Introduction to the Issue on Stochastic Simulation and Optimization in Signal Processing

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Introduction to the Issue on Stochastic Simulation and Optimization in Signal Processing

MANY MODERN signal processing (SP) methods rely very strongly on probability and statistics tools to solve problems; for example, they use stochastic models to represent the data observation process and the prior knowledge available and they obtain solutions by performing statistical inference (e.g., using maximum likelihood or Bayesian strategies). Statistical SP methods are, in particular, routinely applied to many and varied tasks and signal modalities, ranging from resolution enhancement of medical images to hyperspectral image unmixing; from user rating prediction to change detection in social networks; and from source separation in music analysis to automatic speech recognition.

However, expectations and demands are constantly rising and such methods are now expected to deal with ever more challenging SP problems that require ever more complex models, and more importantly ever more sophisticated novel methodologies to tackle them. This has driven the development of computation-intensive SP methods based on stochastic simulation and optimisation. This field, at the interface of SP and computational statistics, has been receiving considerable attention by researchers of late because of its capacity to handle complex models and underpin sophisticated (often Bayesian) statistical inference techniques delivering accurate and insightful results. Promising areas of research in the field include the development of adaptive block-co-ordinate stochastic optimisation algorithms and of efficient simulation techniques for high-dimensional inverse problems.

This special issue seeks to report cutting edge research on stochastic simulation and optimisation methodologies, and their application to challenging SP problems that are *not* well addressed by existing methodologies. We were fortunate to receive 60 papers in total and the selection of the 15, which appear in the special issue was difficult and we are indebted to the many reviewers who assisted us, without their efforts, we would not have been able to produce such a high quality issue. In selecting the 14 papers, we had to make some very difficult choices.

In the survey by Pereyra *et al.*, an introduction to stochastic simulation and optimization methods in signal and image processing is presented. The paper addresses a variety of high-dimensional Markov chain Monte Carlo (MCMC) methods as well as deterministic surrogate methods. It discusses a range of optimization methods adopted to solve stochastic problems, as well as stochastic methods for deterministic optimization and areas of overlap between simulation and optimization, in particular optimization-within-MCMC and MCMC-driven optimization.

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On optimization, we have several interesting papers. Konečný *et al.* present a scheme to improve to the theoretical complexity and practical performance of semistochastic gradient descent (S2GD). The novelty of the method is the introduction of mini-batching into the computation of stochastic steps. In Donmez *et al.* the problem of online optimization under adversarial perturbations is considered. Through a worst-case adversary framework to model the perturbations, they present a randomized algorithm that is provably robust against such adversarial attacks. Kail *et al.* consider the task of online data reduction and outlier rejection when large amounts of data are to be processed for inference. Rather than performing these tasks separately, they propose a joint approach, i.e., robust censoring having formulated the problem as a nonconvex optimization problem based on the data model for outlier-free data, without requiring any prior model assumptions about the outlier perturbations. Verliet *et al.* present a randomized block sampling canonical polyadic decomposition method that combines increasingly popular ideas from randomization and stochastic optimization to tackle computational problems. Instead of decomposing the full tensor at once, updates are computed from small random block samples. Carlson *et al.* propose a new, largely tuning-free algorithm to address the problem of training deep probabilistic graphical models. They propose a new, largely tuning-free algorithm to address this problem and derive novel majorization bounds based on the Schatten-1 norm.

In the area of MCMC methods, we have several interesting papers. Septier *et al.* consider a sequential Markov chain Monte Carlo (SMCMC) technique. They provide a unifying framework for a class of SMCMC approaches, coupled with novel efficient strategies based on the principle of Langevin diffusion and Hamiltonian dynamics to cope with the increasing number of high dimensional applications. Murphy and Godsill examine the use of blocking strategies for Particle Gibbs sampling schemes for high dimensional latent state space models with interacting components. Feron *et al.* propose an optimization-guided Gibbs sampler for models involving high dimensional conditional Gaussian distributions. The paper provides an illustration focused on unsupervised estimation for super-resolution methods. Lindsten *et al.* present a forward backward-type Rao-Blackwellized particle smoother (RBPS) that is able to exploit the tractable substructure present in these models. Akin to the well known Rao-Blackwellized particle filter, the proposed RBPS marginalizes out a conditionally tractable subset of state variables, effectively making use of SMC only for the “intractable part” of the model. Schreck *et al.* introduce a new MCMC method for Bayesian variable selection in high dimensional settings. The algorithm is a Hastings–Metropolis sampler with a proposal mechanism, which combines a Metropolis adjusted Langevin (MALA) step to propose local moves associated with a shrinkage-thresholding step allowing the proposal of new models.

To illustrate the power of the methods that underpin this special issue, we have several papers considering a range of applications. Rached *et al.* consider the evaluation of the outage capacity (OC) at the output of equal gain combining (EGC) and maximum ratio combining (MRC) receivers. This problem consists of computing the cumulative distribution function (CDF) for the sum of independent random variables. Finding a closed-form expression for the CDF of the sum distribution is problematic for a wide class of commonly used distributions, methods based on Monte Carlo (MC) simulations are required. Tan *et al.* consider a compressive hyperspectral imaging reconstruction problem where three-dimensional spatio-spectral information about a scene is sensed by a coded aperture snapshot spectral imager (CASSI). They extend their work on an AMP-Wiener algorithm to three-dimensional hyperspectral image reconstruction, and call it "AMP-3D-Wiener." The matrix that models the CASSI system is highly sparse, and such a matrix is not suitable for normal AMP methods causing convergence difficulties. Chen *et al.* consider the problem of how to develop a system-wide energy and workload management policy for future sustainable data centers. They leverage stochastic optimization tools, using a proposed unified management approach allowing data centers to adaptively respond to intermittent availability of renewables, variability of cooling efficiency, information technology (IT) workload shift, and energy price fluctuations under long-term quality-of-service (QoS) requirements. Mesejo *et al.* consider the problem of how to measure the blood oxygen level-dependent (BOLD) signal in functional MRI (fMRI). This estimation is challenging because there are more than 10 potentially interesting parameters involved in nonlinear equations and whose interactions may result in identifiability issues.

We hope that the SP community will find these papers stimulating, interesting, and useful in advancing our understanding and use of stochastic simulation and optimisation methods in SP.

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