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Contribution ID: **17** Type: **not specified**

Random surfaces and Yang-Mills gauge theory

Thursday 25 January 2024 09:00 (1 hour)

Constructing and understanding the basic properties of Euclidean Yang-Mills theory is a fundamental problem in physics. It is also one of the Clay Institute's famous Millennium Prize problems in mathematics. The basic problem is not hard to understand. You can begin by describing a simple random function from a set of lattice edges to a group of matrices. Then you ask whether you can construct/understand a continuum analog of this object in one way or another. In addition to a truly enormous physics literature, this topic has inspired research within many major areas of mathematics: representation theory, random matrix theory, probability theory, differential geometry, stochastic partial differential equations, low-dimensional topology, graph theory and planar-map combinatorics.

Attempts to understand this problem in the 1970's and 1980's helped inspire the study of "random surfaces" including Liouville quantum gravity surfaces. Various relationships between Yang-Mills theory and random surface theory have been obtained over the years, but many of the most basic questions have remained out of reach. I will discuss our own recent work in this direction, as contained in two long recent papers relating "Wilson loop expectations" (the fundamental objects in Yang-Mills gauge theory) to "sums over spanning surfaces."

1. Wilson loop expectations as sums over surfaces on the plane (joint with Minjae Park, Joshua Pfeffer, Pu Yu)
2. Random surfaces and lattice Yang-Mills (joint with Sky Cao, Minjae Park)

The first paper explains how in 2D (where Yang-Mills theory is more tractable) one can interpret continuum Wilson loop expectations purely in terms of flat surfaces. The second explains a general-dimensional interpretation of the Wilson loop expectations in lattice Yang-Mills theory in terms of discrete-and not-necessarily-flat surfaces, a.k.a. embedded planar maps.

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