

“Hybrid quantum computing problems and algorithms”

ANSIS ZVIRBULIS

SUPERVISOR: PROF., DR. SC. COMP. ANDRIS AMBAINIS

State of computing

- ▶ “Normal” computing (laptops, PCs, servers)
- ▶ Machine learning
- ▶ Supercomputers
- ▶ ?

State of computing – Quantum computing

Next step in evolution:

- ▶ Random number generation
- ▶ Cryptography (breaking of RSA, new protocols)
- ▶ Search problems
- ▶ ??

State of computing – Quantum computing

Issues:

- ▶ We need much more qubits!!!
- ▶ **ERRORS!!!**

Quantum computing query model

5

- ▶ Quantum state: $|\psi\rangle$
- ▶ Unitary transformations: U_0, U_1, \dots, U_T
- ▶ Quantum query transformation: Q on input x_1, x_2, \dots, x_N :
 - ▶ $Q |x_i\rangle \rightarrow (-1)^{x_i} |x_i\rangle$
 - ▶ $Q |x_i\rangle |a\rangle \rightarrow |x_i\rangle |a \oplus x_i\rangle$
- ▶ $|\psi_{end}\rangle = U_T Q U_{T-1} Q \dots U_1 Q U_0 |\psi_{start}\rangle$
- ▶ U_i - doesn't depend on input
- ▶ Counting the number of queries

Quantum computing: algorithms

- ▶ Grover's search: $\Theta\left(\sqrt{\frac{n}{k}}\right)$
- ▶ Element distinctness: $\Theta\left(n^{\frac{2}{3}}\right)$

Quantum computing

Issues \implies Restrictions \implies New model?

Hybrid-computing

- ▶ Classic computing as main
- ▶ Quantum computing for smaller subtasks

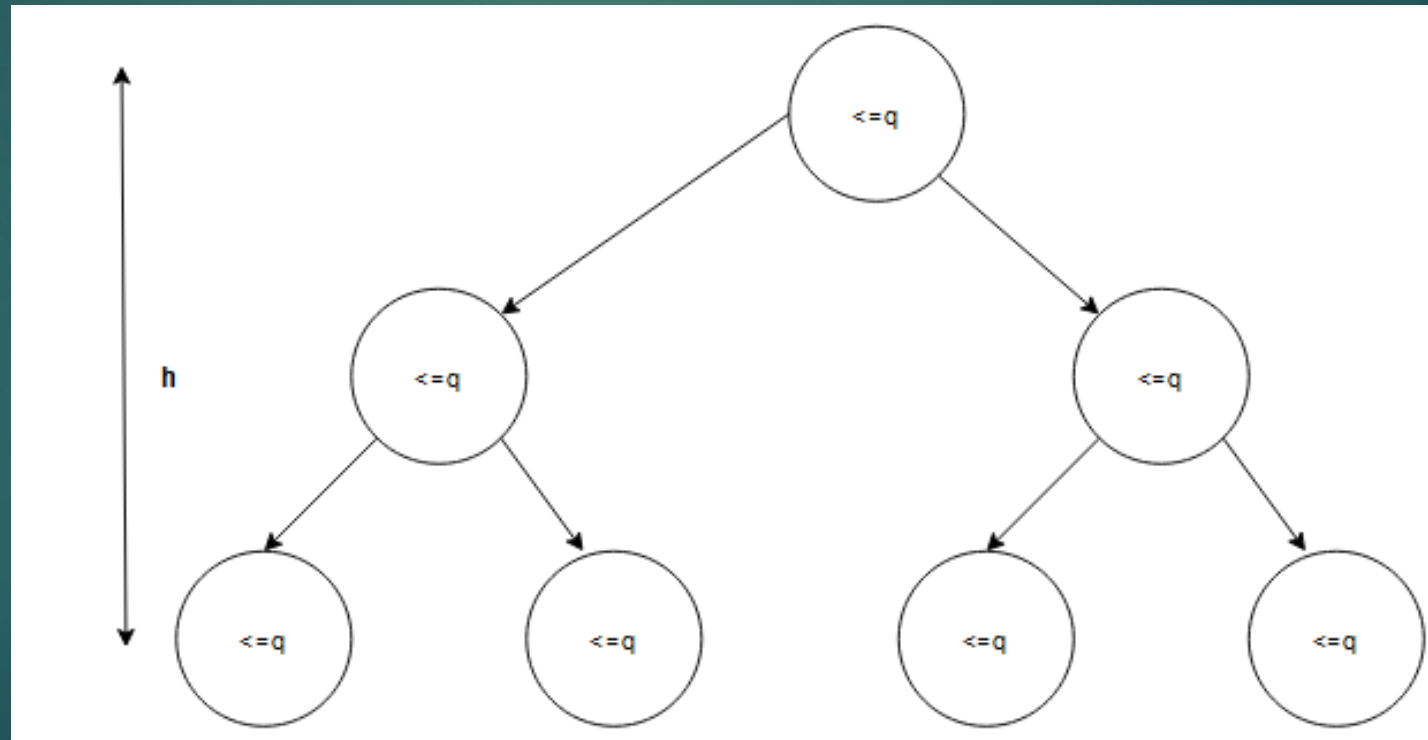
Hybrid computing

X. Sun and Y. Zheng. *Hybrid Decision Trees: Longer Quantum Time is Strictly More Powerful.*
arXiv:1911.13091 [cs.CC]. 2019

Hybrid computing

10

$Q(n, q)$, n – input size, q – max depth of quantum circuit



Prior results

- ▶ $Q(n; q) = \Omega\left(\frac{bs(f)}{q} + \sqrt{bs(f)}\right)$
- ▶ $R(f) \geq Q(f; q) \geq Q(f)$
- ▶ $Q(OR; q) = \Theta\left(\frac{n}{q} + \sqrt{n}\right)$

Current results

$Q(\text{Collision problem}; q)$:

$$O\left(\frac{n}{q^2} + \sqrt[3]{n}\right)$$

$Q(\text{AND} \circ \text{OR}; q)$:


$$O\left(\frac{nm}{q} + \sqrt{nm}\right)$$

Lower bounds?????

Current results

Counting problem (k vs. k+1):

$$\Omega\left(\frac{n}{q} + \sqrt{n * k}\right)$$


$$\tilde{O}\left(\frac{n}{q} + \sqrt{n * k}\right)$$

Remove poly log ???

Further work – with this model

- ▶ **Find lower bounds!**
- ▶ **Algorithms for other problems, e.g., element distinctness?**

Further work

- ▶ Other models (already 2-3 papers waiting to be studied)
- ▶ Implementation on real quantum computer

Thank you!