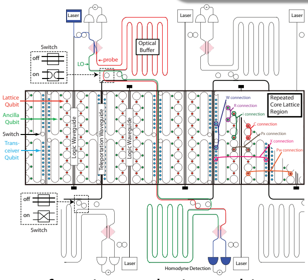
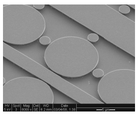
AQUA and the FIRST Project

Advancing Quantum Architecture

Rodney Van Meter and the AQUA Team
http://aqua.sfc.wide.ad.jp/

Our focus is on determining which classical network and system engineering principles apply in the quantum world, and which do not.





rdv, T.D. Ladd, A.G. Fowler, YY, IJQI, 2010
arXiv:0906.2686

We are focusing on device architectures for surface code error correction.
Critical questions:

- How can we handle hard faults (physical defects) in the lattice?
- Can we shorten lattice refresh cycle, and raise error threshold to 3-5%?

We are interested in collaborations to *bridge the gap* between small and large devices, and test our ideas!

Devices

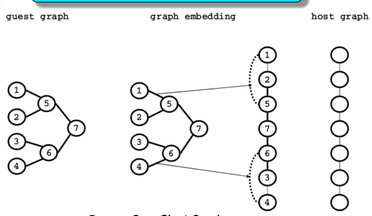
We have a good grasp on how to build a Shor Factoring Machine: we know it's *big* (maybe six billion physical qubits) and that will take a long time (days to months) and a lot of error correction to work properly. What applications will be achievable and production-ready sooner? *What is the smallest **useful** quantum computer?*

Quantum simulations were the first-proposed application of quantum computers, but detailed estimates machine type and size and error correction for executing them are still limited. We are looking at:

- Phase Estimation Algorithm on the surface code

Workloads

Tools

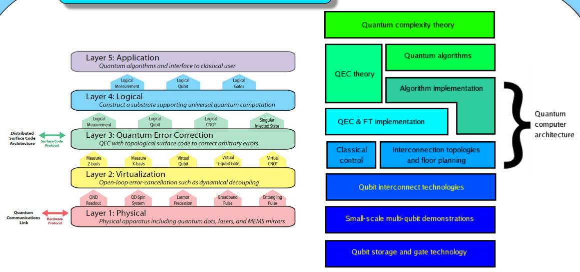


Byung-Soo Choi & rdv,
ACM JETC, to appear, arXiv:0809.4137v3

Software tools done or in progress for:

- Circuit layout & optimization
- Graph embedding for analyzing and optimizing mapping of circuits to architectures
- Complex network simulations, including protocol state machines
- IPsec with QKD (raQoon2 IKE software distribution available)

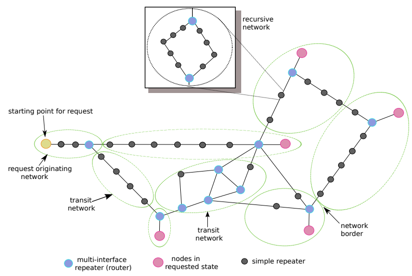
Principles



Architecture for large systems involves much more than just scaling up devices of a few qubits. We adopt a layered architectural approach and use classical principles to handle:

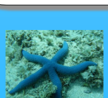
- Physical heterogeneity in technologies
- Asynchrony in operations
- Hard and soft faults

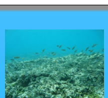
Networks

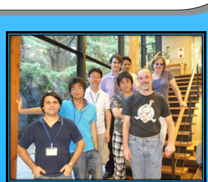


In quantum networks, many of the key issues remain open:

- Debate on long-distance purification v. hop-by-hop teleportation current hot topic
- When to use purification, how to use error correction
- Routing (quantum Dijkstra's algorithm)
- Multiplexing/resource sharing
- Detailed protocol designs emphasizing robustness, minimizing round-trip delays
- Distributed quantum state creation protocols (quantum recursive network architecture, QRNA)
- Management of federated, untrusted networks
- Truly scalable architectures







References and Acknowledgements

[1] rdv, Thaddeus D. Ladd, Austin G. Fowler, Yoshihisa Yamamoto, *Int. J. Quantum Information*,8(1-2), 2010.
[2] rdv, Thaddeus D. Ladd, W. J. Munro, and Kae Nemoto. System Design for a Long-Line Quantum Repeater. *IEEE/ACM Transactions on Networking*, volume 17, number 3, pages 1002-1013, June 2009.
[3] Byung-Soo Choi, rdv, "Effects of Interaction Distance on Quantum Circuits," *ACM J. Emerging Technologies in Computing Systems*, to appear. arXiv:0809.4317 [quant-ph].

FIRST quantum information Processing project (JSPS)