Quantum Error Correction

Lecturer: Matt Wilson, matthew.wilson@centralesupelec.fr

Quantum computers in theory, are predicted to outperform classical computers in certain tasks such as prime factorization and database search. Quantum computers in practice however, are fragile, having to contend with sources of noise and decoherence both in a quantum memory persisting over time and in the implementation of computational gates. Quantum error correction is the study of solutions to this problem based on the encoding of logical variables into larger more protected physical systems. The design of such codes is an active area of research and an inherently interdisciplinary topic, at the intersection of physics, computer science, and mathematics. In this course we will learn the necessary pre-requisites to design, analyze, and use quantum error correcting codes.

Pre-Requisites: Familiarity with linear algebra.

Structure: Each session is split in half, into a 1.5 hour lecture and a 1.5 hour TD.

Syllabus:

- Lecture 1: *Why Quantum Error Correction?* Overview of Quantum Computation, the need for error correction and fault tolerance. Intro to classical error correction.
- Lecture 2: *Principles of Quantum Error Correction.* Introduction to the quantum formalism, basic quantum error correcting codes and their properties.
- Lecture 3: *From Classical to Quantum - The CSS Codes* Introduction to CSS codes and examples - 7 Qubit, 9 Qubit codes.
- Lecture 4: *The Stabiliser Formalism* Pauli groups and stabilizers, the 5 Qubit code.
- Lecture 5: *The Toric Code* Plaquette and vertex operators, logical operators, code distance. Detection, Correction, Threshold.
- Lecture 6: *Topological Codes* Comparison between planar codes, and codes with periodic boundaries. Introduction to basic relevant ideas in topology.
- Lecture 7: *Homological Codes* Rough introduction to ideas in homology relevant to topological code design. Variety of examples of topological codes, their thresholds, and their construction.
- Lecture 8: *Outlook and Fault Tolerance* Analysis of fault tolerance in gate implementation, and the threshold theorem. Discussion of quantum hardware limitations and active research and engineering advances.