SYRACUSE UNIVERSITY
Department of Electrical Engineering and Computer Science

CIS 4XX Introduction to Quantum Simulation
Instructor: Prof. Rodrick Kuate Defo
SPRING 2027

Instructor:	Prof. Rodrick Kuate Defo
	Office: 4-293 CST
	Email: `rkuatede@syr.edu`
Lectures:	TBD, TBD
Office Hours:	T 12:00 PM - 1:00 PM, CST 4-293
	W 11:00 AM - 12:00 PM, CST 4-293
Prerequisites:	Linear Algebra (MAT 331, ECS 204, or PHY 302), and either discrete mathematics (CIS 375) or quantum mechanics (PHY 361 or CHE 356) or permission of instructor

Text: **Noson S. Yanofsky** and **Mirco A. Mannucci**, *Quantum Computing for Computer Scientists*, Pearson Education 2008, 1st Edition.

To purchase the CIS 4XX textbook from Cognella, Inc., please follow this link:
https://store.cognella.com/81090-2A-NI-032
If you experience any difficulties, please email orders@cognella.com or call 858-800-2675. You may also request the book from the library where it has been put on reserve.

Syracuse University has partnered with eCampus.com to deliver you required course materials with great discounts directly within Blackboard. To access your materials, go to your Blackboard course site, click the "View course & institution tools" link under "Details & Actions", and then click the "Orange Instant Access" link for eBooks. If you would like to opt-out of participation in this program, you may do so through the "Orange Instant Access" link in Blackboard.

Please also see this student website for ordering books: https://syracuse.ecampus.com/
Here is a link to the Syracuse support page for OIA: https://www.syrcampusstore.com/oia
The access to the course textbook through OIA is a **rental access** that lasts the length of the semester.

Course Description

Quantum computing is a very exciting field that has garnered significant interest from big industry players including Microsoft, IBM, and Google. We are still at the stage where quantum computers are very noisy and riddled with errors, though some of the big industry players have developed quantum simulation tools to help the general public prepare for the day when quantum computing becomes commonplace. The purpose of this high-structure course is to increase your familiarity with these quantum simulation tools, which include Quirk, QUTIP, and Qisket. A background to quantum mechanics will first be provided, followed by applications of quantum mechanics to cybersecurity and chemistry. I will then introduce the quantum simulation tools and you will get to complete homework assignments to increase your familiarity with the tools. We will wrap up the high-structure course by discussing some codes that have been developed to correct the errors that plague existing quantum computing technologies.

Course Learning Outcomes

At the completion of this high-structure course, students are expected to

1. Handle linear algebra concepts, including those of inner products, tensor products, and operators, and know how to use Bra-Ket notation and execute and design quantum algorithms.
2. Understand single-qubit and multi-qubit gates.
3. Understand the RSA cryptosystem, the quantum Fourier transform, forrelation, and Shor's quantum algorithm for integer factorization.
4. Understand Hamiltonian simulation, the variational quantum eigensolver (VQE), adiabatic quantum computing, and Grover's algorithm.
5. Simulate quantum systems using tools such as Quirk, QUTIP, and Qisket.
6. Be familiar with quantum and classical error correction codes.

High Structure

This is a "high structure" course meaning that you will have many opportunities to succeed and to be an active participant in your learning. You will have weekly pre-class readings and in-class reading question quizzes. Every class, in-class activities and practice questions will be provided. Additionally, every two weeks, you will have problem-based homework. While this sounds like a lot of work, the course is set up this way because we know from educational research that high-structure courses lead to improved student learning and retention (and that means higher grades too!).

Course Requirements:

1. Quizzes (15%): Weekly at the beginning of class.
1. Problem-Based Homework Assignments (25%): Issued every two weeks, due two weeks later (at the beginning of the class).
   The lowest homework grade will be dropped.
2. Three Exams (50%): TBD (TBD), TBD (TBD),
   TBD from TBD (TBD)
   Exam 1 (25%), Exam 2 (25%), and Exam 3 (25%)
   (lowest exam grade will be dropped)
4. Small Group In-Class Practice (10%): Up to 10 absences will be excused.

References:

1. **Eric R. Johnston**, **Nic Harrigan**, and **Mercedes Gimeno-Segovia**, *Programming Quantum Computers: Essential Algorithms and Code Samples*, O'Reilly 2019, 1st Edition.
2. **Michael A. Nielsen** and **Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press 2016, 10th Anniversary Edition.

NOTES to Students and SYRACUSE UNIVERSITY POLICIES:

1. I realize that the learning outcomes are challenging, but I know that you can do it with my feedback and support.
2. Please complete homework assignments in a timely manner (start early). Homeworks that are submitted at the beginning of class on the due date will obtain full credit. Homeworks that are submitted X days late will earn up to $20 \times (5 - X)$ % of the credit. Submission five or more days later will not be able to be graded.
3. **Attendance:** Attendance is expected and can help improve your performance in the class. You will always have an opportunity to earn credit toward your grade by coming to class. The University policy on classroom attendance states that "**Attendance in classes is expected in all courses at Syracuse University**".
4. Office hours are the time that I make myself available as a resource to you. Helping students 1-on-1 is one of the best parts of my job, coming to office hours allows me to help you get the most out of the class.
5. **Key Dates:**
   - **First day of classes** - Monday, Jan. 11

- **Late registration and schedule adjustment** - Monday, Jan. 11 to Tuesday, Jan. 19
- **Martin Luther King Jr. Day (no classes)** - Monday, Jan. 18
- **Add deadline** - Tuesday, Jan. 19
- **Early-semester progress report** - Monday, Jan. 25 to Friday, Jan. 29
- **Deadline to drop class, grading option deadline, and religious observance notification deadline** - Monday, Feb. 1
- **Midterm** - Monday, Mar. 1
- **Mid-semester progress report** - Tuesday, Mar. 2 to Tuesday, Mar. 16
- **Spring break** - Sunday, Mar. 7 to Sunday, Mar. 14
- **Withdrawal deadline** - Tuesday, Apr. 13
- **Last day of classes** - Monday, Apr. 26

6. **Academic Integrity:**

   As a pre-eminent and inclusive student-focused research institution, Syracuse University considers academic integrity at the forefront of learning, serving as a core value and guiding pillar of education. Syracuse University's Academic Integrity Policy provides students with the necessary guidelines to complete academic work with integrity throughout their studies. Students are required to uphold both course-specific and university-wide academic integrity expectations such as crediting your sources, doing your own work, communicating honestly, and supporting academic integrity. The full Syracuse University Academic Integrity Policy can be found by visiting class.syr/edu, selecting, "Academic Integrity," and "Expectations and Policy."

   Upholding Academic Integrity includes the protection of faculty's intellectual property. Students should not upload, distribute, or share instructors' course materials, including presentations, assignments, exams, or other evaluative materials without permission. Using websites that charge fees or require uploading of course material (e.g., Chegg, Course Hero) to obtain exam solutions or assignments completed by others, which are then presented as your own violates academic integrity expectations in this course and may be classified as a Level 3 violation. All academic integrity expectations that apply to in-person assignments, quizzes, and exams also apply online.

   Students found in violation of the policy are subject to grade sanctions determined by the course instructor and non-grade sanctions determined by the School or College where the course is offered. Students may not drop or withdraw from courses in which they face a suspected violation. Any established violation in this course may result in course failure regardless of violation level.

   All generative-AI tools are prohibited in this course because their use inhibits achievement of the course learning objectives. This policy applies to all stages of project and writing processes including researching, brainstorming, outlining, organizing, and polishing. Do not use Generative-AI tools to create any content (i.e., images and video, audio, text, code, etc.). If you have any questions about a feature and whether it is considered Generative-AI, ask your instructor.

7. **Academic Accommodations for Students with Disabilities:**

   Syracuse University values diversity and inclusion; we are committed to a climate of mutual respect and full participation. There may be aspects of the instruction or design of this course that result in barriers to your inclusion and full participation in this course. I invite any student to meet with me to discuss strategies and/or accommodations (academic adjustments) that may be essential to your success and to collaborate with the Center for Disability Resources (CDR) in this process.

   If you would like to discuss disability-accommodations or register with CDR, please visit their website at https://disabilityresources.syr.edu. Please call (315) 443-4498 or email disabilityresources@syr.edu for more detailed information.

   CDR is responsible for coordinating disability-related academic accommodations and will work with the student to develop an access plan. Since academic accommodations may require early planning and generally are not provided retroactively, please contact CDR as soon as possible to begin this process.

   Students who have a particular need to use technology are permitted to do so after speaking with me privately to make that arrangement. We will discuss the parameters of its use in this class. Failure to use technology appropriately may result in losing permission to use it.

8. **Religious Observances Notification and Policy:**

   For accommodations for religious observances, please see:

   https://policies.syr.edu/policies/university-governance-ethics-integrity-and-legal-compliance/religious-observances-policy/

CIS 4XX INTRODUCTION TO QUANTUM SIMULATION
SPRING 2027
TOPICS TO BE COVERED

1. BACKGROUND TO QUANTUM

   (a) Week 1 (will put in dates): Review of linear algebra, review of Bra-Ket notation, qubits, superposition, the Bloch sphere, single-qubit gates.

   Read Ch. 5 of **Noson S. Yanofsky** and **Mirco A. Mannucci**, *Quantum Computing for Computer Scientists,* Pearson Education 2008, 1st Edition. for Week 2 (no need to do exercises).

   (b) Week 2 (will put in dates): Quantum circuit diagrams, qubit registers, complex multi-qubit superpositions, multi-qubit gates (CNOT), entanglement, quantum interference.

   Read Ch. 7 of **Noson S. Yanofsky** and **Mirco A. Mannucci**, *Quantum Computing for Computer Scientists,* Pearson Education 2008, 1st Edition. for Week 3 (no need to do exercises).

   (c) Week 3 (will put in dates): Defining a qubit, uncertainty principle.

   Read Ch. 2.2.5 including Box 2.4 of **Michael A. Nielsen** and **Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press 2016, 10th Anniversary Edition. (no need to do exercises).

   (d) Week 4 (will put in dates): Predicting properties in a quantum state, shadow tomography.

   Read Ch. 8.4.2 including Box 8.5 of **Michael A. Nielsen** and **Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press 2016, 10th Anniversary Edition. (no need to do exercises).

2. CYBERSECURITY

   (a) Week 5 (will put in dates): Toy algorithms (Deutsch–Jozsa, Bernstein–Vazirani (BV), and Simon's algorithm), quantum communication.

   Read Ch. 6.1-6.3 of **Noson S. Yanofsky** and **Mirco A. Mannucci**, *Quantum Computing for Computer Scientists,* Pearson Education 2008, 1st Edition. for Week 3 (no need to do exercises).

   (b) Week 6 (will put in dates): Review of algebra (proof of Fermat's Little Theorem), review of Chebyshev polynomials, quantum Fourier transform over $\{0,1\}^n$, forrelation.

   Read Ch. 7 of **Eric R. Johnston**, **Nic Harrigan**, and **Mercedes Gimeno-Segovia**, *Programming Quantum Computers: Essential Algorithms and Code Samples*, O'Reilly 2019, 1st Edition.

   (c) Week 7 (will put in dates): Quantum signal processing, introduction to phase estimation

   Read Ch. 8 of **Eric R. Johnston**, **Nic Harrigan**, and **Mercedes Gimeno-Segovia**, *Programming Quantum Computers: Essential Algorithms and Code Samples*, O'Reilly 2019, 1st Edition.

(d) Week 8 (will put in dates): RSA cryptosystem, factoring, integer factorization (Shor's algorithm)

Read Ch. 6.5 of **Noson S. Yanofsky** and **Mirco A. Mannucci**, *Quantum Computing for Computer Scientists*, Pearson Education 2008, 1st Edition. for Week 3 (no need to do exercises).

(e) Week 9 (will put in dates): Post-quantum cryptography (single-photon schemes, entangled-photon schemes, random number generators, quantum repeaters).

Read Ch. 12.6, 12.6.1, 12.6.2, and 12.6.3 including Box 12.7 of **Michael A. Nielsen** and **Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press 2016, 10th Anniversary Edition. (no need to do exercises).

3. CHEMISTRY

(a) Week 10 (will put in dates): Hamiltonian simulation, quantum simulation: chemistry (VQE).

Read Ch. 4.7, 4.7.1, 4.7.2, 4.7.3, and 4.7.4 including Box 4.2 of **Michael A. Nielsen** and **Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press 2016, 10th Anniversary Edition. (no need to do exercises).

(b) Week 11 (will put in dates): Adiabatic quantum computing, quantum annealing & polynomial-speedup quantum algorithms, amplitude amplification (Grover's algorithm).

Read Ch. 6.4 of **Noson S. Yanofsky** and **Mirco A. Mannucci**, *Quantum Computing for Computer Scientists*, Pearson Education 2008, 1st Edition. for Week 3 (no need to do exercises).

4. PLATFORMS FOR QUANTUM SIMULATION AND ERROR CORRECTION

(a) Week 12 (will put in dates): Simulating quantum systems and quantum computers, the Quirk tool, QUTIP (see http://qutip.org/docs/latest/installation.html)

(b) Week 13 (will put in dates): Qisket Basics, Qisket Transpiler, Qisket Tutorials, hybrid classical-quantum algorithms

(c) Week 14 (will put in dates): Pauli matrices review, classical error correction codes, logical operators, local indistinguishability.

Read Ch. 10.4.2 of **Michael A. Nielsen** and **Isaac L. Chuang**, *Quantum Computation and Quantum Information*, Cambridge University Press 2016, 10th Anniversary Edition. (no need to do exercises).

(d) Week 15 (will put in dates): Quantum error correcting (CSS codes) and toric codes.