OPTI 596-005: Photonic Gaussian Information

Graduate Course Syllabus

Semester and Year this Document Covers:

Fall 2024

Course Number and Title:

OPTI 596-005: Photonic Gaussian Information

Instructor Information:

Instructor: Professor Daniel Soh
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Teaching Assistant (TA): TA information is announced at the beginning of each semester

Lecture Schedule and Office Hours:

Lecture: Tuesday/Thursday 12:30PM-01:45PM, Meinel 432
Office Hours: To be announced at the beginning of each semester and by appointment

Course Description:

This course is meticulously crafted to establish a robust foundation in continuous-variable quantum information, leveraging the recently established solid formalism of Gaussian Quantum Information. It delves into the two primary approaches of quantum information science. The first approach, discrete-variable, involves defining qubits from discrete quantum states. In contrast, the second approach, continuous-variable, employs observables with continuous quantities to carry quantum information, rather than relying on discrete quantities. This distinction sets the stage for an in-depth exploration of continuous-variable quantum information.

Historically, quantum computation primarily harnessed the discrete-variable quantum information paradigm. However, the pursuit of realizing quantum computers using discrete variables encountered significant challenges. This backdrop sets the stage for the recent and exciting development in the realm of continuous variable quantum information. This new development takes advantage of boson fields, such as photons and phonons, rapidly positioning itself as a potent next-generation quantum information platform. This surge is primarily attributed to the relative "ease" of realization, enabled by well-established photonic devices like amplitude and phase modulators, as well as homodyne detectors.

The course begins with an exploration of the quantum mechanical understanding of photonic fields, specifically through the lens of second quantization. This foundational knowledge leads to an appreciation of continuous-variable observables, particularly the quadrature measurements of photonic fields. A significant focus of the course is on the elegantly simple Gaussian quantum information formalism, celebrated for its beautiful theoretical structure. This formalism is not just an academic exercise; it profoundly influences nearly every research area within modern quantum information, encompassing computation, communication, sensing, and even quantum machine learning.

Lecture topics:

1. Second Quantization of Photonic Fields
2. Quadrature Operators and Displacement Operator
3. Gaussian States
4. Williamson Theorem
5. Symplectic Formalism
6. Characteristic Functions and Quasi-Probability Distributions
7. Gaussian Quantum Channels
8. Gaussian Measurements – Homodyne Detection
9. Gaussian Measurements – Heterodyne Detection
10. Fidelity of Gaussian States
11. Entropies of Gaussian States
12. Entanglement of Gaussian States
13. Dynamics of Gaussian States
14. Bosonic Quantum Teleportation

Learning Outcomes upon completion of this course:

Upon successful completion, students will be able to

- understand basic structures of Gaussian quantum information processing, which is critical for modern quantum information theory and applications,
- calculate the state evolutions and information extraction in Gaussian quantum information processing,
- be prepared more advanced topics in quantum information and particularly for taking the next advanced course: OPTI 647 – Photonic Quantum Information Processing,
- proceed to the next topics of quantum computation, communications, and sensing using photonic Gaussian information.

Course Prerequisite:

Mathematical structure of quantum mechanics including the use of Dirac notation (kets and bras), orthogonal basis, Schrodinger and Heisenberg equations, matrix representation of operators. It is highly recommended that students should have taken OPTI570, which covers all the required basics of quantum mechanics.

Grading Policy:

Homework Assignments		70%
Final presentation		30%
	TOTAL	**100%**

Grading scale: A (>=90%), B (>=80%), C (>=70%), D (>=60%), E (<60%)

Homework Assignments:

There will be a homework problem set assigned approximately every two weeks. The problem set is due in class. The due date will be listed in the problem set handouts. *Late homework will be accepted up to a week after it was due, and will be graded at 50% off. All materials that are over a week late will receive zero credit.* For distance learning students, you can email scanned/electronics copies of your homework to the TA before the deadline. Recording of class lectures will be available online to distance learning students only.

Final Presentation:

Each student will give a ~20 minute presentation at the end of semester. The presentation topics should be the literature (journal articles) of a recently published continuous-variable quantum information research. The topic could be either theoretical or experimental.

Textbook and Lecture Materials:

This course uses Dr. Soh's own lecture notes, which will be distributed after each lecture in D2L. A useful textbook is

- Alessio Serafini – Quantum Continuous Variables, Second Edition, CRC Press (2023)

Course Policies:

It is ***very important*** to attend all lectures. If you must be absent, it is your responsibility to obtain and review the information you missed. The students are encouraged to ask questions during the lecture. Attendance is not mandatory. If you miss an exam, it may not be made up unless you have a documented medical or family emergency.

If you need to leave the room during lecture, please do so discretely, so that you won't disturb the professor and the students.

You are encouraged to work with each other as a team. You should not, however, copy each other's homework.

Additional Information:

Nondiscrimination and Anti-harassment Policy
The University of Arizona is committed to creating and maintaining an environment free of discrimination. In support of this commitment, the University prohibits discrimination, including harassment and retaliation, based on a protected classification, including race, color, religion, sex, national origin, age, disability, veteran status, sexual orientation, gender identity, or genetic information. For more information, including how to report a concern, please see:
http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy

University Policies
All university policies related to a syllabus are available at:
https://academicaffairs.arizona.edu/syllabus-policies. By placing this link in your syllabus, you no longer need to have each individual policy included in your syllabus.

Subject to Change Notice
Information contained in the course syllabus, other than the grade and absence policies, may be subject to change with reasonable advance notice, as deemed appropriate by the instructor of this course.

Graduate Student Resources
Please refer to the University of Arizona's Basic Needs Resources page
http://basicneeds.arizona.edu/index.html