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Editorial: Data Assimilation and Control: Theory and Applications in Life Sciences

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Editorial on the Research Topic

Data Assimilation and Control: Theory and Applications in Life Sciences

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The understanding of complex systems, such as insecticides or the mammalian heart, is a key element to predict and control the system's dynamics. To gain deeper insights into the underlying actions of complex systems, today, more and more data of diverse types are analyzed that mirror the systems dynamics, whereas system models are still hard to derive. Consequently, developing techniques that permit the construction of models which are well-adapted to observed data is one of the great challenges. To match system models with diverse experimental data, data assimilation and control theory provide important techniques. They use a combination of observations and models to achieve optimal fitting of model parameters, providing optimal forecast estimations or control of the system's dynamics to make the system perform a specific task. The present Research Topic (and the corresponding e-book) brings together both recent theoretical work and applications in life sciences.

Typical research in the life science aims to understand the complex system under study involving diverse system models and observations. If a model of the system dynamics exists, it is insightful to validate the model by comparing the model's dynamical solutions with observations, either quantitatively or qualitatively. For instance, one may consider the experimental setup of a control experiment in a real-world system and simulate the experimental setup in the model framework by computing the model system's response to an equivalent external stimulation. Kasap and van Opstal have chosen this approach and simulated the control of eye saccades by electric stimulation. Their study shows good qualitative and quantitative agreement between the model dynamics and observations, validating their model. Since their effective model describes well major observation features, the successful model features can be interpreted as the major features in the brain structure.

Another approach may aim to improve or extract a model by observations. For instance, in psychology, the statistical ex-Gaussian distribution describes well the subjects' reaction times. To construct a statistical model of cognitive processes, it is important to estimate parameters of the ex-Gaussian distribution in an efficient way. Moret-Tatay et al. have developed a software library to efficiently estimate the coefficients of the ex-Gaussian distribution. Similarly, Shabbir et al. fit statistical distributions to experimental gene data to understand better why the Asian corn borer can develop resistance to genetically modified maize that is supposed to be toxic to the insect. Both latter studies aim to understand complex behavior by identifying statistical models.

Dynamical neural models that describe mathematically the temporal evolution of neural populations play an important role in neuroscience. Escuain-Poole et al. consider a dynamical model of neural populations in the brain, that allows to explain the electroencephalogram (EEG) measured on the scalp, i.e., outside of the brain. The work shows in several theoretical studies how to estimate brain model parameters from synthetic EEG-data that are observed on the head surface. This estimation is done by the well-known Unscented Kalman filter. A similar analysis approach is *statistical data assimilation* that allows to estimate model parameters and system forecasts. Typically, statistical data assimilation provides efficient tools to estimate the posterior probability density function of model parameters. In the article of Miller et al. the authors successfully performed parameter estimations of an avian song model by statistical data assimilation and predicted the evolution of optimal model solutions.

Typical dynamical models are differential equation systems whose parameters are estimated. In the last decades, more and more of such differential equation models have been extended or even replaced by methods borrowed from artificial intelligence, such as artificial neural networks. Herzog et al. show how to estimate an underlying chaotic dynamical model by a combination of a convolutional neural network and a conditional random network. The neural network is fit to synthetic data generated from a heart tissue model. The authors show in detail that the neural network allows to faithfully reproduce the dynamics of single elements of the underlying model.

Parameter estimation is an important application of data assimilation, as demonstrated in the contributions described above. Beyond this, data assimilation techniques also provide improved forecasts. For instance, in meteorology, the solution of an atmospheric physical model represents a short-time forecast, e.g., a spatial distribution of atmospheric state variables after 1 h. A subsequent data assimilation step transforms this spatial distribution to a new spatial distribution (called analysis) that is closer to observations. One of the major aims in atmospheric data assimilation is to obtain free forecasts, i.e., long-time model solutions with the analysis as initial condition, that accurately predict the weather. Hence, in this context, data assimilation provides optimal initial conditions for forecasts. One of the limits of standard data assimilation techniques is the condition that observations must be sufficiently dense in reasonably long fixed intervals. Potthast and Welzbacher have studied in detail a rapid data assimilation technique based on an ensemble Kalman filter that considers observations in very short time intervals. The authors show that the ultra-rapid update of the analysis significantly improves forecasts. Possible applications of the new technique range from meteorology to neuroscience.

More generally, the prediction of neural activity has attracted increasing attention over the last decade. Hutt and Potthast have proposed to forecast the spectral power of forecast time series in certain frequency bands, since it is well-known that the brain encodes and decodes information by oscillations in certain frequency ranges. To this end, the authors have applied a data assimilation cycle utilizing an ensemble Kalman filter and have computed ensemble forecasts and their time-frequency power spectral distributions. It is shown by statistical ensemble verification that these time-frequency distributions of forecasts better explain underlying oscillatory content than forecast time series.

Future research in the field may involve data assimilation of non-local observations from a theoretical perspective and more applications in biology and neuroscience.

AUTHOR CONTRIBUTIONS

AH wrote the Editorial and all authors re-read and edited the manuscript.

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