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CYBER SEMINAR SERIES

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Parameter Estimation in Dynamic Models: A Framework for the Investigation of Degeneracy and Unidentifiability

Parameter estimation from observable or experimental data is a crucial stage in any modeling study. The ability of models to make predictions, provide mechanistic explanations, and be useful for decision-making all depends on the accuracy and reliability of the parameter estimation process. Several difficulties conspire against our ability to successfully achieve this goal. These difficulties are data-related (lack of access to all state variables, inconsistent gaps across trials), computational (algorithmic nature), statistical (data is noisy and therefore one can at best expect to estimate distributions of parameter values around a ``true" mean), and structural (degeneracy, mathematical nature). Identifiability refers to one's ability to uniquely estimate the model parameters from the available data. Structural unidentifiability in dynamic models, the opposite of identifiability, is associated with the notion of degeneracy where multiple parameter sets produce the same pattern, therefore the inverse function of determining the model parameters from the data is not well defined. Degeneracy is not only a mathematical property of models but it has also been reported in biological experiments of neuronal oscillations. Classical studies on structural unidentifiability focused on the notion that one can at most identify combinations of unidentifiable model parameters. We have identified a different type of structural degeneracy/unidentifiability present in a family of models, which we refer to as the Lambda-Omega models (extensions of the classical lambda-omega models). We show that the Lambda-Omega models feature infinitely many parameter sets that produce identical stable oscillations, except possible for a phase-shift (reflecting the initial phase). These degenerate parameters are not identifiable combinations of unidentifiable parameters as is the case in structural degeneracy. In fact, the number of model parameters in the Lambda-Omega models is minimal in the sense that each one controls a different aspect of the model dynamics and reducing the number of parameters would reduce the dynamic complexity of the system. We argue that the family of Lambda-Omega models serves as a framework for the systematic study of degeneracy and identifiability in dynamic models and for the investigation of the interplay between structural and other forms of unidentifiability resulting from the lack of information from the experimental/observational data. Our results have implications for the development of parameter estimation algorithms and the development of algorithmic tools for data-driven discovery of nonlinear dynamics governing the generation of these data.

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