Exact simulation of interacting one-dimensional quantum systems

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Thesis possibility after internship: Yes, requires an official application to UofT's graduate program.

Summary:

The quantum many-body problem is one of the most fundamental challenges in quantum physics. In condensed matter, it refers to the motion of interacting electrons in a periodic lattice of ions. Exact solutions are out of reach for large systems due to the exponential growth of the Hilbert space, and many approximate methods have been devised over the years. One limit where we can gain deep insights is lower-dimensional systems. In one dimension, quantum statistics is significantly simplified: fermions can almost be treated as hard-core bosons, connected by a simple Jordan–Wigner string. As a result, for one-dimensional systems with Coulomb-like interactions, *Diffusion Monte Carlo (DMC)* offers an exact approach under well-controlled conditions, enabling access to ground-state properties without the bias inherent to variational ansätze or approximate methods.

A robust, open numerical library for 1D DMC would serve as a **benchmarking standard** and a **platform for theory development**, guiding effective models of correlated phases and informing analytical treatments. Beyond accuracy, such a tool can illuminate scaling behaviors, correlation functions, and phase stability in regimes relevant to **moiré superlattices**, **quantum wires**, and **trapped-ion chains**—key arenas where strong interactions and reduced dimensionality conspire to produce exotic physics.

Project:

Design and implement a high-quality, well-documented numerical library that performs Diffusion Monte Carlo for one-dimensional many-body systems with Coulomb-like interactions in an arbitrary periodic potential. Beyond the design of the core DMC engine (drift–diffusion dynamics, branching/population control), we will be interested in speedup via GPU acceleration and inclusion of internal degrees of freedom (spin, but also valley) to model more realistic systems. This tool will provide a reference implementation for exact ground-state calculations in 1D, enabling rigorous benchmarking of approximate methods and supporting theoretical development for strongly correlated phases in moiré systems and beyond.