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Distributed Quantum Advantage

What tasks can be solved faster in ***large computer networks*** *with the help of quantum computation and communication?*

One computer: *Shor, Grover, etc.*

Computer network: *???*

Three flavors of quantum advantage in networks:

Local computation

Less work done between communication steps

One quantum computer more powerful than one classical computer

Communication bandwidth

Less work done during communication steps

Sending one qubit more useful than sending one bit

Communication rounds

Smaller number of communication steps

Sending *some* qubits more useful than sending *any* number of bits!

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Quantum-CONGEST

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CONGEST

- Limited communication bandwidth
- **Classical CONGEST:** in each round you can send $O(\log n)$ bits to each neighbor
- **Quantum-CONGEST:** in each round you can send $O(\log n)$ qubits to each neighbor

Quantum-CONGEST

- **Key tool for algorithm design:** *distributed Grover search*
- **Example:** *computing diameter*
  - quadratic improvement in running time
  - in these tasks quantum-LOCAL ≈ classical LOCAL with $n^{1/2}$ bandwidth
- Benefits beyond bandwidth savings??

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Quantum-LOCAL

Quantum-LOCAL

- Quantum known to help with some problems
  - very significantly, e.g., constant vs. linear
- ***All known examples are artificial problems***
  - engineered to be quantum-easy
  - nontrivial: show that they are classically hard

Quantum-LOCAL

- **Key tool for problem engineering:** ***quantum games***
  - games where players can win without communication if they share qubits before the game starts and inputs are revealed

Quantum-LOCAL

Symmetry-breaking problems
(e.g. ***3-coloring cycles***)

- all are quantum-easy?
- some are quantum-easy?
- none are quantum-easy?

Quantum-LOCAL

Symmetry-breaking problems
(e.g. ***3-coloring cycles***)

- all are quantum-easy?
- ~~some are quantum-easy?~~
- none are quantum-easy?

My conjecture, new proof techniques needed

Quantum-LOCAL

Local coordination problems
(e.g. ***maximal matching***)

- all are quantum-easy?
- some are quantum-easy?
- none are quantum-easy?

Quantum-LOCAL

Local coordination problems
(e.g. ***maximal matching***)

- ~~all are quantum-easy?~~
- some are quantum-easy
- ~~none are quantum-easy?~~

But which? Major open question, new techniques needed

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Traditional quantum computing research

Shor, Grover…

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Quantum-CONGEST

Distributed Grover, quadratic improvements

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Quantum-LOCAL

Quantum games, big improvements, but ***so far only some artificial problems***