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BACHELORARBEITEN SS 2023 – Themenliste

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BACHELORARBEITEN SS 2023 – Themenbeschreibungen

Univ.-Prof. Dr. Hans J. Briegel

Projective Simulation

A promising application of quantum computers is quantum machine learning. This Bachelor thesis considers a specific quantization of a classical machine learning algorithm called Projective Simulation (PS) suitable for quantum simulator hardware. PS models a decision making process as a random walk on a memory graph. The student will investigate a quantization scheme that implements PS in a quantum many-body system. A central part of the project will be the analysis of dissipation and decoherence effects.

References

[1] H. Briegel and G. Cuevas, "Projective simulation for artificial intelligence," Sci. Rep., vol. 2, p. 400, 2012.

[2] H. P. Breuer and F. Petruccione, The theory of open quantum systems, Oxford University Press, 2002, doi:10.1093/acprof:oso/9780199213900.001.0001

Univ.-Prof. Dr. Thomas Franosch

Driven Lattice Lorentz Gas

The Lattice-Lorentz Gas (LLG) is a minimal model for the description of particle transport through a random medium (see [1] and references therein). In the LLG a tracer particle performs a random walk on a lattice in the presence of randomly distributed fixed obstacles. At low obstacle density and for arbitrary strong driving force F the model admits an exact solution, allowing thus to investigate the non equilibrium regime beyond the level of linear response theory.

Within this project we aim at investigating by computer simulations the driven LLG in two dimensions. The student will learn how to implement stochastic simulations for the study of the dynamics in a complex environment in which the tracer particle hops on the honeycomb lattice (Fig. 1). If time permits, analytical approaches and/or computer simulations for further generalizations of the model will also be addressed.

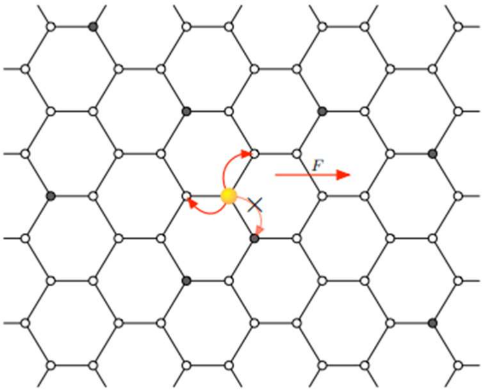


Figure 1: Driven tracer particle on the honeycomb lattice with obstacles.

References

[1] S. Leitmann, T. Schwab, and T. Franosch, *Time-dependent perpendicular fluctuations in the driven lattice Lorentz gas*, Phys. Rev. E **97**, 022101 (2018).

Sliding dynamics of a ring along closed polymer chains: A computational study on chains with topological constraints

In recent years, rotaxanes (mechanically interlocked molecular architectures consisting of a ring which is threaded through a long polymer) and other mechanically interlocked molecular architectures have attracted much attention for their unique molecular dynamics and because of their relevance in biological systems and their potential as artificial new materials [1].

The most important feature of rotaxane is that the ring can move along the threaded chain generating fascinating sliding dynamics. While the sliding dynamics of rings along simple polymeric chains has been extensively studied [2,3], only very recently some attention was given to axial chains which are knotted [4].

In this project, the student will learn how to simulate polymeric systems and will investigate the diffusive motion of a small ring threading chains with non-trivial topological constraints, like knots and links to other chains [5], with the aim of understanding how the topology affects the properties of the rotaxane.

References

[1] Leigh D.A., Marcos V., Wilson M.R., ACS Catal. **4** 4490 (2014).

[2] Yasuda Y., Toda M., Mayumi K., Yokoyama H., Morita H., and Ito K., Macromolecules **52** 3787 (2019).

[3] Li K., Wang Y.X., Guo F.C., He L.L., and Zhang L.X., Soft Matter **17**, 2557 (2021).

[4] Guo F.C., Li K., Wu J.X., Wang, Y.X., and Zhang, L.X., Polymer **235**, 124226 (2021).

[5] Caraglio M., Micheletti C., and Orlandini E., Scientific Report **7**, 1156 (2017).

Univ.-Prof. Mag. Dr. Helmut Ritsch

Quantenoptik Simulationen mit der Julia Quantum Optics Toolbox

Julia is an open source programming language developed at MIT allowing efficient and easy to read framework for physics simulations. The additional package QuantumOptics.jl (https://www.qojulia.org/) developed in Innsbruck allows effective implementations of typical quantum optics systems in Julia. This should be demonstrated by means of an example in this thesis. Topically, the thesis will deal with the far-field radiation intensity profile of a transversally illuminated array of dipole-coupled two-level emitters.

References

[1] Krämer, S., Plankensteiner, D., Ostermann, L., & Ritsch, H. (2018). QuantumOptics. jl: A Julia framework for simulating open quantum systems. Computer Physics Communications, 227, 109-116.

[2] Cremer, J., Plankensteiner, D., Moreno-Cardoner, M., Ostermann, L., & Ritsch, H. (2020). Polarization control of radiation and energy flow in dipole coupled nanorings. New Journal of Physics, 22(8), 083052.

Photon-induced entanglement among distant Bose-Einstein condensates (BECs)

A BEC is state of a matter composed of many bosons macroscopic occupying a same quantum state, and therefore can be described by a single wave function. When a BEC is located inside an optical cavity (in the simplest case consisting of two very small, high quality mirrors), cavity photons induce interaction and entanglement among the atoms of the BEC [1]. In this thesis, this idea will be extended by placing two BEC inside a cavity, and the photon induced entanglement among two distant BECs will be studied.

Reference

[1] F. Mivehvar, F. Piazza, T. Donner, H. Ritsch, *Cavity QED with quantum gases: new paradigms in many-body physics*, Advances in Physics 70 (1), 1-153 (2021).

Assoz. Prof. Mag. Dr. Wolfgang Dür

Messungsbasierte Verschränkungsreinigung

Quantenmechanische Verschränkung ist eine zentrale Ressource für viele Anwendungen im Bereich der Quanteninformationsverarbeitung. Die Herstellung von verschränkten Zuständen mit hoher Güte, insbesondere über große Entfernungen, ist aber schwierig. Verschränkungsreinigung stellt eine Möglichkeit dar, aus mehreren verrauschten Kopien von verschränkten Zuständen wenige Kopien mit einer höheren Güte zu erzeugen. Dazu wurden mehrere Verfahren entwickelt die in der Lage sind verschränkte Zustände zu reinigen. Üblicherweise ist dazu die Anwendung von kohärenten Operationen (Ein- und Zwei-qubit Gatter) notwendig. Ein alternativer Ansatz verfolgt die Verwendung von messungsbasierten Elementen für die Verschränkungsreinigung. Dabei werden bestimmte verschränkte Ressourcenzustände dazu verwendet, um die notwendigen Manipulationen alleinig durch Messungen durchzuführen. Dieses Verfahren ist dabei besonders robust gegenüber Rauschen und Imperfektionen. Ziel der Bachelorarbeit ist es, die zentralen Elemente dieses Zugangs zu erarbeiten, und eigenständig konkrete Beispiele auszuarbeiten und zu untersuchen.

Literatur

- C.H. Bennett, G. Brassard, S. Popescu, B. Schumacher, J.A. Smolin, and W.K. Wootters, Phys. Rev. Lett. 76, 722 (1996); (E-print: https://arxiv.org/abs/quant-ph/9511027).
- W. Dür and H.-J. Briegel, Rep. Prog. Phys. 70, 1381 (2007). (E-print: https://arxiv.org/abs/0705.4165).
- M. Zwerger, H. J. Briegel and W. Dür, Phys. Rev. Lett. 110, 260503 (2013). “Universal and optimal error thresholds for measurement-based entanglement purification”;
(E-print: https://arxiv.org/abs/1303.2852).

Assoz. Prof. Dr. Wolfgang Lechner

QAOA

QAOA, short for “Quantum approximate optimization algorithm”, aims to find an approximate solution to combinatorial optimization problems. The performance of the algorithm is of great interest for near-term NISQ-devices (Noisy intermediate scale quantum), where proper error-correction methods are still out of reach. To implement optimization problems we use a technique based on the Ising model, which requires 4-body-interactions. This gives certain advantages and raises other challenges.

In this work you will understand and implement QAOA, while investigating different aspects of it.

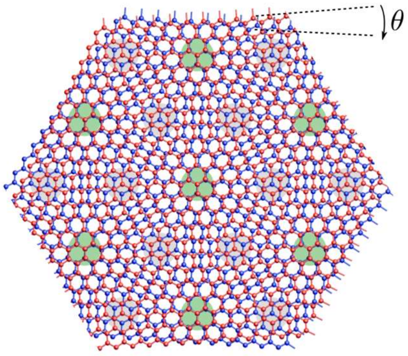
Literature

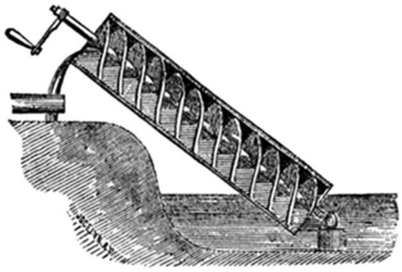
- W. Lechner, P. Hauke, and P. Zoller, A quantum annealing architecture with all-to-all connectivity from local interactions, Science Advances 1 (2015).
- Lechner, Wolfgang. (2018). Quantum Approximate Optimization With Parallelizable Gates. IEEE Transactions on Quantum Engineering. 1. 10.1109/TQE.2020.3034798.
- E. Farhi, J. Goldstone, and S. Gutmann, A Quantum Approximate Optimization Algorithm, arXiv:1411.4028 (2014).

Ass.-Prof. Dr. Mathias Scheurer

Thouless pumps in moiré superlattices

Graphene, a truly two-dimensional material consisting of a honeycomb arrangement of carbon atoms, has many interesting properties, probably best reflected in the 2010 Nobel prize of physics awarded for its experimental realization. In the last few years, it has been noticed that new and even more exciting systems can be designed by stacking several graphene layers with a finite relative twist angle. This leads to a spatial interference pattern – a so-called moiré superlattice (see figure) – and extraordinary electronic properties [1,2]. The study of graphene-based moiré systems has, thus, taken center stage in modern condensed matter research as a novel versatile playground for exotic many-body physics.





In this bachelor-thesis project, we will learn how a so-called Thouless pump, which can be seen as a quantum-mechanical analogue of a screw pump (see figure on the left), can be realized in moiré superlattice systems. We will not only learn the underlying concepts but also study the effect explicitly in a simple one-dimensional toy model.

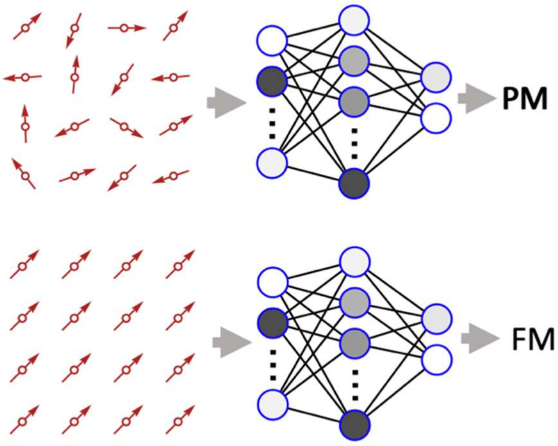
References

[1] Gast, *Der Magische Winkel*, Spectrum der Wissenschaft, 2019.

[2] MacDonald, *Bilayer Graphene's Wicked, Twisted Road*, Physics 12, 12 (2019).

Machine learning of the Schrödinger equation

Motivated by the success of machine learning in every-day applications, these techniques have also been very actively applied to a variety of problems of physics in recent years. For instance, neural networks have been used [1] to "learn" phases from samples, e.g., to distinguish paramagnetic (PM) and ferromagnetic (FM) phases in spin systems, see figure on the right.



In this bachelor thesis, we will first write a numerical solver for the one-dimensional Schrödinger equation in an arbitrary potential. We will then train a neural network to predict different properties of the spectrum of the Schrödinger equation based on the potential.

Reference

[1] Carrasquilla & Melko, *Machine learning phases of matter*, Nature Physics **13**, 431 (2017).