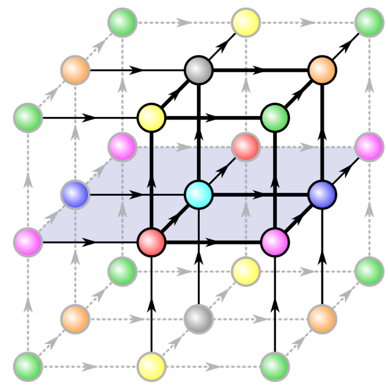
M.Sc. Project: Confinement in (1+1)-dimensional lattice quantum electrodynamics



Gauge field theories are a cornerstone of modern theoretical physics. They correspond to quantum field theories that are invariant under local symmetry transformations. Applications range from describing the low-energy properties of strongly correlated condensed matter models to the fundamental structure of matter in high-energy particle theory. One of the most prominent examples is the Standard Model of particle physics, which provides a full classification of all known elementary particles and the fundamental forces among them besides gravity.

Despite their significant role in modern theoretical physics, gauge field theories pose substantial challenges, and a full analytical solution remains elusive for many relevant cases. A prime example is Quantum Chromodynamics (QCD), which describes the gluon-mediated strong force interactions between quarks, which are the fundamental constituents of atomic nuclei. QCD falls into the strong coupling regime at low energies, causing perturbative methods to fail. This leaves many critical questions unresolved, such as those related to nonequilibrium behavior and the mechanism of confinement, which describes the phenomenon that quarks are bound into pairs at low energies.

A standard tool for exploring gauge theories in the nonperturbative limit is lattice gauge theory (LGT). Discretizing the field theory on a lattice allows for a numerical treatment and was used to reveal mass spectra, phase diagrams and many other static properties. Recently, Hamiltonian LGT has gained a lot of attention since the discretized Hamiltonian can directly be addressed with novel quantum and quantum-inspired methods, allowing to simulate dynamical problems. Such situations arise for example in nonequilibrium matter like the quark-gluon plasma, relevant to our understanding of the early universe and matter under extreme conditions such as heavy-ion collisions.

The objective of this M.Sc. thesis project is to study Hamiltonian LGT for quantum electrodynamics (QED) in (1+1)-dimensions. This simplified model of QED in one spatial and one time dimension is also known as the Schwinger model. Despite its simplicity, the model shares many relevant features with more complicated theories such as (3+1)-dimensional QED or QCD. Using the Schwinger model as a testbed, we will explore properties such as charge confinement in static and dynamical settings using numerical approaches such as exact diagonalization, tensor network techniques and quantum algorithms. The thesis provides an opportunity to learn about the fundamentals of LGT as well as learning state-of-the-art numerical methods for simulating strongly correlated quantum systems on classical and quantum computers.

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