Quantum computing: algorithms and complexity
Project Presentations
On: 24.05.2023, 13:00

Your final assignment is to give a talk on a research topic in quantum computing and complexity. You will divide yourself into two roughly equally-sized teams. Each team will present one of the research topics below in approximately one hour on May 24th. You will have to divide the presentation among your team members so that each of you gets to present something. The goal of this is for you to read and understand state-of-the-art research papers on quantum computing so as to be able to present their results to your peers. The talk you give should be similar to the lectures from the latter half of the course (i.e. you should aim to present things at that level). I would recommend that you give a board talk, but you can also use slides if you prefer that. As in the lectures, you should be able to answer questions that come up during your presentation. In fact, each team is encouraged to ask questions during the presentation of the other team.

Choose one of the topics below (some of which were mentioned in the lectures) to present:

1. **The need for structure in quantum speedups** - https://arxiv.org/abs/0911.0996. This paper investigates the structure of problems that achieve an exponential quantum speed-up in the query complexity setting.
2. **Verfiable quantum advantage without structure** - https://arxiv.org/abs/2204.02063. This was the first result to give an oracle separation between BQP and BPP relative to a random oracle and such that the resulting problem is also in NP. An equivalent statement of the result is that it gives a one round proof-of-quantumness protocol whose only computational assumption is that hash functions behave like random functions (the random oracle heuristic).
3. **A polynomial-time classical algorithm for noisy random circuit sampling** - https://arxiv.org/abs/2211.03999. As the name suggests, this gave an efficient classical algorithm for approximately sampling from the output distribution of random quantum circuits when each gate is subject to a constant rate of noise.
4. **Computational pseudorandomness, the wormhole growth paradox, and constraints on the AdS/CFT duality** - https://arxiv.org/abs/1910.14646. This paper explores potential applications of quantum complexity theory to quantum gravity.
5. **On the need for large quantum depth** - https://arxiv.org/abs/1909.10303. This was one of the first papers to give oracle evidence that deep quantum circuits can solve problems which cannot be solved

by short depth quantum circuits, even when augmented with polynomial-time classical computation. The other paper was this one https://arxiv.org/abs/1909.10503. You are free to present either one.

6. **Concentration bounds for quantum states and limitations on the QAOA from polynomial approximations** - https://arxiv.org/abs/2209.02715. This paper investigates limitations of a certain class of near-term quantum algorithms (the Quantum Approximate Optimisation Algorithm, or QAOA). In particular, the paper shows that certain problems cannot be solved with short depth QAOA.
7. **Improved hardness results for the guided local hamiltonian problem** - https://arxiv.org/abs/2207.10250. This paper investigates the complexity of a problem known as the Guided Local Hamiltonian (GLH) problem. GLH is similar to the LH problem, that we discussed in the lectures. However, while LH is QMA-complete, GLH is BQP-complete for certain parameter choices. See also this concurrent paper https://arxiv.org/abs/2207.10097.
8. **A distribution testing oracle separation between QMA and QCMA** - https://arxiv.org/abs/2210.15380. This paper gave the first *classical* oracle separation between QMA and QCMA.
9. **Oracle separation of BQP and PH** - https://eccc.weizmann.ac.il/report/2018/107/download/. This paper gave the first oracle separation between BQP and PH (in the sense that there's a problem in BQP but not PH).
10. **Unconditional quantum advantage for sampling with shallow circuits** - https://arxiv.org/abs/2301.00995. In the lectures we saw that there are problems solvable by constant depth quantum circuits which are provably not solvable by constant depth classical circuits. This paper showed that there are also distributions that constant depth quantum circuits can sample from, that cannot be sampled from by constant depth classical circuits.
11. **A quantum-inspired classical algorithm for recommendation systems** - https://arxiv.org/abs/1807.04271. This paper showed that a quantum machine learning algorithm for the recommender system problem can be dequantized (i.e. turned into a classical algorithm). This inspired a sequence of works on "quantum-inspired" classical algorithms (efficient classical algorithms resulting from the dequantization of efficient quantum algorithms).

A couple of things to note:

- Some of these papers have multiple results. You don't need to present all of them, it's fine to just pick one and present that one in more detail.
- For pretty much all of these topics you can find talks about them on youtube. I encourage you to watch these talks to get a better understanding of the results and also as inspiration for how to present the chosen topic.
- You should coordinate with the other team so that **each team chooses a different topic**. You are also allowed to present something that's not in the list, but ask me about it first (ideally it should be something algorithms or complexity focused).