Entanglement and complexity in QFT and holography

3 lecture series by Dr. Shira Chapman (University of Amsterdam)

Lecture 1: May 27th, 13:10 (Physics seminar room)

Lecture 2: May 30th, 10:10 (to be announced)

Lecture 3: June 2nd, 13:10 (Physics seminar room)

General Description

I will be giving a series of three introductory talks about entanglement and complexity in quantum field theory and holography aimed at building a basic knowledge of the field, after which, the audience should be able to access the large body of literature on the subject without difficulty. The talks are aimed at anyone with basic knowledge of quantum field theory and general relativity. I will not assume prior familiarity with the holographic correspondence (AdS/CFT). Each of the three sessions will consist of two 45-50 minutes talks with a 10-15 minutes break between the two.

Talk 1 – Entanglement Entropy in Quantum Field Theory

I will introduce the concept of entanglement entropy and review its main properties. I will review results for Gaussian states in free field theories as well as a number of exact results in conformal field theory, including the relation to the central charge, anomalies and monotonicity theorems. I will describe the replica method for evaluating entanglement entropy.

References:

1. Entanglement entropy in free quantum field theory –Casini, Huerta [https://arxiv.org/abs/0905.2562]
2. Entanglement Entropy and Quantum Field Theory - Calabrese, Cardy [https://arxiv.org/abs/hep-th/0405152]
3. Entanglement Entropy in Field Theory and Gravity - Iqbal [https://pos.sissa.it/271/002/pdf]

Talk 2 – Complexity in Quantum Mechanics and Quantum Field Theory

I will review the concept of quantum computational complexity and its main properties. I will emphasize the distinction between state and unitary complexity as well as between gate complexity and the continuous complexity geometry due to Nielsen. I will extensively review the complexity geometry and demonstrate how it works in some simple examples. I will review the properties of complexity in systems with fast scrambling Hamiltonians which will be of particular interest in the next talk. I will then discuss the definition of complexity in quantum field theory and in particular I will review a number of analytic results for complexity of Gaussian states in free scalar quantum field theory and will comment on similar results for fermionic systems.

References:

1. The geometry of quantum computation - Dowling, Nielsen [https://arxiv.org/abs/quant-ph/0701004]
2. The Complexity Geometry of a Single Qubit - Brown, Susskind [https://arxiv.org/abs/1903.12621]
3. Three Lectures on Complexity and Black Holes – Susskind [https://arxiv.org/abs/1810.11563]
4. Towards Complexity for Quantum Field Theory States - Chapman, Heller, Marrochio, Pastawski [https://arxiv.org/abs/1707.08582]
5. Circuit complexity in quantum field theory - Jefferson, Myers [https://arxiv.org/abs/1707.08570]
6. Circuit complexity for free fermions - Hackl, Myers [https://arxiv.org/abs/1803.10638]
7. Complexity and entanglement for thermofield double states - Chapman, Eisert, Hackl, Heller, Jefferson, Marrochio, Myers [https://arxiv.org/abs/1810.05151]

Talk 3 – Entanglement and Complexity in Holography

I will start with a brief review of the holographic correspondence between conformal field theory and gravity in Anti-de Sitter space. I will then describe the gravitational dual quantities to entanglement entropy and quantum computational complexity and will demonstrate how to evaluate them in simple examples. I will review various results obtained using this machinery, including the structure of divergences, time dependence under Hamiltonian evolution, and the reaction to perturbations. This will include identifying the influences of chaos and scrambling on entanglement and complexity and explaining how they match what we expect to see on the field theory side.

References:

1. Holographic Entanglement Entropy: An Overview - Nishioka, Ryu, Takayanagi [https://arxiv.org/abs/0905.0932].
2. Time Evolution of Entanglement Entropy from Black Hole Interiors – Hartman, Maldacena [https://arxiv.org/abs/1303.1080]
3. Black holes and the butterfly effect - Shenker, Stanford [https://arxiv.org/abs/1306.0622]
4. Computational Complexity and Black Hole Horizons; Addendum to Computational Complexity and Black Hole Horizons - Susskind [https://arxiv.org/abs/1402.5674, https://arxiv.org/abs/1403.5695].
5. Complexity and Shock Wave Geometries - Stanford, Susskind [https://arxiv.org/abs/1406.2678].
6. Complexity Equals Action; Complexity, action, and black holes - Brown, Roberts, Susskind, Swingle, Zhao [https://arxiv.org/abs/1509.07876, https://arxiv.org/abs/1512.04993].
7. Complexity of Formation in Holography - Chapman, Marrochio, Myers [https://arxiv.org/abs/1610.08063]
8. On the Time Dependence of Holographic Complexity - Carmi, Chapman, Marrochio, Myers, Sugishita [https://arxiv.org/abs/1709.10184]
9. Comments on Holographic Complexity - Carmi, Myers, Rath [https://arxiv.org/abs/1612.00433]
10. Holographic Complexity in Vaidya Spacetimes I, II - Chapman, Marrochio, Myers [https://arxiv.org/abs/1804.07410, https://arxiv.org/abs/1805.07262]