様式３

論　文　内　容　の　要　旨

氏　名　（　白石　祥之　）	
論文題名	Understanding the non-linear functional systems of neural networks at multiple scales with dimensionality reduction techniques (次元圧縮法による神経ネットワークの非線形機能システム解釈)

論文内容の要旨

An objective of systems neuroscience is to clarify the functional significance of single neuron and/or neural networks, and to identify task-related neural activities in real brains or in artificial neural networks at various hierarchies. The input-output relationship of networks are usually nonlinear. There are a lot of internal and measurement noise in the neuronal response measurements. Moreover, neuronal outputs are usually high-dimensional. These factors make it difficult to interpret the functional significance of the corresponding neural networks. Applying dimensionality reduction techniques to the high-dimensional neural data will make the underlying mechanisms and functional significance of the neural networks simple and understandable, and remove noise components. This framework will work in various hierarchical layers, such as responses of a single neuron, of small neural networks, and of whole brain. To examine this hypothesis, in this study, I applied dimensionality reduction techniques to two distinctive levels: 1) reverse correlation analysis for a single unit activity of a Deep Convolutional Neural Network (DCNN), which is considered as a good model for the ventral visual pathway and 2) applied dynamic mode decomposition (DMD) analysis to the electrocorticography (ECoG) recorded from electrodes placed just above the motor cortex. Using the reverse correlation technique, I successfully reconstructed spatial profiles of receptive field of DCNN units as clusters of excitatory and suppressive linear sub-filters. Using the sub-filters with a simple liner-nonlinear model, I predicted responses of the units to Cartesian gratings and natural image stimuli at least to some extent. However, the model did not work at output layers in DCNNs, which may be attributed to the arbitrarily chosen nonlinear function. In contrast, DMD analysis successfully extracted ECoG patterns corresponding to a particular motor movement task by the Koopman operator as the composition operator of dynamics and observation function. In the DMD analysis, system nonlinearities were identified in a data-driven manner, and no arbitrary nonlinear functions needed to be introduced. Taken together, the findings strongly suggested that dimensionality reduction techniques, especially the DMD analysis, can be effective tools for understanding the functional significance of neural networks at various levels of hierarchy.

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論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

白石祥之は、観測データが高次元で、かつノイズが生じやすい非線形システムである神経システムの推定に対する手法として、次元圧縮法の活用可能性とその限界について研究を行った。先行研究では非線形システムに対する推定手法として、線形システムへの近似が行われてきたが、この近似による予測性能から限界が見えていた。一方で、別の推定手法として、線形システムへの近似に対する恣意的な非線形変換を導入するという方策が視覚システムの解明に用いられてきたが、実験の困難性からその方策の限界が見極められずにいた。ここに対して白石は実験系を深層畳み込みニューラルネットワークに移植することでこの方策の有用性について研究を行った。ここに関しても、恣意性などの限界が見えてきたことから、これに対する打開策として、非線形システムの状態量から観測を生み出す観測関数のダイナミクスを表す線形システムKoopman作用素の導入を行い、この手法の有用性を示した。よって、博士の学位を授与するに値するものと認める。