Experimental Quantum Computing

and

Quantum Error Correction

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The course

Introduction and overview: qbits, gates, circuits and errors…

Module 1: Hardware

Qubits based on atoms and ions.
Qubits based on superconducting circuits.
Other qubits: photons, electron spins & NMR.

Module 2: Algorithms and their experimental implementations

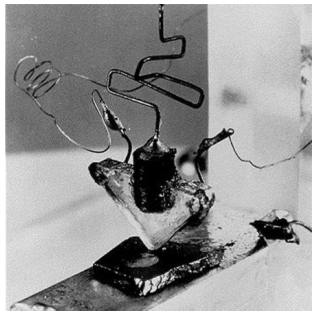
Quantum algorithms 1: the modules (QFFT, Phase estimation…)
Quantum algorithms 2: Grover, Shor and experimental demonstrations.

Module 3: Quantum error correction

Quantum error correction and description of codes
Construction of a fault-tolerant architecture.

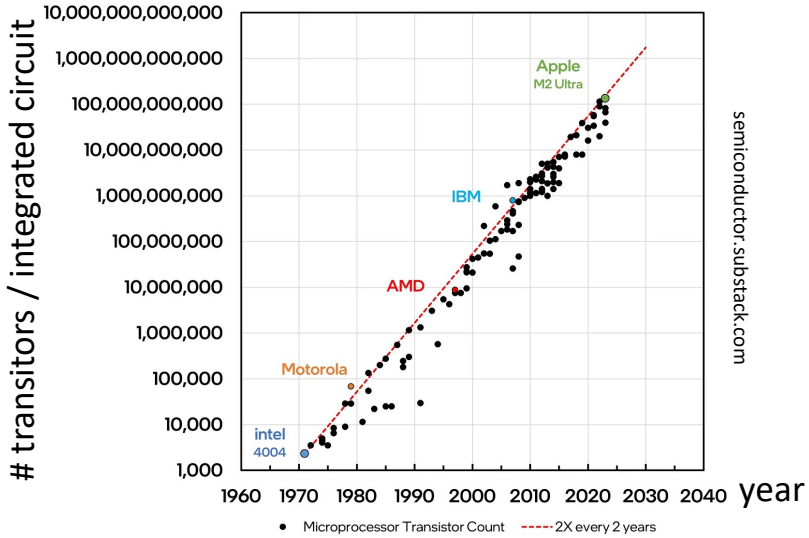
One motivation for QC: The Moore's law

~ 10 cm

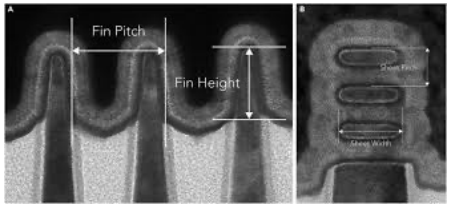


Bardeen, Brattain & Shockley, **1947**

G. Moore

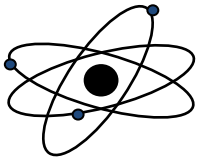


~ 5 nm



IBM
2017

2030 ?



0.1 nm

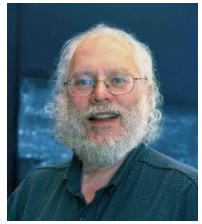
Below nm, « world is quantum»

$\Rightarrow$ new way to encode information, to calculate?

A brief history of QC…

1985 David Deutsch first quantum algorithm and idea of CNOT gate

1994 Peter Shor: factoring algorithm with exponential speedup



1995 Lev Grover: search algorithm with quadratic speedup

1995 Peter Shor: idea of quantum error correction code

Scheme for reducing decoherence in quantum computer memory

Peter W. Shor*
AT&T Bell Laboratories, Room 2D-149, 600 Mountain Avenue, Murray Hill, New Jersey 07974
(Received 17 May 1995)

Recently, it was realized that use of the properties of quantum mechanics might speed up certain computations dramatically. Interest has since been growing in the area of quantum computation. One of the main difficulties of quantum computation is that decoherence destroys the information in a superposition of states contained in a quantum computer, thus making long computations impossible. It is shown how to reduce the effects of decoherence for information stored in quantum memory, assuming that the decoherence process acts independently on each of the bits stored in memory. This involves the use of a quantum analog of error-correcting codes.

PRA **52**, 2493 (1995)

Quantum simulation

R.P. Feynman

International Journal of Theoretical Physics, Vol. 21, Nos. 6/7, 1982

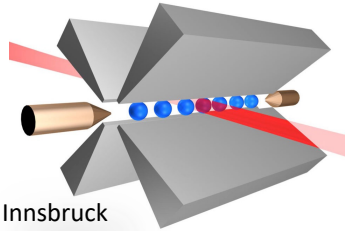
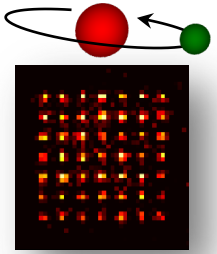
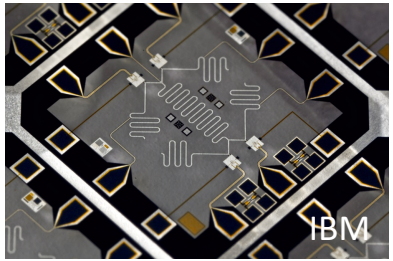
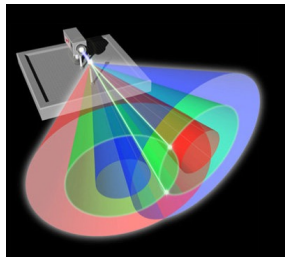
Simulating Physics with Computers

Richard P. Feynman

4. QUANTUM COMPUTERS—UNIVERSAL QUANTUM SIMULATORS

with it, with quantum-mechanical rules). For example, the spin waves in a spin lattice imitating Bose-particles in the field theory. I therefore believe it's true that with a suitable class of quantum machines you could imitate any quantum system, including the physical world. But I don't know whether the general theory of this intersimulation of quantum systems has ever been worked out, and so I present that as another interesting problem: to work out the classes of different kinds of quantum mechanical systems which are really intersimulatable—which are equivalent—as has been done in the case of classical computers. It has been found that there is a kind of universal computer that can do anything, and it doesn't make much difference specifically how it's designed. The same way we should try to find

The qubit zoo (selection…)

	Trapped ions	Atoms	Superconducting circuits	Photons
	 Innsbruck		 IBM	
2-qbit gate	2002	2010	2010	2004
QEC	2004	2023	2016	2008

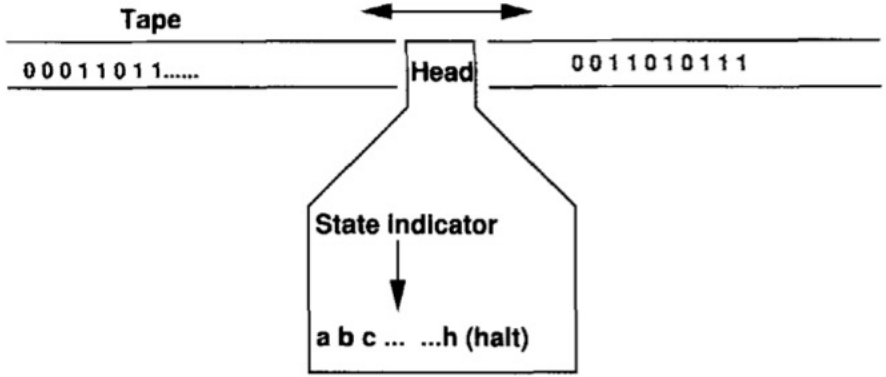
IONQ
AQT
QUANTINUUM

atom computing
PASQAL
IQuEra
Infleqtion
planqc

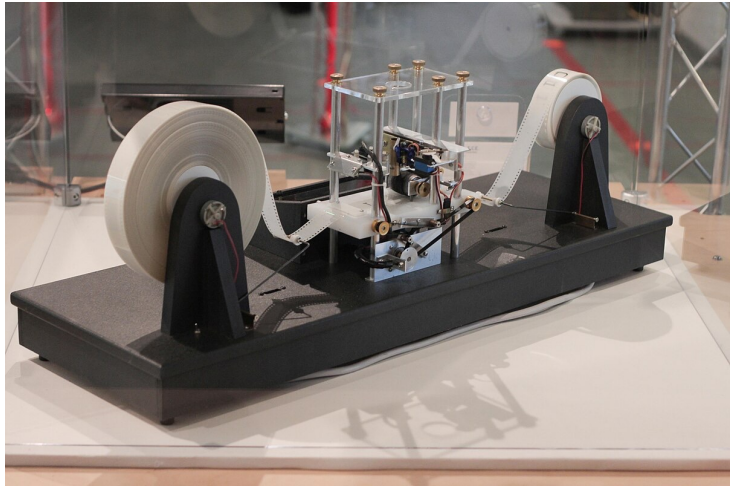
IBM Quantum System One
Google AI
IQM

PsiQuantum
QUANDELA

The Turing Machine



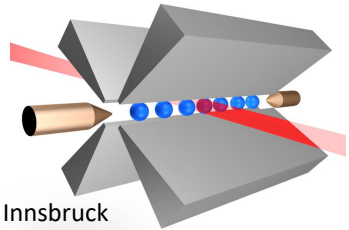
Stolze & Suter



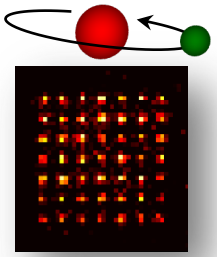
wikipedia

The qubit zoo (extended)

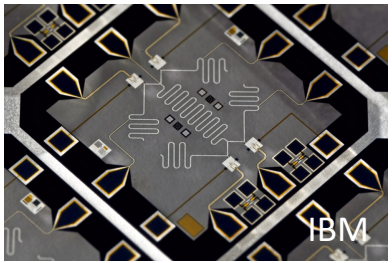
Trapped ions



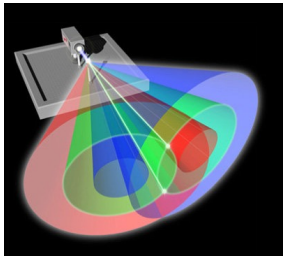
Atoms



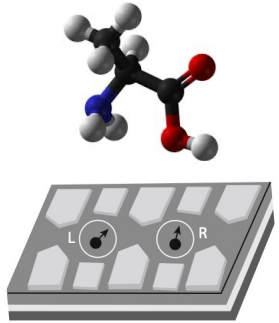
Superconducting circuits



Photons



NMR & e^- spin

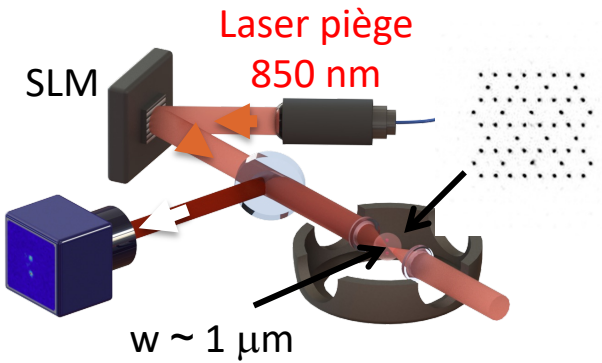


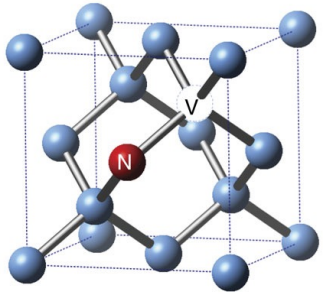
Lecture 2

Lecture 3

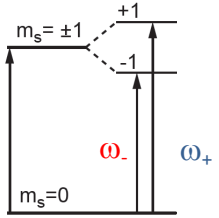
Lecture 4

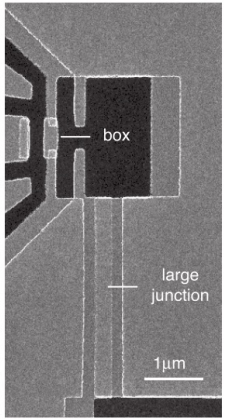
Coherence of qubits: examples

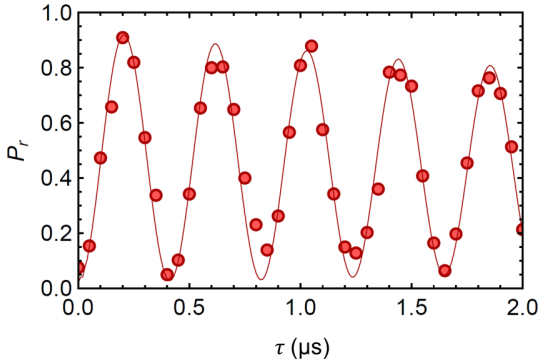


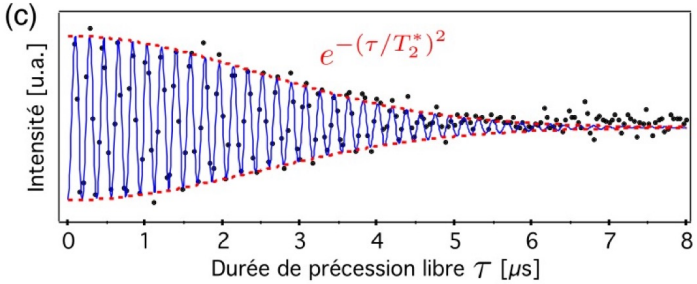


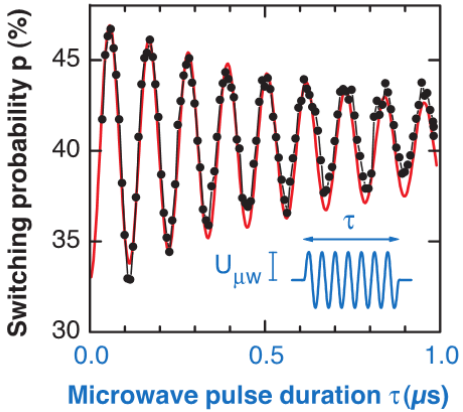
2.9 GHz





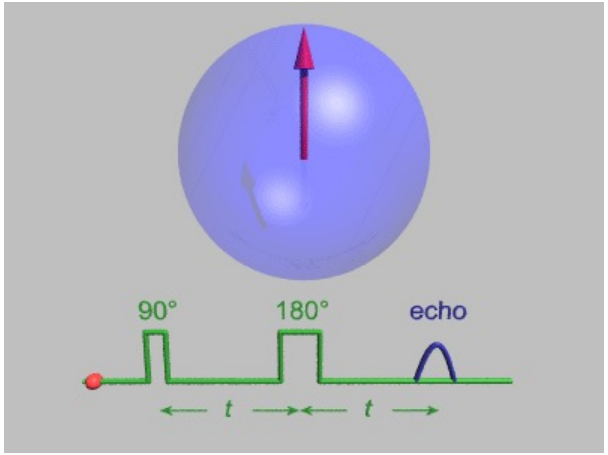


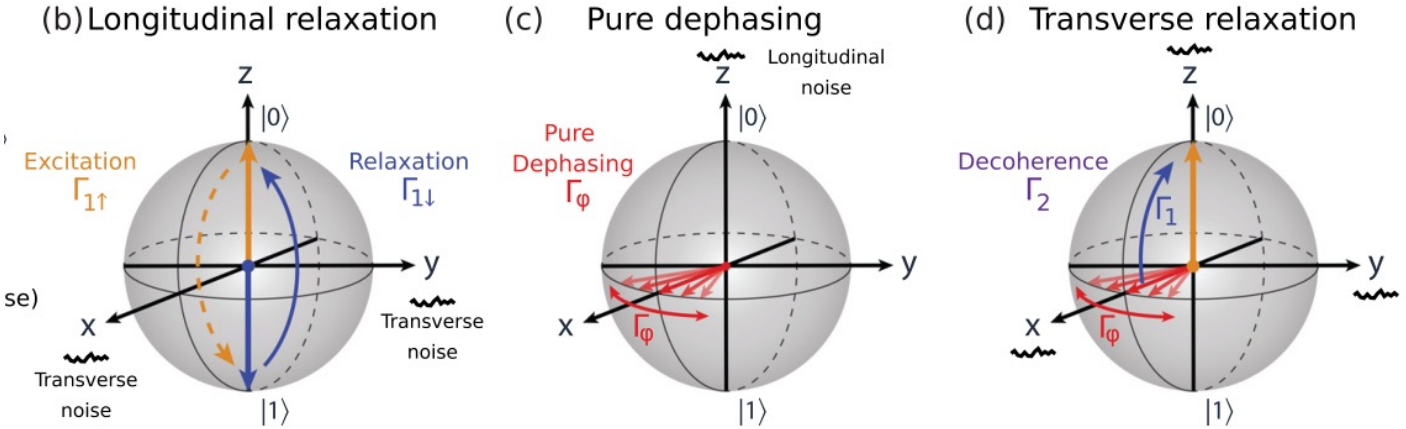




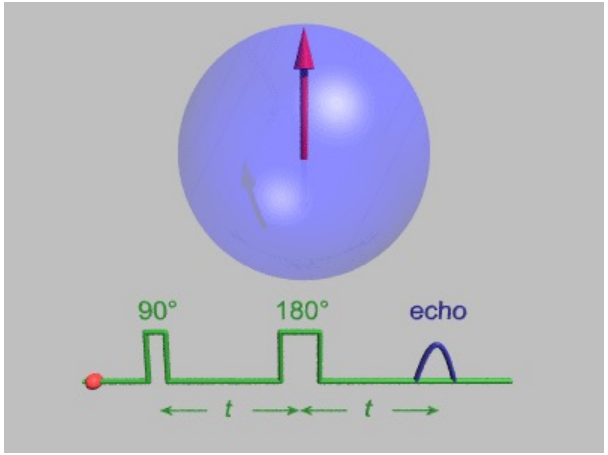
Vion, Science 2002

Rephasing qubits with spin echo

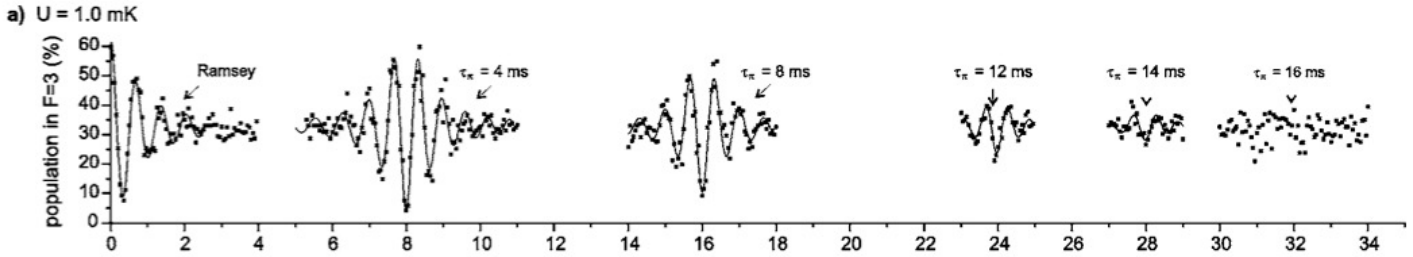




Rephasing qubits with spin echo

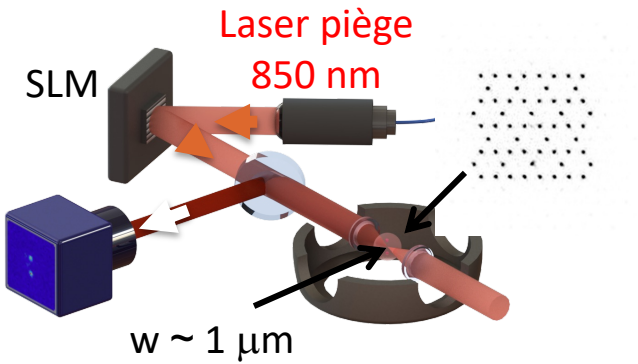


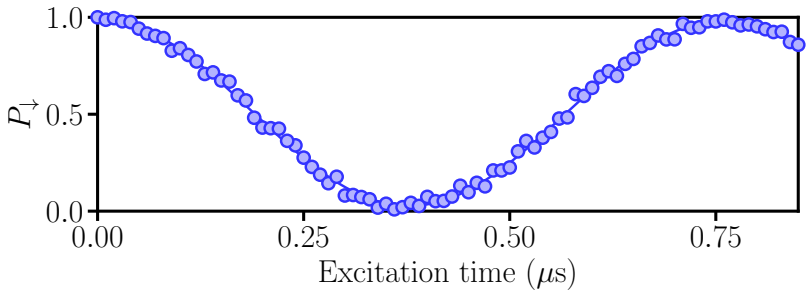
Examples: microwaves (9.2 GHz) on single Cs atom

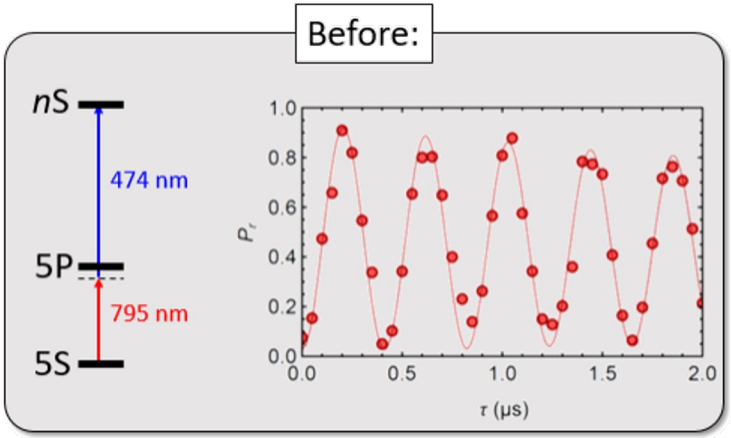


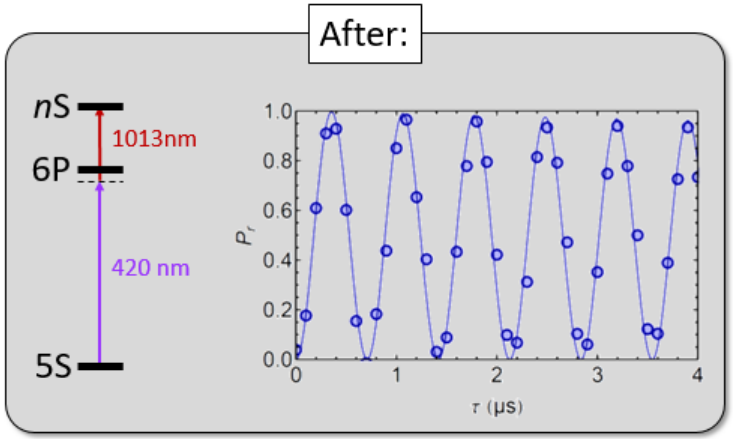
Kuhr, PRA (2005)

Example of improvements: Atoms in tweezers

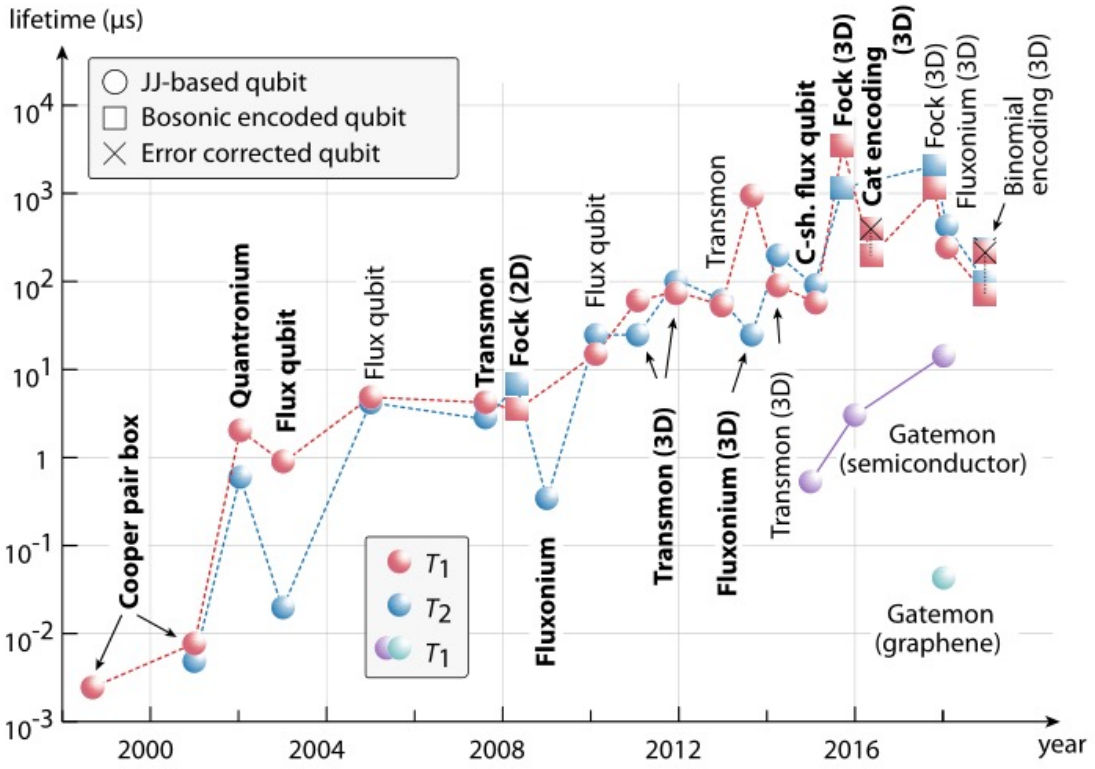








Example of improvements: quantum circuits



M. Kjaergaard et al., Annual Review of Condensed Matter Physics, Vol. 11:369-395