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Improving Brain Simulation Accuracy: Sensitivity Analysis and Realistic Time Delays in Neural Mass Models

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The classical Jansen and Rit Neural Mass Model has been a cornerstone in computational neuroscience, offering valuable insights into brain activity and neural dynamics. However, traditional implementations of this model often fall short in capturing the complexities of real neural systems, particularly in terms of conduction delays and parameter sensitivity.

To address these limitations, we have reformulated the Jansen and Rit Neural Mass Model using Algebraic Random Differential Equations. The Local Linearization Method was employed as the numerical integrator due to its established advantages in efficiency and accuracy over traditional numerical methods. Furthermore, we introduced a more realistic modeling framework for distributed conduction delays by considering axonal properties such as length, diameter, myelination, and g-ratio. This innovative approach enables the simulation of thousands of interconnected cortical columns, achieving more accurate representations of neural dynamics.

A key aspect of our study involved conducting a comprehensive sensitivity analysis to evaluate the robustness and reliability of the model. To achieve this, we combined Machine Learning approaches using decision trees and Random Forests, focusing on characteristics that define healthy and epileptiform rhythms, such as amplitude, frequency, and the number of peaks per period. This analysis identified the most influential parameters affecting neural dynamics, providing critical insights into the factors essential for accurate simulations. By systematically varying each parameter and observing the resulting changes in the model's output, we identified both excitatory and inhibitory postsynaptic potentials (EPSP and IPSP, respectively), the inflection points of the sigmoid function (v0), and the axonal diameter (diam) as the most important. EPSPs are crucial for driving neural activity, while IPSPs are essential for regulation and stability. The parameter v0 can shift the entire sigmoid function along the membrane potential axis, changing the firing rate for a given membrane potential. Axonal diameter influences multiple aspects of neural dynamics; even small changes in this parameter can lead to significant alterations in model outputs, such as firing rates, oscillatory patterns, and synchronization. These findings not only validate our modeling approach but also highlight areas for further investigation and optimization.

These results highlight the potential of this new approach for advancing our understanding of neural mass models and improving the accuracy of large-scale brain simulations. This work provides a framework for multiscale analysis, allowing the incorporation of real information such as electrophysiology, neurotransmitters, and receptors. It offers a powerful tool for exploring brain activity and understanding neurological diseases, paving the way for new insights and therapeutic strategies.

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