Lectures on quantum information scrambling

Beni Yoshida

Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada

1 References

1.1 Lecture 1: Operator Growth and OTOCs

This lecture was based on the first and second papers. For gravity oriented researchers, a next step would be to read the third paper.

- D. A. Roberts, D. Stanford, and L. Susskind, "Localized shocks," *JHEP* **3** (2015) 51.
- P. Hosur, X.-L. Qi, D. A. Roberts, and B. Yoshida, "Chaos in quantum channels," *JHEP* **02** (2016) 004.
- D. A. Roberts, D. Stanford, and A. Streicher, "Operator growth in the syk model," *JHEP* **6** (2018) 122.

During the lecture, many people asked questions concerning operator growth in a continuum system (oscillators). It is discussed in the following paper.

- Q. Zhuang, T. Schuster, B. Yoshida, N. Y. Yao, "Scrambling and complexity in phase space," arXiv:1902.04076

1.2 Lecture 2: Haar randomness

This lecture was mostly based on section 2 of the first paper. For a longer lecture series, I would cover the second and third papers too.

- D. A. Roberts and B. Yoshida, "Chaos and complexity by design," *JHEP* **4** (2017) 121.
- P. Hayden, S. Nezami, X.-L. Qi, N. Thomas, M. Walter, and Z. Yang, "Holographic duality from random tensor networks," *JHEP* **11** (2016) 9
- A. Nahum, S. Vijay, and J. Haah, "Operator spreading in random unitary circuits," *Phys. Rev. X* **8** (2018) 021014.

1.3 Lecture 3: Hayden-Preskill thought experiment

This lecture is based on the following three papers.

- P. Hayden and J. Preskill, "Black holes as mirrors: quantum information in random subsystems," *JHEP* **09** (2007) 120.
- P. Hosur, X.-L. Qi, D. A. Roberts, and B. Yoshida, "Chaos in quantum channels," *JHEP* **02** (2016) 004.
- B. Yoshida and A. Kitaev, "Efficient decoding for the hayden-preskill protocol," `arXiv:1710.03363`.

For those who are interested in experimental aspects of scrambling, the following paper reports experimental realization of the Hayden-Preskill recovery.

- K. A. Landsman, C. Figgatt, T. Schuster, N. M. Linke, B. Yoshida, N. Y. Yao, C. Monroe, "Verified quantum information scrambling," *Nature* 567 (7746), 61.

1.4 Further reading for gravity oriented researchers

If Lecture 4 would exist, the following papers would be covered.

- T. Dray and G. 't Hooft, "The gravitational shock wave of a massless particle," *Nucl. Phys. B* **253** (1985) 173.
- K. Sfetsos, "On gravitational shock waves in curved spacetimes," *Nucl. Phys. B* **436** (1995) 721–745.
- S. H. Shenker and D. Stanford, "Black holes and the butterfly effect," *JHEP* **3** (2014) 67.