A Machine Learning Approach to Improving the Disruption of Sharp-Wave Ripples

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Question to Answer.
Can we improve current algorithms for sharp-wave ripple complex detection and disruption by uncovering predictive features of these complexes, and what approaches should we take to do so?

1 Thesis

It has been established that there exists a hippocampal circuit, in which different regions within the circuit lead electrophysiological activity in others. Specifically, there exists theoretical evidence alongside *in vitro* and *in vivo* correlations in support of signatures within this circuit leading sharp-wave ripple complexes (SWRs), which are typically viewed as indicators of memory consolidation and recall. However, integration of predictive signatures into detection and disruption algorithms for complete interrogation of SWRs is lacking. By exploring electrophysiological signals from different regions within the hippocampus, we hope to construct a more accurate algorithm for SWR detection and disruption. Ideally, we would uncover some predictive signature that will enable us to interact with the entirety of an SWR event, as state of the art algorithms only allow disruption of $40\% - 60\%$ of the events (Shay's paper).

2 Motivation

Interference of sharp-wave ripple complexes (SWRs) by means of electrical stimulation has lead to powerful revelations in the processes of learning and memory — specifically, how one consolidates something learned in a previous training session. By disrupting these complexes, we have effectively been able to impair memory consolidation, ultimately preventing learning of a task from reaching a level of proficiency equivalent to those observed in an unimpaired rodent. However, current methodologies to detect and subsequently disrupt SWRs miss the leading $40 - 60\%$ of the SWR event, making it difficult to prove the impact of a SWR complex on the process of learning.

3 Methods

3.1 Required Resources

For the purposes of this project, it is imperative we have a strong computing system set up. In order to maximize efficiency, it would be ideal we run our algorithms on at least one nVidia GPU (we have two GTX 1080s at the moment, which is more than perfect), and a desktop with the capabilities of powering said GPUs (currently debugging systems we already own — may need to build a new system based on the number of PCIE ports we have, and potentially upgrading power supplies). This would enable the initial training of predictive networks on electrophysiological data we already have access to, courtesy of the Buszaki lab at NYU. Having this hardware, and the provided data, will enable the first part of this project.

From there, in order to test the *in vivo* performance of our predictive algorithm (once it is built), we will need materials of a different sort. By the nature of *in vivo* testing, at least one rodent (ideally 3-4) will be needed to be implanted with a microdrive. The Kemere lab builds microdrives in house, and thus we already possess the materials necessary to construct such an implant (i.e. several 3D printers, tubing of gauges ranging from 30g to 25g, etc). However, we will need to special order stimulation electrodes, the design of which we already have standardized from previous implants.

3.2 Literature Review

1. Glaser JI, Chowdhury RH, Perich MG, Miller LE, Kording KP. 2017. Machine learning for neural decoding. arXiv. https://arxiv.org/abs/1708.00909.

2. Fazle Karim, Somshubra Majumdar, Houshang Darabi, and Samuel Harford. Multivariate lstm-fcns for time series classification. ArXiv, 2018.

3. Fernández-Ruiz et al., 2017 A. Fernández-Ruiz, A. Oliva, G.A. Nagy, A.P. Maurer, A. Berényi, G. Buzsáki Entorhinal-CA3 dual-input control of spike timing in the hippocampus by theta-gamma coupling Neuron, 93 (2017), pp. 1213-1226.e5

4. Oliva, A., Fernández-Ruiz, A., Buzsáki, G. & Berényi, A. Role of hippocampal CA2 region in triggering sharp-wave ripples. Neuron 91, 1342–1355 (2016).

5. Colgin, L.L. Rhythms of the hippocampal network. Nat. Rev. Neurosci. 17, 239–249 (2016).

6. Makarov, Valeri A., Julia Makarova, and Oscar Herreras. "Disentanglement of local field potential sources by independent component analysis." Journal of computational neuroscience 29, no. 3 (2010): 445-457.

7. Łęski, Szymon, Ewa Kublik, Daniel A. Świejkowski, Andrzej Wróbel, and Daniel K. Wójcik. "Extracting functional components of neural dynamics with Independent

Component Analysis and inverse Current Source Density." Journal of Computational Neuroscience 29, no. 3 (2010): 459-473.

3.3 Advisor Meeting Frequency

We plan on meeting once every other week, as a team (Dr. Kemere and Shay, perhaps James eventually).

3.4 Anticipated Segmentation

1. Replicate others' results
2. Explore machine learning approaches for time series classification
3. Implement said algorithms for time series classification
4. Evaluate realtime performance
5. Fine-tune algorithms and explore other brain regions/algorithmic approaches, as needed

Once the above has been iterated through several times, do the following:

1. Purchase rodents and silicon probes
2. Implement realtime algorithms based on above list
3. Construct implant
4. Conduct in vivo investigation

4 Written Work Deadline

April 30^{th}, 2019

5 RURS Abstract Deadline

March 31^{st}, 2019

6 Anticipated Difficulties

1. Narrowing our focus to a specific network architecture
2. Comprehend the computational methodologies at a high level
3. Time management ☹

7 Proposed Timeline

Jan. 12	Computing Setup
Next week	Contact Collaborators for additional behavioral data (requires completion of ICA)
Jan. 17	Sharp-Wave and Ripple correlation
Jan. 28	Replicate results showing CA2 preceding CA1 during slow wave non-REM sleep
Jan. 31	Perform realtime performance check of above
Feb. 10	Come up with multivariate time series prediction plan
Feb. 24	Some form of ripple prediction (Start with non-REM; Explore prediction of next theta event and gamma sequence)
Mar. 4	Perform realtime performance check of above
Mar.-May	Fine-tuning & exploring predictive algorithms
Summer?	Implant rodent, and perform in vivo testing