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Structured Dictionary Learning and its Applications in Neural Recording

Dissertation Defense by

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Abstract

Widely utilized in the field of neuroscience, implantable neural recording devices could capture neuron activities with an acquisition rate on the order of megabytes per second. In order to efficiently transmit neural signals through wireless channels, these devices require compression methods that reduce power consumption. Although recent Compressed Sensing (CS) approaches have successfully demonstrated their power, their full potential is yet to be explored, particularly towards exploring a more efficient representation of the neural signals. As a promising solution, sparse representation not only provides better signal compression for bandwidth/storage efficiency, but also leads to faster processing algorithms as well as more effective signal separation for classification purpose. However, current sparsity - based approaches for neural recording are limited due to several critical drawbacks: (i) the lack of an efficient data-driven representation to fully capture the characteristics of specific neural signal; (ii) most existing methods do not fully explore the prior knowledge of neural signals (e.g., labels), while such information is often known; and (iii) the capability to encode discriminative information into the representation to promote classification.

Using neural recording as a case study, this dissertation presents new theoretical ideas and mathematical frameworks on structured dictionary learning with applications in compression and classification. Start with a single task setup, we provide theoretical proofs to show the benefits of using structured sparsity in dictionary learning. Then we provide various novel models for the representation of a single measurement, as well as multiple measurements where signals exhibit both with-in class similarity as well as with-in class difference. Under the assumption that the label information of the neural signal is known, the proposed models minimize the data fidelity term together with the structured sparsity terms to drive for more discriminative representation. We demonstrate that this is particularly essential in neural recording since it can further improve the compression ratio, classification accuracy and help deal with non-ideal scenarios such as co-occurrences of neuron firings. Fast and efficient algorithms based on Bayesian inference and alternative direction method are proposed. Extensive experiments are conducted on both neural recording applications as well as some other classification task, such as image classification.

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