Effective qubit mapping, routing and scheduling

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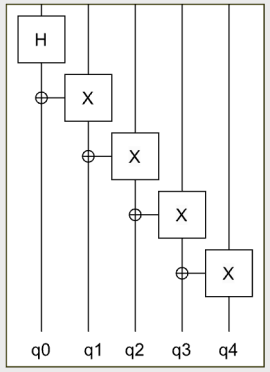
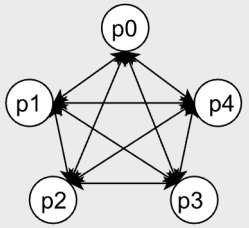
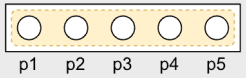
Qubit Mapping and Routing

Quantum hardware suffers from low physical connectivity between qubits, calling for optimal mapping of logical qubits to physical qubits followed by swap insertion.



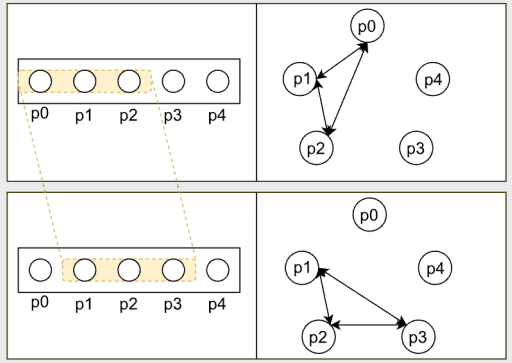


All-to-all connectivity



Trapped-ion shuttling based architectures

- Linear tape of ions with a moveable head of lasers allows for scaling of trapped-ion architectures through shuttling[1].
- This leads to a dynamically evolving physical connectivity graph that requires scheduling the noisy tape movement.



Max-SAT based encoding for tape scheduling

- Prior work has used SAT based solvers for qubit mapping and routing on static circuits [2].
- We can extend this formulation to a dynamically evolving connectivity for shuttling architecture.

Hard constraints

$$H_i \implies \bigwedge_{i=1,j=1}^{i=L-1,j=H-1} \text{edge}(p_i, p_{i+j}) \wedge \neg\text{edge}(p_k, p_{k+l}) \qquad \bigvee_{i=1}^{L-H} (H_i \wedge (\bigwedge_{j\neq i} \neg H_j))$$

Soft constraints

$$\bigvee_{i,k} ((H_a(i-1,k) \wedge H_a(i,k))$$

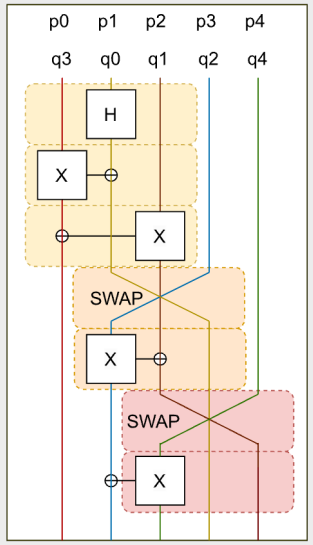
Shuttling sequence generation between our approach and SOTA

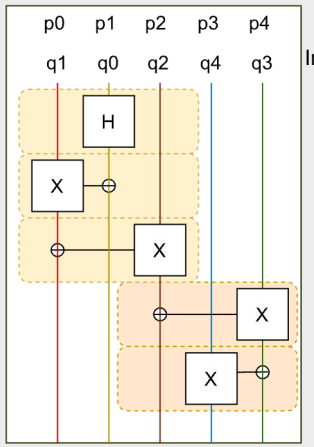
Initial mapping in LINQ

q0	p1
q1	p0
q2	p2
q3	p3
q4	p4

LINQ

Swaps inserted = 2
Tape movement = 2





Initial mapping in MALT

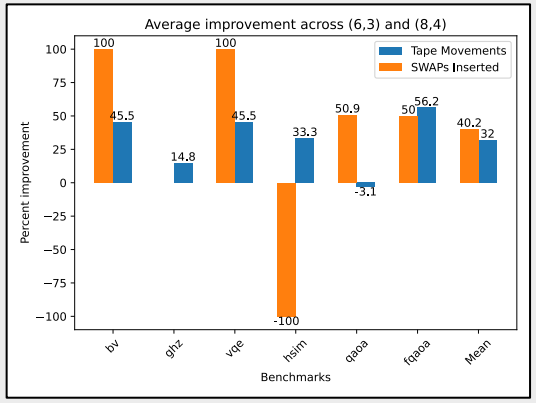
q0	p1
q1	p0
q2	p2
q3	p4
q4	p3

MALT

Swaps inserted = 0
Tape movement = 1

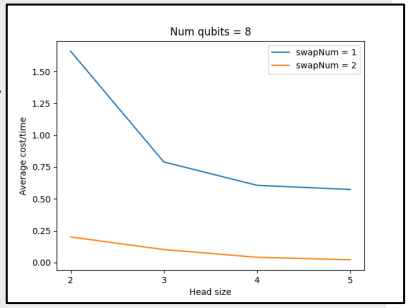
- Insertion of a swap gate can increase circuit depth by the equivalent of three CNOTs.
- Tape movement introduces noise to the system causing degradation to the circuit fidelity
- MALT tries to find a near optimal solution and provides lower cost in terms of swaps.

Performance Analysis



Future Work

- Scalability for longer tape length.
- Noise modelling for cost of swaps and tape movement
- Experiments across algorithms and solvers



[1] Wu, Xin-Chuan & Debroy, Dripto & Ding, Yongshan & Baker, Jonathan & Alexeev, Yuri & Brown, Kenneth & Chong, Frederic. (2021). TILT: Achieving Higher Fidelity on a Trapped-Ion Linear-Tape Quantum Computing Architecture
[2] Molavi, Abtin et al. "Qubit Mapping and Routing via MaxSAT." *2022 55th IEEE/ACM International Symposium on Microarchitecture (MICRO)* (2022): 1078-1091.

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