FORUM GURU BESAR
INSTITUT TEKNOLOGI BANDUNG

Revolusi Kuantum Kedua

FGB ITB Future Science and Technology Talk
24 Juni, 2022

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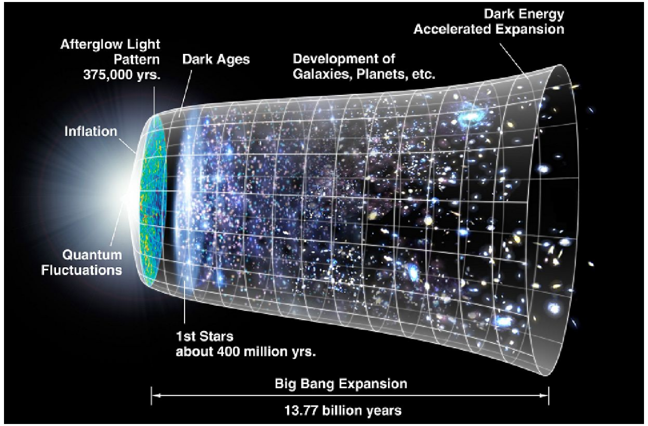
Sekolah Teknik Elektro dan Informatika, ITB

STEI-ITB
+HEBAT

Daftar Isi

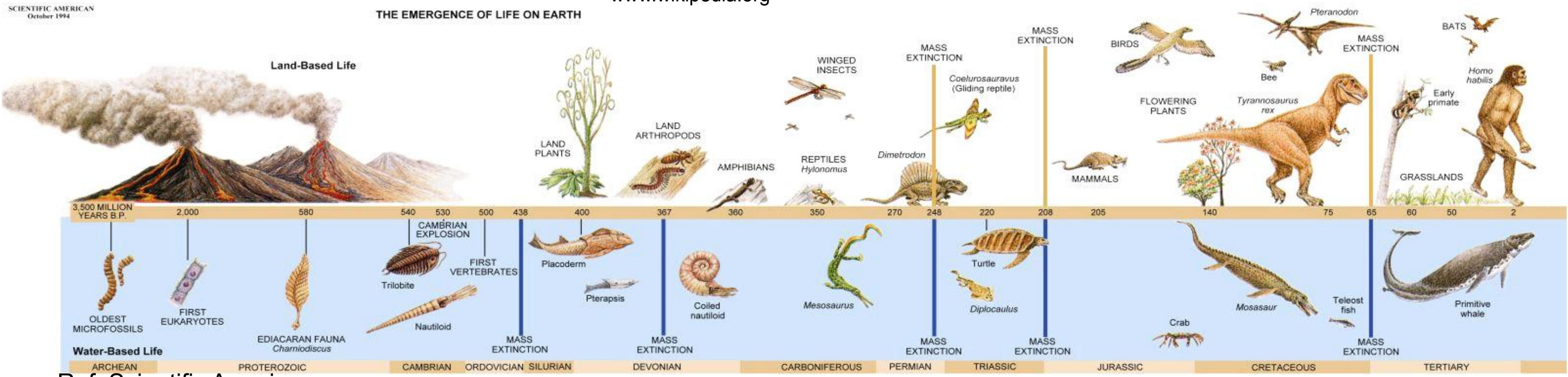
Pendahuluan

Semesta Informasi



www.wikipedia.org

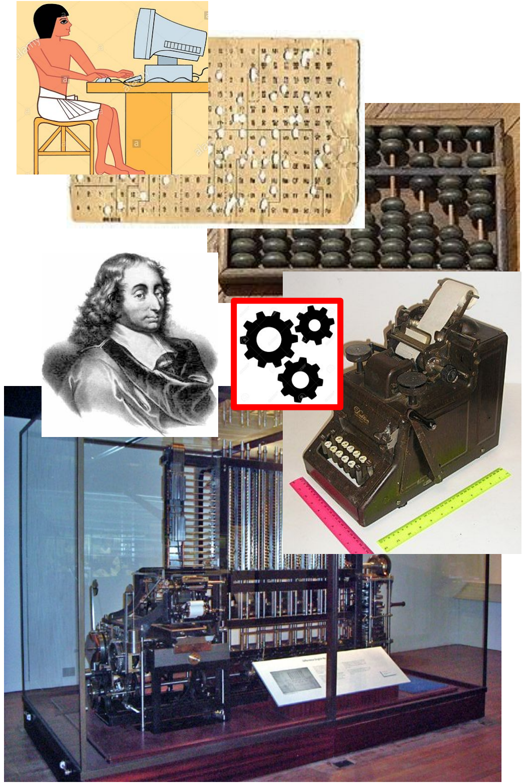
https://www.lisbdnetwork.com/information-gathering/



Ref: Scientific American

Teknologi Informasi
Kemampuan dan Keterbatasannya

Komputer: mekanik → lampu tabung → transistor



www.wikipedia.org

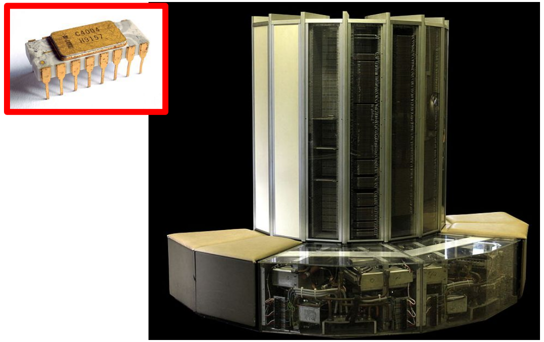
www.wikipedia.org

www.wikipedia.org

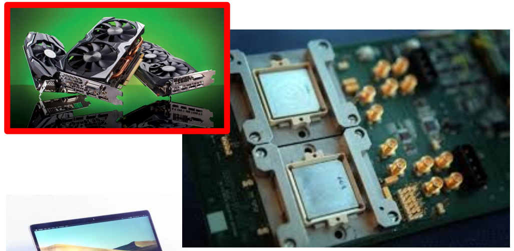
Komputer: IC →μProc→ multi-Proc, AI,GPU…

www.nobelprize.org

www.wikipedia.org

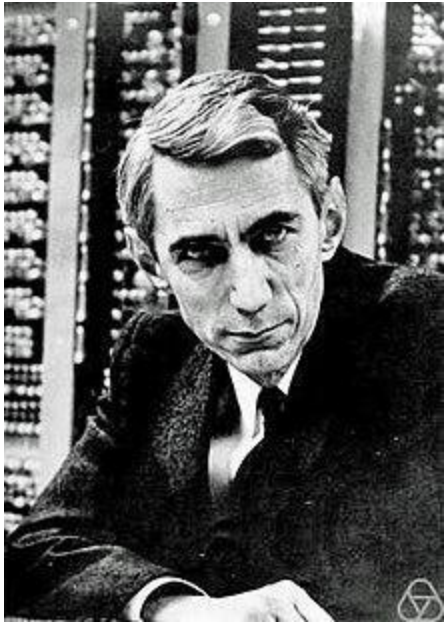


www.wikipedia.org



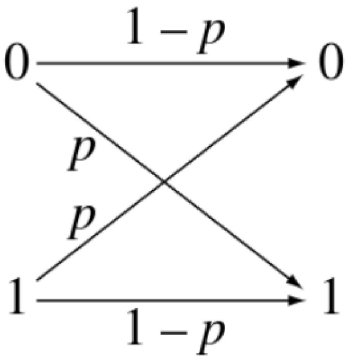
Teori Informasi

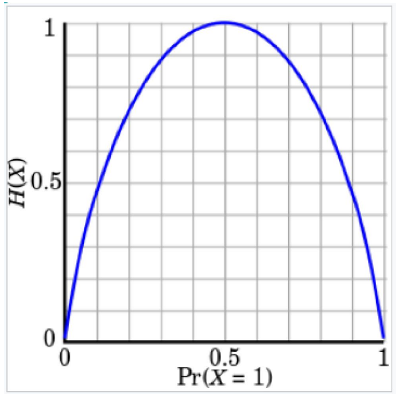
- Source coding
- Channel Coding
- Information Theory



www.wikipedia.org

Claude Shannon:
"The Mathematical Theory of Communications"

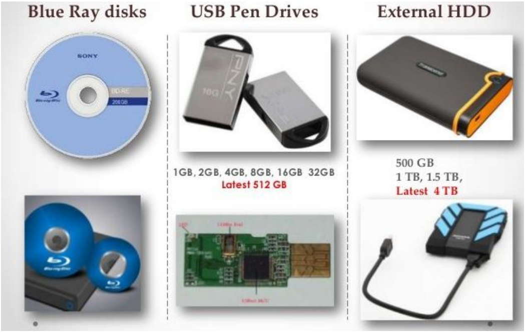




www.wikipedia.org

Teknologi Informasi

Penyimpan Informasi



Pengolah Informasi

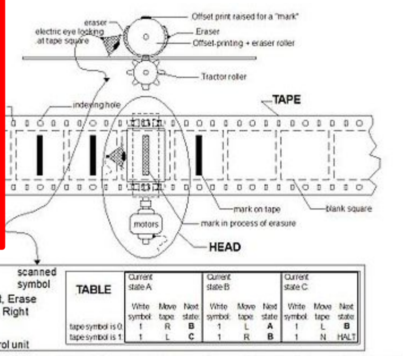
www.pinterest.com

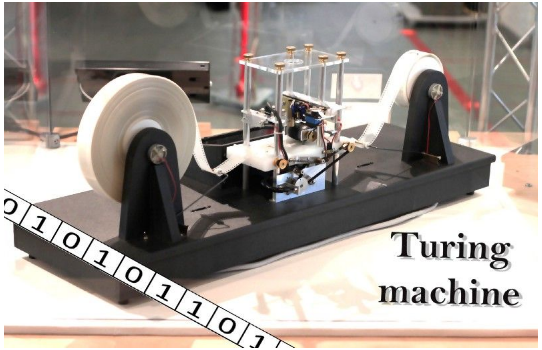
Alat Komunikasi

MesinTuring

www.bharatskills.gov.in

$\cong$



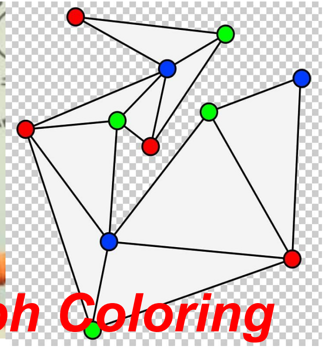


https://simple.wikipedia.org/

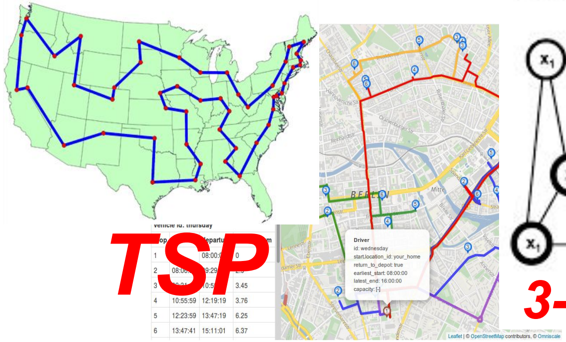
Extended Church-Turing Thesis [Bernstein-Vazirani]

"Any realistic model of computation can be efficiently simulated by (probabilistic) Turing Machine."

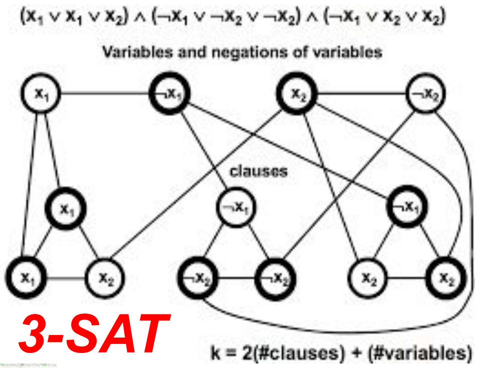
Hard Problems



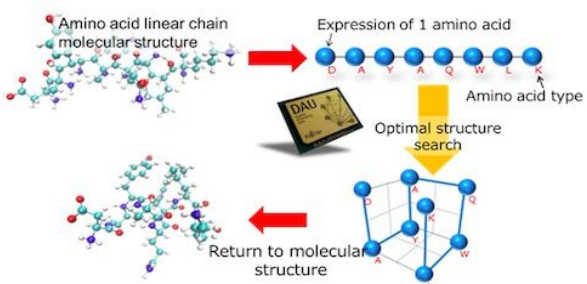
Graph Coloring



TSP



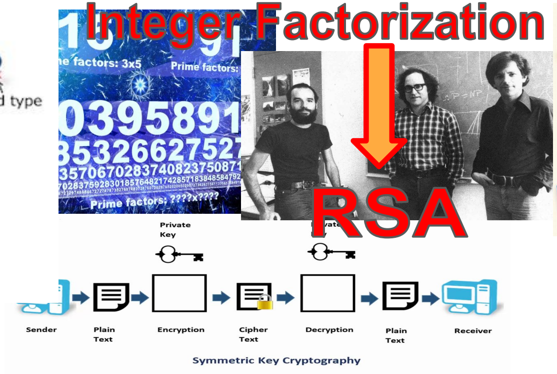
3-SAT



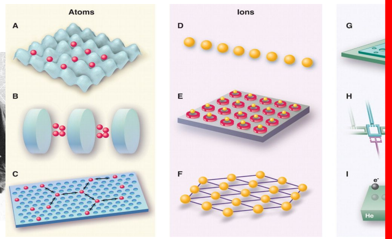
https://fujitsu.com/

Protein Folding

Integer Factorization

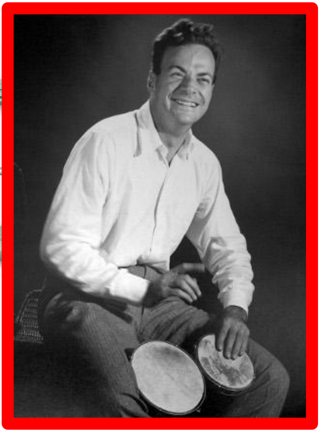


RSA



https://science.org/

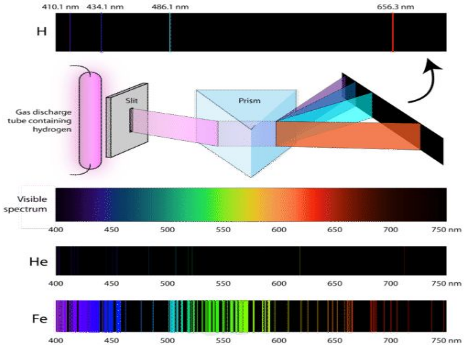
Quantum Simulation



https://cosmolearning.org/

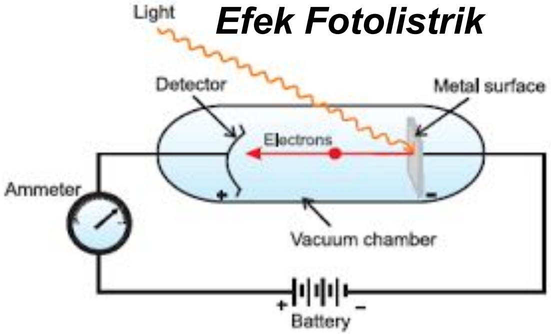
Sekilas Fisika Kuantum: Revolusi Kuantum Pertama

Mengapa Perlu Fisika Kuantum ?

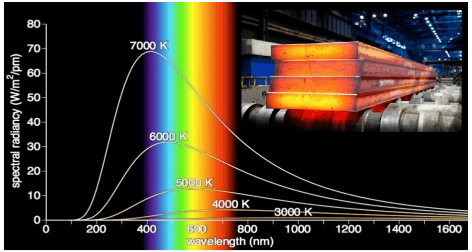


Spektrum Radiasi Atom

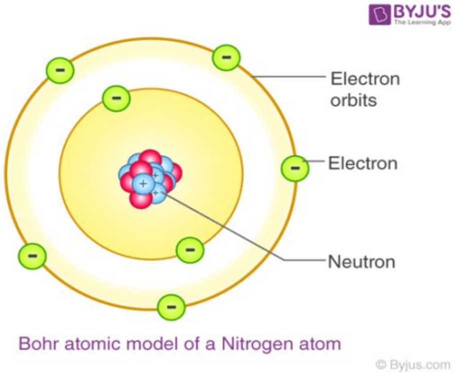
Fenomena yang tidak dapat dijelaskan dengan Fisika Klasik



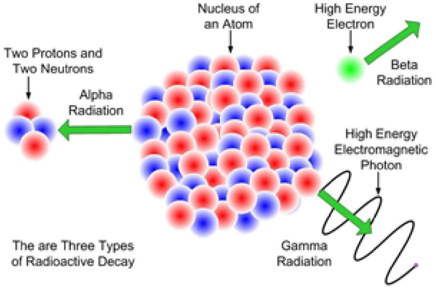
Efek Fotolistrik



Radiasi Benda Hitam

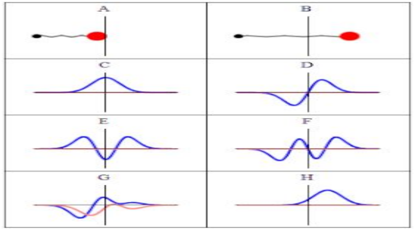


Atom yang Stabil

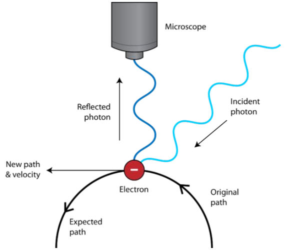


Radioaktivitas

Fondasi dan Fenomena Kuantum

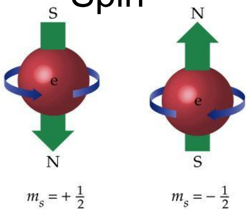


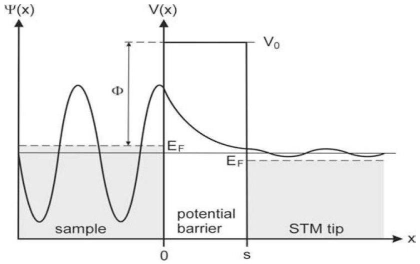
Fungsi Gelombang



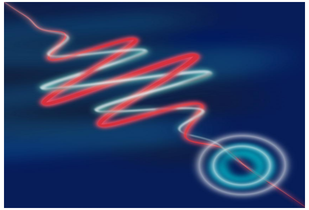
Prinsip Ketidakpastian

Spin



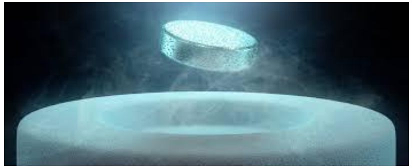


Penerobosan Kuantum

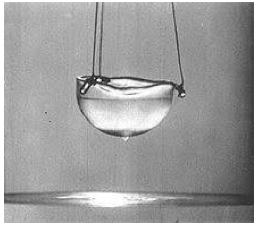


Dualitas gelombang-partikel

Interpretasi Born



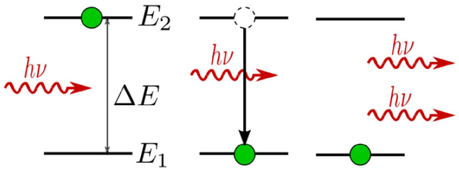
Superkonduktivitas



Superfluiditas

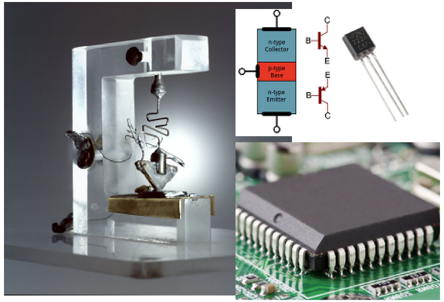
$$H(t)\,|\,\psi(t)\rangle = i\hbar\frac{d}{dt}\,|\,\psi(t)\rangle$$

Persamaan Schroedinger



Emisi terstimulasi

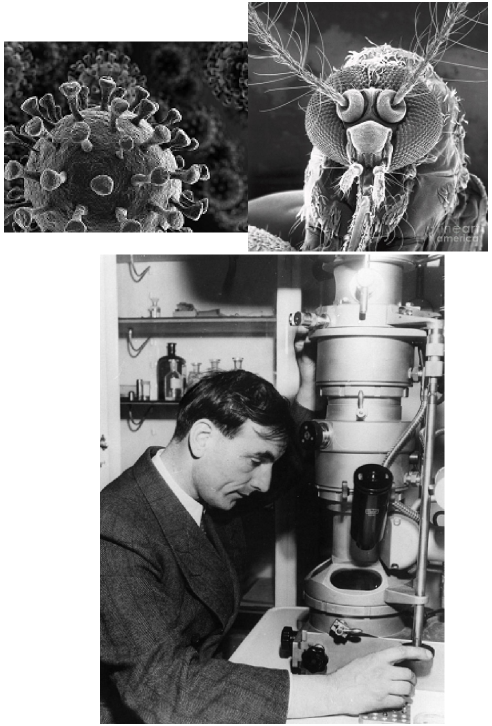
Teknologi Kuantum: Revolusi Kuantum Pertama



Divais semikonduktor
(transistor, IC, Dioda)

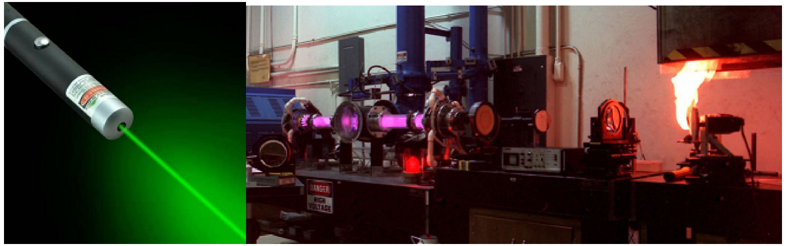
Kamera Dijital

MRI



Mikroskop Elektron

Panel Surya



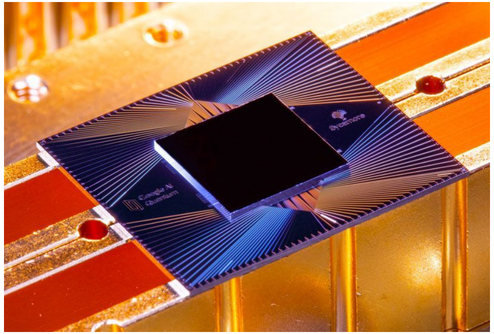
LASER

https://wikipedia.org/

Teknologi Informasi Kuantum: Revolusi Kuantum Kedua

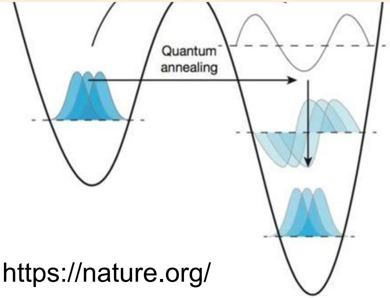
Komputasi Kuantum

https://www.techrepublic.com/

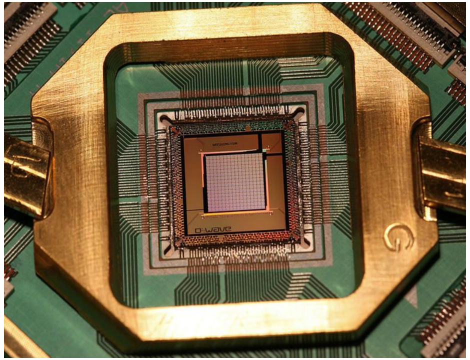


https://nytimes.com/

Quantum Annealer

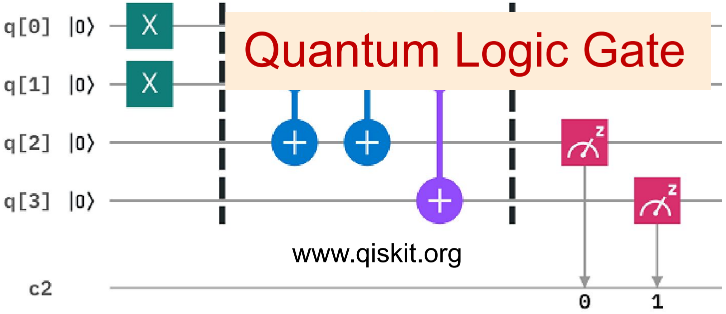


https://nature.org/



https://dwave.com/

Quantum Logic Gate



www.qiskit.org

Supremasi Kuantum

Article

Quantum supremacy using a programmable superconducting processor

https://doi.org/10.1038/s41586-019-1666-5

Received: 22 July 2019

Accepted: 20 September 2019

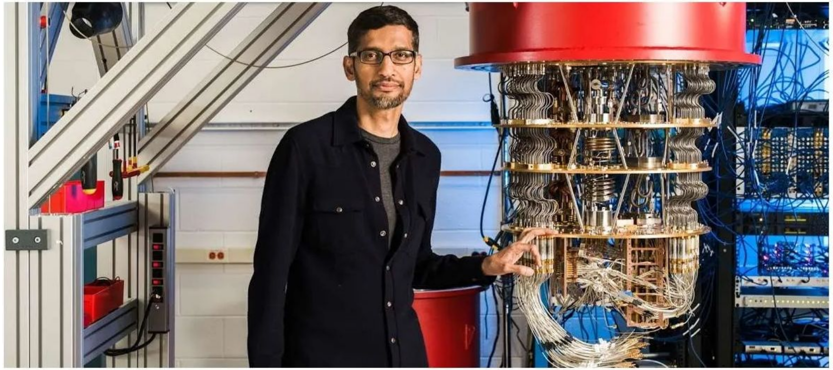
Published online: 23 October 2019

nature

Frank Arute[1], Kunal Arya[1], Ryan Babbush[1], Dave Bacon[1], Joseph C. Bardin[1,2], Rami Barends[1], Rupak Biswas[3], Sergio Boixo[1], Fernando G. S. L. Brandao[1,4], David A. Buell[1], Brian Burkett[1], Yu Chen[1], Zijun Chen[1], Ben Chiaro[5], Roberto Collins[1], William Courtney[1], Andrew Dunsworth[1], Edward Farhi[1], Brooks Foxen[1,5], Austin Fowler[1], Craig Gidney[1], Marissa Giustina[1], Rob Graff[1], Keith Guerin[1], Steve Habegger[1], Matthew P. Harrigan[1], Michael J. Hartmann[1,6], Alan Ho[1], Markus Hoffmann[1], Trent Huang[1], Travis S. Humble[7], Sergei V. Isakov[1], Evan Jeffrey[1],

The promise of quantum computers is that certain computational tasks might be executed exponentially faster on a quantum processor than on a classical processor[1]. A fundamental challenge is to build a high-fidelity processor capable of running quantum algorithms in an exponentially large computational space. Here we report the use of a processor with programmable superconducting qubits[2–7] to create quantum states on 53 qubits, corresponding to a computational state-space of dimension 2^{53} (about 10^{16}). Measurements from repeated experiments sample the resulting probability distribution, which we verify using classical simulations. Our Sycamore processor takes about 200 seconds to sample one instance of a quantum circuit a million times—our benchmarks currently indicate that the equivalent task for a state-of-the-art classical supercomputer would take approximately 10,000 years. This dramatic increase in speed compared to all known classical algorithms is an experimental realization of

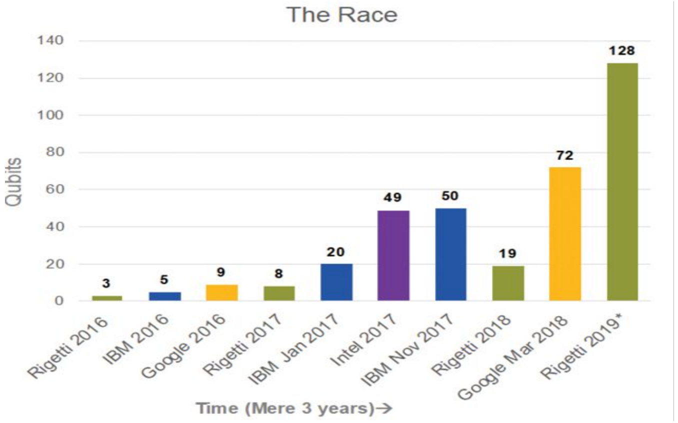
www.youtube.com

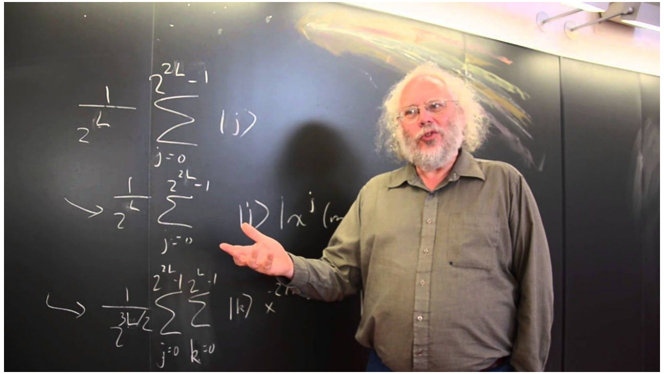


www.wired.com

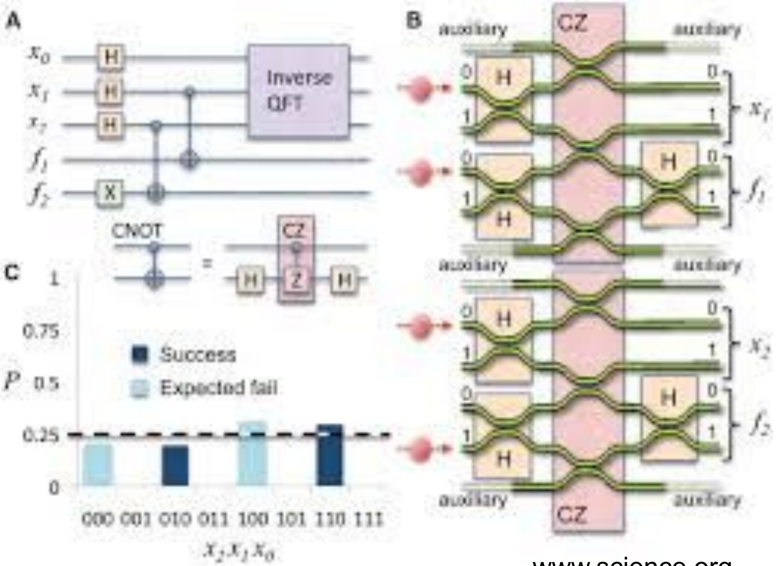
200 seconds in Sycamore
~ 10,000 years in a Supercomputer
Menyanggah *Extended Church-Turing Thesis*

Implikasi





www.youtube.com

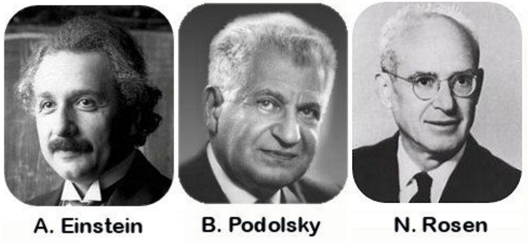


www.science.org

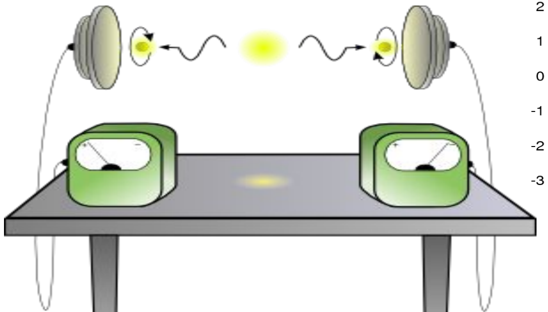
Algoritma Shor

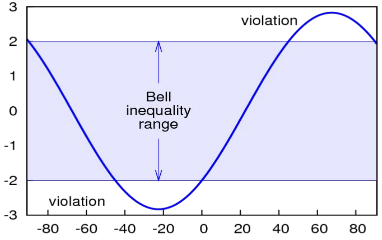
Pemfaktoran Bilangan

Kriptografi Pasca-Kuantum

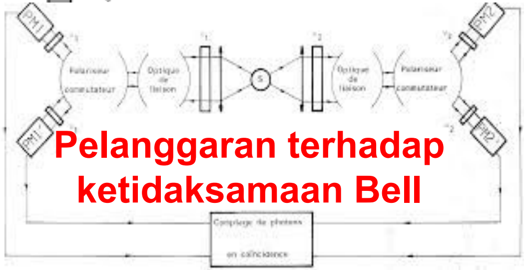


Paradoks EPR

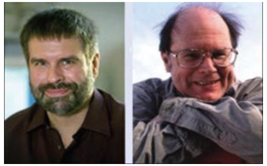




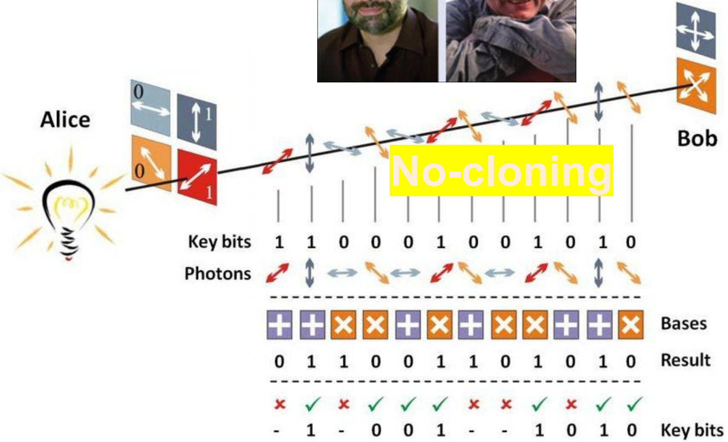
A.Aspect



Pelanggaran terhadap ketidaksamaan Bell

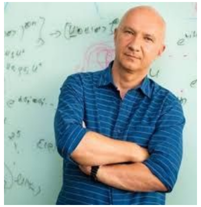


BB84

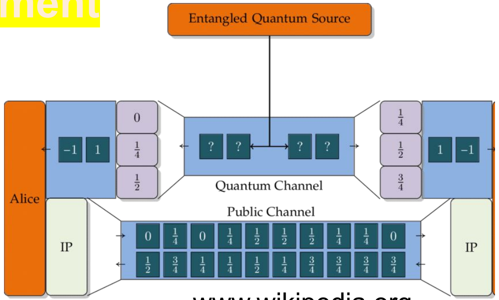


No-cloning

Entanglement

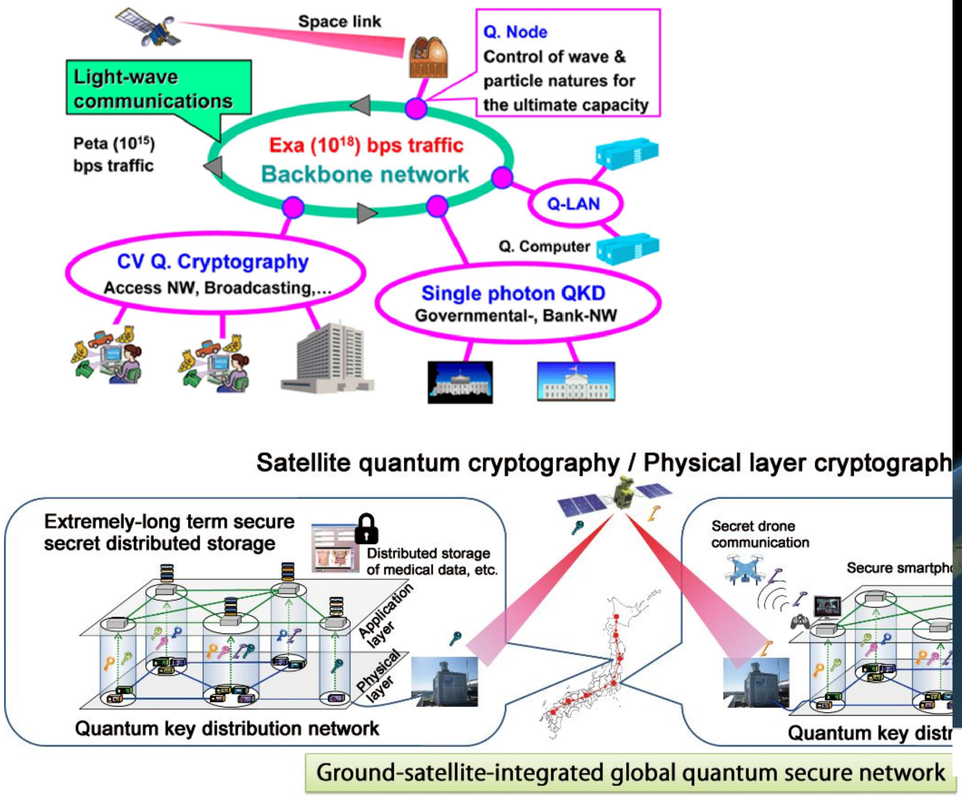


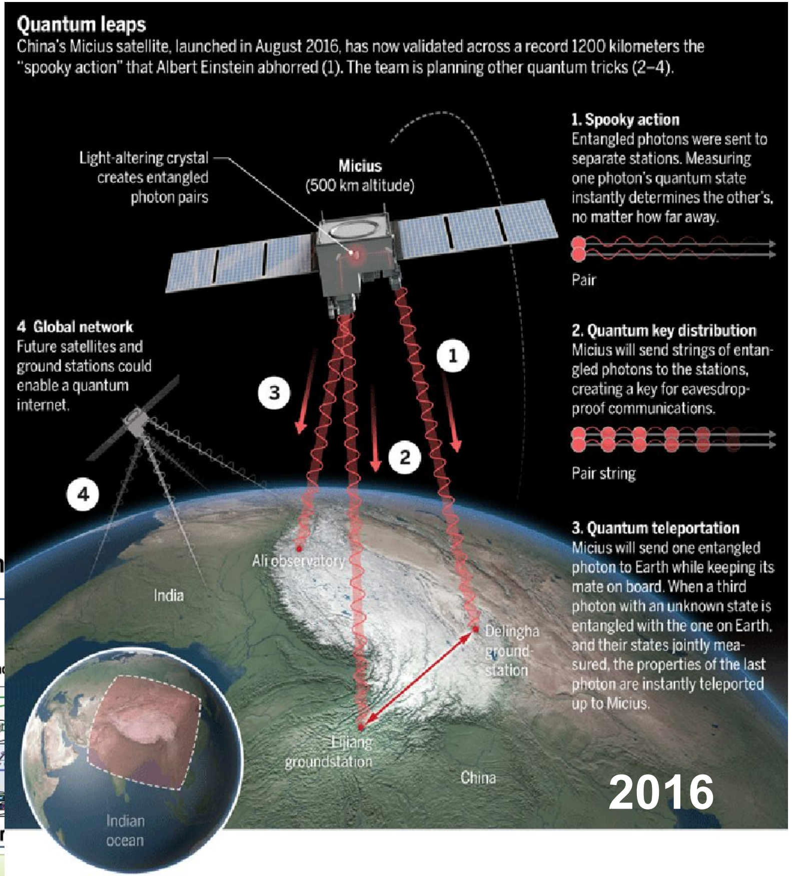
E91



www.wikipedia.org

Satelit Kuantum



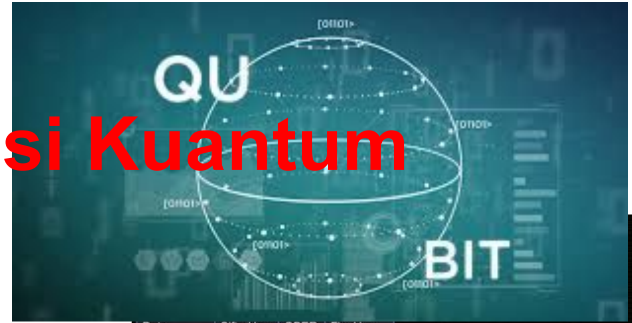


https://www.science.org/content/article/china-s-quantum-satellite-achieves-spooky-action-record-distance

- Sumber: NICT (Jepang)

Sektor Teknologi dalam Revolusi Kuantum Kedua

Komputasi Kuantum



Komunikasi Kuantum

Penginderaan Kuantum

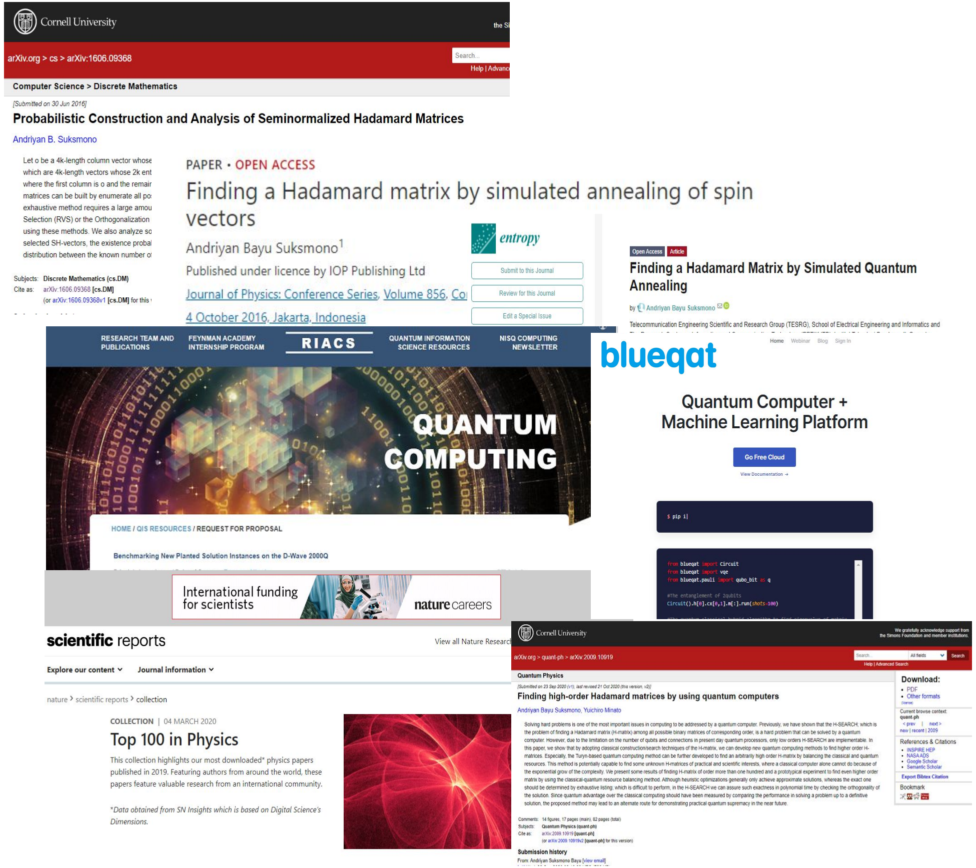
Inisiatif Pengembangan Teknologi Kuantum di STEI-ITB

… toward practical quantum supremacy

Lingkup Kegiatan

Pencarian matriks biner orthogonal (Hadamard)

- Teknik Spin Vector: JoP, 2017
- Proposal to RIACS/USRA
- Kerjasama dengan MDR Inc./ Bluеqat Inc., Tokyo
    - Sci.Rep 2019: 100 in Physics, 2019 (ranked 8).
    - Sci.Rep. 2022: H-92 and beyond
- Pendirian Lab. Teknologi Kuantum STEI, 2021.

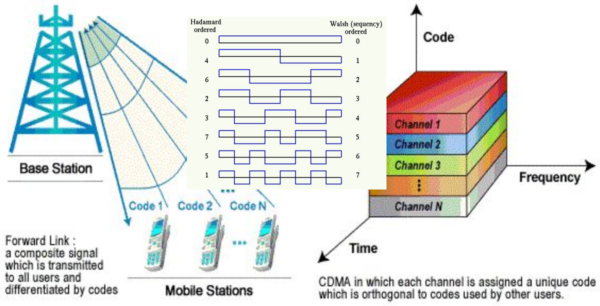


Tentang Matriks Hadamard

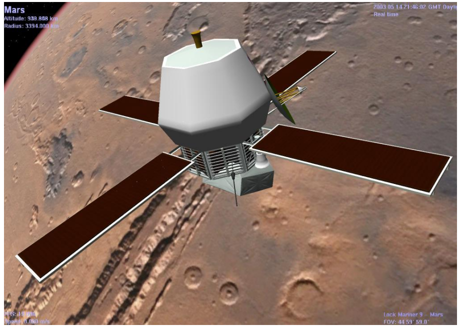
- **Definisi**: orthogonal binary {-1,1} matrix
- **Aplikasi**: orthogonal codes pada CDMA, ECC (Error Correction Code) with maximal error correction capability, employed in Mariner-9
- **Sains/Matetika**: H-matrix conjecture: ~100 years old unsolved problem

Mengapa menemukan H-matrix itu sulit?

- Untuk M-order matrix, ada
  - [2^(M^2)] ~ exp (M^2) matriks biner.
- Ramalan H-matrix **conjecture**: "... there is a H-matrix for every M=4k, k positive integer."
- Bagaimana menemukannya?
- >>Brute force, worst-case: periksa semua matriks biner, kompleksitas O[exp(M^2)] --> **a hard problem**.
- **>>Usulan Solusi: Gunakan Komputer Kuantum !**

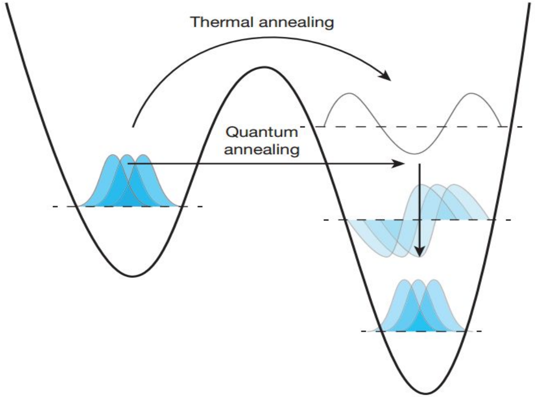


CDMA Communication System employs Walsh-Hadamard Orthogonal Code



Mariner-9 employed Hadamard's ECC to protect Mars's images sent to Earth

Quantum Annealing



[Source: *Nature*, Biamonte 2017]

$$\hat{H}_{QA}(\hat{\sigma}, t) = \left(1 - \frac{t}{\tau}\right)\hat{H}_{kin}(\hat{\sigma}) + \frac{t}{\tau}\hat{H}_{pot}(\hat{\sigma})$$

$$\hat{H}_{pot}(\hat{\sigma}) \equiv -\sum J_{ij}\hat{\sigma}_i^z\hat{\sigma}_j^z - \sum_i h_i\hat{\sigma}_i^z$$

$$\hat{H}_{kin}(\hat{\sigma}) \equiv -\Gamma\sum_i \hat{\sigma}_i^x$$

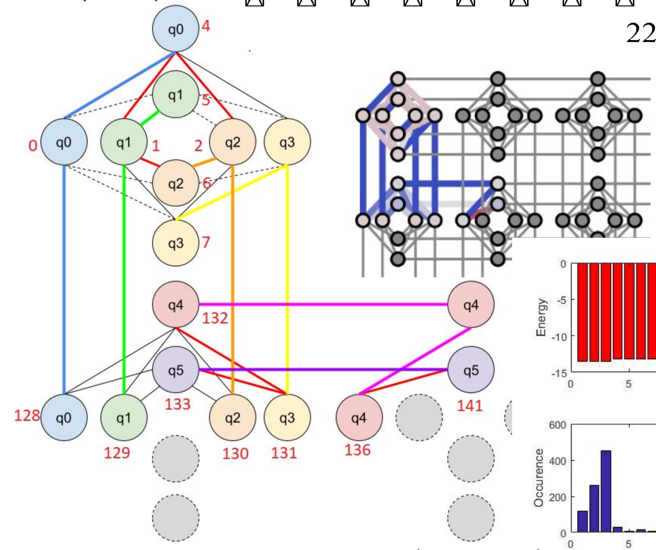
Quantum Annealer

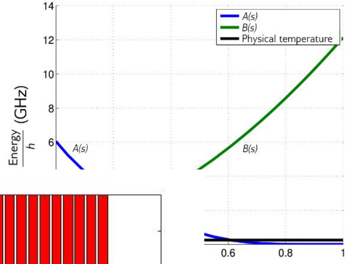
Source: D-Wave Systems

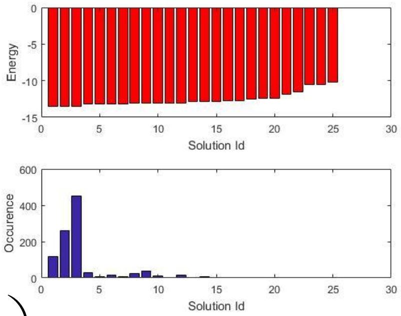
Eksperimen dengan DW2000Q

- **2-order H-matrix**

$$\hat{H}_2\left(\hat{\sigma}_i^z\right) = \underbrace{28 + 6\hat{\sigma}_0^z + \ldots - 12\hat{\sigma}_5^z + 2\hat{\sigma}_0^z\hat{\sigma}_1^z + \ldots + 8\hat{\sigma}_4^z\hat{\sigma}_5^z}_{22-terms}$$





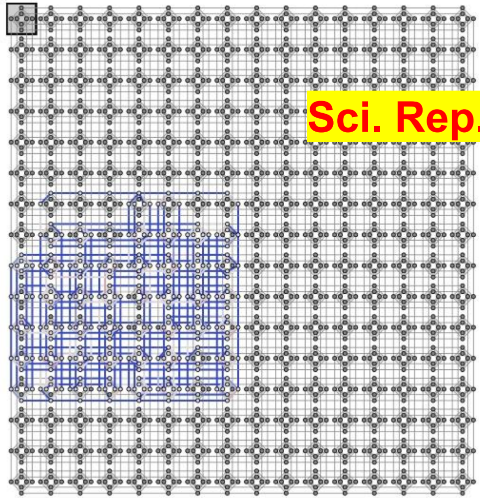


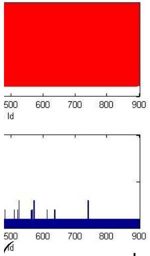
Minimum energy
E = -13.52

$$\begin{pmatrix} + & - \\ - & - \end{pmatrix}$$

- **Finding 4-order H-matrix**

Sci. Rep. 2019



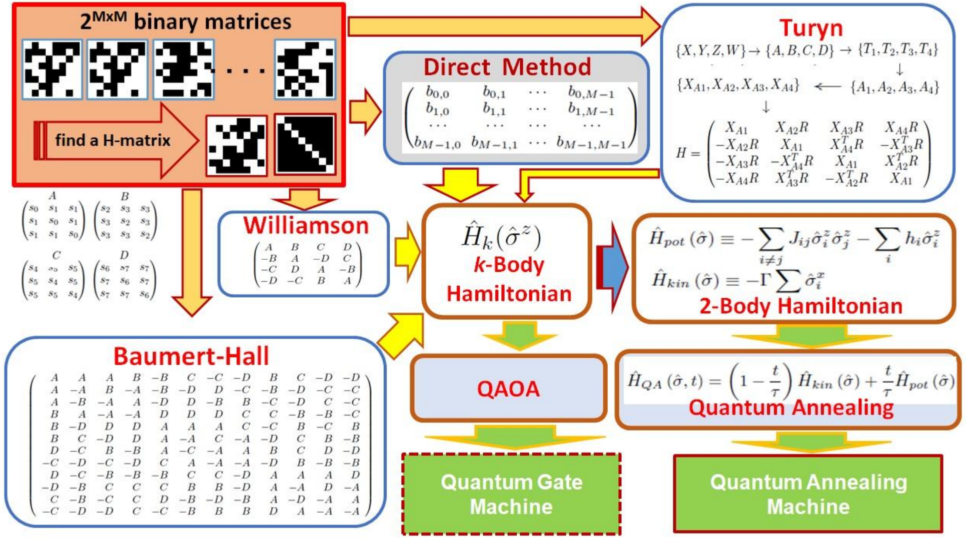


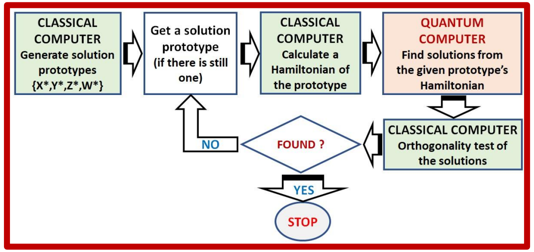
Minimum energy, E= -322.91

$$\begin{pmatrix} - & - & + & + \\ + & - & + & - \\ - & - & - & - \\ - & + & + & - \end{pmatrix}$$

$$\hat{H}_2\left(\hat{\sigma}_i^z\right) = \underbrace{1{,}248 + 66\hat{\sigma}_0^z + \ldots - 44\hat{\sigma}_{39}^z + 6\hat{\sigma}_0^z\hat{\sigma}_1^z + \ldots + 8\hat{\sigma}_{38}^z\hat{\sigma}_{39}^z}_{389-terms}$$

Perkembangan terkini: (1) H-matrix orde tinggi

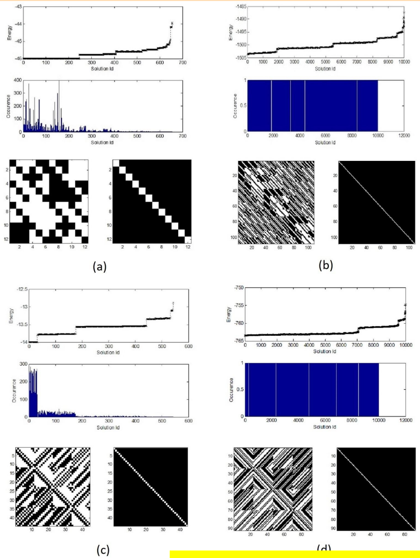




Balancing Classical-Quantum Resources

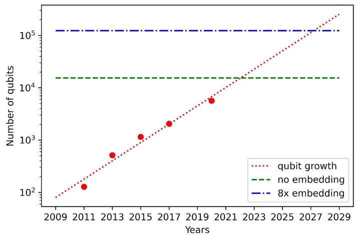
Discovery of 92-order H-Matrix

- **1961 by JPL; IBM Mainframe**
- **2020 by STEI; DW2000Q**

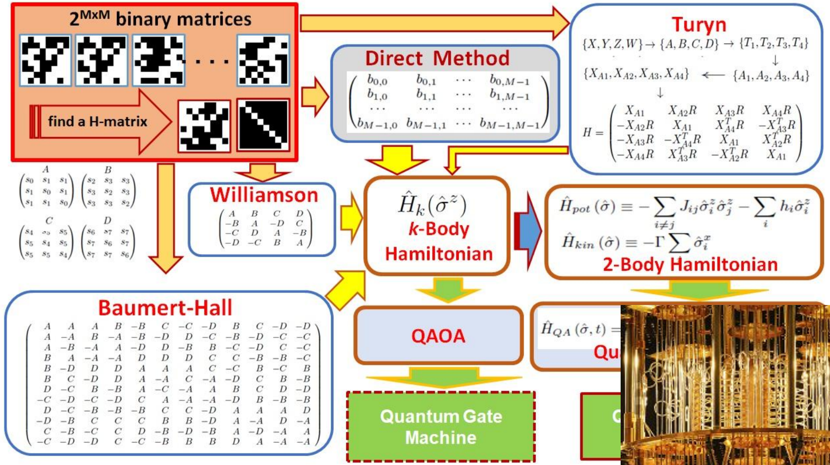


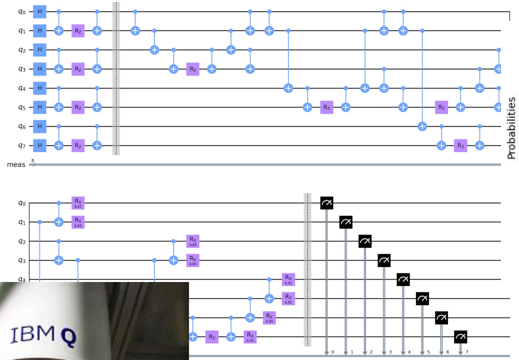
Sci. Rep. 2022

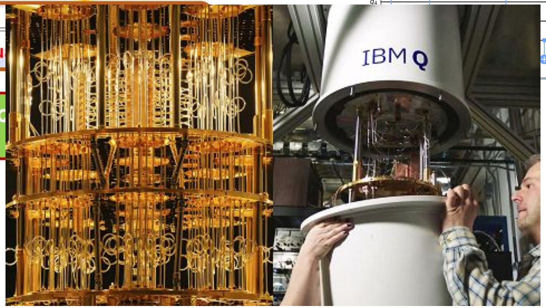
https://www.jpl.nasa.gov/

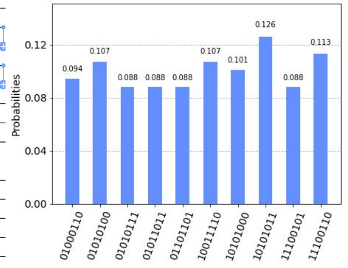


Perkembangan terkini: (2) H-matrix Search via QAOA

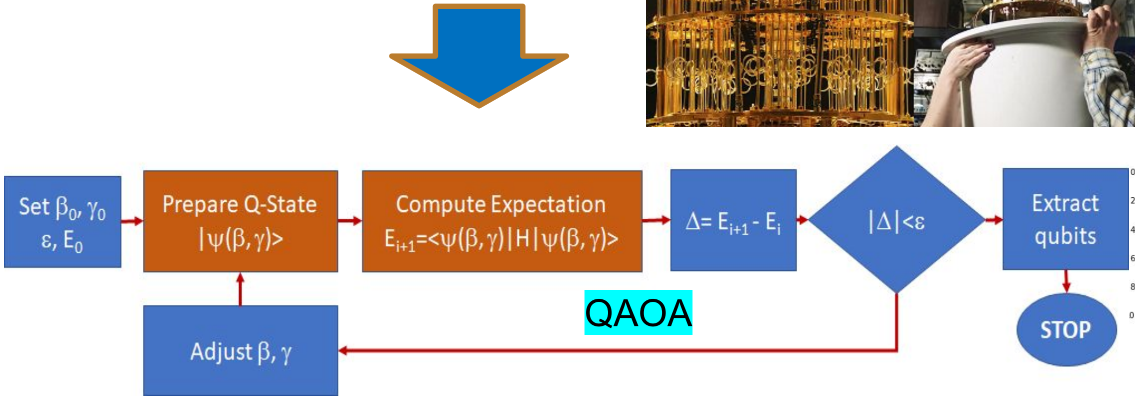




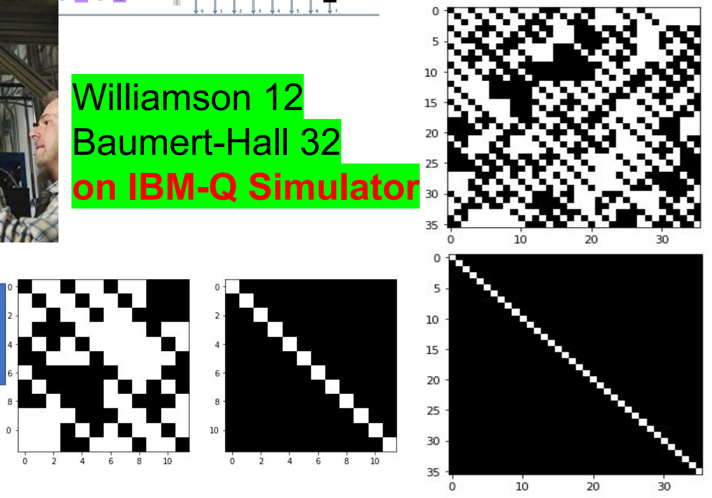




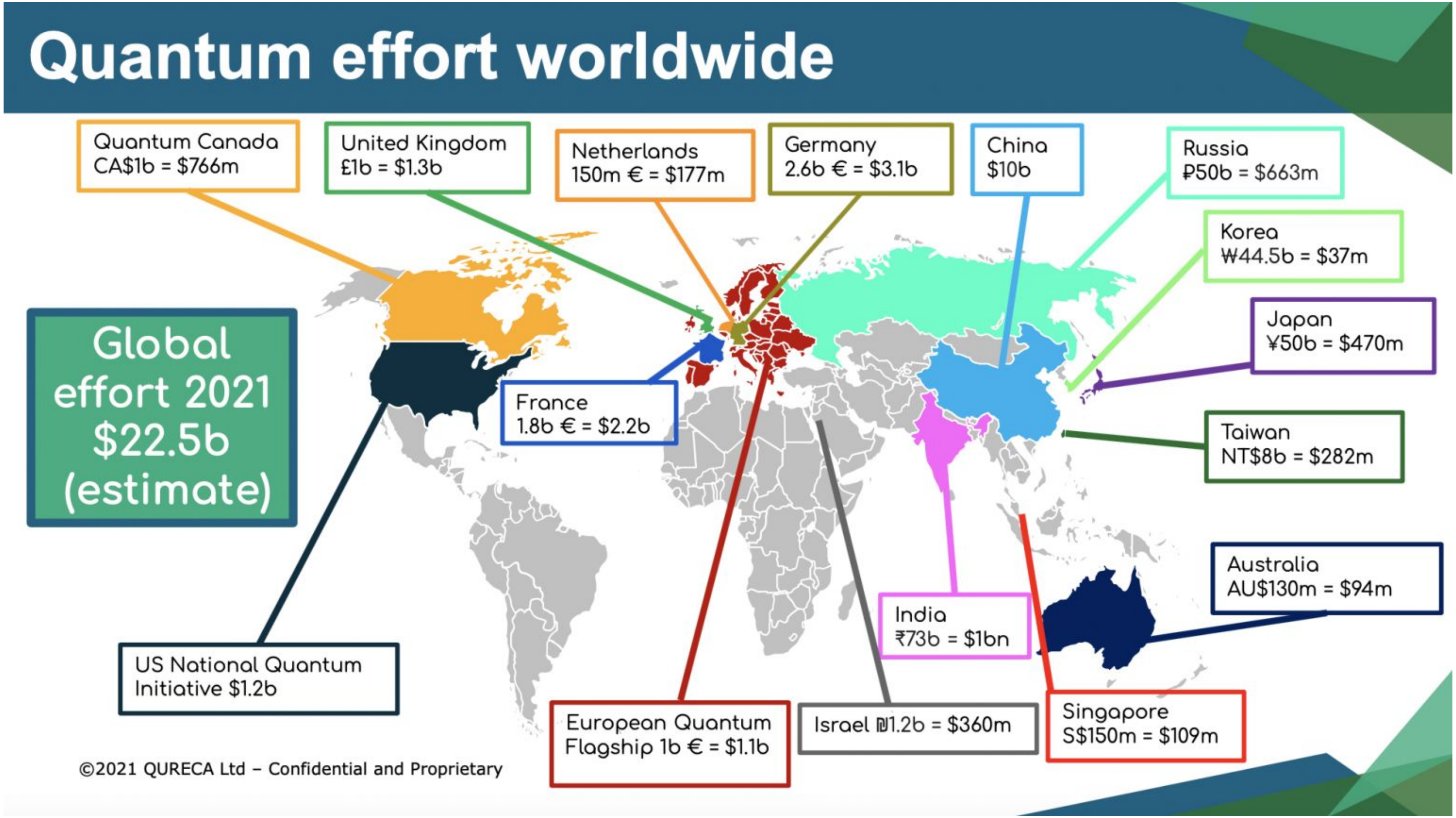
Williamson 12
Baumert-Hall 32
on IBM-Q Simulator



QAOA



Issue Penting, Tantangan, dan Peluang

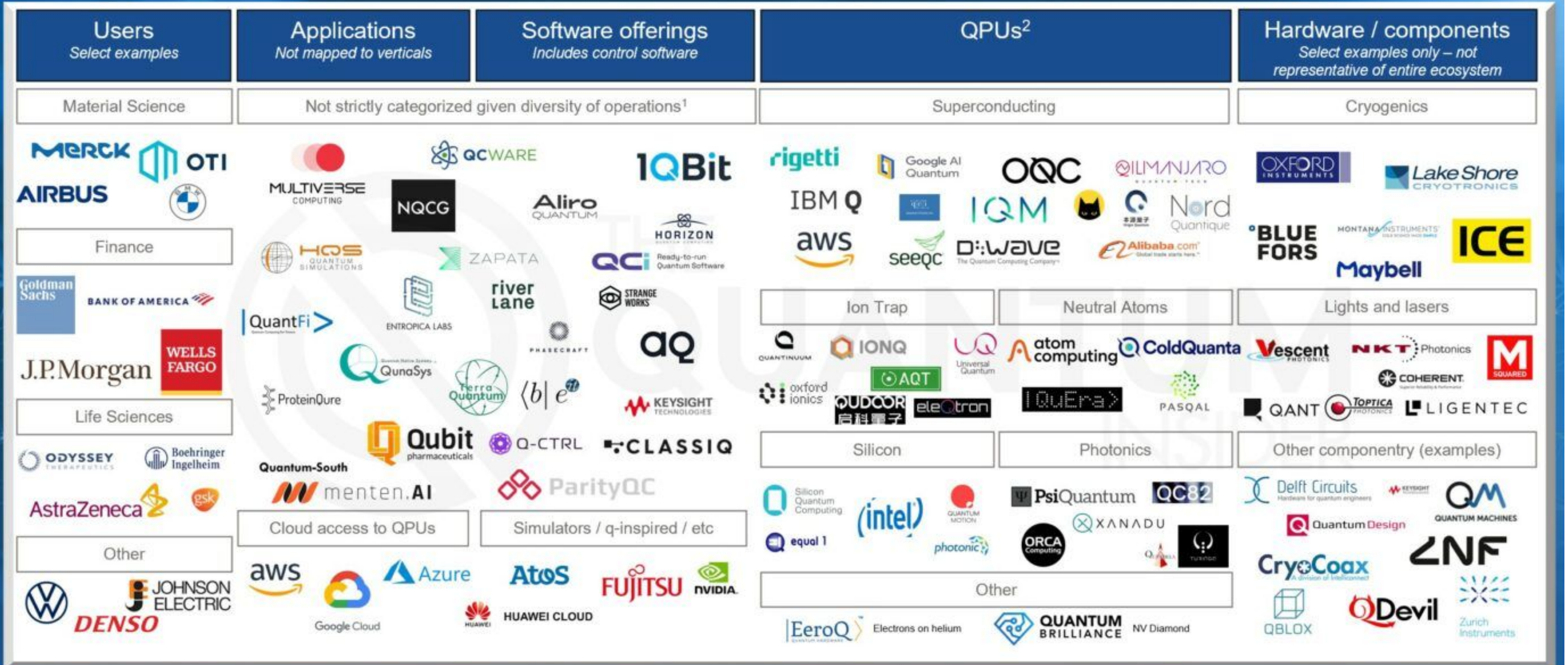


https://qureca.com/overview-on-quantum-initiatives-worldwide/

THE QUANTUM INSIDER

Quantum Computing Market Map

Non exhaustive and in no particular order. Excludes details on control systems, assembly languages, circuit design, etc.



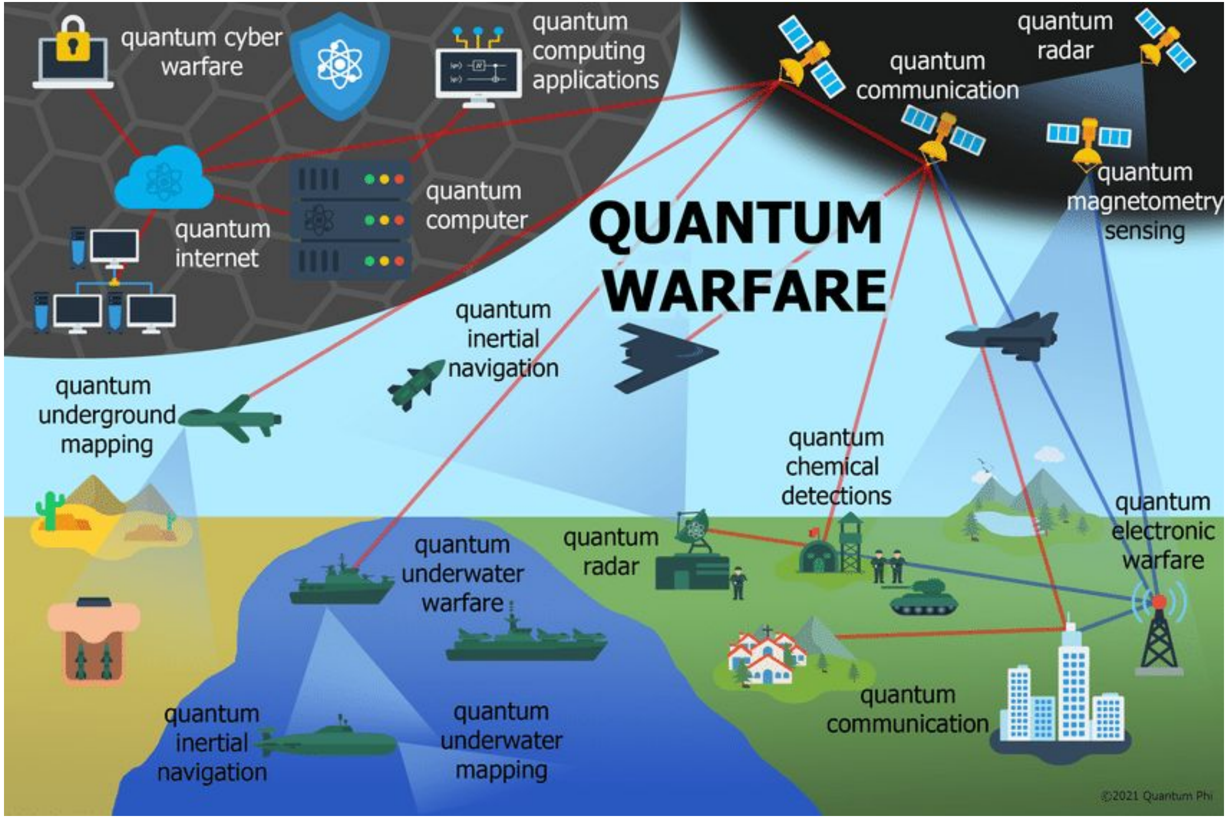
[1] Software offerings can be further classified into SDKs, firmware / enablers, algorithms / applications, simulators etc. but many companies are offering a mixture across the stack

[2] Many QPU providers are offering full stack services (e.g. Pasqal acquired Qu&Co, Quantinuum was originally CQC prior to merger with HQS, etc.

Perang Kuantum

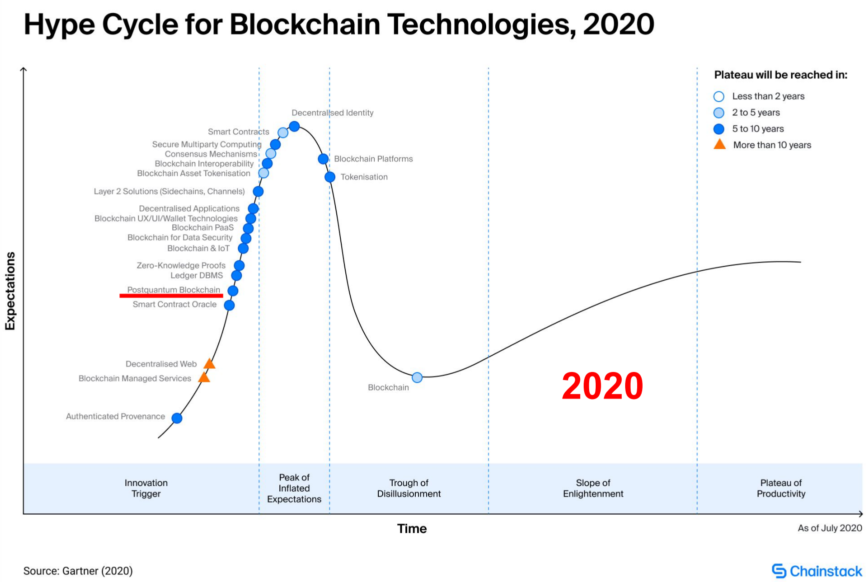
Quantum Doomsday
(Cryptographic Quantum Apocalypse)

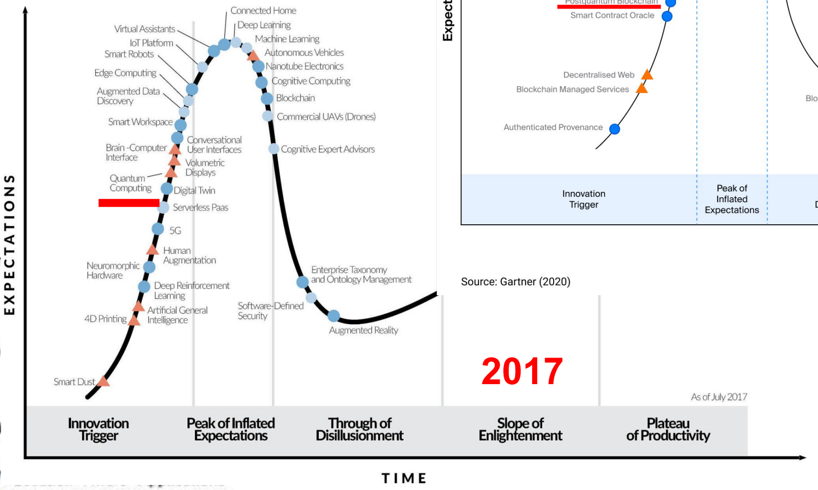
- Algoritma Shor terimplementasi
- Persandian RSA (+kurva eliptik) runtuh
- Password, pesan rahasia, data-data (financial, pemerintahan, ...) terancam.

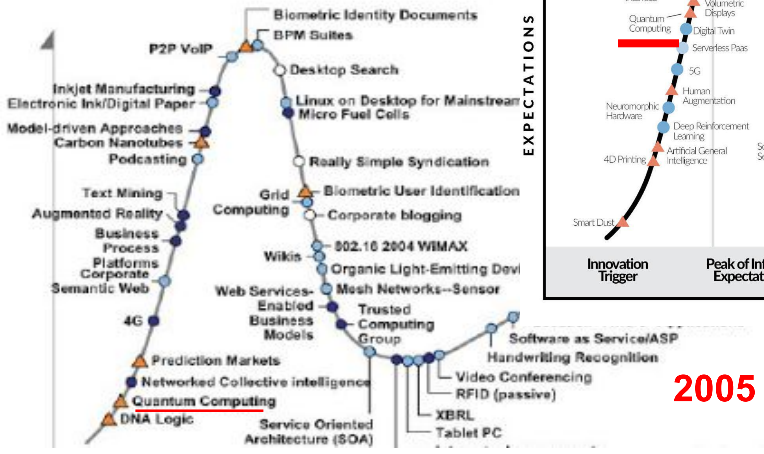


https://www.researchgate.net/figure/Sketch-of-quantum-warfare-utilizing-various-quantum-technology-systems_fig1_350341569

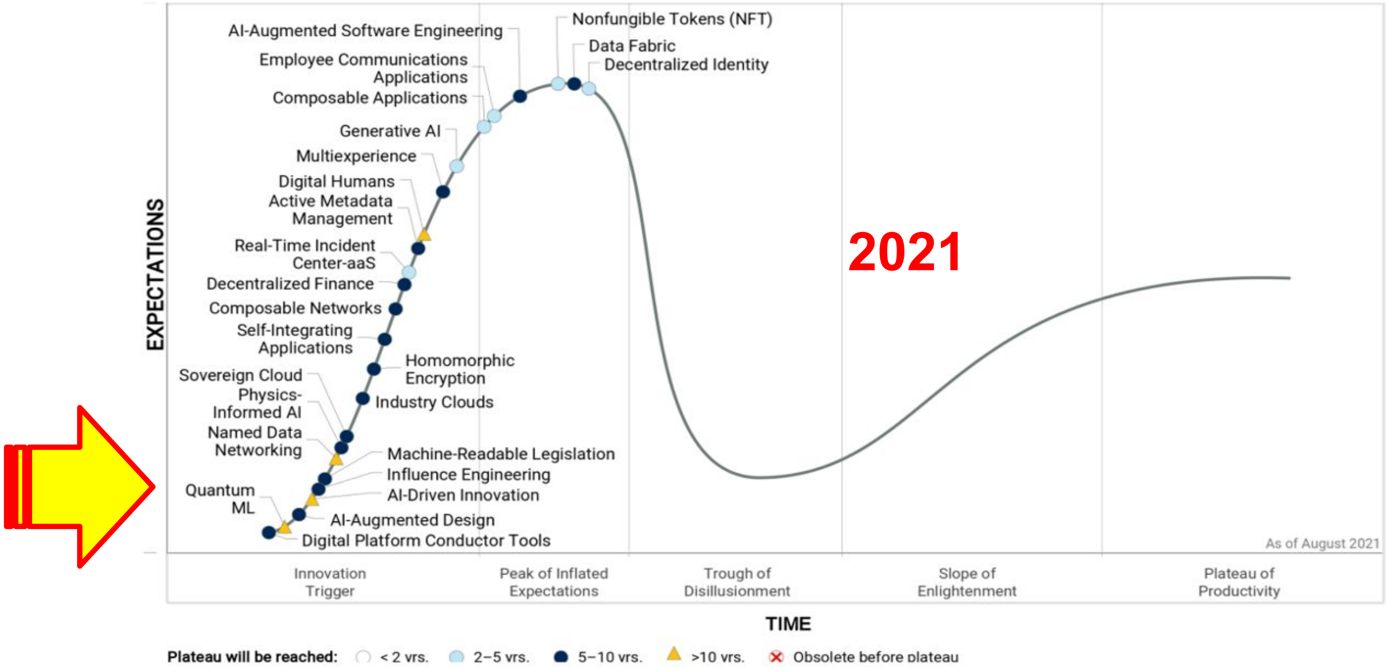
Gartner's Hype Cycle







Peluang



Source: Gartner (August 2021)

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Terimakasih