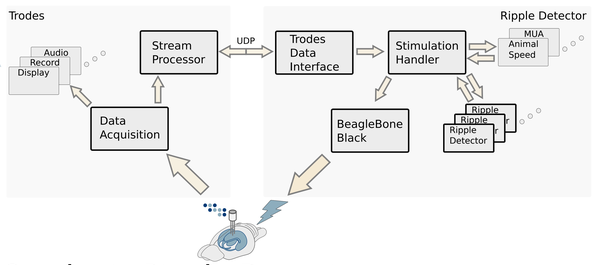
Why do we care about them?

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 and Kovács et al. PLoS One 2016, respectively, indicating selective disruption efficacy quantifications are required.



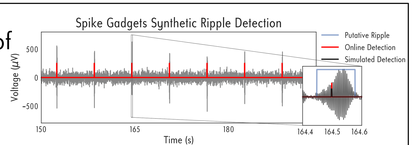
Detection Algorithm



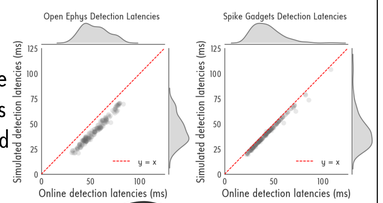


Synthetic Ripple Detections

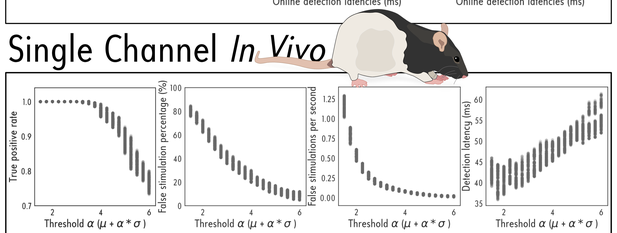
Accurate detections of synthetic signal with closed-loop latency.



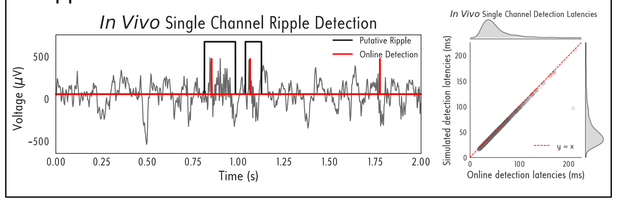
USB and ethernet cause delays in between online and simulated detections for Open Ephys (left) and Spike Gadgets (right).



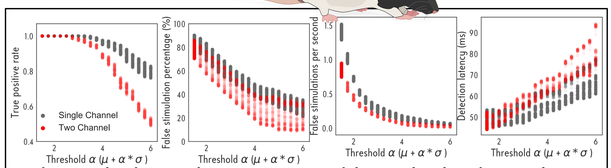
Single Channel *In Vivo*



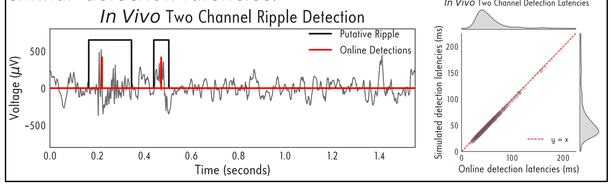
Algorithmic evaluations reveal a threshold of 4 standard deviations above the mean will report ~4.7 false detections per minute while detecting greater than 95% of ripple events.



Two Channel *In Vivo*

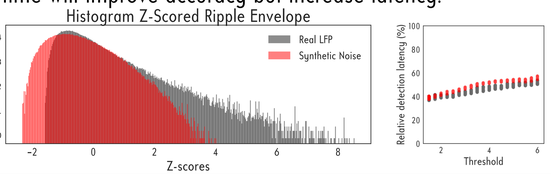


In the multichannel case, we enable multiple channels to vote on ripple events prior to sending a stimulation pulse. Higher accuracy is achievable at lower thresholds with similar detection latencies.



Discussion

System performance depends on ripple band dynamics. Due to timing requirement in ground truth definition, detecting threshold crossings online will result in false detections. Adding timing in real-time will improve accuracy but increase latency.



Conclusion & Future Works

We have built an open-source, closed-loop system for online SWR detection and evaluated algorithmic performance. Furthermore, we identified tradeoffs that impact efficacy of ripple disruptions. Future works involve lowering false detection counts and integrating with existing Trodes camera module and spike detector module for temporally specific detections and multi-unit activity based detections, respectively.

References

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