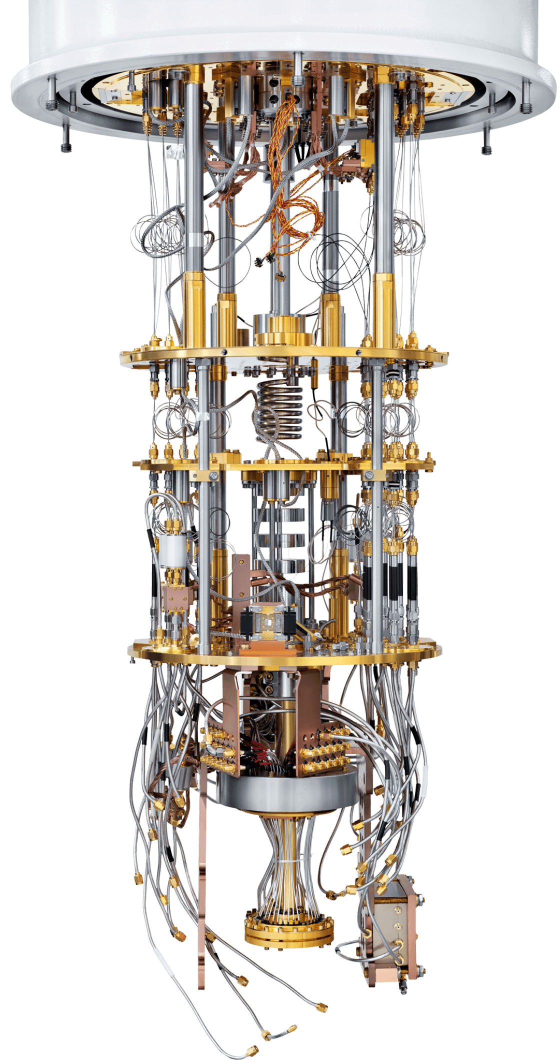
**COMP 458/558 - QUANTUM COMPUTING ALGORITHMS**



## Instructor Information

**Instructor:** Tirthak Patel
**Email:** tp53@rice.edu
**Office:** DH 3130

**TAs:**
Jason Han (jh146@rice.edu)
Vaibav Malpeddi (vm56@rice.edu)
Wanbing Zhao (wz56@rice.edu)

## Meeting Information

**Location:** HRZ 212
**Time:** 4 pm – 5:15 pm TR
**Office Hours:** 5:15 pm – 6:15 pm R. Email the instructor or the TAs to schedule additional meeting appointments as required.

## Course Description

Quantum computing is an emerging field with the potential to revolutionize various industries, including cryptography, scientific computation, optimization, and machine learning. Quantum Computing Algorithms is a course designed to introduce students to the foundations and practical algorithms of quantum computing from a systems perspective to equip them for the evolving technological landscape. The course will first refresh students on required mathematical concepts in linear algebra, probabilities, and statistics. Students will also learn about fundamental quantum principles, including superposition, entanglement, reversibility, interference, and circuits. The course will then delve into advanced quantum algorithms, especially variational and parameterized codes, including search, optimization, machine learning, and quantum simulation. Students will gain hands-on experience with Python-based quantum programming languages, Cirq and Pennylane, to program current quantum computers.

## Course Objectives and Learning Outcomes

The learning outcomes and objectives of this course are as follows:

- **Preparing Students for Quantum Computing:** Quantum computing is an emerging field with significant potential in cryptography, optimization, scientific computation, and machine learning. By providing students with a comprehensive understanding of quantum computing principles and algorithms, this course will prepare them to contribute to the development and application of quantum technologies.

- **Bridging the Interdisciplinary Gap:** Quantum computing requires a unique skill set that combines knowledge from computer science, mathematics, and quantum physics. This course will help students bridge the gap between these disciplines, equipping students with the necessary background in linear algebra, probabilities and statistics, and quantum concepts to engage with quantum computing research and development effectively.

- **Practical Programming Skills:** By focusing on Python-based quantum programming languages, Cirq and Tensorflow Quantum, the course will enable students to gain practical experience in designing and implementing quantum algorithms, circuits, and simulations. These programming skills are invaluable for students pursuing careers in quantum software, research, or academia.

## Prerequisites

**COMP 458:** COMP 382 and (CMOR 302 or CMOR 303 or MATH 355 or MATH 354)
**COMP 558:** Graduate Standing

## Texts and Materials

The course does not have any required textbooks. Optional textbooks:
1. *Quantum Computing: An Applied Approach* by Jack D. Hidary
2. *Quantum Machine Learning with Python* by Shantanu Pattanayak

The coding references are as follows:
1. *Cirq:* https://quantumai.google/cirq
2. *Pennylane:* https://pennylane.ai

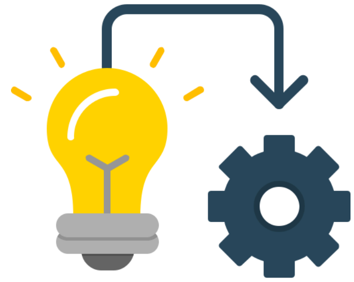
## Grading Policy

**Grade Distribution:** Lecture quizzes: 45%; Homework: 40%; Class Participation: 10%; Project 5%. The project will also contribute an extra credit of up to 5%.

*Every graded task is graded out of precisely the same score as its percentage grade.* For example, the project is graded out of exactly 10 points because it is worth 10%. This is done so that it is easy for students to track their grades throughout the semester.

**Lecture Quizzes:** The lecture quizzes are worth 45% of the total grade. They will take place in the last 15 minutes of designated Thursday lectures. These are not pop or surprise quizzes – see the course schedule at the end of this document for exact dates. There will be 10 quizzes in total. Each quiz is graded out of 5 points. Notice that 10*5 = 50, not 45. This is done to ensure that students have an extra 5 points of leeway for missed quizzes or low quiz grades. For instance, if a student scores perfectly on the first 9 quizzes, they would have achieved 9*5 = 45 points or 45% already so that they may skip the last quiz. Alternatively, if the student achieves an average of 4/5 on the first 5 quizzes (their total so far is 4*5 = 20), they may score perfectly on the last 5 quizzes to make up for lost grades and achieve a perfect score of 20 + 5*5 = 45 points. Note that the maximum that a student can score on quizzes is 45 points; any additional points will not count as extra credit toward other tasks. For example, if a student's total is 48 points for the quizzes, they will receive 45%

for the quizzes. The remaining 3 points will be discarded. No make-up quizzes or assignments will be provided in lieu of missed quizzes. The quizzes are open notes (no digital devices).



**Why Lecture Quizzes?** Research has shown that frequent and well-spaced quizzing is the best method to achieve long-term retention of knowledge and information[1]. Quizzing students on subjects that build on each other over a certain space of time (e.g., weekly or biweekly) helps them retain information much longer, not just during the course of an academic semester but beyond the length of the semester. *Therefore, this course has (almost) weekly quizzes.*

The goal of these quizzes is simply to help students retain what they learn. Thus, the questions asked in the quizzes will be structured to promote this goal. *Additionally, the quizzes are open notes.* Students are expected to refer back to concepts from *previous lectures* and apply them to answer the quiz questions. All quizzes will take place during the last 20 minutes of lectures. Quizzes will not cover content from the lectures during which they take place.

**Homework:** There are five homework assignments that include written and coding questions. Students are allotted 12 days for each homework assignment (see the course schedule at the end). Each homework assignment will be graded out of 9 points (total 45%).

**Class Participation:** Class participation is worth 10%. It is awarded based on participation in polls that will be conducted throughout the lectures. Each lecture will have 1-2 polls where the instructor will ask questions, and all students will have the opportunity to answer them. This allows all students to interact with the class material, again improving course content retention[2]. Each poll participation earns a student 0.5 points; thus, a student must answer 20 polls in total during the semester to score the full 10%. No extra credit is awarded for answering additional polls. Points are awarded regardless of the correctness of the answer. Students must create an account on [https://www.polleverywhere.com](https://www.polleverywhere.com) before the beginning of the second lecture using the Rice email address. Students must use the email address with the Rice NetID. Respond to each poll at [https://pollev.com/patel](https://pollev.com/patel).

Students are also strongly encouraged to participate by asking questions. Questions can be broadly classified into three flavors. **1. Logistical Questions:** These are questions related to the logistics of the course (e.g., will quantum entanglement be covered in the next quiz?). Please ask these questions immediately, as other students may have the same questions. **2 Knowledge Questions:** These are questions related to gaps in knowledge (e.g., can you explain the concept of quantum entanglement again?). These questions should also be asked right away so the instructor can clarify the concept, as future concepts may depend on it. 3. **Thinking and Application Questions:** These questions are related to deeper thinking and application of the piece of knowledge just presented in the lecture (e.g., how can we apply

[1] Regan AR Gurung, and Kathleen Burns. "Putting Evidence-Based Claims to the Test: A Multi-Site Classroom Study of Retrieval Practice and Spaced Practice." *Applied Cognitive Psychology* 33 (5): pp. 732-743 (2019).

[2] Burr Settles. Active Learning Literature Survey. Computer Sciences Technical Report 1648, University of Wisconsin–Madison. 2009.

quantum entanglement to teleportation?). You may also ask these questions right away, but you are encouraged to think about them until the next lecture and ask them in the next lecture if you still have the question. Thinking critically will enhance your understanding and retention of the piece of knowledge.

**Project:** The project has 5% contributing toward the mandatory quotient and 5% that can be used as extra credit. This extra credit is added to the course total. So, it can be used to make up for lost grades in any other tasks, including quizzes, homework, and class participation. It is a small-sized project that will be assigned in the last third of the course. The project code and report are worth 5 points in total, and the presentation is worth 5 points.

**Standard Letter Conversion:** The minimum percentage grade requirement for a letter grade is as shown in the table below:

| A+ | A | A- | B+ | B | B- | C+ | C | C- | D+ | D | D- | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | 92 | 88 | 84 | 80 | 76 | 72 | 68 | 64 | 60 | 55 | 50 | 0 |

For example, you will get an A if you score 92%, you will get an A+ if you score 97%, you will get a D+ if you score 61%, and you will get a B- if you score a 79.75% – decimals always get rounded down.

## Late Submission Policy

Students have **two days** of late submission allowance that can be used toward homework and project due dates. The two days can be divided across two different due dates or can be used toward one due date, i.e., you may submit two homework assignments late by one day or one homework assignment late by two days. If the late submission is within the allowance limit, there will be no related negative impact on the respective grade. Any late submissions beyond the allowance will receive a grade of 0 – exceptions will be made for extraordinary circumstances with permission from the instructor. Any delay beyond the due time, no matter how small, counts as a full day. For late submissions beyond the two allowance days, 10% of the grade will be deducted per day up to a maximum of 50% deduction. *All homework and project assignments are due at 11:59 p.m. on the day of the due date.*

## Use of Generative AI Tools

In this course, we recognize AI tools as an integrated part of your learning. Students are encouraged to use generative AI tools such as ChatGPT, Github Copilot, and GPT-4 for all homework assignments and projects. *For each submission for which generative tools are used, students **are required to** attach an appendix that lists all the prompts provided to the generative tools and the corresponding answers provided by the generative tools.* Note that this is not necessary for the use of Grammarly or any such AI-based editing tools. These prompts and answers will be used to identify plagiarism (e.g., two students have similar prompts provided to Github Copilot). Student grades will not be affected by the degree of use of generative tools (e.g., two prompts vs. ten prompts).

**Caution:** It is essential that you critically engage with any AI-generated content. This means thoroughly reviewing, analyzing, fact-checking, and refining the output to ensure it aligns with your understanding and the course objectives. Your final submissions should reflect your own comprehension and effort. Generative tools often generate incorrect or irrelevant answers to prompts. Students must verify the correctness of their submission, as they are ultimately responsible for the work that they submit.

### Rice Honor Code

In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-system-handbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

### Disability Resource Center

If you have a documented disability or other condition that may affect your academic performance, you should: 1) make sure this documentation is on file with the Disability Resource Center (Allen Center, Room 111 / adarice@rice.edu / x5841) to determine the accommodations you need; and 2) talk with the instructor to discuss your accommodation.

### Syllabus Change Policy

This syllabus is only a guide for the course and is subject to change with advanced notice.

### Course Schedule

| Lecture | Week of | Lecture Topics | Important Dates |
|---|---|---|---|
| | | **Phase I: Introduction and Background** | |
| 1-2 | 01/13/25 | • Introduction to the course format and syllabus<br>• Overview of quantum computing concepts and applications<br>• Historical background and current state of quantum computing<br>• Review of linear algebra concepts, notation, and vector spaces | Homework 1 Assigned on 01/16/25 |
| 3 | 01/20/25 | • Quantum state representation and quantum bits (qubits)<br>• Probability theory and its application to quantum systems<br>• Measurement and quantum state collapse | |

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|---|---|---|---|
| | | ● Statistical analysis of quantum measurements | |
| 4 | 01/27/25 | ● Quantum gates and transformations<br>● Unitary matrices and their properties<br>● Quantum circuits, systems, and properties<br>● Multi-qubit systems and entanglement | Quiz 1 on 01/30/25 |
| 5-6 | 02/03/25 | ● Reversibility property and no-cloning theorem<br>● Bell-state and GHZ state generation circuits | Homework 1 Due on 02/04/25<br><br>Quiz 2 on 02/06/25<br><br>Homework 2 Assigned on 02/06/25 |
| **Phase II: Fundamentals of Quantum Algorithms** | | | |
| 7 | 02/10/25 | ● Basic quantum algorithms<br>● Quantum computing using Cirq | |
| 8-9 | 02/17/25 | ● Grover's search algorithm and coding | Homework 2 Due on 02/18/25<br><br>Quiz 3 on 02/20/25<br><br>Homework 3 Assigned on 02/20/25 |
| 10-11 | 02/24/25 | ● Introduction to variational quantum algorithms<br>● Training and optimization of variational algorithms | Quiz 4 on 02/27/25 |
| **Phase III: Advanced Quantum Algorithms** | | | |
| 12-13 | 03/03/25 | ● Introduction to quantum optimization problems<br>● Quantum approximate optimization algorithm (QAOA) | Homework 3 Due on 03/04/25<br><br>Quiz 5 on 03/06/25<br><br>Homework 4 Assigned on 03/06/25 |
| 14-15 | 03/10/25 | ● Quantum machine learning using Tensorflow Quantum | Quiz 6 on 03/13/25 |
| 16-17 | 03/24/25 | ● Quantum Simulations for Physics and Chemistry<br>● Variational Quantum Eigensolver (VQE) | Homework 4 Due on 03/25/25 |

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| | | | Quiz 7 on 03/27/25<br><br>Homework 5 Assigned on 03/27/25 |
| **Phase IV: Special Topics in Quantum Computing** | | | |
| 18-19 | 03/31/25 | • Introduction to quantum annealing<br>• Quantum annealing algorithms and applications | Project Assigned on 04/01/25<br><br>Quiz 8 on 04/03/25 |
| 20-21 | 04/07/25 | • Overview of quantum compilers and their role in quantum computing<br>• Analysis of compiler optimizations and circuit transformations<br>• Architectural challenges and constraints in building quantum systems | Homework 5 Due on 04/08/25<br><br>Quiz 9 on 04/10/25 |
| **Phase V: Concluding Lectures** | | | |
| 22-23 | 04/14/25 | • Overflow content, project Q&A, and guest lectures | Quiz 10 on 04/17/25 |
| 24-25 | 04/21/25 | • Project presentations<br>• Course feedback | Project Presentations on 04/22/25 and 04/24/25 |
| N/A | 04/28/25 | • Project report completion | Project Report+Code Due on 04/29/25 |

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