From networks to spin glasses: Machine learning and statistical inference in discrete systems through the lens of random walks

Alexandre Morozov
Rutgers University, Piscataway, United States

Complex, large-scale networks represent a broad spectrum of systems in nature, science, technology, and human societies [1]. Computer networks such as the World Wide Web and the Internet, social networks such as Twitter and Facebook, and online knowledge-sharing platforms such as Wikipedia exert considerable influence on our everyday lives. Many of these networks are very large and may evolve with time, making predictions of their properties a challenging task. I will describe a novel methodology, based on random walks, for the inference of various properties of complex networks with weighted or unweighted symmetric edges [2]. I will show that this formalism yields reliable estimates of global network properties, such as the network size, after only a small fraction of nodes has been explored. I will also introduce a novel algorithm for partitioning network nodes into non-overlapping communities - a key step in revealing network modularity and hierarchical organization [3]. The problem of network community detection is similar to the well-known problem of clustering datapoints in machine learning. I will apply this algorithm to various benchmarks, including a state-of-the-art collection of synthetically generated networks with tunable community structure and a large-scale map of roads and intersections in the state of Colorado. Finally, I will demonstrate how these ideas can be used to estimate key thermodynamic quantities such as free energies in physical systems with discrete states, solely on the basis of small-size non-equilibrium samples. The main ingredient of the free energy reconstruction is so-called coincidence counting - the numbers of times the discrete states of the system are visited by random walks. In summary, random walks reveal modular organization and global structure of complex networks and at the same time provide a computationally efficient approach to inferring key statistical mechanics quantities in physical systems with discrete states.

References

[1] S.H. Strogatz, Exploring complex networks, Nature 410, 268-276 (2001).
[2] W.B. Kion-Crosby, A.V. Morozov, Rapid Bayesian inference of global network statistics using random walks, Phys. Rev. Lett. 121, 038301 (2018).
[3] A. Ballal, W.B. Kion-Crosby, A.V. Morozov, Network community detection and clustering with random walks, Phys. Rev. Res. 4, 043117 (2022).