The current state of quantum computing

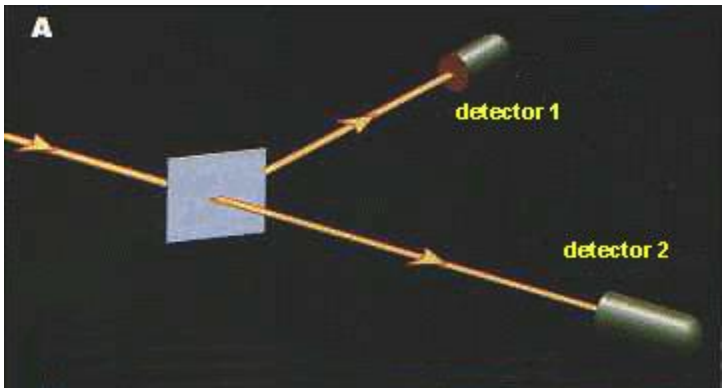
Vlatko Vedral

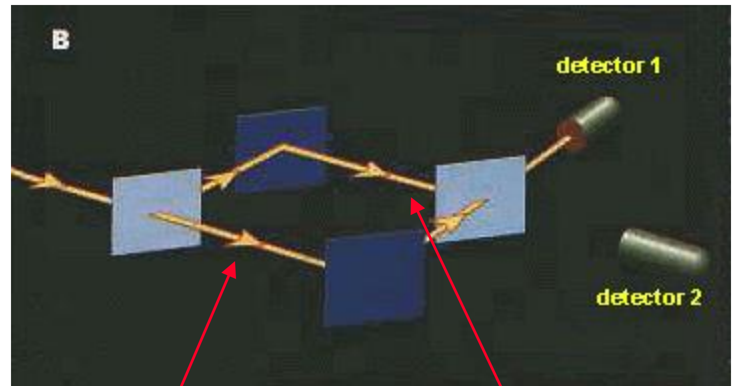
vlatko.vedral@qubit.org

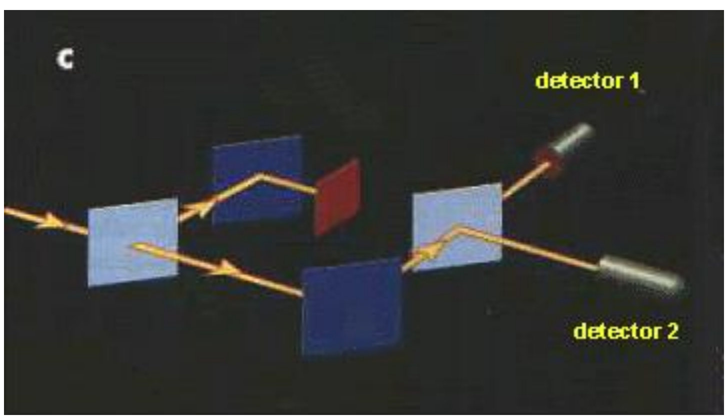
Talk Summary

- Basics of quantum physics
- Models of quantum computation
- Qubit Implementations
- Applications

Quantum bits





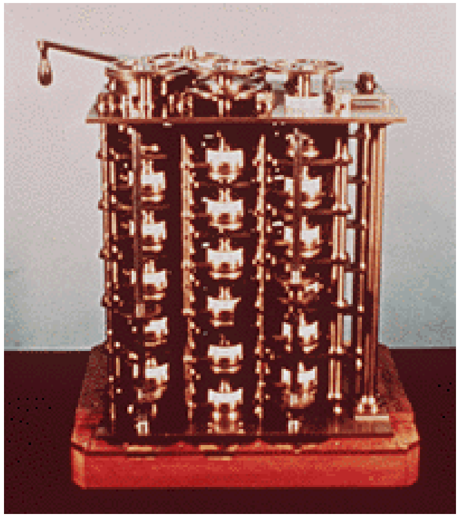


Which path is taken?

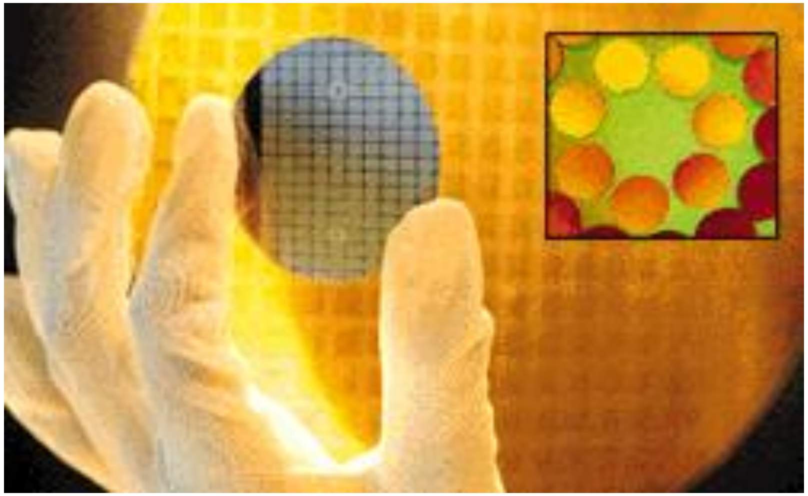
BOTH

Shrinking computer

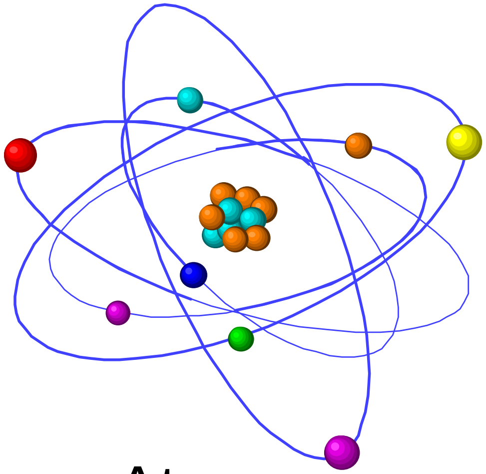
Every 18 months microprocessors double in speed
FASTER = SMALLER



Babbage's Engine



Silicon Wafers



Atoms

1 metre

0.000001 m

0.0000000001 m

Different modes of quantum computation

1. Circuit based (wires, gates)

2. Measurement based (entanglement)

3. Annealing (Adiabatic)

Common elements: Qubits & Quregisters

<u>Classical Bit</u>

0 or 1

<u>Quantum Bit</u>

0 or 1 or 0 1

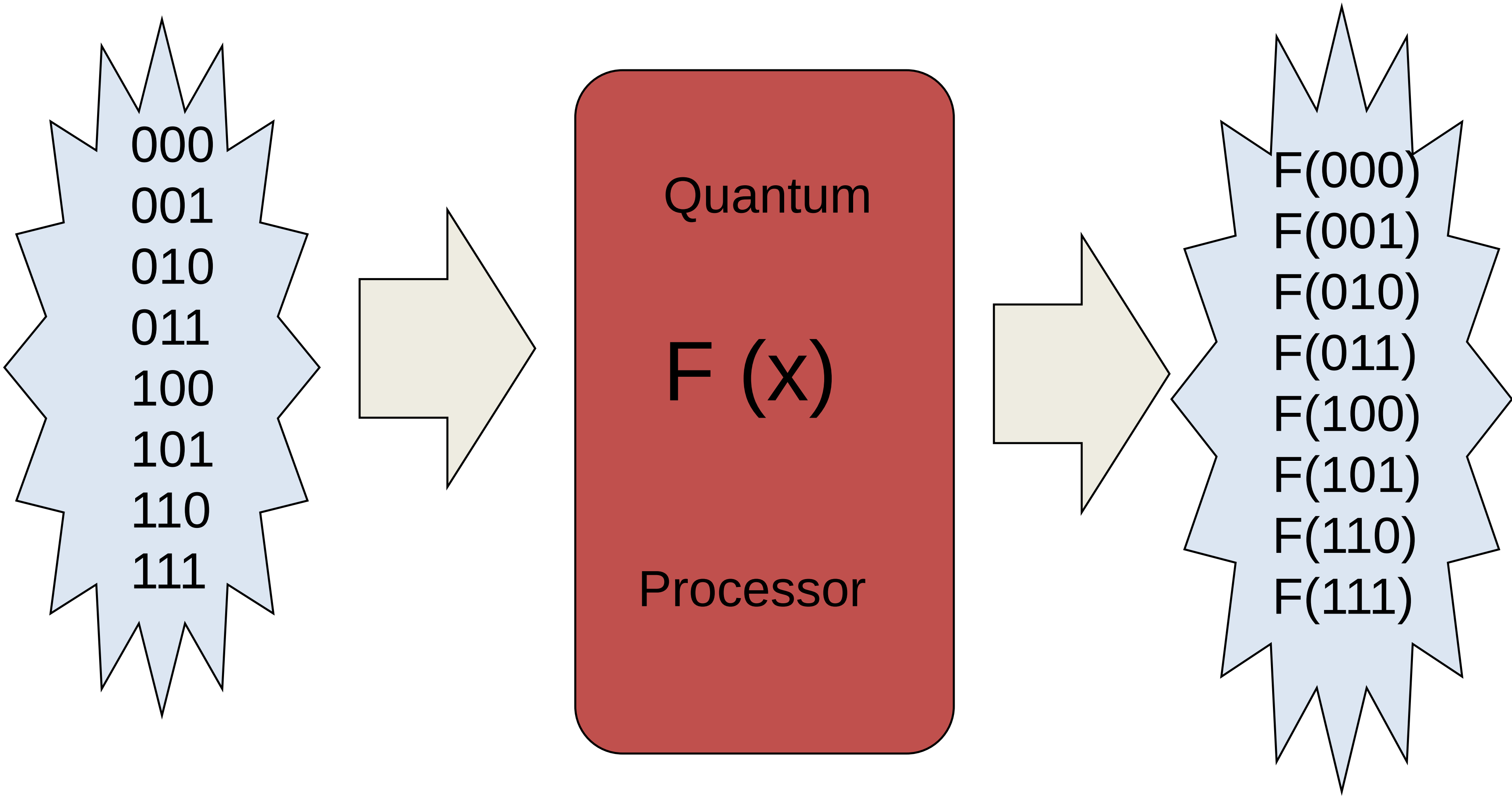
<u>Classical register</u>

101

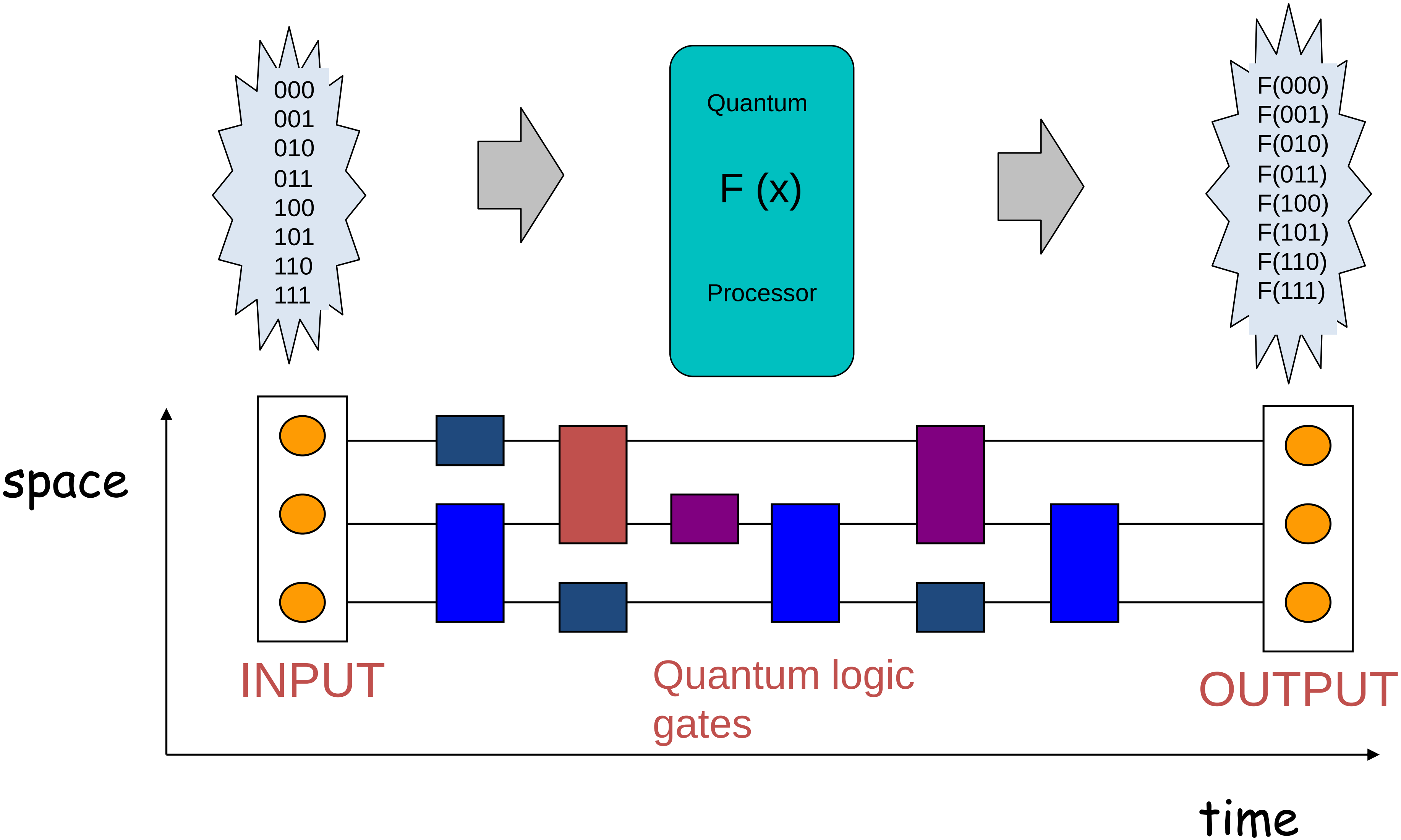
<u>Quantum register</u>

000 001 010 011
100 101 110 111

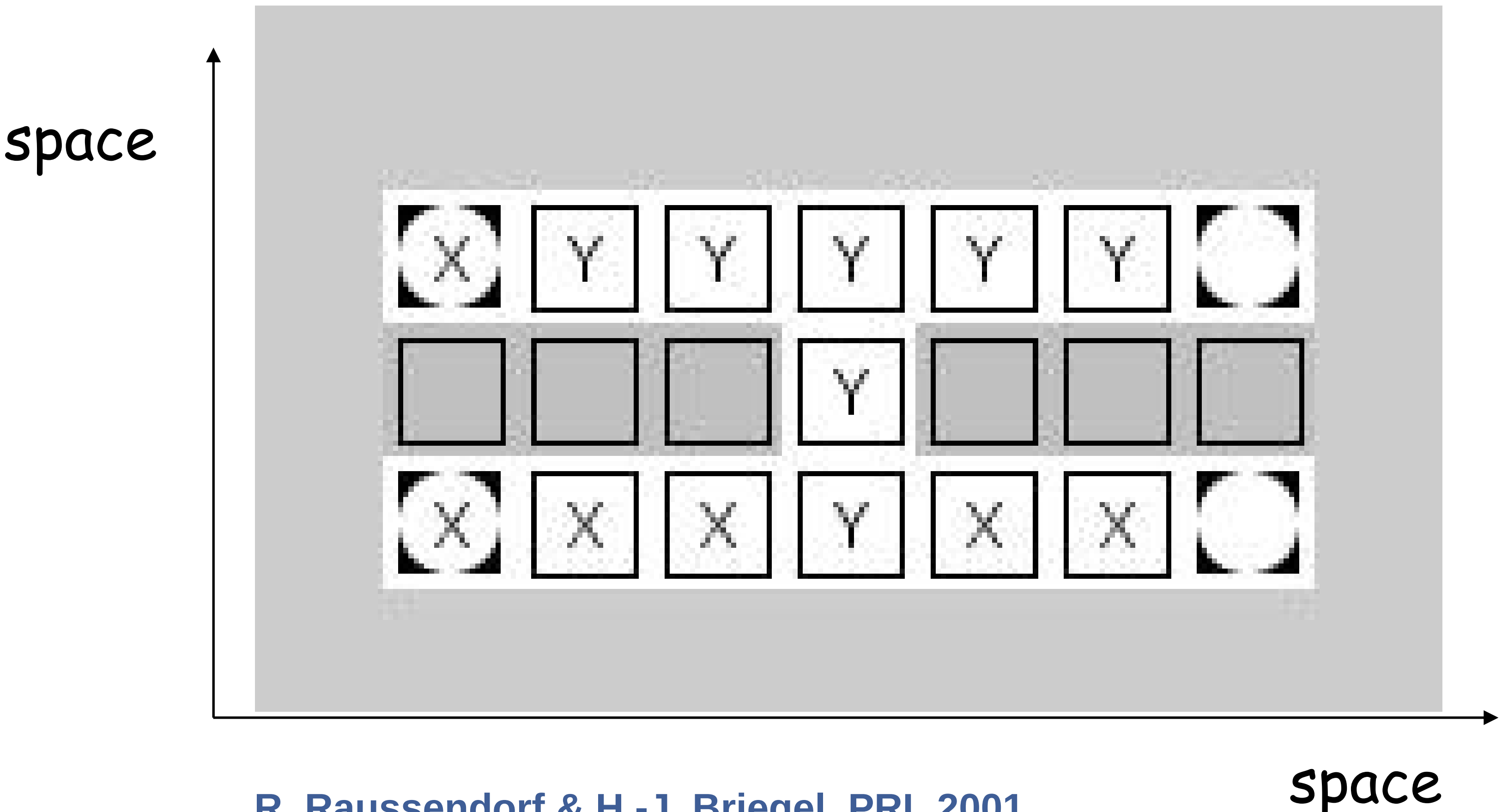
Quantum Parallel Processing



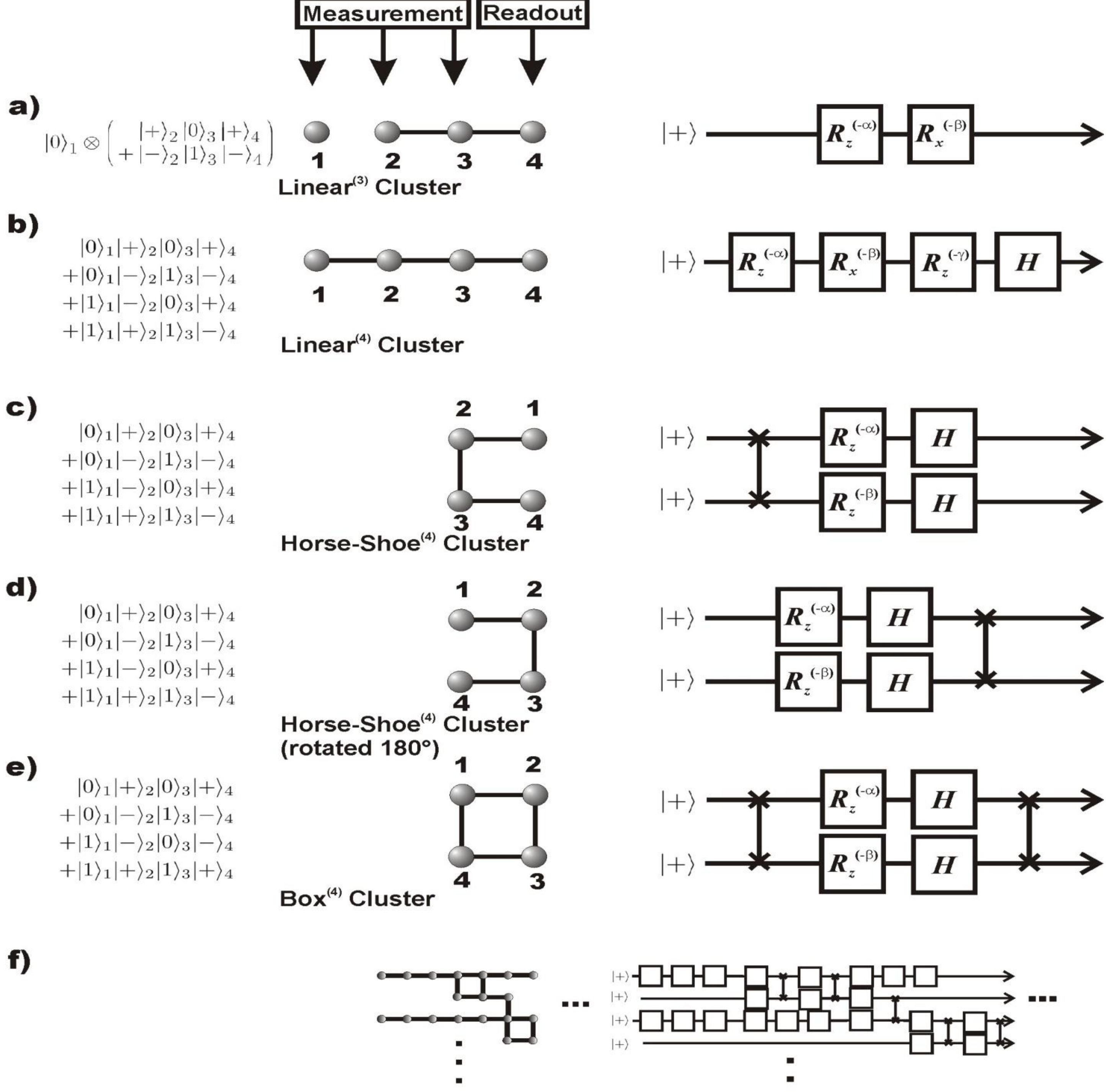
Model I: Quantum Networks



Model II: Measurement based QC

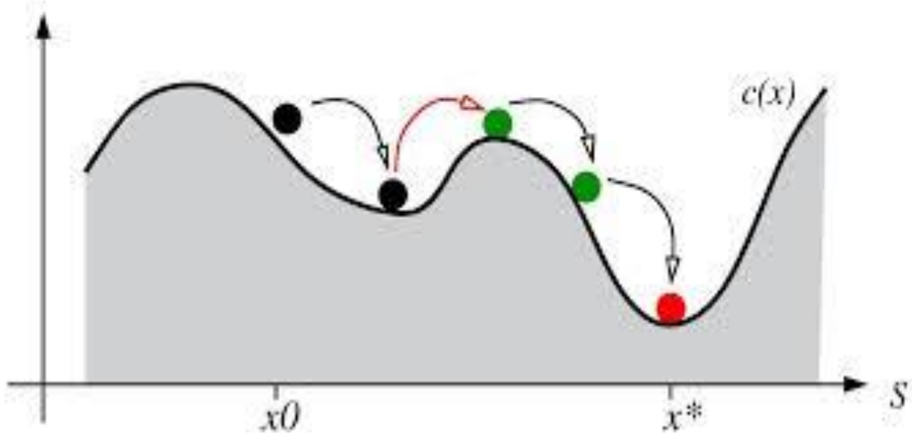


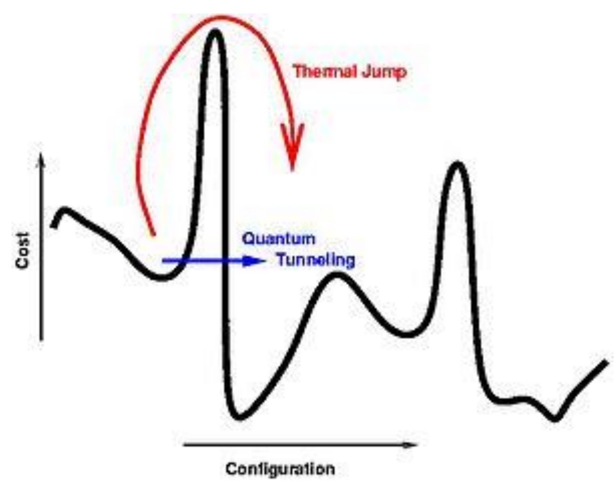
R. Raussendorf & H.-J. Briegel, PRL 2001



Measurement
Readout
a)
$|0\rangle_1 \otimes \left(\begin{array}{c} |+\rangle_2 |0\rangle_3 |+\rangle_4 \\ + |-\rangle_2 |1\rangle_3 |-\rangle_4 \end{array} \right)$
1 2 3 4
Linear$^{(3)}$ Cluster
$|+\rangle$ $R_z^{(-\alpha)}$ $R_x^{(-\beta)}$
b)
$|0\rangle_1|+\rangle_2|0\rangle_3|+\rangle_4$
$+|0\rangle_1|-\rangle_2|1\rangle_3|-\rangle_4$
$+|1\rangle_1|-\rangle_2|0\rangle_3|+\rangle_4$
$+|1\rangle_1|+\rangle_2|1\rangle_3|-\rangle_4$
1 2 3 4
Linear$^{(4)}$ Cluster
$|+\rangle$ $R_z^{(-\alpha)}$ $R_x^{(-\beta)}$ $R_z^{(-\gamma)}$ H
c)
$|0\rangle_1|+\rangle_2|0\rangle_3|+\rangle_4$
$+|0\rangle_1|-\rangle_2|1\rangle_3|-\rangle_4$
$+|1\rangle_1|-\rangle_2|0\rangle_3|+\rangle_4$
$+|1\rangle_1|+\rangle_2|1\rangle_3|-\rangle_4$
2 1 3 4
Horse-Shoe$^{(4)}$ Cluster
$|+\rangle$ $R_z^{(-\alpha)}$ H
$|+\rangle$ $R_z^{(-\beta)}$ H
d)
$|0\rangle_1|+\rangle_2|0\rangle_3|+\rangle_4$
$+|0\rangle_1|-\rangle_2|1\rangle_3|-\rangle_4$
$+|1\rangle_1|-\rangle_2|0\rangle_3|+\rangle_4$
$+|1\rangle_1|+\rangle_2|1\rangle_3|-\rangle_4$
1 2 4 3
Horse-Shoe$^{(4)}$ Cluster
(rotated 180°)
$|+\rangle$ $R_z^{(-\alpha)}$ H
$|+\rangle$ $R_z^{(-\beta)}$ H
e)
$|0\rangle_1|+\rangle_2|0\rangle_3|+\rangle_4$
$+|0\rangle_1|-\rangle_2|1\rangle_3|-\rangle_4$
$+|1\rangle_1|-\rangle_2|0\rangle_3|-\rangle_4$
$+|1\rangle_1|+\rangle_2|1\rangle_3|+\rangle_4$
1 2 4 3
Box$^{(4)}$ Cluster
$|+\rangle$ $R_z^{(-\alpha)}$ H
$|+\rangle$ $R_z^{(-\beta)}$ H
f)
$|+\rangle$
$|+\rangle$
$|+\rangle$
$|+\rangle$

Model III: Annealing/adiabatic





Error correction

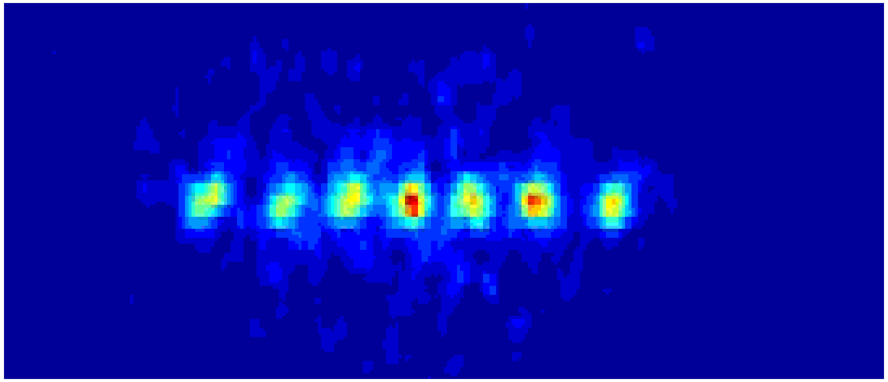
We can show that if the reliability of qubits (preparation, gate fidelity and readout) is high enough then error correction can lead to arbitrarily accurate large scale computation.

Error correction is usually done by using redundancy (namely, using a number of physical qubits to encode one logical one)

or, by choosing a self-correcting part of a physical system (quantum protectorate) – topological quantum computation.

Qubit implementations: Cold Atoms

Glowing and vibrating beryllium ions in a linear ion trap.



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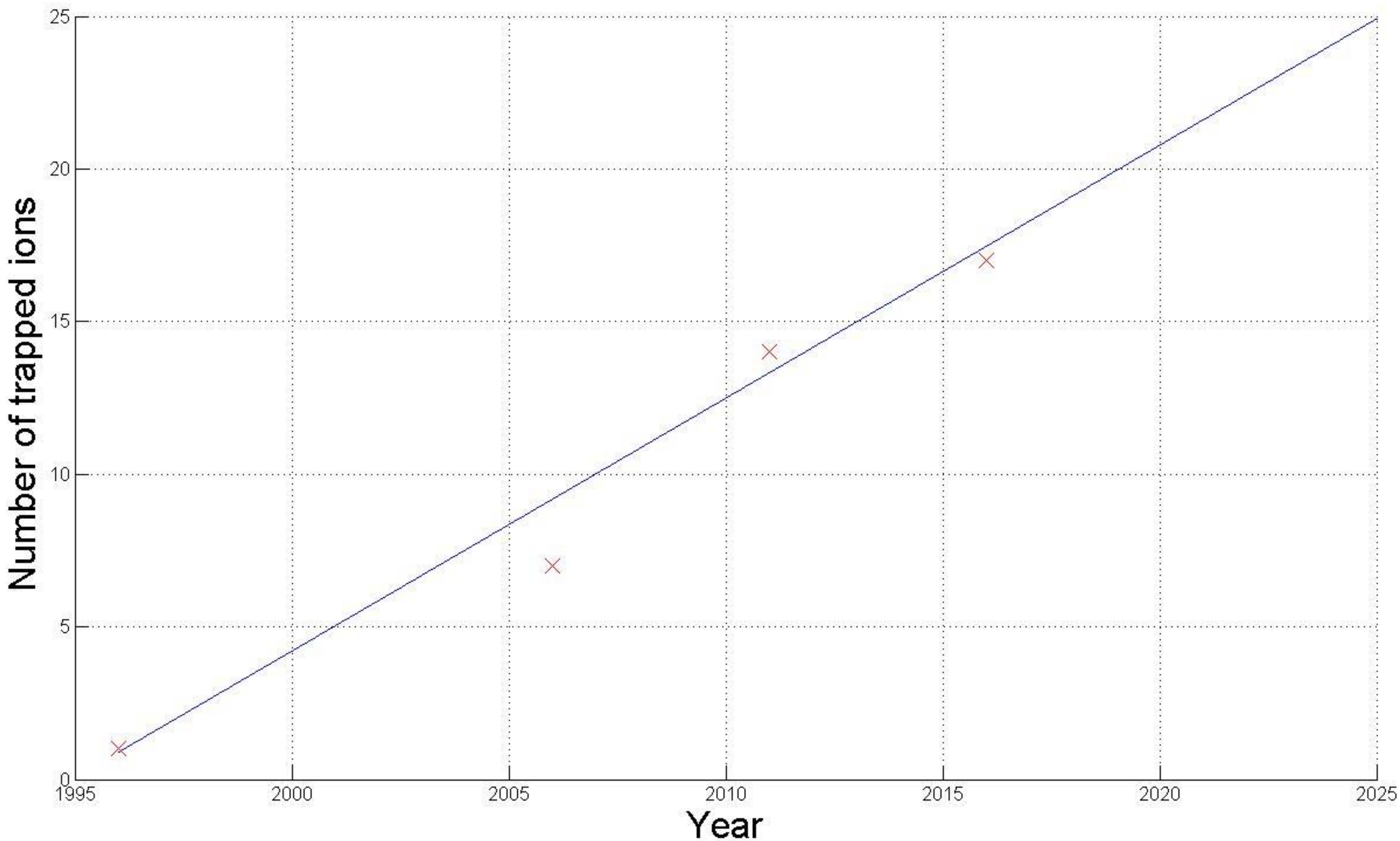
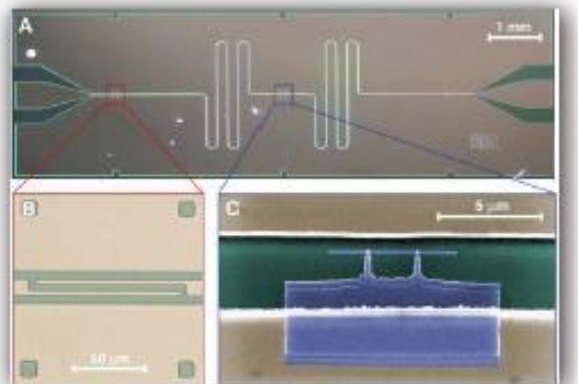
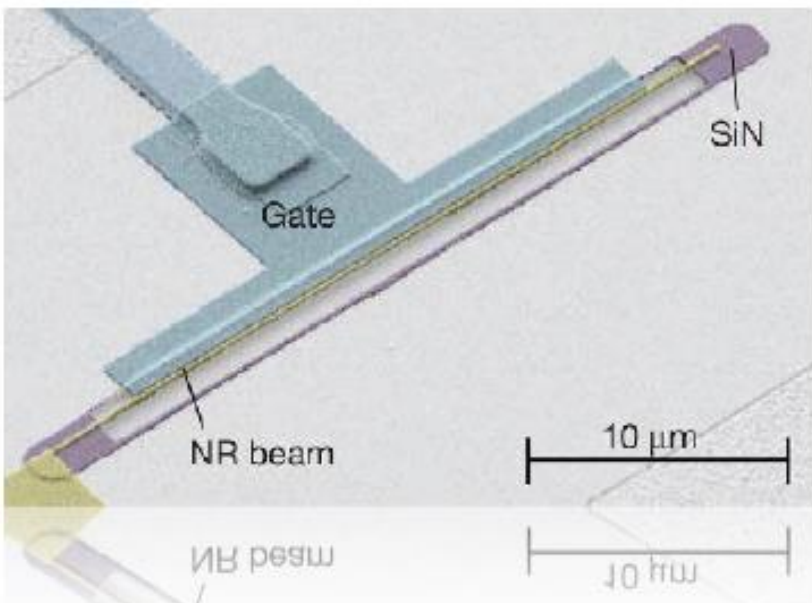
Extrapolation: Ions



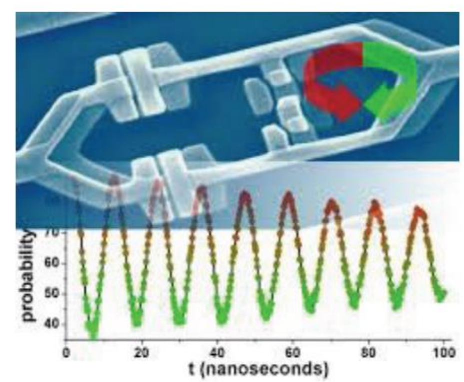
Superconducting nanostructures



ETH (Zurich)

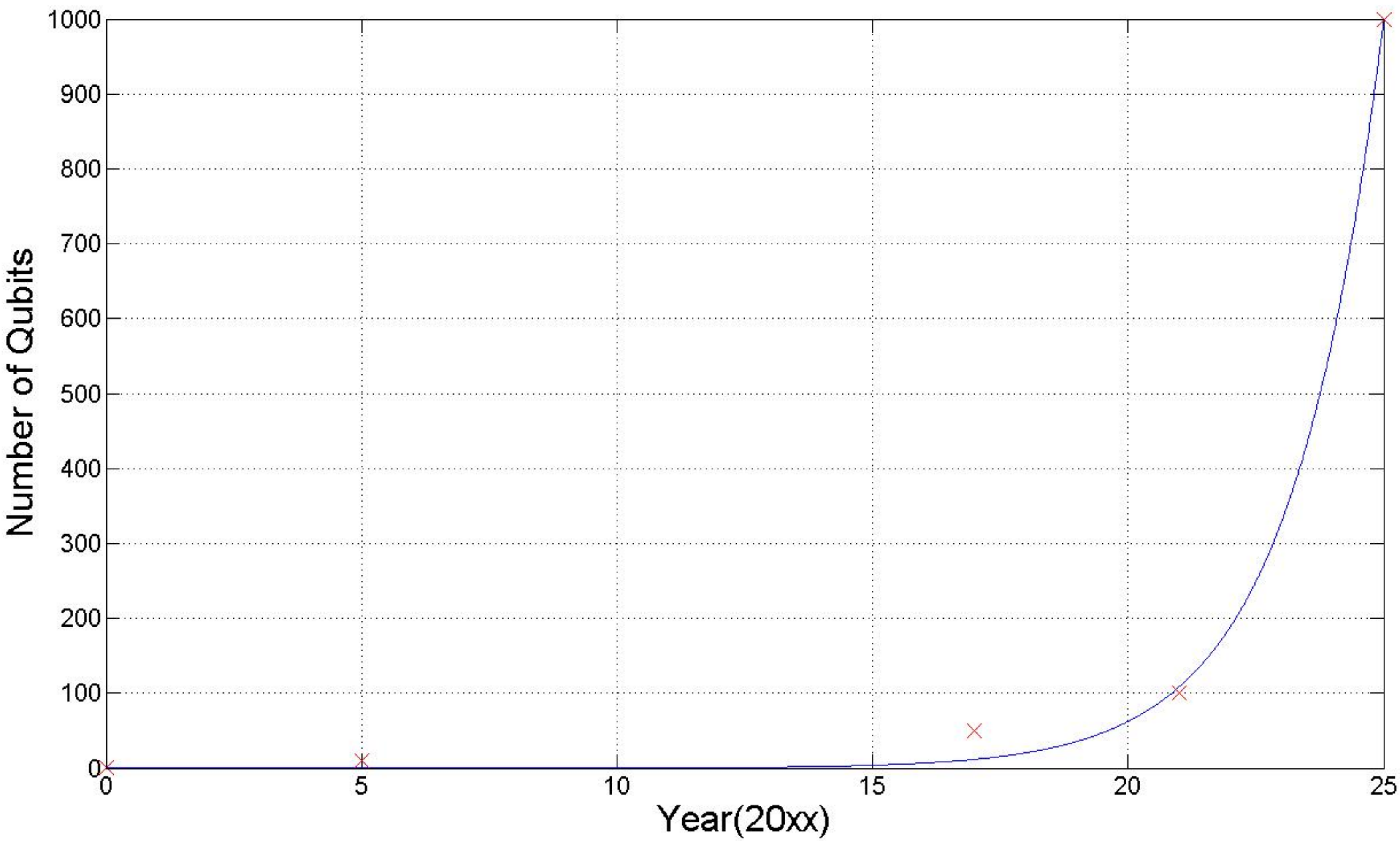


Caltech



Delft

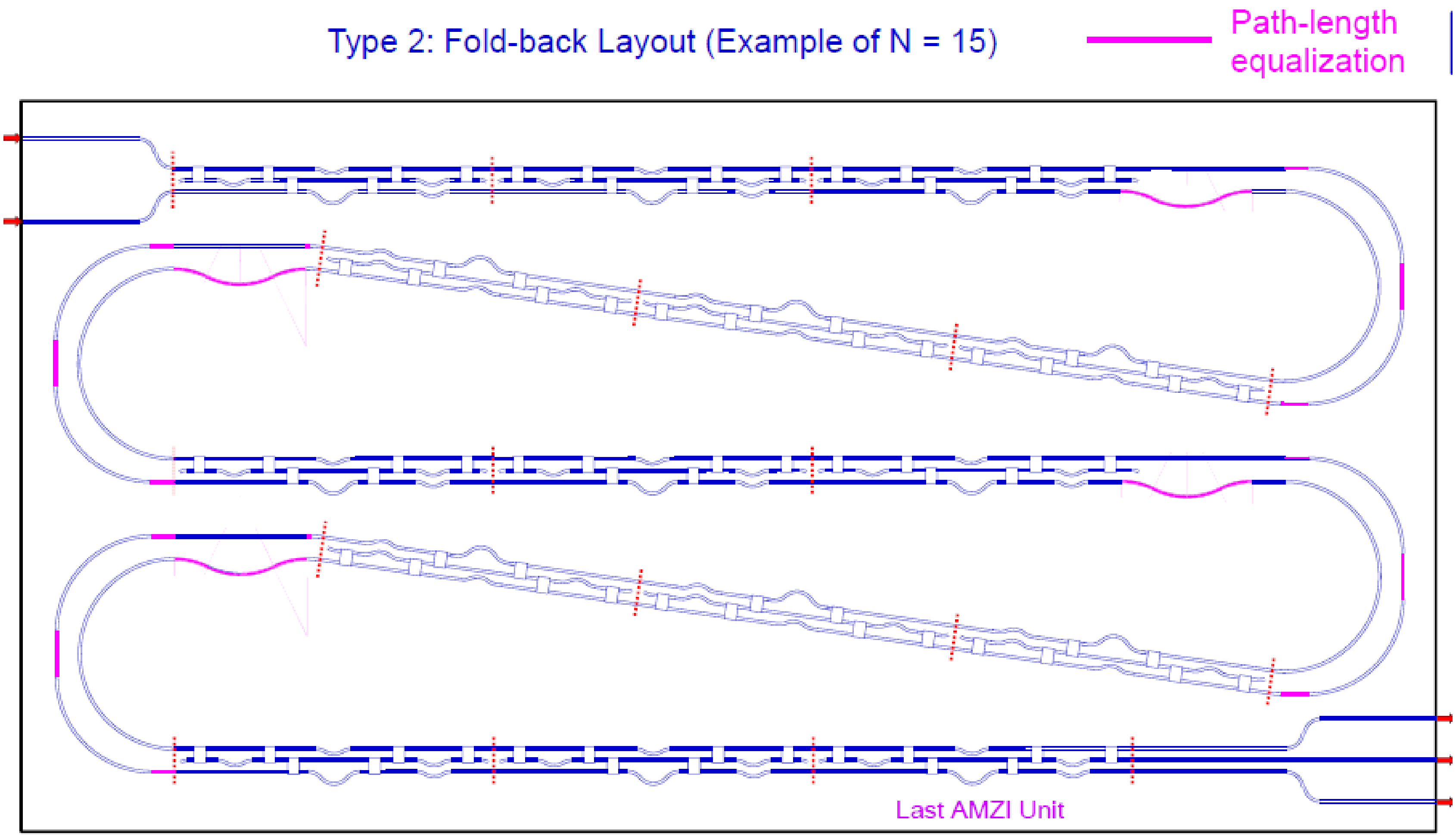
Extrapolation: Squids



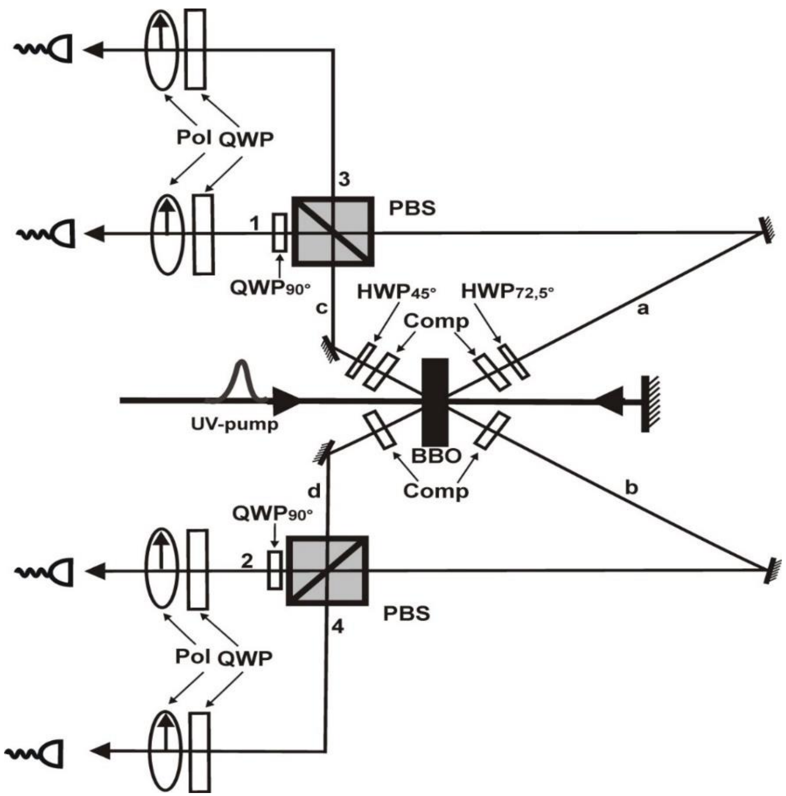
Photonics

Concatenated AMZIs with Delay-equalization Paths

Type 2: Fold-back Layout (Example of N = 15)



Measurement based photonics

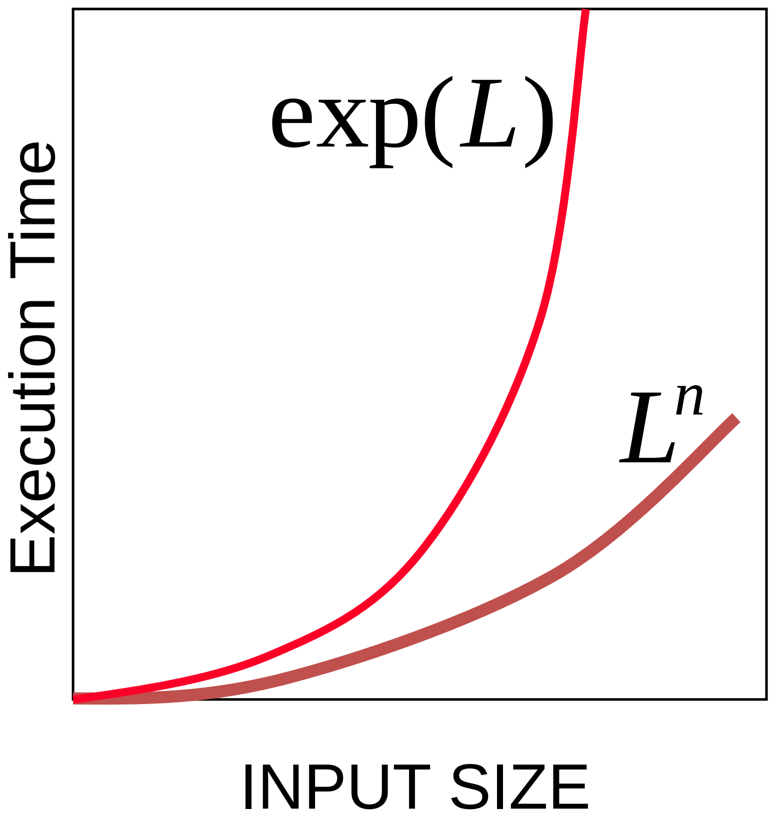


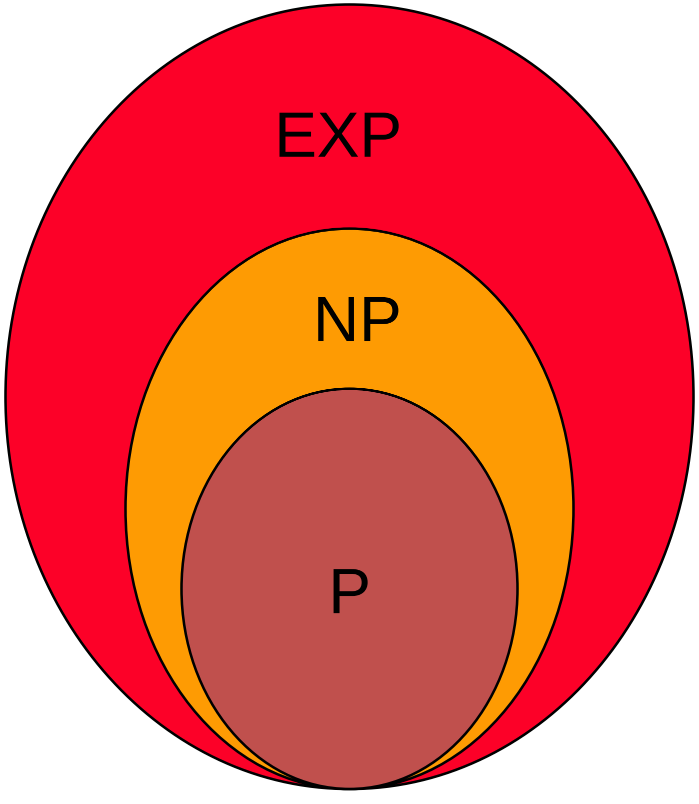
In 2016 O'Brien claimed PsiQuantum
will make an all optical Quantum Computer with 100 qubits by 2020 (not true as far as I am aware ☺).

Applications

1. Quantum algorithms (Factorization, Search, Linear Equations)
2. Quantum cryptography/communications
3. Quantum metrology (including atomic clock, gravimeters and so on)
4. Simulations (of complex physical systems and dynamics, e.g. boson sampling)
5. Chemistry and biology (improving models as well as designing quantum probes).

Computational Complexity





Some subtleties

Quantum search is the most ubiquitous application, however, one should bear in mind that the database to be searched must be conducive to quantum interrogations.

At present we envisage some kind of a hybrid approach in which small scale quantum computations are executed as subroutines.

Summary

- There are many models of quantum computers and many applications

- Superconductors the most invested in qubit implementation (flexibility, control, quantum enhanced performances, integration, scalability)

- Some applications on the horizon (communication, metrology), others on the time-scales of 10 years plus (full-scale quantum computation with 1000 plus logical qubits).