Progress in Diagrammatic Monte Carlo Methods for Quantum Field Theories in Particle-, Nuclear-, and Condensed Matter Physics

Monday 18 September 2017 - Friday 29 September 2017

Mainz Institute for Theoretical Physics, Johannes Gutenberg University

Scientific Programme

Scientific background and motivation

Over the past decade, different communities have discovered a variety of new approaches to perform Monte Carlo calculations relevant for understanding many body quantum systems and relativistic quantum field theories. The unifying theme behind these new approaches are the diagrammatic expansions that emerge naturally in perturbation theory at both weak and strong couplings. While such expansions have played an important role in analytic calculations for many years, until recently they were of limited use for studying strongly interacting theories, either due to the inability to perform large orders of perturbation theory calculations analytically or due to convergence issues of the perturbative series. It is exciting that these diagrammatic approaches and their variants can sometimes be used in Monte Carlo calculations where large orders of the expansion can easily be reached. This is especially true when the series is convergent and positive. In the presence of infrared and ultraviolet cutoffs, expansions can be designed where convergence is often not an issue. One can also view the new approaches as formulating the problem with new sets of variables, such as world-lines, fermion bags or world-sheets, that can be used in Monte Carlo sampling. These new variables arise when perturbative diagrams are interpreted appropriately. Some sign problems are also absent in these new variables, suggesting that they are more natural for Monte Carlo methods than traditional approaches.

The new Monte Carlo approaches have already yielded an impressive set of results. A variety of systems including quantum and classical spin systems, Yukawa models, four- fermion models and Abelian gauge-Higgs theories at finite density have been solved using these new variables. Some new and interesting instances of quantum critical behavior have been identified in these studies. There are also connections between the new variables and tensor-networks, a field that has recently become popular in condensed matter calculations and first steps towards applications in lattice field theories were taken. Renormalization group approach based on tensor network theory has yielded impressive results for simple spin systems. Thus we believe that the true potential of the new methods for a whole range of quantum systems remains unexplored. In particular the applicability of the new methods to nuclear EFT calculations could be an exciting development in the context of nuclear physics and needs to be explored.

Based on this opportunity we wish to propose a focused one-week topical workshop on ”Progress in Diagrammatic Monte Carlo Methods for Quantum Field Theories in Particle-, Nuclear- and Condensed Matter Physics” with three main goals:

(1) Exchange ideas among practitioners of the new methods so that we can all understand better what can be achieved and what are the limitations,

(2) Exchange of information between the practitioners of the new methods and other physicists who wish to learn about the new methods, and

(3) Explore new physics applications for the new methods.

Potential participants of the workshop would include physicists from condensed matter, nuclear and particle physics communities. We will focus on bringing to Mainz a substantial number of younger participants who may wish to explore new research opportunities that the new methods bring to the table.

Outline of the program

The program we envision will cover five broad conceptual areas which overlap with each other by using diagrammatic Monte Carlo techniques:

1. Dual Variables : (Physics Topics: QCD, Gauge Higgs Systems)

2. World-line Methods: (Physics Topics: Quantum Spins, Emergent Gauge Fields)

3. Diagrammatic/Auxiliary Field Methods (Physics Topics: Nuclear EFT, Atomic Gases)

4. Fermion Bag Approach: (Physics Topics: Criticality with Massless Fermions)

5. Connections to Tensor Networks: (Physics Topics: Entanglement, Holography)

Our idea is to have a schedule that will allow participants to learn about new opportunities through slightly longer review talks and focused shorter results talks while giving sufficient time for discussions and hands-on work in smaller groups