Classical simulation of near-term quantum computers

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Main Results

- Photonic quantum computers have a lot of exciting potential, but there are practical issues such as when photon are distinguishable or lossy.
- We adapt a classical simulation algorithm to take these imperfections into account.
- From this we assess how large photonic quantum computers need to be to still offer an advantage.

1. What are quantum computers?

- Computers which take advantage of the bizarre properties of quantum physics.
- Many applications including search & optimisation, simulating physical systems, and machine learning.
- Small demonstration devices, such as those by IBM [IBM], already available and usable by the general public.

2. How are we building them?

- Focus at Bristol is on photonics, using the quantum properties of light.
- Integrated linear optics allows us to develop large devices at scale.
- Information is encoded in which waveguide a photon is in.
- Controllable interferometers are known and can be implemented [CHS+15].

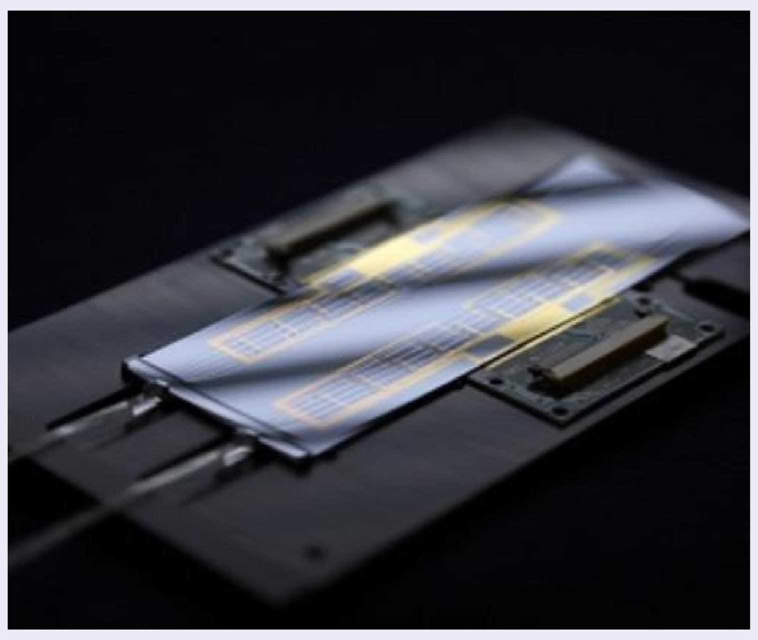


Figure: A reprogrammable chip from [CHS+15]

3. What issues do we have?

- Photon sources are not deterministic, so photons might not be generated at the same time.
- This leads to distinguishability, where photons can be identified from wavelength, time, polarisation etc.
- Photons might also be lost due to issues such as coupling or absorption.
- These cause photons to behave individually, rather than collectively.

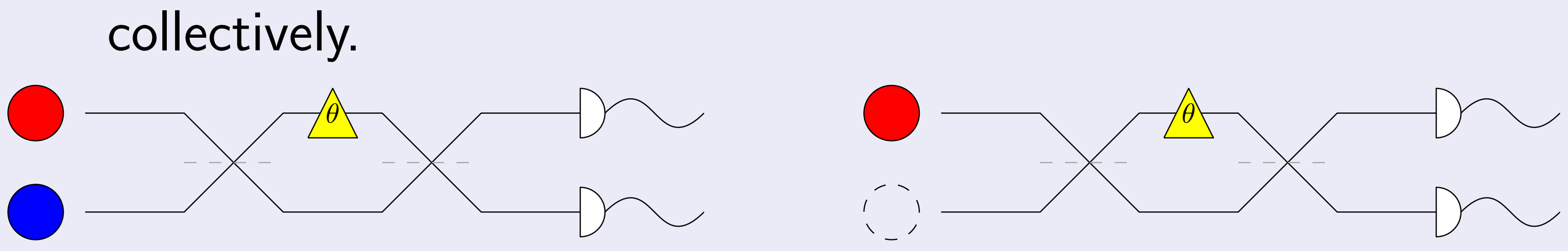
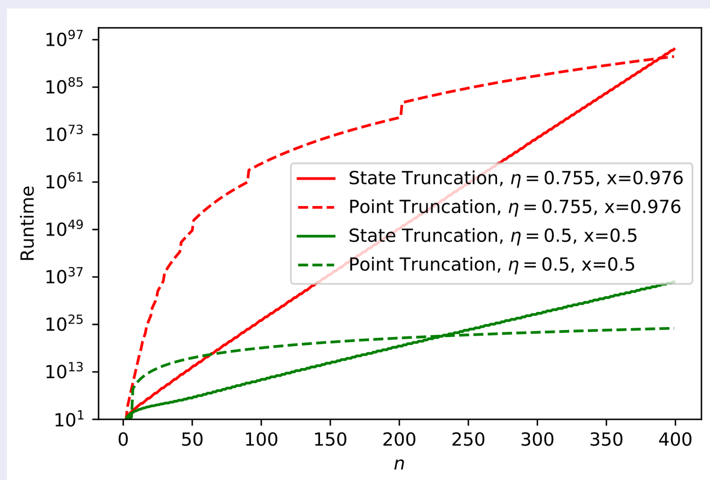


Figure: Example issues: Distinguishability (left) and Loss (right).

4. A new classical simulator

- We show that models for distinguishability x [RMC+18] and loss η [RSG-P18] are equivalent to sampling from the binomial distribution.
- A classical simulator for n-photon quantum computers:
  1. Sample up to n photons which survive
  2. Sample up to $k < n$ indistinguishable photons
  3. Efficiently simulate the $n - k$ distinguishable photons
  4. Simulate the k indistinguishable photons in $O(k^2 2^k)$ time via [CC18]

5. How well does our simulator perform?



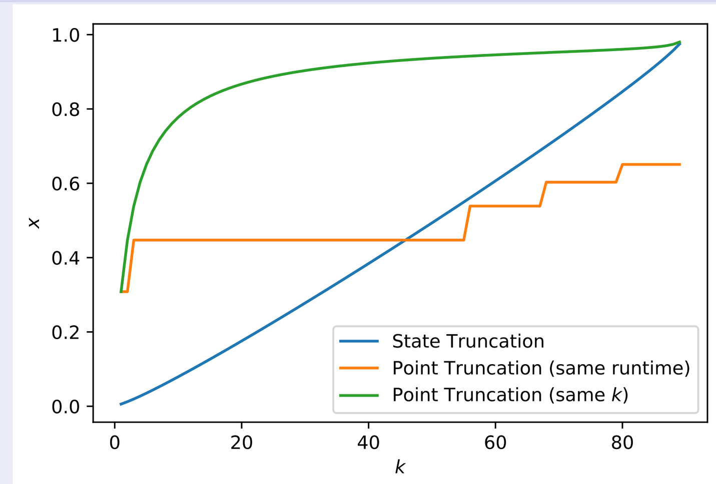


Figure: Estimated performance of our algorithm compared to methods of [RMC+18, RSG-P18].

- We approximate our algorithm's performance under various amounts of distinguishability (x) and loss (η).
- We demonstrate that for near-term quantum computers with 50-90 photons our algorithm can simulate more distinguishability and loss than other approaches.

6. Loss from circuit depth

- Suppose each photon has some probability τ of surviving with every component it interacts with.
- Probability of photons surviving after s components scales as τ^s.
- Leads to efficient classical simulation if

$$s > \frac{\log n - \log 1/x - \log k}{\log 1/\tau}. \quad (1)$$

- Currently all fully reprogrammable designed have at least linear depth in n.

7. Future work

- Can we adapt classical simulation algorithms to other systems, such as quantum computers with nonlinear optics?
- The quantum computers considered here are non-universal. Are there ways of simulating universal quantum computers with these techniques?

References

[CC+18] P. Clifford and R. Clifford, in Proc. SODA'18, 146-155 (2018)
[CHS+15] J. Carolan et al., Science 349, 711-716 (2015)
[IBM] IBM Quantum Experience, https://quantum-computing.ibm.com/
[RMC+18] J. J. Renema et al., Phys. Rev. Lett. 120, 220502 (2018)
[RSG-P18] J. J. Renema et al., [arXiv:1809.01953] (2018)

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