Engineering Entanglement

Quantum Computation, Quantum Communications, and Re-conceptualizing Information

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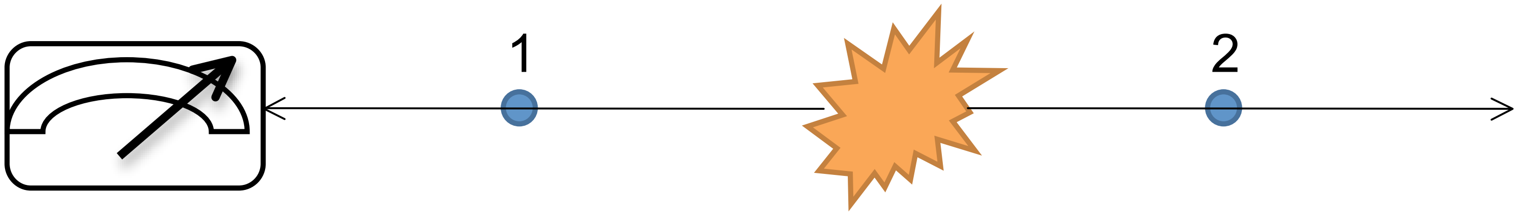
The Einstein-Podolsky-Rosen Thought Experiment

$$\Psi(x_1, x_2) = \int_{-\infty}^{\infty} e^{i2\pi/h(x_1 - x_2 + x_0)p}\, dp$$



Measure momentum, get *p*

Measure position, get *x*

Momentum = -*p*

Position = -*x*-x_0

Bohmian reformulation of the EPR state: spin up $|0\rangle$ spin down $|1\rangle$

$$|EPR\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle|1\rangle - |1\rangle|0\rangle\right)$$

Epistemic Turn: *Why QM is strange?*

◊ *How to use QM's strange properties?*

Entanglement as *explanandum* ◊ entanglement as *resource*

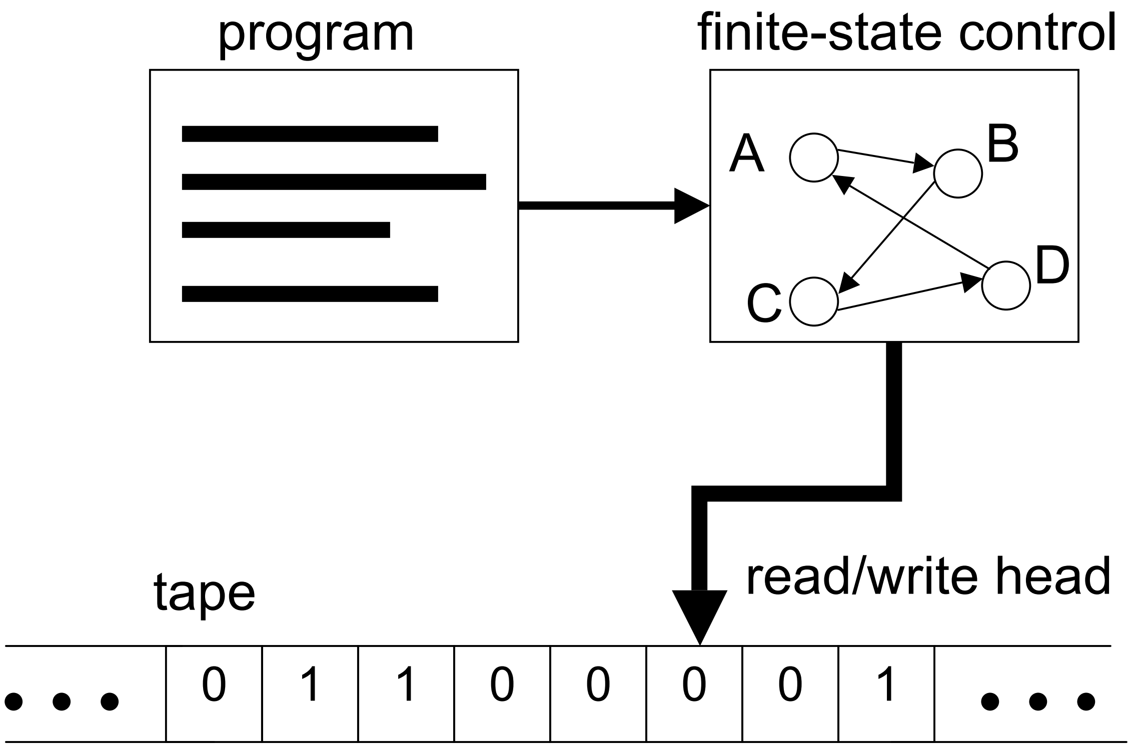
Engineering in three senses:

Manipulate simple quantum states of single particles

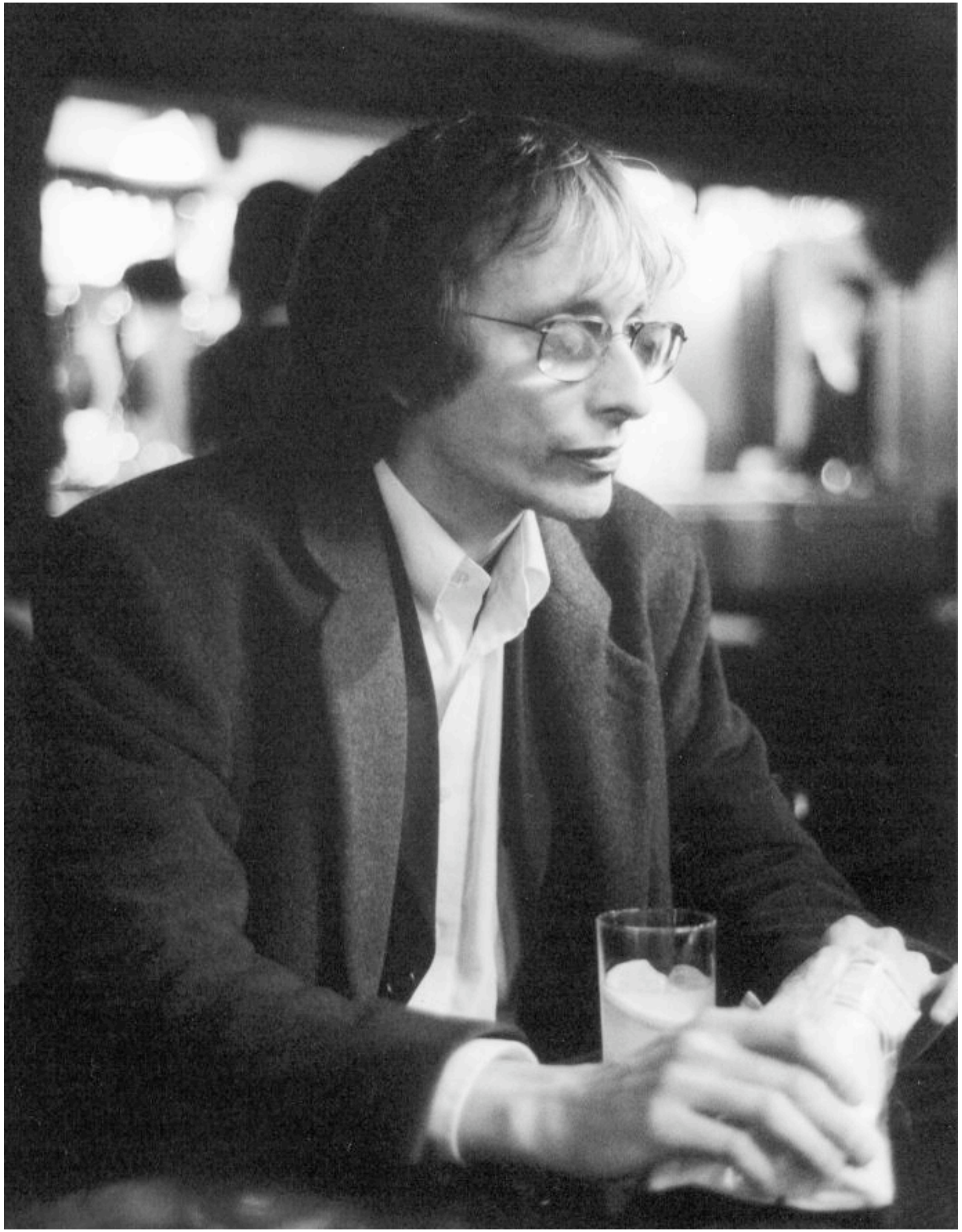
Gauge the fundamental limits of all approaches

Seek "killer applications" for extraordinary resource

Turing Machine

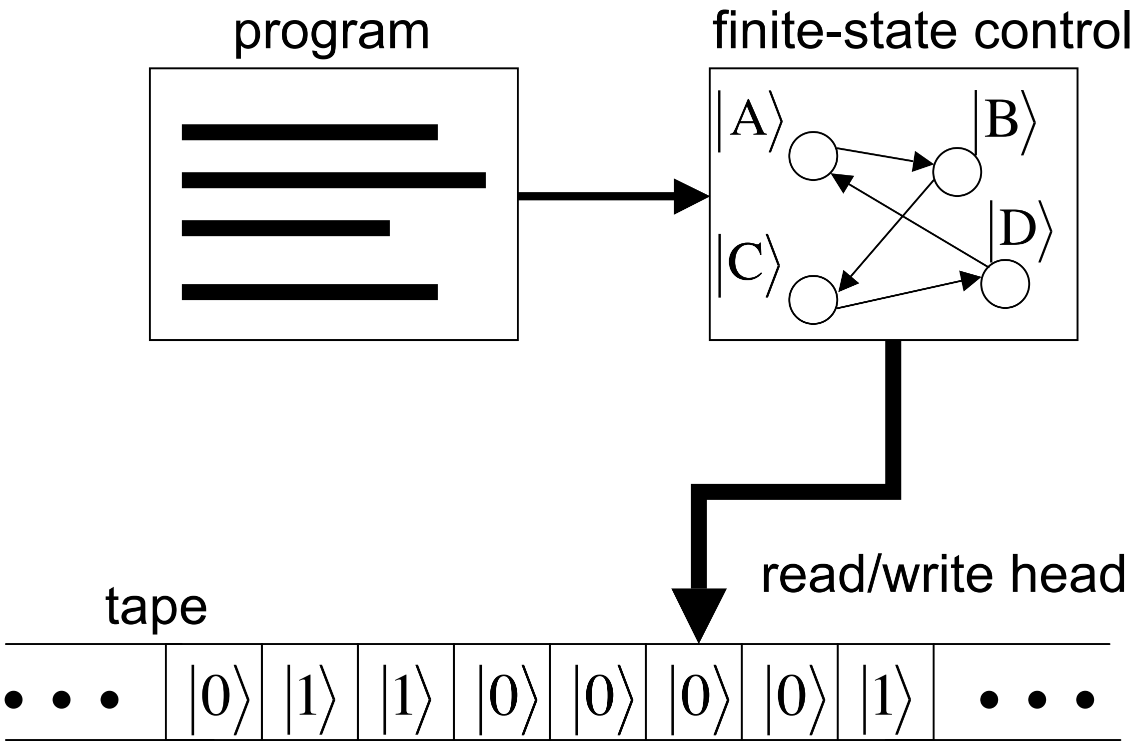


Question: How is it possible to implement TM with physical means?



David Deutsch

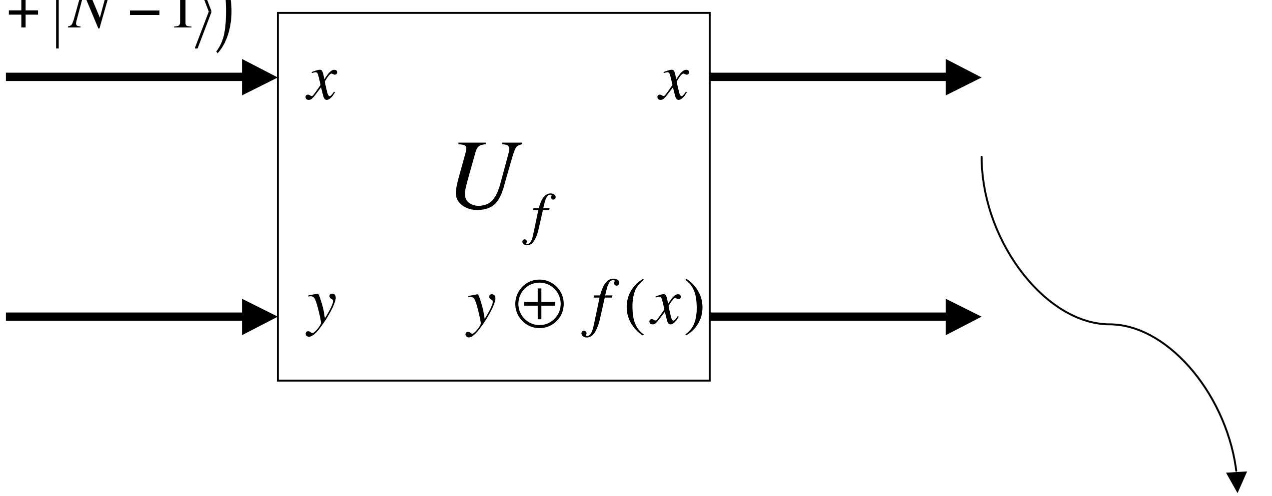
Deutsch's Quantum Turing Machine



Quantum Parallelism

$$\frac{1}{\sqrt{N}}\left(|0\rangle + |1\rangle + \ldots + |N-1\rangle\right)$$

$$|0\rangle$$



$$\frac{1}{\sqrt{N}}\left(|0, f(0)\rangle + |1, f(1)\rangle + \ldots + |N-1, f(N-1)\rangle\right)$$

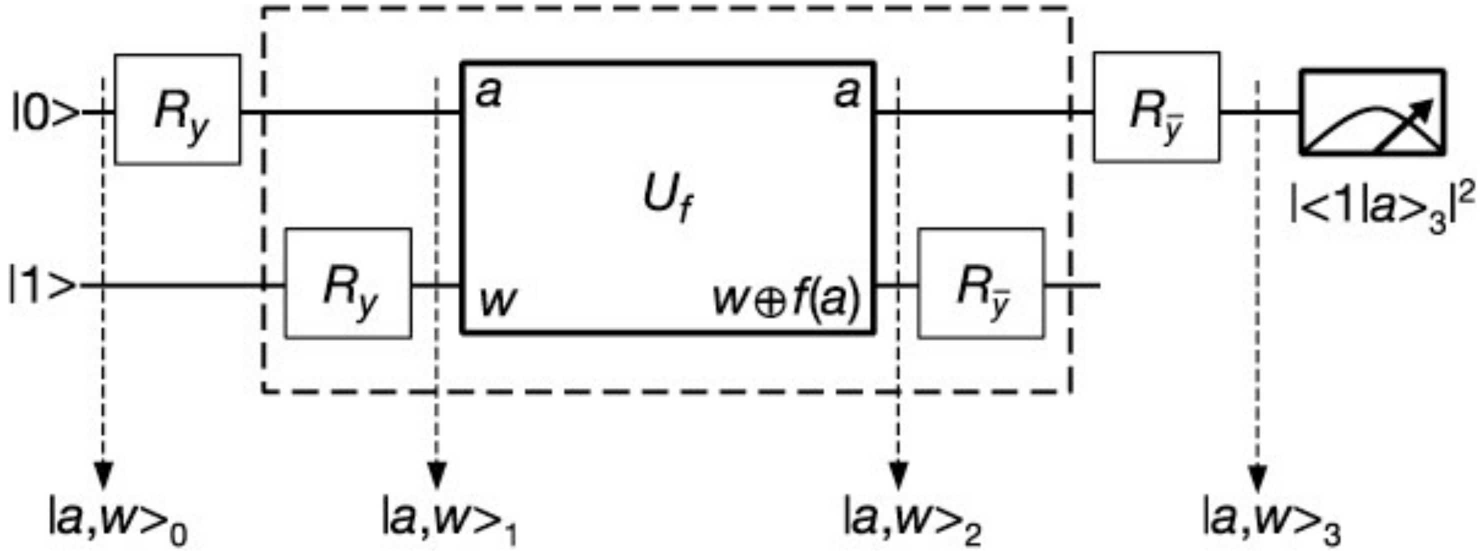
Richard Jozsa

Deutsch-Jozsa Algorithm

Constant: $f(x) = k$ for $x = 0, 1, 2, \ldots, 2^n-1$

Balanced: $f(x) = 0$ for half of $x = 0, 1, 2, \ldots, 2^n-1$
1 for the other half

Task: determine $f(.)$ is constant or balanced

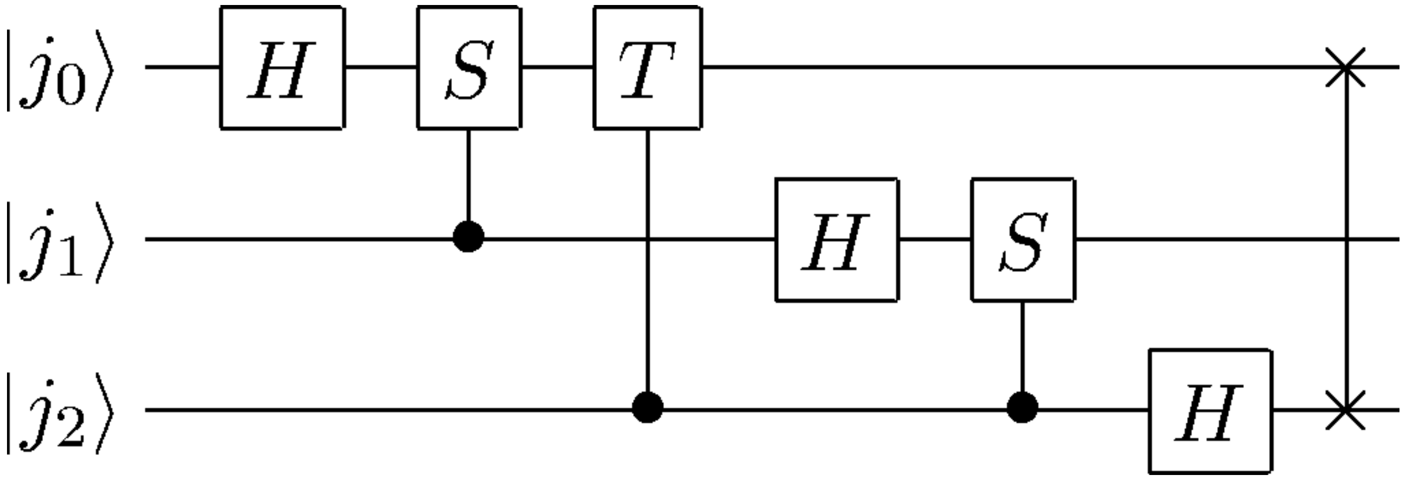


A 2-element example

Source: Gulde et al., *Nature*, 412 (2003), 48-50

Peter Shor

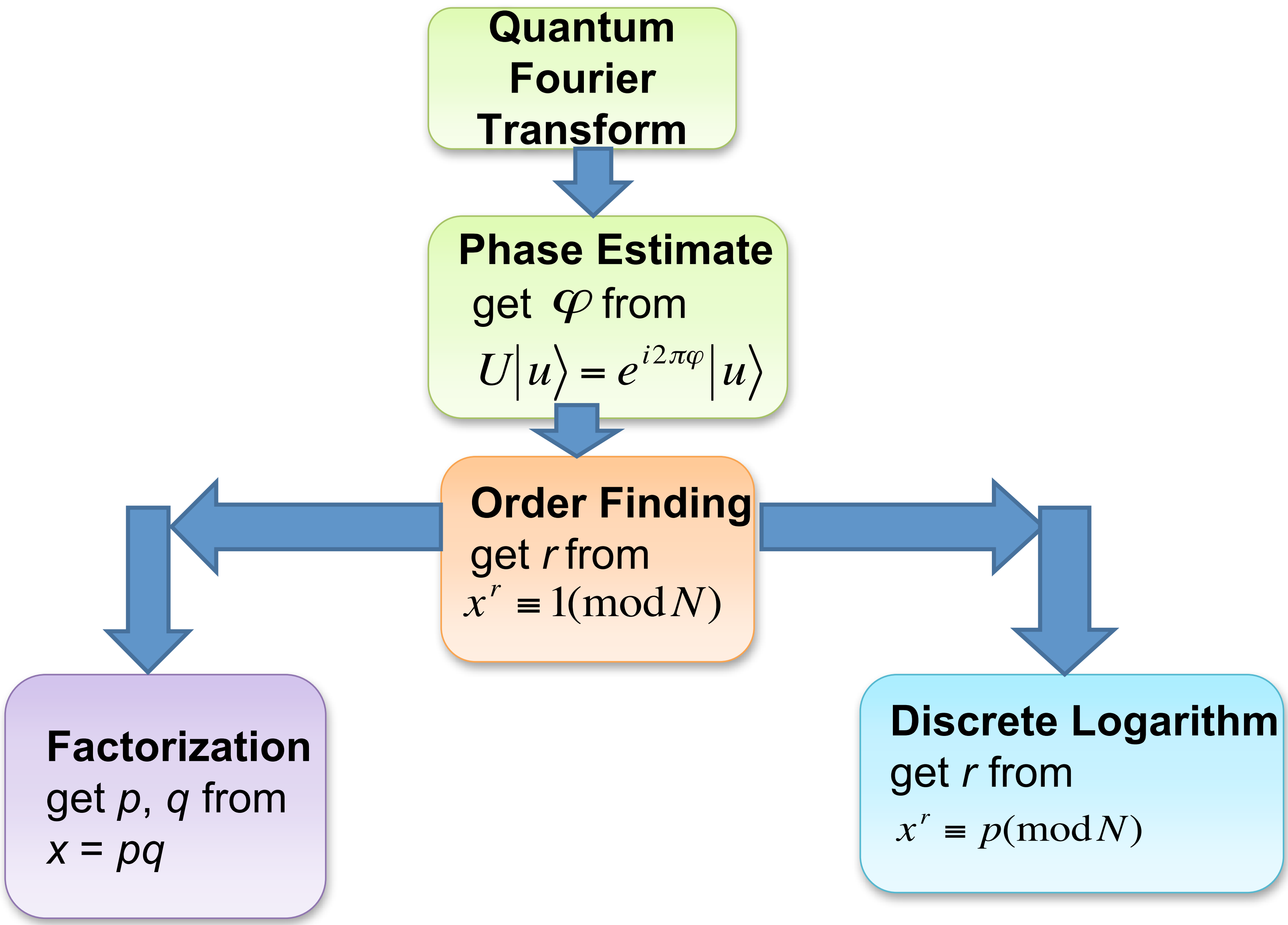
Shor's Quantum Fourier Transform

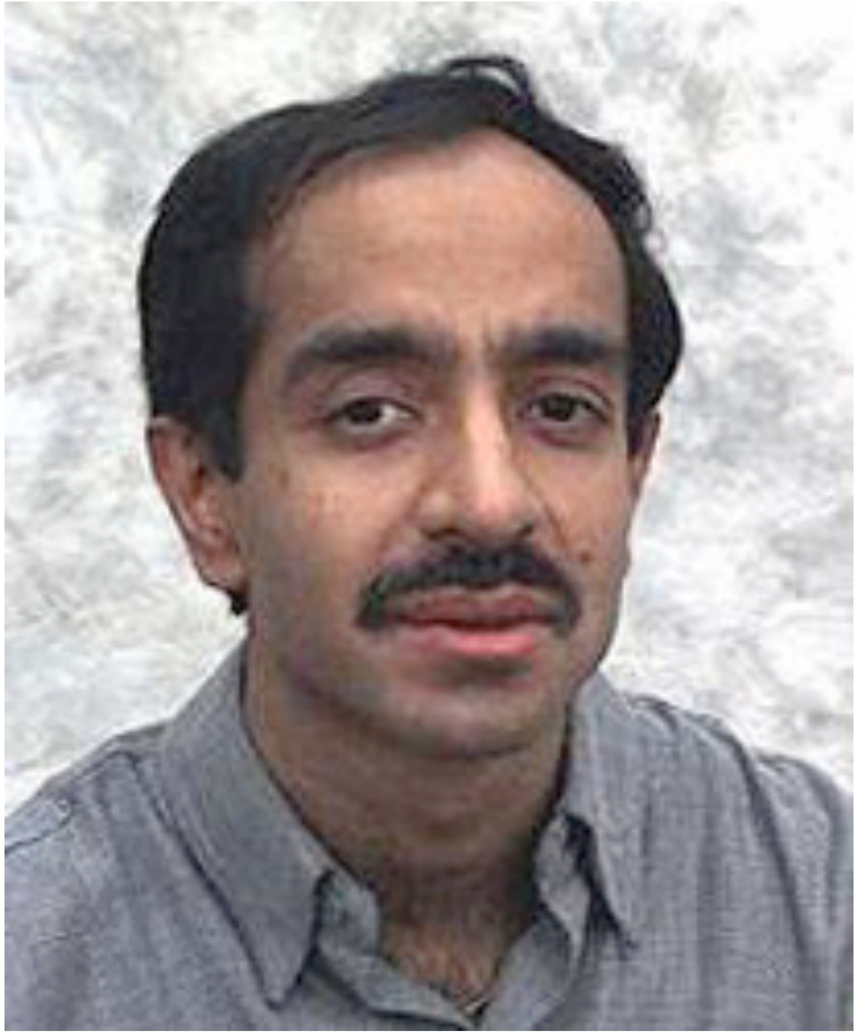


A 3-element example

Source: http://www.media.mit.edu/quanta/qasm2circ/

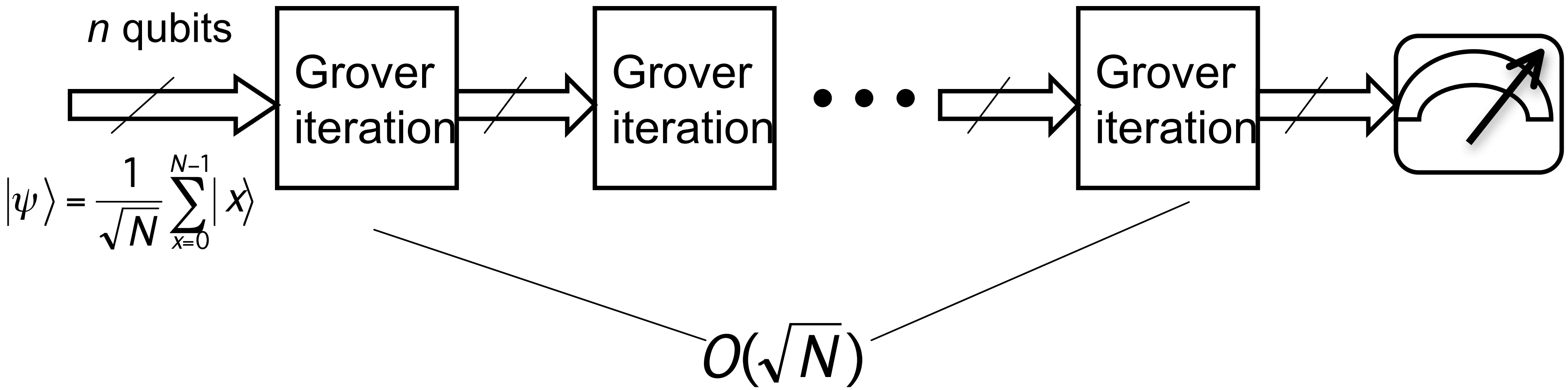
Shor's Quantum Algorithms

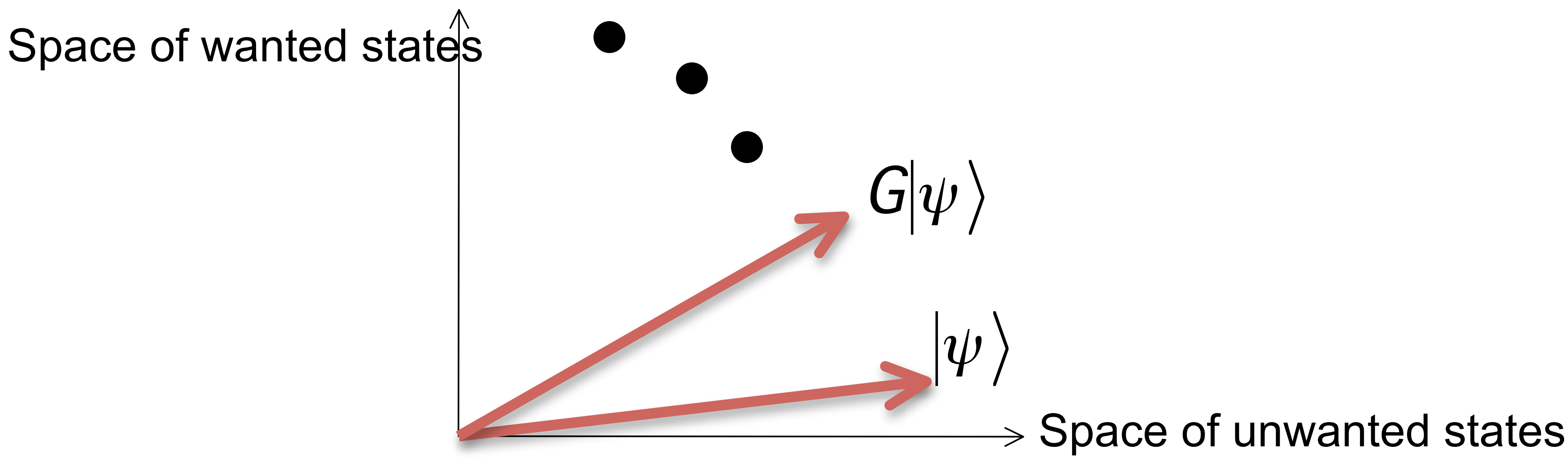




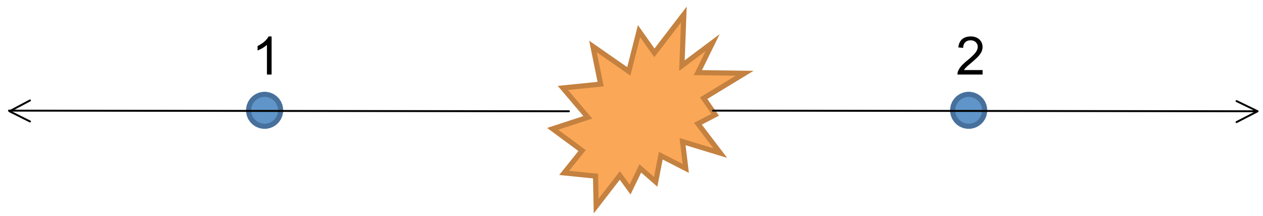
Lov Grover

Grover's Quantum Search Algorithm





EPR Pairs and Communications



$$|EPR\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle|1\rangle - |1\rangle|0\rangle\right) \qquad \frac{1}{\sqrt{2}}\left(|0\rangle|1\rangle + |1\rangle|0\rangle\right)$$

$$\frac{1}{\sqrt{2}}\left(|0\rangle|0\rangle + |1\rangle|1\rangle\right) \qquad \frac{1}{\sqrt{2}}\left(|0\rangle|0\rangle - |1\rangle|1\rangle\right)$$

Two particles are perfectly correlated.

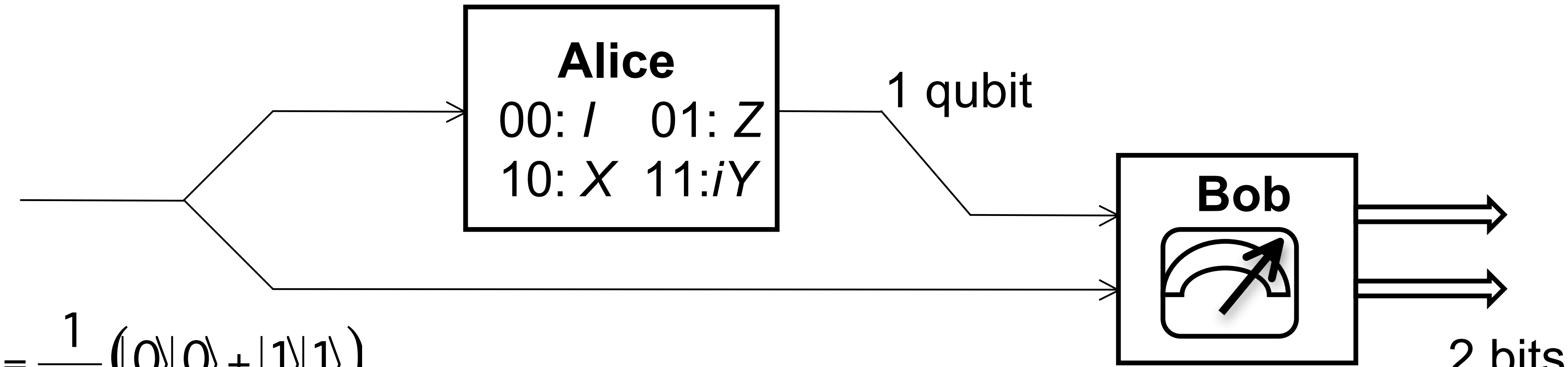
Spontaneous information transmission?

Not possible

But can be used as resource for communications

Charles H. Bennett

Superdense Coding



$$|EPR\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle|0\rangle + |1\rangle|1\rangle\right)$$

Alice Bob

$$00: \frac{1}{\sqrt{2}}\left(|0\rangle|0\rangle + |1\rangle|1\rangle\right)$$

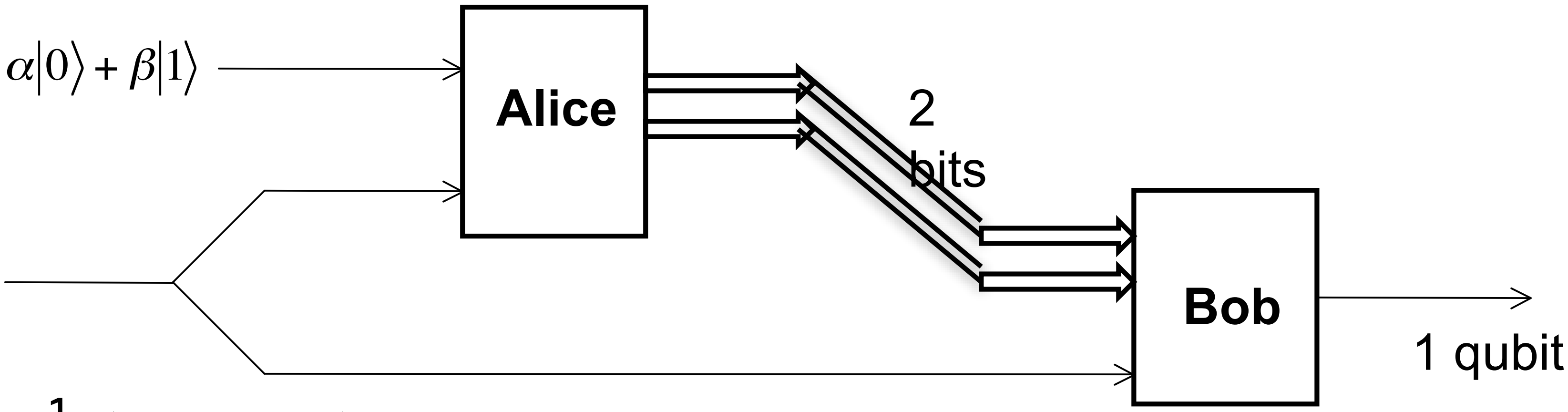
$$01: \frac{1}{\sqrt{2}}\left(|0\rangle|0\rangle - |1\rangle|1\rangle\right)$$

$$10: \frac{1}{\sqrt{2}}\left(|0\rangle|1\rangle + |1\rangle|0\rangle\right)$$

$$11: \frac{1}{\sqrt{2}}\left(|0\rangle|1\rangle - |1\rangle|0\rangle\right)$$

Quantum Teleportation

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$



$$|EPR\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle|0\rangle + |1\rangle|1\rangle\right)$$

Alice Bob

00: $\alpha|0\rangle + \beta|1\rangle$

01: $\alpha|1\rangle + \beta|0\rangle$

10: $\alpha|0\rangle - \beta|1\rangle$

11: $\alpha|1\rangle - \beta|0\rangle$

Ongoing Research on Quantum Information

Physical Implementation

Optoelectronics
Ion Traps
Nuclear Magnetic Resonance
etc.

Theory

The effects of noise
Error Correction Codes
Quantum Information Theory
etc.