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Hierarchical Matérn fields and Cauchy difference priors for Bayesian inversion

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ABSTRACT

We will construct novel Gaussian and Cauchy hierarchical models, and consider their applications in Bayesian statistical inverse problems. We first construct a hierarchical model based on stochastic partial differential equation presentation of Gaussian Markov random fields (GMRF). We model GMRF length-scaling as another random field, like another GMRF, or non-Gaussian field. Then we use iid Cauchy (or more general Lévy α -stable) distributed random fields – with simple 1D example being Cauchy walk – for promoting edge-preserving inversion. Typical alternatives for edge-preserving inversion are total variation prior, and Besov space prior which is constructed on wavelet basis. However total variation priors converge to a Gaussian priors in the discretisation limit, and due to the dyadic structure of the wavelets, the Besov priors tend to favour edges in different parts of the domain in different ways. With Cauchy random fields, we have well-behaving infinite-dimensional limits and our construction promotes edgepreserving inversion uniformly in the domain. We will develop mathematical theory of infinite-dimensional Bayesian inversion, especially discretisation and convergence of the hierarchical and non-Gaussian models. For computational inverse problems, we use Metropolis-within-Gibbs, elliptical slice sampling, HMC-NUTS and optimisation methods. We show the benefits of the priors via numerical examples with simple 1D and 2D regression problems, and 2D X-ray tomography for tomographic imaging of mixed-wet carbonate reservoir rocks. Thus we construct methods for imaging material interfaces for example in subsurface imaging.

Geometrically Convergent Simulation of the Extrema of Levy processes

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ABSTRACT

In this talk we describe a novel simulation algorithm for the joint law at a fixed time of the position, the supremum and the time of the supremum of a general Lévy process. Unlike the Euler scheme where the bias is known to decay according to a power law, in our case the bias decays geometrically. Moreover, we identify the law of the error, construct non-asymptotic confidence intervals, provide a CLT and analyse the numerical complexity of the algorithm (including its MLMC version). We illustrate the algorithm with numerical examples.

On some Stability and Uniform Fluctuation Estimates of Ensemble Kalman-Bucy Filters

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ABSTRACT

The ensemble Kalman filter is a data assimilation method for filtering in high dimensional state-space models arising in, e.g., fluid mechanics, weather forecasting, and geophysical sciences. In the linear case, this Monte Carlo method can be interpreted as a mean-field McKean-Vlasov type particle interpretation of a particular nonlinear Kalman-Bucy diffusion (related to the classical Kalman-Bucy filter). This talk presents a series of new fluctuation and stability results on these nonlinear diffusion processes; and importantly on their mean-field approximations. Results focused on the behaviour of the flow of the relevant sample covariance arising in the mean-field approximation are central. This latter idea amounts to the study of particular matrix-valued Riccati diffusions. Results under weak signal/observation model assumptions are sought; in particular, unstable signals and classical observability conditions are accommodated.

Extending Simulation-Based Bayesian Inference to Higher Dimensions

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ABSTRACT

Approximate Bayesian computation (ABC) is now a well-known method for performing approximate Bayesian inference for models with intractable likelihoods. Likelihood evaluations are avoided by repeated model simulation for various parameter values and keeping those that generate simulated data "close" to the observed data. ABC bases this comparison on a summary statistic believed to be informative about the model parameter, and its choice involves a trade-off between dimensionality and information loss. Standard ABC methods are known to scale poorly with summary statistic and model parameter dimension. In this talk I will describe how likelihood-free methods can be extended to handle a higher dimensional summary statistic and/or model parameter. The methodologies involve some combination of the synthetic likelihood (multivariate normal approximation of the intractable summary statistic likelihood), shrinkage estimation of covariance matrices and variational Bayes methods. I will also explore the robustness of the methods when the multivariate normal synthetic likelihood assumption is violated. This is joint work with Leah South, Ziwen An, Victor Ong, David Nott, Scott Sisson and Minh-Ngoc Tran.

Particle Filters in High Dimensions

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ABSTRACT

Particle filters are a set of probabilistic algorithms used to solve filtering problems arising in signal processing and Bayesian statistical inference. Their area of applicability is currently being extended to solve high dimensional problems such as those encountered in data assimilation problems for numerical weather prediction. The talk will contain a recent application of particle filters a partially observed solution of a damped and driven incompressible 2D Euler equation with stochastic advection by Lie transport (further details of the model can be found in https://arxiv.org/abs/1801.09729). I will discuss the specific difficulties encountered when applying particle filters to high dimensional problems as well as procedures required for their successful implementation.

Langevin MCMC: theory and methods

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ABSTRACT

We consider in this talk the problem of sampling a high-dimensional probability distribution π having a density with respect to the Lebesgue measure on \mathbb{R}^d , known up to a normalization constant $x \mapsto \pi(x) = e^{-U(x)} / \int_{\mathbb{R}^d} e^{-U(y)} dy$. Such problem naturally occurs for example in Bayesian inference and machine learning. Under the assumption that U is continuously differentiable, ∇U is globally Lipschitz and U is strongly convex, we obtain non-asymptotic bounds for the convergence to stationarity in Wasserstein distance of order 2 and total variation distance of the sampling method based on the Euler discretization of the Langevin stochastic differential equation, for both constant and decreasing step sizes. The dependence on the dimension of the state space of these bounds is explicit. The convergence of an appropriately weighted empirical measure is also investigated and bounds for the mean square error and exponential deviation inequality are reported for functions which are measurable and bounded.

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Approximate Bayesian Forecasting

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ABSTRACT

Approximate Bayesian Computation (ABC) has become increasingly prominent as a method for conducting parameter inference in a range of challenging statistical problems, most notably those characterized by an intractable likelihood function. In this paper, we focus on the use of ABC not as a tool for parametric inference, but as a means of generating probabilistic forecasts; or for conducting what we refer to as 'approximate Bayesian forecasting'. The four key issues explored are: i) the link between the theoretical behavior of the ABC posterior and that of the ABC-based predictive; ii) the use of proper scoring rules to measure the (potential) loss of forecast accuracy when using an approximate rather than an exact predictive; iii) the use of forecasting criteria to inform the selection of ABC summaries in empirical settings. The primary finding of the paper is that ABC can provide a computationally efficient means of generating probabilistic forecasts that are nearly identical to those produced by the exact predictive, and in a fraction of the time required to produce predictions via an exact method.

Keywords: Bayesian prediction , Likelihood-free methods, Predictive merging, Proper scoring rules, Particle filtering, Jump-diffusion models.

MSC2010 Subject Classification: 62E17, 62F15, 62F12

JEL Classifications: C11, C53, C58.

Particle rolling MCMC with double block sampling: conditional SMC update approach

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ABSTRACT

An efficient simulation-based methodology is proposed for the rolling window estimation of state space models. Using the framework of the conditional sequential Monte Carlo update in the particle Markov chain Monte Carlo estimation, weighted particles are updated to learn and forget the information of new and old observations by the forward and backward block sampling with the particle simulation smoother. These particles are also propagated by the MCMC update step. Theoretical justifications are provided for the proposed estimation methodology. The computational performance is evaluated in illustrative examples, showing that the posterior distributions of model parameters and marginal likelihoods are estimated with accuracy. Finally, as a special case, our proposed method can be used as a new sequential MCMC based on Particle Gibbs, which is shown to outperform SMC2 that is the promising alternative method based on Particle MH in the simulation experiments.

Spectral embedding of networks

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ABSTRACT

Finding a statistical framework under which to perform inference about graphvalued data has proved to be surprisingly challenging, considering the wealth of prior work in the fields of (broader) Mathematics and Computer Science. In this talk, a probabilistic model is presented that allows more refined analysis of spectral embedding and clustering as statistical estimation procedures, and which has several other advantages including generality (e.g. the mixed membership and standard stochastic block models are special cases), scalability (e.g. by some arguments requiring computation of only the first few singular vectors of the adjacency matrix), and interpretability (e.g. mixtures of connectivity behaviours are represented as convex combinations in latent space). Corresponding to this canonical statistical interpretation of spectral embedding is an indefinite orthogonal group that describes the identifiability limitations on the latent positions defined by the model. This group, which is most famously relevant to the theory of special relativity, can consist of transformations that affect inter-point distances, with worrying implications for spectral clustering. All such issues are resolved by simple statistical insights on the effect of linear transformations on volumes and Gaussian mixture models, confirming a more generally emerging guideline in data science: Gaussian clustering should be preferred over K-means. Methodology and ideas are illustrated with cyber-security applications.

Unbiased Hamiltonian Monte Carlo with couplings

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ABSTRACT

As with any Markov chain Monte Carlo method, estimators based on Hamiltonian Monte Carlo (HMC) are justified in the limit of the number of iterations. Algorithms which rely on such asymptotics face the risk of becoming obsolete if computational power keeps increasing through the number of available processors and not through clock speed. To address this issue, we propose to run pairs of HMC chains, for a random but finite number of iterations, and combine them in such a way that the resulting estimators are unbiased. One can then produce independent replicates in parallel and average them to obtain estimators that are valid in the limit of the number of replicates.

The Coupled Conditional Backward Sampling Particle Filter

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ABSTRACT

We consider the coupled conditional backward sampling particle filter (CCBPF) algorithm, which is a practically implementable coupling of two conditional backward sampling particle filter (CBPF) updates with different reference trajectories. We find that the algorithm is stable, in the sense that with fixed number of particles, the coupling time in terms of iterations increases only linearly with respect to the time horizon under a general (strong mixing) condition. This result implies a convergence bound for the iterated CBPF, without requiring the number of particles to grow as a function of time horizon. This complements the earlier findings in the literature for conditional particle filters, which assume the number of particles to grow (super)linearly in terms of the time horizon. We then consider unbiased estimators of smoothing functionals using CCBPF, and also the coupled conditional particle filter without backward sampling (CCPF) as suggested by Jacob, Lindsten and Schon [arXiv:1701.02002]. In addition to our results on the CCBPF, we provide quantitative bounds on the (one-shot) coupling of CCPF, which is shown to be well-behaved with a finite time horizon and bounded potentials, when the number of particles is increased.

Approximate Bayesian computation with the Wasserstein distance

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ABSTRACT

A growing range of generative statistical models prohibit the numerical evaluation of their likelihood functions. Approximate Bayesian computation has become a popular approach to overcome this issue, simulating synthetic data given parameters and comparing summaries of these simulations with the corresponding observed values. We propose to avoid these summaries and the ensuing loss of information through the use of Wasserstein distances between empirical distributions of observed and synthetic data. We describe how the approach can be used in the setting of dependent data such as time series, and how approximations of the Wasserstein distance allow in practice the method to scale to large data sets. In particular, we propose a new approximation to the optimal assignment problem using the Hilbert space-filling curve. We provide an in-depth theoretical study, including consistency in the number of simulated data sets for a fixed number of observations and posterior concentration rates. The approach is illustrated on various examples, including a multivariate g-and-k distribution, a toggle switch model from systems biology, a queueing model, and a Lévy-driven stochastic volatility model.

Histogram-Free Multicanonical Monte Carlo Sampling Method for Statistical Physics of Systems with Continous Phase Space

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ABSTRACT

We present a new efficient algorithm for Monte Carlo calculations in statistical physics [1] that is particularly well suited for systems with continuous phase space variables. The state of a physical system is given by $\xi \in \Omega$, where the phase space Ω has typically very high dimensionality. The finite temperature behaviour of a system is determined by its energy landscape: $H: \Omega \to \mathbb{R}$. The probability for the system to be in a state ξ at temperature T is proportional to $p(\xi) \sim e^{H(\xi)/T}$. This distribution can be sampled using the traditional Metropolis Monte Carlo method [2]. Since its inception, multiple improved Monte Carlo algorithms have been proposed and implemented to overcome its shortcomings in sampling physical systems at low temperatures and near phase transitions. Our approach has been inspired by multi-canonical sampling methods [3] and the Wang-Landau Monte-Carlo algorithms. [4] In contrast to these previous methods, we construct an expansion of the density of states g(E) (*i.e.* the phase space volume with energy E) of the system as an expansion in an orthonormal basis. Our algorithm iteratively finds a sequence of refinements of g(E) based on an initial guess and using a sequence of samples generated using multi-canonical acceptance probabilities. We demonstrate, that for test cases in numerical integration this new algorithm can be an order of magnitude more efficient than traditional Wang-Landau or multi-canonical approaches that record q(E) in discrete bins, which makes our algorithm especially well suited for systems with continuous $H(\xi)$.

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High-dimensional Inferencing for Multi-object Dynamical Systems

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ABSTRACT

In a multi-object state space model, the hidden state is a finite set. Such a state space model describes a system in which the number of objects and their states are unknown and vary randomly with time. Multi-object systems arise in many research disciplines including surveillance, computer vision, robotics, biomedical research and machine learning. Indeed, most systems in nature can be regarded as multi-object systems. This talk presents numerical techniques for high-dimensional problems in smoothing and large-scale filtering for finite-set-valued state space models. Illustrations of these solutions via applications in multiple object tracking, especially large-scale problems, and sensor scheduling, will be presented.

Delayed Sampling and Automatic Rao–Blackwellization of Probabilistic Programs

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ABSTRACT

Firstly, I will give a brief introduction to probabilistic programming, and in particular the class of programmatic models, an extension of graphical models, where structure is not known a priori, but rather depends on random choices made during program execution. Secondly, I will introduce a dynamic mechanism for the solution of analytically-tractable substructure in such models, using conjugate priors and affine transformations to reduce variance in Monte Carlo estimators. For inference with Sequential Monte Carlo, this automatically yields improvements such as locally-optimal proposals and Rao–Blackwellization. I will demonstrate with examples from a new probabilistic programming language called Birch (www.birch-lang.org), an overhaul of the LibBi software.

Particle Filtering for Stochastic Navier-Stokes Signal Observed with Additive Noise

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ABSTRACT

Traditional particle filtering methodology has been extremely successful in low dimensional non-linear non-Gaussian applications (e.g. Doucet et. al), but their application in high dimensional settings has been very challenging partly due to the difficulty to perform importance sampling efficiently in high dimensions (Snyder et. al., Bengtsson et. al., Bui Quang et. al). Despite this challenge a few successful high dimensional particle filtering implementations have appeared recently for data assimilation applications when the hidden signal obeys discrete time dynamics (Chorin et. al., Papadakis et. al., Reich, Van Leeuwen, Weare). In this talk we present our work for addressing problems where the signal of interest obeys continuous time dynamics and in particular is modelled by the stochastic Navier Stokes in 2D that is observed at discrete times with additive noise. The setup is relevant to data assimilation for numerical weather prediction and climate modelling, where similar models are used for unknown ocean or wind velocities. We will present a particle filter that uses adaptive tempering (like Jasra et. al.), likehood informed importance proposals (similar to Golightly and Wilkinson), and pre-conditioned Crank Nicholson MCMC steps (similar to Hoang et al., Cotter et al). We will show some numerical results that demonstrate the necessity of each step in terms of achieving good performance and efficiency. This is joint work with Francesc Pons-Llopis (Imperial), Alex Beskos (UCL), Ajay Jasra (NUS).

Bayesian Nonparametric Autoregressive Models via Latent Variable Representation

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ABSTRACT

We propose a probability model for a collection of random distribution indexed by time. The model is based on the dependent Dirichlet process prior and dependence among the random measures is introduced via latent variables. We impose an autoregressive structure on the distribution of the latent variables which allows to introduce time dependence among the random distribution. We propose a Sequential Monte Carlo algorithm to perform posterior inference. Typical applications involve multiple time series. Advantages of the proposed approach include wide applicability, ease of computations, interpretability and time dependent clustering of the observation. Kstep nonparametric predictive density functions can be derived. The model retains desirable statistical properties for inference, while achieving substantial flexibility. We illustrate the approach though simulations and medical applications.

Nonlinear Filtering with Local Couplings

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ABSTRACT

We introduce a class of structure-exploiting nonlinear filters for high dimensional state-space models. The idea is to transform a forecast ensemble into samples from the current filtering distribution via a sequence of local (in state-space) nonlinear transport maps, computed mostly via low-dimensional convex optimization. Construction of the maps is regularized by leveraging potential structure in the filtering problem—e.g., decay of correlations, approximate conditional independence, and local likelihoods— thus extending notions of localization to nonlinear updates. Many square-root ensemble filters can be interpreted as special instances of the proposed framework when we restrict our attention to linear transformations. We consider applications to chaotic dynamical systems.

Optimisation-based Sampling Approaches for Hierarchical Bayesian Inference

TIANGANG CUI

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ABSTRACT

Markov chain Monte Carlo (MCMC) relies on efficient proposals to sample from a target distribution of interest. Recent optimization-based MCMC algorithms for Bayesian inference, e.g. randomize-then-optimize (RTO), repeatedly solve optimization problems to obtain proposal samples. We interpret RTO as an invertible map between two random functions and find that this mapping preserves the random functions along many directions. This leads to a dimension independent formulation of the RTO algorithm for sampling the posterior of large-scale Bayesian inverse problems. We applied our new methods on Hierarchical Bayesian inverse problems.

Variance Estimation in the Particle Filter

ANTHONY LEE

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ABSTRACT

Particle filters, or sequential Monte Carlo methods, are random algorithms for approximating certain types of integrals that arise in the analysis of data. I will present new variance estimators for the resulting approximations that can be computed using a single run of the algorithm. This builds upon advances on the one hand by Chan and Lai, who proposed the first variance estimator with this feature, and by Cérou, Del Moral and Guyader, who derived non-asymptotic second moment expressions for particle filter approximations. As the number of particles grows, the variance estimators we propose are weakly consistent for asymptotic variances of the Monte Carlo approximations and some of them are also non-asymptotically unbiased. The asymptotic variances can be decomposed into terms corresponding to each time step of the algorithm, and we show how to estimate each of these terms consistently.

The Correlated Pseudo Marginal Method

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ABSTRACT

The pseudo-marginal algorithm is a popular variant of the Metropolis-Hastings scheme which allows us to sample asymptotically from a target probability density π , when we are only able to estimate an unnormalized version of π pointwise unbiasedly. It has found numerous applications in Bayesian statistics as there are many scenarios where the likelihood function is intractable but can be estimated unbiasedly using Monte Carlo samples. Using many samples will typically result in averages computed under this chain with lower asymptotic variances than the corresponding averages that use fewer samples. For a fixed computing time, it has been shown in several recent contributions that an efficient implementation of the pseudo-marginal method requires the variance of the log-likelihood ratio estimator appearing in the acceptance probability of the algorithm to be of order 1, which in turn usually requires scaling the number N of Monte Carlo samples linearly with the number T of data points. We propose a modification of the pseudo-marginal algorithm, termed the correlated pseudo-marginal algorithm, which is based on a novel log-likelihood ratio estimator computed using the difference of two positively correlated log-likelihood estimators. We explore the performance of the method for discretely observed stochastic differential equations which arise in the modeling of stochastic volatility. The issue of recursive parameter estimation is also examined.

Filtering and smoothing through Lagrangian interacting particle representations

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ABSTRACT

The ensemble Kalman filter (see, for example, [1]) has become a very popular method for approximating the nonlinear filtering and smoothing problem of partially observed stochastic processes [2]. At its core it leads to a very robust approximations of the associated marginal distributions by equally weighted interacting particles. In this talk, the EnKF will be put into the more general framework of Lagrangian formulations of the filtering and smoothing problem – in the same spirit as one can distinguish between Eulerian and Lagrangian formulations of fluid dynamics – which allows for non-Gaussian extensions of the EnKF [1, 3]. We will also discuss the stability and accuracy of the EnKF for finite number of particles [4].

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A duality formula and a particle Gibbs sampler for continuous time Feynman-Kac measures on path spaces

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ABSTRACT

Continuous time Feynman-Kac measures on path spaces are central in applied probability, partial differential equation theory, as well as in quantum physics. This article presents a new duality formula between normalized Feynman-Kac distribution and their mean field particle interpretations. Among others, this formula allows us to design a reversible particle Gibbs-Glauber sampler for continuous time Feynman-Kac integration on path spaces. We present new propagation of chaos estimates for continuous time genealogical tree based particle models with respect to the time horizon and the size of the systems. These results allow to obtain sharp quantitative estimates of the convergence rate to equilibrium of particle Gibbs-Glauber samplers.

Distributions of Persistence Diagrams and Approximations

VASILEIOS MAROULAS

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ABSTRACT

In this talk, a nonparametric way is introduced to estimate the global probability density function of a random persistence diagram. A kernel density function centered at a given persistence diagram and a given bandwidth is constructed. Our approach encapsulates the number of topological features and considers the appearance or disappearance of features near the diagonal in a stable fashion. In particular, the structure of our kernel individually tracks long persistence features, while considering features near the diagonal as a collective unit. The choice to describe short persistence features as a group reduces computation time while simultaneously retaining accuracy. Indeed, we prove that the associated kernel density estimate converges to the true distribution as the number of persistence diagrams increases and the bandwidth shrinks accordingly. We also establish the convergence of the mean absolute deviation estimate, defined according to the bottleneck metric. Lastly, examples of kernel density estimation are presented for typical underlying datasets.

High-dimensional Bayesian Semiparametric Quantile Models

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ABSTRACT

Model misspecification can compromise valid inference in conventional parametric quantile regression models. To address this issue, we propose a flexible Bayesian model structure for high-dimensional quantile semiparametric regression. The proposed model structure robustifies conventional parametric quantile regression methods by the use of a sparse signal shrinkage prior and combines a parametric quantile regression and a nonparametric regression model using a Gaussian process prior. Computational complexity is alleviated by the use of fast mean field variational Bayes methods, and we compare results obtained by variational methods with those obtained using Markov chain Monte Carlo (MCMC). In addition, the propose model structure is extended to deal with a generalized asymmetric Laplace distribution and shape-restricted functions. This talk is based on the joint work of Lim et al. [1] and Kobayashi et al. [2].

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Importance sampling type estimators based on approximate marginal MCMC

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ABSTRACT

We consider importance sampling (IS) type weighted estimators based on Markov chain Monte Carlo (MCMC) targeting an approximate marginal of the target distribution. In the context of Bayesian latent variable models, the MCMC typically operates on the hyperparameters, and the subsequent weighting may be based on IS or sequential Monte Carlo (SMC), but allows for multilevel techniques as well. The IS approach provides a natural alternative to delayed acceptance (DA) pseudo-marginal/particle MCMC, and has many advantages over DA, including a straightforward parallelisation and additional flexibility in MCMC implementation. We discuss briefly general theory, including consistency, central limit theorems, and guarantees against DA alternative. We then discuss several applications of the (related) methodology, and our experimental results, which are promising. They show that the IS type approach can provide substantial gains relative to an analogous DA scheme, and is often competitive even without parallelisation.

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Biased Importance Sampling Schemes and the Weight Degeneracy Problem

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ABSTRACT

The main obstacle for the application of importance sampling methods (including particle filters and sequential Monte Carlos samplers) to high dimensional, or otherwise complex, computational inference problems is the so-called weight degeneracy problem. The importance weights degenerate when their variance explodes, typically because there is a single biggest weight which is many orders of magnitude greater than all other weights. In this talk we explore two simple approaches to the design of modified importance samplers that can mitigate weight degeneracy considerably, compared to conventional schemes. The key common feature of the two types of algorithms is that the weights are allowed to be *improper*, i.e., they are computed to yield a biased approximation of the target probability distribution. We discuss a family of methods with nonlinearly transformed weights, intended to be used in adaptive importance sampling algorithms, and then another class of techniques that rely on *nudging* the importance samples and can be naturally applied in particle filtering. Examples are shown for both approaches.

The Viterbi process and parallelized estimation in high-dimensions

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ABSTRACT

The Viterbi process is the limiting maximum a-posteriori estimate of the unobserved path in a hidden Markov model as the length of the time-horizon grows. The existence of a such a process suggests that approximate inference algorithms which process data segments in parallel may be accurate. It is shown that for models on state-space \mathbb{R}^d satisfying a type of field-dissipative condition related to convexity, such approximations are indeed accurate and moreover scaleable to high dimensional problems because the rate of convergence to the Viterbi process does not necessarily depend on d.

Piecewise-deterministic Markov chain Monte Carlo schemes

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ABSTRACT

I will describe some novel continuous-time and discrete-time piecewise deterministic MCMC schemes and some efficient schemes to implement them relying on subsampling and prefetching ideas.