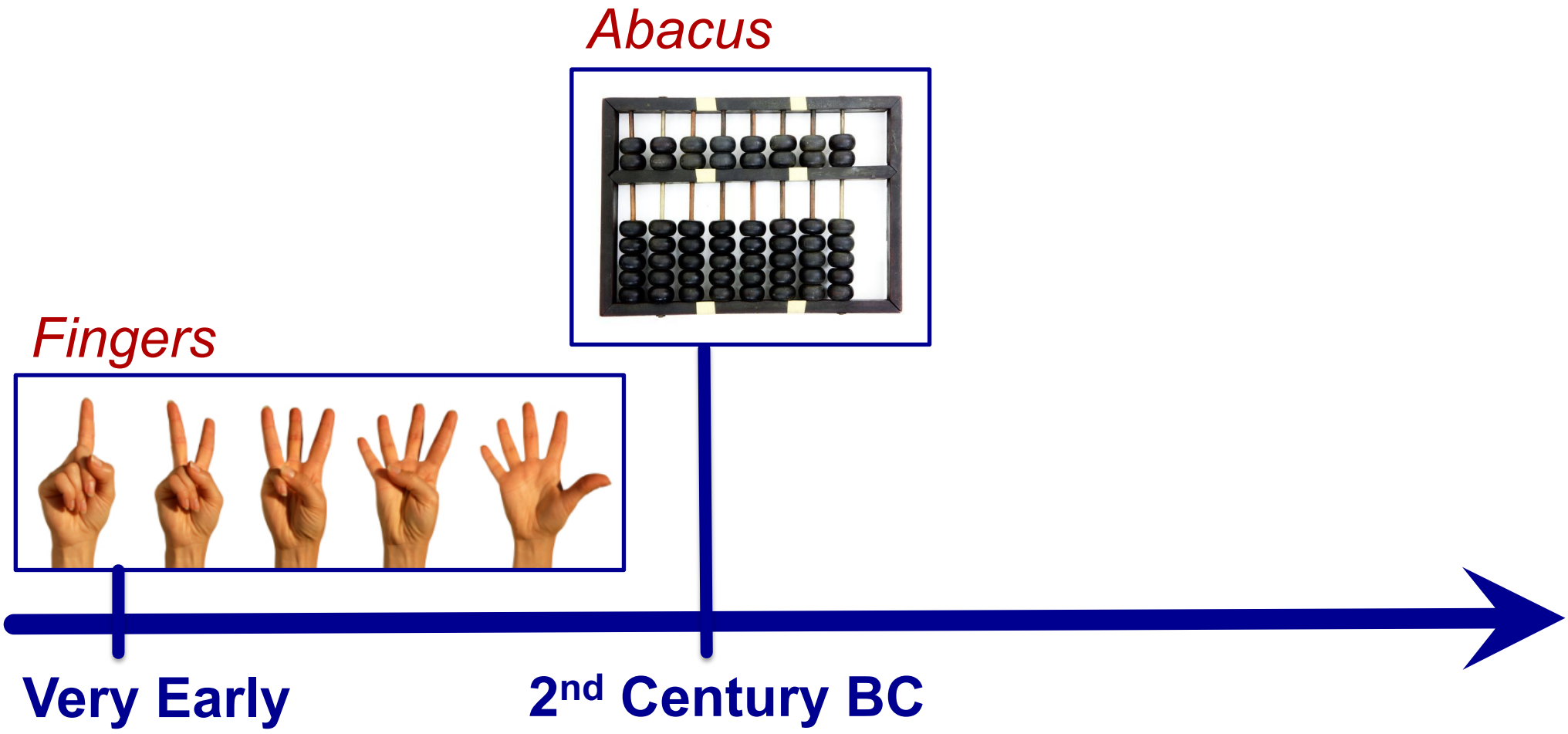
Computing throughout History

Fingers

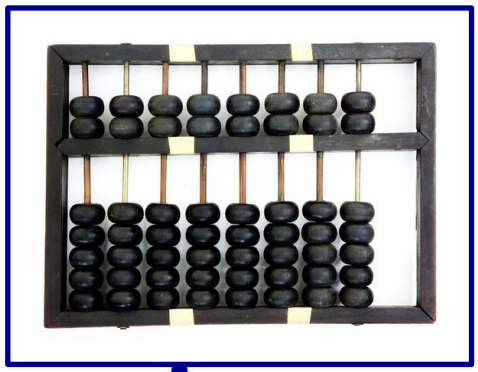
Very Early

Computing throughout History

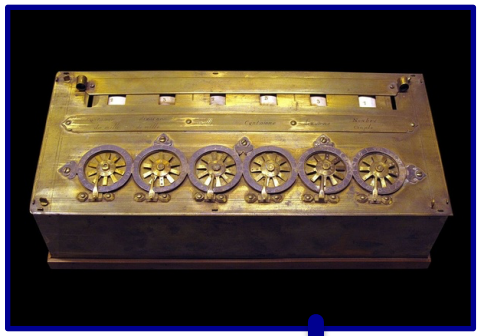


Computing throughout History

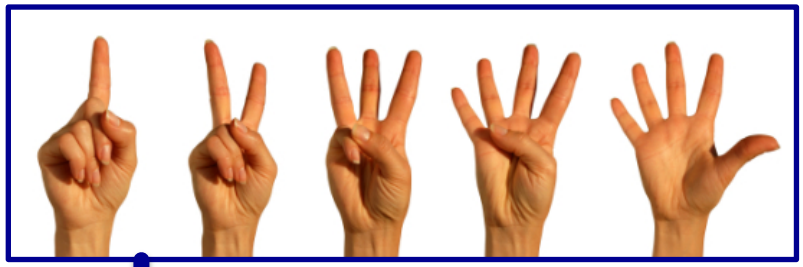
Abacus



Pascaline

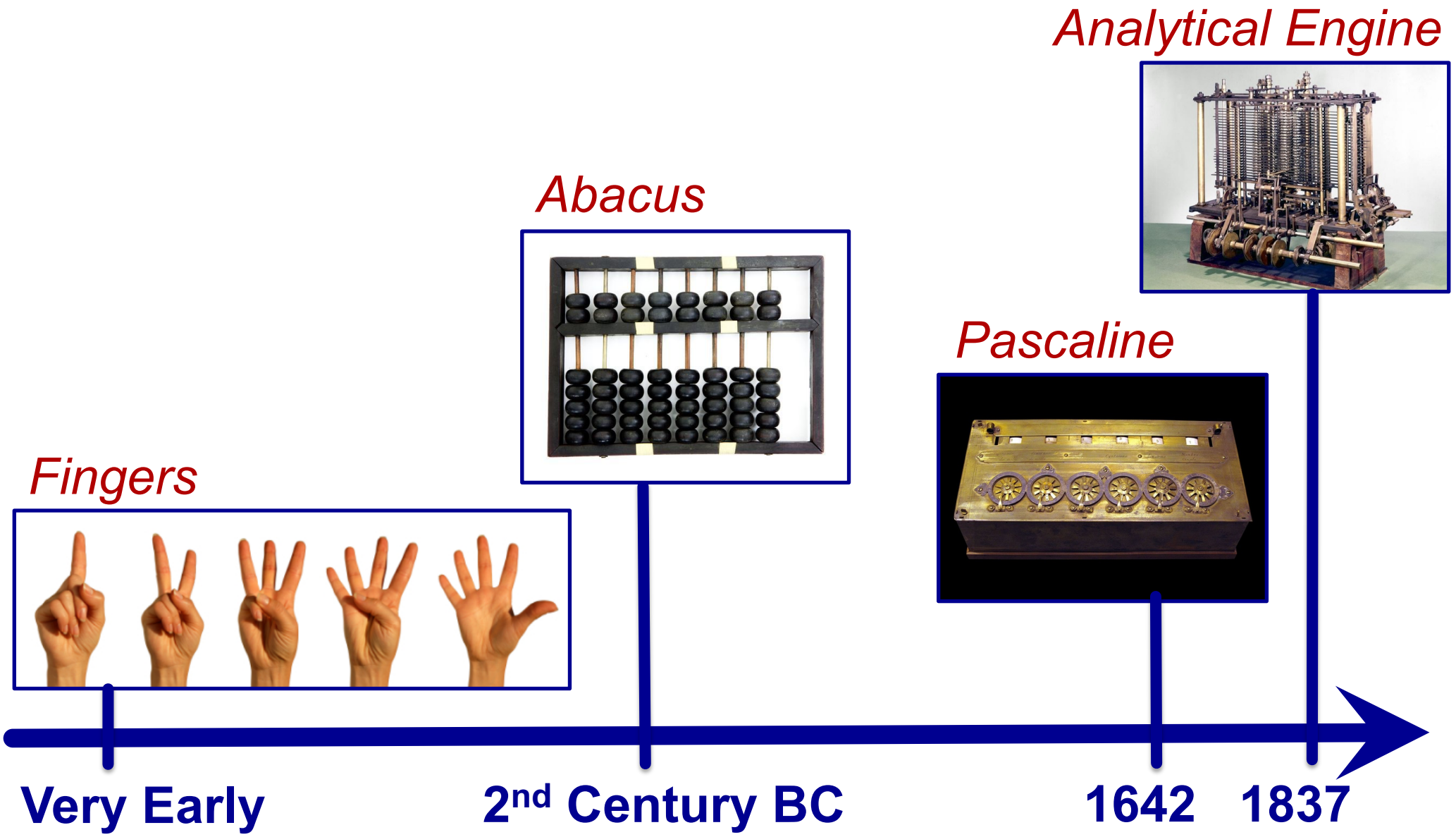


Fingers



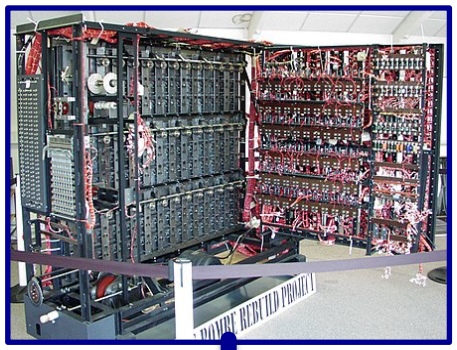
Very Early — **2nd Century BC** — **1642**

Computing throughout History



Computing throughout History

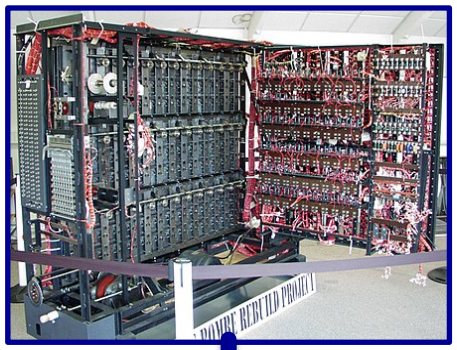
Bombe



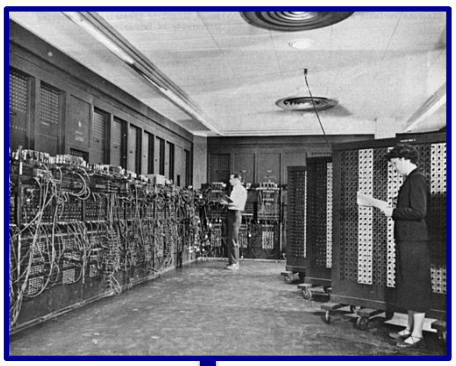
1939

Computing throughout History

Bombe



ENIAC

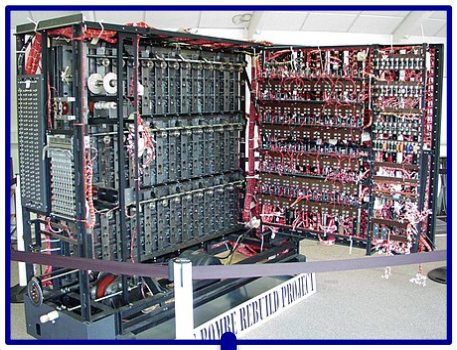


1939 **1943-5**

Computing throughout History

Zuse Z22

Bombe



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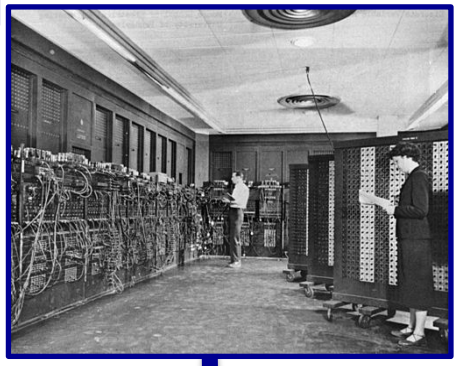


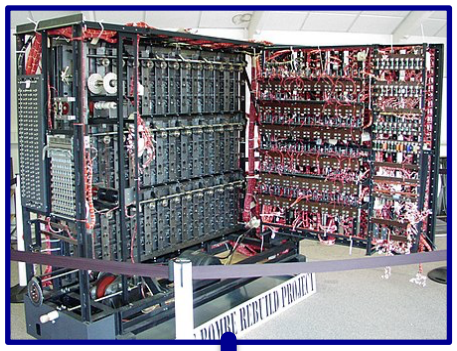
1939 1943-5 1955

Computing throughout History

Zuse Z22

IBM Standard Modular System

Bombe



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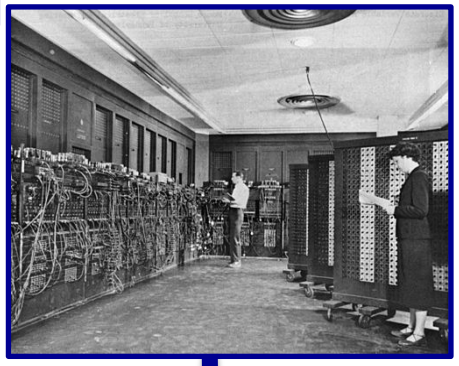
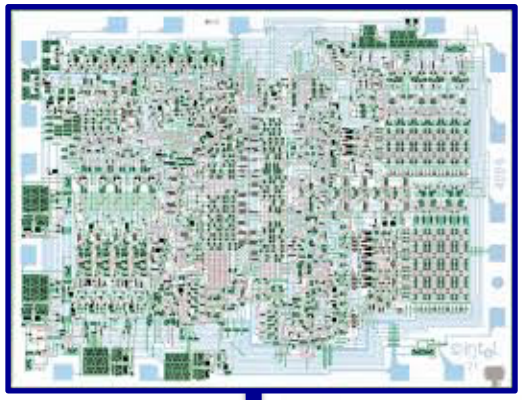
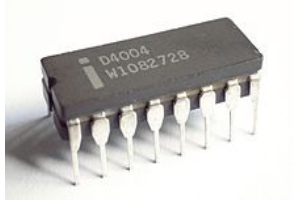


1939 1943-5 1955 Late 1950's

Computing throughout History

Intel 4004



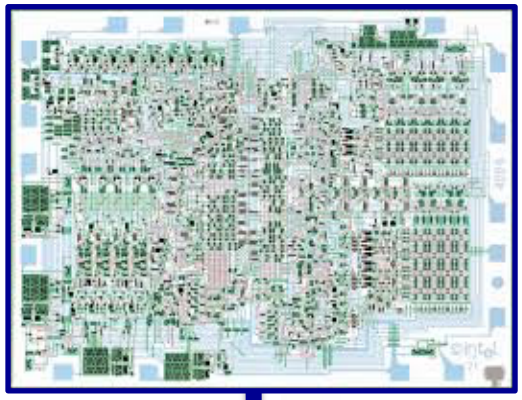


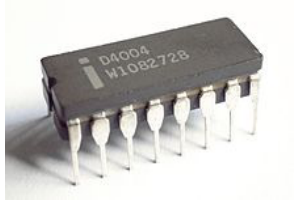
1971

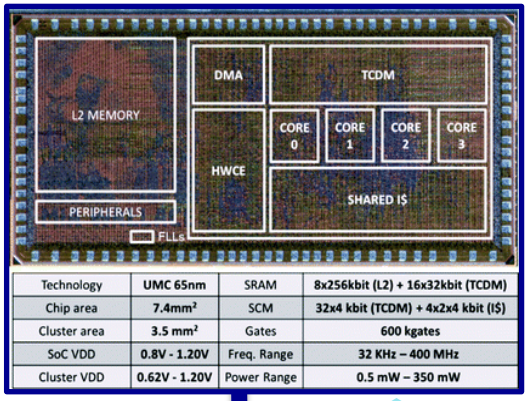
Computing throughout History

ARM Cortex

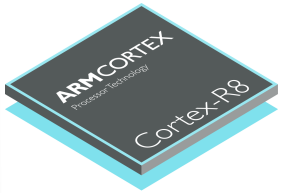
Intel 4004







Technology	UMC 65nm	SRAM	8x256kbit (L2) + 16x32kbit (TCDM)
Chip area	7.4mm²	SCM	32x4 kbit (TCDM) + 4x2x4 kbit (I$)
Cluster area	3.5 mm²	Gates	600 kgates
SoC VDD	0.8V - 1.20V	Freq. Range	32 KHz – 400 MHz
Cluster VDD	0.62V - 1.20V	Power Range	0.5 mW – 350 mW

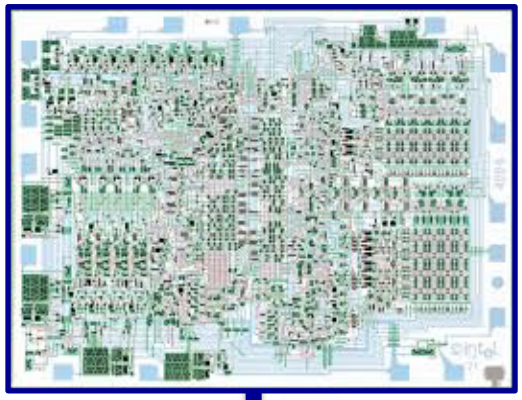


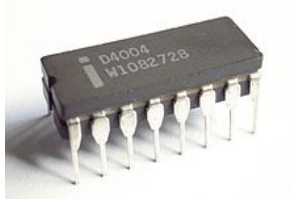
1971

2010

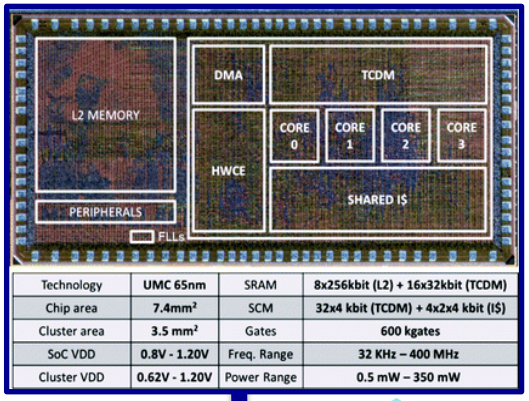
Computing throughout History

Intel 4004





ARM Cortex



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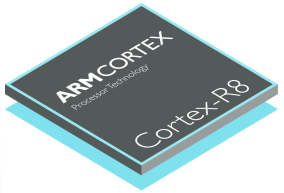
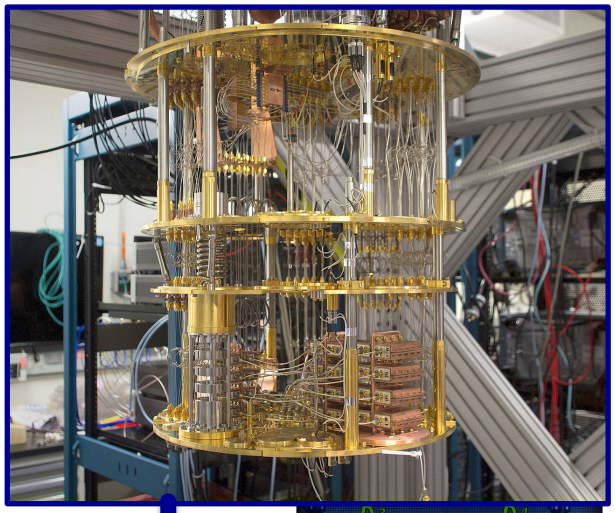
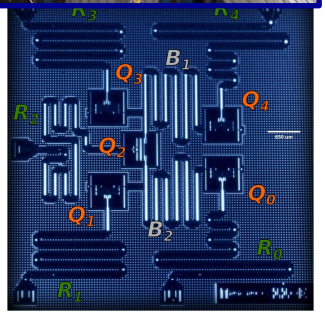


IBM Quantum Computer





1971 2010 2017

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

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)†

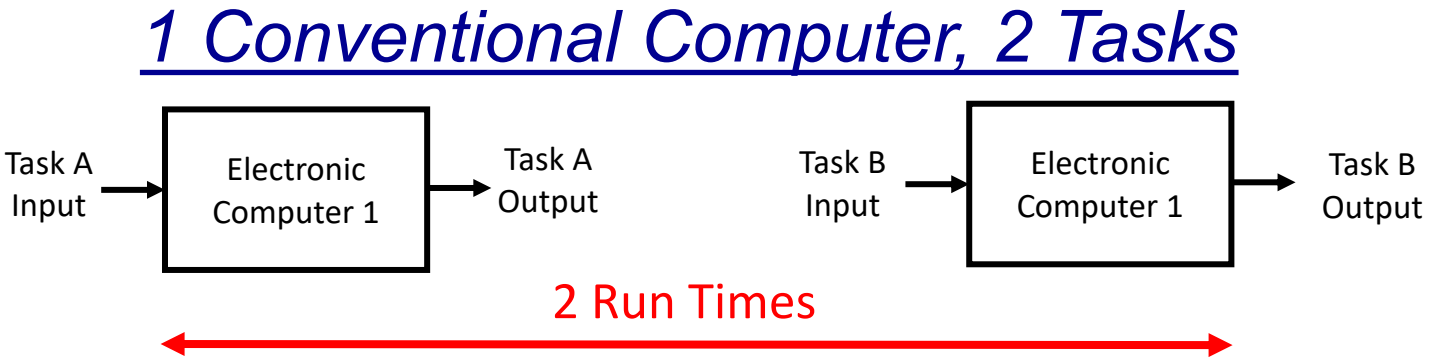
(*Communicated by R. Penrose, F.R.S. — Received 13 July 1984*)

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-

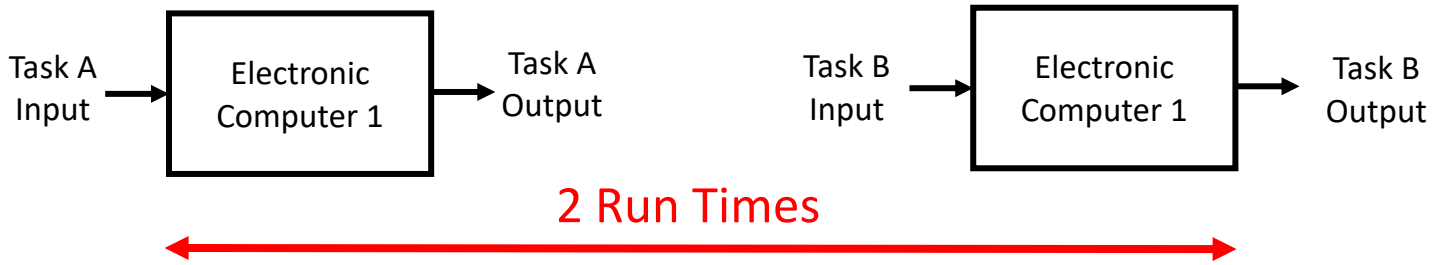
quantum computer' are compatible with the principle. Computing machines resembling the universal quantum computer could, in principle, be built and would have many remarkable properties not reproducible by any Turing machine. These do not include the computation of non-recursive functions, but they do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

What is quantum parallelism?

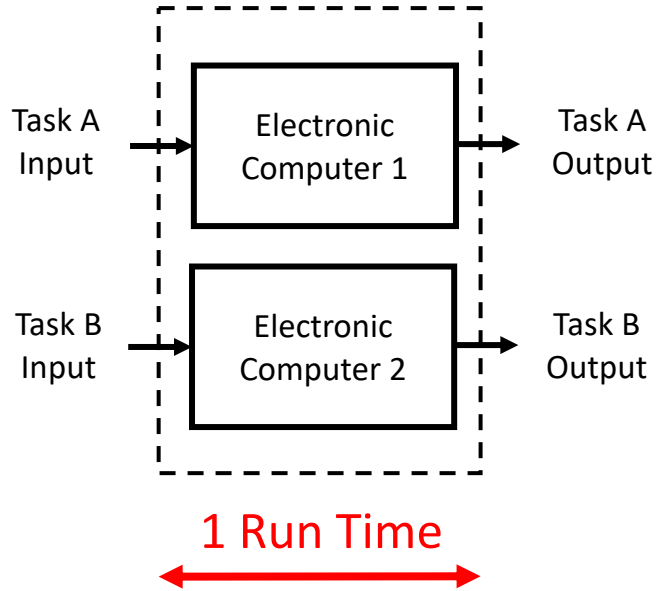


What is quantum parallelism?

1 Conventional Computer, 2 Tasks



2 Conventional Computers, 2 Tasks



What is quantum parallelism?

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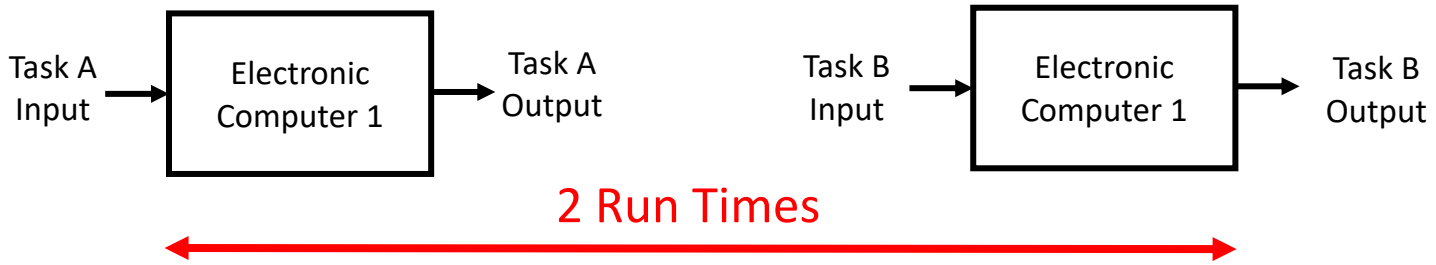
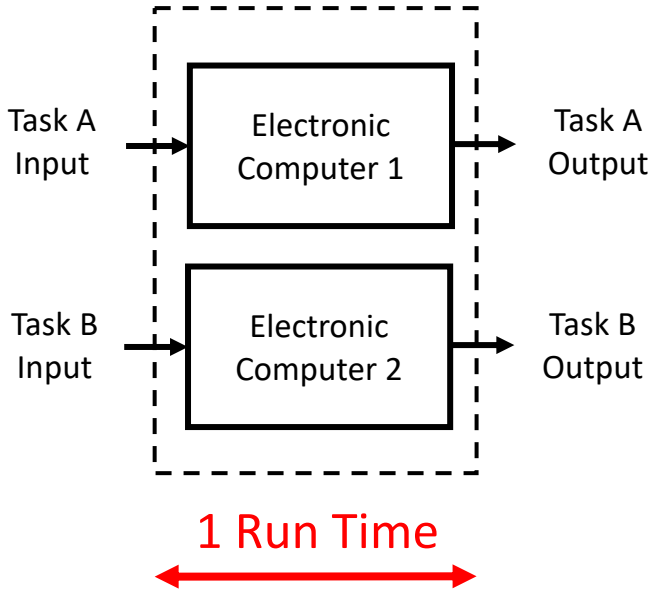
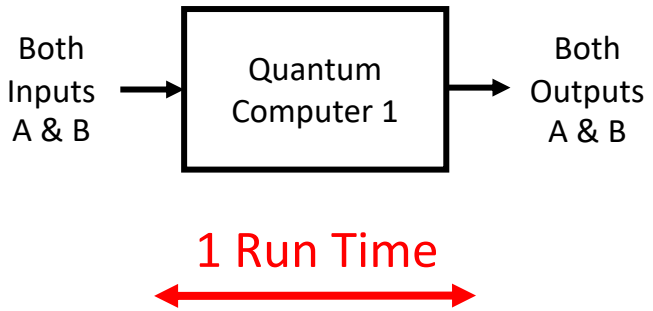


2 Conventional Computers, 2 Tasks



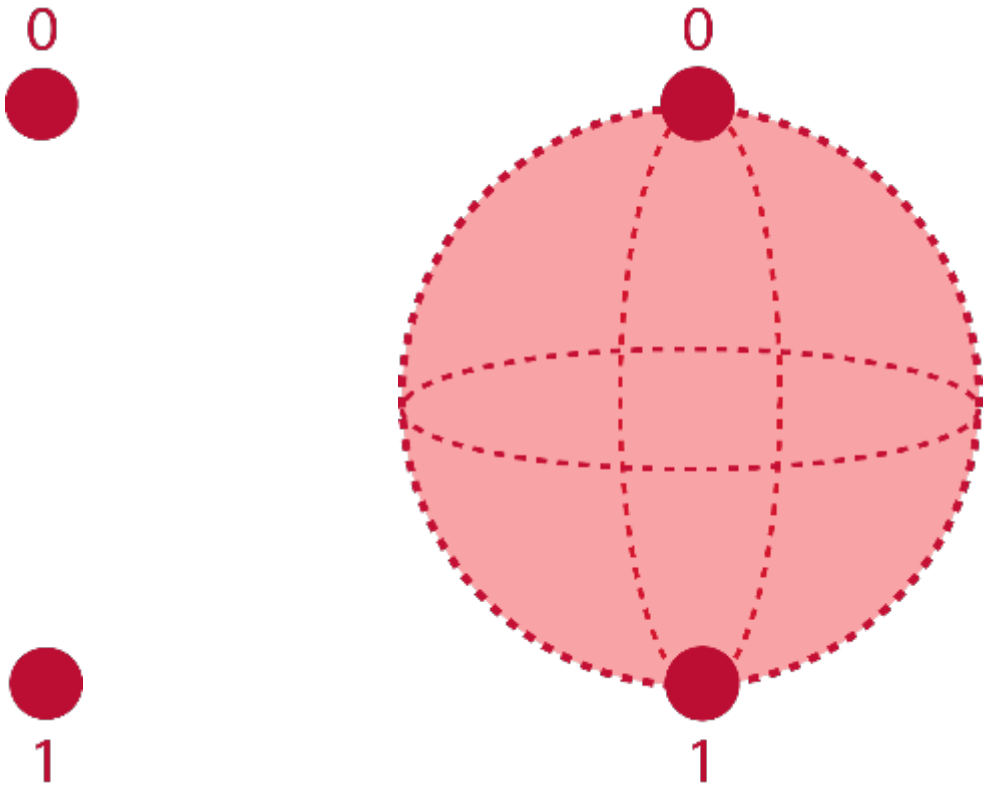
1 Quantum Computer, 2 Tasks



How is quantum parallelism possible?

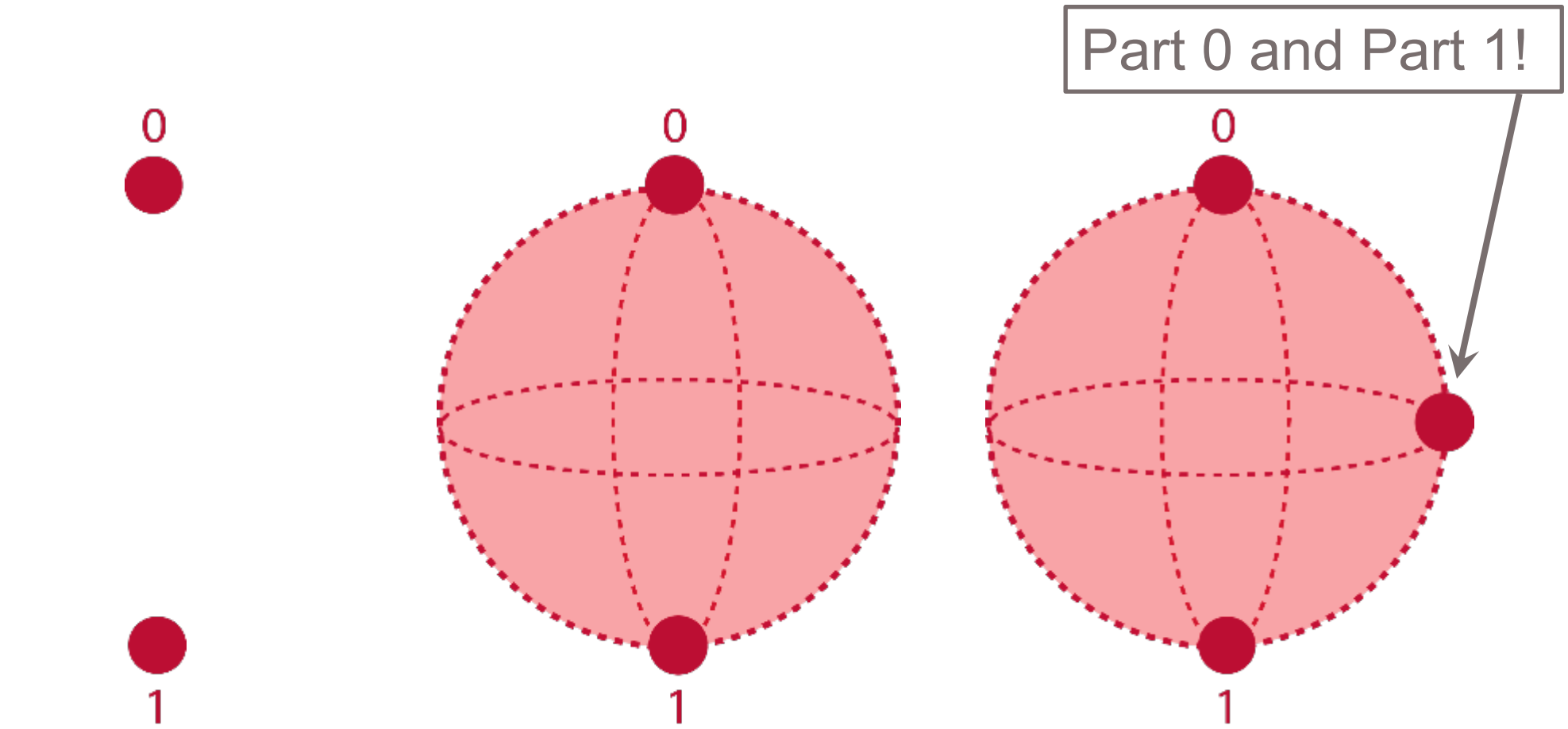
Bit (electronic)

How is quantum parallelism possible?



Bit (electronic) Qubit (quantum)

How is quantum parallelism possible?



Parallelism in Information Representation

What happened between 1984 and now?

Better Components (Improvements in precision and performance):

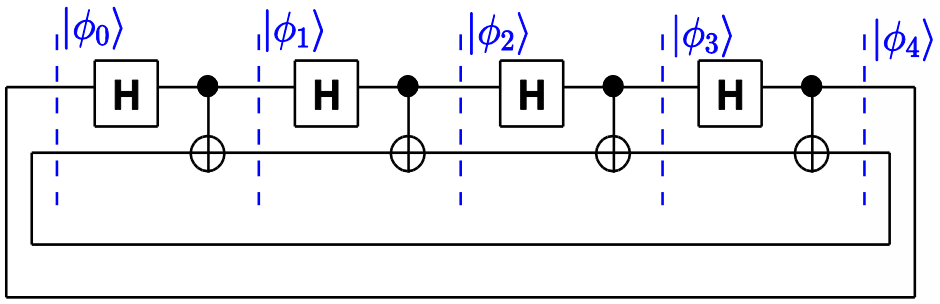
Feature	1984	Today
Semiconductor Feature Size	1000 nm	14 nm
Single Photon Source Efficiency	9%	70%
Single Photon Detector Efficiency	20%	90%

Better Infrastructure (Access to that performance):

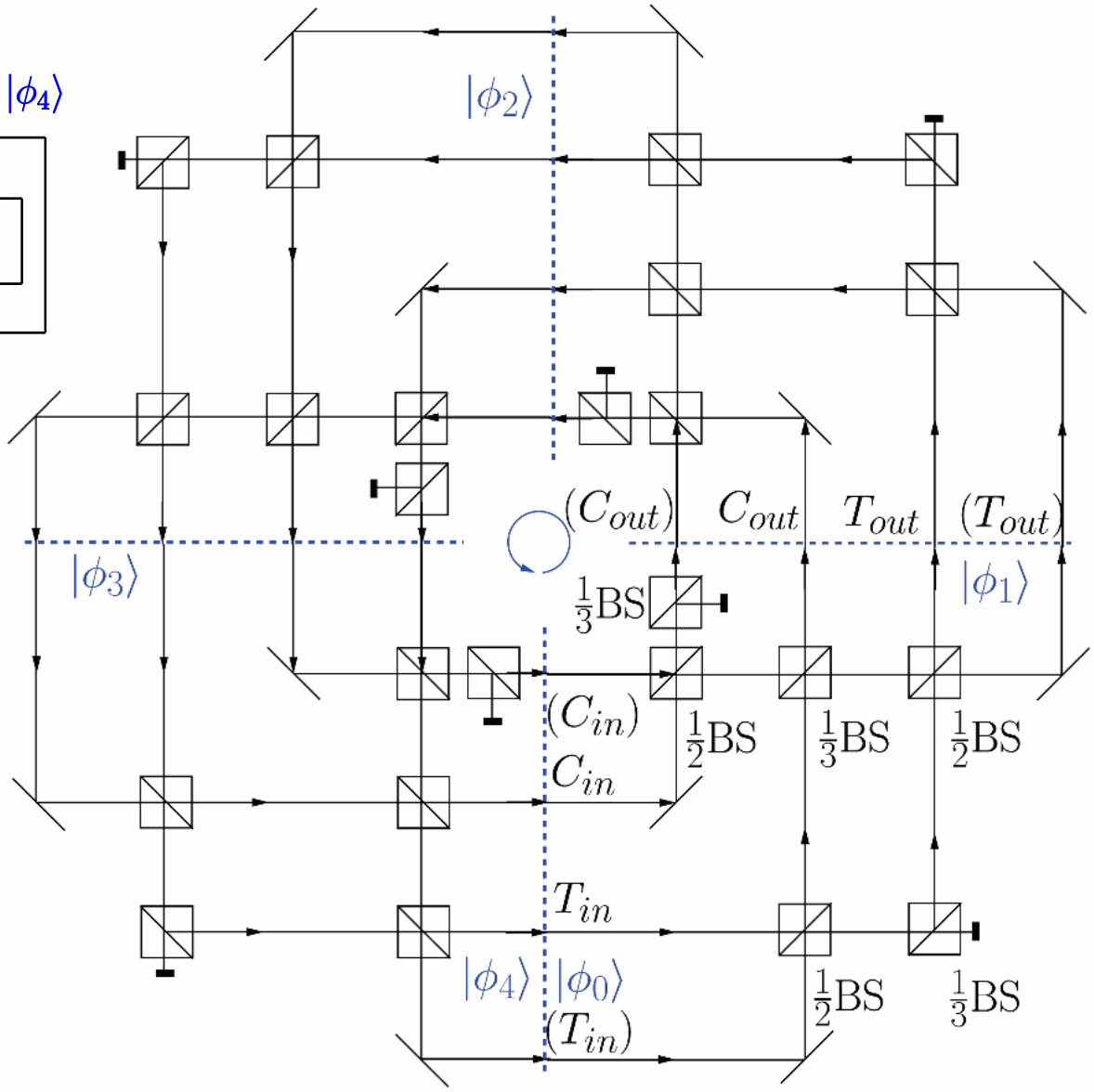
- *Design SW,*
- *Foundries for Electronics … now photonics*

Quantum Informatics is moving from Physics to Engineering

Bell State Oscillator

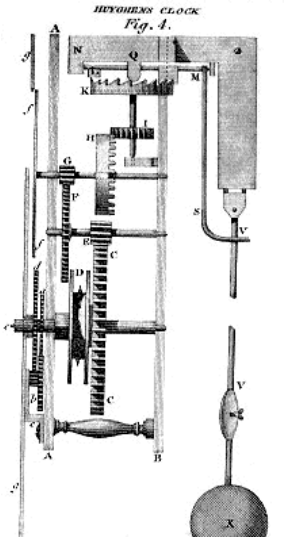


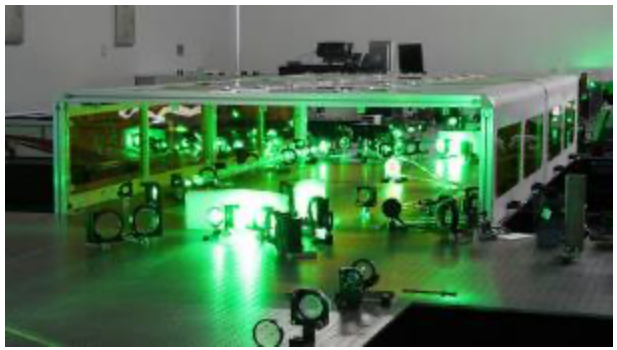
- First Quantum Oscillator
- "Bell State Oscillator"
- First incidence of feedback in a quantum system



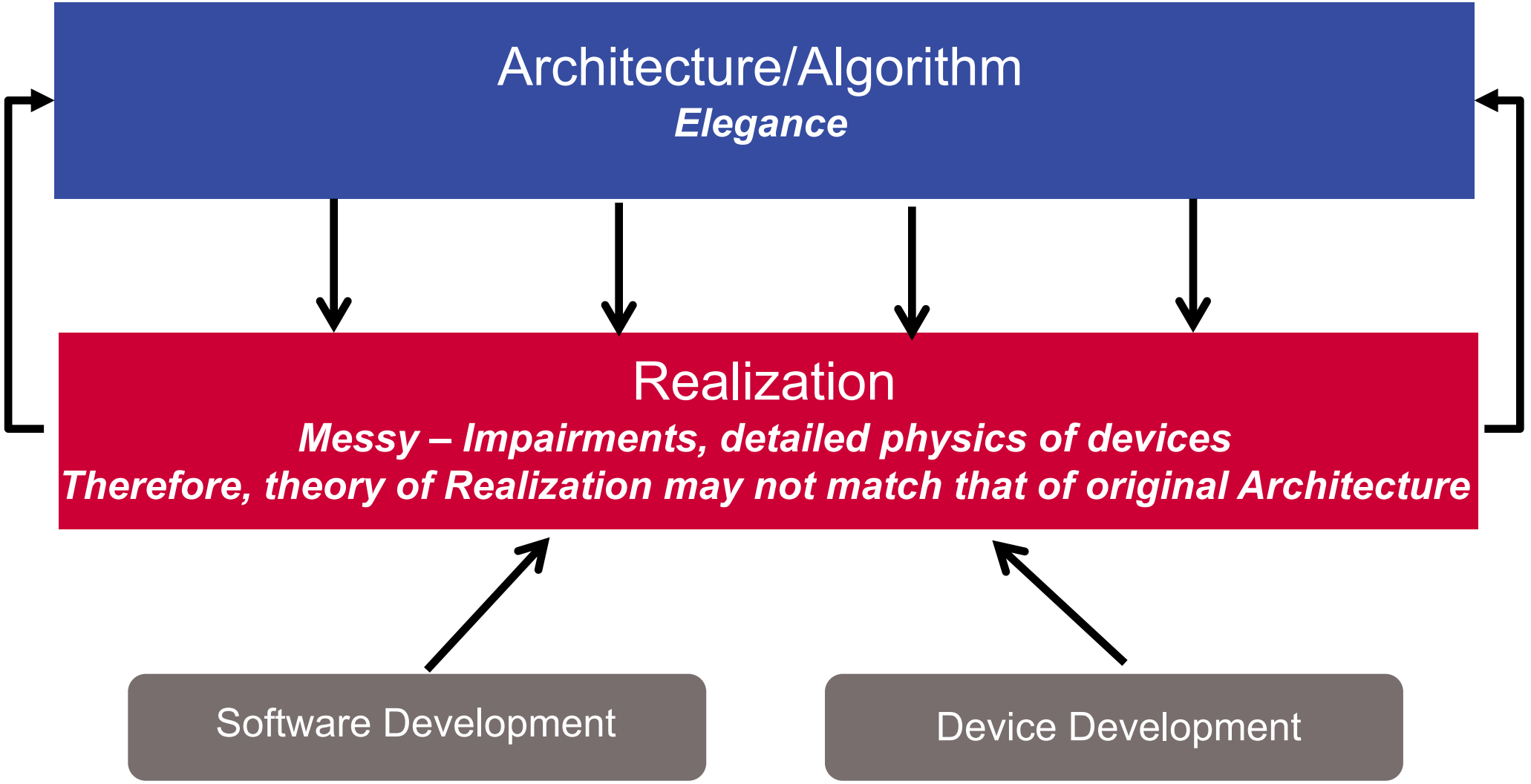
Why Oscillators?

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



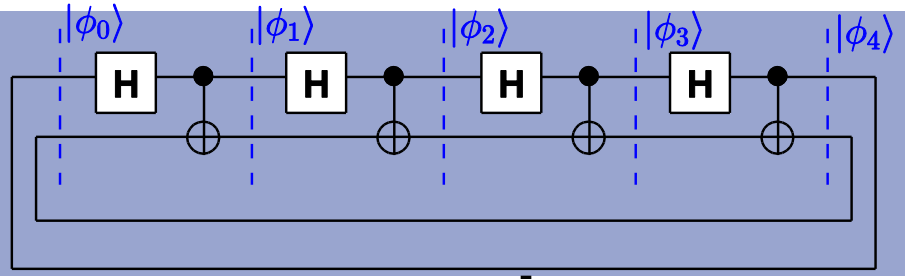


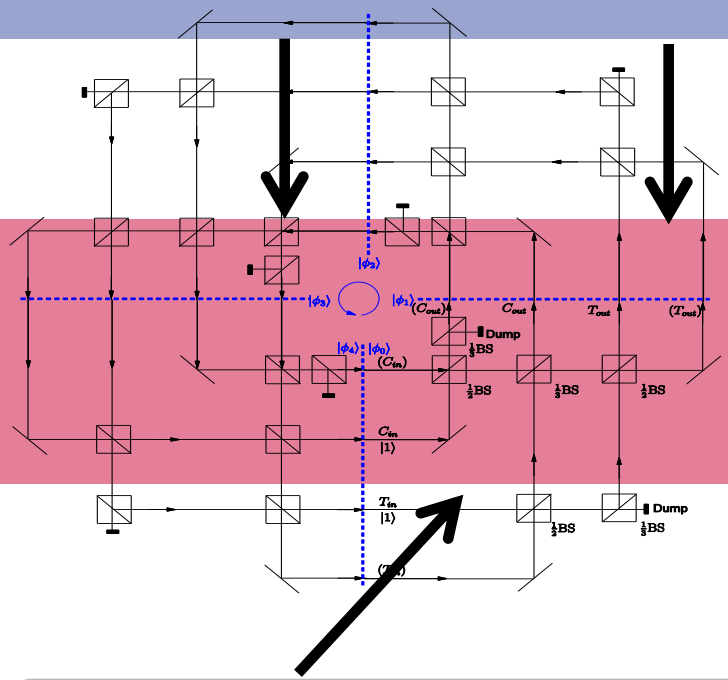
Engineering Doctrine – QIS Design

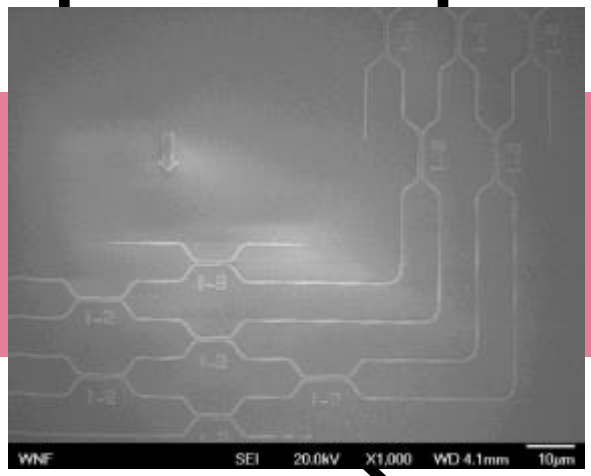


BSO Example

Quantum State Oscillator

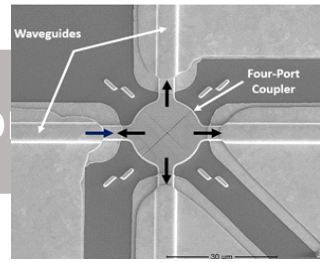




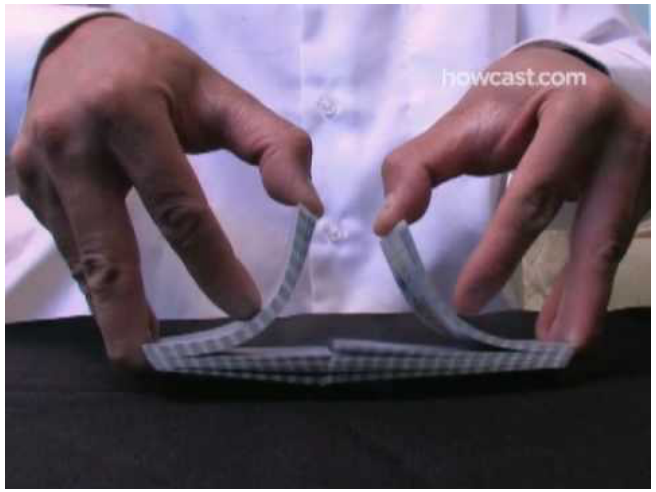


MustangQ re Development

Device Develop



The Basic Search Problem



EXAMPLE PROBLEM

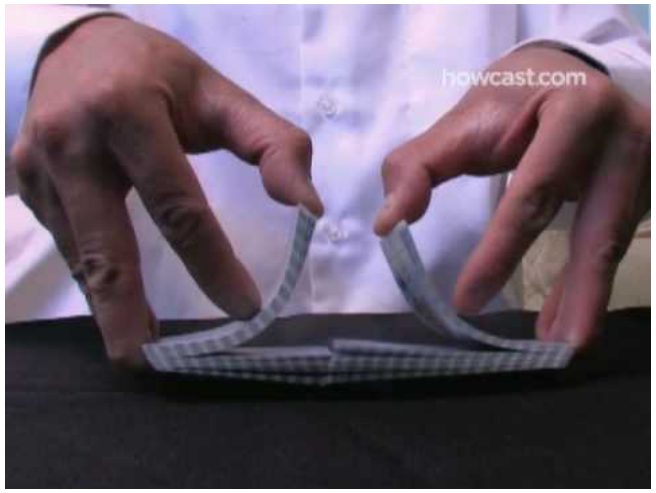
Input: Shuffled Deck of 52 Cards

Output: Search for 5 of Diamonds

Worst Case: Examine all 52 Cards

Average Case: Examine 26 Cards

Amazingly Fast Searching



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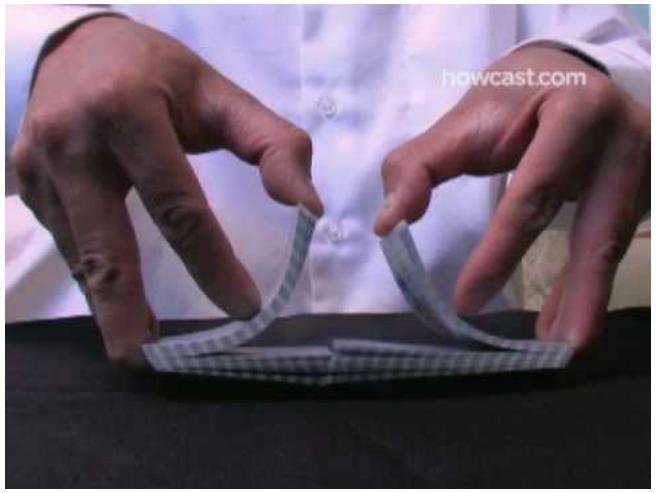
Search Program on Quantum Computer:

8 Operations !!!! (~Square Root of 52)

Amazingly Fast Searching → Basic Technique



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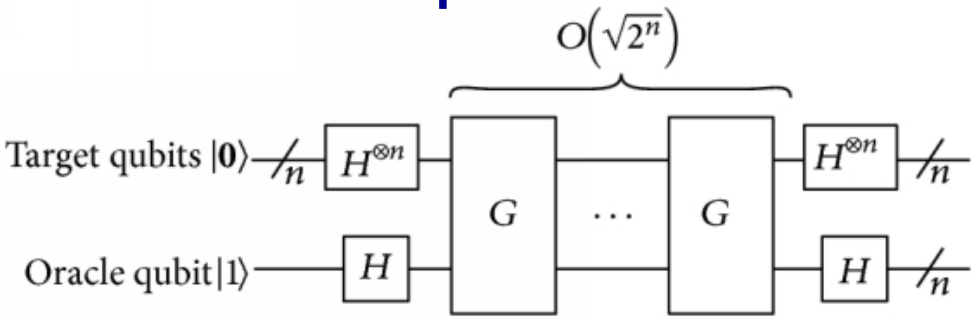
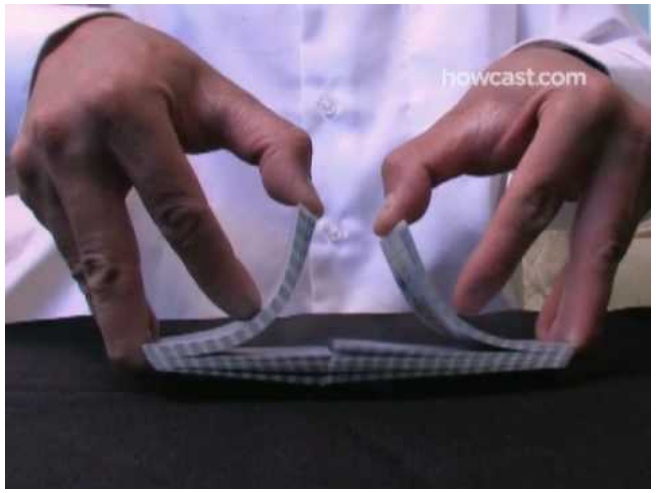


Grover's Search Method

Fast Searching → Quantum AI/ML



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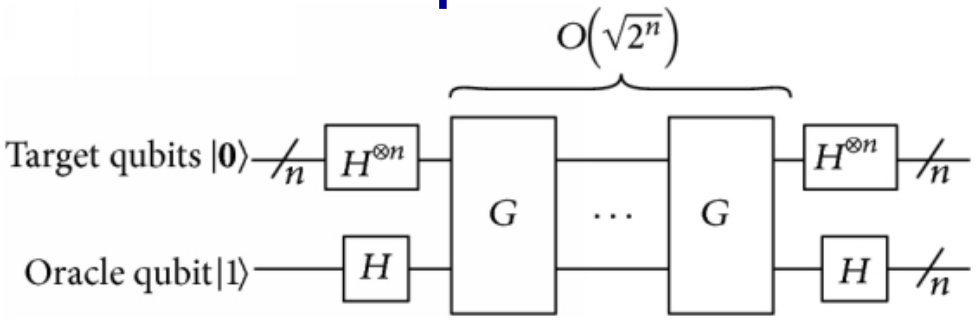

Grover's Search Method

Quantum Machine Learning

Drug Discovery - Pharmaceutical

EXAMPLE PROBLEM

Input: List of Candidate Compounds

Output: New Drug

Worst Case: Create/Test Each Compound in the Laboratory

Drug Discovery - Pharmaceutical

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Input: List of Candidate Compounds

Output: New Drug

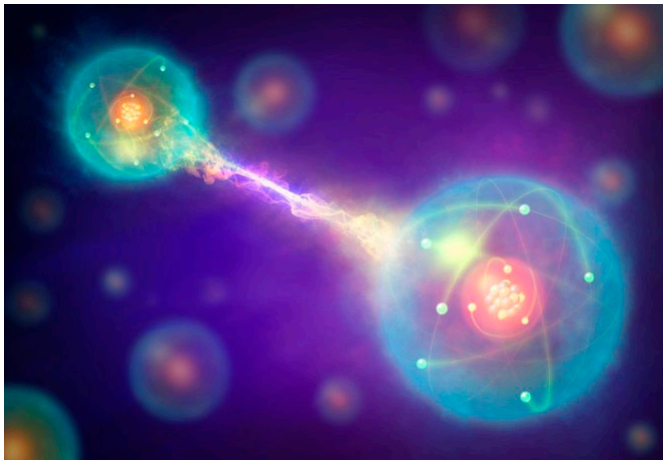
Worst Case: Create/Test Each Compound in the Laboratory

Richard Feynman's 1981 Paper

Original Motivation was to Simulate Atomic Structures at Particle Level

Quantum Chemistry Simulation

Entanglement: Another QM Phenomenon



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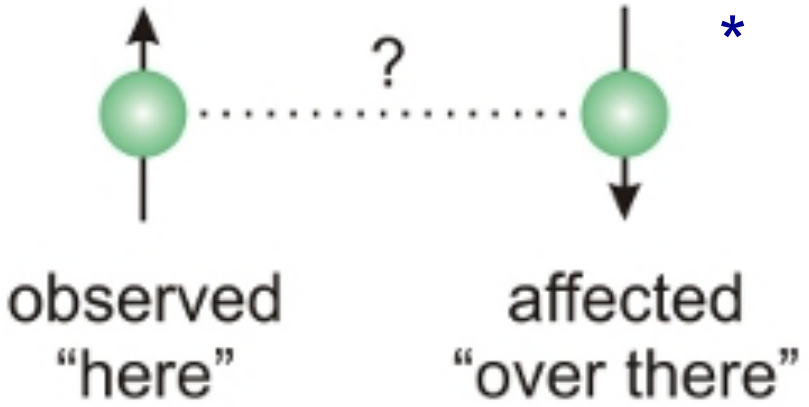

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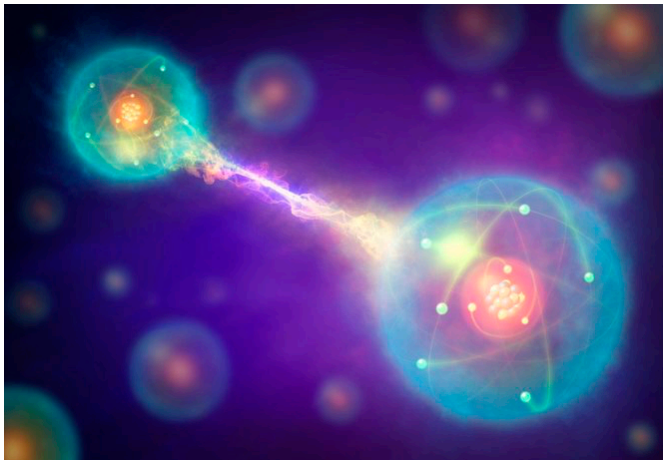
* from Google images

Entanglement: Generation



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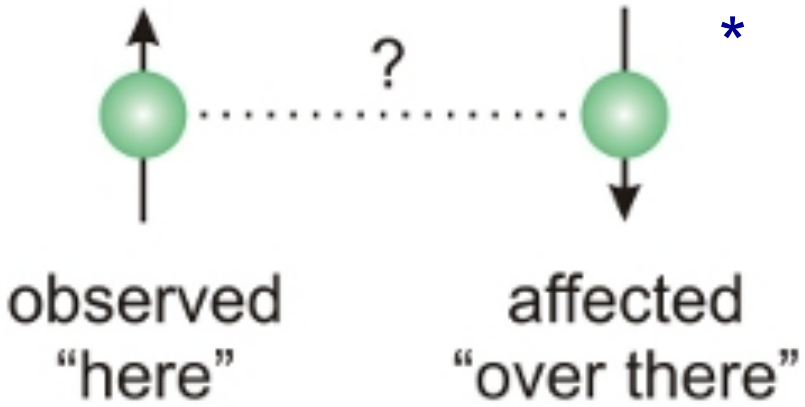

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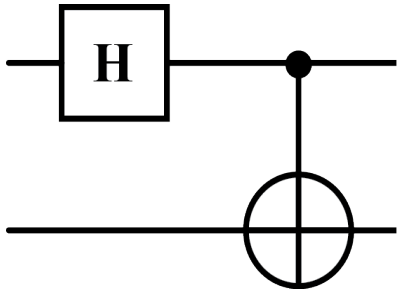
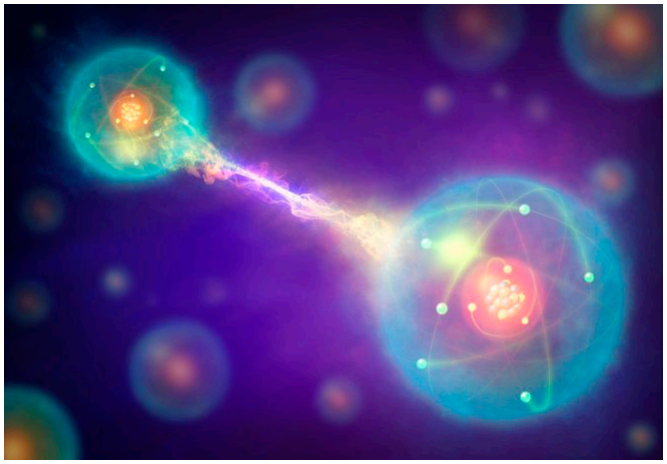
GENERATE ENTANGLEMENT

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

Action at a Distance



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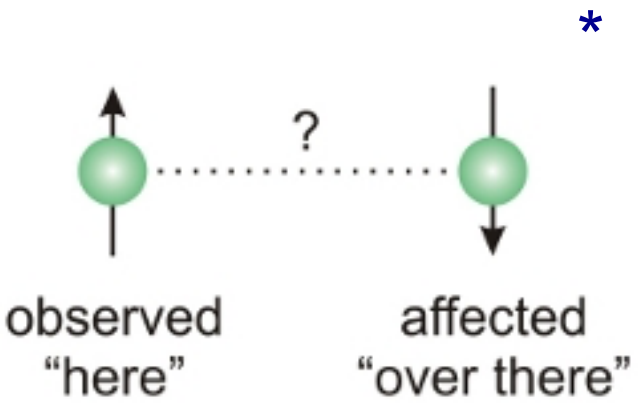

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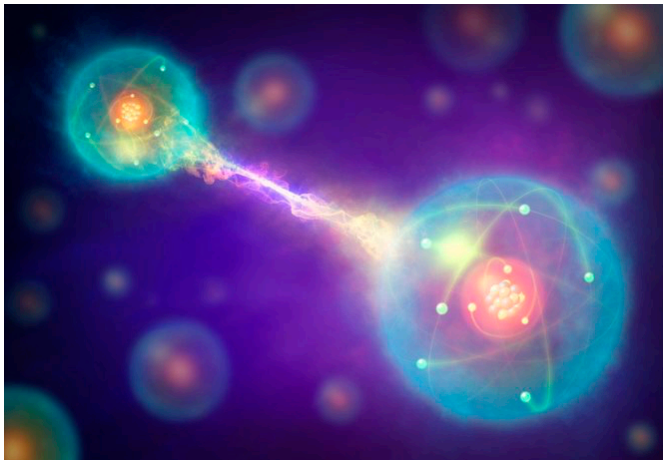
* from Google images

Action at a Distance



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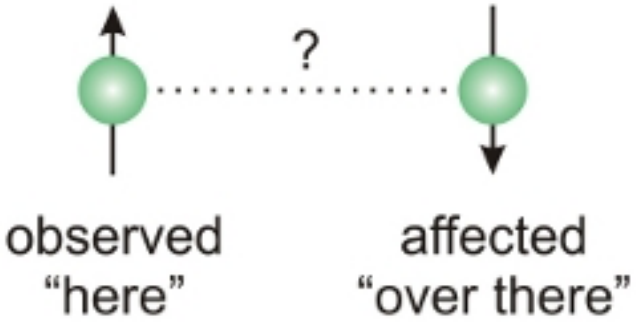

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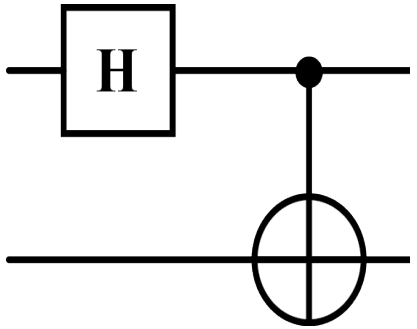
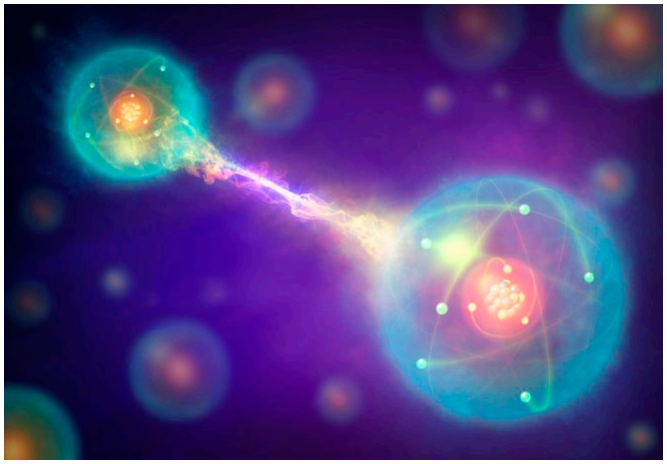


* from Google images

Action at a Distance



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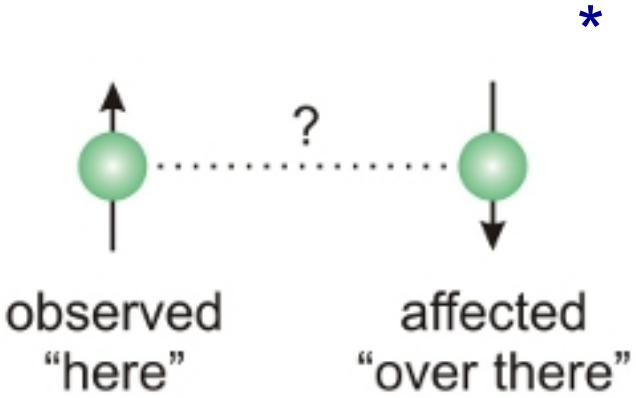

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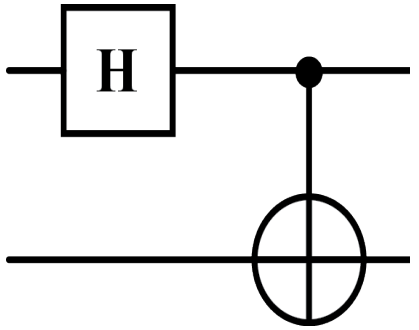

GENERATE ENTANGLEMENT

1) Initialize and process 2 Particles
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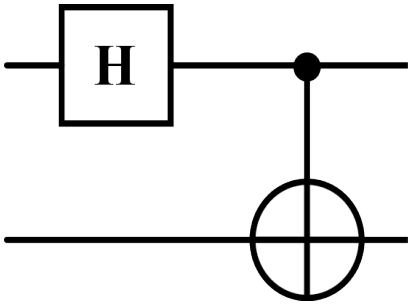
* from Google images

Entanglement Generation



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

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

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

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

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