Quantum Information and Geometry

Zhongwu Chen
Supervisor: Constantin Bachas (ENS)

June 6, 2022

Academic Training

- 2016.9 - 2020.7, Undergraduate, Physics.
  Peking University, Beijing, China.
  86.00/100.
- 2020.9 - 2021.7, Master 1, Physics.
  Ecole Normale Supérieure, Paris, France.
  16.47/20.
- 2021.9 - 2022.7, Master 2, Theoretical Physics.
  Ecole Normale Supérieure, Paris, France.
  (1st semester) **19.02**/20,
  (2nd semester, without internship) **18.13**/20.

Courses - M1

- Relativistic quantum mechanics and introduction to quantum field theory (Adel Bilal, 6ETCS) **18.10**/20.
- Introduction to general relativity and cosmology (Nick Kaiser, 6ECTS) **14.60**/20.
- Numerical methods for differential equations in physics (Laurette Tuckerman, 6ECTS) **16.50**/20.
- Dynamical systems : deterministic dynamics and fluctuations (Stephan Fauve, 6ECTS) **14.50**/20.

- Library-based project (Jan Troost, 6ECTS) **16.00**/20.
  State Operator Correspondence and AdS/CFT Correspondence.
- Research internship (Costas Bachas, 30ECTS) **17.00**/20.
  Steady States of Holographic Interfaces [*JHEP* **11** (2021) 095].

Courses - M2

- Quantum field theory (Amir-Kian Kashani Poor, 6ECTS) **19.00**/20.
- General relativity (Daniele Steer, 6ECTS) **20.00**/20.
- Lie groups, Lie algebras and representations (David Hernandez, 6ECTS) **19.00**/20.
- Advanced statistical physics and new applications (Giulio Biroli, Gregory Schehr, 6ECTS) **19.10**/20.
- Statistical field theory and applications (Adam Nahum, 6ECTS) **18.00**/20.

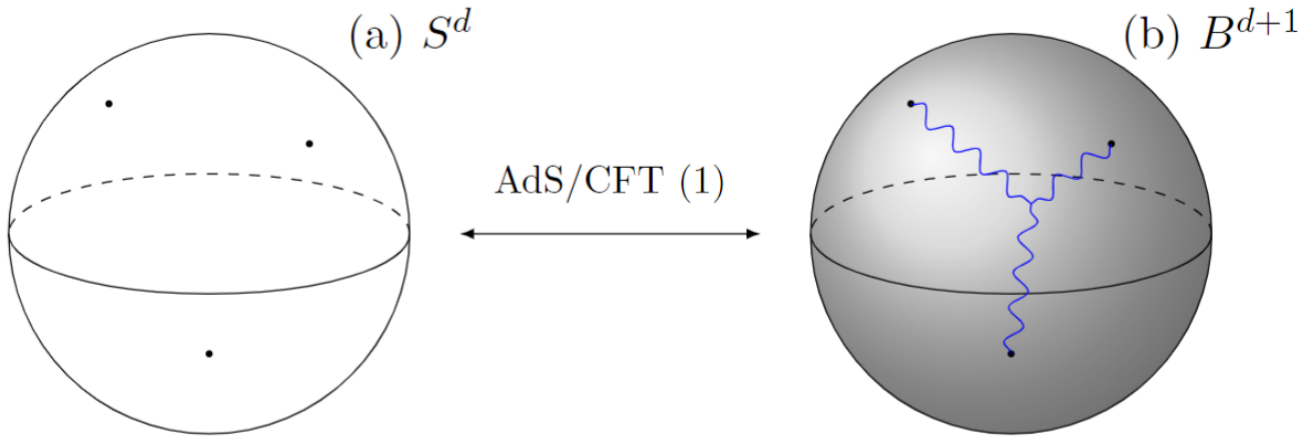
Courses - M2

- String theory (Dan Israel, 3ECTS) **20.00**/20.
- Quantum field theory II (Stéphane Lavignac, 3ECTS) **17.50**/20.
- Advanced topics in quantum field theory (Paul Windey, 3ECTS) **19.00**/20.
- Conformal field theory (Benoît Estienne, Yacine Ikhlef, 3ECTS) **16.00**/20.

- Research internship (Costas Bachas, 18ECTS)
  Holography and Tensor Networks.

Internships

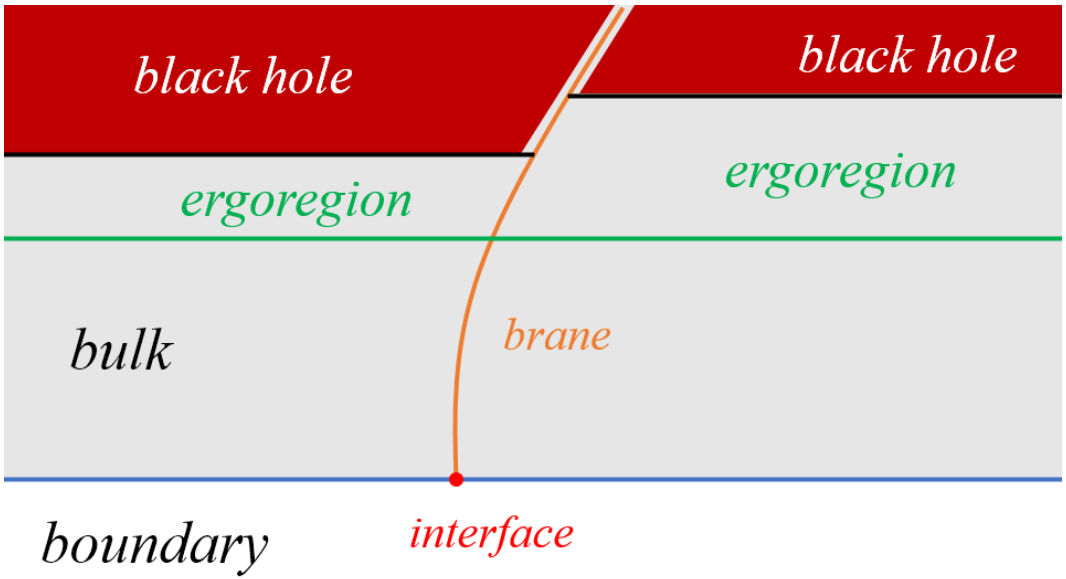
- The AdS/CFT correspondence is a duality relation between a gravitational theory in asymptotically AdS bulk spacetime and a non-gravitational conformal field theory on the boundary.



- Conformal field theories are quantum field theories which enjoy a larger symmetry group, called the conformal group.
- The AdS spacetime is the maximally symmetric spacetime with a negative Ricci curvature.

Internship - M1

- Our case: AdS_3/CFT_2.
- Rotating BTZ black holes on the two sides of a brane.
- We solve the shape of the brane using the Israel-Lanczos matching condition.
- An example of non-Killing horizon.

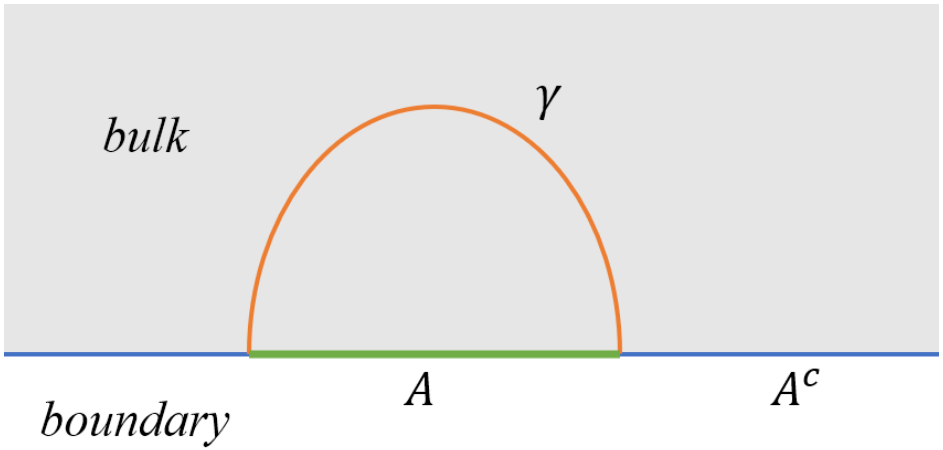


- Reduced density matrix $\rho_A = \mathrm{Tr}_{A^c}\,\rho$.
- Entanglement entropy and Rényi entropy

$$S(\rho_A) = -\,\mathrm{Tr}(\rho_A \log \rho_A), \qquad S^{(q)}(\rho_A) = \frac{1}{1-q} \ln \mathrm{Tr}\,\rho_A^q. \tag{1}$$

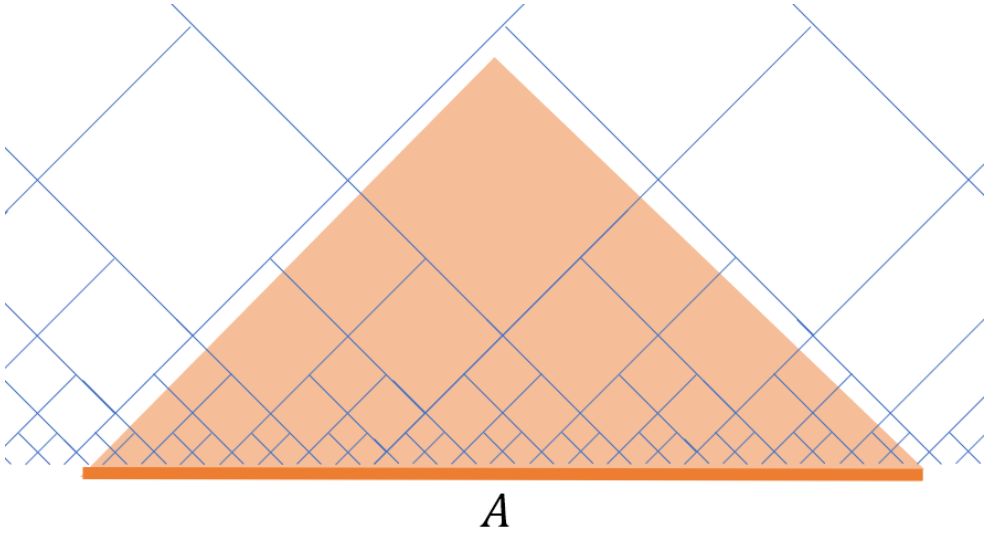
- Ryu-Takayanagi formula

$$S(\rho_A) = \frac{\mathrm{Area}(\gamma)}{4G_N\hbar}. \tag{2}$$



Internship - M2

- The tensor network structure serves as a variational ansatz for the ground state of a many body system.
- Each vertex represents a tensor, and each bond implies a tensor contraction.
- The minimal cut provides a bound on entanglement entropy, similar to the RT surface.



- Tensor network: discretization of a spacial slice of the bulk spacetime.
- Generalize this to interface CFT?

Thesis Project

- Reconstruction of bulk geometry from quantum information properties of the boundary theory.
- Studying the simple examples of holographic interfaces.
- Horizon and quantum entanglement?

$$S_{BH} = \frac{\text{Area(Horizon)}}{4G_N\hbar}. \tag{3}$$

- Reconstruction of island regions behind the horizon could explain how unitarity is preserved in black hole evaporation.
- Relation between energy and entropy, e.g. the Quantum Null Energy Condition:

$$\langle T_{kk} \rangle \geq \frac{\hbar}{2\pi a} S''[\Sigma]. \tag{4}$$

- *How to mention ER=EPR?*
- *Initial condition for cosmology from the relation between energy and entropy?*