

# Monte Carlo Methods

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This course will introduce to students some advanced Monte Carlo methods, with an aim to provide them a toolbox for simulations of complex systems encountered in research.

## Lecture Syllabus:

1. Introduction: This lecture will introduce to students the basic concepts of Bayesian inference and MCMC methods.
  - Bayesian Inference
  - Markov Chain Monte Carlo Simulations
  - Convergence diagnostic
  - Some Examples
2. The Gibbs sampler and Beyond: This lecture will provide an overview for the Gibbs sampler.
  - The Gibbs sampler
  - Data Augmentation
  - Hit-and-Run Algorithm
  - Collapsing, Grouping and Subspace-Spanning in a Gibbs Sampler
3. The Metropolis-Hastings Algorithm and Beyond: This lecture will provide an overview for the Metropolis-Hastings algorithm.
  - The Metropolis-Hastings Algorithm
  - The Reversible Jump MH Algorithm
4. Auxiliary Variable Methods: This lecture will provide an overview for the auxiliary variable methods. The applications of the methods in Ising models and image processing will be revisited.
  - The Swendsen-Wang Algorithm
  - Simulated Annealing
  - Simulated Tempering
  - Parallel Tempering
  - Sequential Parallel Tempering for Sampling of High Dimensional Systems

5. Population-Based Methods: This lecture will describe how the population-based methods make use of the past sample information to accelerate the convergence of MCMC simulations. The applications of the methods in model selection, gene clustering, nonlinear time series forecasting, Bayesian neural networking learning will be revisited.
  - Adaptive Direction Sampling
  - Conjugate Gradient Monte Carlo
  - Evolutionary Monte Carlo
6. Dynamic Weighting: This lecture will describe the dynamic weighting algorithms and the concept of IWIW (invariance with respect to the importance weights), a much more general MCMC principle than the detailed balance condition. In the dynamic weighting algorithms, the past sample information is carried by a variable, the so-called dynamic weight, which enables the system to be immune to the local-trap problem. The applications of the algorithms in traveling salesman problems and spin-glasses simulations will be revisited.
  - IWIW Principle
  - Dynamic Weighting
  - Dynamically weighted Importance Sampling
  - Sequential Monte Carlo
7. Stochastic Approximation Monte Carlo: This lecture will give a detailed description of the stochastic approximation Monte Carlo (SAMC) algorithm and its variants. The asymptotic theory and applications of the algorithms in Bayesian model selection, marginal density estimation, phylogeny analysis, Bayesian network learning, and spatial model estimation will be revisited.
  - Multicanonical Sampling
  - The Wang-Landau Algorithm
  - Stochastic Approximation Monte Carlo
  - Variants of Stochastic Approximation Monte Carlo
  - Sequential SAMC for Sampling of High Dimensional Systems
  - Smoothing SAMC for Model Selection Problems
  - Continuous SAMC for Marginal Density Estimation
  - Annealing SAMC for Global Optimization
  - Theory of Stochastic Approximation Monte Carlo
  - Convergence
  - Ergodicity and its IWIW property
  - Trajectory Averaging: Toward the Optimal Convergence Rate

– Applications

8. Adaptive Markov Chain Monte Carlo Algorithms: This lecture will provide an overview for the adaptive MCMC algorithms for which the proposal functions are adapted with iterations.

– Adaptive Metropolis-Hastings Algorithm

– Adaptive Evolutionary Monte Carlo

– Convergence theory

**Recommended texts/references:**

1. Liang, F., Liu, C. and Carroll, R.J. (2010) *Advanced Monte Carlo Methods: Learning from Past Samples*. Wiley.
2. Liu, J.S. (2001). *Monte Carlo Strategies in Scientific Computing*. Springer.
3. Robert, C.P. and Casella, G. (2004). *Monte Carlo Statistical Methods* (2nd edition). Springer.

**Prerequisites:** STAT610, STAT611, or approved by instructor.

**Grade:** There will be assigned readings from books and research articles. The course grade will consist of 10% class partition and 90% a semester research project. A part of this project will consist of each student giving a 30-45 minutes oral presentation.