Fault Tolerant QIP Using Probabilistic Entanglement
The basic question:
How should we perform quantum computation (and communication) when the entanglement operations are very prone to heralded failure?

- How will the failure rate affect error accumulation and resource overhead?
- Can we find thresholds for fault tolerant QIP as a function of both failure rate and error rate?
One example to have in mind:

Matter qubits entangled via optical emission
Fast switched optical multiplexer

Potentially nice scalability
With 2+ qubits per module, it’s easy to see options


How about with only one qubit per module?
Easy to tolerate modest heralded failure rates, e.g. 60%

Logical qubits perpetually driven to right by measurements

Bell pair reservoir

(a)

(b)

Easy to tolerate modest heralded failure rates, e.g. 60%

Logical qubits

trim nodes to form regular graph state

fuse nodes to form bridges (see (b))

branch growth (see (a))

So, efficient universal QIP with one 3-level system per node!

But what if photon loss is really bad!?


output ports, there is an additional factor of $1/4$ in our success probability: $P = \frac{1}{4} [(1/2)\eta_\zeta T \rho P_{\text{exc}} (\Delta \Omega / 4\pi)]^2 \approx (0.25)[(0.5)(0.15)(0.2)(0.8)(0.995)(0.5)(0.02)]^2 \approx 3.6 \times 10^{-9}$. With an experiment repetition rate of $R \approx 5.5 \times 10^5$ s$^{-1}$, this results in a heralded entanglement event approximately every 8.5 min.

NV centres - still a lot of losses

Two-photon quantum interference from separate nitrogen vacancy centers in diamond

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We report on the observation of quantum interference of the emission from two separate nitrogen vacancy (NV) centers in diamond. Taking advantage of optically induced spin polarization in combination with polarization filtering, we isolate a single transition within the zero-phonon line of the non-resonantly excited NV centers. The time-resolved two-photon interference contrast of this filtered emission reaches 66%. Furthermore, we observe quantum interference from dissimilar NV centers tuned into resonance through the dc Stark effect. These results pave the way towards measurement-based entanglement between remote NV centers and the realization of quantum networks with solid-state spins.

arXiv:1110.3329
So let’s think about how to do QIP when there are *bad* (e.g. >90%) heralded failures
Target: A large cluster state type thing

The plan (& do this with only logarithmic errors):

- Make a bunch of “building block” resources: blobs each with enough qubits that they can probably connect to four other blobs
- Join them all up (~ one step)
- Prune the resulting structure down.
OK so building blocks...
...what kind of blocks?
OK so building blocks...
...what kind of blocks?
Remember our machine is something like this:

- Parallel operations
- Total connectivity (well...)
Inside, this is going on:
OK for some connections to fail (percolation).
Time steps required

No buffer, No recycling.
Buffer but No recycling.
Buffer and recycling.

$p_s$
The graph shows the worst case age as a function of the number of physical qubits for different values of $p_s$.

- Blue line: $p_s = 1/16$
- Green line: $p_s = 1/10$
- Red line: $p_s = 1/8$
Yuichiro Matsuzaki, Simon C. Benjamin, and Joseph Fitzsimons, PRL 104, 050501 (2010)
That’s merely showing that errors can be kept to (poly) log rates.

How about actually getting a threshold!
Then instead of this target...

...make this thing.
Will that work?
We need some kind of threshold for tolerance of missing edges
...for the simple cluster state we had percolation.

What in this case?
...Now we have Barrett/Stace result for missing qubits

Each snowflake attempts to bond to four others.

The core node in each snowflake becomes a node of the ultimate Raussendorf lattice.
Error tracking from sup material
Ying Li, Sean Barrett, Tom Stace and Simon Benjamin, PRL 105, 250502 (2010).
Snowflake

- Gate errors only
- Gate and Memory errors: $p_M/p_G=1/10$
also
K. Fujii and Y. Tokunaga,
PRL 105, 250503 (2010).
Encore: Let’s get a threshold for communication.
Ying Li, Sean Barrett, Tom Stace and Simon Benjamin, in preparation.

Friday, 9 December 11
Final thought:
Couldn’t we do similar tricks with multiple qubits?