Linear optical quantum computing

Novel architectures and assessment of performance

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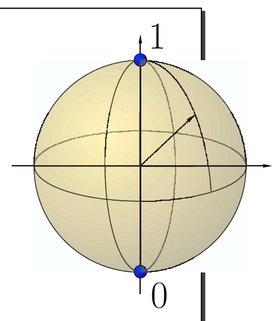
Quantum computing

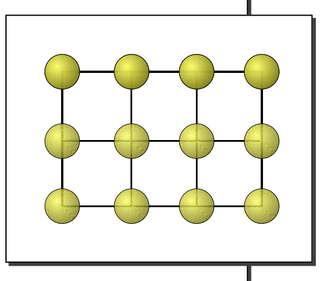


What's this? Exploiting quantum mechanics enables us to solve unsolved problems and find more efficient algorithms. Rather than dichotomic variables (bits), this approach allows for variables containing both values at once with variable complex amplitudes, *qubits* [1]. The possible values now populate the surface of a sphere with the poles representing 0 and 1.

What is it good for?

- **Secure communication**, based on the laws of physics rather than insufficient computational power.
- **Exponential speed-up** between the best known classical and quantum algorithms could be shown when factoring large numbers [2].
- **Quadratical improvement** in time consumption is possible in the problem of searching an unsorted database [3].

How is it done?



- Completely new concept of computation: so-called *cluster model* [4].
- Computation is performed solely by measuring properties of single particles.
- Sophisticated multi-particle state has required in advance.
- This state can be imagined as a square lattice where each site is realised by a qubit and each bond by *entanglement* (which is the crucial non-classical resource) between the neighboring sites.

What do I need? To actually implement these new algorithms, information carriers have to be realised by physical systems governed by quantum mechanics, e. g. trapped atoms, super conductors, or *single photons*. We investigate the potential of the latter ones when allowing only for a special set of manipulation devices.

Questions and tasks

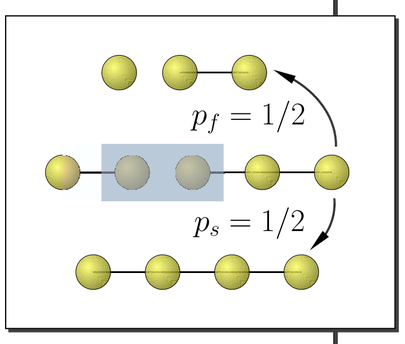
Identify limits of linear optics

- Determine optimal success probabilities of elementary gates.
- Find minimum overhead in cluster state production.

Alternative setups or architectures

- Identify ways to produce universal resource states.
- Consider single-shot setups (decreasing the "expensive" rerouting of photons) and study the threshold behavior leading to useful output states. This might be interesting for use in interferometric stable optical chips.
- Try to exploit more of light's degrees of freedom.
- Include light-matter interfaces into the toolbox to increase success probabilities.

Results so far

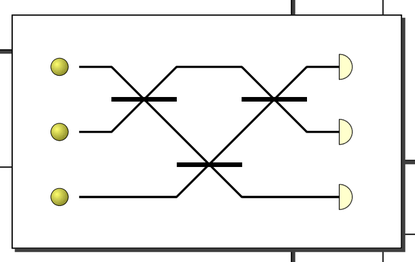


Cluster state production with *fusion* [5] gates:

- Optimal success probability of fusion gates: $p_s = 1/2$ [6]
- To build a chain of length N, $5N$ EPR pairs is a lower bound to resource consumptions [6, 7]. Tools from Markov processes and convex optimization methods were used.
- $n \times n$ cluster states may be produced with an arbitrary high success probability using $O(n^2)$ EPR pairs.

Characterization of beam splitter networks

- Photon number resolving detection is not possible with linear optics and bucket detectors (not shown in full generality, yet).
- Beam splitter networks that act on n modes, using vacuum detector events, may only use up to n additional vacuum modes and n^2 beam splitters.

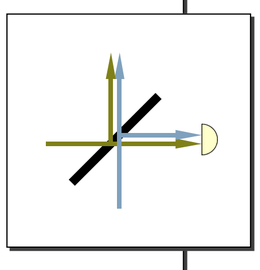


Linear optics

Using *linear optics* means restriction to the following ingredients:

- vacuum (darkness)
- single photon (●) and *EPR* (1×2 cluster states, ●–●) sources
- beam splitters (coated glass plates)
- photodetectors

Quantum mechanics tells us that many of the interesting gates one could build with these tools have a probabilistic nature (failing with a certain probability $1 - p_f$, thus destroying the input qubits).



Vision

Understand what linear optics can do

- Which states can be prepared and measured in a simple way?
- What are the gates that can be realised?

Find ways to use linear optics that are more suitable for experimentalists than today's schemes.

Bibliography

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