An Invitation to Topological Quantum Computation (5 hp)

Period 2, Academic Year 2026/27

Short Description

Entanglement is a central concept in quantum physics and underlies many of today's emerging quantum technologies. Over the past two decades, developments in the study of quantum matter have revealed deep connections between entanglement structures, topological phases, and topological quantum field theories (TQFTs). These insights form the conceptual and mathematical foundations of **topological quantum computation**.

This interdisciplinary course introduces these ideas to advanced students from diverse backgrounds in mathematics, physics, and computer science. On one side, the course covers the modern theory of quantum entanglement and the basics of quantum computation. On the other, it provides a rigorous mathematical introduction to TQFTs and topological invariants.

Building on these foundations, the course explores the interplay between entanglement and topology, culminating in applications to topological quantum computation. Special emphasis is placed on quantum error detection and correction, topological quantum memories, and elements of fault-tolerant quantum computation.

Learning Outcomes

After completing the course, students will be able to:

- Understand key aspects of the modern quantum theory of entanglement and introductory quantum computation, including quantum codes, gates, and logical operations.
- Explore the mathematical foundations of topological field theories and their role in classifying phases of quantum matter, including higher categories, interfaces, and topological orders.
- Apply concepts from TQFT to topological quantum computation, including magic state distillation and the principles of fault-tolerant quantum computation.

Preliminary Bibliography

- M. A. Nielsen and I. Chuang, Quantum Computation and Quantum Information, Cambridge University Press (2000).
- D. Gottesman, An Introduction to Quantum Error Correction and Fault-Tolerant Quantum Computation, arXiv:0904.2557.
- D. S. Freed, *Lectures on Field Theory and Topology*, CBMS Regional Conference Series in Mathematics 133, AMS (2019).
- A. Y. Kitaev, Fault-Tolerant Quantum Computation by Anyons, arXiv:quant-ph/9707021.
- E. Dennis, A. Kitaev, A. Landahl, J. Preskill, *Topological Quantum Memory*, arXiv:quant-ph/0110143.

Additional materials and lecture notes will be provided throughout the course.

Evaluation

The exam for this course consists of a small independent project that will be evaluated based on a short written report and a presentation.

Registration

Interested master students in physics, mathematics and computer science are welcome to take this course as a project course. To register to the course and for additional information please contact Michele Del Zotto, michele.delzotto@math.uu.se