Multilinear neural encoding models capture nonlinearities and contextual influences in cortical responses

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We describe a class of neural encoding models that is expressed in multilinear form. Neural encoding models typically predict a neuron's firing rate from a time-varying stimulus. The parameters of these models reflect the encoding properties of the respective neurons, which in turn may shed light on the function of the corresponding brain area.

We use multilinear methods to extend traditional neural encoding models in various directions: the linear encoding model is extended to include an "input nonlinearity" (a nonlinear transformation of stimulus value applied before temporal filtering [1]); such a nonlinearity is also added to the LNP model [2], resulting in the "NLNP model". In the auditory domain, when STRF models [3] are extended with the input nonlinearity, the resulting structure allows for the identification of new inseparabilities in sound processing (such as inseparabilities in time and sound level) beyond the traditionally studied time-frequency inseparability.

A further multilinear extension to the auditory STRF model results in the "context model", an easily interpretable model that includes context effects such as cross-frequency suppression and short-term stimulus-specific adaptation.

Due to their multilinear structure, these models benefit from a sound alternating-least-squares estimation procedure. We place the models in a probabilistic framework, so that the estimation procedure can be extended to include regularization methods, and methods for estimating error bars around the estimated parameters. Such error bars are important when interpreting the models and relating them to neural function.

Model fits on rodent somatosensory and auditory cortex data illustrate the interpretability and utility of the multilinear model. In somatosensory cortical neurons, fits of the simplest models show a bowl-shaped input nonlinearity, invariant to the direction of whisker displacement. More complex versions of the model augment this picture through the inclusion of a slower, direction-sensitive response. In auditory cortical neurons, the input nonlinearity models have an improved predictive power over STRF models. They reveal inseparabilities in time and sound level, and in frequency and sound level. The context model shows a strong dependency of firing rate on the context of a sound, i.e. on nearby frequencies and recent stimulus history; including these stimulus-stimulus interactions results in a substantial increase in predictive power. The multilinear models provide a powerful, rich and compact description of dynamic neuronal responses.

References

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