“Forward Modeling Approaches for Cosmological Analysis”

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Abstract

Upcoming cosmological surveys such as DESI, LSST, Euclid will probe our Universe at the largest volumes with a variety of cosmological observables, including galaxy clustering and weak lensing. The statistical power of these datasets provides an exciting opportunity to constrain cosmological parameters with unprecedented precision and answer longstanding fundamental questions about the birth, and evolution of our Universe, and the nature of dark energy and dark matter. However, current approaches to cosmological analysis will be insufficient in extracting all the information from this high quality data. In this talk, I will discuss the limitations of these traditional methods, and motivate how they can be overcome using computational forward models. I will then present two forward modeling approaches in detail. The first approach is “simulation-based inference” which allows us to use new, powerful summary statistics without having access to theoretical models and analytic likelihood for the data. The second approach is “field-level inference”, which promises to eventually be the optimal way of doing cosmological analysis. By simultaneously inferring the cosmological parameters and the initial conditions of the Universe, field-level inference also opens doors to completely new science cases, not possible before. I will discuss the advances made in cosmology, statistics and machine learning over the last 5 years that have made these approaches possible. Finally, I will present challenges in applying forward modeling approaches at the scale necessary for the next generation of cosmological surveys and outline strategies to overcome them.

Biography

Chirag Modi is a research fellow at the Flatiron Institute, with joint appointments at the Center for Computational Astrophysics (CCA) and the Center for Computational Mathematics (CCM). Before this, he completed his Ph.D in Physics at the University of California, Berkeley. He is broadly interested in astrophysics, machine learning and statistical inference. His main research focus is on developing new frameworks for cosmological analysis with the goal of maximizing the information that can be extracted from the next generation of large-scale structure galaxy surveys to understand the nature of our Universe. Specifically, he develops forward modeling approaches that combine computational simulations with the state of the art Bayesian inference algorithms and machine learning tools for analyzing cosmological observations. As a result, he works on a broad range of topics such as, building automatically differentiable simulations, generative models for galaxy observables and hybrid techniques that combine theoretical models and simulations in novel ways. In parallel, he also collaborates with statisticians to develop algorithms for high-dimensional inference. This includes developing asymptotically exact Markov Chain Monte Carlo methods and approximate variational methods for statistical inference in a more general setting of data-driven sciences. Occasionally, he forays into other scientific disciplines, such as doing causal inference in econometrics, data analysis for COVID-19 and inferring the structure of matter inside the neutron stars.