

Quantum Computing

Course Outline

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Who? Me?

- Nickname: Arm (P'N' Arm, etc.)
- Born: Aug 1981
- Work
 - Researcher at NECTEC 2005-2024
 - Lecturer at SIIT, Thammasat University 2025-now
- Education
 - B.Eng & M.Eng in Computer Engineering, Kasetsart University, Thailand
 - Obtained Ministry of Science and Technology Scholarship of Thailand in early 2008
 - Did a PhD in Informatics (AI & Computational Linguistics) at University of Edinburgh, UK from 2008 to 2013



Course Description

- This course provides a comprehensive introduction to quantum computing, bridging the gap between theoretical physics and practical engineering applications.
- Starting with the mathematical foundations of complex linear algebra, students will progress through the core principles of qubits, quantum logic gates, and circuit design.
- The curriculum covers essential quantum algorithms (including Shor's, Grover's, and HHL), error correction, and system dynamics. A significant portion of the course is dedicated to the emerging fields of Quantum Machine Learning (QML) and variational algorithms (VQE, QAOA).
- Through the sessions, students will gain hands-on experience simulating quantum circuits and algorithms using the PennyLane framework, preparing them to tackle problems in cryptography, optimization, and system simulation on Noisy Intermediate-Scale Quantum (NISQ) devices.

<https://github.com/kaamanita/quantum-computing>

Course Syllabus/1

Format: 15 sessions (2+1 hours)

1. Introduction & Complex Numbers ([CH1](#))

- Complex numbers, polar forms, wave representation, inner/outer products, phase synchronicity.

2. Complex Matrices ([CH1](#))

- Hermitian and Unitary matrices, eigen-decomposition, matrix exponentials, Householder reflection.

3. Qubits, Operators, & Bloch Sphere ([CH2](#))

- Probability distributions, Dirac notation, Bloch sphere visualization, Universal rotation, global phase vs. relative phase.

Tools: Python, PennyLane, generative AI

4. Quantum Logic & Entanglement ([CH2](#))

- Tensor products, multi-qubit systems, entanglement (Bell/GHZ/W-states), measurement bases.

5. Circuit Design & PennyLane Basics ([CH3](#))

- The Clifford Set (Levels 1-3), constructing circuits in PennyLane, QNode decorators, state preparation algorithms.

6. Measurement & Dynamic Circuits ([CH4](#))

- Analytical vs. Projective measurement, expectation values, variance. Introduction to dynamic circuits (loops, conditionals).

Course Syllabus/2

Format: 15 sessions (2+1 hours)

7. Non-Clifford Gates & Noise ([CH4](#))

- Toffoli gates, generalized rotation, density matrices, mixed states, and simulating noise/decoherence.

8. Foundational Algorithms ([CH5](#))

- Oracle separation, Phase Kickback technique. Bernstein-Vazirani and Deutsch-Jozsa algorithms.

9. Communication & Error Correction ([CH5](#))

- No-Cloning theorem, Teleportation, Superdense coding. Quantum Error Correction (Repetition codes, Shor code).

Tools: Python, PennyLane, generative AI

10. Grover's Search Algorithm & QFT ([CH6](#))

- Unstructured search, amplitude amplification, geometric interpretation, optimal iteration counts, Quantum Fourier Transform (QFT), Inverse QFT.

11. QPE & Cryptography ([CH6](#))

- Quantum Phase Estimation (QPE), logic behind Shor's Algorithm and RSA breaking.

12. System Dynamics & Automata ([CH7](#))

- Deterministic vs. Probabilistic vs. Quantum Finite-State Automata (QFA), Szegedy's algorithm, Quantum Walks.

Format: 15 sessions (2+1 hours)

13. Advanced Simulation ([CH7](#))

- Hamiltonian simulation, Trotter-Suzuki decomposition, HHL algorithm for linear systems, Quantum Signal Processing (QSP).

14. Quantum Machine Learning ([CH8](#))

- Variational Quantum Algorithms (VQA), Ansatz design (HEA, TEN, ALT), Quantum Support Vector Machines (QSVM), Quantum Neural Networks (QNN), gradients (Parameter Shift Rule).

Tools: Python, PennyLane, generative AI

15. Optimization & VQE ([CH9](#))

- Variational Quantum Eigensolver (VQE), QAOA for graph problems (Max-Cut, Max-Clique, Traveling Salesman Problem).

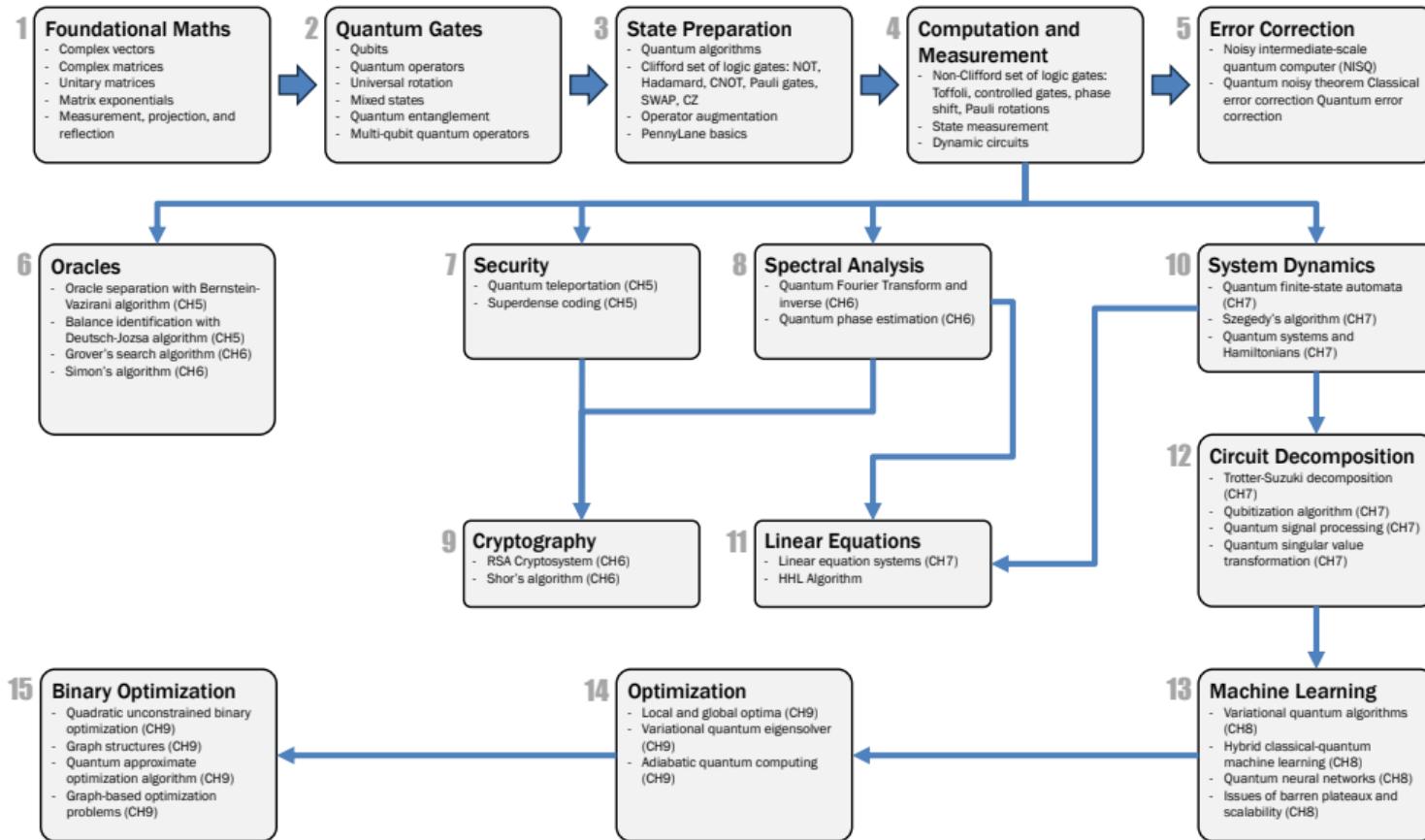


Figure 1: Course map and epistemological flow

Scoring and Exams

- Midterm exam (2 hours) and final exam (3 hours) are open-book and dictionary, but generative AI is still **NOT** allowed
- Two assignments are based on the exercises incorporated in the slides
- Two popup quizzes are done on Google Forms and the questions are quite easy

Midterm	30
Final	30
Assignments × 2	20
Popup quizzes × 2	20
Total	100

Table 1: Scoring

- You are **allowed** to use generative AI while doing assignments, but be aware that it frequently hallucinates when dealing with complex math equations! Even the pro version still does! Be **vigilant** ...
- Midterm and final exams will be based on the target learning outcomes listed in the next slides, so be prepared
- Majority of my exam questions are generally conceptual, intended to assess your basic understandings
- But there may also be 1-2 analytical math questions, intended to assess your basic math skills

Program Learning Outcomes

- PLO-1 (Theoretical Foundation):** Apply principles of linear algebra (complex vectors, Hermitian/Unitary matrices, eigen-decomposition) to model quantum mechanical phenomena such as superposition and entanglement.
- PLO-2 (Algorithmic Implementation):** Construct and simulate quantum algorithms (including Grover's, Shor's, and HHL) using the PennyLane Python library to solve computational problems.
- PLO-3 (Circuit Design):** Design and optimize quantum circuits using Clifford and non-Clifford gate sets, dynamic circuits, and state preparation techniques to achieve specific quantum states.
- PLO-4 (System Analysis):** Analyze the behavior of quantum systems, including noise modeling, error correction, and system dynamics, to evaluate the robustness and fidelity of quantum computations.
- PLO-5 (Advanced Application):** Develop hybrid classical-quantum solutions for machine learning (QNN, VQE) and combinatorial optimization (QAOA) problems.

Target Learning Outcomes/1

- TLO-1:** Convert between standard and polar forms of complex numbers to represent wave amplitudes and calculate inner/outer products to determine phase synchronicity.
- TLO-2:** Identify Hermitian and Unitary matrices and perform eigen-decomposition to interpret quantum gates as rotations and projections.
- TLO-3:** Decompose quantum operators into universal rotations and represent multi-qubit systems using tensor products and density matrices.
- TLO-4:** Construct quantum circuits using the Clifford gate set and implement state preparation algorithms for Bell and GHZ states in PennyLane.
- TLO-5:** Implement mid-circuit measurements and dynamic logic (loops, conditionals) to control quantum algorithm flow.
- TLO-6:** Differentiate between analytical, projective, and expectation-based measurements to extract information from quantum systems.

Target Learning Outcomes/2

- TLO-7:** Implement oracle-based algorithms (Bernstein-Vazirani, Deutsch-Jozsa) to demonstrate quantum speedup and phase kickback.
- TLO-8:** Apply Quantum Error Correction codes (Shor code) and model noisy channels (bit-flip, depolarization) to mitigate decoherence.
- TLO-9:** Construct the Quantum Fourier Transform (QFT) and Quantum Phase Estimation (QPE) circuits as subroutines for factoring and period finding.
- TLO-10:** Simulate quantum system dynamics (Hamiltonian evolution) and solve linear systems using the HHL algorithm.
- TLO-11:** Train Parametrized Quantum Circuits (PQC) and Hybrid Neural Networks (QNN) using backpropagation and variational techniques.
- TLO-12:** Solve combinatorial optimization problems (Max-Cut, TSP) using the Quantum Approximate Optimization Algorithm (QAOA).

Let's begin our quantum journey!