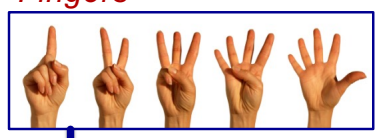
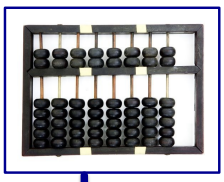
Computing throughout History

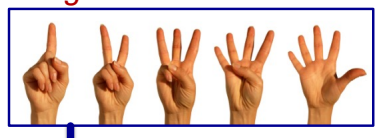


Very Early

1

Computing throughout History



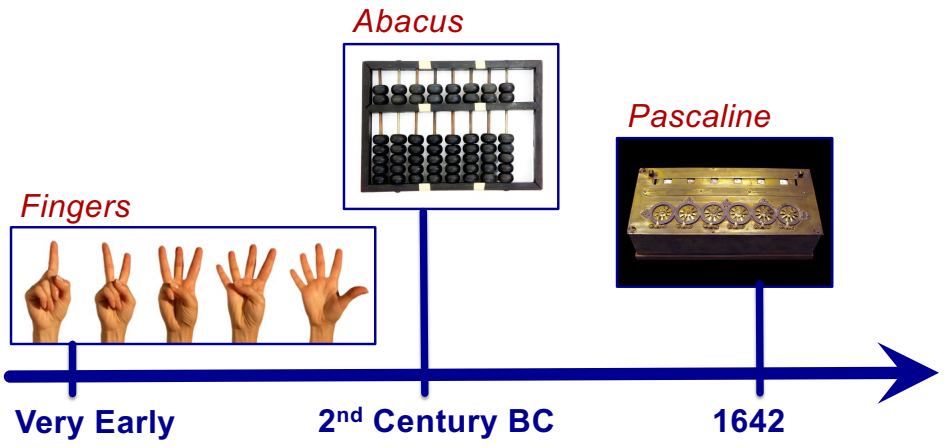


Very Early

2nd Century BC

2

Computing throughout History



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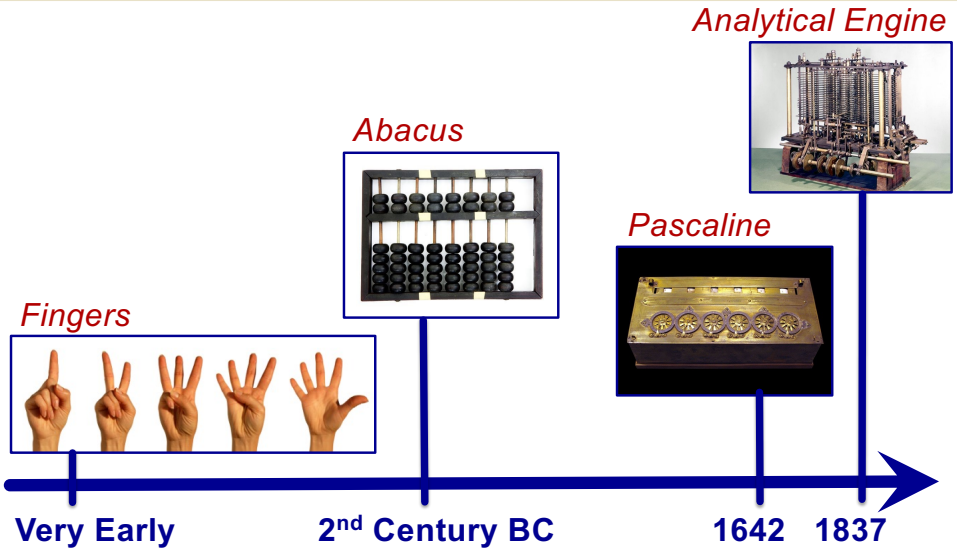
Computing throughout History



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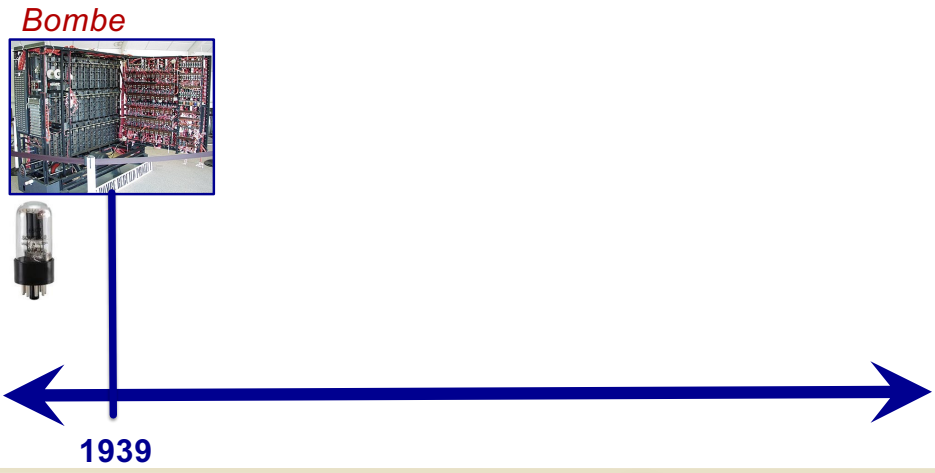
Computing throughout History



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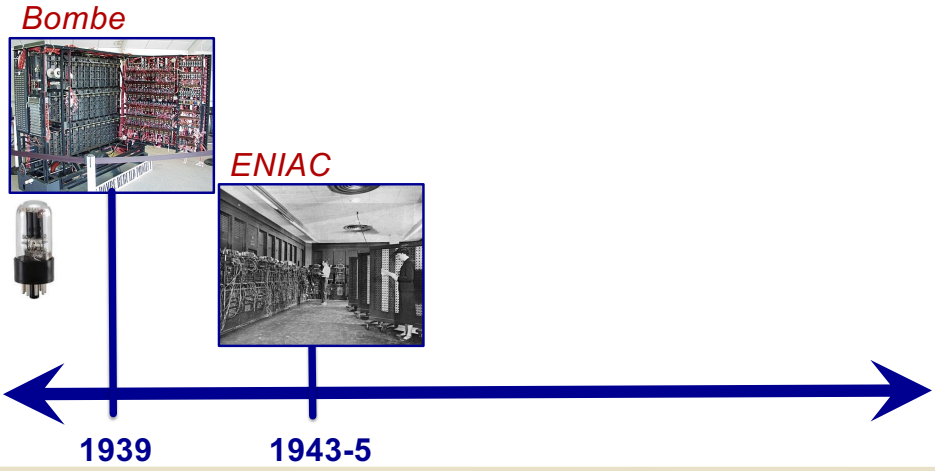
Computing throughout History



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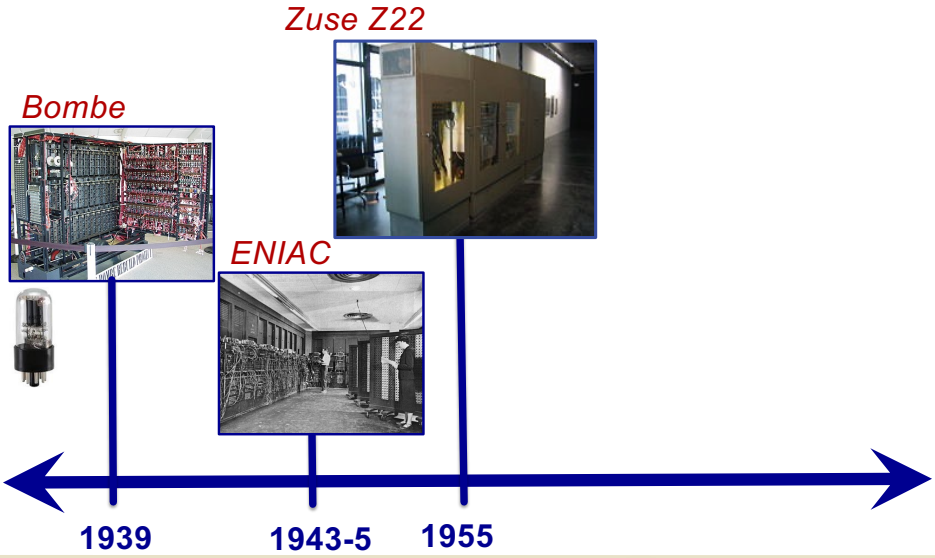
Computing throughout History



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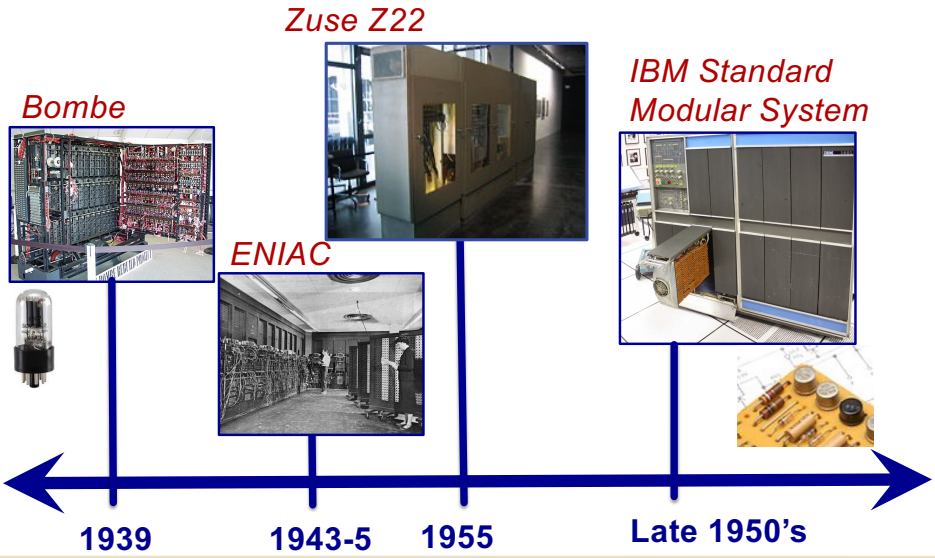
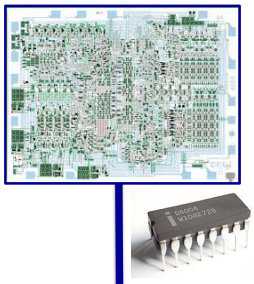
Computing throughout History



8

Computing throughout History

Intel 4004

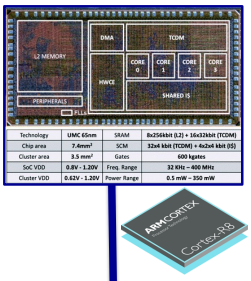


1971

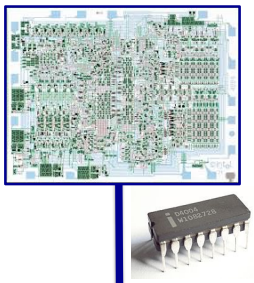
9

Computing throughout History

ARM Cortex



Intel 4004



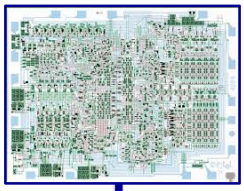
1971

2010

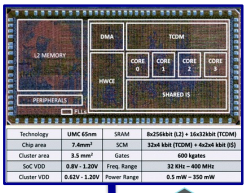
10

Computing throughout History

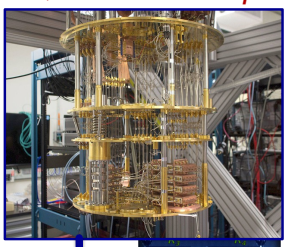
Intel 4004

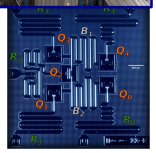


ARM Cortex



IBM Quantum Computer





1971 2010 2017

11

May 7, 1981

Simulating Physics with Computers

Richard P. Feynman

Department of Physics, California Institute of Technology, Pasadena, California 91107

Received May 7, 1981

1. INTRODUCTION

On the program it says this is a keynote speech—and I don't know what a keynote speech is. I do not intend in any way to suggest what should be in this meeting as a keynote of the subjects or anything like that. I have my own things to say and to talk about and there's no implication that anybody needs to talk about the same thing or anything like it. So what I want to talk about is what Mike Dertouzos suggested that nobody would talk about. I want to talk about the problem of simulating physics with computers and I mean that in a specific way which I am going to explain. The reason for doing this is something that I learned about from Ed

The first branch, one you might call a side-remark, is, Can you do it with a new kind of computer—a quantum computer? (I'll come back to the other branch in a moment.) Now it turns out, as far as I can tell, that you can simulate this with a quantum system, with quantum computer elements. It's not a Turing machine, but a machine of a different kind. If we disregard

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July 13, 1984

Quantum theory, the Church-Turing principle and the universal quantum computer

DAVID DEUTSCH*

Appeared in *Proceedings of the Royal Society of London A* **400**, pp. 97-117 (1985)†

(*Communicated by R. Penrose, F.R.S. — Received 13 July 1984*)

Abstract

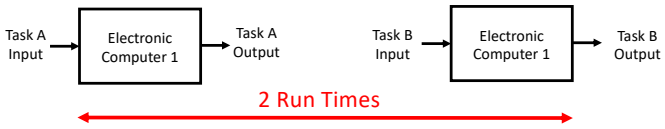
It is argued that underlying the Church-Turing hypothesis there is an implicit physical assertion. Here, this assertion is presented explicitly as a physical principle: 'every finitely realizable physical system can be perfectly simulated by a universal model computing machine operating by finite means'. Classical physics and the universal Turing machine, because the former is continuous and the latter discrete, do not obey the principle, at least in the strong form above. A class of model computing machines that is the quantum generalization of the class of Tur-

quantum computer' are compatible with the principle. Computing machines resembling the universal quantum computer could, in principle, be built and would have many remarkable properties not reproducible by any Turing machine. These do not include the computation of non-recursive functions, but they do include 'quantum parallelism', a method by which certain probabilistic tasks can be per-

13

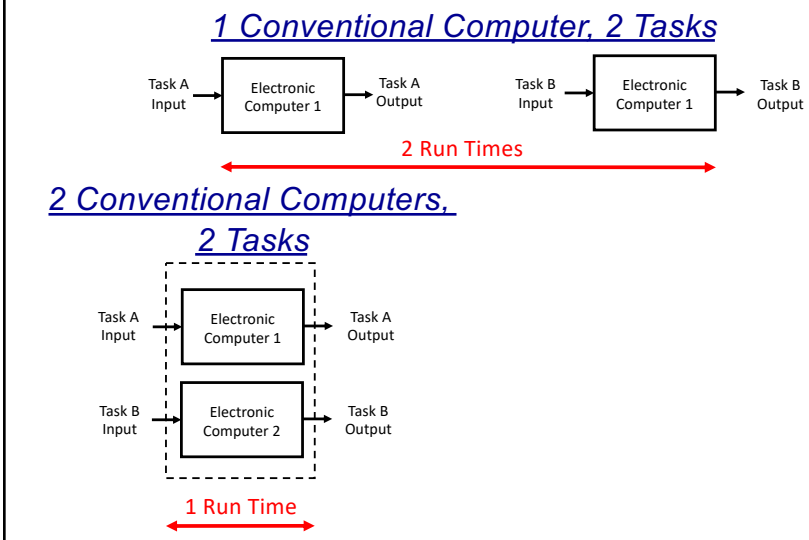
What is quantum parallelism?

1 Conventional Computer, 2 Tasks



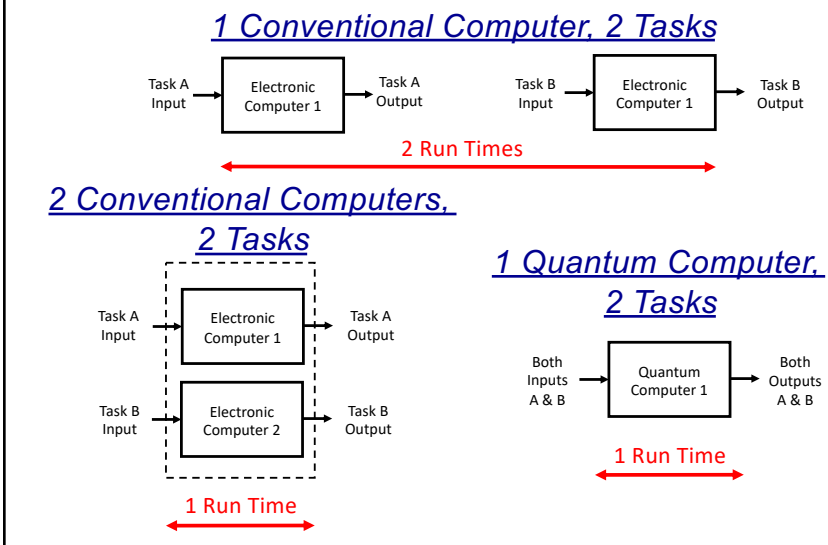
14

What is quantum parallelism?



15

What is quantum parallelism?



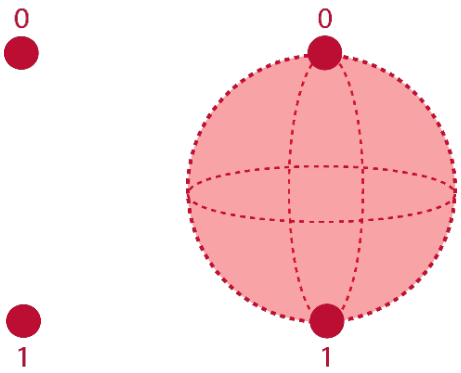
16

How is quantum parallelism possible?

Bit (electronic)

17

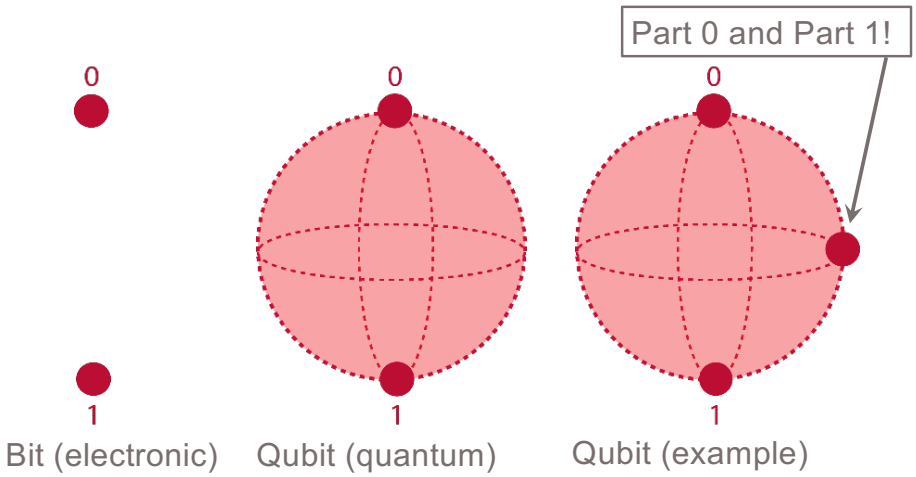
How is quantum parallelism possible?



Bit (electronic) Qubit (quantum)

18

How is quantum parallelism possible?



Parallelism in Information Representation

What happened between 1984 and now?

Better Components (Improvements in precision and performance):

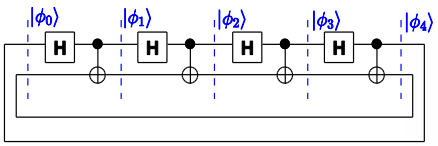
Feature	1984	Today
Semiconductor Feature Size	1000 nm	14 nm
Single Photon Source Efficiency	9%	70%
Single Photon Detector Efficiency	20%	90%

Better Infrastructure (Access to that performance):

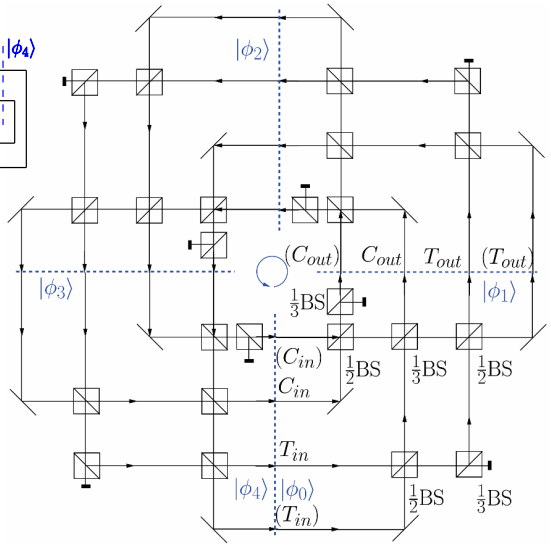
- *Design SW,*
- *Foundries for Electronics … now photonics*

Quantum Informatics is moving from Physics to Engineering

Bell State Oscillator

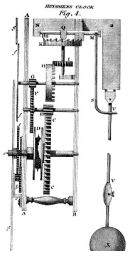


- First Quantum Oscillator
- "Bell State Oscillator"
- First incidence of feedback in a quantum system

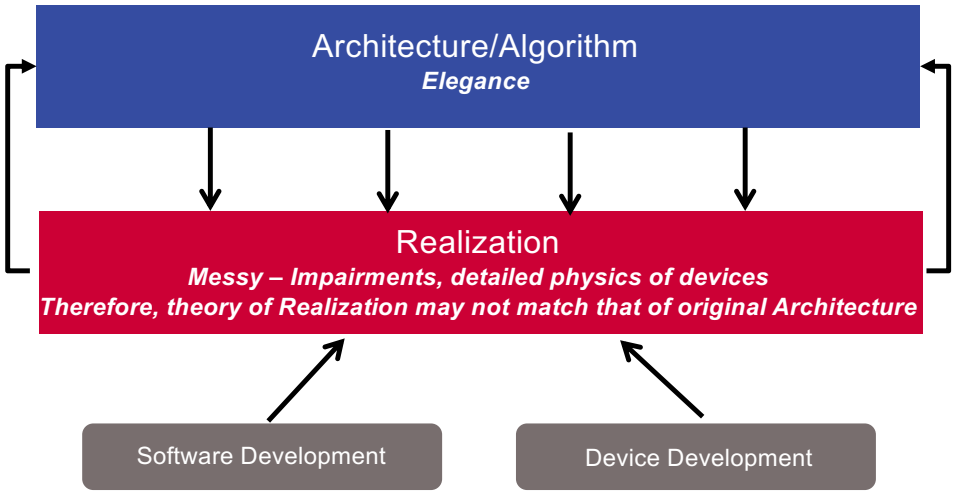


Why Oscillators?

- Clock
- Synchronization
- Counters
- Memory
- Sensors
- Random number generators



Engineering Doctrine – QIS Design



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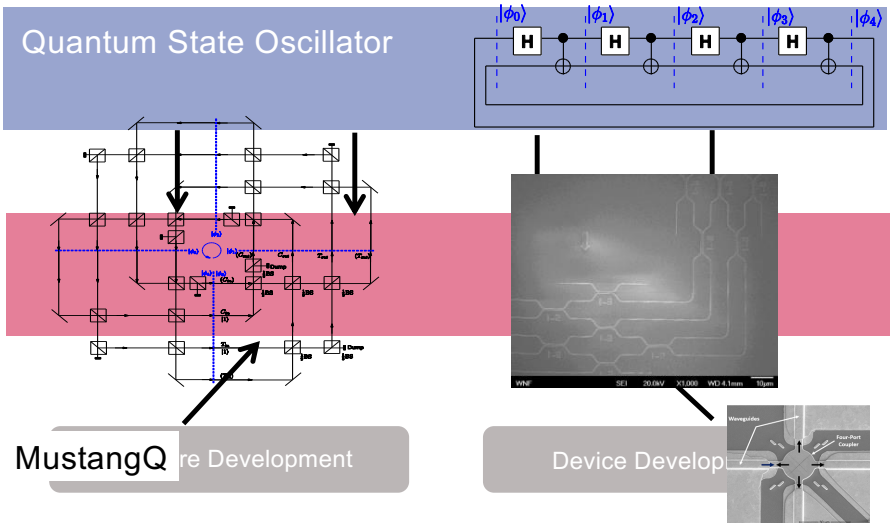
BSO Example



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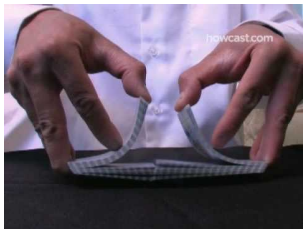
The Basic Search Problem

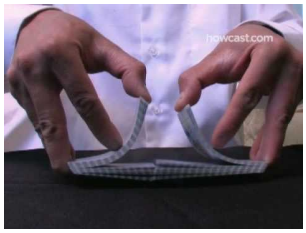


EXAMPLE PROBLEM
Input: Shuffled Deck of 52 Cards
Output: Search for 5 of Diamonds

Worst Case: Examine all 52 Cards
Average Case: Examine 26 Cards

25

Amazingly Fast Searching



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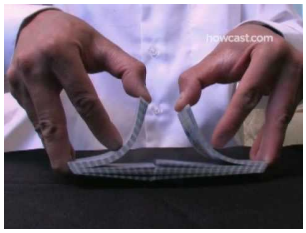
Search Program on Quantum Computer:
8 Operations !!!! (~Square Root of 52)

26

Amazingly Fast Searching → Basic Technique



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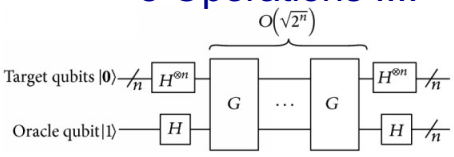

Grover's Search Method

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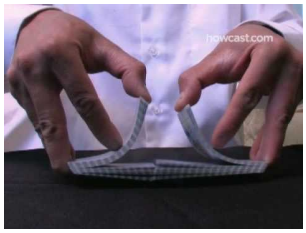
Fast Searching → Quantum AI/ML



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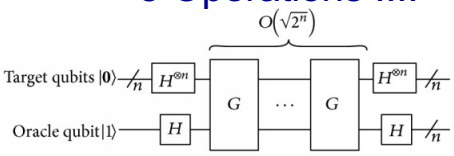

Grover's Search Method

Quantum Machine Learning

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Drug Discovery - Pharmaceutical

EXAMPLE PROBLEM
Input: List of Candidate Compounds
Output: New Drug

Worst Case: Create/Test Each Compound in the Laboratory

29

Drug Discovery - Pharmaceutical

EXAMPLE PROBLEM
Input: List of Candidate Compounds
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Worst Case: Create/Test Each Compound in the Laboratory

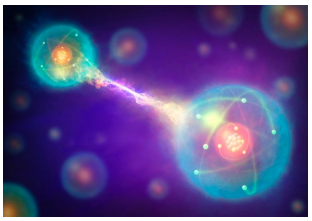
Richard Feynman's 1981 Paper

Original Motivation was to Simulate Atomic Structures at Particle Level

Quantum Chemistry Simulation

30

Entanglement: Another QM Phenomenon



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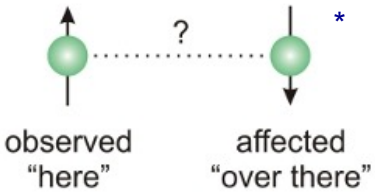

* from Google images

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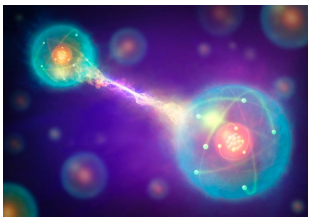
Entanglement: Generation



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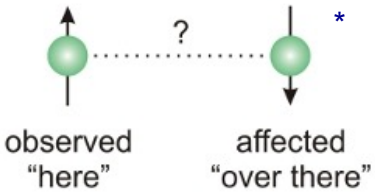
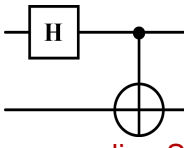


GENERATE ENTANGLEMENT

1) Initialize and process 2 Particles
2) Transmit 1 particle and "keep" the second
3) When second particle is measured
   → First particle is "forced" to change into a Corresponding State



* from Google images

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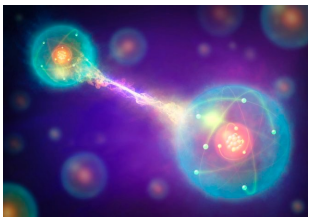
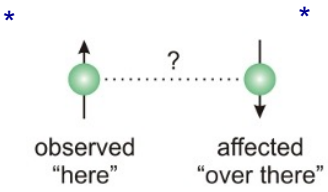
Action at a Distance





* from Google images

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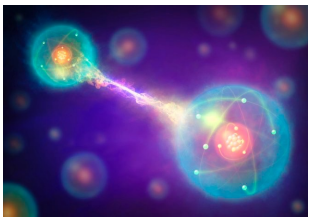
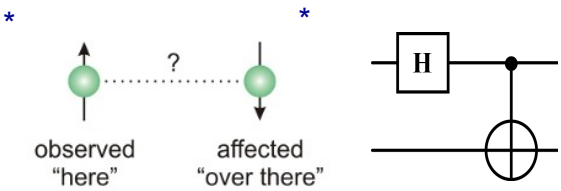
Action at a Distance





* from Google images

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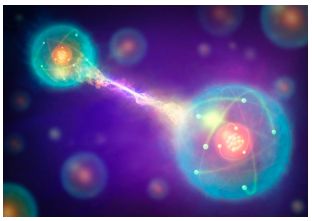
Action at a Distance



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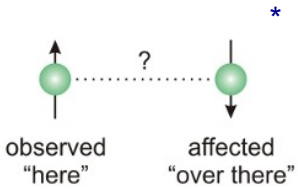

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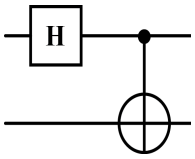

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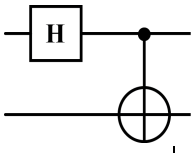
Entanglement Generation



$$|\psi_t\rangle = |00\rangle \qquad C_X(H\otimes I)|\psi_t\rangle \rightarrow |\psi_{t+1}\rangle$$

$$|\psi_{t+1}\rangle = C_X(H\otimes I)|00\rangle = \begin{bmatrix} 1&0&0&0\\ 0&1&0&0\\ 0&0&0&1\\ 0&0&1&0 \end{bmatrix} \left(\frac{1}{\sqrt{2}} \begin{bmatrix} 1&1\\ 1&-1 \end{bmatrix} \otimes \begin{bmatrix} 1&0\\ 0&1 \end{bmatrix} \right) \left(\begin{bmatrix} 1\\ 0 \end{bmatrix} \otimes \begin{bmatrix} 1\\ 0 \end{bmatrix} \right)$$

$$= \frac{1}{\sqrt{2}} \begin{bmatrix} 1&0&0&0\\ 0&1&0&0\\ 0&0&0&1\\ 0&0&1&0 \end{bmatrix} \begin{bmatrix} 1&0&1&0\\ 0&1&0&1\\ 1&0&-1&0\\ 0&1&0&-1 \end{bmatrix} \begin{bmatrix} 1\\ 0\\ 0\\ 0 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1&0&1&0\\ 0&1&0&1\\ 0&1&0&-1\\ 1&0&-1&0 \end{bmatrix} \begin{bmatrix} 1\\ 0\\ 0\\ 0 \end{bmatrix}$$

$$= \frac{1}{\sqrt{2}} \begin{bmatrix} 1\\ 0\\ 0\\ 1 \end{bmatrix} = \frac{1}{\sqrt{2}} \left(\begin{bmatrix} 1\\ 0\\ 0\\ 0 \end{bmatrix} + \begin{bmatrix} 0\\ 0\\ 0\\ 1 \end{bmatrix} \right) = \frac{1}{\sqrt{2}} \left[\left(\begin{bmatrix} 1\\ 0 \end{bmatrix} \otimes \begin{bmatrix} 1\\ 0 \end{bmatrix} \right) + \left(\begin{bmatrix} 0\\ 1 \end{bmatrix} \otimes \begin{bmatrix} 0\\ 1 \end{bmatrix} \right) \right]$$

$$= \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

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