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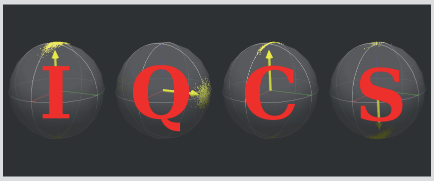


# Improving Quantum Computer Simulations

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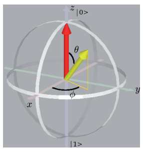
## Quantum Bits

Classical Bit | Quantum Bit

**0**

**1**



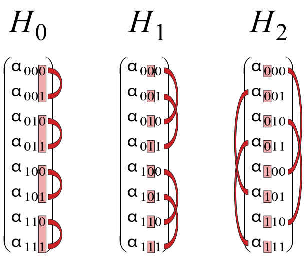
**0 or 1** $|\psi\rangle = \alpha_0\,|0\rangle + \alpha_1\,|1\rangle \Leftrightarrow \begin{pmatrix}\alpha_0\\ \alpha_1\end{pmatrix}$

## Need for Simulation

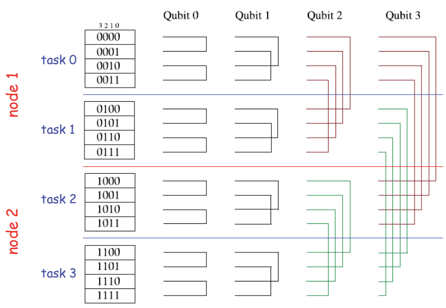
- Develop quantum algorithms
- Analyze robustness to decoherence and gate errors
- Test scalability of error correction codes
- Optimize pulse sequences for ion trap quantum computers

## Quantum Operations


$H = \frac{1}{\sqrt{2}}\begin{pmatrix}1 & 1\\ 1 & -1\end{pmatrix}$

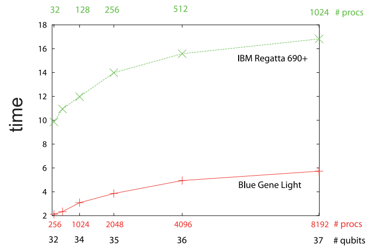



## Communication scheme




## Scaling Properties

Highly efficient up to 37 qubits using 1k (8k) Procs and 3 TB Memory




## Quantum Error Model

### Gate imperfections

Rotations $R(\theta) = \begin{pmatrix}\cos\theta & -\sin\theta\\ \sin\theta & \cos\theta\end{pmatrix}$

Phase shifts $P(\phi) = \begin{pmatrix}1 & 0\\ 0 & e^{i\phi}\end{pmatrix}$

- Decompose e.g. $H = R(\pi/4)\,P(\pi)$
- Introduce errors $\theta' = \theta + \epsilon_\theta$, $\phi' = \phi + \epsilon_\phi$

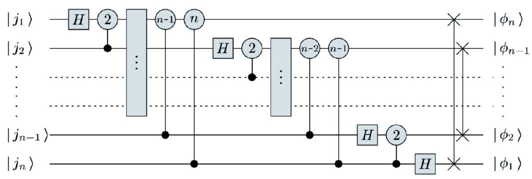
gaussian distributed with standard deviation $\sigma$

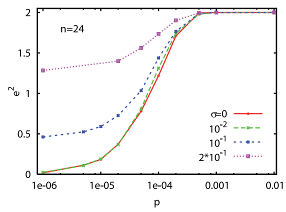
### Decoherence

Apply with probability p/3 each:

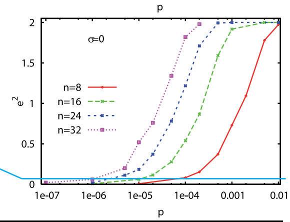
- Bit-flip $\sigma_x = \begin{pmatrix}0 & 1\\ 1 & 0\end{pmatrix}$
- Phase-flip $\sigma_z = \begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix}$
- Both $-i\sigma_y = \begin{pmatrix}0 & -1\\ 1 & 0\end{pmatrix}$

## Application: Robustness of the Quantum Fourier Transform

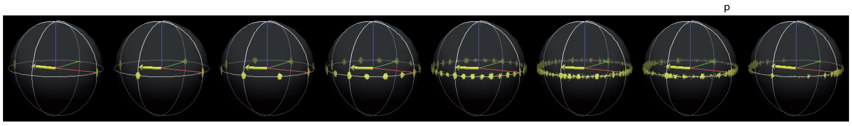





- Errornorm $e^2(\sigma,p) = |\psi - \psi_{exact}|^2$ reveals threshold at $\sigma \approx 10^{-2}$ (more robust than Grover)
- Dependence of the decoherence error on the system size: n ➞ 2n ➡ p ➞ 1/10 p




- Visualisation of Qubit measurement:



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