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Detection of Hidden Additivity and Inference Under Model Uncertainty for Unreplicated Factorial Studies via Bayesian Model Selection and Averaging P. 283-296
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Abstract
The two-way unreplicated layout remains a popular study design in the physical sciences. However, detection of statistical interaction and subsequent inference has been problematic in this class of designs. First, lack of replication precludes inclusion of standard interaction parameters. Second, while several restricted forms of interaction have been considered, existing approaches focus primarily on accept/reject decisions with respect to the presence of interaction. Approaches to estimate cell means and error variance are lacking when the possibility of interaction exists. For these reasons, we propose model selection and averaging-based approaches to facilitate statistical inference when the presence of interaction is uncertain. Hidden additivity, a recently proposed and intuitive form of interaction, is used to accommodate latent group-based nonadditive effects. The approaches are fully Bayesian and use the Zellner–Siow formulation of the mixture *g*-prior. The method is illustrated on three empirical datasets and simulated data. The estimates from the model averaging approach are compared with a customized regularization approach which shrinks interaction effects toward the additive model. The study concludes that Bayesian model selection is a fruitful approach to detect hidden additivity, and model averaging allows for inference on quantities of interest under model uncertainty with respect to interaction effects within the two-way unreplicated design.

Deterministic Sampling of Expensive Posteriors Using Minimum Energy Designs P. 297-308
V. Roshan Joseph, Dianpeng Wang, Li Gu, Shiji Lyu & Rui Tuo

Abstract
Markov chain Monte Carlo (MCMC) methods require a large number of samples to approximate a posterior distribution, which can be costly when the likelihood or prior is expensive to evaluate. The number of samples can be reduced if we can avoid repeated samples and those that are close to each other. This is the idea behind deterministic sampling methods such as quasi-Monte Carlo (QMC). However, the existing QMC methods aim at sampling from a uniform hypercube, which can miss the high probability regions of the posterior distribution and thus the approximation can be poor. Minimum energy design (MinED) is a recently proposed deterministic sampling method, which makes use of the posterior evaluations to obtain a weighted space-filling design in the region of interest. However, the existing implementation of MinED is inefficient because it requires several global optimizations and thus numerous evaluations of the posterior. In this article, we develop an efficient algorithm that can generate MinED samples with few posterior evaluations. We also make several improvements to the MinED criterion to make it perform better in high dimensions. The advantages of MinED over MCMC and QMC are illustrated using an example of calibrating a friction drilling process.

Controlling Sources of Inaccuracy in Stochastic Kriging P. 309-321
Wenjia Wang & Benjamin Haaland

Abstract
Scientists and engineers commonly use simulation models to study real systems for which actual experimentation is costly, difficult, or impossible. Many simulations are stochastic in the sense that repeated runs with the same input configuration will result in different outputs. For expensive or time-consuming simulations, stochastic kriging is commonly used to generate predictions for simulation model outputs subject to uncertainty due to both function approximation and stochastic variation. Here, we develop and justify a few guidelines for experimental design, which ensure accuracy of stochastic kriging emulators. We decompose error in stochastic kriging predictions into nominal, numeric, parameter estimation, and parameter estimation numeric components and provide means to control each in terms of properties of the underlying experimental design. The design properties implied for each source of error are weakly conflicting and broad principles are proposed. In brief, space-filling properties, “small fill distance” and “large separation distance,” should be balanced with replication at distinct input configurations, with number of replications depending on the relative magnitudes of stochastic and process variability. Nonstationarity implies higher input density in more active regions, while regression functions imply a balance with traditional design properties. A few examples are presented to illustrate the results. Supplementary materials providing proofs of the theoretical results and code for comparisons are available online.

Spatial Statistical Downscaling for Constructing High-Resolution Nature Runs in Global Observing System Simulation Experiments P. 322-340
Pulong Ma, Emily L. Kang, Amy J. Braverman & Hai M. Nguyen

Abstract
Observing system simulation experiments (OSSEs) have been widely used as a rigorous and cost-effective way to guide development of new observing systems, and to evaluate the performance of new data assimilation algorithms. Nature runs (NRs), which are output from deterministic models, play an essential role in building OSSE systems for global atmospheric processes because they are used both to create synthetic observations at high spatial resolution, and to represent the “true” atmosphere against which the forecasts are verified. However, most NRs are generated at resolutions coarser than actual observations from satellite instruments or predictions from data assimilation algorithms. Our goal is to develop a principled statistical downscaling framework to construct high-resolution NRs via conditional simulation from coarse-resolution numerical model output. We use nonstationary spatial covariance function models that have basis function representations to capture spatial variability. This approach not only explicitly addresses the change-of-support problem, but also allows fast computation with large volumes of numerical model output. We also propose a data-driven algorithm to select the required basis functions adaptively, in order to increase the flexibility of our nonstationary covariance function models. In this article we demonstrate these techniques by downscaling a coarse-resolution physical numerical model output at a native resolution of 1° latitude×1.25° longitude of global surface CO2 concentrations to 655,362 equal-area hexagons.

Construction of Two-Level Nonregular Designs of Strength Three With Large Run Sizes P. 341-353
Alan R. Vazquez & Hongquan Xu

Abstract
Two-level orthogonal arrays of strength 3 permit the study of the main effects and the two-factor interactions of the experimental factors. These arrays are classified into regular and nonregular designs. Good regular designs are available in the literature for large run sizes that are a power of 2. In contrast, good nonregular designs, which have run sizes that are multiples of 8 and are more flexible alternatives to regular designs, are not available for large numbers of runs because their construction is challenging. In this article, we introduce a collection of strength-3 nonregular designs with large run sizes that, to the best of our knowledge, have not been explored before in the design literature. Using theoretical results and algorithmic approaches, we construct nonregular designs with up to

1280 runs. Our designs fill the gaps between the available strength-3 designs with large run sizes and outperform many comparably sized benchmark designs in terms of the aliasing among the two-factor interactions. We show the applicability of our collection of strength-3 designs using an infrared sensor experiment. Supplementary materials for this article are available online.

A Hierarchical Model for Heterogenous Reliability Field Data P. 354-368

Eric Mittman, Colin Lewis-Beck & William Q. Meeker

Abstract

When analyzing field data on consumer products, model-based approaches to inference require a model with sufficient flexibility to account for multiple kinds of failures. The causes of failure, while not interesting to the consumer per se, can lead to various observed lifetime distributions. Because of this, standard lifetime models, such as using a single Weibull or lognormal distribution, may be inadequate. Usually cause-of-failure information will not be available to the consumer and thus traditional competing risk analyses cannot be performed. Furthermore, when the information carried by lifetime data are limited by sample size, censoring, and truncation, estimates can be unstable and suffer from imprecision. These limitations are typical, for example, lifetime data for high-reliability products will naturally tend to be right-censored. In this article, we present a method for joint estimation of multiple lifetime distributions based on the generalized limited failure population (GLFP) model. This five-parameter model for lifetime data accommodates lifetime distributions with multiple failure modes: early failures (sometimes referred to in the literature as “infant mortality”) and failures due to wearout. We fit the GLFP model to a heterogenous population of devices using a hierarchical modeling approach. Borrowing strength across subpopulations, our method enables estimation with uncertainty of lifetime distributions even in cases where the number of model parameters is larger than the number of observed failures. Moreover, using this Bayesian method, comparison of different product brands across the heterogenous population is straightforward because estimation of arbitrary functionals is easy using draws from the joint posterior distribution of the model parameters. Potential applications include assessment and comparison of reliability to inform purchasing decisions. Supplementary materials for this article are available online.

Image-Based Prognostics Using Penalized Tensor Regression P. 369-384

Xiaolei Fang, Kamran Paynabar & Nagi Gebraeel

Abstract

This article proposes a new methodology to predict and update the residual useful lifetime of a system using a sequence of degradation images. The methodology integrates tensor linear algebra with traditional location-scale regression widely used in reliability and prognostics. To address the high dimensionality challenge, the degradation image streams are first projected to a low-dimensional tensor subspace that is able to preserve their information. Next, the projected image tensors are regressed against time-to-failure via penalized location-scale tensor regression. The coefficient tensor is then decomposed using CANDECOMP/PARAFAC (CP) and Tucker decompositions, which enables parameter estimation in a high-dimensional setting. Two optimization algorithms with a global convergence property are developed for model estimation. The effectiveness of our models is validated using two simulated datasets and infrared degradation image streams from a rotating machinery.

Structured Point Cloud Data Analysis Via Regularized Tensor Regression for Process Modeling and Optimization P. 385-395

Hao Yan, Kamran Paynabar & Massimo Pacella

Abstract

Advanced 3D metrology technologies such as coordinate measuring machine and laser 3D scanners have facilitated the collection of massive point cloud data, beneficial for process monitoring, control and optimization. However, due to their high dimensionality and structure complexity, modeling and analysis of point clouds are still a challenge. In this article, we use multilinear algebra techniques and propose a set of tensor regression approaches to model the variational patterns of point clouds and to link them to process variables. The performance of the proposed methods is evaluated through simulations and a real case study of turning process optimization.

A Multicategory Kernel Distance Weighted Discrimination Method for Multiclass Classification P. 396-408

Boxiang Wang & Hui Zou

Abstract

Distance weighted discrimination (DWD) is an interesting large margin classifier that has been shown to enjoy nice properties and empirical successes. The original DWD only handles binary classification with a linear classification boundary. Multiclass classification problems naturally appear in various fields, such as speech recognition, satellite imagery classification, and self-driving vehicles, to name a few. For such complex classification problems, it is desirable to have a flexible multicategory kernel extension of the binary DWD when the optimal decision boundary is highly nonlinear. To this end, we propose a new multicategory kernel DWD, that is, defined as a margin-vector optimization problem in a reproducing kernel Hilbert space. This formulation is shown to enjoy Fisher consistency. We develop an accelerated projected gradient descent algorithm to fit the multicategory kernel DWD. Simulations and benchmark data applications are used to demonstrate the highly competitive performance of our method, as compared with some popular state-of-the-art multiclass classifiers.

An Interactive Greedy Approach to Group Sparsity in High Dimensions P. 409-421

Wei Qian, Wending Li, Yasuhiro Sogawa, Ryohei Fujimaki, Xitong Yang & Ji Liu

Abstract

Sparsity learning with known grouping structure has received considerable attention due to wide modern applications in high-dimensional data analysis. Although advantages of using group information have been well-studied by shrinkage-based approaches, benefits of group sparsity have not been well-documented for greedy-type methods, which much limits our understanding and use of this important class of methods. In this paper, generalizing from a popular forward-backward greedy approach, we propose a new interactive greedy algorithm for group sparsity learning and prove that the proposed greedy-type algorithm attains the desired benefits of group sparsity under high dimensional settings. An estimation error bound refining other existing methods and a guarantee for group support recovery are also established simultaneously. In addition, we incorporate a general M-estimation framework and introduce an interactive feature to allow extra algorithm flexibility without compromise in theoretical properties. The promising use of our proposal is demonstrated through numerical evaluations including a real industrial application in human activity recognition at home. Supplementary materials for this article are available online.