

Quantum simulation of partially distinguishable boson sampling

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Main Results

- ▶ We provide an explicit polynomial time quantum circuit for Boson Sampling with photons of arbitrary distinguishability.
- ▶ This is through reducing Boson Sampling to the problem of sampling from irreducible representations of the Unitary group [RSdG99].
- ▶ This is solvable through known circuits for the Schur transform [BCH07].

1. Boson Sampling

- ▶ Sampling from n photons on an m -mode interferometer.

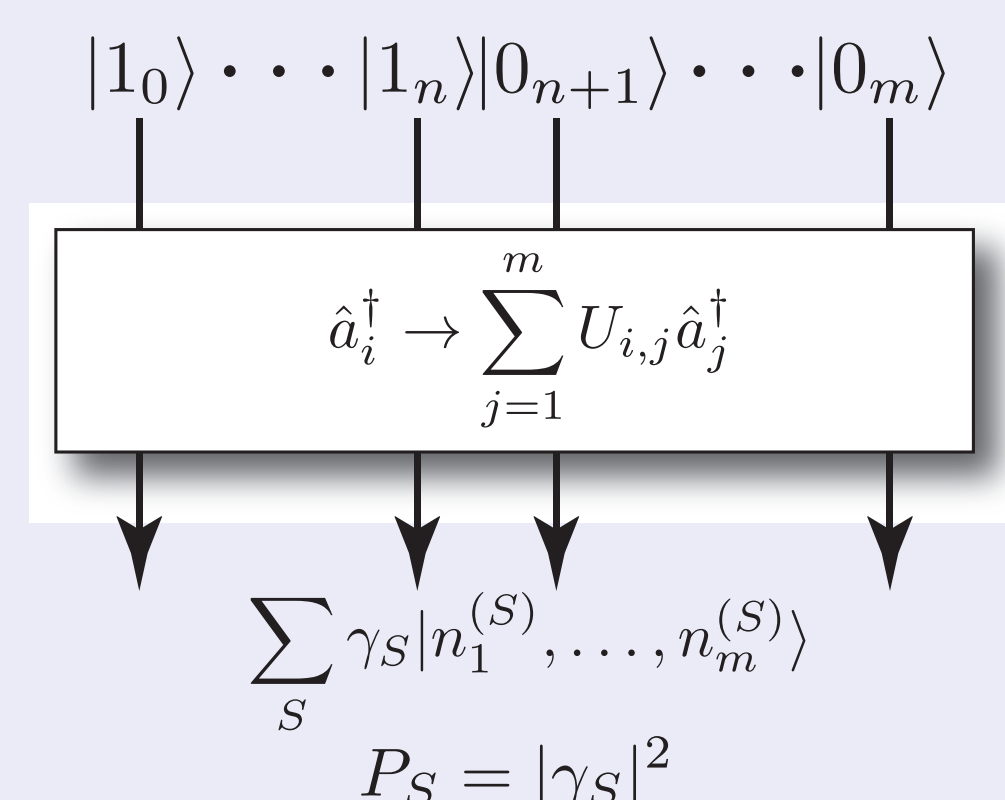


Figure: Boson Sampling model of quantum computation. Reproduced from [GMO+15]

- ▶ Efficient classical simulation would imply collapse of the polynomial hierarchy [AA11].
- ▶ Though practical algorithms for up to 50 photons exist [NSC+17].

2. Unitary group representations

- ▶ The Hilbert space $(\mathbb{C}^m)^{\otimes n}$ carries irreps of $U(m)$ and S_n .
- ▶ An efficient quantum circuit, denoted W , allows us to map between this space and the irreps [BCH08].

$$W|\Psi\rangle = \sum_{\lambda} \sum_{q_{\lambda}, p_{\lambda}} C_{q_{\lambda}, p_{\lambda}}^{\lambda} |\lambda\rangle |q_{\lambda}\rangle |p_{\lambda}\rangle$$

- ▶ There is also an efficient mapping from occupation numbers to the symmetric $\lambda = (n)$ irrep of $U(m)$ [RSdG99].
- ▶ The fully symmetric irrep of S_n is one state, denoted $|p_{(n)=1}\rangle$.

3. Quantum circuit for Boson Sampling

- ▶ Circuit works by creating a single particle representation of our occupation numbers through the methods in part 2.
- ▶ Our interferometer U can then be implemented by applying U to each qudit.

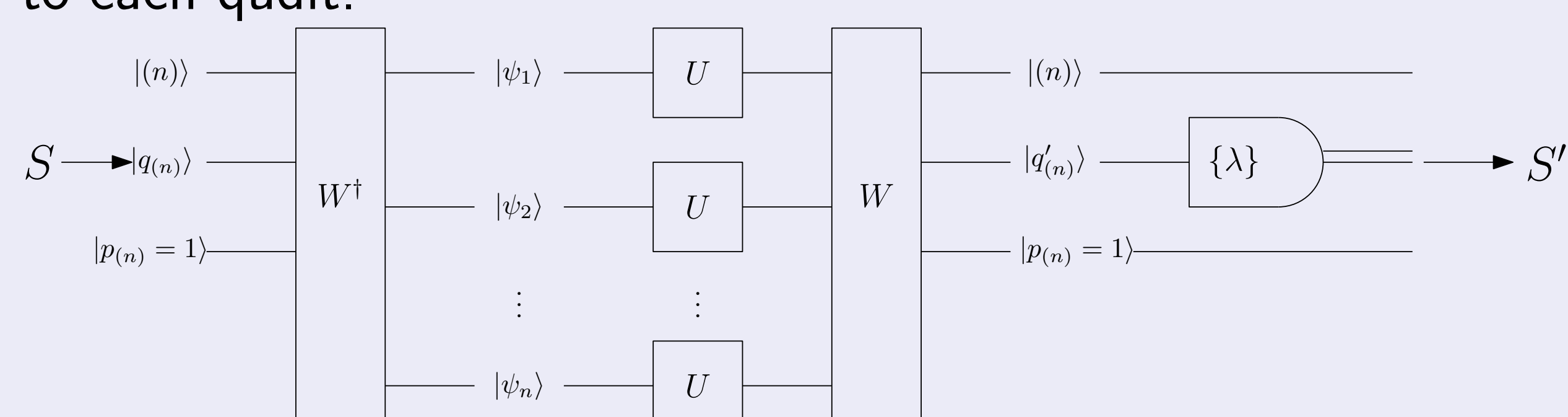


Figure: Circuit for Boson Sampling with indistinguishable photons. This circuit has accuracy $\delta + \epsilon$ due to approximating $U^{\otimes n}$ and W , and runs in polynomial time in terms of $n, m, \log \delta^{-1}$ and $\log \epsilon^{-1}$.

- ▶ We can also see the same distribution if we remove the second W circuit and just measure each qubit in the computational basis.

4. Boson Sampling with partially distinguishable photons

- ▶ For distinguishability, we introduce a second mode.
- ▶ Occupation numbers map to the fully symmetric irrep of $U(m \times n)$.
- ▶ Unitary-Unitary duality decomposes this into irreps of $U(m) \otimes U(n)$ [RCR12].

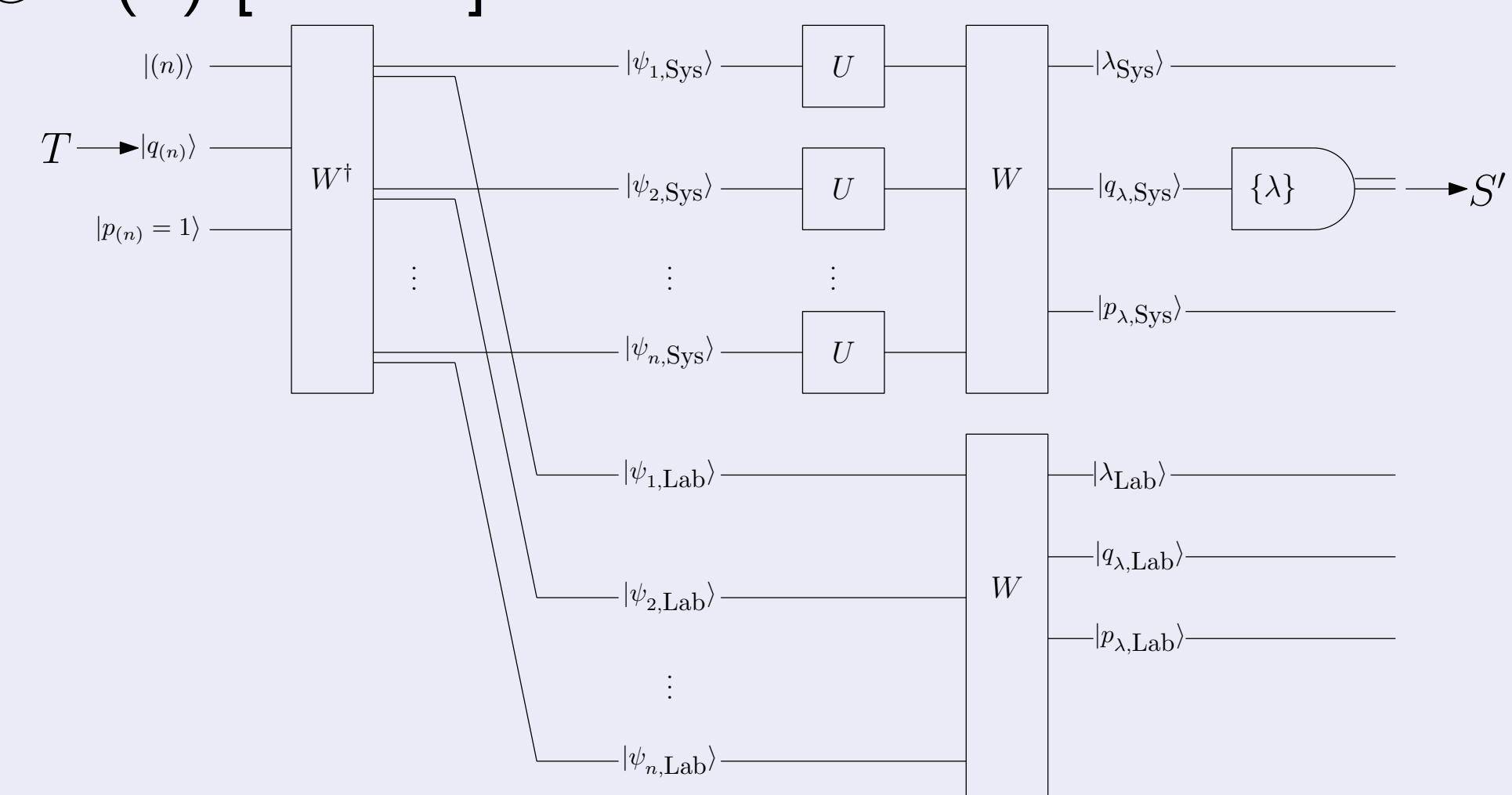


Figure: Circuit for Boson Sampling with photons of arbitrary distinguishability.

5. Boson Sampling with loss

- ▶ Distribution known for $n + k$ photons with k lost [AB16].
- ▶ This can be modelled by tracing out k qudits.

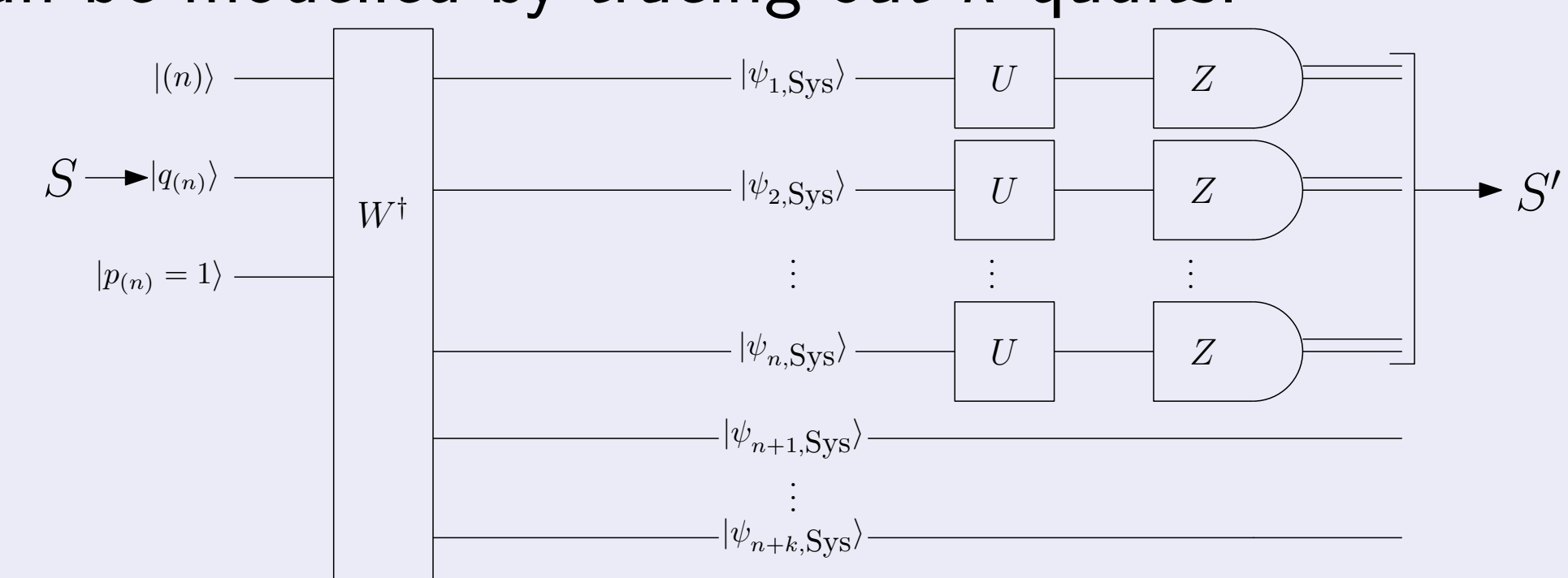


Figure: Circuit for Boson Sampling when k photons are lost.

6. Other results and future work

- ▶ Postselecting on $|\lambda_{\text{Sys}}\rangle = |(n)\rangle$ allows us to perform indistinguishable Boson Sampling.
- ▶ Even small amounts of indistinguishability might be able to guarantee an entangled qudit state.

Questions

- ▶ Can we learn how distinguishability affects complexity?
- ▶ Are there any applications which irrep sampling can be used for?
- ▶ What do more realistic distinguishability models look like?
- ▶ Can we model lossy components?

References

- [AA11] S. Aaronson and A. Arkhipov, Proc. STOC'11, 333-342 (2011)
- [AB16] S. Aaronson and D. Brod, Phys. Rev. A **93**, 012335 (2016)
- [BCH07] D. Bacon, I. L. Chuang and A. W. Harrow, Proc. SODA'07, 1235-1244 (2007)
- [GMO+15] B. T. Gard et al., From Atomic to Mesoscale: The Role of Quantum Coherence in Systems of Various Complexities, Chapter 8 (2015)
- [NSC+17] A. Neville et al., Nat. Phys. **13**, 11531157 (2017)
- [RCR12] D. J. Rowe, M. J. Carvalho and J. Repka, Rev. Mod. Phys. **84**, 711-757 (2012)
- [RSdG99] D. J. Rowe, B. C. Sanders and H. de Guise, J. Math. Phys., **40** 7, 3604-3615 (1999)