INSTITUTO DE PESQUISAS TECNOLÓGICAS

COMUNICAÇÃO TÉCNICA

Nº 179799

Princípio da computação quântica

Elisa Morande Sale

Palestra apresentada para SEBRAE e IPT. 42 slides.

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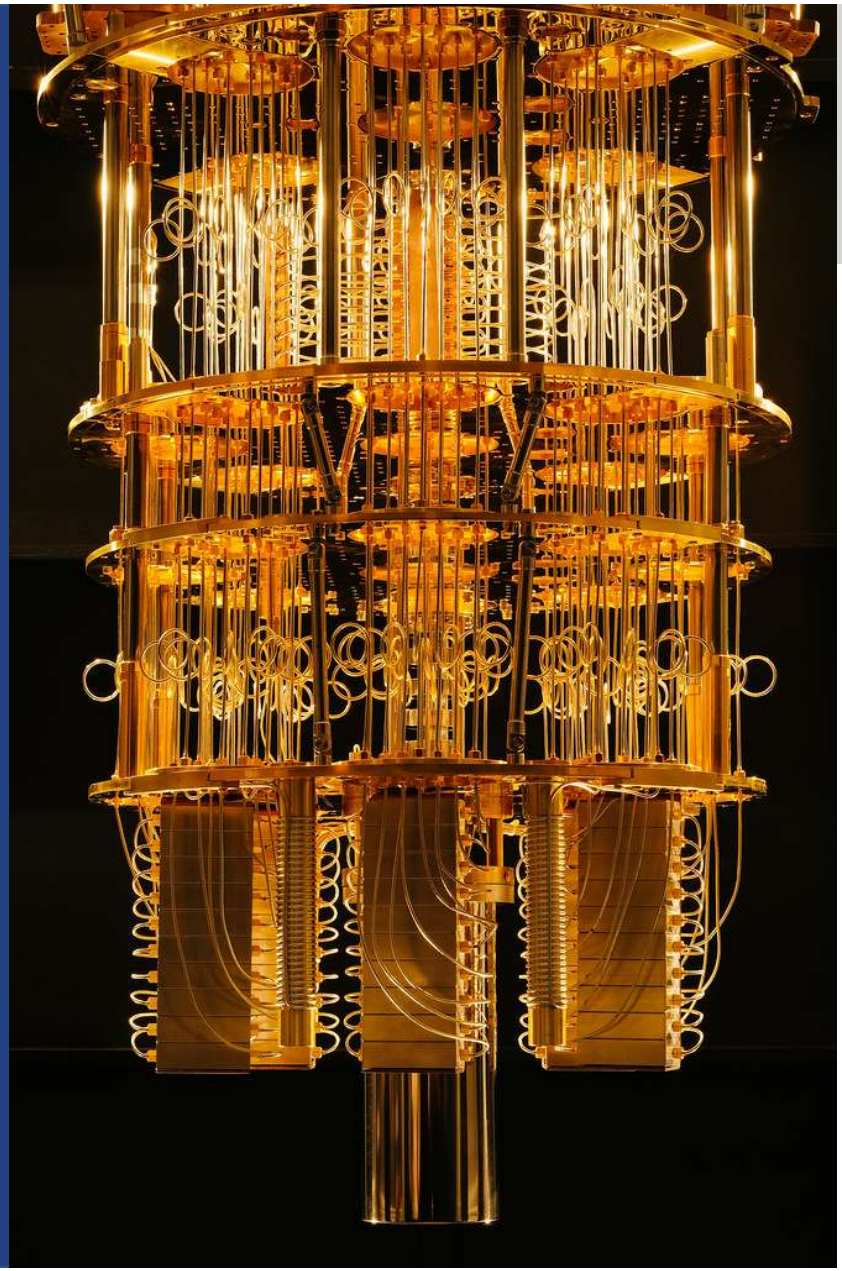
INSTITUTO DE PESQUISAS TECNOLÓGICAS

PRINCÍPIOS DA COMPUTAÇÃO QUÂNTICA

Elisa Morandé Sales
Seção de Inteligência Artificial e Analytics
29.08.25

SÃO PAULO GOVERNO DO ESTADO

COMPUTAÇÃO QUÂNTICA



POR QUE FALAR NISSO?

ipt

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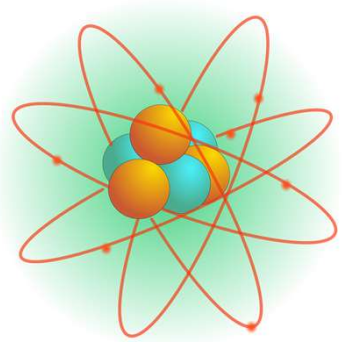
COMPUTADORES QUÂNTICOS USAM A FÍSICA QUÂNTICA

O que é a física quântica?

- Fenômenos na escala atômica e subatômica



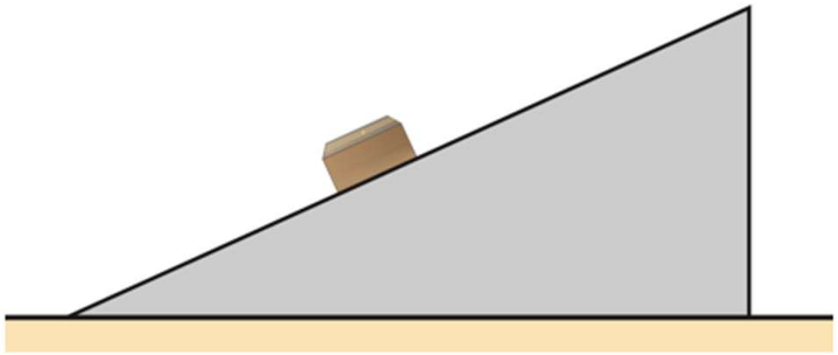
- Menos intuitiva que a física clássica
- Conceitos importantes para a computação quântica:
  - Superposição
  - Entrelaçamento
  - Interferência

QUANTUM

Quantum

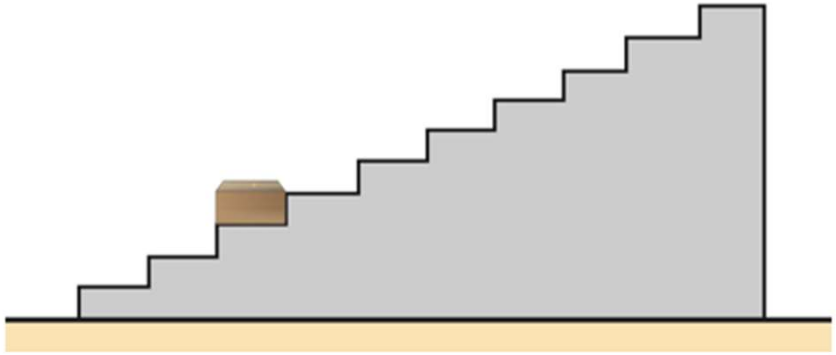
Quantidade mínima de energia da qual as outras quantidades são múltiplas

Como se fossem “centavos” de energia



Inicialmente pensava-se que energia era uma grandeza contínua

Mas Planck disse que energia é “quantizada”



REVOLUÇÕES QUÂNTICAS

first quantum revolution

manipulating

groups of quantum particles

photons, electrons and atoms interactions

transistors, lasers, fiber optics, GPS

photovoltaic cells, atom clocks

medical imaging, digital photography and video

LEDs, LCD TV quantum dots

second quantum revolution

manipulating

superposition and **entanglement**

and/or **individual particles**

quantum computing

quantum telecommunications

quantum cryptography

quantum sensing

https://www.oezratty.net/wordpress/2024/understanding-quantum-technologies-2024/

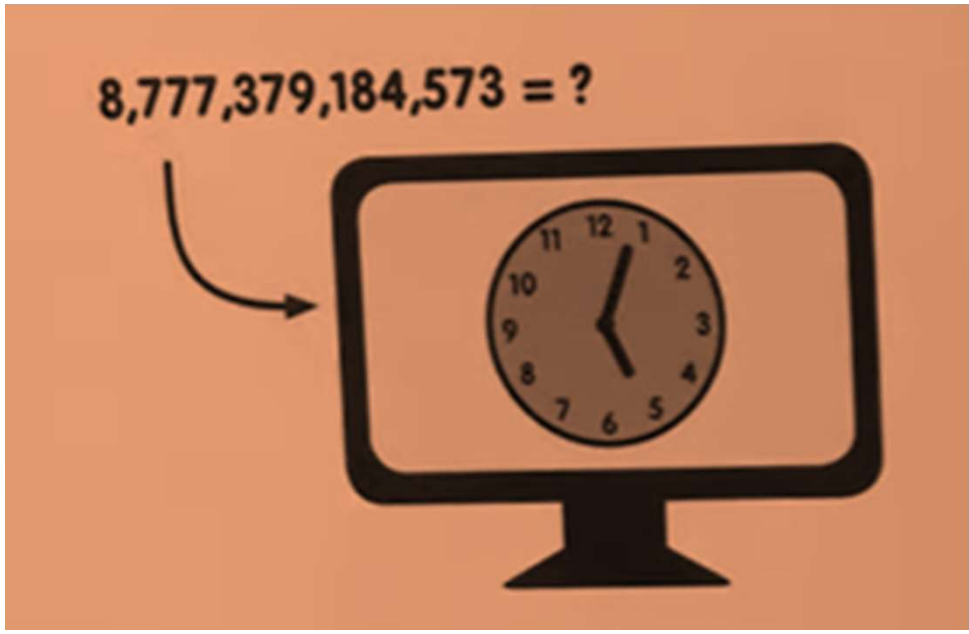
QUANDO É VANTAJOSO?

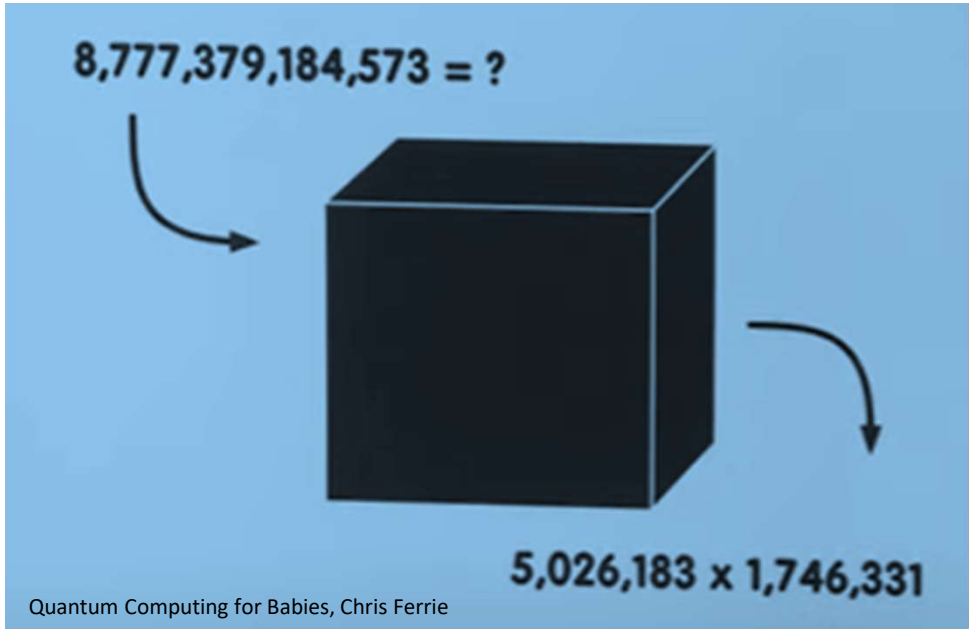
- Quando o problema é **muito demorado** (ou até não factível) em computadores clássicos

Exemplos:

  - fatorar números enormes
  - simular moléculas

- Quando há um **algoritmo quântico** que consegue atacar esse problema de forma mais eficiente





Quantum Computing for Babies, Chris Ferrie

QUANDO É VANTAJOSO?

Quantidade de operações

Clássico

$2^{42/2} = 2\ 097\ 152$

$2^{4096/2} = 3{,}2 \times 10^{616}$

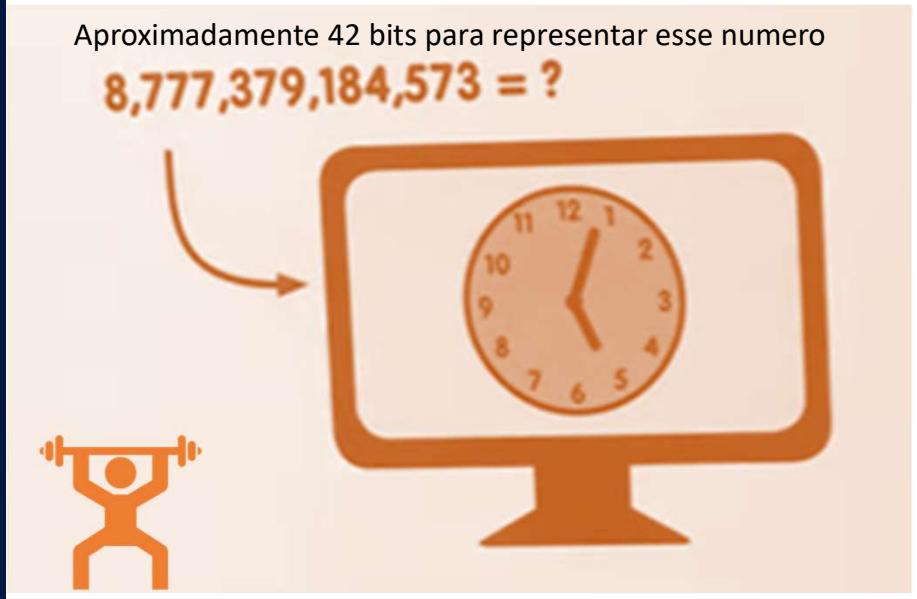
Quântico

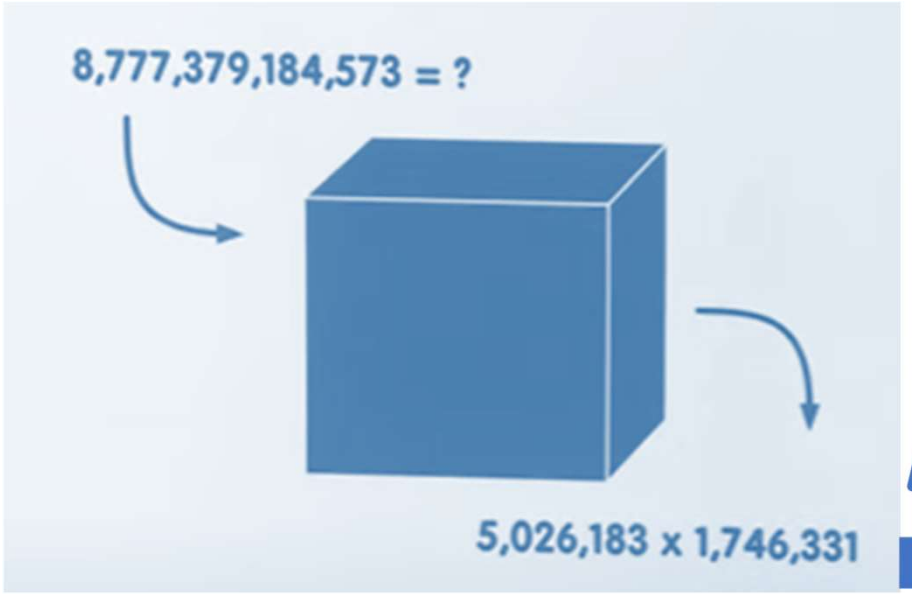
$42^3 = 74\ 088$ -> 3,5%

$4096^3 = 68\ 719\ 476\ 736$

4096 Bits em alguns serviços criptografados

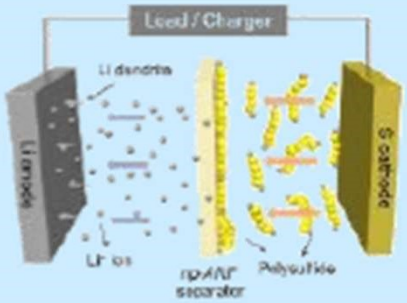
Aproximadamente 42 bits para representar esse numero



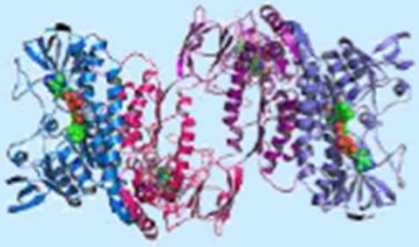


Quantum Computing for Babies, Chris Ferrie

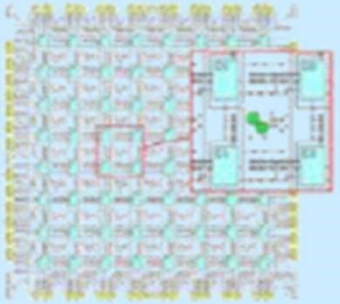
Aplicações Possíveis em Pesquisas



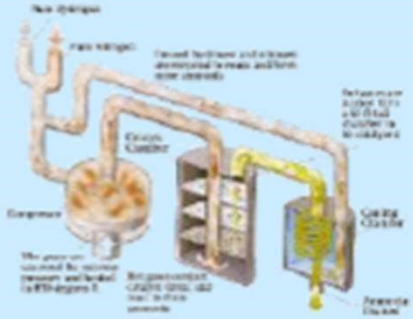
batteries



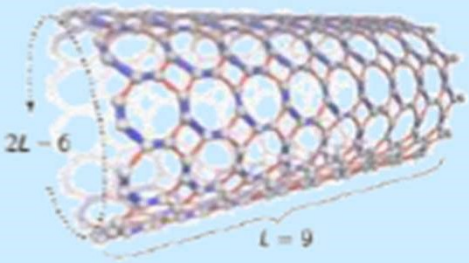
drugs



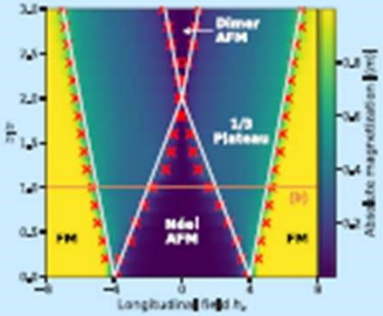
semiconductors



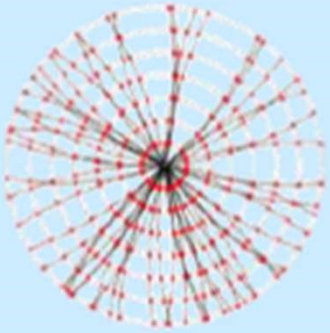
fertilizers production



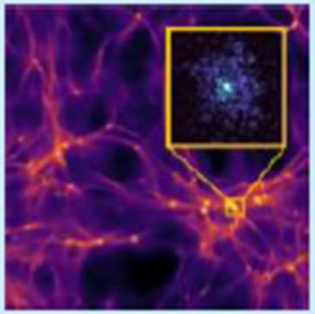
materials design



condensed matter physics



high-energy particle physics

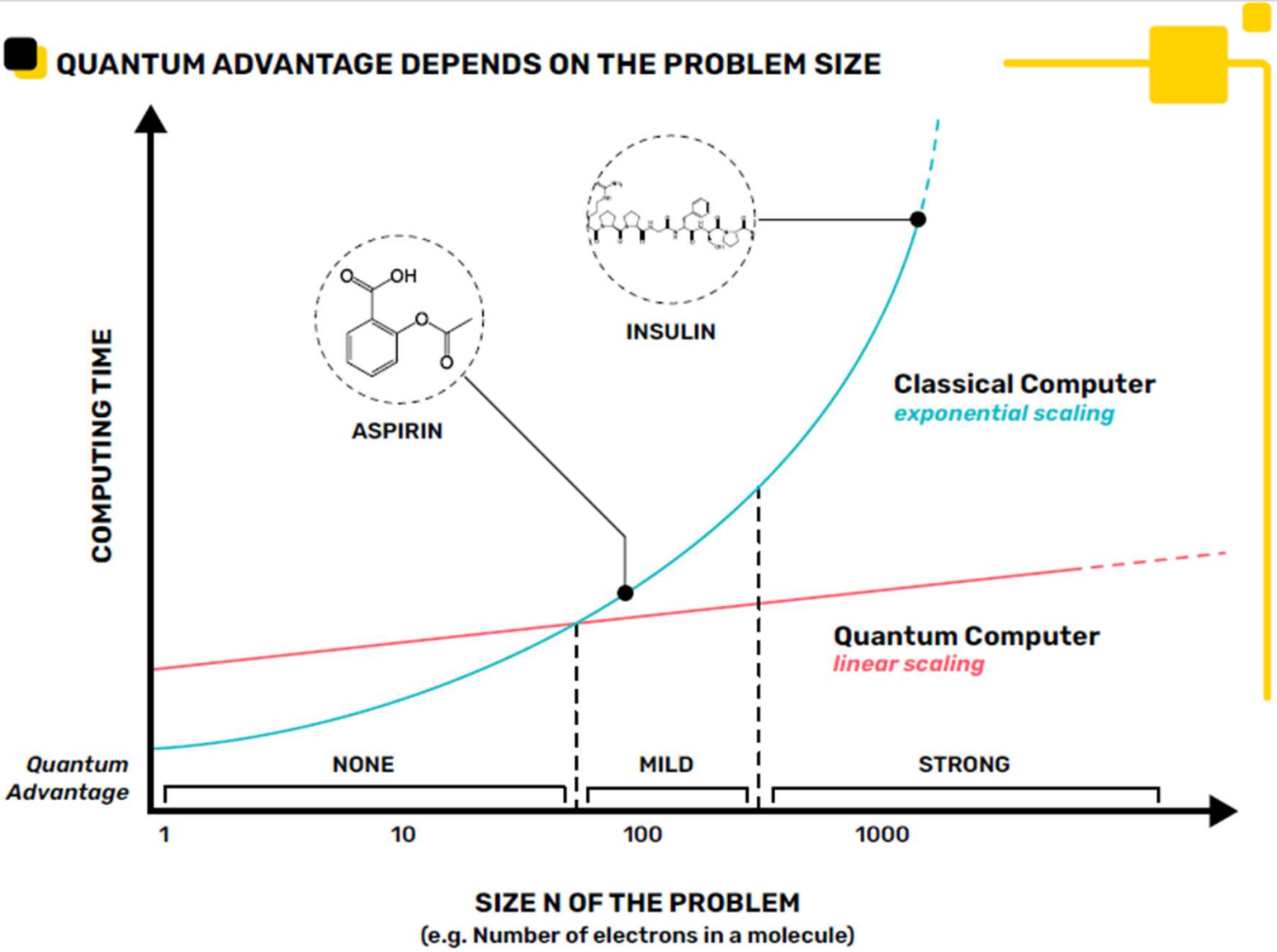


astrophysics

https://www.oezratty.net/wordpress/2024/understanding-quantum-technologies-2024/

Potencial:

Resolver problemas **impossíveis** para computadores comuns



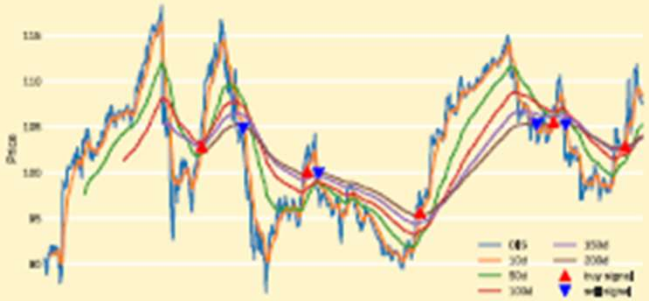
https://alice-bob.com/wp-content/uploads/2024/12/Think-Inside-The-Box-Alice-Bob-Whitepaper.pdf

Aplicações Possíveis em Operações

n destinos
n! possibilidades

4! = 24
20! = 2.432.902.008.176.640.000

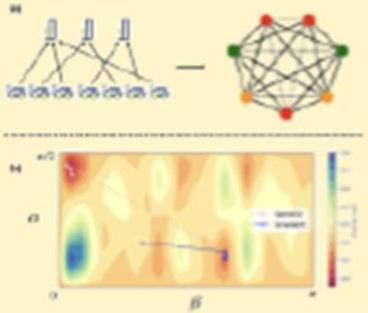
transportation



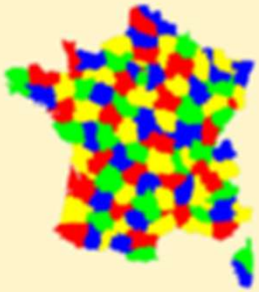
financial services

logistics

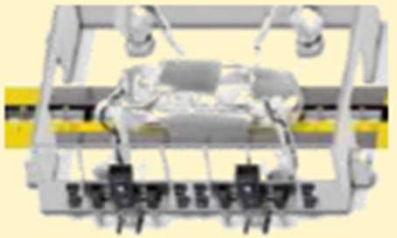
delivery



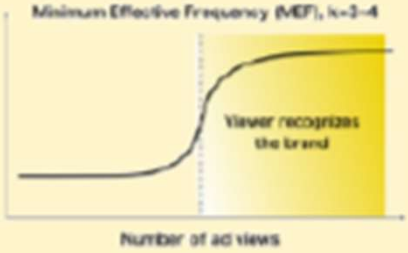
energy utilities



telecoms



manufacturing



marketing

https://www.oezratty.net/wordpress/2024/understanding-quantum-technologies-2024/

ONDE O COMPUTADOR QUÂNTICO NÃO AJUDA

- **Navegação na internet**
  o limite é a rede, não o processador
- **Planilhas e cálculos básicos**
- **Ordenação de listas pequenas**
- **Redes sociais e apps**
- **Jogos eletrônicos**
- **Edição de fotos e vídeos**

POR QUE ISSO ACONTECE?

- Um computador quântico não pode acelerar algo que já está no limite da eficiência
- Para usar um computador quântico é necessário que o problema possa ser codificado em estados quânticos e o resultado possa ser extraído sem perder informação

2025: QUANTUM YEAR

unesco

INTERNATIONAL YEAR OF
Quantum Science
and Technology

100 YEARS OF QUANTUM IS JUST THE BEGINNING

The 2025 International Year of Quantum Science and Technology (IYQ) recognizes 100 years since the initial development of quantum mechanics. Join us in engaging with quantum science and technology and celebrating throughout the year!

https://quantum2025.org/

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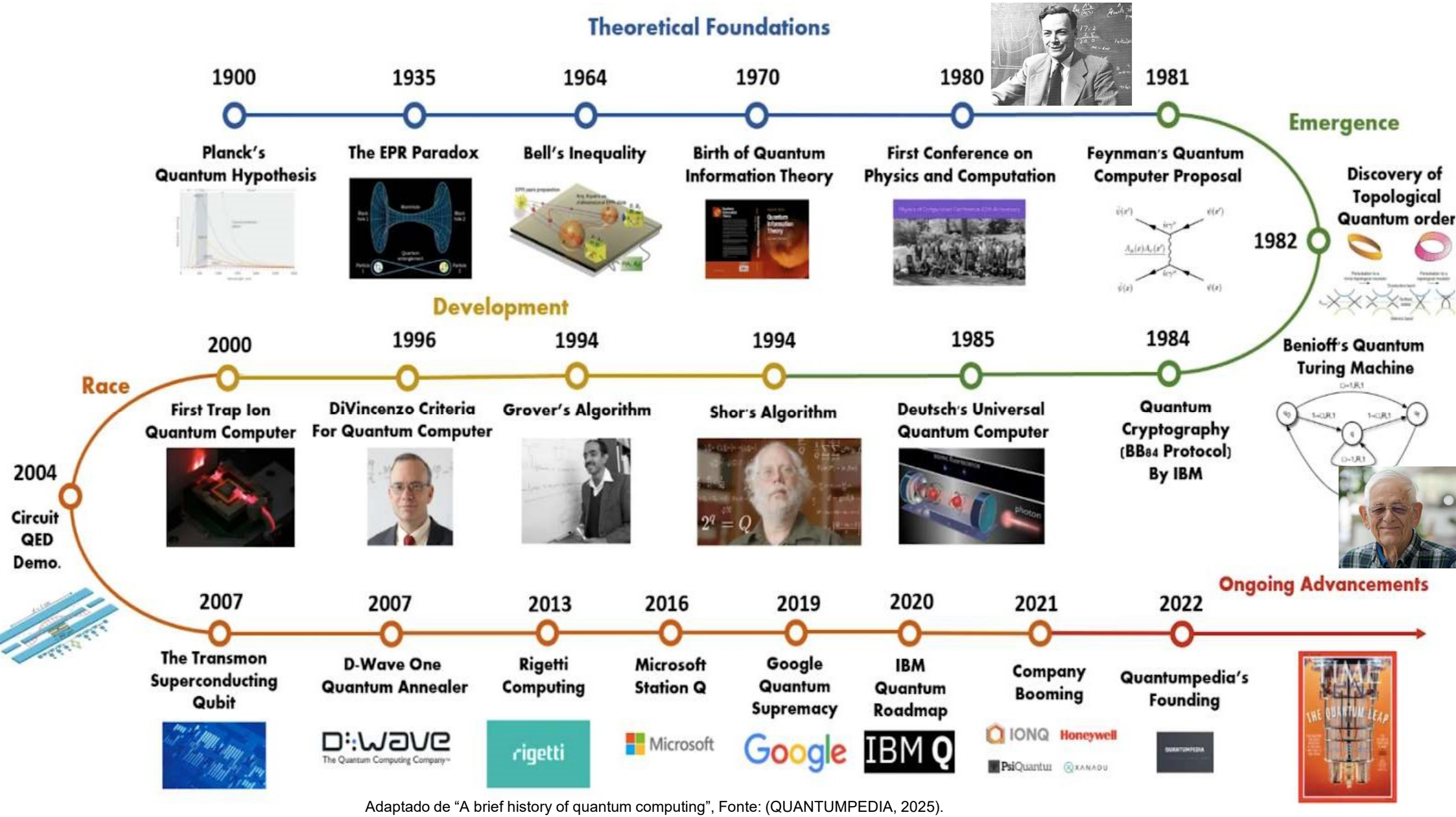
GOVERNO DO ESTADO

1925: PRINCÍPIO DA INCERTEZA DE HEISENBERG

- A medição altera o sistema que estamos medindo
- Δx é a incerteza na posição de uma partícula
- Δp é a incerteza da quantidade de movimento $p = mv$
- $\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$
- Não dá para saber ambos com boa precisão, e isso é fato da teoria, não é problema de nossos instrumentos!

Werner Heisenberg



Adaptado de “A brief history of quantum computing”, Fonte: (QUANTUMPEDIA, 2025).

Investimentos Atualmente

Market size and value at stake: QC companies began a shift toward revenue generation, earning an estimated $650 million to $750 million in 2024.

Quantum technology market size scenarios in 2035 and 2040

Based on existing development road maps and assumed adoption curve

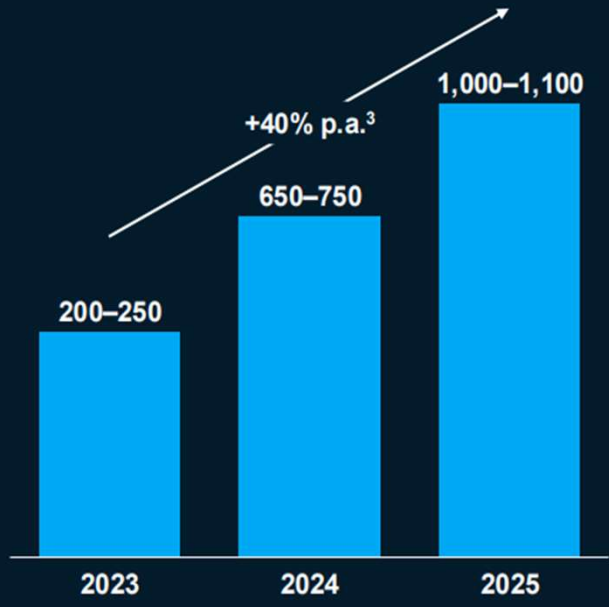
	QC	QComm	QS[1]
2035	$28B–$72B	$11B–$15B	$7B–$10B
2040	$45B–$131B	$24B–$36B	$18B–$31B

Potential economic value[2] from QC in 2035:

~$0.9T–$2.0T

Potential value driven by four industries by 2035: global energy and materials, pharmaceuticals and medical products, financial industry, and travel, transport, and logistics

Revenue estimates of QC companies, $ million



1. Approach for QS updated through clusters of use cases based on recent development, announcements, and breakthroughs.
2. Economic value is defined as the additional revenue and saved costs that the application of QC can unlock.
3. Per annum.

Source: Crunchbase; expert interviews; Oxford Economics; PitchBook; *Quantum Computing Report*; S&P Capital IQ; McKinsey analysis

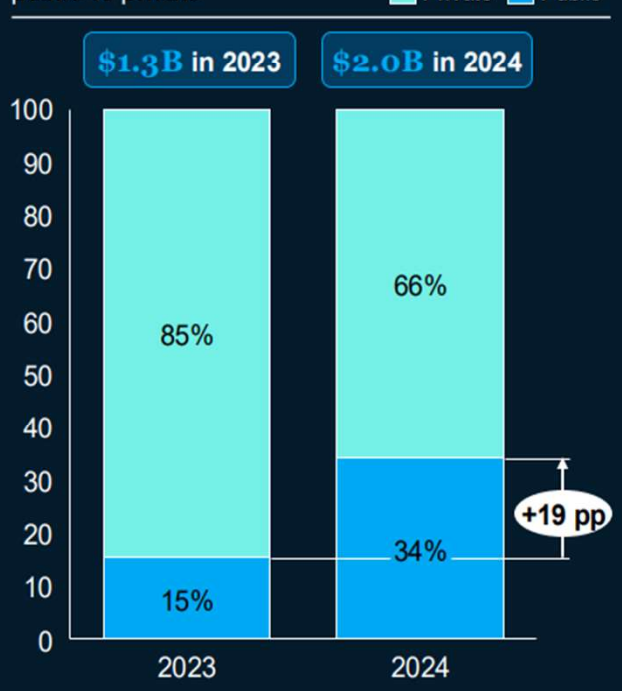
McKinsey & Company 8

https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025

Investimentos Atualmente

Investment landscape: Funding for QT start-ups in 2024 nearly doubled year over year, to $2 billion.

Total investment,
public vs private



Total number of start-ups founded

+42% YoY

Geographic factors driving start-up creation:

EU fragmentation: 8 of 19 newly founded quantum start-ups originated in the EU, reflecting the EU's continuing push to start new companies rather than focusing only on mature start-ups

Asia accelerating: Asian countries are rapidly catching up (with 5 of 19 start-ups), driven by increased government support and strategic partnerships aimed at scaling quantum technologies

Public announcements

Government announcements totaled $1.8B in 2024, with early 2025 investments already exceeding $10.0B—driven largely by Japan's $7.4B quantum investment—indicating a breakout year for the sector

Funding breakdown

Quantum computing accounts for ~80% of total quantum investments, with superconducting technologies receiving the highest funding, followed by photonic networks

Funding by start-up stage

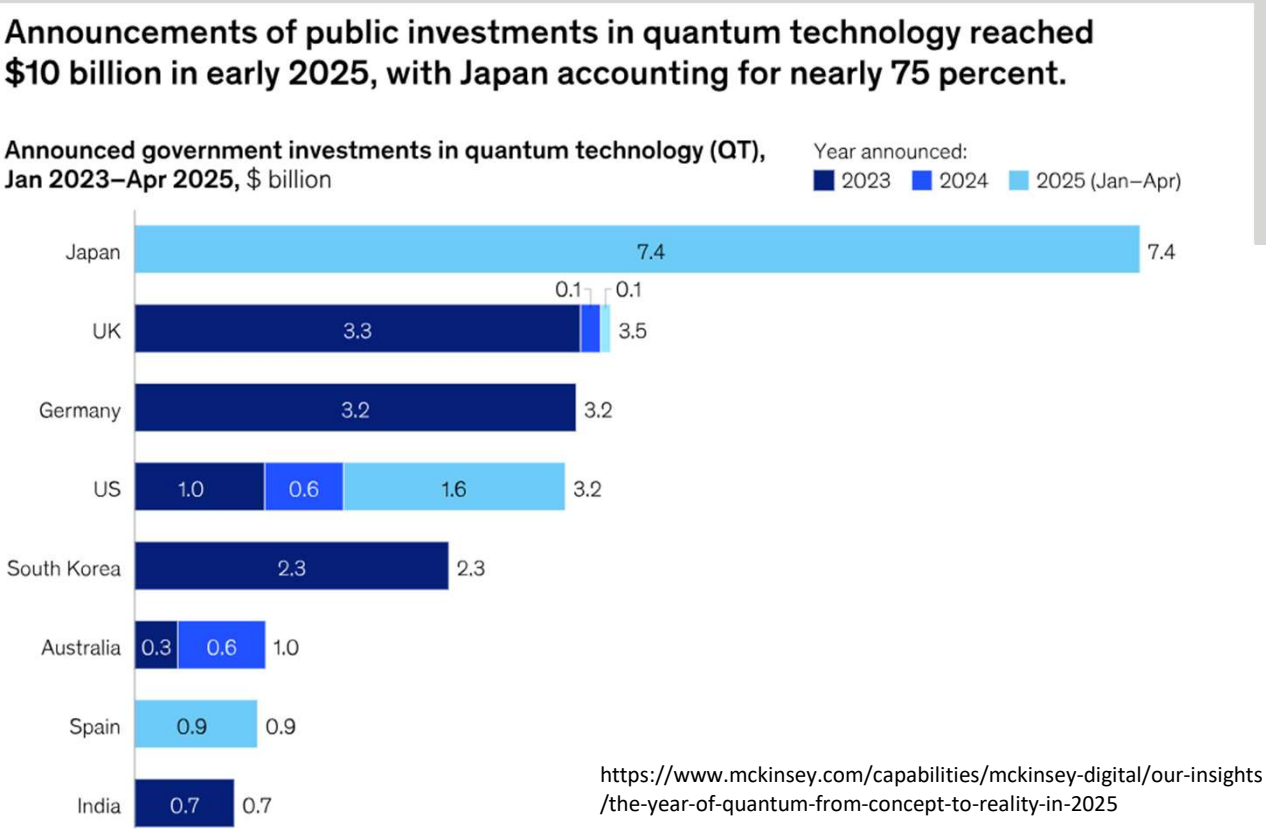
Funding is shifting away from scaling quantum start-ups as investors focus on early innovation and mature start-ups (~70% of total investment), driven by a desire to maximize return on innovation or reduce risk

Source: Crunchbase; PitchBook; press search, including national and regional government press releases

McKinsey & Company 9

https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025

Investimentos Públicos



https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-year-of-quantum-from-concept-to-reality-in-2025

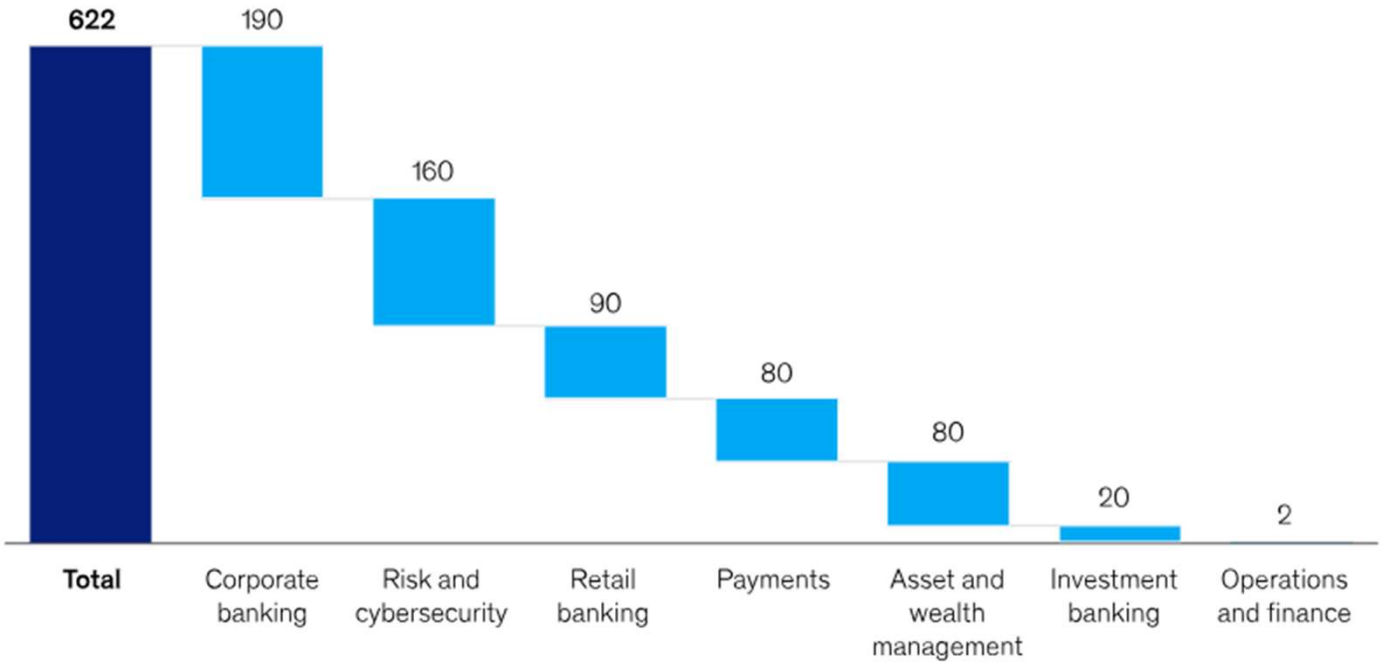
- Ministério da Ciência, Tecnologia e Inovação (MCTI), planeja destinar até R$ 5 bilhões para o desenvolvimento de tecnologias quânticas até o ano de 2034

https://www1.folha.uol.com.br/tec/2025/04/governo-quer-mobilizar-r-5-bi-em-investimento-para-plano-de-computacao-quantica.shtml

Perspectivas Mercado Financeiro

By 2035, quantum-computing use cases in the finance industry could create $622 billion in value.

Value of quantum-computing use cases, by business unit, $ billion

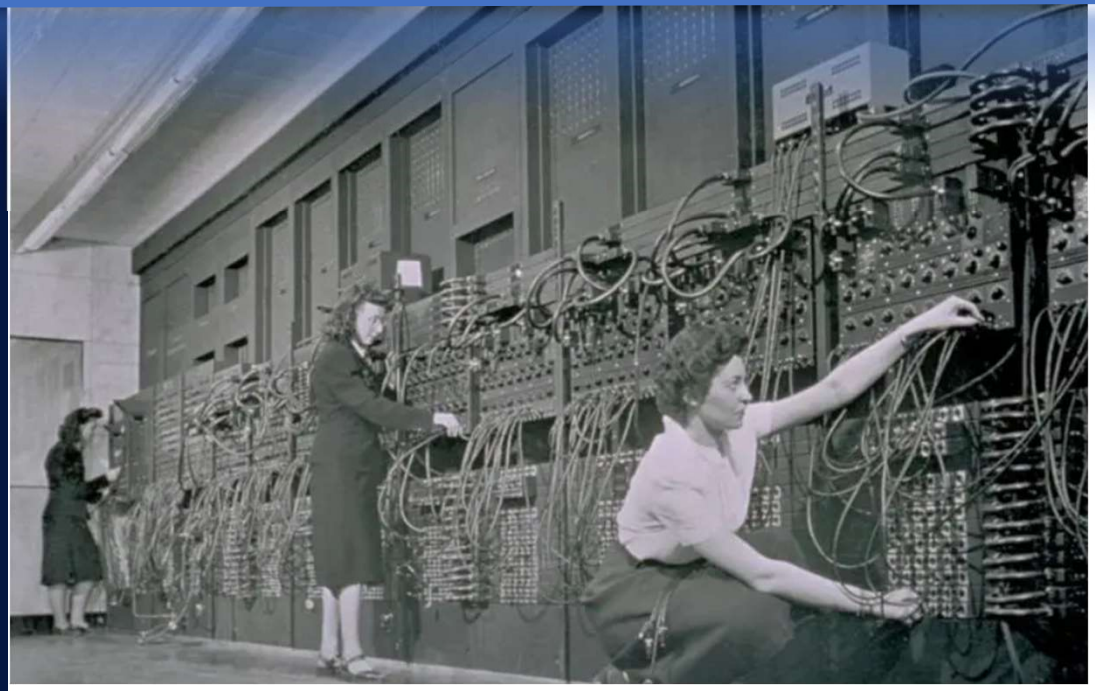


Note: Assumes that 50% of the full potential in the finance industry will be realized by 2035.

https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/tech-forward/quantum-technology-use-cases-as-fuel-for-value-in-finance

DIFERENÇAS COMPUTAÇÃO CLÁSSICA E QUÂNTICA

Hardware e processamento de informação



ENIAC (*Electronic Numerical Integrator and Computer*), um dos primeiros computadores eletrônicos de uso geral

https://www.computerhistory.org/

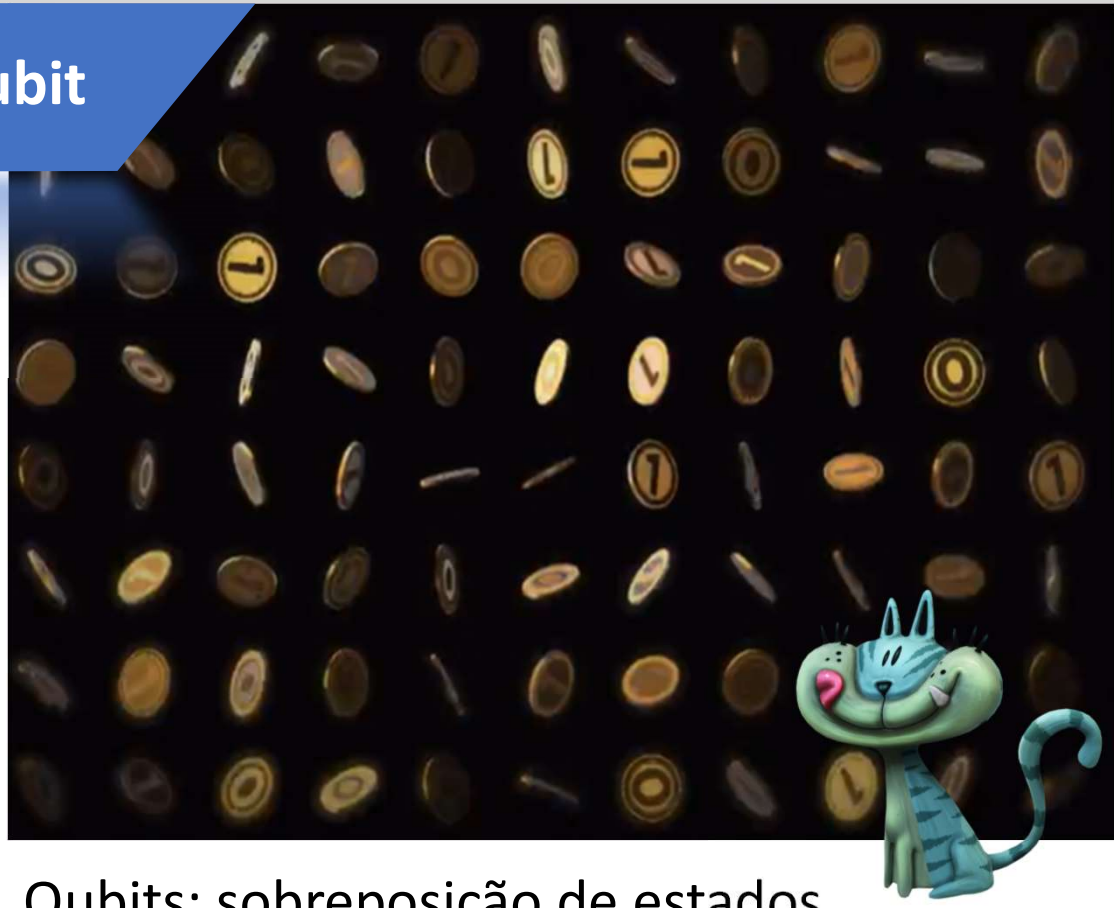
IBM's Thomas J. Watson Research Center

https://spectrum.ieee.org/ibm-condor

DIFERENÇAS COMPUTAÇÃO CLÁSSICA E QUÂNTICA

Processamento de informação: Bit x Qubit

Bits: 0 ou 1

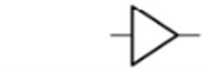


Qubits: sobreposição de estados

https://globoplay.globo.com/v/13550697/

Portas Lógicas Clássicas

YES



INPUT A	OUTPUT
0	0
1	1

NOT

INPUT A	OUTPUT
0	1
1	0

AND

INPUT A	INPUT B	OUTPUT
0	0	0
1	0	0
0	1	0
1	1	1

OR

INPUT A	INPUT B	OUTPUT
0	0	0
1	0	1
0	1	1
1	1	1

XOR

INPUT A	INPUT B	OUTPUT
0	0	0
1	0	1
0	1	1
1	1	0

NAND

INPUT A	INPUT B	OUTPUT
0	0	1
1	0	1
0	1	1
1	1	0

NOR

INPUT A	INPUT B	OUTPUT
0	0	1
1	0	0
0	1	0
1	1	0

XNOR

INPUT A	INPUT B	OUTPUT
0	0	1
1	0	0
0	1	0
1	1	1

https://www.researchgate.net/figure/Summary-of-the-common-Boolean-logic-gates-with-symbols-and-truth-tables_fig3_291418819

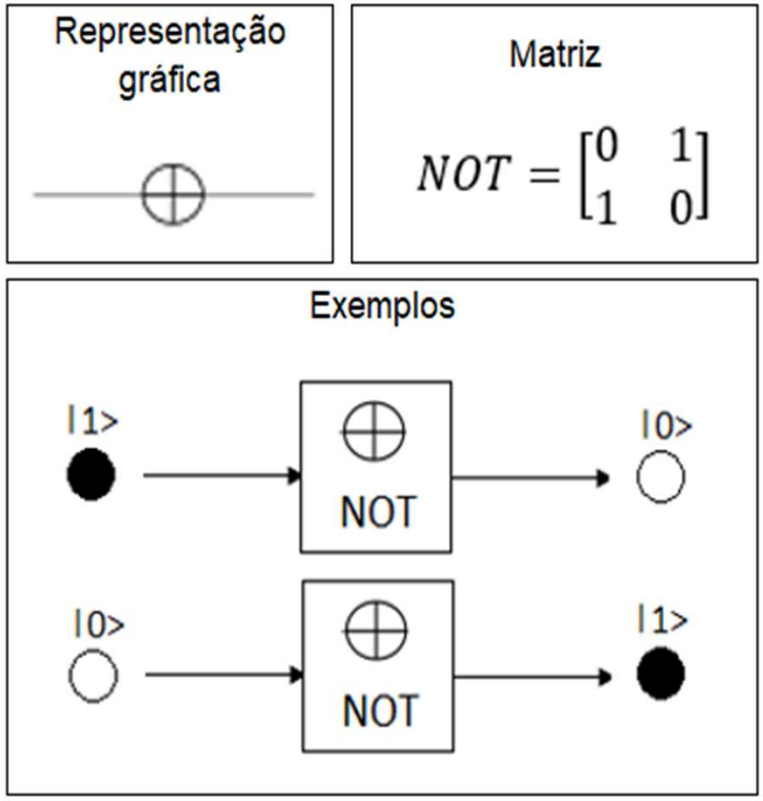
PORTAS LÓGICAS QUÂNTICAS: 1 QUBIT

- Portas lógicas quânticas precisam ser reversíveis
- Representação de Dirac e matricial:

$$|1> = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$|0> = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

- Exemplo com 1 qubit



PORTAS LÓGICAS QUÂNTICAS: 2 QUBITS

- Representação de Dirac e matricial

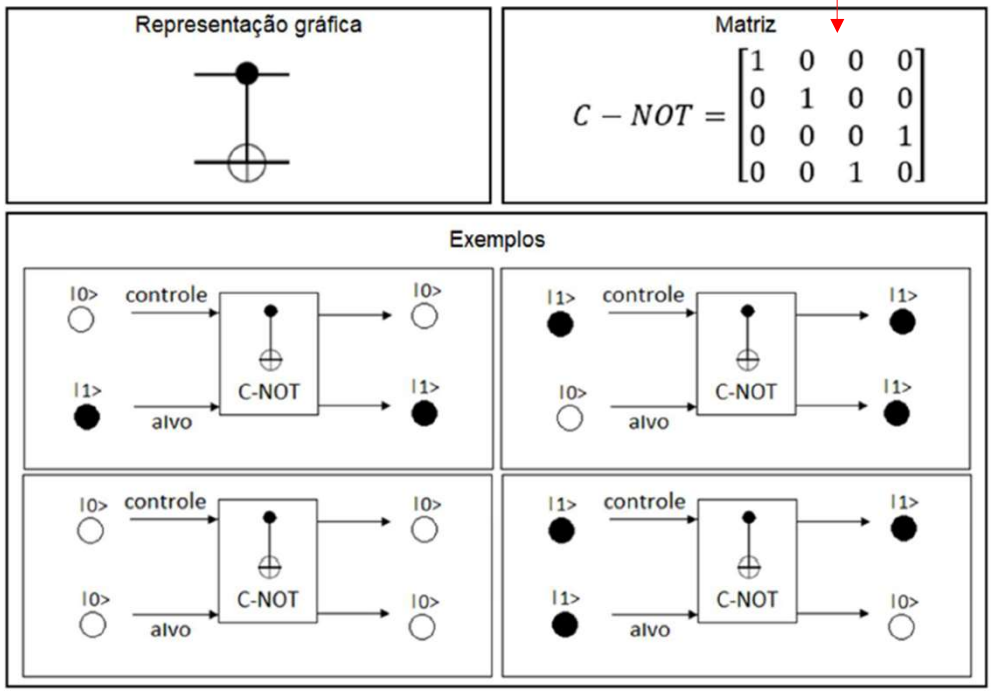
$$|00> = \begin{bmatrix}1\\0\\0\\0\end{bmatrix} \quad |01> = \begin{bmatrix}0\\1\\0\\0\end{bmatrix}$$

$$|10> = \begin{bmatrix}0\\0\\1\\0\end{bmatrix} \quad |11> = \begin{bmatrix}0\\0\\0\\1\end{bmatrix}$$

2^n linhas

- Exemplo com 2 qubits

dimensão 2^n x 2^n



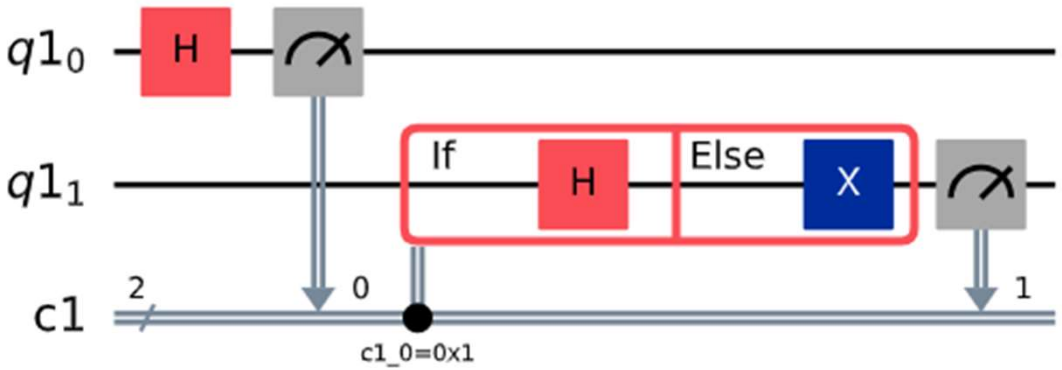
Exemplo: 8 qubits: 256 linhas!

HARDWARE MUDA E O ALGORITMO TAMBÉM

- Desenvolvimento do código ainda está mais em baixo nível
- Bibliotecas e frameworks: Cirq, Qiskit, PennyLane...

HARDWARE MUDA E O ALGORITMO TAMBÉM

Portas lógicas quânticas -> circuitos quânticos -> algoritmos quânticos

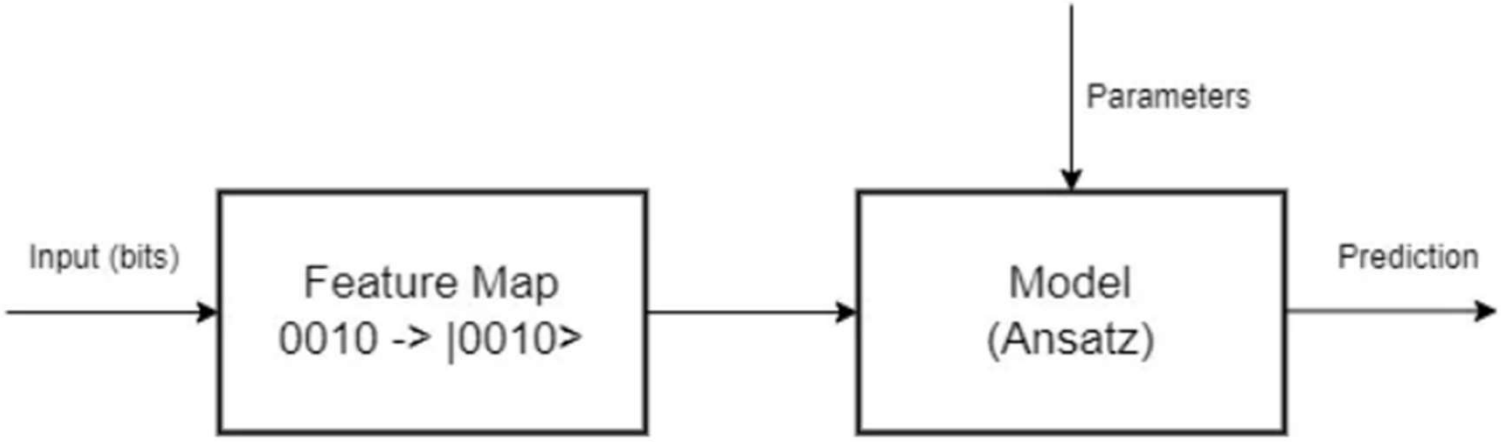



```python
qubits = QuantumRegister(2)
clbits = ClassicalRegister(2)
circuit = QuantumCircuit(qubits, clbits)
(q0, q1) = qubits
(c0, c1) = clbits

circuit.h(q0)
circuit.measure(q0, c0)
with circuit.if_test((c0, 1)) as else_:
    circuit.h(q1)
with else_:
    circuit.x(q1)
circuit.measure(q1, c1)

circuit.draw("mpl")
```

https://quantum.cloud.ibm.com/docs/en/guides/classical-feedforward-and-control-flow

REGRESSOR QUÂNTICO VARIACIONAL
(VQC, *VARIATIONAL QUANTUM CLASSIFIER*)

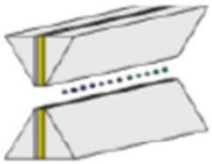
- Principais adaptações:
  - *Feature map*: codificação de dados clássicos para qubits
  - *Ansatz*: suposição inicial sobre a parametrização do circuito quântico. Este circuito é construído com as portas lógicas quânticas



https://medium.com/@matheuscammarosanohidalgo/a-very-simple-variational-quantum-classifier-vqc-64e8ec26589d

AINDA NÃO HÁ TECNOLOGIA DOMINANTE

atoms | **electrons** *controlled spin and microwave cavities* | **photons**

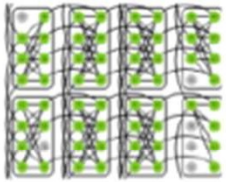


trapped ions

IONQ, AQT, QUANTINUUM, oxford ionics, eleQtron, FOXCONN, Quantum Art, CRYSTAL QUANTUM COMPUTING, NEQXT, QUDORA TECHNOLOGIES

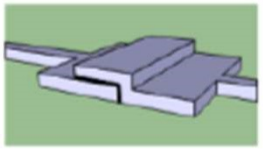
cold atoms

Pasqal, QuEra, Infleqtion, atom computing, planqc, QUANTIOR, NanoQT, Atom Quantum Labs



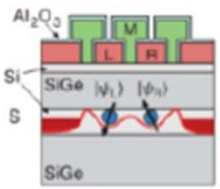
annealing

D-Wave The Quantum Computing Company, KILIMANJARO, NEC



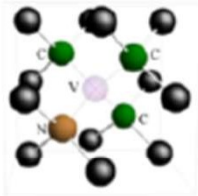
superconducting

IBM, rigetti, amazon, Google, qci, Nord Quantique, OQC, IQM, ORIGIN QUANTUM, ANYON, ATLANTIC QUANTUM, bleximo, FUJITSU



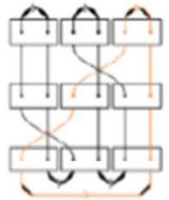
silicon

intel, quobly, QUANTUM MOTION, Silicon Quantum Computing, diraq, EeroQ, equal1.labs, C12, ARQUE, ARCHER



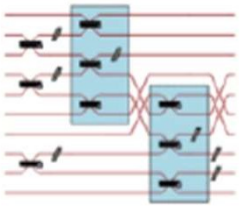
vacancies

QUANTUM BRILLIANCE, SaxonQ, TURING, photonic, NTT, XEED, Quantum Transistors



topological

Microsoft, QUOHERENT, QUANTUM



photons

PsiQuantum, QUANDELA, ORCA COMPUTING, XANADU, DUALITY, QUIX QUANTUM, BardeenQ, nBosonN, QCi photonicsQ, QUANFLUENCE

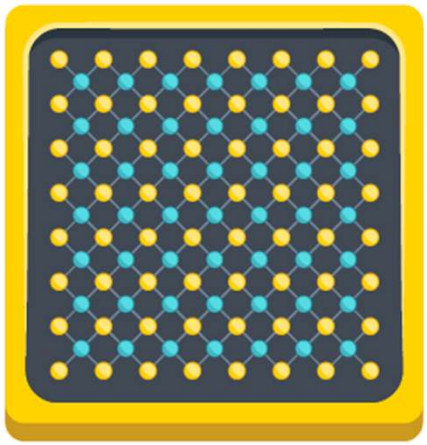
https://www.oezratty.net/wordpress/2024/understanding-quantum-technologies-2024/

ipt | SÃO PAULO GOVERNO DO ESTADO

A 'useful,' fault tolerant, quantum computer would solve classically intractable problems in relatively short timeframes, but the quantum circuits for this would require at least 100 error-corrected qubits and at least 100 million gates[12].

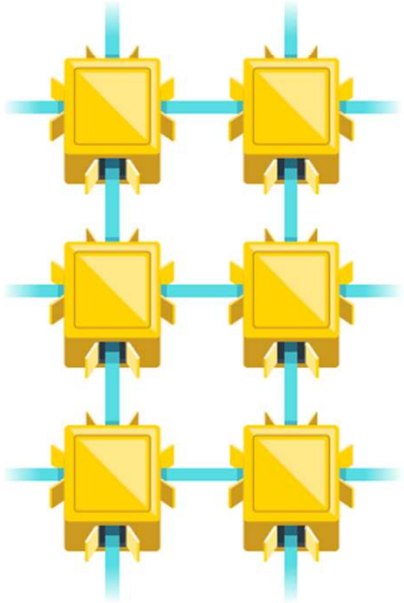
THE ROAD TO A MACHINE CAPABLE OF RUNNING SUCH CIRCUITS IS A LONG ONE. HOWEVER, IT CAN BE DIVIDED INTO THREE MAJOR INDUSTRY-WIDE STEPS:

1



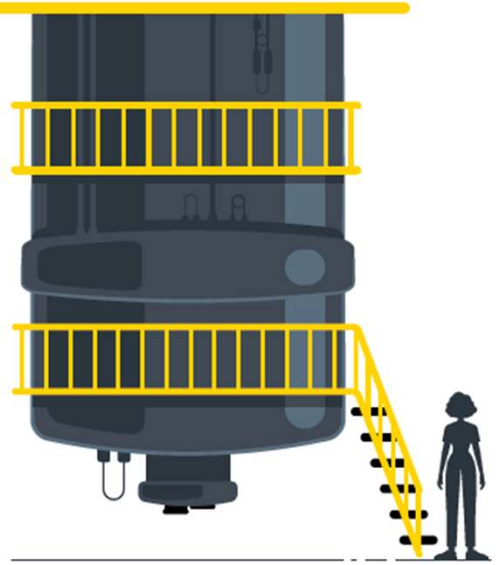
FIRST STEP: Fault-Tolerance
Control error-corrected qubits, a so-called 'logical qubits,' and logical gates capable of escaping decoherence.

2



SECOND STEP: Universality
Implement a universal set of error-corrected gates between these logical qubits, enabling any type of algorithm to run.

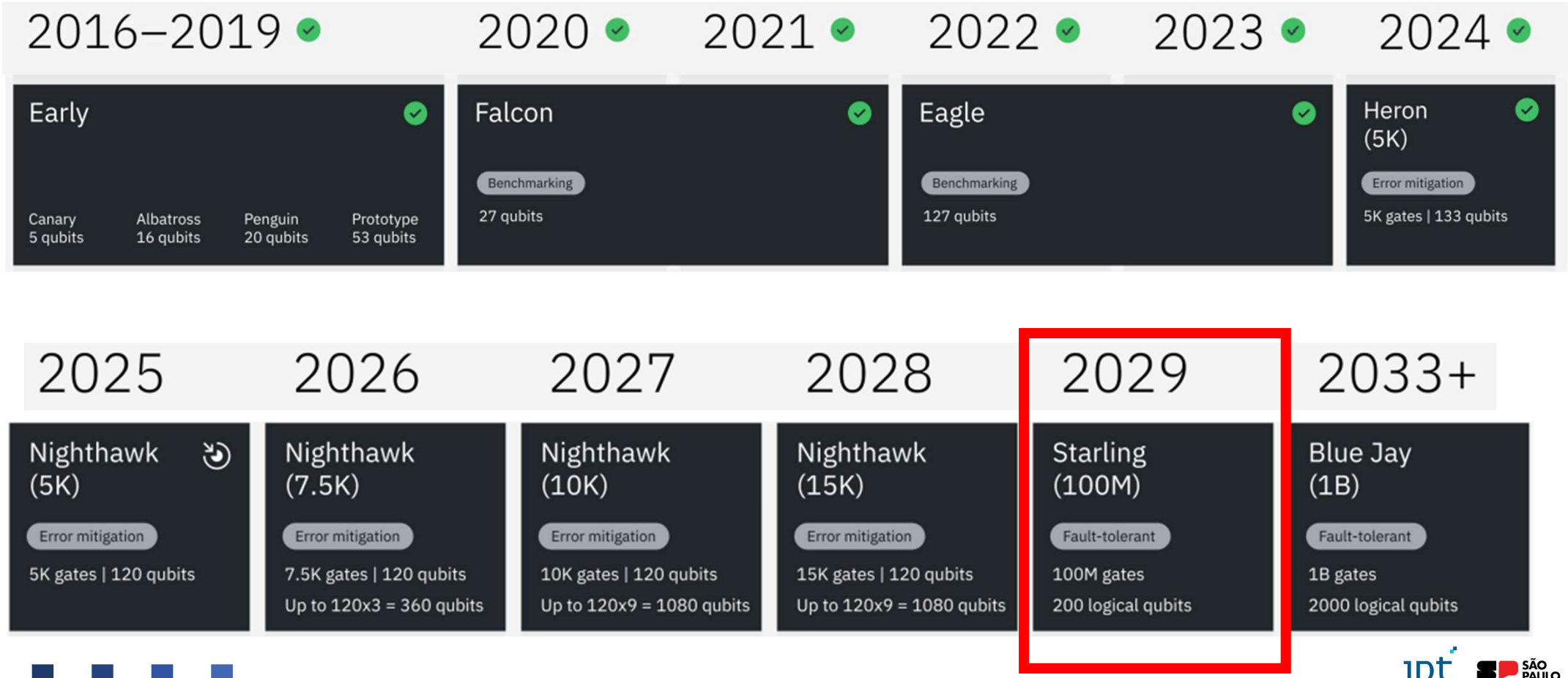
3



THIRD STEP: Scale
Have quantitatively and qualitatively enough logical qubits to achieve quantum advantage.

https://alice-bob.com/wp-content/uploads/2024/12/Think-Inside-The-Box-Alice-Bob-Whitepaper.pdf

EXEMPLO DO ROADMAP DA IBM



https://www.ibm.com/downloads/documents/us-en/131cf87ab63319bf

APLICAÇÕES ATUAIS – PESQUISAS

Fase de utilidade quântica: começamos a ter resultados

Computadores quânticos utilizados em combinação com HPCs

nature > scientific reports > articles > article

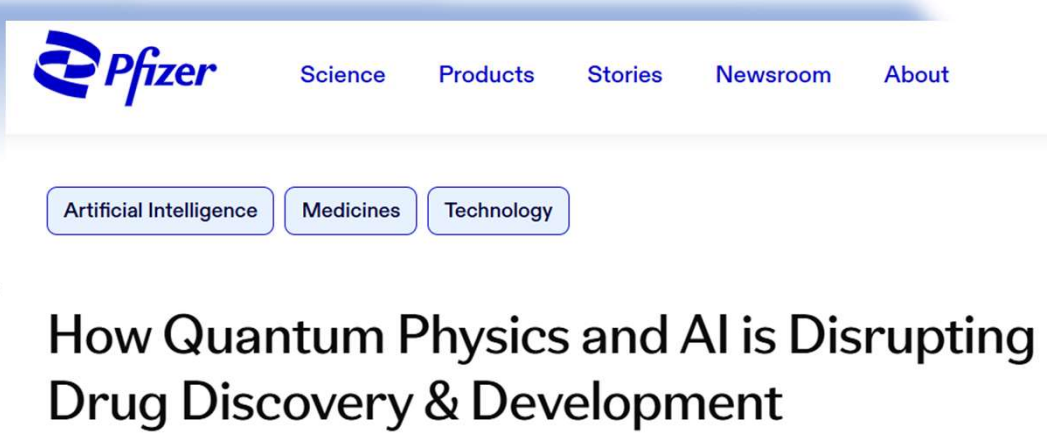
Article | Open access | Published: 23 July 2024

A hybrid quantum computing pipeline for real world drug discovery

Weitang Li, Zhi Yin, Xiaoran Li, Dongqiang Ma, Shuang Yi, Zhenxing Zhang, Chenji Zou, Kunliang Bu, Maochun Dai, Jie Yue, Yuzong Chen, Xiaojin Zhang & Shengyu Zhang

Scientific Reports **14**, Article number: 16942 (2024) | Cite this article

16k Accesses | **20** Citations | **39** Altmetric | Metrics



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How Quantum Physics and AI is Disrupting Drug Discovery & Development

https://www.nature.com/articles/s41598-024-67897-8

https://www.pfizer.com/news/articles/how_quantum_physics_and_ai_is_disrupting_drug_discovery_development

APLICAÇÕES ATUAIS – PESQUISAS

SPRINGER NATURE Link

https://link.springer.com/article/10.1186/s40854-025-00751-6

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From portfolio optimization to quantum blockchain and security: a systematic review of quantum computing in finance

Review | Open access | Published: 26 February 2025

Volume 11, article number 88, (2025) Cite this article

Amira Abbas, Andris Ambainis, et al. | 2024 | *Nature Reviews Physics*

Challenges and opportunities in quantum optimization

Emanuele Dri, Antonello Aita, et al. | 2023 | *Entropy*

A More General Quantum Credit Risk Analysis Framework

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Quantum Finance

https://research.ibm.com/topics/quantum-finance

Few datasets are as complex as those in finance, and quantum computing could reveal hidden patterns in complex data. We're developing algorithms to reveal once-invisible dynamic arbitrage opportunities, better react to volatility, and serve other crucial unmet needs in the financial sector.

DIFERENCIAL TECNOLÓGICO PARA AS EMPRESAS
ALGUNS EXEMPLOS

Volkswagen optimizes traffic flow with quantum computers

https://www.volkswagen-group.com/en/press-releases/volkswagen-optimizes-traffic-flow-with-quantum-computers-16995

MEDTECH

Roche taps into quantum computing software for Alzheimer's disease research

By **Conor Hale** · Jan 28, 2021 11:25am

https://www.fiercebiotech.com/medtech/roche-taps-into-quantum-computing-software-for-alzheimer-s-disease-research

BMW GROUP · MINI · ROLLS-ROYCE MOTOR CARS LTD

Quantum Computing at the BMW Group

materials science, engineering and processes.

https://www.bmwgroup.com/en/news/general/2025/quantum-computing.html

World's Largest Chemical Company Leverages Neutral Atom Quantum Processors for Weather Modeling Applications

Paris, July 20, 2022- PASQAL, the leading full stack manufacturer of neutral atoms quantum processors, today announced a collaboration with BASF, the world's largest chemical company, for weather and other computational fluid dynamics applications. BASF has begun to explore how PASQAL's proprietary quantum algorithms could one day be used to predict weather patterns. The learnings from this project can build a foundation for future extensions of PASQAL's methods to support climate modeling.

BASF

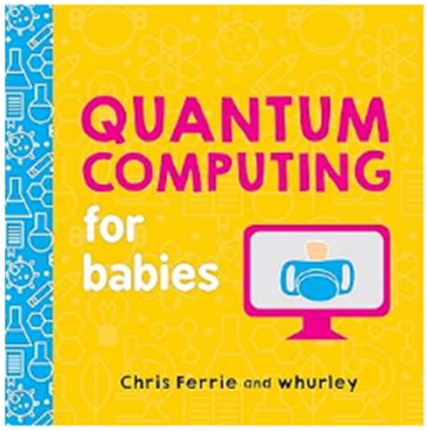
https://www.pasqal.com/success-story/basf/

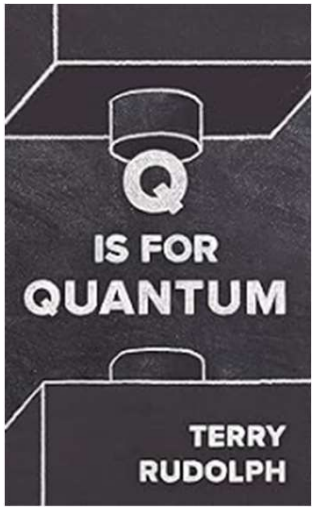
ipt · SÃO PAULO GOVERNO DO ESTADO

“Quero começar, mas não sei por onde...

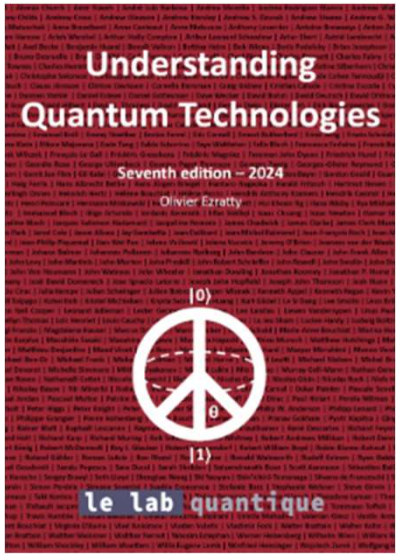
Onde será que o começo se esconde?”

- Livros

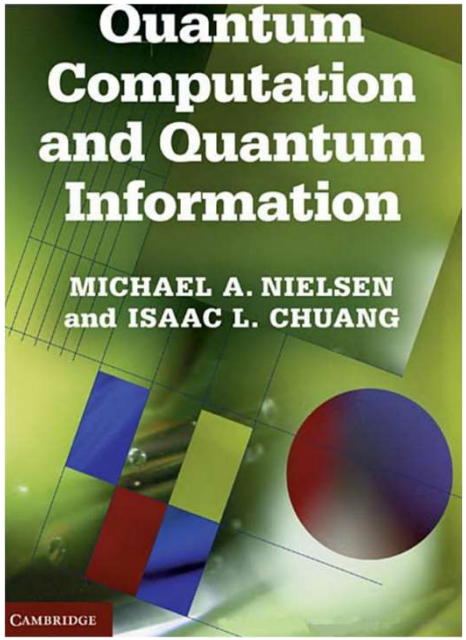




Crianças, adolescentes, público geral



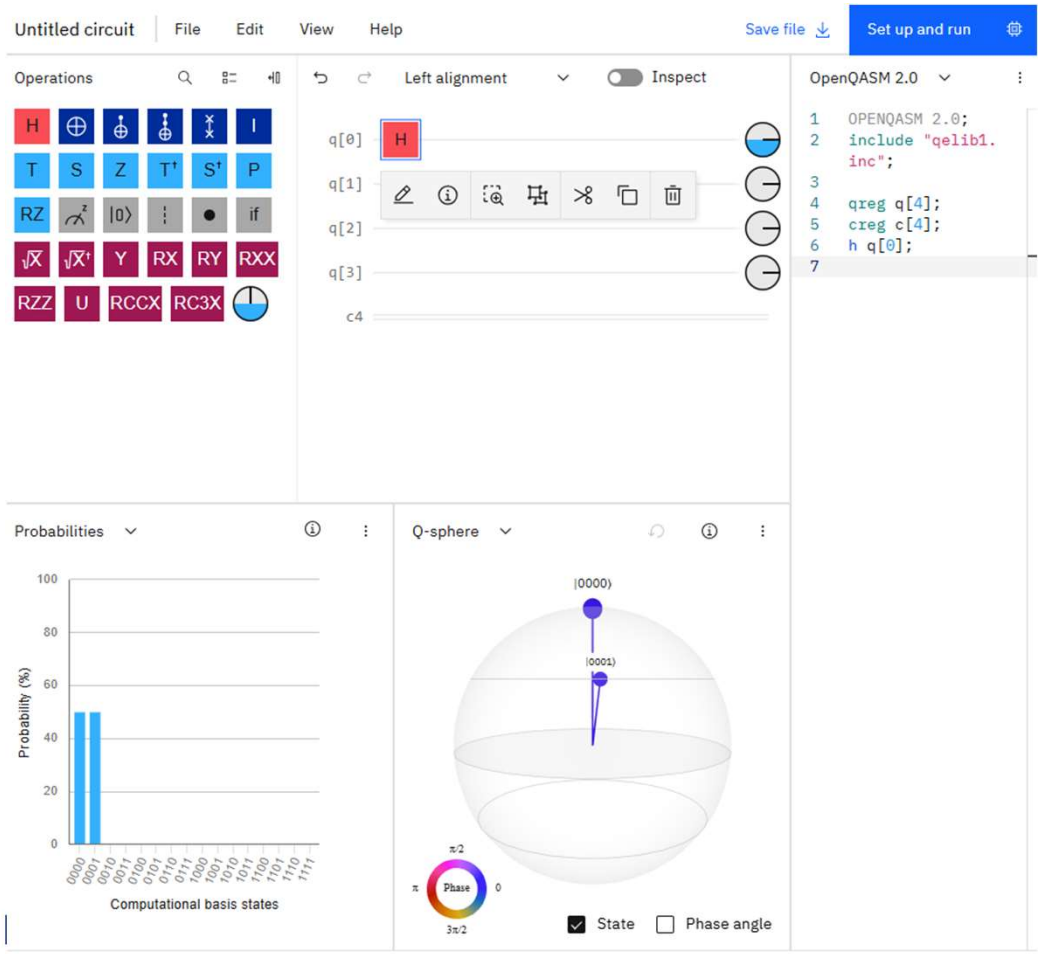
https://www.oezratty.net/wordpress/2024/understanding-quantum-technologies-2024/



Livros técnicos introdutórios

“Quero começar, mas não sei por onde...

Onde será que o começo se esconde?”



- Simulador de portas lógicas e circuitos quânticos

https://quantum.cloud.ibm.com/composer

“Quero começar, mas não sei por onde...

Onde será que o começo se esconde?”

- Tutoriais, curso online

Quantum learning

Kickstart your quantum learning journey with a selection of courses designed to help you learn the basics or explore more focused topics. If you’re an instructor, explore content specifically tailored to incorporating quantum in the classroom.

https://quantum.cloud.ibm.com/learning/en

“Quero começar, mas não sei por onde...
Onde será que o começo se esconde?”

- Tutoriais, documentação

IBM **Quantum Platform**

Tutorials

Use these tutorials to learn how to apply Qiskit to common quantum computing use cases.

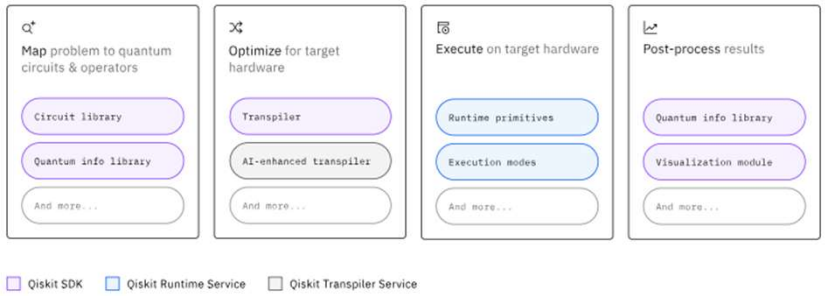
- Start with the set of tutorials in the Get started section if it is your first time running code on a quantum computer.
- The section on workflows toward advantage contains end-to-end examples of using a quantum computer to solve real-world problems. These tutorials focus on algorithms that are promising candidates for achieving computational advantage by a quantum computer over a classical computer.
- The section on Qiskit capabilities contains examples that use the latest and most advanced techniques in the Qiskit ecosystem to improve part or the whole of a particular workflow.

https://quantum.cloud.ibm.com/docs/en/tutorials

Introduction to Qiskit

The name "Qiskit" is a general term referring to a collection of software for executing programs on quantum computers. Most notably among these software tools is the open-source Qiskit SDK, and the runtime environment (accessed using Qiskit Runtime) through which you can execute workloads on IBM® quantum processing units (QPUs). As quantum technology evolves, so does Qiskit, with new capabilities released every year that expand this core collection of quantum software.

In addition, many open-source projects are part of the broader Qiskit ecosystem. These software tools are not part of Qiskit itself, but rather interface with Qiskit and can provide valuable additional functionality.



https://quantum.cloud.ibm.com/docs/en/guides

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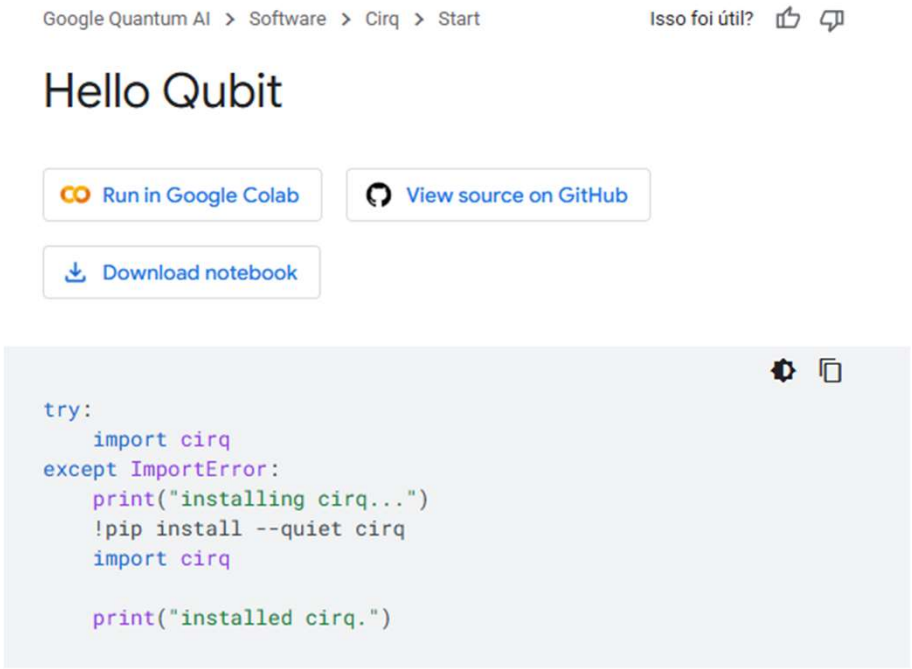
“Quero começar, mas não sei por onde...
Onde será que o começo se esconde?”

- Tutoriais, documentação, curso online

Google Quantum AI

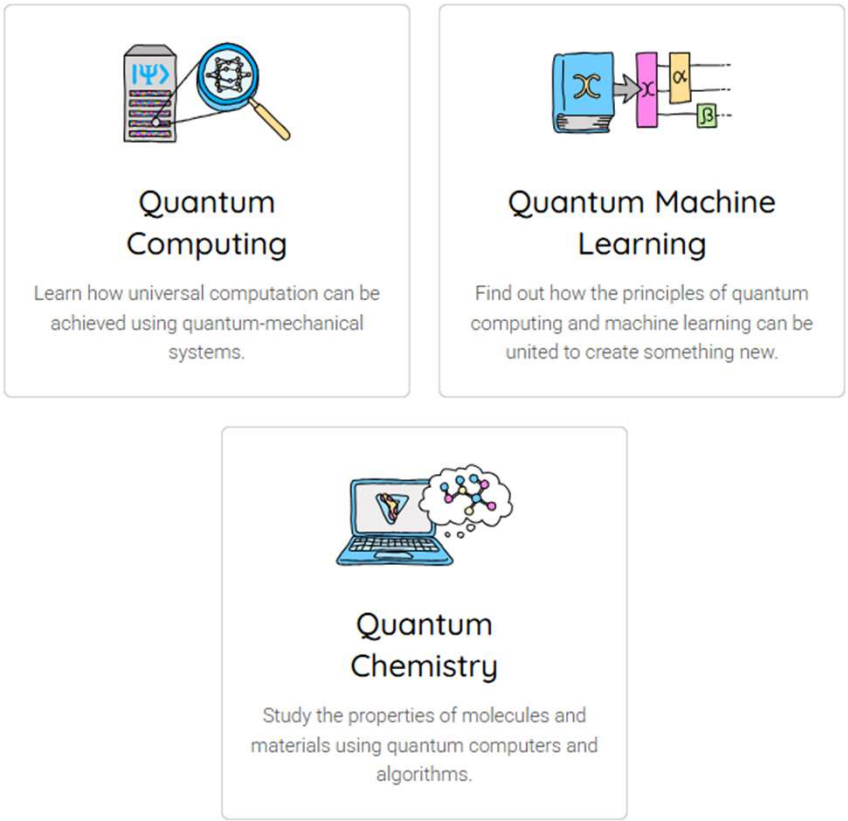
Cirq



https://quantumai.google/cirq/start/start

“Quero começar, mas não sei por onde...
Onde será que o começo se esconde?”

- Tutoriais, documentação, curso online



PENNYLANE

Learn quantum programming with PennyLane

https://pennylane.ai/qml

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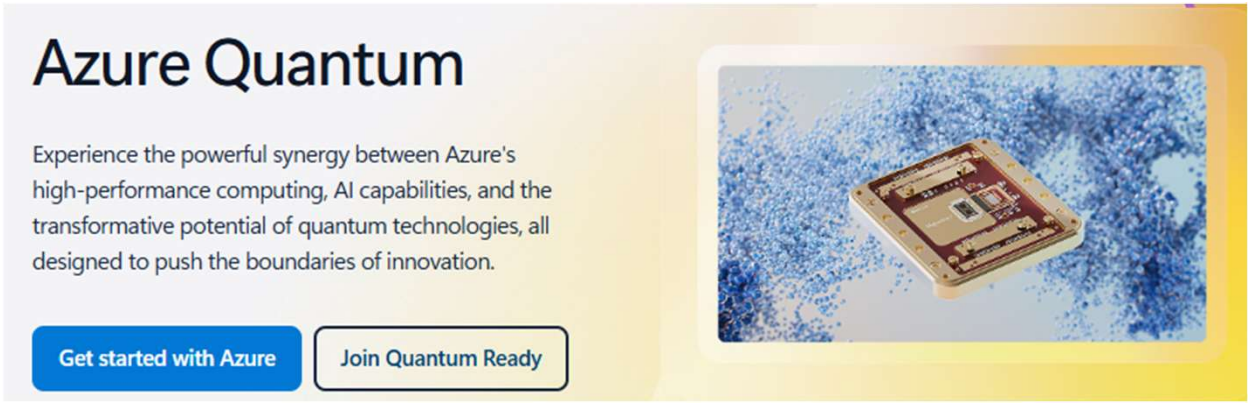
“Quero começar, mas não sei por onde...

Onde será que o começo se esconde?”

- Serviços de nuvem

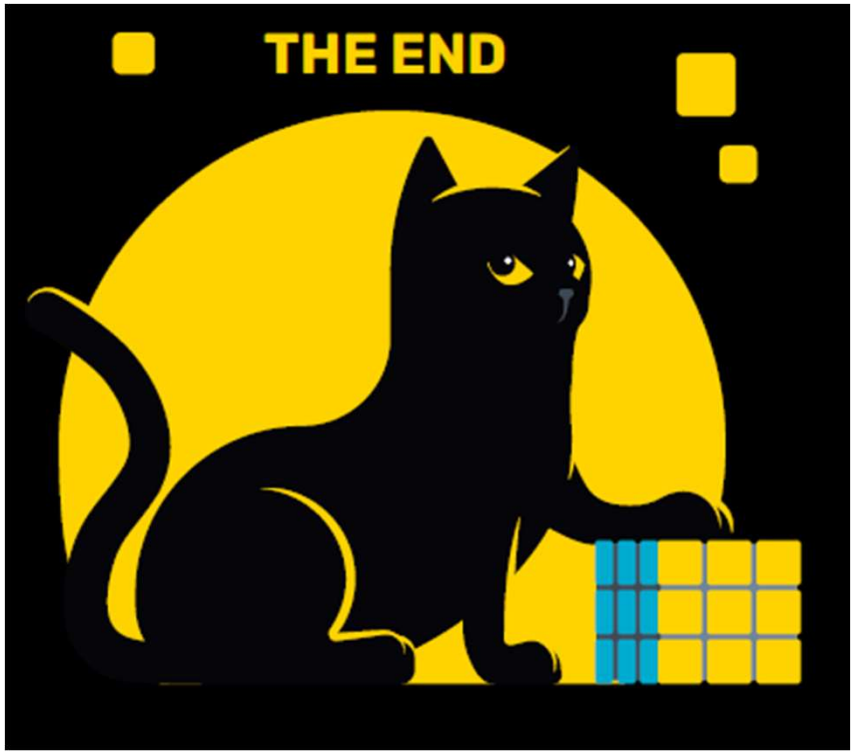


https://aws.amazon.com/pt/braket/

https://azure.microsoft.com/en-us/solutions/quantum-computing

CONCLUSÃO

- Tecnologia em desenvolvimento
- Desafios:
  - Escalabilidade, sustentabilidade energética, correção de erros
- Início da fase de aplicações em problemas reais



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