Alternative algorithms to MCMC methods for the simulation of the Ising model

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Research topic:
The Ising model comes from statistical physics where it describes the coupled distribution of 2-state particles arranged on a regular grid. The simulation of this model, particularly difficult, is usually treated by MCMC (Monte Carlo Markov Chain) methods which consist in seeing the target law as the invariant distribution of a Markov chain easy to simulate.

The objective of this internship is to explore alternative algorithms to MCMC methods for the simulation of the Ising model through the study of two recent papers: [1] on algorithmic Pirogov-Sinai theory about approximated simulation through contour models, and [2] on neural network models trained on simulated data. The internship could take place as follows:

1. Study and implementation of state-of-the-art MCMC algorithms.
2. Study of the paper [1] with in mind the implementation of an effective simulation algorithm.
3. Study of the paper [2] with in mind the development and implementation of neural network models for learning the distribution of the Ising model. Training data will be obtained from MCMC simulations.
4. Development of quantitative methods for the comparison and validation of these algorithms using MCMC methods as references.

Steps 2 and 3 could be treated in parallel which will allow to alternate between probability and machine learning problems. This internship will be a success if it leads to the implementation of new simulation algorithms comparable to the MCMC methods, at least qualitatively, on grids of reasonable size.

Seeked profile: Master 2 student in applied mathematics with major in applied probability and statistics. Serious experience in programming and fluency in `Python` are expected. Simulations will ideally be done with `Unity/C#` but no specific knowledge is required.

Info: This 4 to 6-months internship will start between February and April 2023 and will be hosted by the Inria team MOSAIC at École Normale Supérieure de Lyon. Continuation in PhD could be considered.

References

[1] T. Helmuth, W. Perkins, and G. Regts, "Algorithmic Pirogov-Sinai theory," *Probability Theory and Related Fields*, 2020.

[2] A. Morningstar and R. G. Melko, "Deep learning the Ising model near criticality," *Journal of Machine Learning Research*, 2018.