Application of Quantum Computing

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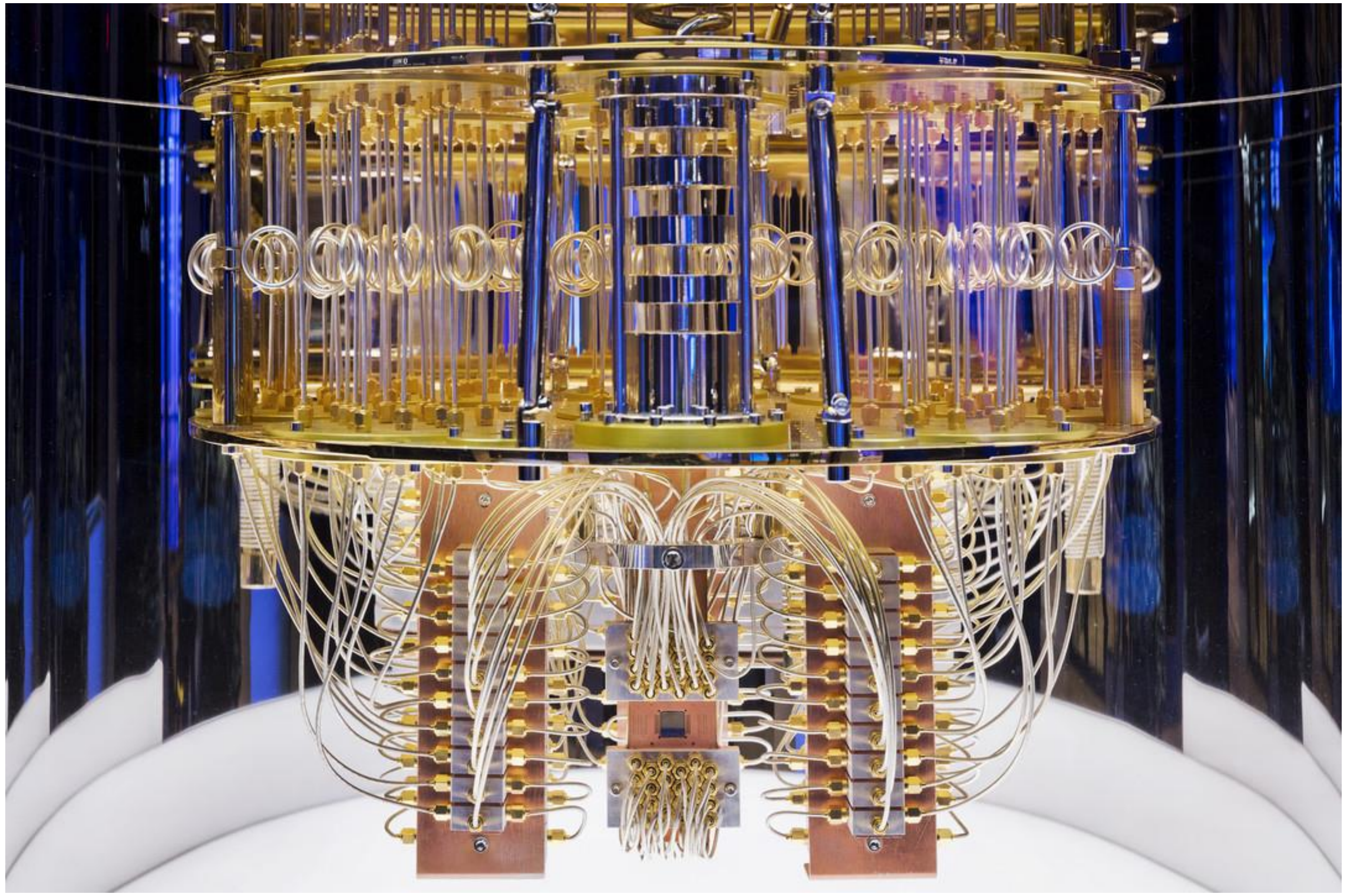
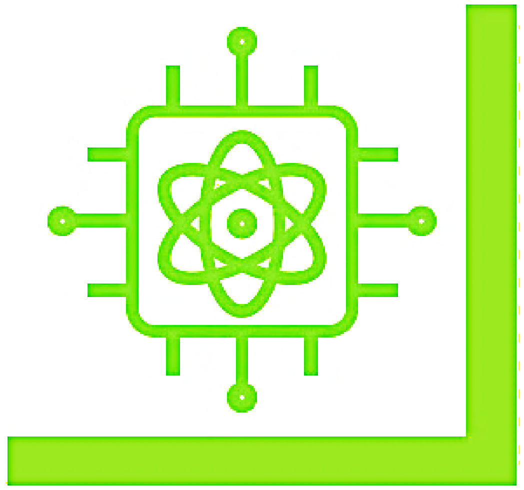
Assistant Professor

1. Impact of Quantum technology



Application of Quantum Technoloy



Quantum computing

Quantum computing solves advanced computational problems by leveraging quantum phenomena to process information and make calculations.

Enterprise use of quantum computers is expected to ramp up over the next several years, likely growing dramatically within a decade with the appearance of fault-tolerant quantum machines.

Quantum communication

Quantum communication creates secure, theoretically tamper-proof communication networks that can detect interception or eavesdropping.

Several quantum communication networks either have been deployed or are in progress, but it likely will be several years before they can overcome the unpredictability of quantum particles.

Quantum sensing

Quantum sensing devices provide higher responsiveness, accuracy, and performance than conventional sensors, due to the nature and sensitivity of subatomic particles.

Quantum sensors are available today for limited production use cases and their availability and capability likely will increase substantially within five to 10 years.

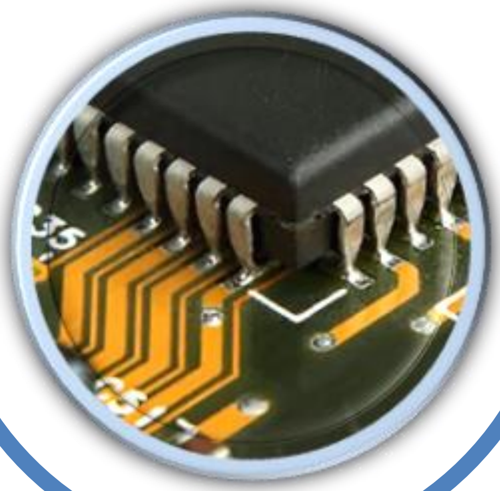
Source: Deloitte analysis.

History of Development in Computing

Computing Milestones: From Valves to Qubits

1940s–50s

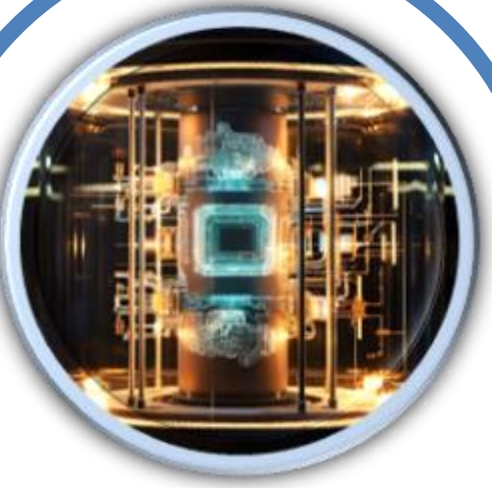
1960s–70s



1980s–90s

2000s–10s

2020s→



Vacuum-tube

Transistors & VLSI

PCs, Internet and WWW

Mobile, cloud, IoT & AI

Quantum computing promises exponential gains in chemistry, optimization and ML.

Application of Quantum Computing

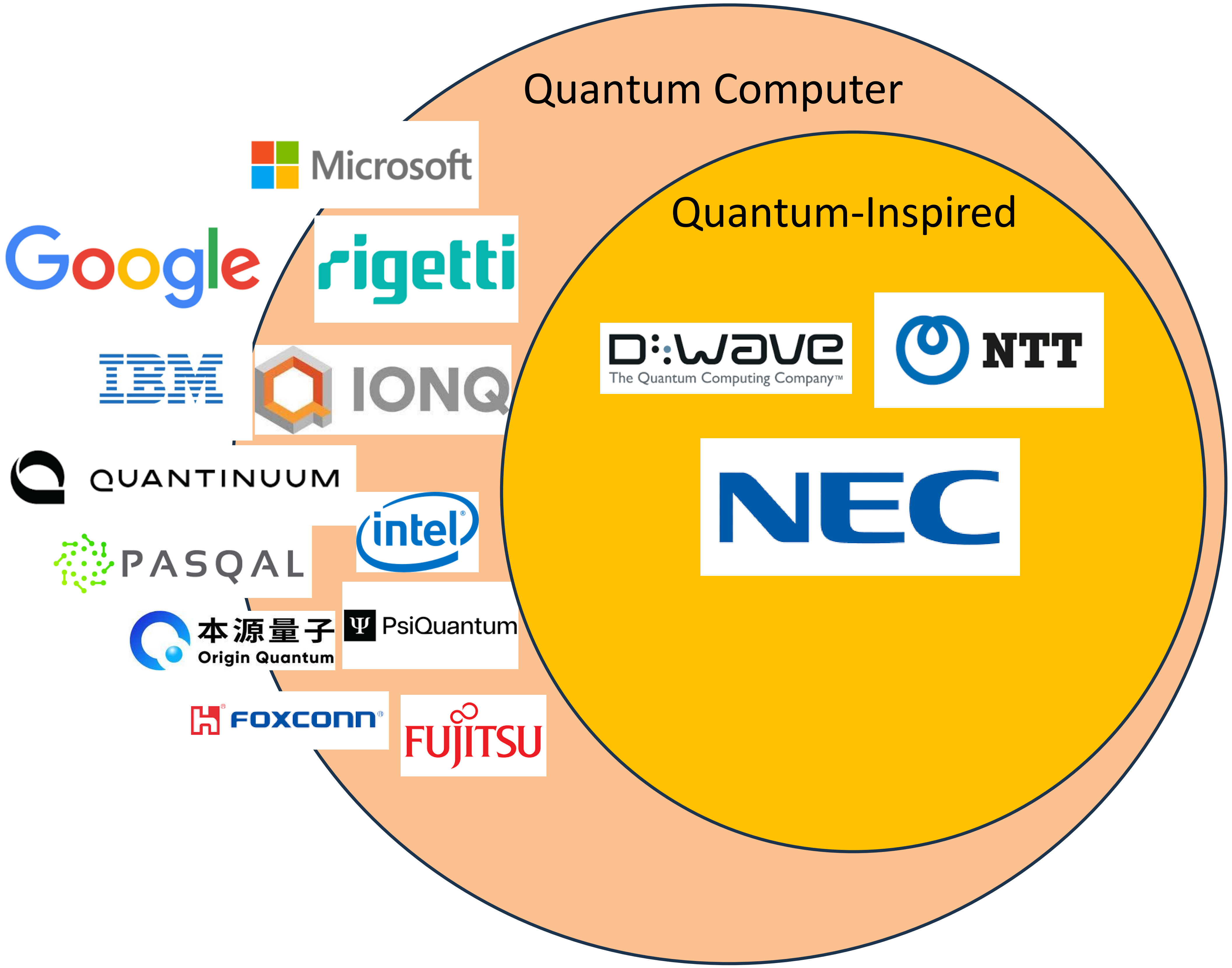
Quantum and Quantum-inspired Hardware

Quantum Computer

Microsoft
Google
IBM
rigetti
本源量子 Origin Quantum
QUANTINUUM
IONQ
PsiQuantum
PASQAL
intel
FUJITSU
FOXCONN

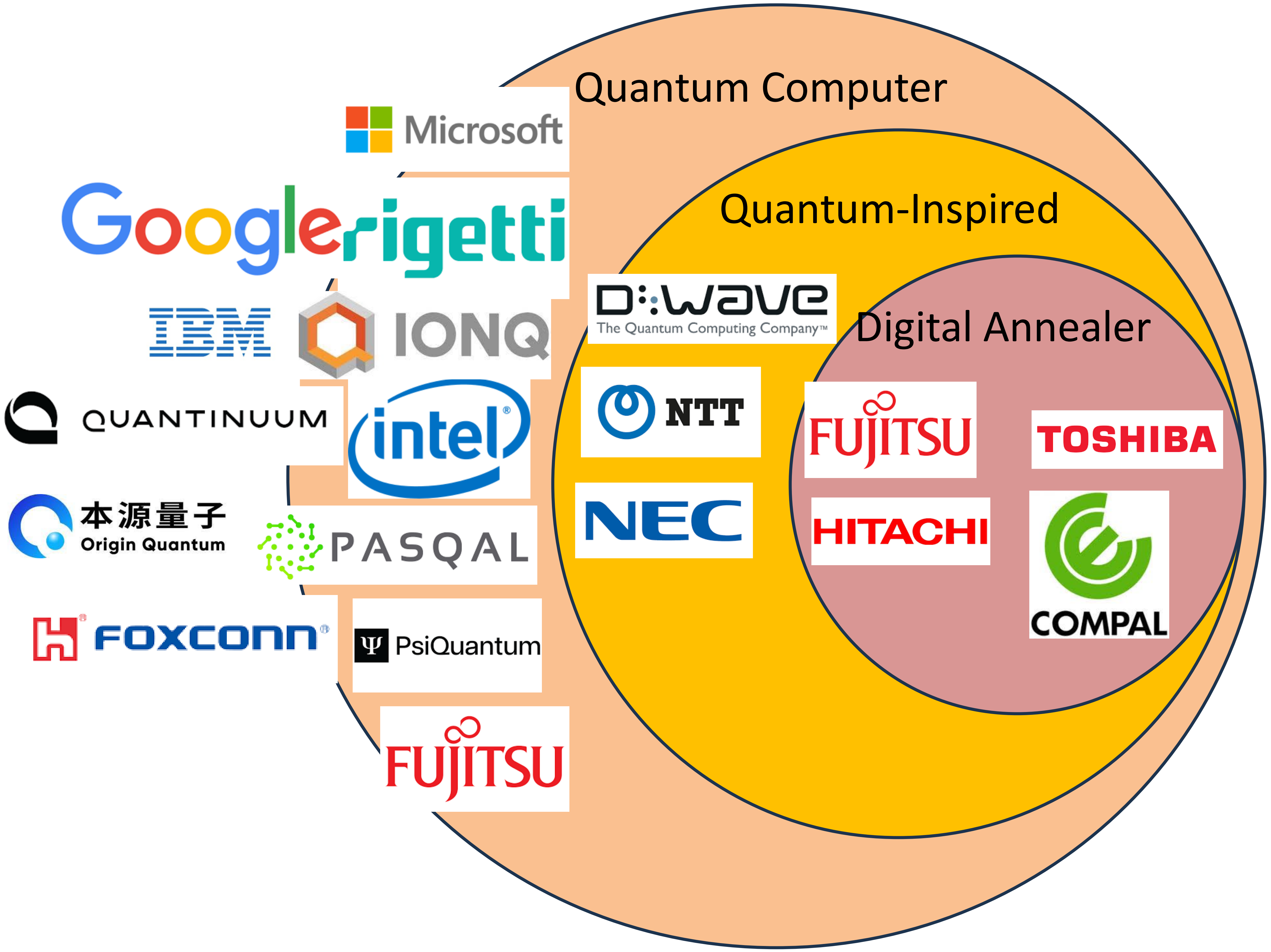
Application of Quantum Computing

Quantum and Quantum-inspired Hardware



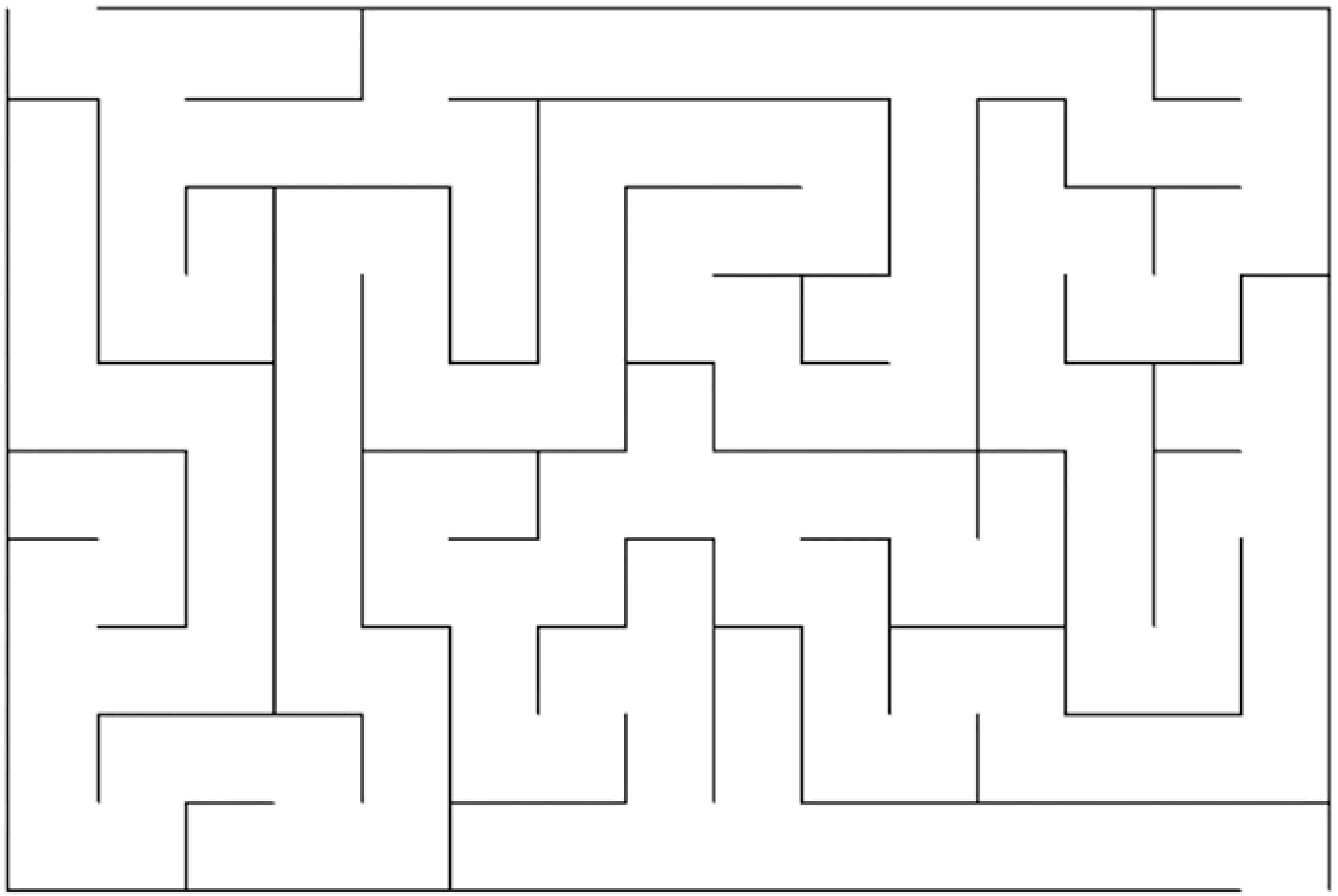
Application of Quantum Computing

Quantum and Quantum-inspired Hardware

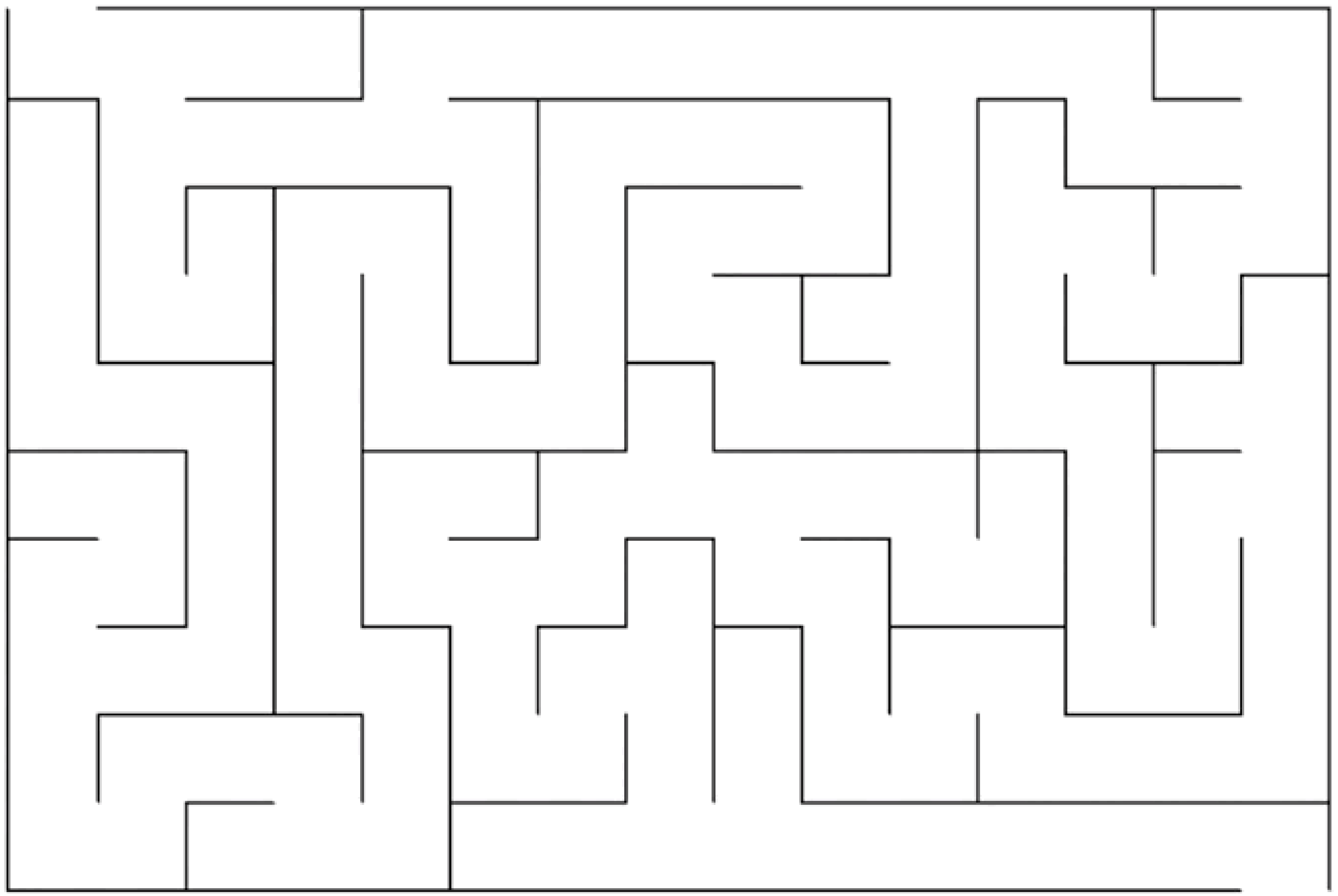


Application of Quantum Computing

Quantum



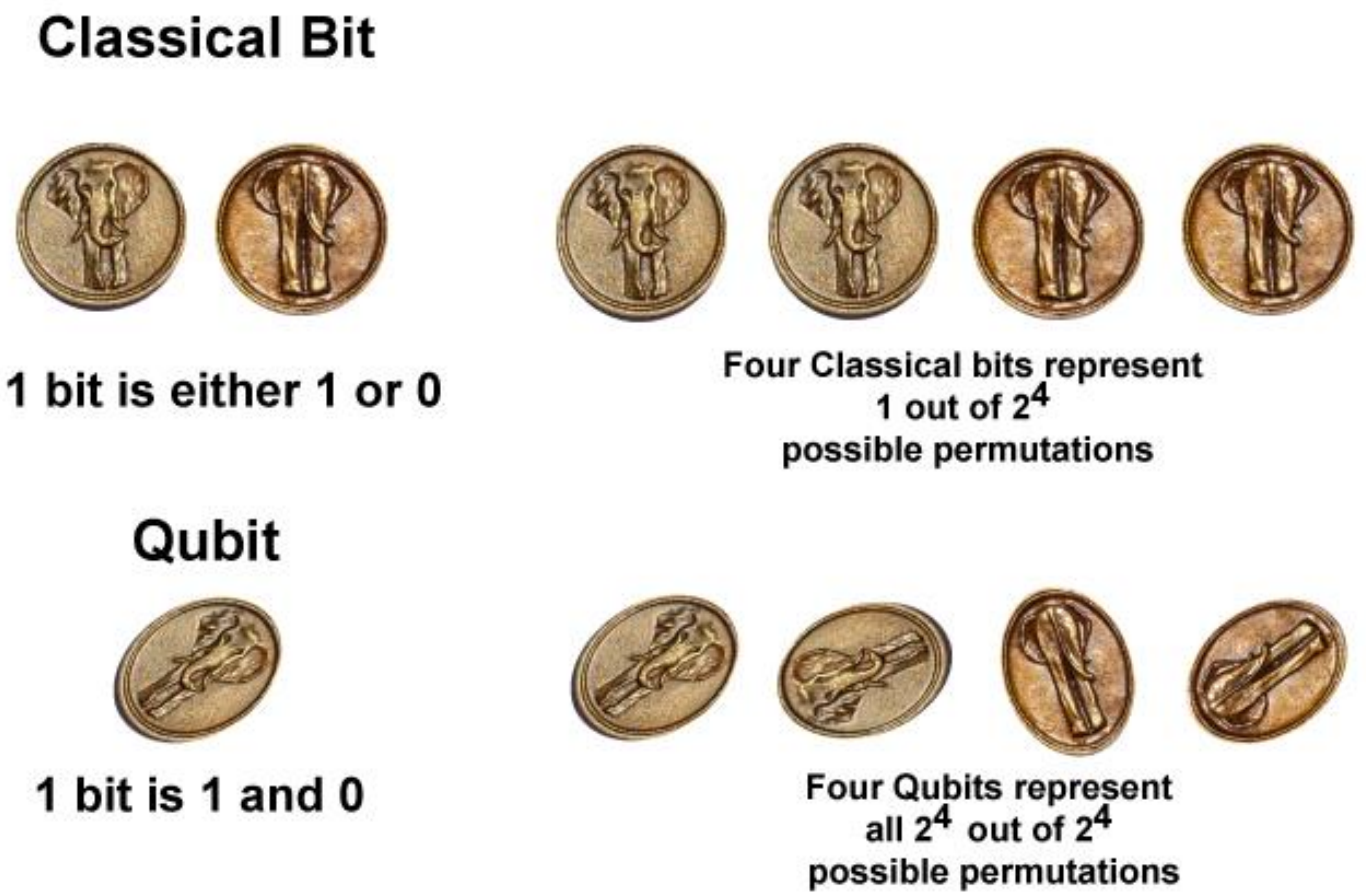
Classical



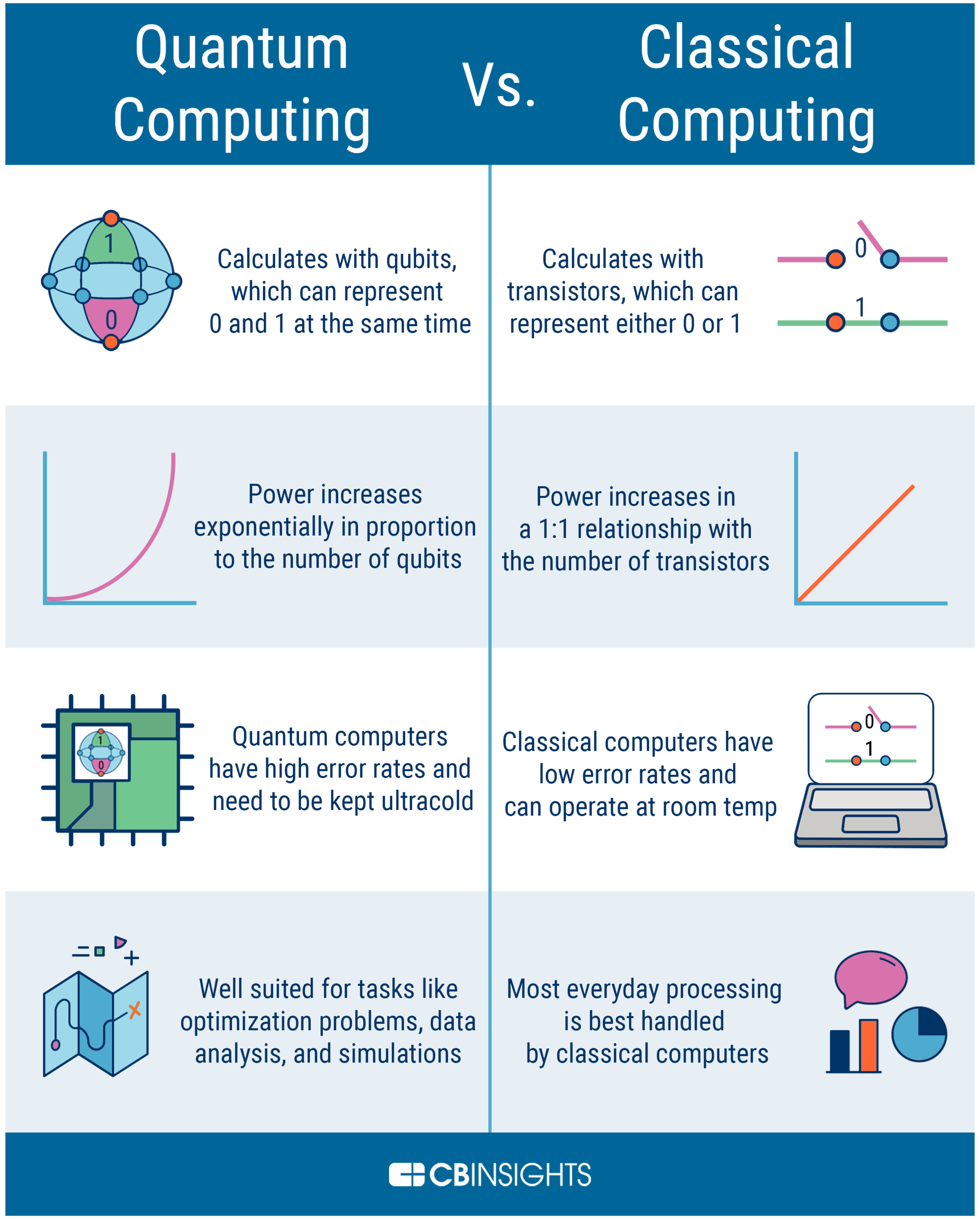
https://becominghuman.ai/quantum-superposition-and-what-that-means-to-quantum-computation-3fbb5a711b9a

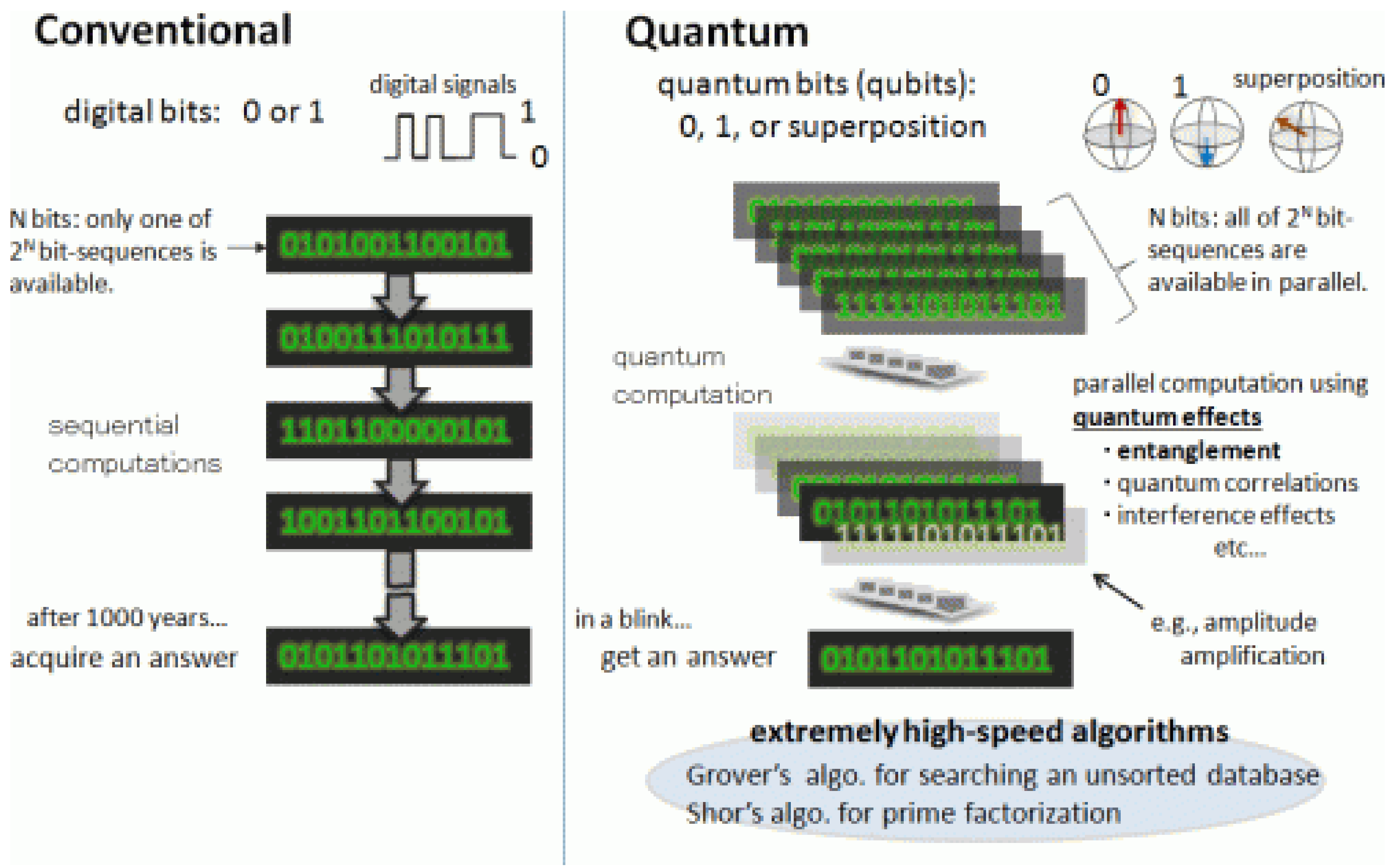
What is Quantum Computer

- A device that harnesses the quantum phenomenon such as superposition and entanglement.



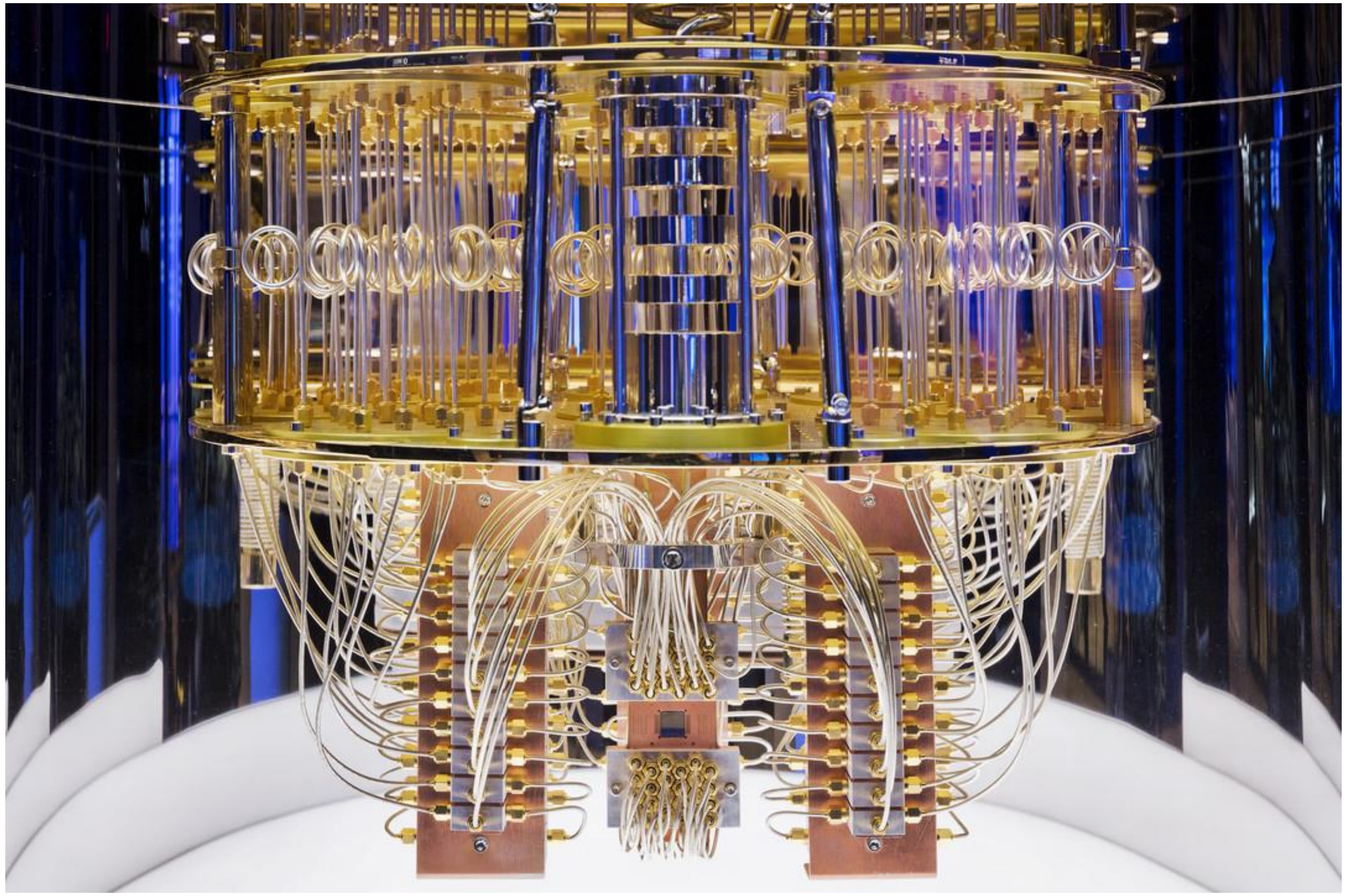
What is Quantum Computer



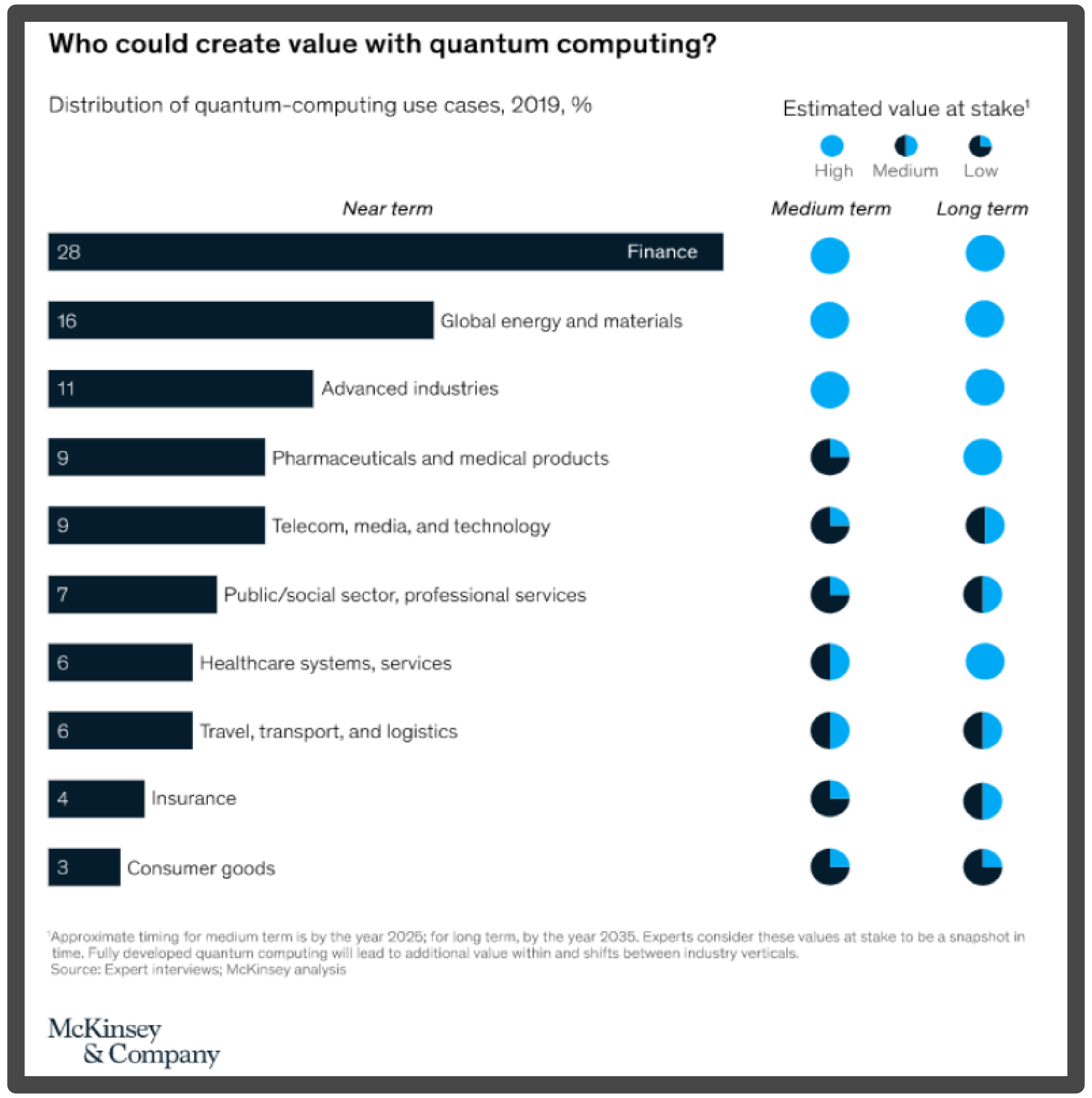


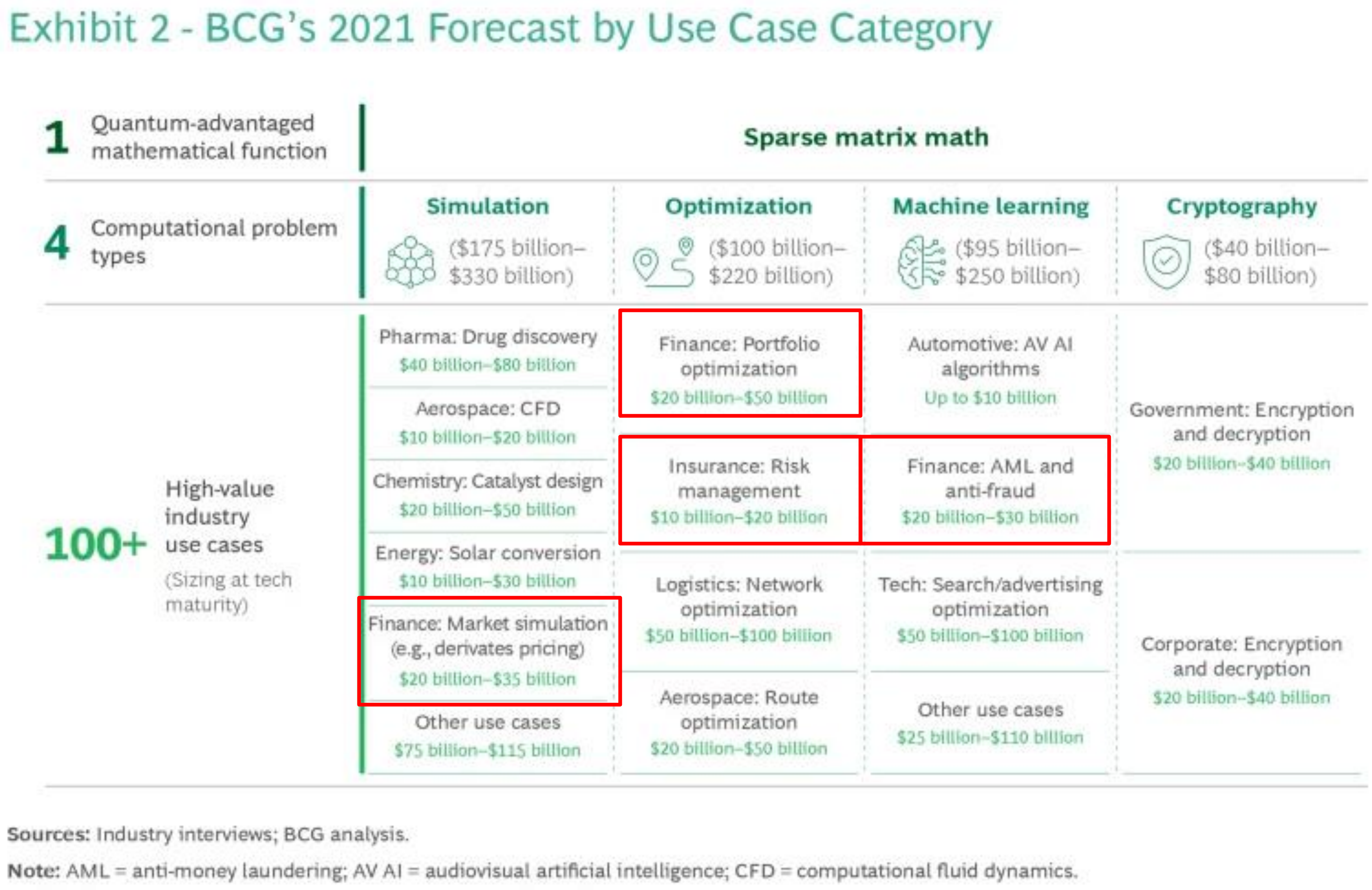
https://phys.org/news/2014-03-entangling-atoms-optical-lattice-quantum.html

2. Applications of Quantum Computing



Application of Quantum Computing in Finance





How will businesses use quantum compute

1. Cut development time for chemicals and pharmaceuticals with simulations
2. Solve optimization problems with unprecedented speed
3. Accelerate autonomous vehicles with quantum AI
4. Transform cybersecurity

Application of Quantum Computing in Finance

Why Quantum, Why Now?

QC presents a $1T to $2T opportunity, with rapid acceleration expected in the coming five to ten years.

Preliminary

Deep dive next   Economic value: + Low ++ Medium +++ High

Industry	Key segment for QC	Economic value[1] ~2025–2030	Economic value[1] ~2030–2035	2035 market size, $ trillion
Financial industry[1]	Financial services	++	+++	14.1
Global energy & materials	Oil and gas	+	++	
	Sustainable energy[2]	+	+++	
	Chemicals	++	+++	6.1
Travel, transport, & logistics	Travel, transport, and logistics	+	+++	14.1
Pharmaceuticals & medical products	Pharmaceuticals	++	+++	3.1
Advanced industries	Automotive	+	++	8.3
	Aerospace and defense	+	++	
	Advanced electronics	+	++	
	Semiconductors	+	++	
Insurance	Insurance	+	++	
Telecommunications, media, & technology	Telecommunications	+	++	
	Media	+	+	
				Total

Value at stake with incremental impact of QC by 2035, $ billion

[1]Quantum computing technologies and industry is immature and has high uncertainty for viability and value of use cases. Business-value estimates are preliminary and intended to guide research toward high-value-potential areas, not as definitive projections for business value. Insurance is not included.
[2]Sustainable energy market is expected to grow rapidly from 2022–2035; however, the 2035 market size is influenced by numerous factors and challenging to predict.

Source: McKinsey analysis; Oxford Economics

[Quantum Technology Monitor 2024]

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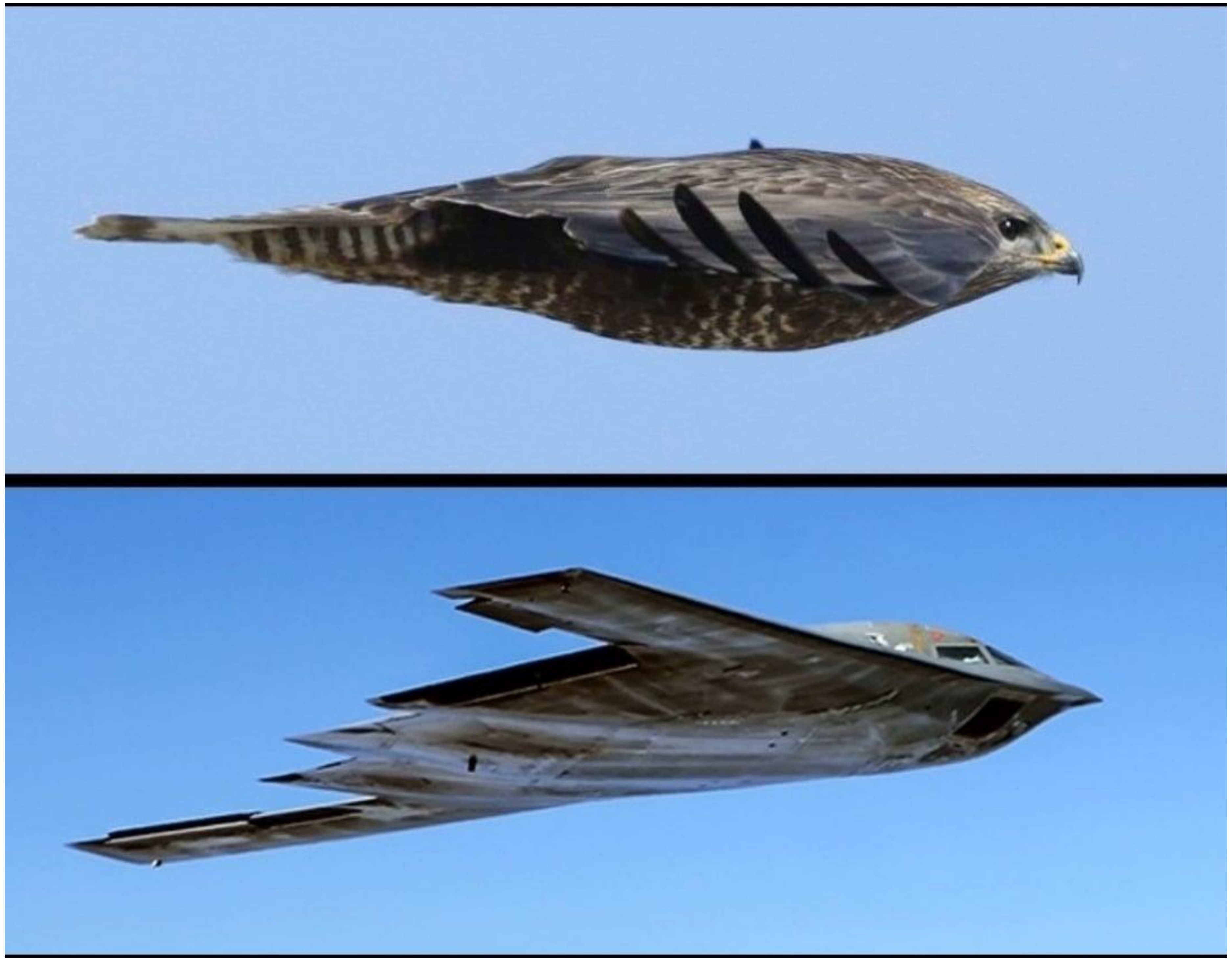
Learning from Nature



Quantum Computing → Real-World Impact

Hybrid Quantum Stack in Action

Applications
- Financial Simulation
- Portfolio Optimization
- ML
- Algorithmic Trading
- Risk management

Modeling
- Quantum Simulation | Quantum Machine Learning | Optimization

Hardware
- Quantum Annealer (D-Wave)
- Gate-based QC (IBM / Quantinuum)
- Simulated Annealer (Fujitsu DAU / Compal CGA)
- GPU Simulator (NVIDIA)

應用	加密與資安 / 投資組合優化 / 風險管理與模擬 / 量子機器學習 / 演算法交易
建模	量子模擬 ｜ 量子神經網路 ｜ 最佳化模型
硬體	量子退火 D-Wave / 量子電腦 IBM / Quantinuum / 模擬退火 Fujitsu DAU / Compal CGA / CUDAQ模擬 NVIDIA

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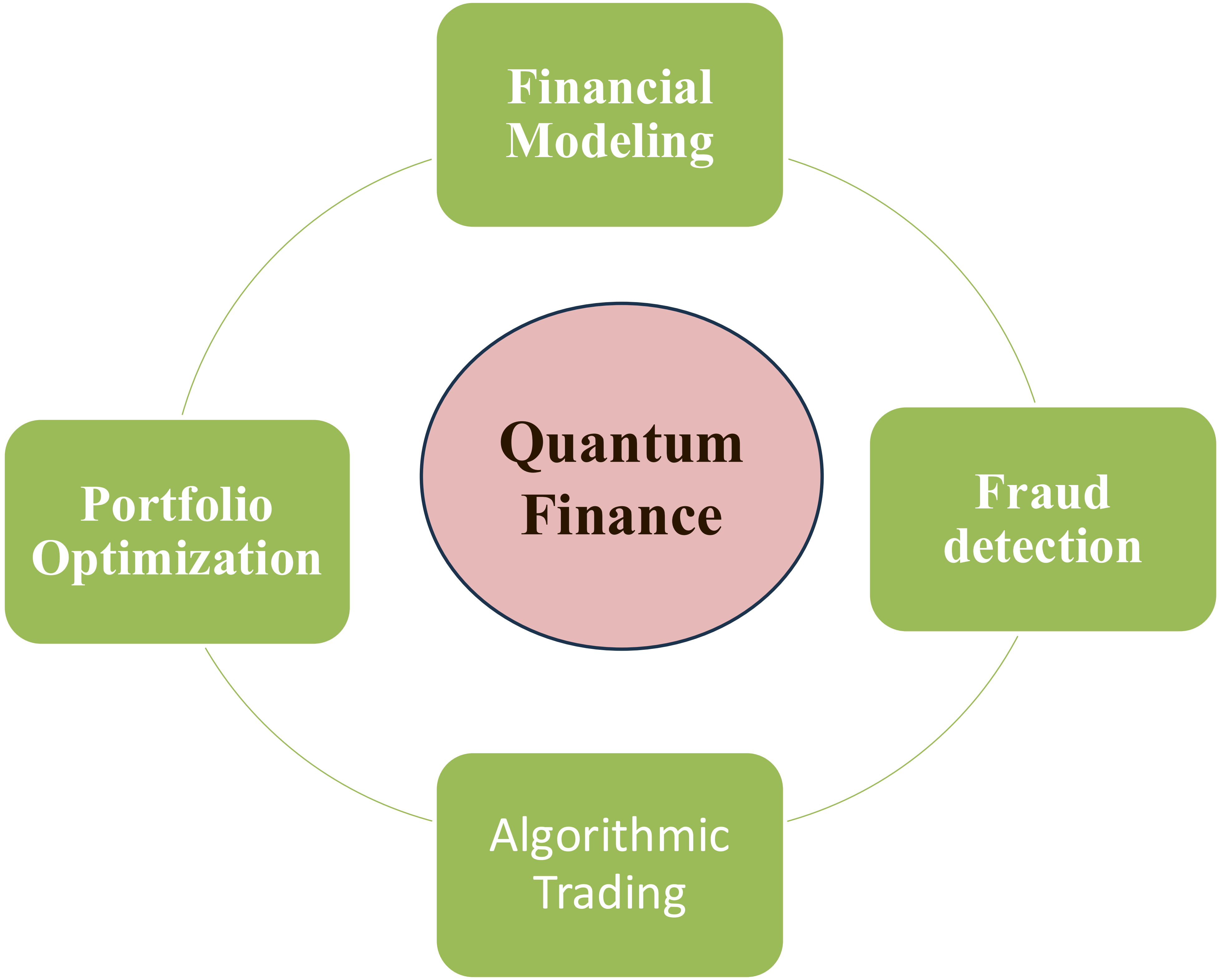

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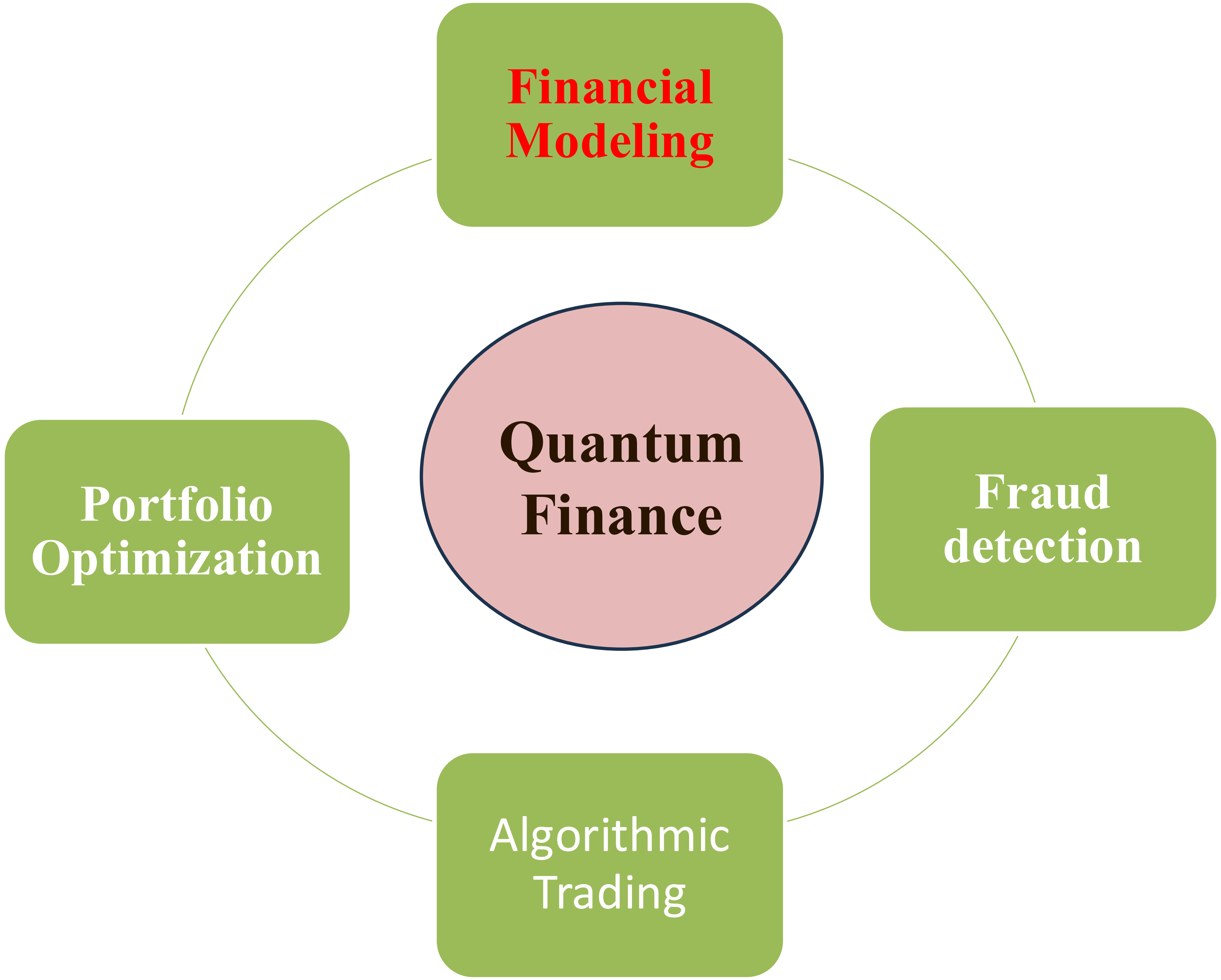


Application of Quantum Computing in Finance

Financial Modeling

MOTIVATION

Why the financial market is super uncertain?

Application of Quantum Computing in Finance

MOTIVATION

Design a quantum model that simulate various investor sentiments to simulate the distribution of short-term prices

Advancing quantum state preparation approach for quantum ML

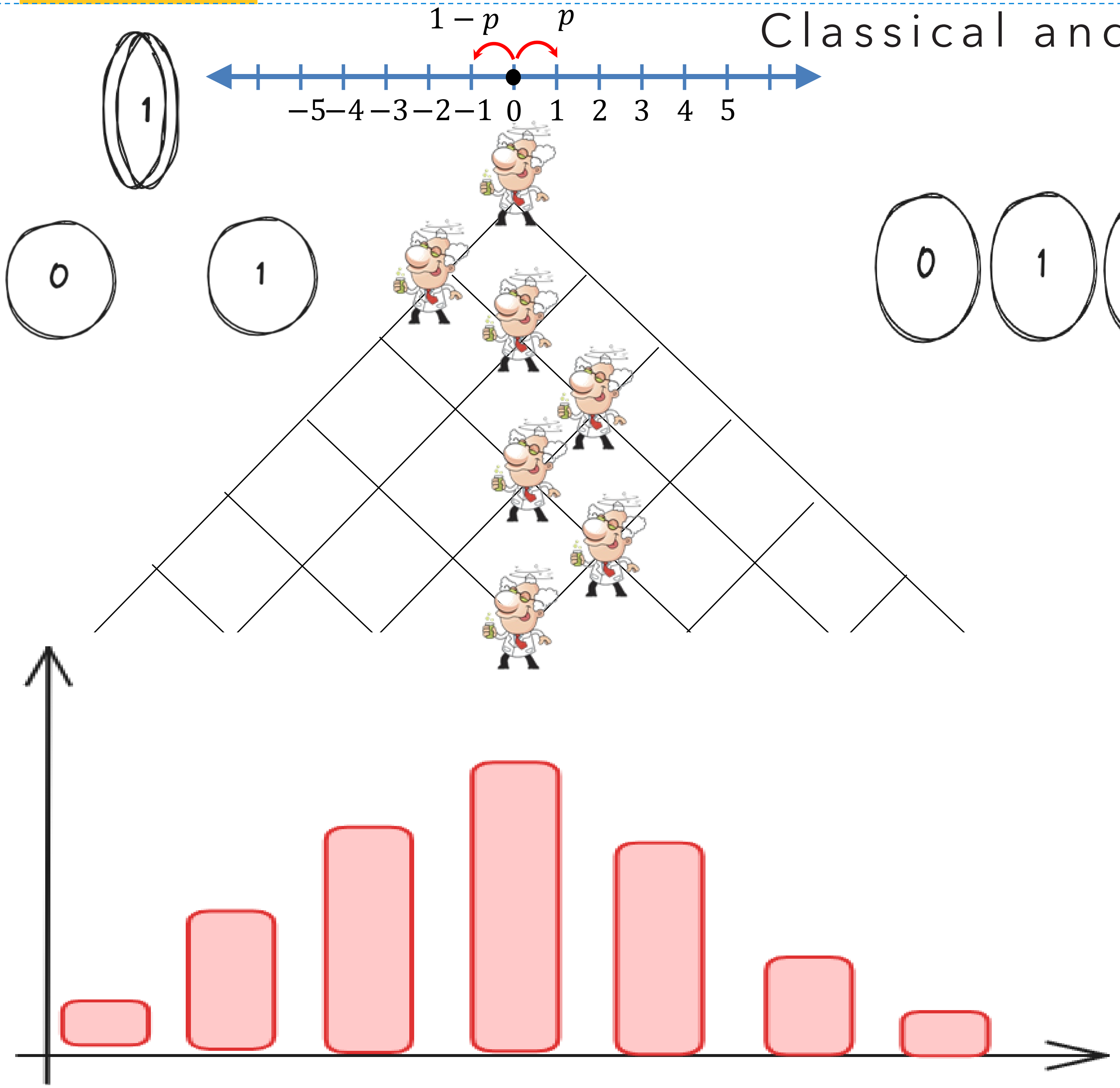
$|\psi_f\rangle = U(\theta)|0\rangle$

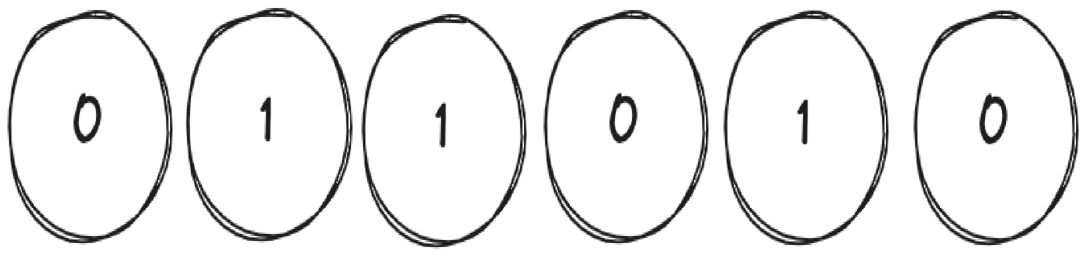
$U(\theta)$:Evolution operation

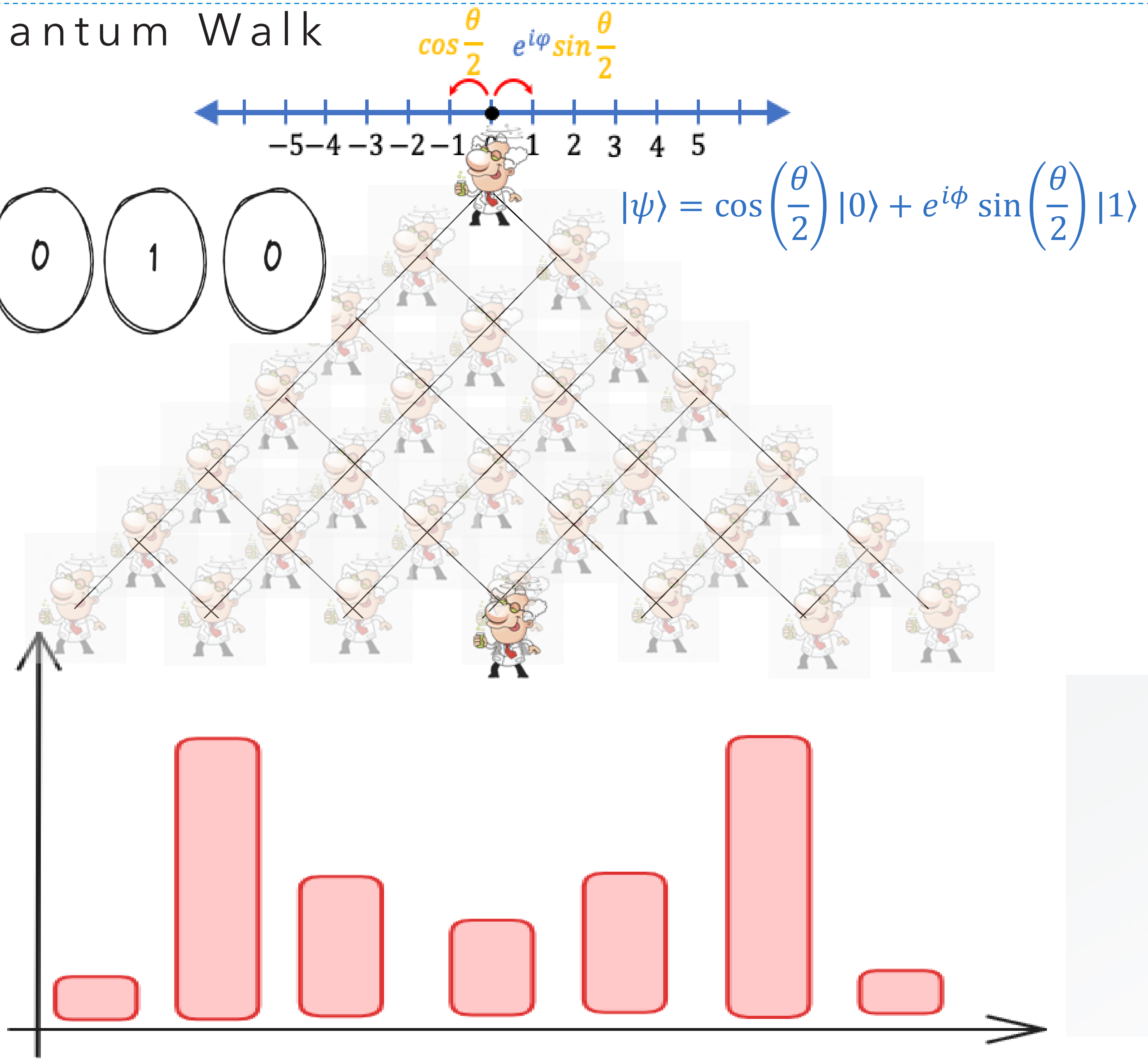
$|\psi_f\rangle$: The specific quantum state that encodes the probability distribution of financial market outcomes

Application of Quantum Computing in Finance

Classical and Quantum Walk







Discrete-Time Quantum Walk

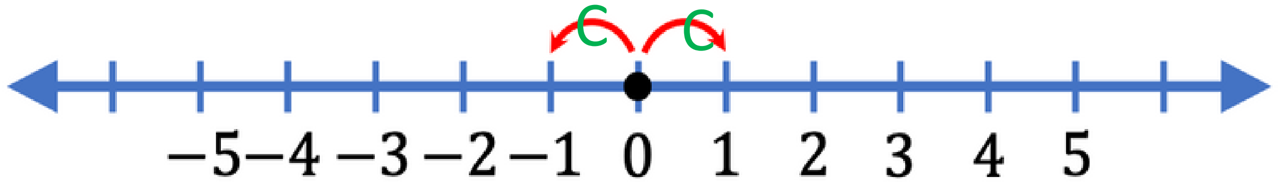
Hilbert space of quantum walk $\mathrm{H} = \mathrm{H}_c \otimes \mathrm{H}_p$, where H_c is the coin Hilbert space and H_p is the position Hilbert space.

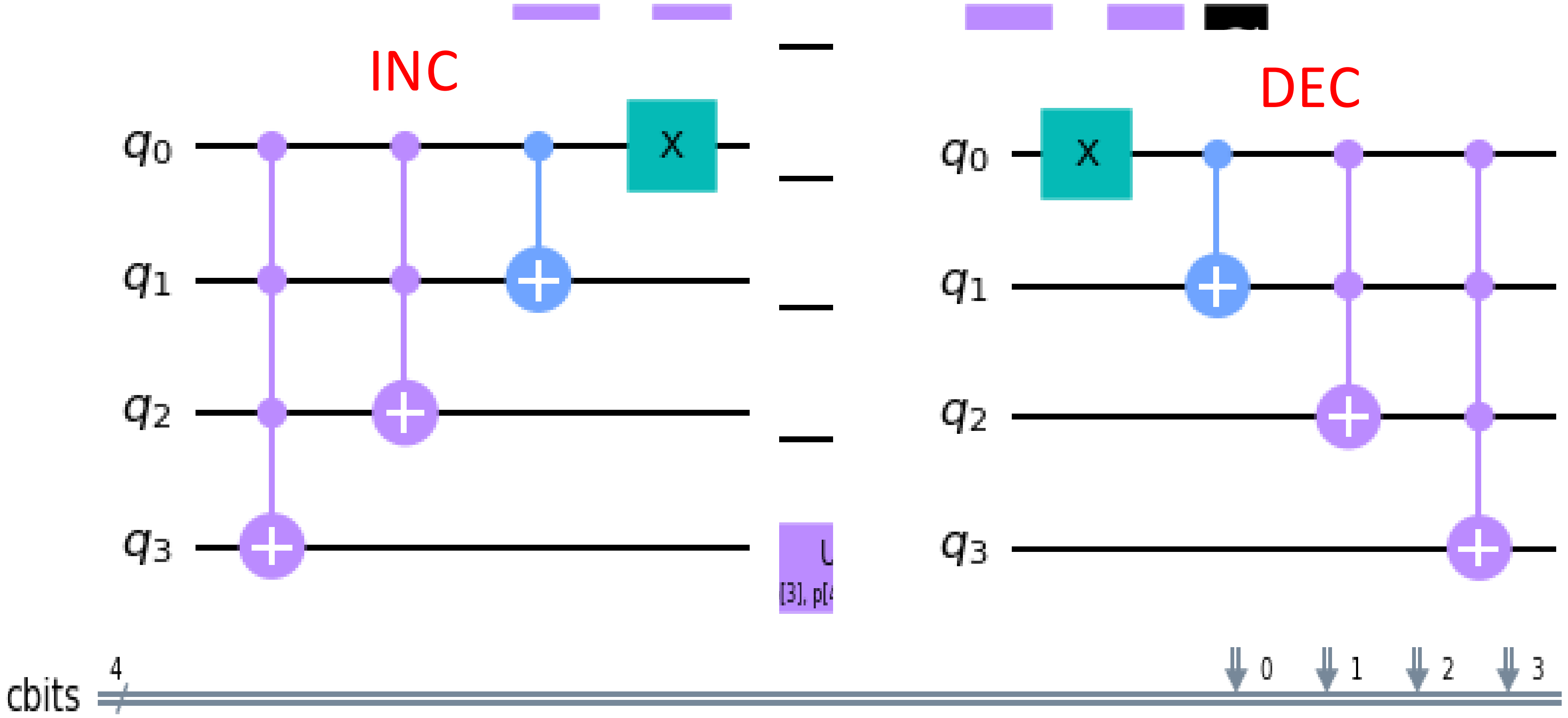
W=SC

$$S = \underbrace{\boxed{|\downarrow\rangle\langle\downarrow| \otimes \sum_x |x-1\rangle\langle x|}}_{\text{DEC}} + \underbrace{\boxed{|\uparrow\rangle\langle\uparrow| \otimes \sum_x |x+1\rangle\langle x|}}_{\text{INC}};$$

$$C = \begin{pmatrix} \cos(\frac{\theta}{2}) & -e^{i\lambda}\sin(\frac{\theta}{2}) \\ e^{i\lambda}\sin(\frac{\theta}{2}) & e^{i(\phi+\lambda)}\cos(\frac{\theta}{2}) \end{pmatrix} \otimes \sum_x |x\rangle\langle x|$$

$$|\psi_f\rangle = W^N\,|\psi_i\rangle;$$





DTQW

QUANTUM CIRCUIT

Introduction-Quantum Walk

Introduction

Quantum walk is the quantum version of classical random walk and harnesses the properties of quantum mechanics to simulate the dynamics of systems.

Types

The discrete-time quantum walk (DTQW) and the continuous-time quantum walk (CTQW).

Innovation

Tuning a QW's coin operators and parameters can provide flexible modeling for complex systems

Discrete-Time Quantum Walk

Hilbert space of quantum walk $\mathrm{H} = \mathrm{H}_c \otimes \mathrm{H}_p$, where H_c is the coin Hilbert space and H_p is the position Hilbert space.

W=SC

$$S = \overset{\text{DEC}}{\boxed{|{\downarrow}\rangle\langle{\downarrow}| \otimes \sum_x |x-1\rangle\langle x|}} + \overset{\text{INC}}{\boxed{|{\uparrow}\rangle\langle{\uparrow}| \otimes \sum_x |x+1\rangle\langle x|;}}$$

$$C = \begin{pmatrix} \cos(\frac{\theta}{2}) & -e^{i\lambda}\sin(\frac{\theta}{2}) \\ e^{i\lambda}\sin(\frac{\theta}{2}) & e^{i(\phi+\lambda)}\cos(\frac{\theta}{2}) \end{pmatrix} \otimes \sum_x |x\rangle\langle x|$$

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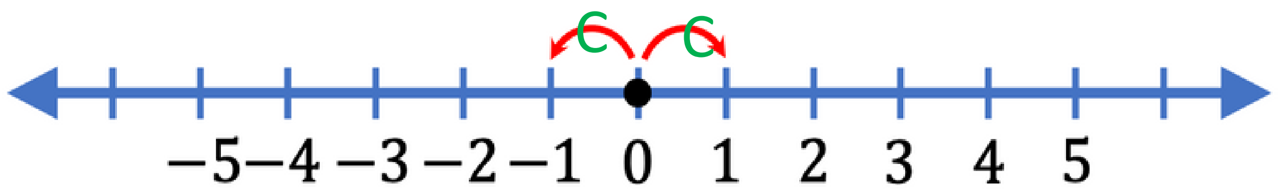
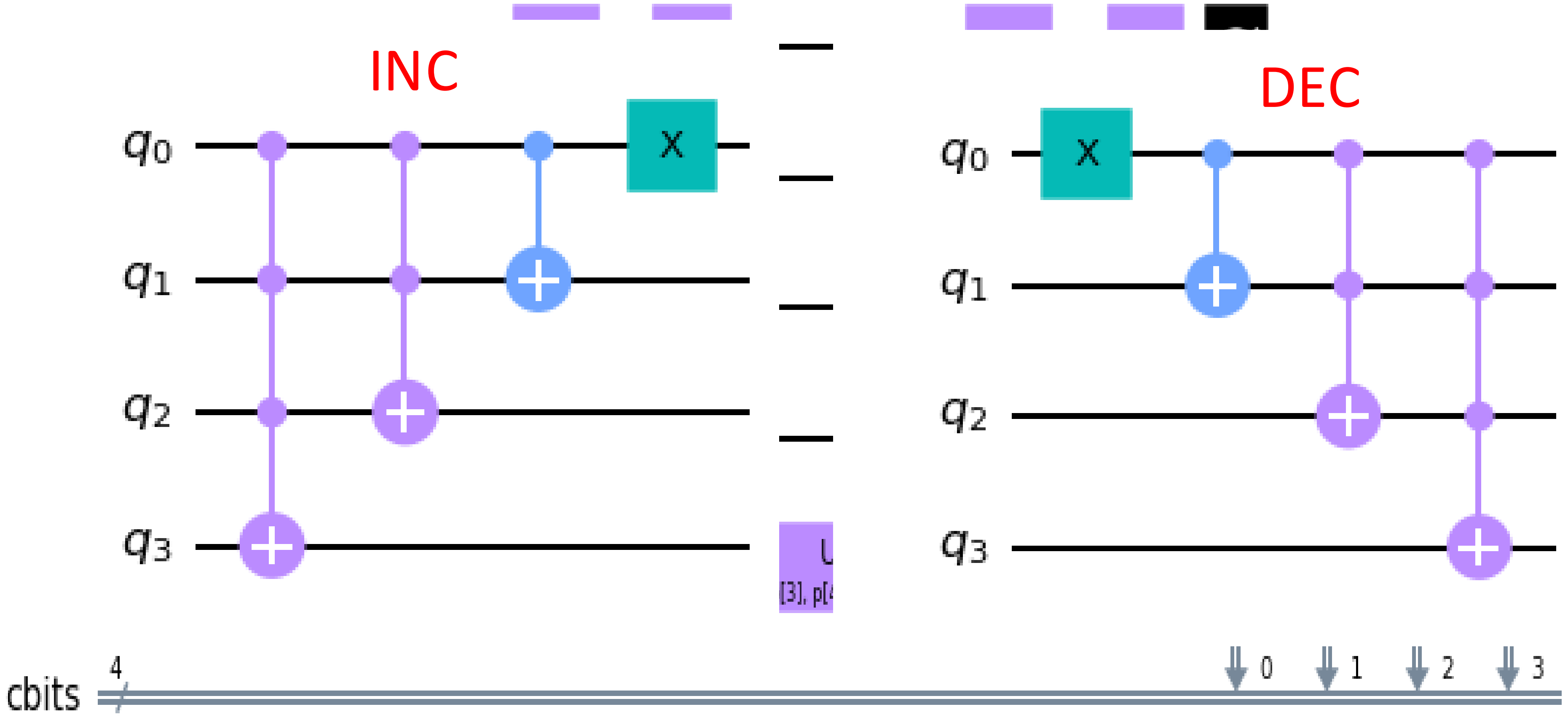




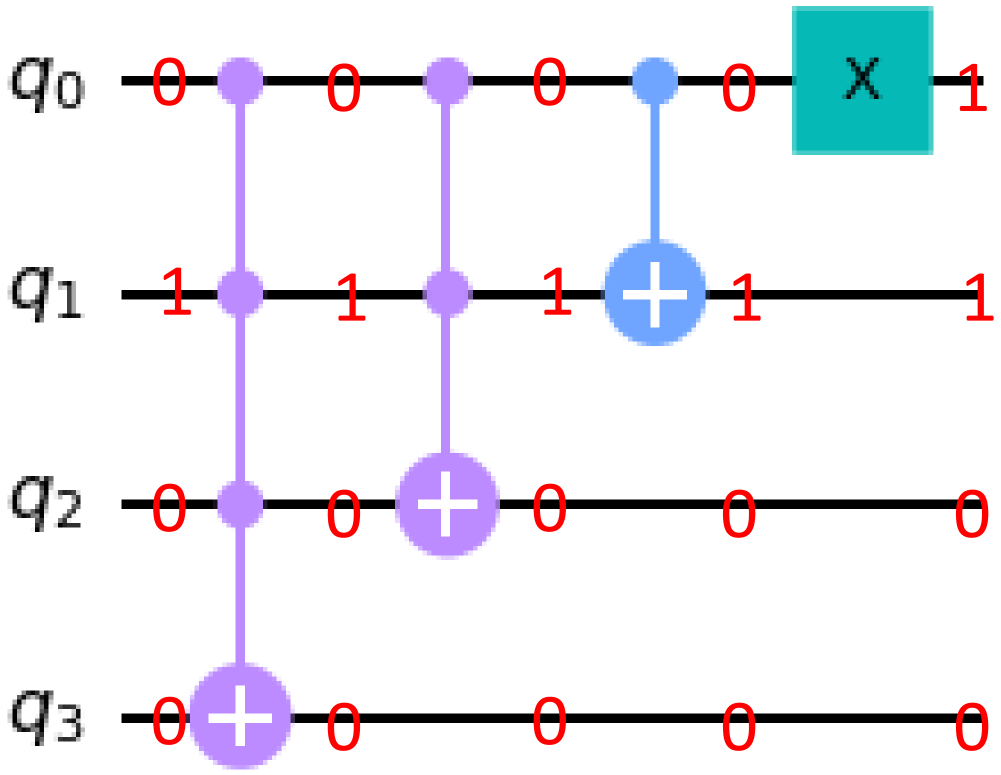
DTQW

QUANTUM CIRCUIT

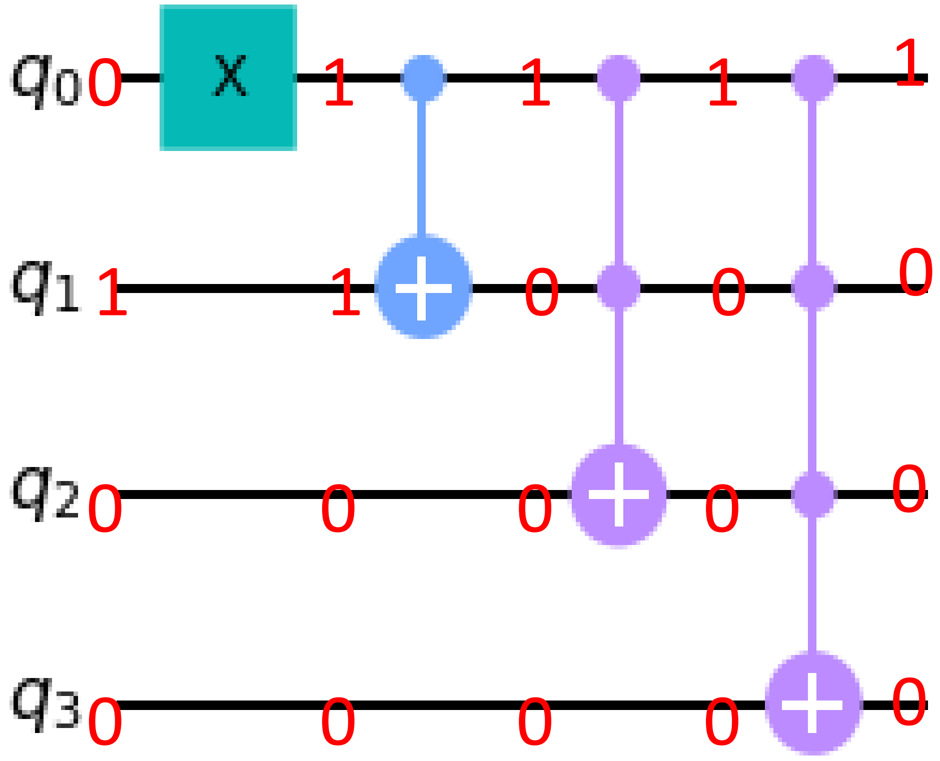
Discrete-Time Quantum Walk

For example: $|2\rangle = |0010\rangle$ $(|q_3q_2q_1q_0\rangle)$

INC



DEC

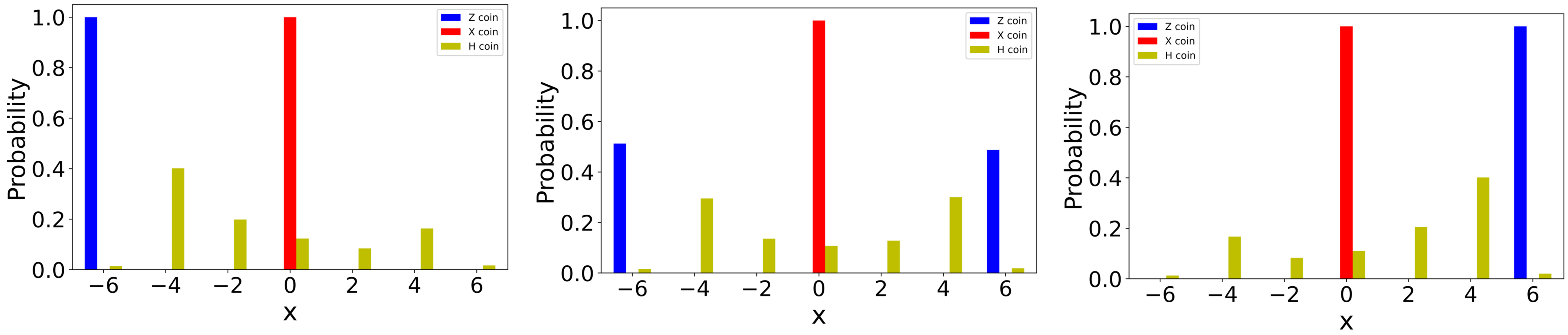


$|0011\rangle = |3\rangle$

$|0001\rangle = |1\rangle$

Preliminary Experiments on DTQW

$$H = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}, X = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}, Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

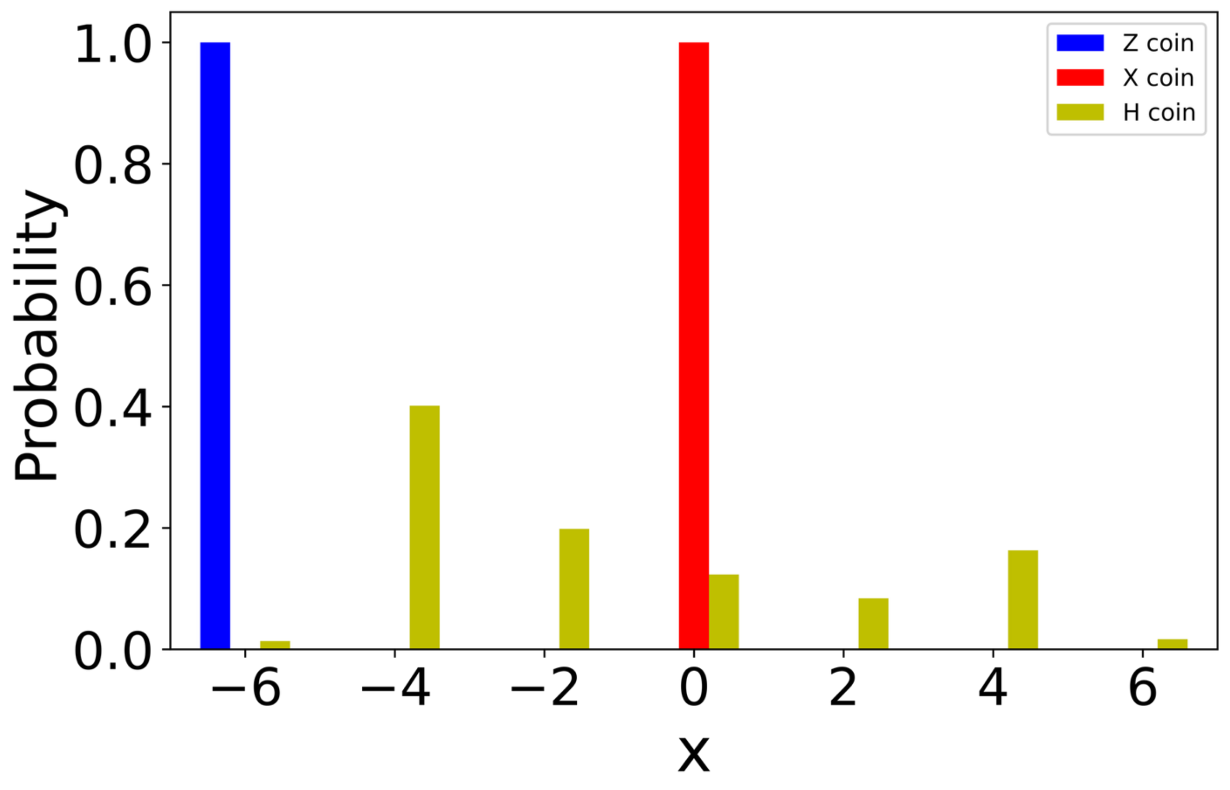


$$|\Psi(0)\rangle = |\downarrow\rangle \otimes |x = 0\rangle$$

$$|\Psi(0)\rangle = \frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x = 0\rangle$$

$$|\Psi(0)\rangle = |\uparrow\rangle \otimes |x = 0\rangle$$

Demonstration



$|\Psi(0)\rangle = |\downarrow\rangle \otimes |x=0\rangle$

$$\boxed{X|\uparrow\rangle = |\downarrow\rangle, X|\downarrow\rangle = |\uparrow\rangle}$$

$$W = S \otimes X, |\Psi(0)\rangle = |\downarrow\rangle \otimes |x=0\rangle$$

$$|\Psi(1)\rangle = (S \otimes X)(|\downarrow\rangle \otimes |x=0\rangle) = S(|\uparrow\rangle \otimes |x=0\rangle)$$

$$= (|\uparrow\rangle \otimes |x=1\rangle)$$

$$|\Psi(2)\rangle = (S \otimes X)(|\uparrow\rangle \otimes |x=1\rangle) = S(|\downarrow\rangle \otimes |x=1\rangle)$$

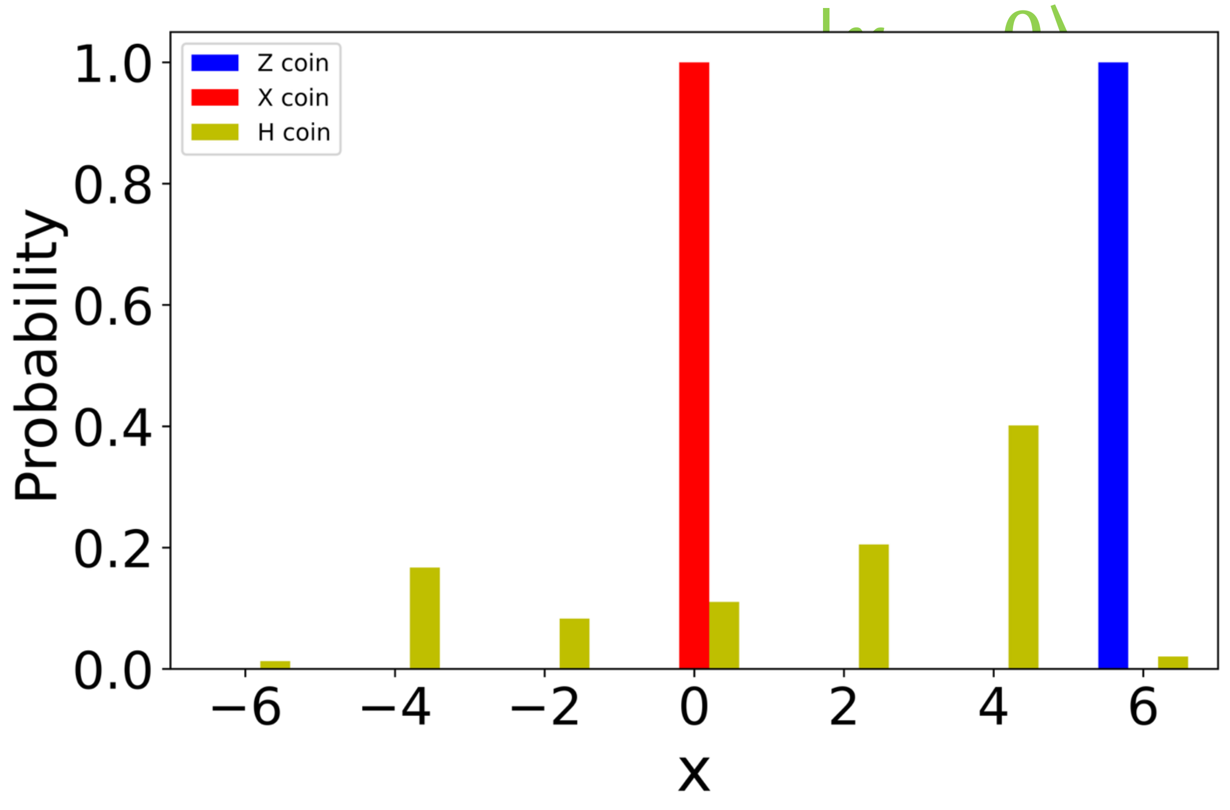
$$= (|\downarrow\rangle \otimes |x=0\rangle)$$

$$|\Psi(2k+1)\rangle = (|\uparrow\rangle \otimes |x=1\rangle$$

$$|\Psi(2k)\rangle = (|\downarrow\rangle \otimes |x=0\rangle$$

Demonstration

Exercises: X *on* $|\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle$ *and* $\frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle$



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$$W = S \otimes X, |\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle$$

$$|\Psi(1)\rangle = (S \otimes X)(|\uparrow\rangle \otimes |x=0\rangle) = S(|\downarrow\rangle \otimes |x=0\rangle)$$

$$= (|\downarrow\rangle \otimes |x=-1\rangle)$$

$$|\Psi(2)\rangle = (S \otimes X)(|\downarrow\rangle \otimes |x=-1\rangle) = S(|\uparrow\rangle \otimes |x=0\rangle)$$

$$= (|\uparrow\rangle \otimes |x=0\rangle)$$

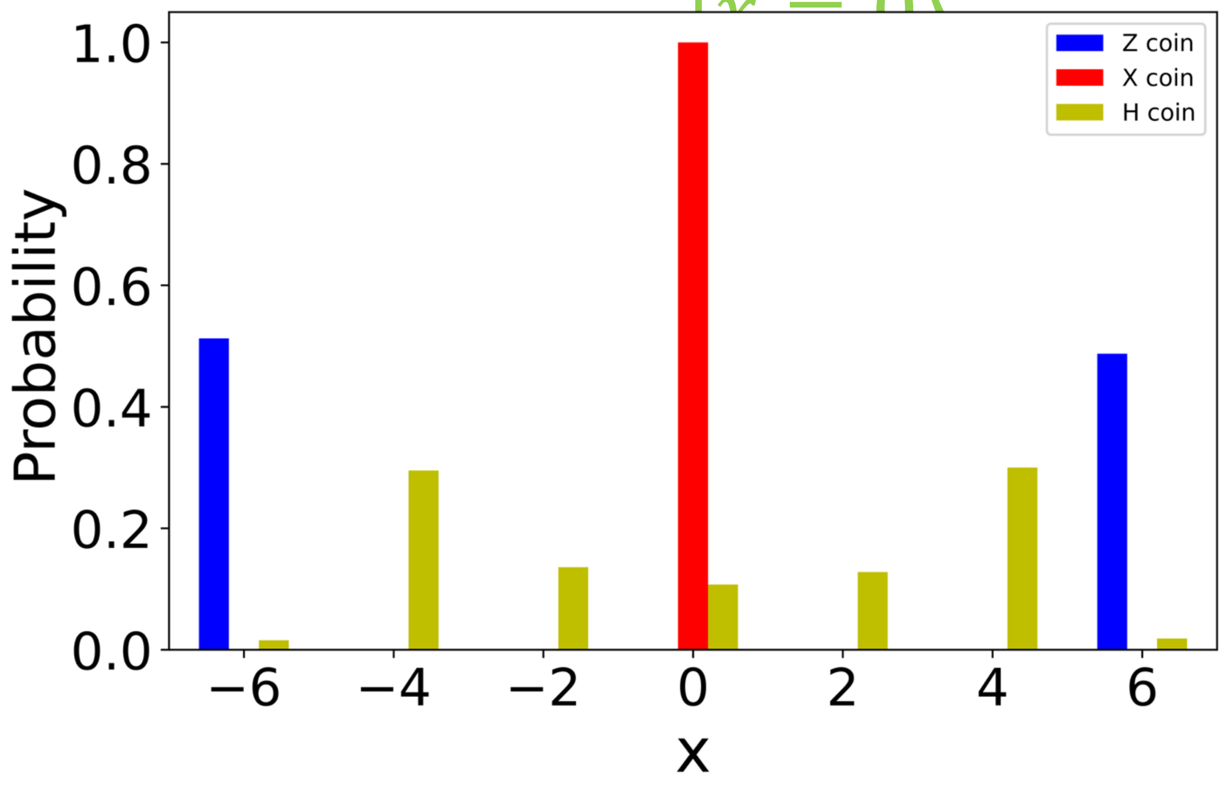
$$\boxed{|\Psi(2k+1)\rangle = (|\downarrow\rangle \otimes |x=-1\rangle}$$

$$\boxed{|\Psi(2k)\rangle = (|\uparrow\rangle \otimes |x=0\rangle}$$

$$\boxed{X|\uparrow\rangle = |\downarrow\rangle, X|\downarrow\rangle = |\uparrow\rangle}$$

Demonstration

Exercises: X on $|\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle$ and $\frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle$



$$|\Psi(0)\rangle = \frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle$$

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$$|\Psi(1)\rangle = (S \otimes X)(\frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle)$$

$$= S(\frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=0\rangle)$$

$$= \frac{1}{\sqrt{2}}\left(|\uparrow\rangle \otimes |x=1\rangle + \frac{1}{\sqrt{2}}|\downarrow\rangle\right) \otimes |x=-1\rangle)$$

$$|\Psi(2)\rangle = (S \otimes X)(\frac{1}{\sqrt{2}}\left(|\uparrow\rangle \otimes |x=1\rangle + \frac{1}{\sqrt{2}}|\downarrow\rangle\right) \otimes |x=-1\rangle))$$

$$= S(\frac{1}{\sqrt{2}}\left(|\downarrow\rangle \otimes |x=1\rangle + \frac{1}{\sqrt{2}}|\uparrow\rangle\right) \otimes |x=-1\rangle))$$

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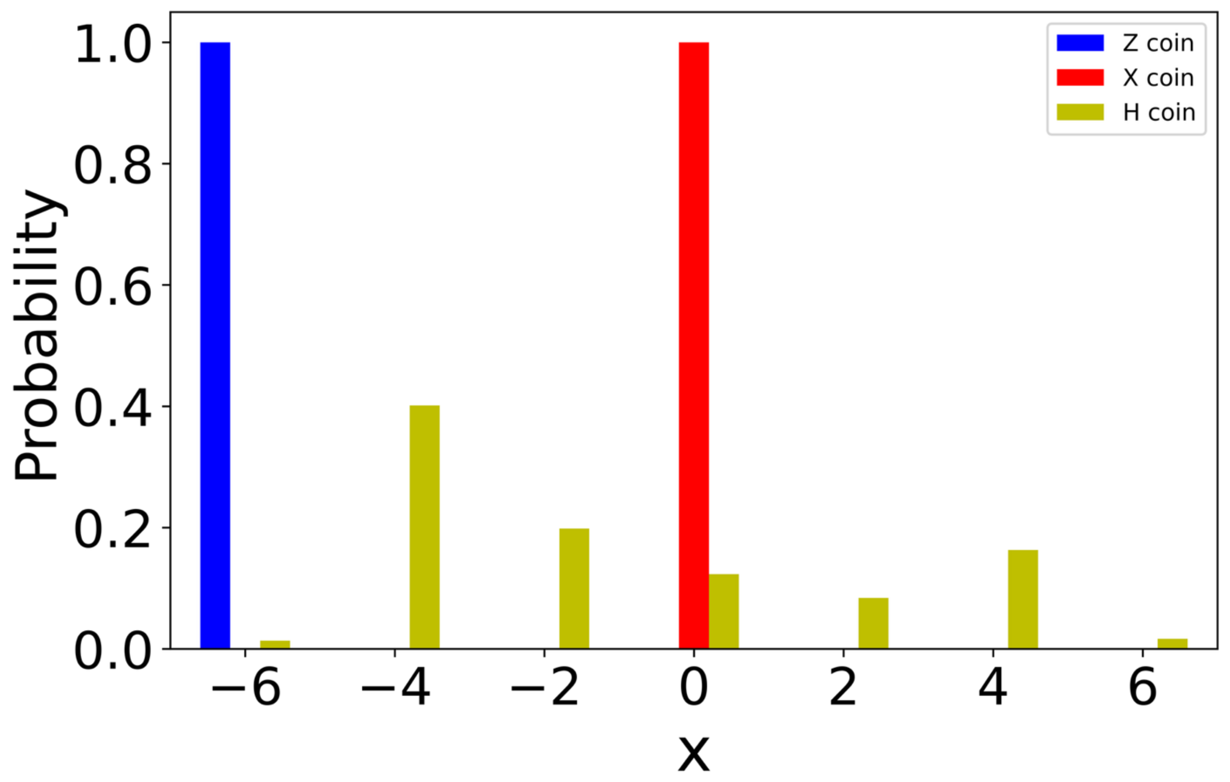
Demonstration



$$W = S \otimes Z, |\Psi(0)\rangle = |\downarrow\rangle \otimes |x=0\rangle$$

$$|\Psi(1)\rangle = (S \otimes Z)(|\downarrow\rangle \otimes |x=0\rangle) = S(-|\downarrow\rangle \otimes |x=0\rangle)$$

$$= (-|\downarrow\rangle \otimes |x=-1\rangle)$$

$$|\Psi(2)\rangle = (S \otimes Z)(-|\downarrow\rangle \otimes |x=-1\rangle) = S(|\downarrow\rangle \otimes |x=-1\rangle)$$

$$= (|\downarrow\rangle \otimes |x=-2\rangle)$$

$$|\Psi(k)\rangle = (-1)^k|\downarrow\rangle \otimes |x=-k\rangle$$

$$|\Psi(0)\rangle = |\downarrow\rangle \otimes |x=0\rangle$$

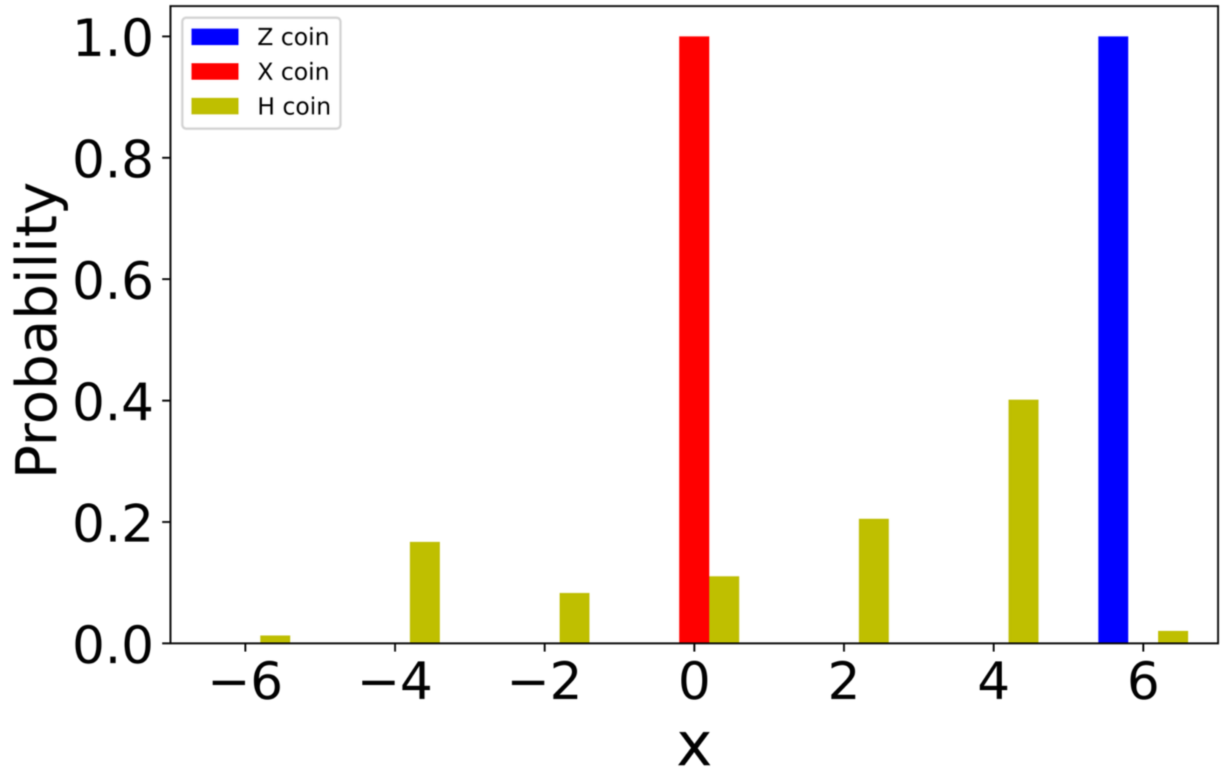
$$Z|\uparrow\rangle = |\uparrow\rangle, \qquad Z|\downarrow\rangle = -|\downarrow\rangle$$

Exercises:

$$: Zon|\Psi(0)\rangle = \frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle and |\uparrow\rangle\, |x=0\rangle$$

Demonstration

Exercises: $Z\ on\ |\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle\ and\ \frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle$



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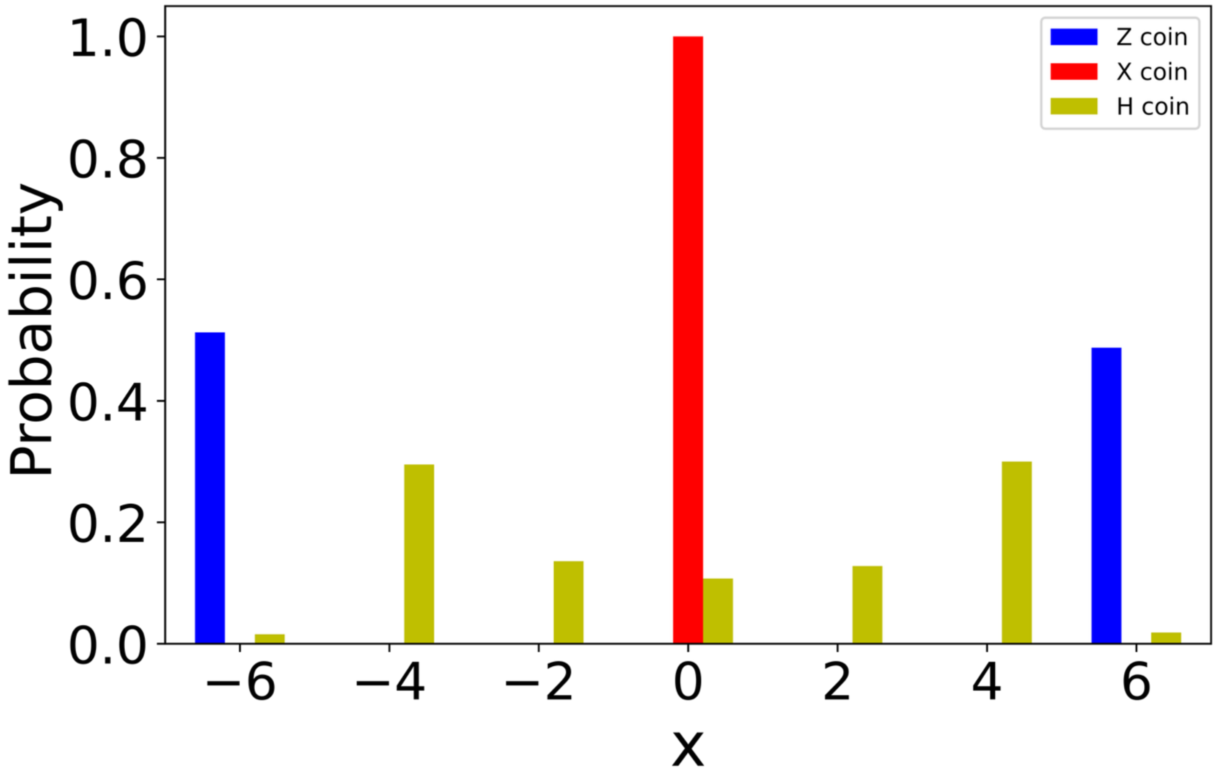
Demonstration

Exercises: $Z \ on \ |\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle \ and \ \frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle$



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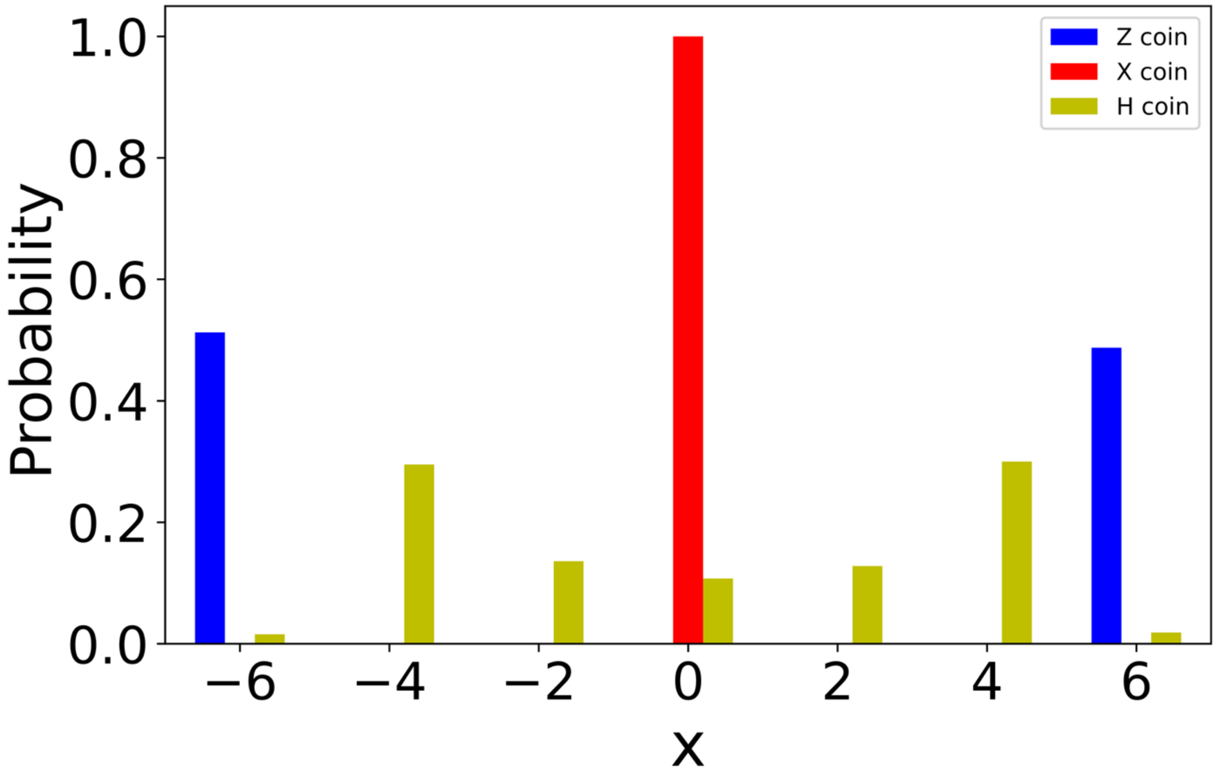

$$|\Psi(0)\rangle = \frac{1}{\sqrt{2}}(|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle$$

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$$= S(\frac{1}{\sqrt{2}}(-|\downarrow\rangle + |\uparrow\rangle) \otimes |x=0\rangle)$$

$$= \frac{1}{\sqrt{2}}(-|\downarrow\rangle \otimes |x=-1\rangle + |\uparrow\rangle) \otimes |x=1\rangle)$$

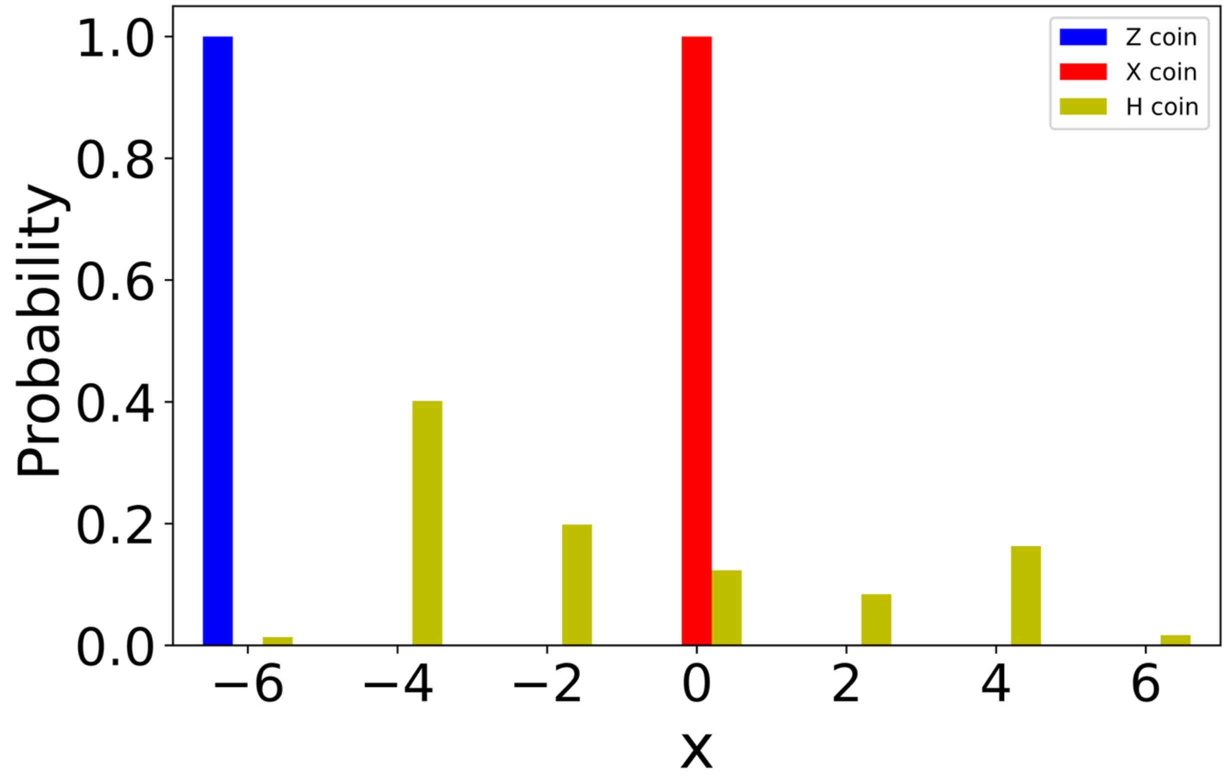
$$|\Psi(2)\rangle = (S \otimes Z)(\frac{1}{\sqrt{2}}(-|\downarrow\rangle \otimes |x=-1\rangle + |\uparrow\rangle) \otimes |x=1\rangle)$$

$$= S(\frac{1}{\sqrt{2}}(|\downarrow\rangle \otimes |x=-1\rangle + |\uparrow\rangle) \otimes |x=1\rangle)$$

$$= \frac{1}{\sqrt{2}}(|\downarrow\rangle \otimes |x=-2\rangle + |\uparrow\rangle) \otimes |x=2\rangle)$$

$$\boxed{|\Psi(k)\rangle = \frac{1}{\sqrt{2}}\big((-1)^k|\downarrow\rangle \otimes |x=-k\rangle + |\uparrow\rangle\big) \otimes |x=k\rangle)}$$

Demonstration



$$|\Psi(0)\rangle = |\downarrow\rangle \otimes |x=0\rangle$$

$$H|\uparrow\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle)$$

$$H|\downarrow\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle - |\downarrow\rangle)$$

$$Excercise: Finish\ all\ the\ steps\ to\ the\ 3\ different\ state$$

$$W = S \otimes H, |\Psi(0)\rangle = |\downarrow\rangle \otimes |x=0\rangle$$

$$|\Psi(1)\rangle = (S \otimes H)(|\downarrow\rangle \otimes |x=0\rangle) = S(\tfrac{1}{\sqrt{2}}(|\uparrow\rangle - |\downarrow\rangle) \otimes |x=0\rangle)$$

$$= (\tfrac{1}{\sqrt{2}}|\uparrow\rangle \otimes |x=1\rangle - \tfrac{1}{\sqrt{2}}|\downarrow\rangle \otimes |x=-1\rangle)$$

$$|\Psi(2)\rangle = (S \otimes H)(\frac{1}{\sqrt{2}}|\uparrow\rangle \otimes |x=1\rangle - \frac{1}{\sqrt{2}}|\downarrow\rangle \otimes |x=-1\rangle)$$

$$= S(\frac{1}{2}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=1\rangle - \frac{1}{2}(|\uparrow\rangle - |\downarrow\rangle) \otimes |x=-1\rangle)$$

$$= \frac{1}{2}|\uparrow\rangle \otimes |x=2\rangle + \frac{1}{2}|\downarrow\rangle \otimes |x=0\rangle - \frac{1}{2}|\uparrow\rangle \otimes |x=0\rangle + \frac{1}{2}|\downarrow\rangle \otimes |x=-2\rangle)$$

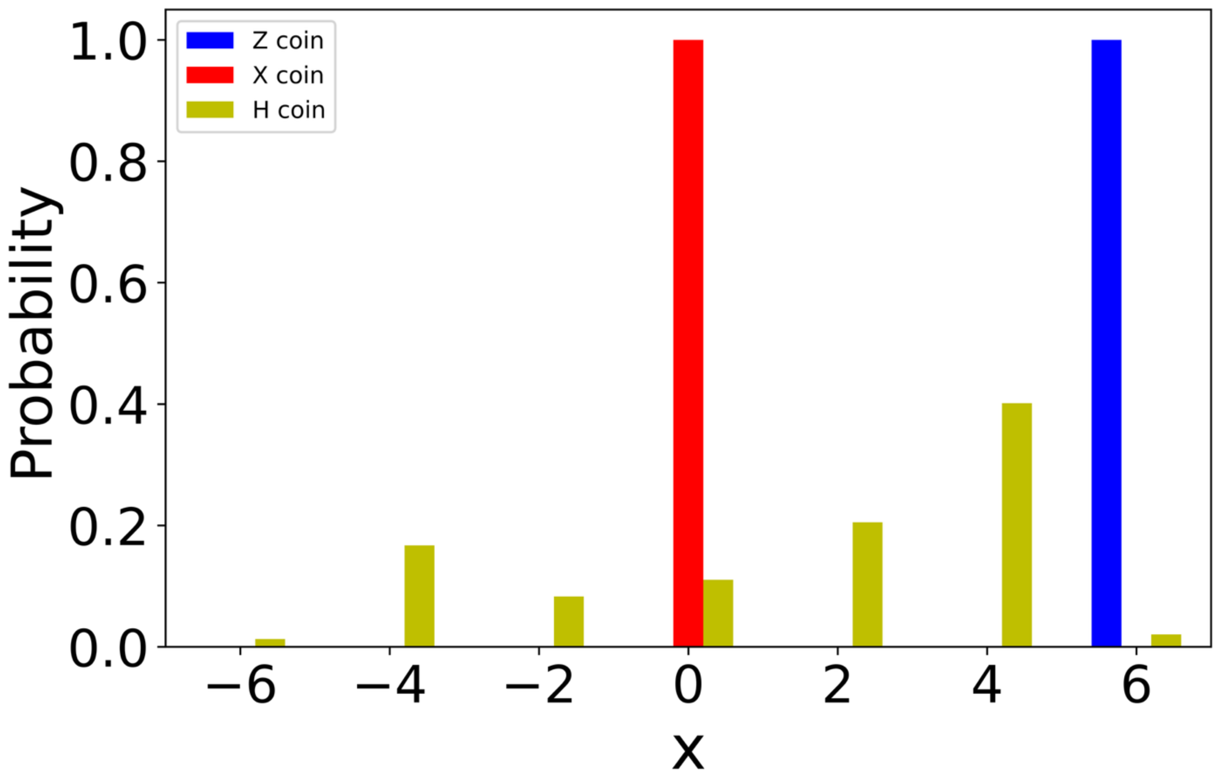
$$= \frac{1}{2}\left(|\uparrow\rangle \otimes |x=2\rangle - \frac{1}{2}(|\uparrow\rangle - |\downarrow\rangle\right) \otimes |x=0\rangle + \frac{1}{2}|\downarrow\rangle) \otimes |x=-2\rangle)$$

$$|\Psi(3)\rangle = S\left(\frac{1}{2\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=2\rangle - \frac{1}{\sqrt{2}}|\downarrow\rangle \otimes |x=0\rangle + \frac{1}{2\sqrt{2}}(|\uparrow\rangle - |\downarrow\rangle) \otimes |x=-2\rangle\right)$$

$$= \tfrac{1}{2\sqrt{2}}|\uparrow\rangle \otimes |x=3\rangle + \tfrac{1}{2\sqrt{2}}|\downarrow\rangle \otimes |x=1\rangle + (-\tfrac{1}{\sqrt{2}}|\downarrow\rangle + \tfrac{1}{2\sqrt{2}}|\uparrow\rangle) \otimes |x=-1\rangle$$

$$- \tfrac{1}{2\sqrt{2}}|\downarrow\rangle \otimes |x=-3\rangle$$

Demonstration



$$|\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle$$

$$H|\uparrow\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle)$$

$$H|\downarrow\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle - |\downarrow\rangle)$$

$$W = S \otimes H, |\Psi(0)\rangle = |\uparrow\rangle \otimes |x=0\rangle$$

$$|\Psi(1)\rangle = (S \otimes H)(|\uparrow\rangle \otimes |x=0\rangle) = S(\frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=0\rangle)$$

$$= (\frac{1}{\sqrt{2}}|\uparrow\rangle \otimes |x=1\rangle + \frac{1}{\sqrt{2}}|\downarrow\rangle \otimes |x=-1\rangle)$$

$$|\Psi(2)\rangle = (S \otimes H)(\frac{1}{\sqrt{2}}|\uparrow\rangle \otimes |x=1\rangle + \frac{1}{\sqrt{2}}|\downarrow\rangle \otimes |x=-1\rangle)$$

$$= S(\frac{1}{2}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=1\rangle + \frac{1}{2}(|\uparrow\rangle - |\downarrow\rangle) \otimes |x=-1\rangle)$$

$$= \frac{1}{2}|\uparrow\rangle \otimes |x=2\rangle + \frac{1}{2}|\downarrow\rangle \otimes |x=0\rangle + \frac{1}{2}|\uparrow\rangle \otimes |x=0\rangle - \frac{1}{2}|\downarrow\rangle \otimes |x=-2\rangle)$$

$$= \frac{1}{2}(|\uparrow\rangle \otimes |x=2\rangle - \frac{1}{2}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=0\rangle - \frac{1}{2}|\downarrow\rangle) \otimes |x=-2\rangle)$$

$$|\Psi(3)\rangle = S\left(\frac{1}{2\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle) \otimes |x=2\rangle + \frac{1}{\sqrt{2}}|\uparrow\rangle \otimes |x=0\rangle - \frac{1}{2\sqrt{2}}(|\uparrow\rangle - |\downarrow\rangle) \otimes |x=-2\rangle\right)$$

$$= \frac{1}{2\sqrt{2}}|\uparrow\rangle \otimes |x=3\rangle + \left(\frac{1}{\sqrt{2}}|\uparrow\rangle + \frac{1}{2\sqrt{2}}|\downarrow\rangle\right) \otimes |x=1\rangle - \frac{1}{2\sqrt{2}}|\downarrow\rangle) \otimes |x=-1\rangle$$

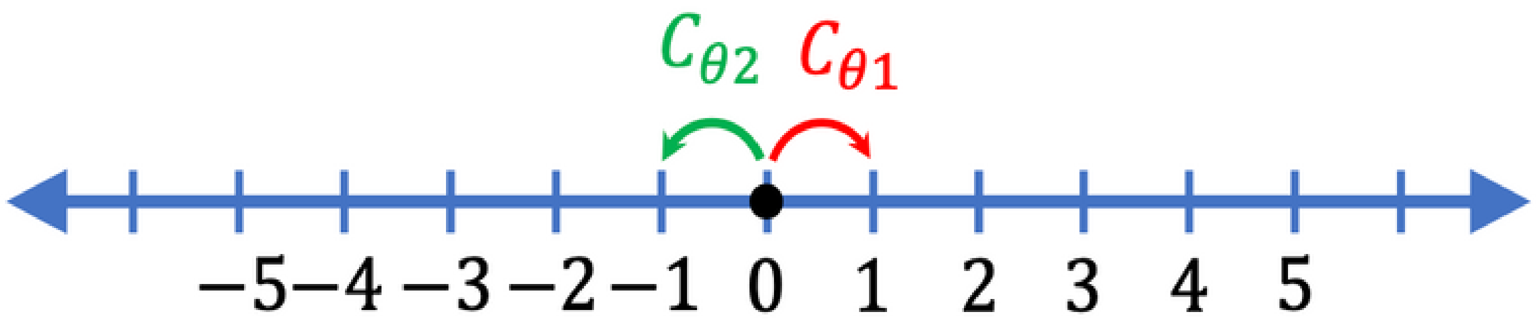
$$+ \frac{1}{2\sqrt{2}}|\downarrow\rangle \otimes |x=-3\rangle$$

INTRODUCTION:SPLIT-STEP QUANTUM WALK

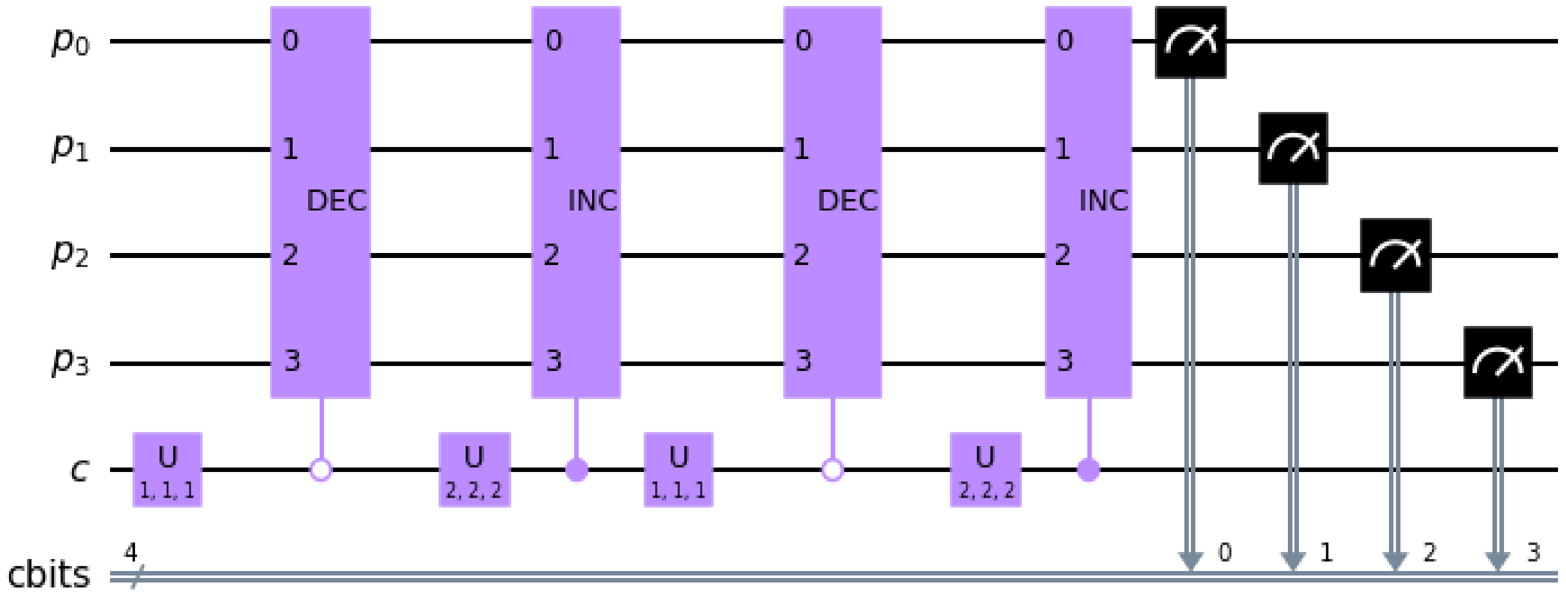
$$W_{SS} = S_+ C_{\theta 2} S_- C_{\theta 1}$$

$$S_+ = |\downarrow\rangle\langle\downarrow| \otimes \sum_x |x\rangle\langle x| + |\uparrow\rangle\langle\uparrow| \otimes \sum_x |x+1\rangle\langle x|;$$

$$S_- = |\downarrow\rangle\langle\downarrow| \otimes \sum_x |x-1\rangle\langle x| + |\uparrow\rangle\langle\uparrow| \otimes \sum_x |x\rangle\langle x|;$$



Split-Step QW



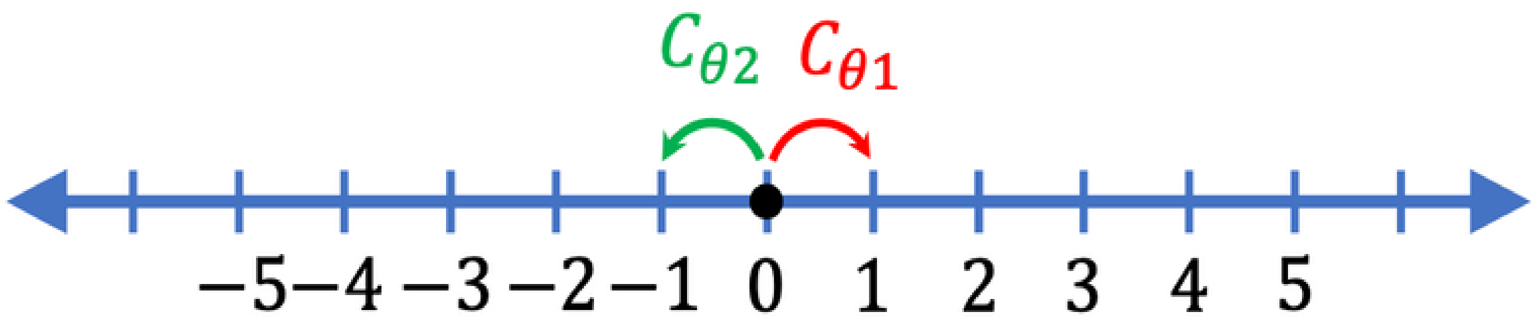
QUANTUM CIRCUIT

INTRODUCTION:SPLIT-STEP QUANTUM WALK

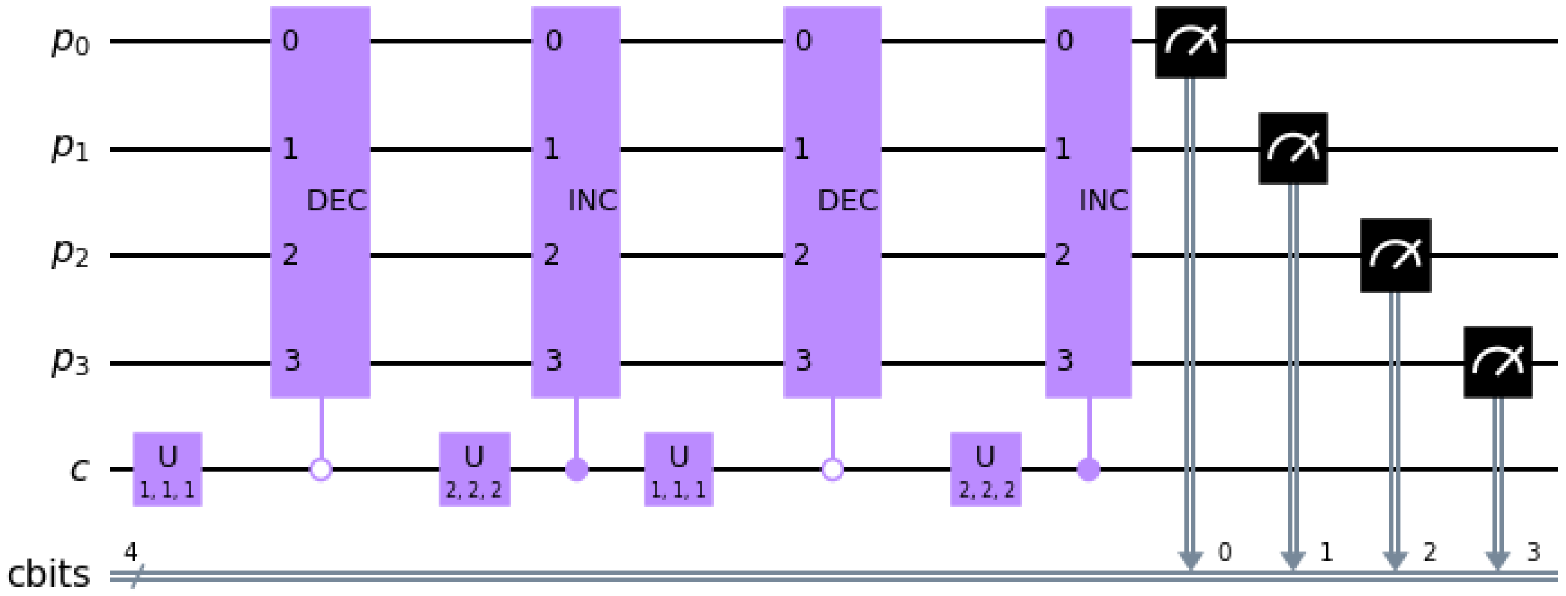
$$W_{SS} = S_+ C_{\theta 2} S_- C_{\theta 1}$$

$$S_+ = |\downarrow\rangle\langle\downarrow| \otimes \sum_x |x\rangle\langle x| + |\uparrow\rangle\langle\uparrow| \otimes \sum_x |x+1\rangle\langle x|;$$

$$S_- = |\downarrow\rangle\langle\downarrow| \otimes \sum_x |x-1\rangle\langle x| + |\uparrow\rangle\langle\uparrow| \otimes \sum_x |x\rangle\langle x|;$$



Split-Step QW



QUANTUM CIRCUIT

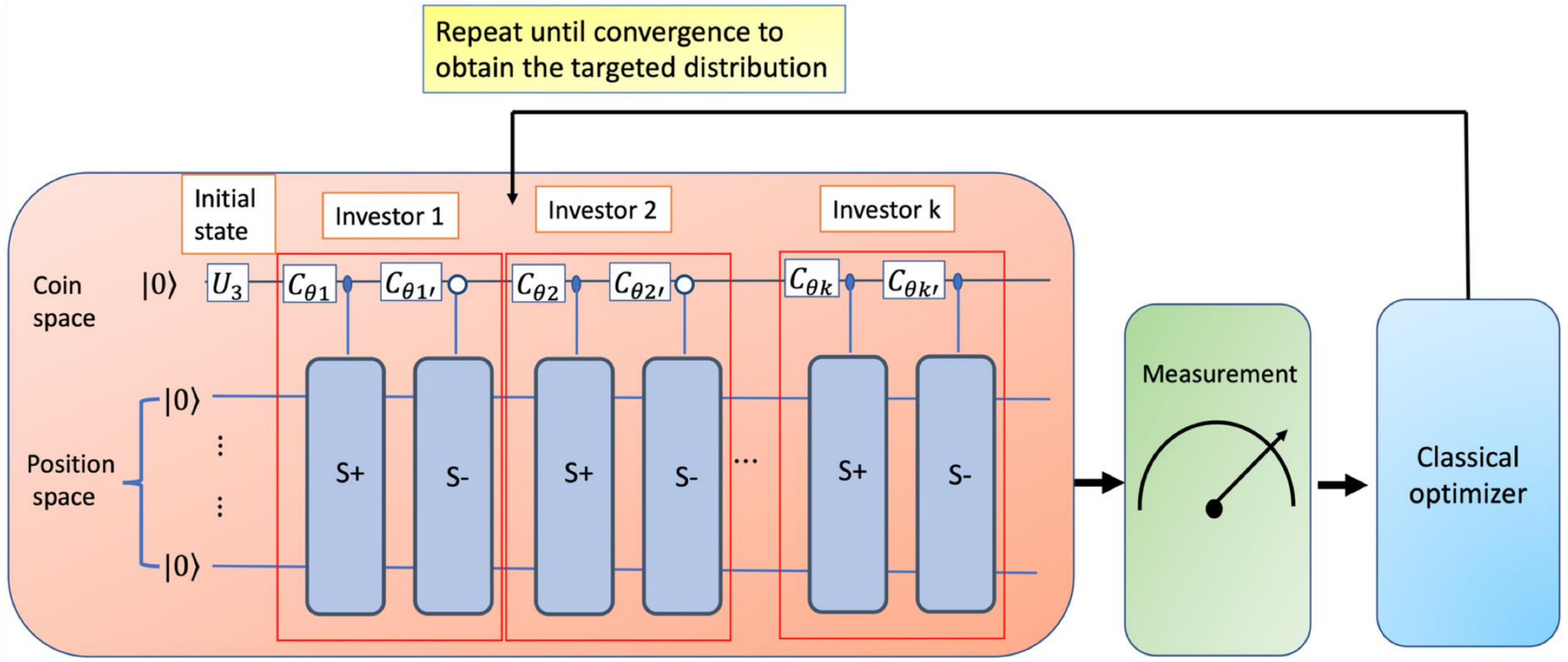
Application of Quantum Computing in Finance

Financial Modeling

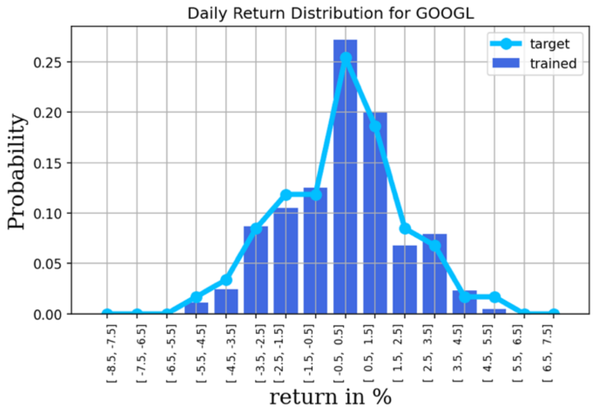
$|\psi_f\rangle = \mathrm{U}(\theta)|0\rangle$

$U(\theta)$: Evolution operation

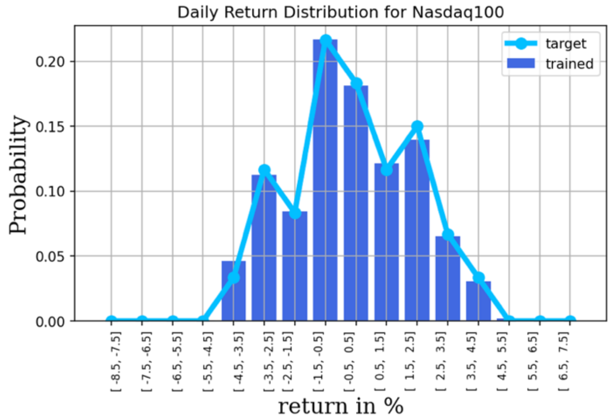
$|\psi_f\rangle$: The specific quantum state that encodes the probability distribution of financial market outcomes



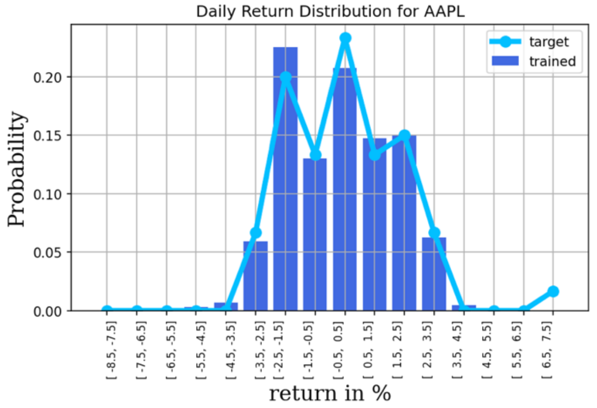
GOOGLE



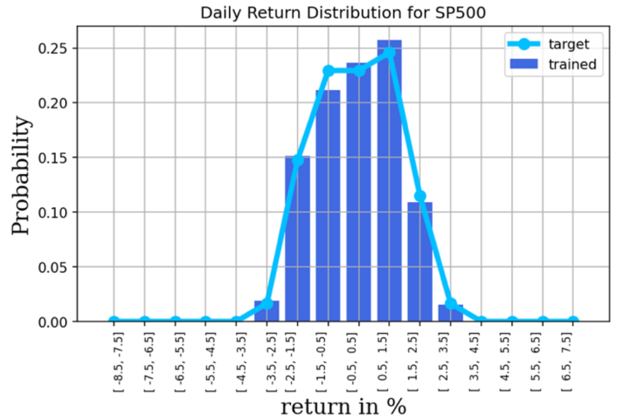
Nasdaq 100



APPLE



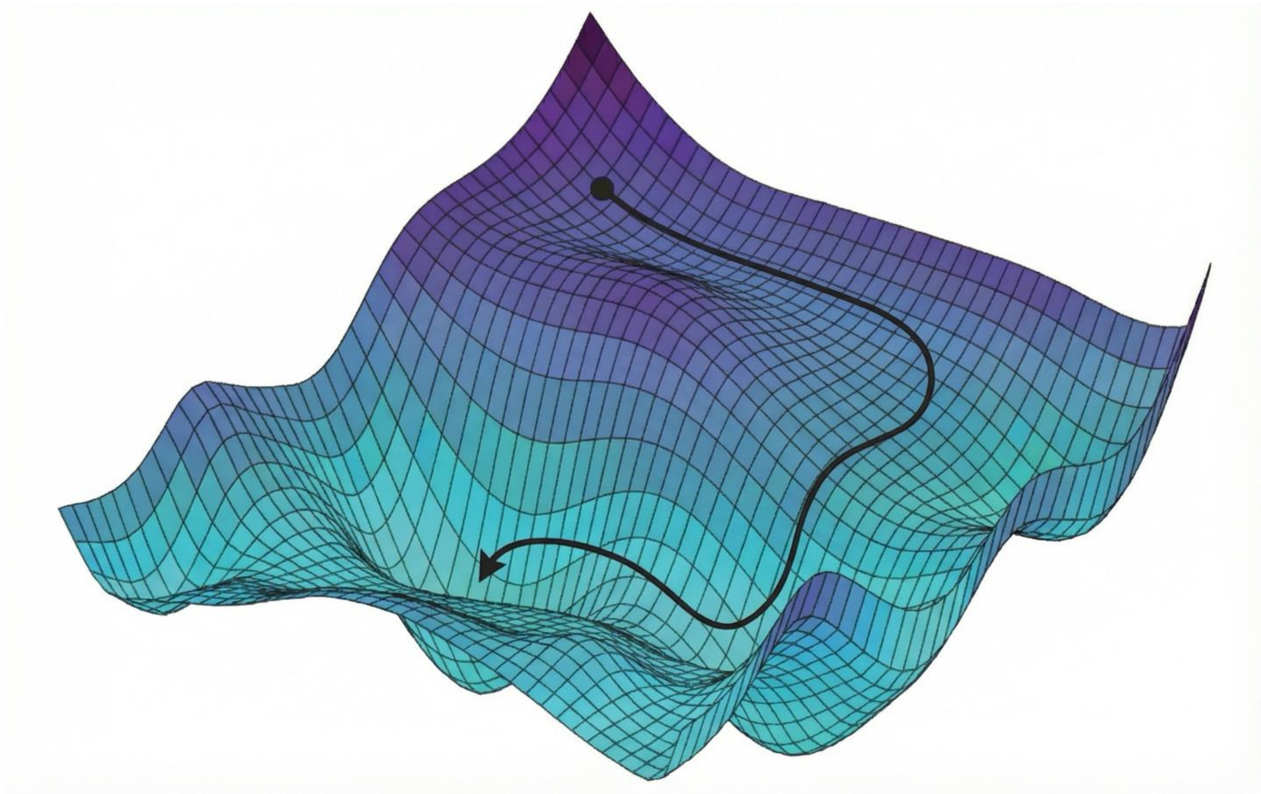
S&P 500



Chang, YJ., Wang, WT., Chen, HY. et al. A novel approach for quantum financial simulation and quantum state preparation. Quantum Mach. Intell. 6, 24 (2024).

What's the Problem? – An Introduction to Optimization

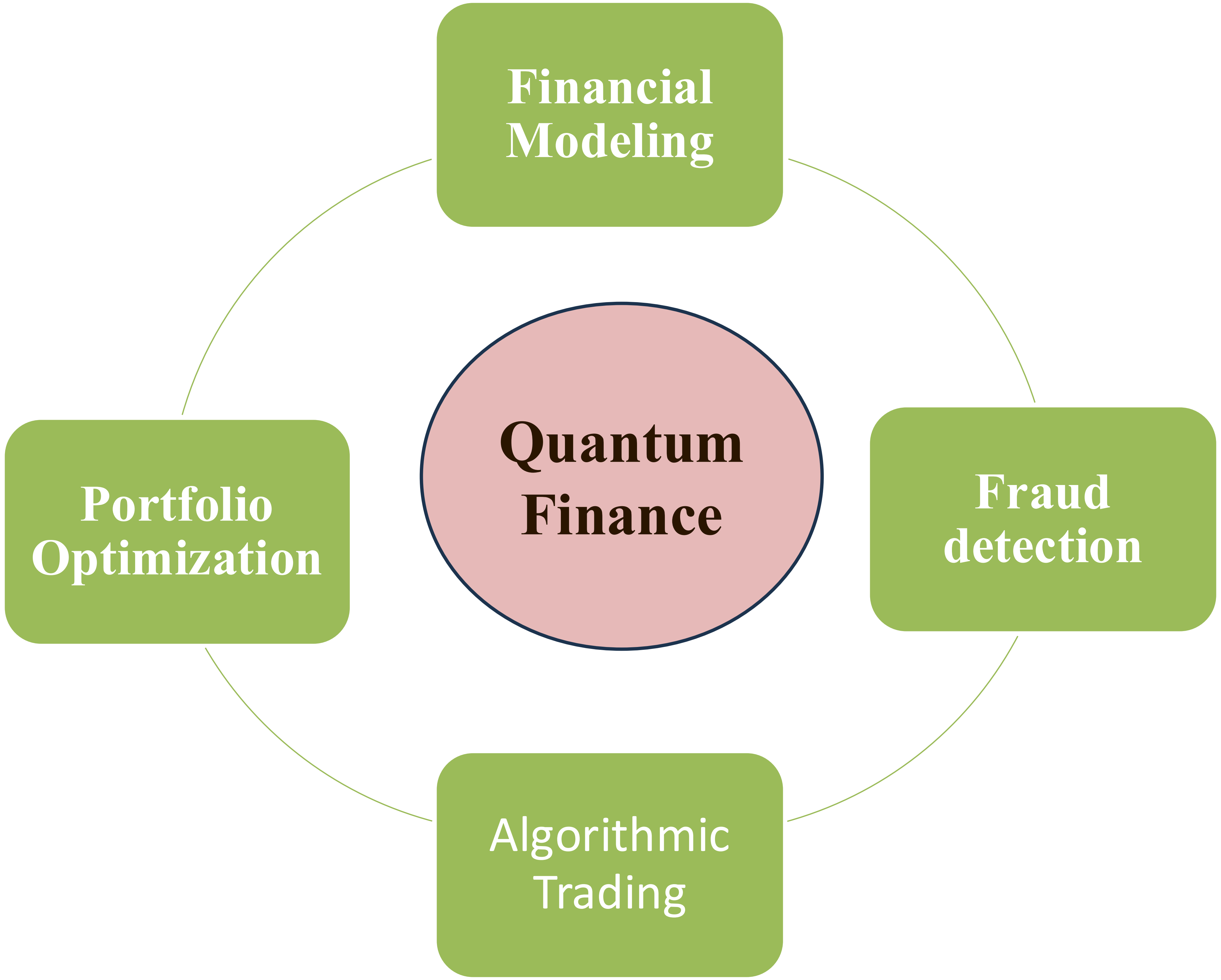
Finding the "Best" Answer Among Countless Choices



1. Optimization is the process of finding the best possible solution from all available options, given a set of constraints, to maximize or minimize a specific goal.
2. Real-world examples:

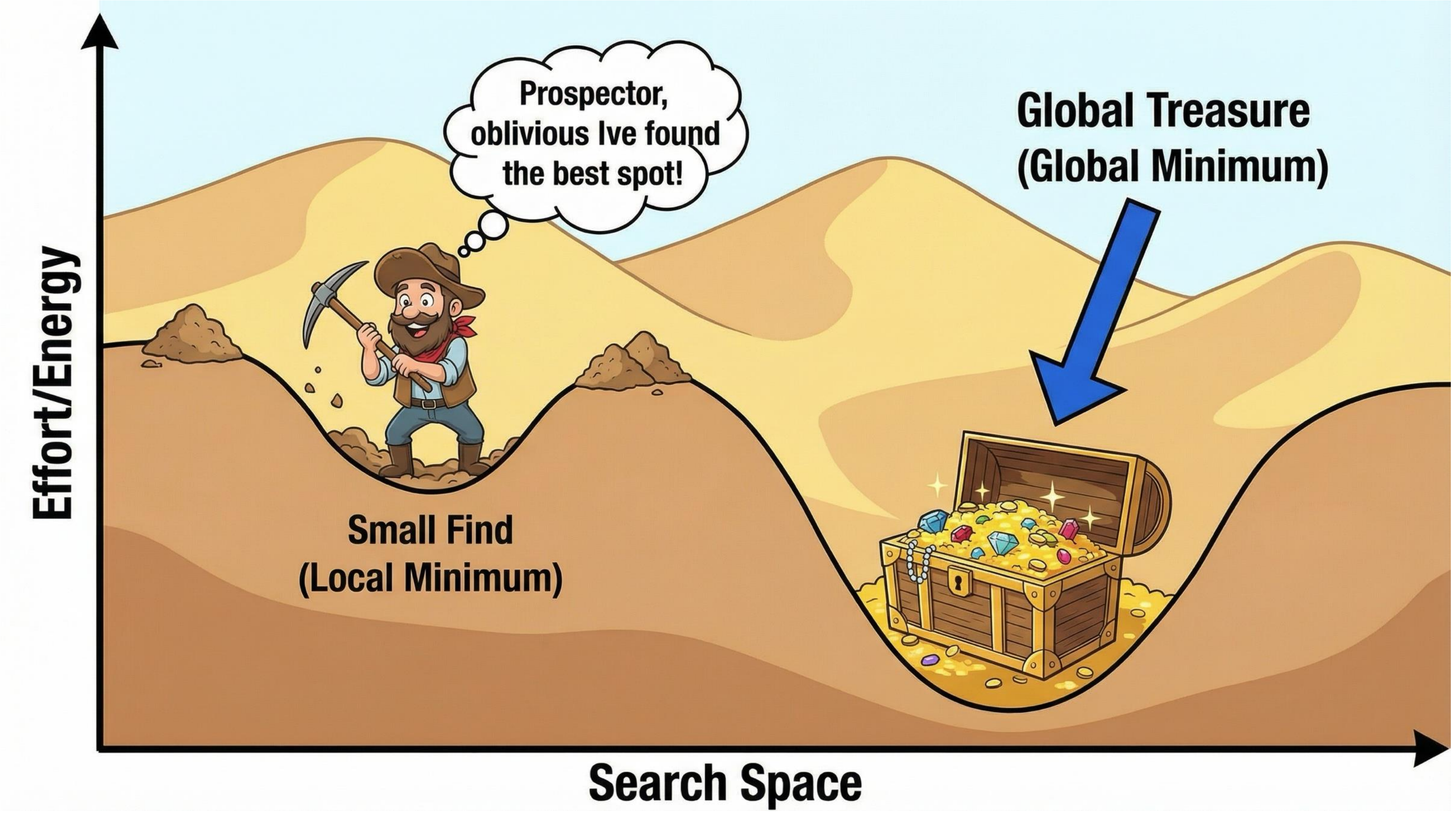
- **Traveling Salesperson Problem (TSP):** What is the shortest possible route that visits a set of cities and returns to the origin city?
- **Knapsack Problem:** Given a set of items with weights and values, what's the most valuable combination of items you can fit in a backpack with a limited capacity?
- **Resource Allocation:** How do you assign employees, budget, and machinery to tasks to achieve maximum efficiency?

Application of Quantum Computing in Finance



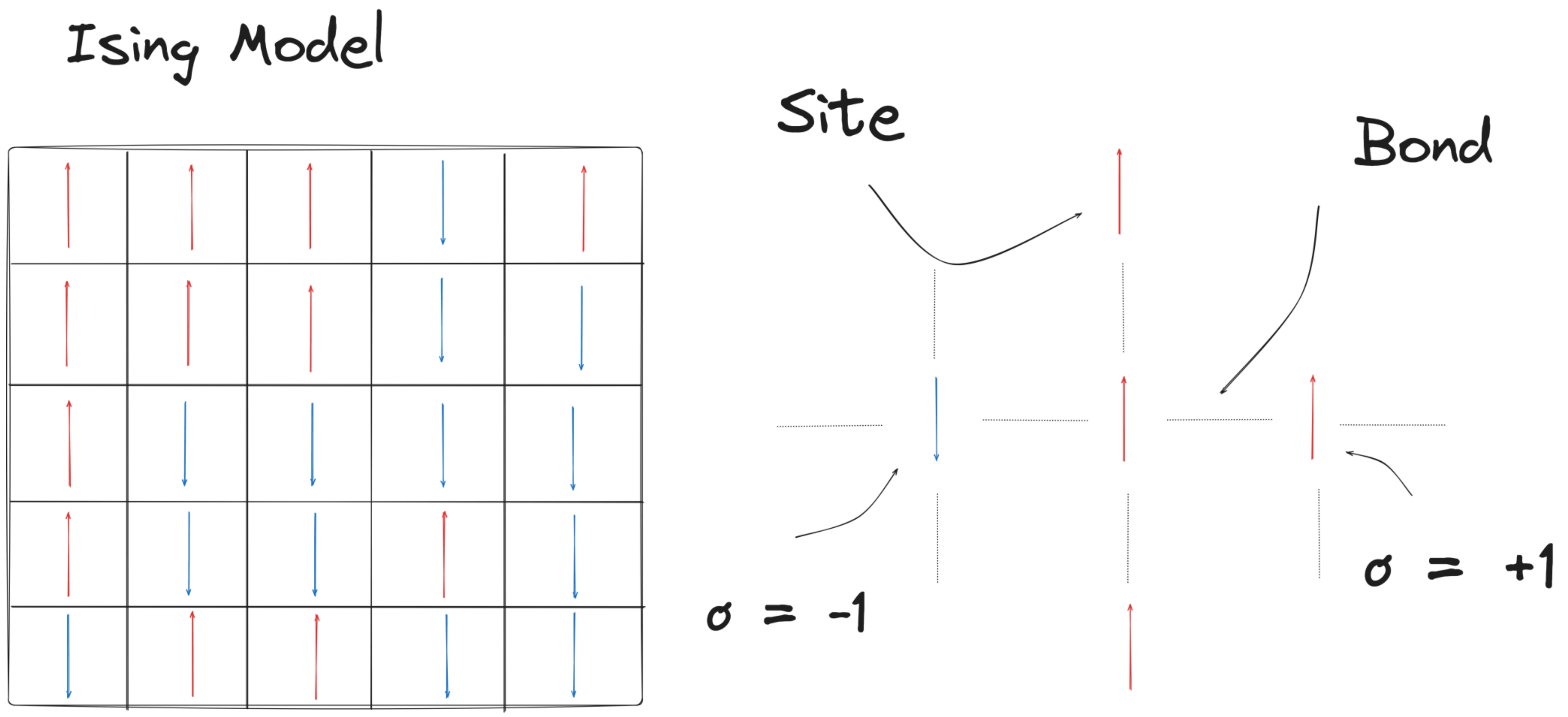
Why Is It Hard? – The Trap of "Local Optima"

Short-Sighted Greed vs. Global Vision



Annealing

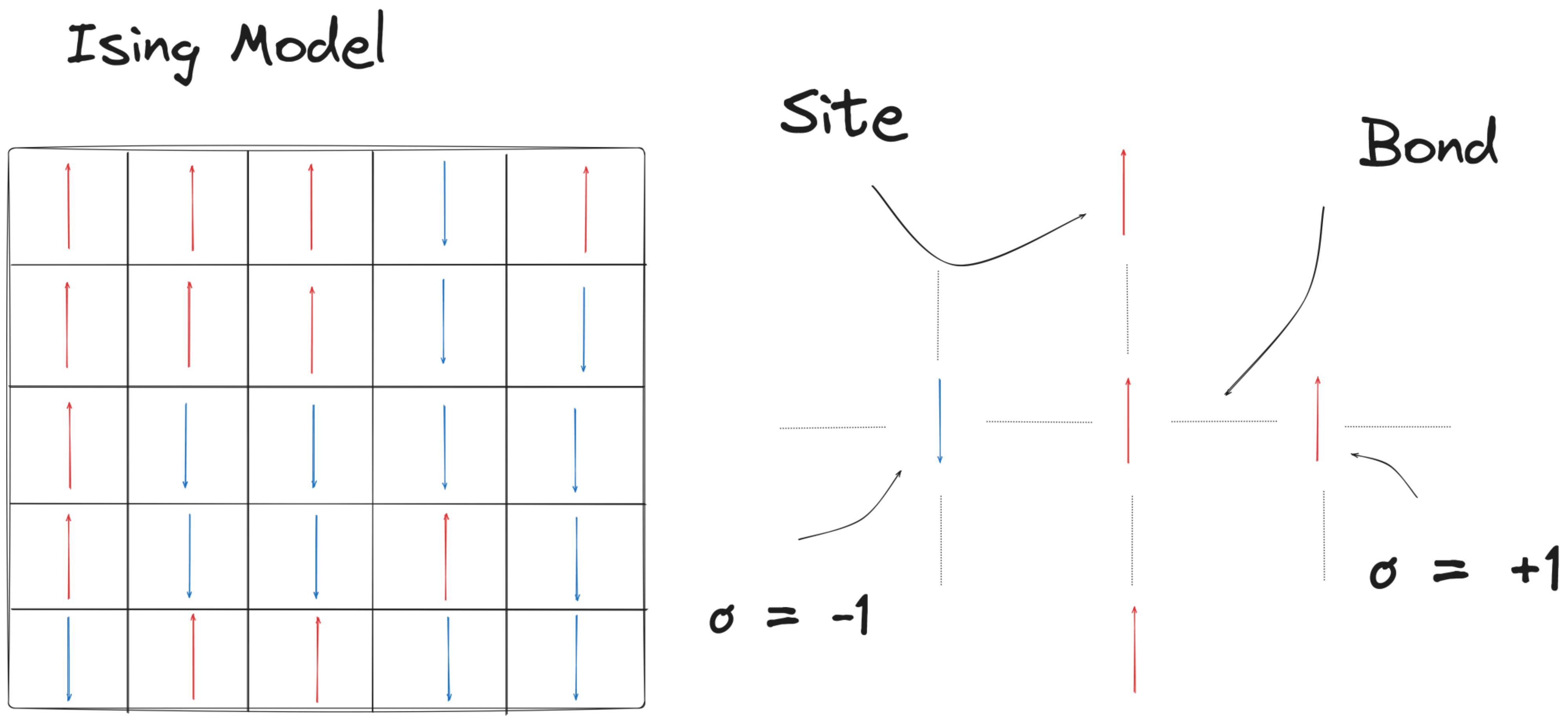
- Ising Model



$$H = \underbrace{-J\sum_{i,j}\sigma_i^z\sigma_j^z}_{\text{Interation}} \underbrace{- h\sum_{i}\sigma_i^z}_{\text{Site}}$$

Annealing

- Ising Model



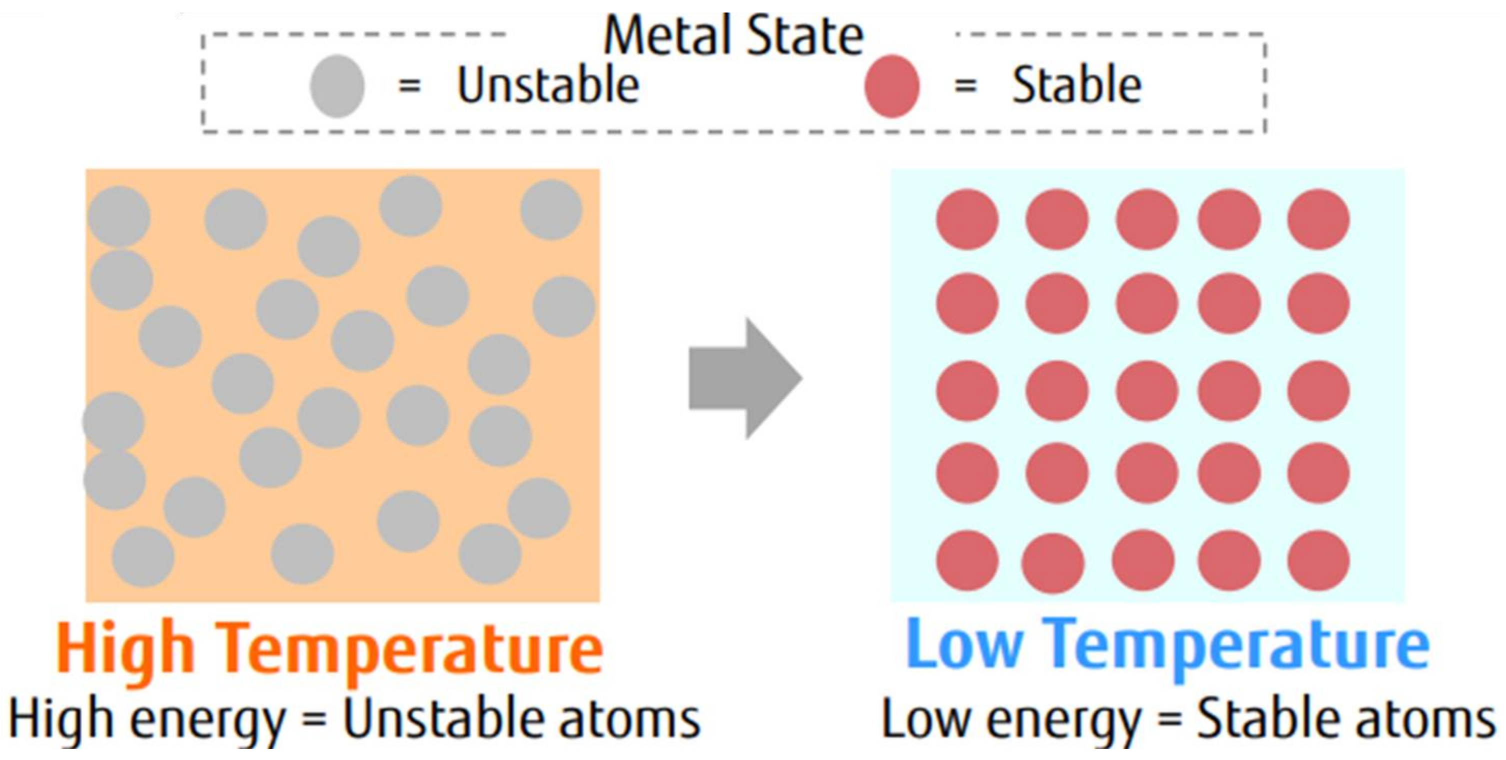
$$H = -J\sum_{i,j}\sigma_i^z\sigma_j^z - h\sum_i \sigma_i^z$$

Interation Site

Annealing

Simulated Annealing

Concepts



$$H = \underbrace{-J\sum_{i,j}\sigma_i^z\sigma_j^z}_{\text{Interation}} \underbrace{- h\sum_{i}\sigma_i^z}_{\text{Site}}$$

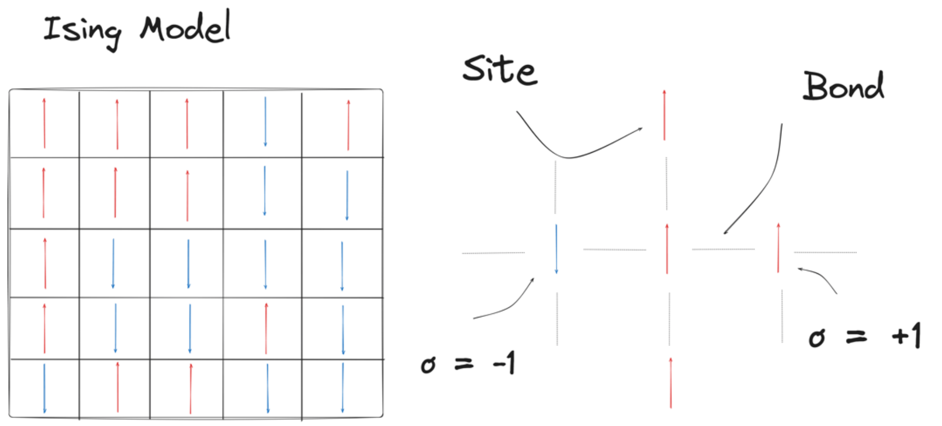
Metropolis–Hastings Process

1. Start with a random configuration $E(x_0)$and high "temperature" T
2. Repeatedly propose small changes $x \to x'$
3. Accept improvements automatically Accept worse solutions with probability $p = e^{-\Delta E/T}$, where $\Delta E = E(x') - E(x)$
1. Gradually decrease the temperature according to a "cooling schedule"
2. Continue until the system "freezes" into a good solution

Annealing

Quantum Annealing

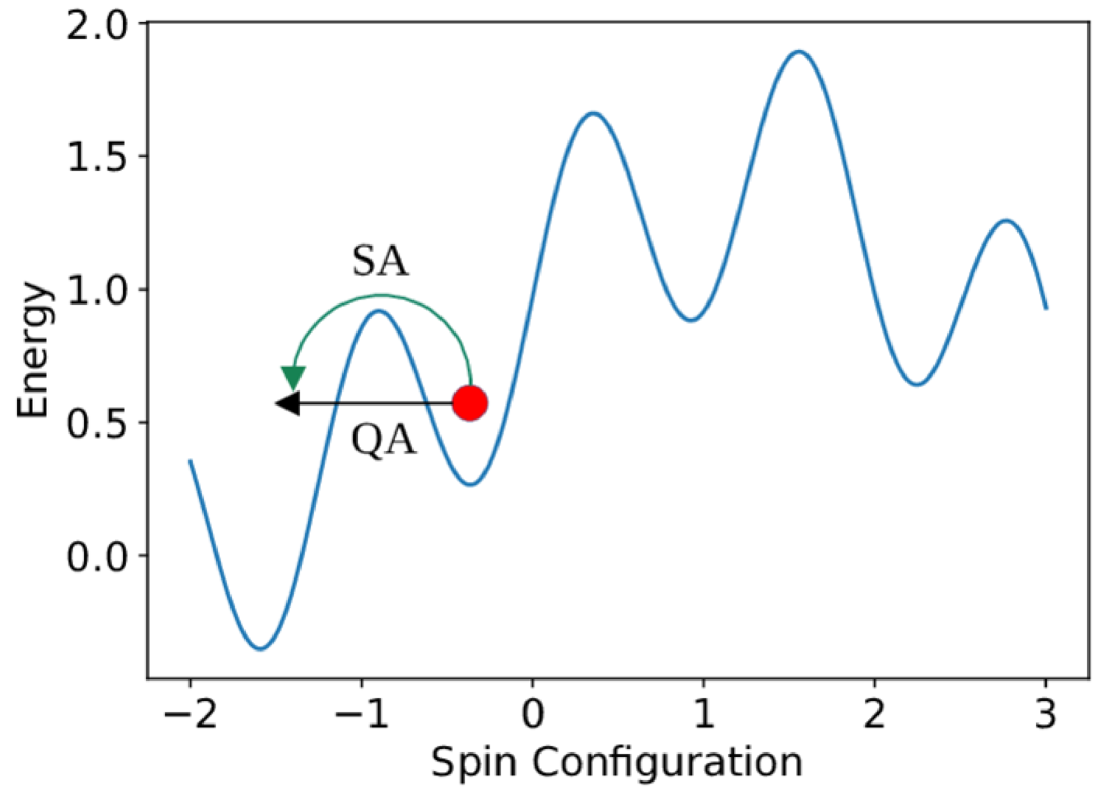
Concepts



$$H_p = -J \sum_{i,j} \sigma_i^z \sigma_j^z - h \sum_i \sigma_i^z$$

$$H_D = \Gamma \sum_i \sigma_i^x$$

$$H(t) = A(t) \cdot H_D + B(t) \cdot H_p$$



Process

1. Initial Setup (t = 0): **A(0) >> B(0)**
   Ground state: Equal superposition
   System is in quantum superposition of ALL possible spin configurations

2. Annealing Process (0 < t < T): **A(t) decreases, B(t) increases.** System gradually transitions from quantum to classical regime. Quantum tunneling allows exploration of solution space

3. Final State (t = T): **A(T) << B(T)**
   $H(T) = B(t) \cdot H_p$
   Ground state encodes the optimal solution to the problem

Annealing

Key Differences

Aspect	Simulated Annealing	Quantum Annealing
Escape mechanism	Thermal hopping over barriers	Quantum tunneling through barriers
Control parameter	Temperature (T)	Transverse field (Γ)
States	Classical bit strings	Quantum superposition
Hardware	Classical computers	Quantum processors
Exploration	Sequential random walk	Parallel quantum exploration

Annealing

QUBO & Ising Formulations

Quadratic unconstrained binary optimization(QUBO)

Ising model

$$f(x) = \sum_{i=1}^{n} Q_{ii} x_i + \sum_{i=1}^{n} \sum_{j=i+1}^{n} Q_{ij} x_i x_j = x^T\, Qx$$

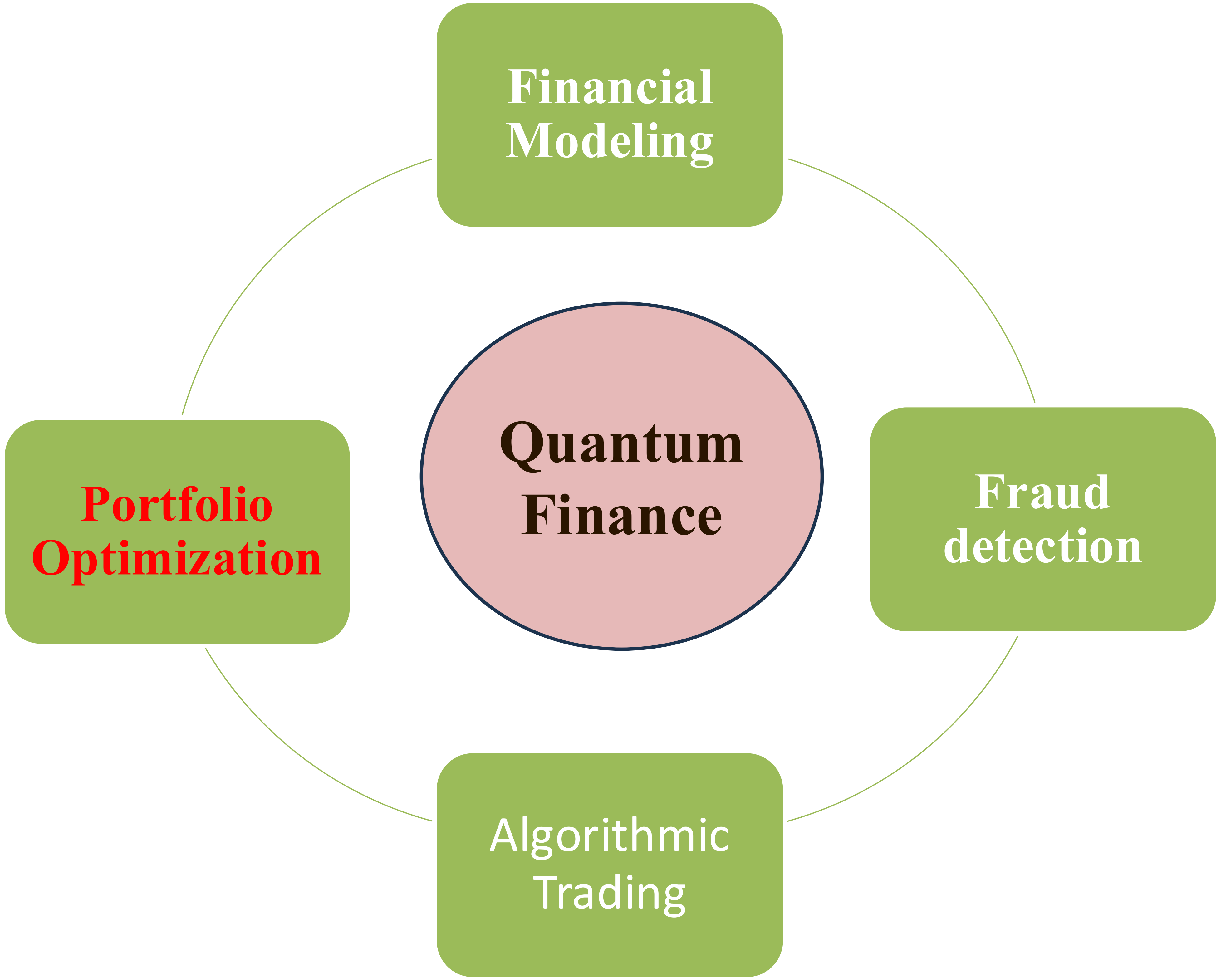
$$s_i = 2x_i - 1$$

$$H = -J \sum_{i,j} \sigma_i^z \sigma_j^z - h \sum_i \sigma_i^z$$

$x_i \in \{0,1\}^n$: binary vector
$x_i = x_i^2$

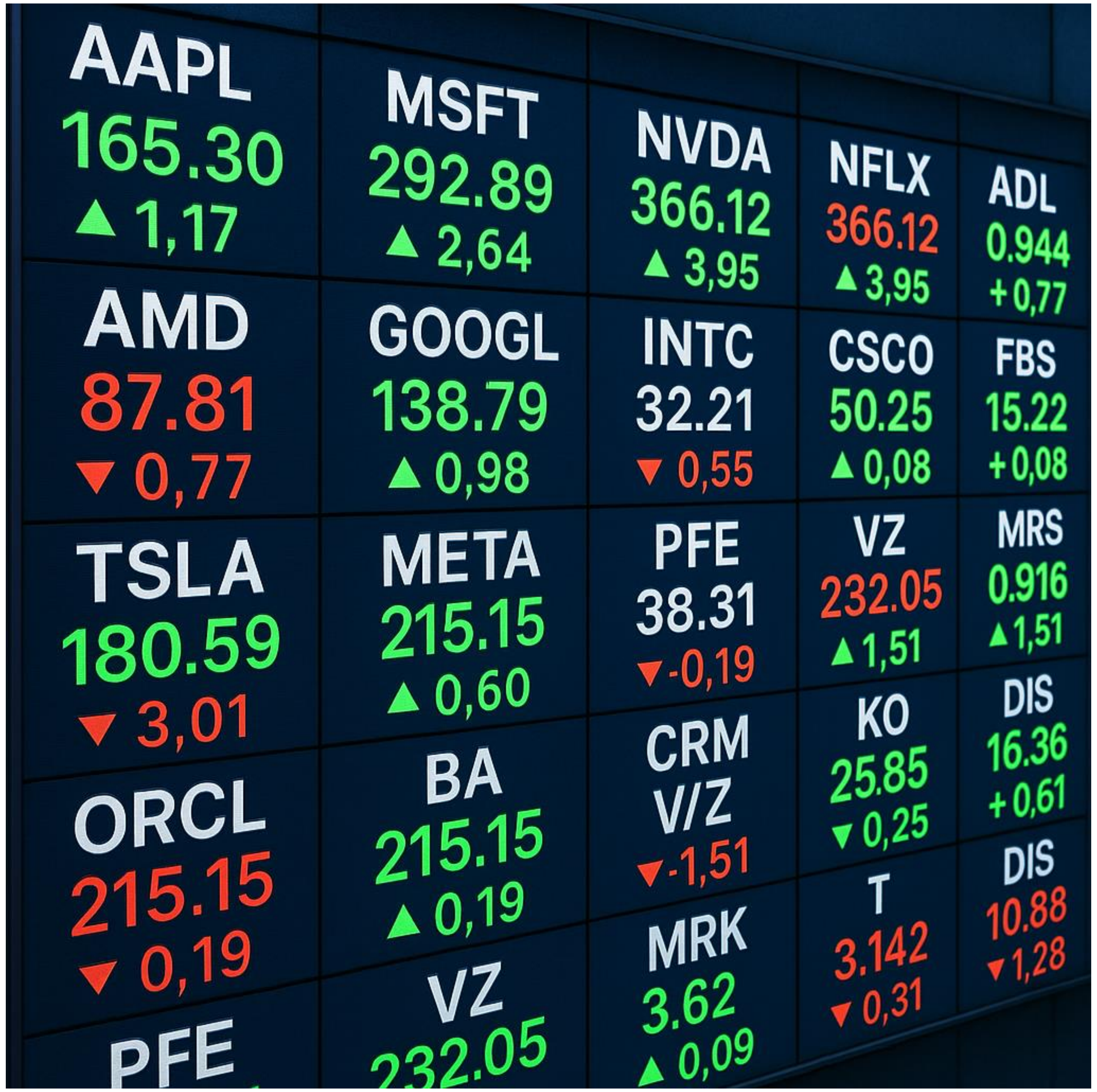
$\sigma_i \in \{-1,1\}^n$: binary vector

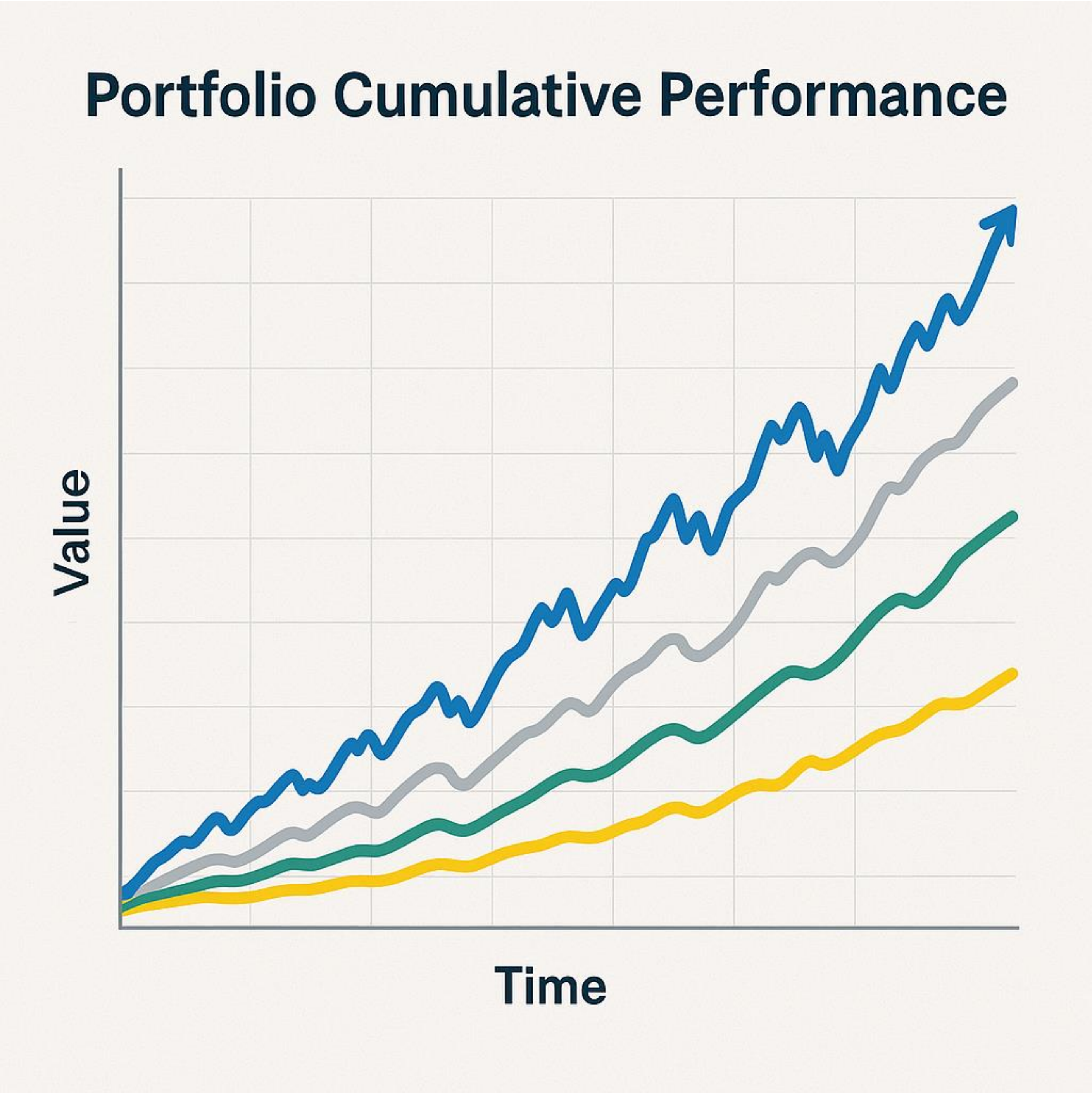
Application of Quantum Computing in Finance



Application of Quantum Computing in Finance

Mean-Risk Portfolio Optimization



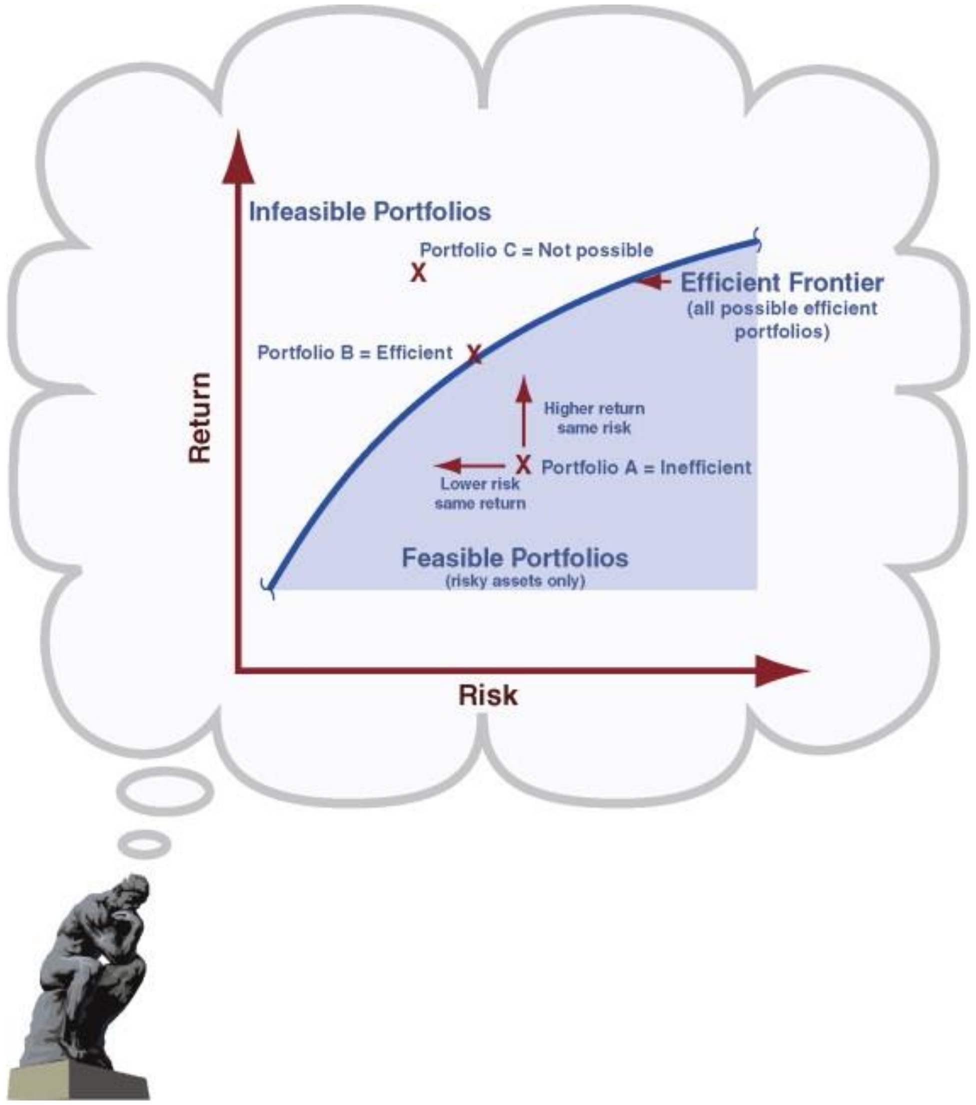


Application of Quantum Computing in Finance

Mean-Risk Portfolio Optimization

Goals: Maximize returns & Minimize risk

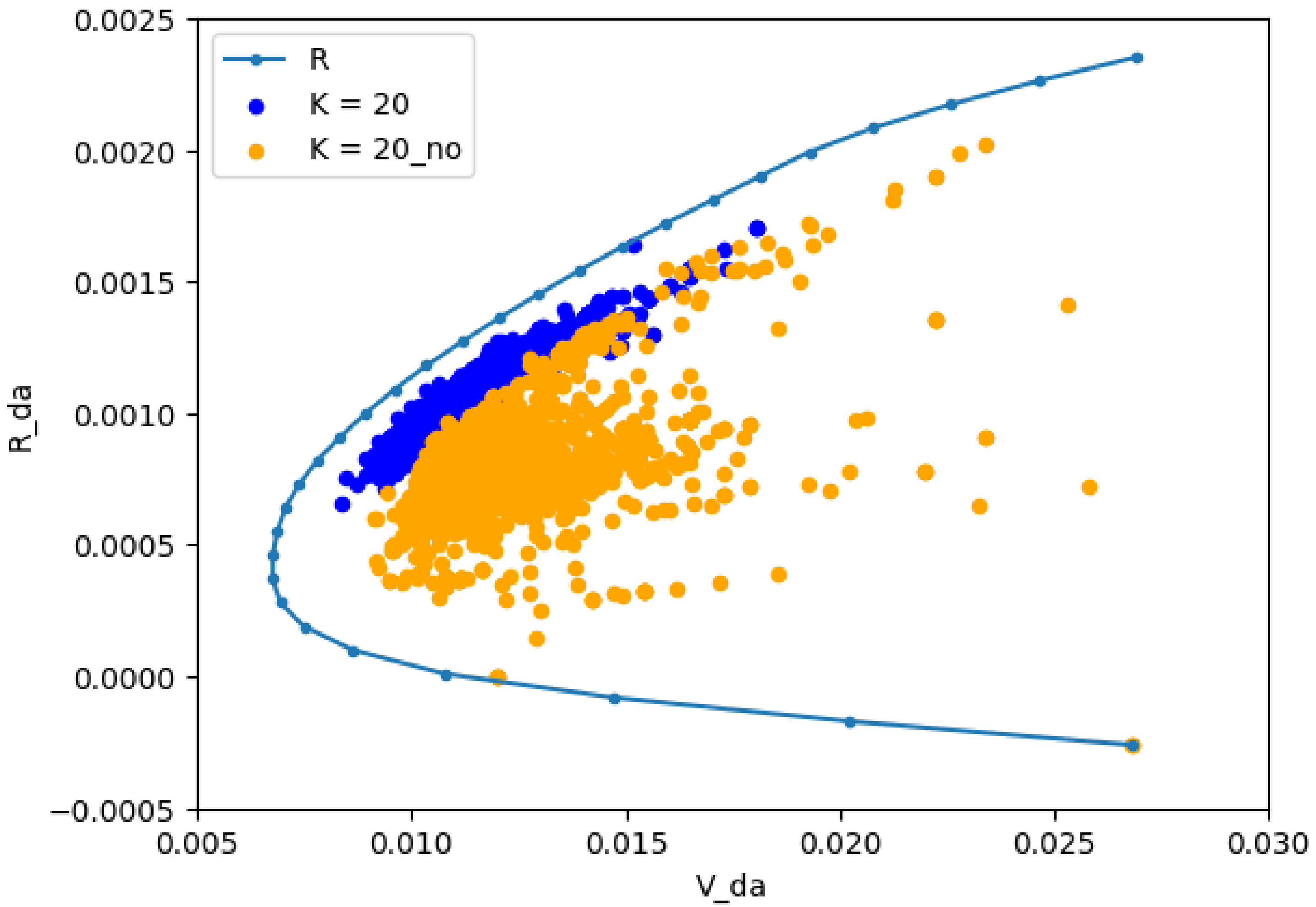
$$f(x) = -\theta_1 \sum_i r_i x_i + \theta_2 \sum_{i,j} x_i cov\left(h_i, h_j\right) x_j$$



Weight: $\omega_i = \sum_{k=1}^{20} x_{ik} \cdot 2^{-k}$

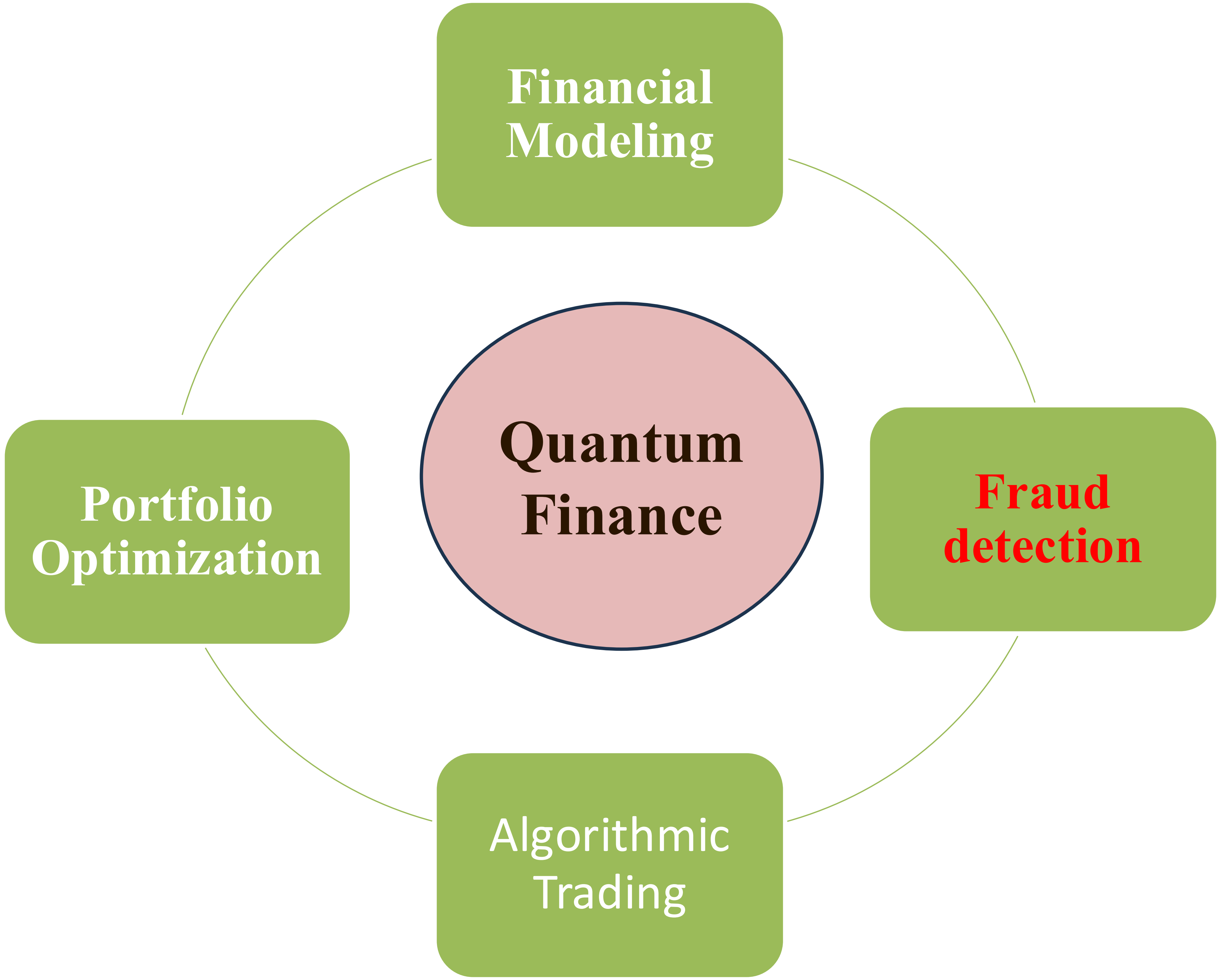
Return–target penalty : $\theta_1 (\sum_i \omega_i \cdot r_i - R)^2$

Risk term: $\theta_2 \sum_{i,j} \omega_i \cdot cov(h_i, h_j)\omega_j$



Quantum-Inspired Portfolio Optimization In The QUBO Framework, Ying-Chang Lu, Chao-Ming Fu, Lien-Po Yu, Yen-Jui Chang, Ching-Ray Chang, arXiv:2410.05932

Application of Quantum Computing in Finance



Application of Quantum Computing in Finance

Annealing Feature Selection

- Problem description :
  Transaction History Summarization with four types of features: Basic Statistics, Extra Statistics, Moments, and Deciles.

- Preprocessing:

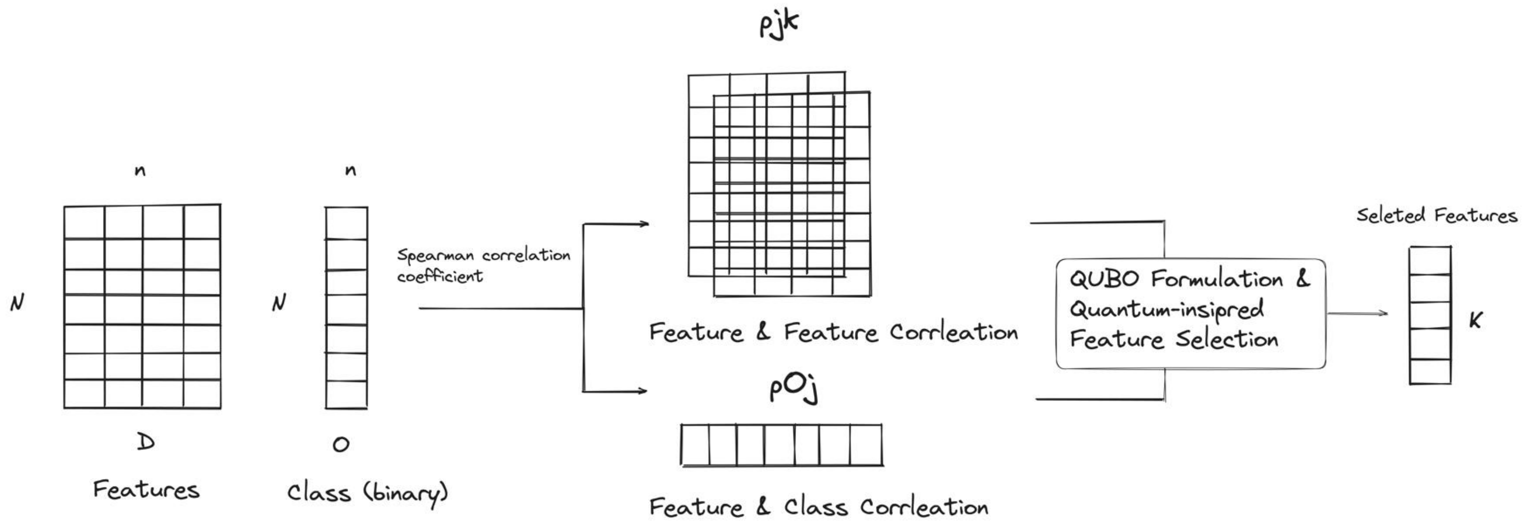
Each column represents a feature, and each row represents the specific data values for a particular address

$$U = \begin{bmatrix} u_{11} & u_{12} & u_{13} & \dots & u_{1n} \\ u_{21} & v_{22} & u_{23} & \dots & u_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ u_{m1} & u_{m2} & u_{m3} & \dots & u_{mn} \end{bmatrix}$$

The data on past addresses can inform us of the class.

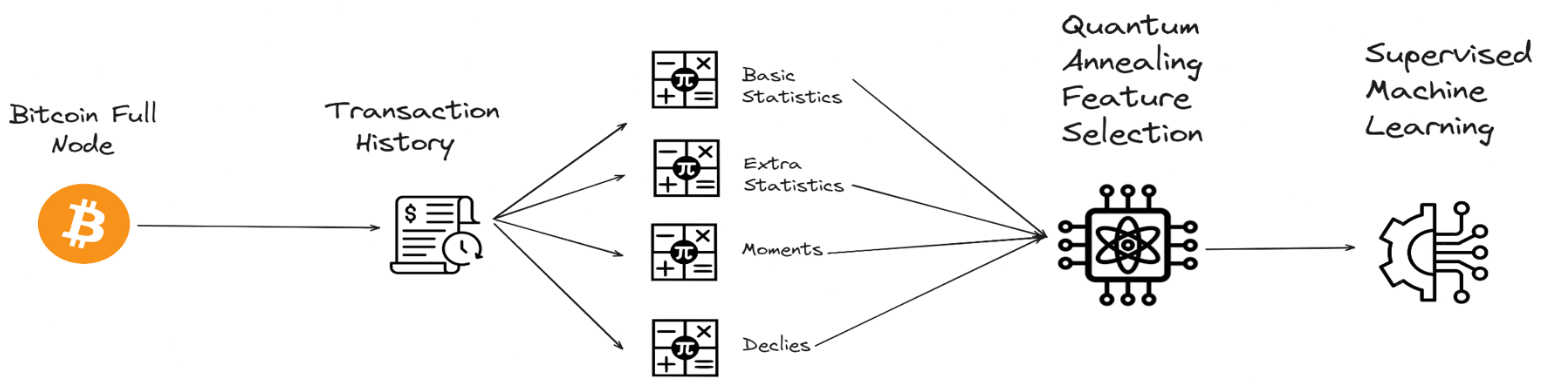
$$V = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_m \end{bmatrix}$$

- Annealing Feature Selection:
  The expression overall to optimize at the minimum to obtain



Influence | Independence

$$f(\mathbf{x}) = -\left[\alpha \boxed{\sum_{j=1}^{n} x_j |\rho_{Vj}|} - (1-\alpha) \boxed{\sum_{j=1}^{n} \sum_{\substack{k=1,\\ k\neq j}}^{n} x_j x_k |\rho_{jk}|}\right].$$

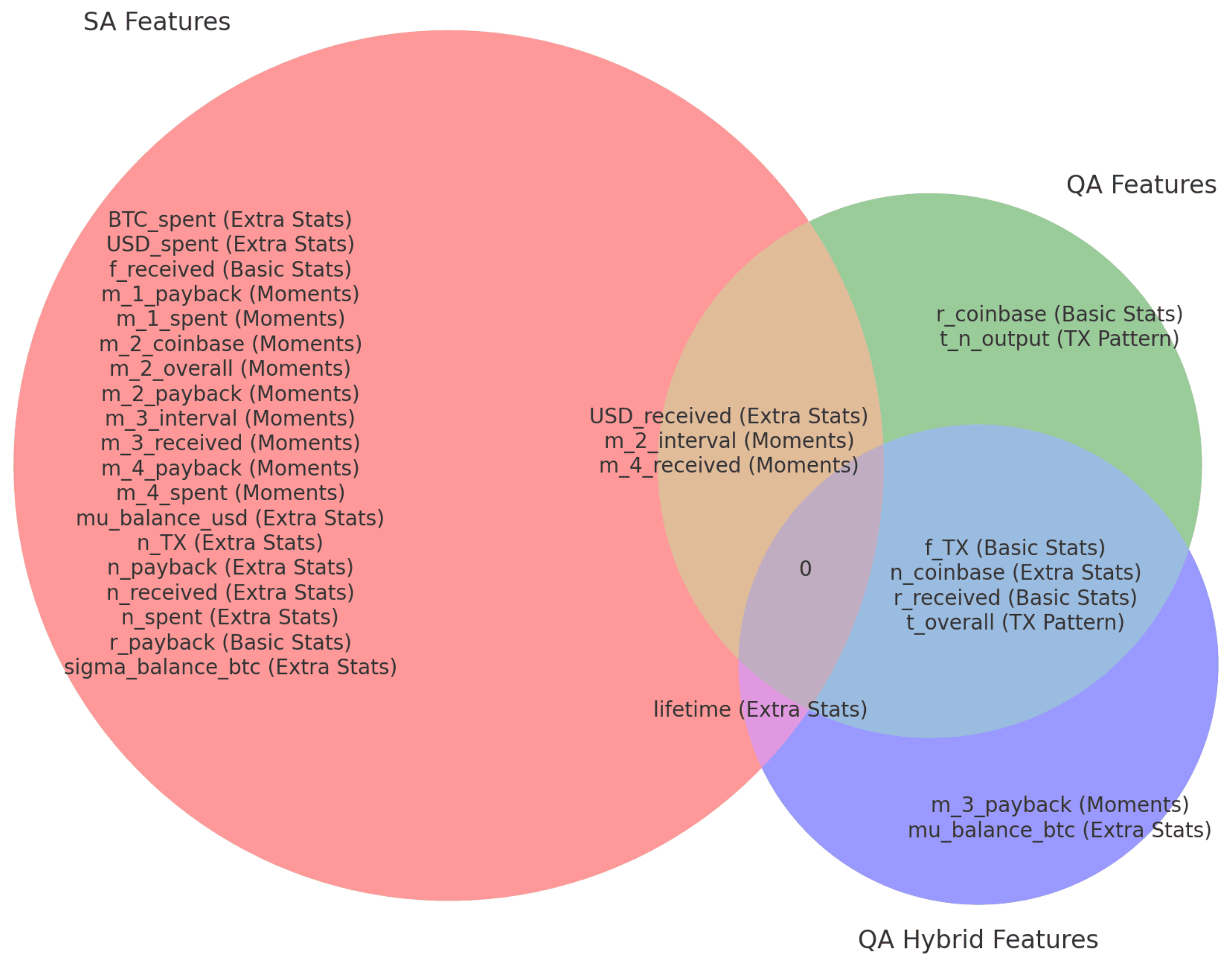


Application of Quantum Computing in Finance

Improved fraud detection

Type	Quantum Algorithms	Features	Time
Classical	Simulated Annealing	23	**0.0055 s**
Quantum	Quantum Annealing	9	6.644 s
Hybrid	Quantum Annealing	7	6.0041 s

Intersection Of SA, QA, And QA Hybrid Select Features



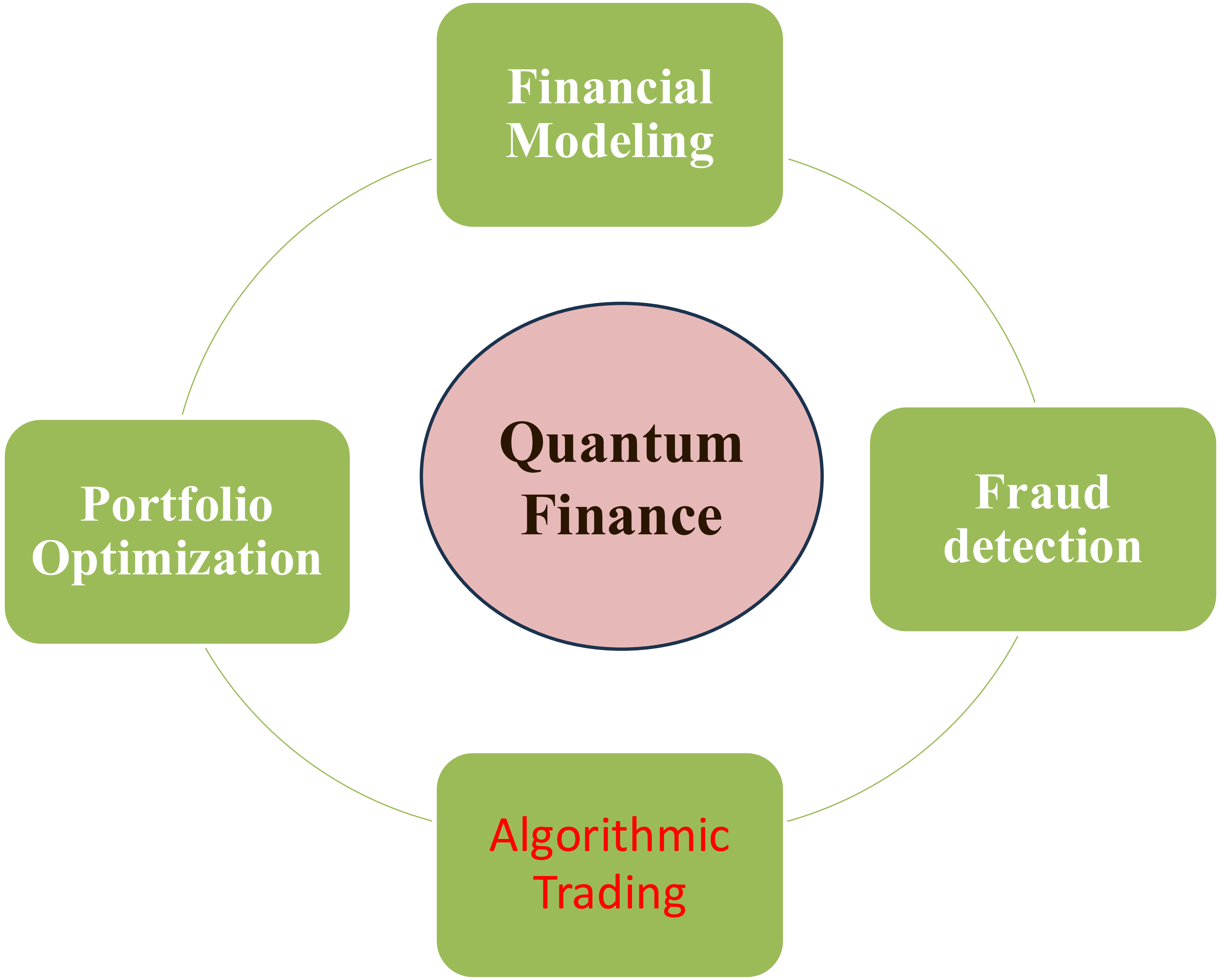
23 Features selected by SA

9 Features selected by QA

Method	Precision ↑	Recall ↑	F1 ↑	Accuracy ↑	AUC ↑	Training Time ↓
Logistic Regression	0.6	0.57	0.58	0.84	0.92	10 mins 56.8 s
AdaBoost	0.4	0.81	0.53	0.84	0.74	1106 mins 52.8 s
Random Forest	**0.87**	0.97	**0.92**	**0.95**	**0.99**	305 mins 5.7 s
XGBoost	0.86	0.89	0.88	**0.95**	**0.99**	70 mins 5 s
LightGBM	0.85	0.88	0.87	0.94	0.98	56 mins 1.8 s
SVM *10%[1]	0.73	0.37	0.49	0.85	0.96	532 mins 58.9 s
Neural Network *10%[2]	0.68	0.93	0.79	0.85	0.98	87 mins 51.5 s
SA Logistic Regression	0.53	0.8	0.59	0.91	0.83	10 mins 49.6 s
SA AdaBoost	0.33	0.65	0.44	0.81	0.69	589 mins 21.1 s
SA Random Forest	0.85	0.97	0.91	0.94	**0.99**	212 mins 23.2 s
SA XGBoost	0.54	0.63	0.58	0.87	0.89	67 mins 13.2 s
SA LightGBM	0.81	0.84	0.83	0.94	0.96	37 mins 43.9 s
SA SVM *10%[3]	0.22	1	0.36	0.42	0.71	4465 mins 27.2 s
SA Neural Network *10%[4]	0.66	0.94	0.77	0.83	0.98	83 mins 3.7 s
QA Logistic Regression	0.49	0.54	0.50	0.82	0.82	6 mins 47.8 s
QA AdaBoost	0.57	0.49	0.52	0.85	0.84	513 mins 5.6 s
QA Random Forest	0.58	0.62	0.60	0.86	0.88	125 mins 27.7 s
QA XGBoost	0.54	0.63	0.58	0.87	0.89	63 mins 29.5 s
QA LightGBM	0.55	0.62	0.58	0.87	0.89	37 mins 43.9 s
QA SVM *10%[5]	0.26	1	0.41	0.51	0.86	4492 mins 26.3 s
QA Neural Network *10%[6]	0.54	0.60	0.57	0.85	0.88	87 mins 7.3 s
QA BQM Logistic Regression	0.51	0.56	0.53	0.85	0.84	**6 mins 44.1 s**
QA BQM AdaBoost	0.47	0.74	0.57	0.84	0.89	563 mins 56.8 s
QA BQM Random Forest	0.65	0.76	0.75	0.90	0.93	183 mins 17.5 s
QA BQM XGBoost	0.48	0.76	0.59	0.85	0.90	63 mins 36.6 s
QA BQM LightGBM	0.48	0.75	0.58	0.85	0.90	38 mins 25 s
QA BQM SVM *10%[7]	0.54	0.09	0.16	0.83	0.86	4391 mins 7.1 s
QA BQM Neural Network *10%[8]	0.54	0.58	0.56	0.85	0.88	83 mins 49.5 s

Efficient Bitcoin Address Classification Using Quantum-Inspired Feature Selection,
Ming-Fong Sie, Yen-Jui Chang, Chien-Lung Lin, Ching-Ray Chang, Shih-Wei Liao, https://doi.org/10.48550/arXiv.2411.15425

Application of Quantum Computing in Finance

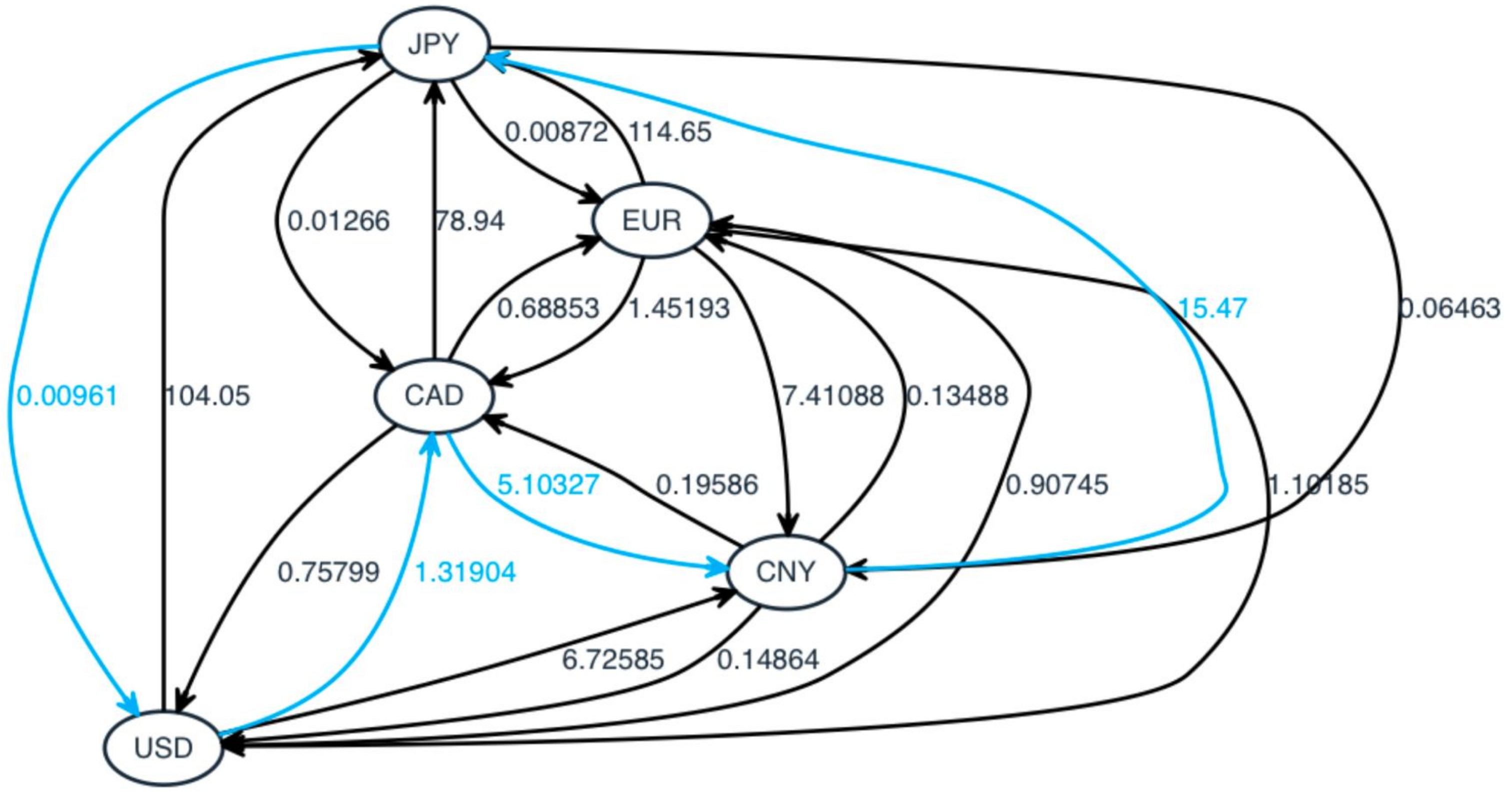


Application of Quantum Computing in Finance

Currency Arbitrage

Objective | Constraints

$$C_{tot} = argmin\left\{\underbrace{\boxed{-\sum_{i,j} x_{ij} log r_{ij}}}_{\text{profit}} + M_1\boxed{\left[\underbrace{\sum_{i}\sum_{j\neq j'} x_{ij}x_{ij'} + \sum_{j}\sum_{i\neq i'} x_{ij}x_{i'j}}_{\text{Used at most once}} + \underbrace{\sum_{i}\left(\sum_{j} x_{ij} - \sum_{j} x_{ji}\right)^2}_{\text{In = out}} + \underbrace{\sum_{i,j} x_{ij}x_{ji}}_{\text{Both way}}\right] + \underbrace{M_2\sum_{i,j} x_{ij}d_{ij}}_{\text{cost}}}\right\}$$

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AUD/JPY 84.321 84.444 2021-05-02 21:12:26.950000
AUD/NZD 1.07469 1.07827 2021-05-02 21:12:26.950000
AUD/USD 0.77174 0.77259 2021-05-02 21:12:27.390000
AUD/JPY 84.315 84.462 2021-05-02 21:12:30.092000
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USD/CAD 1.22788 1.23011 2021-05-02 21:12:41.197000
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EUR to JPY: 2.118843179485495
GBP to EUR: 0.06027113856748581
Profit Rate = 0.9999388975158292
2021-05-02 23:37:44.257000
AUD to JPY: 1.9260078492662447
JPY to USD: -2.03860426799073
USD to AUD: 0.11255712754965508
Profit Rate = 0.9999095328189521
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EUR to JPY: 2.118843179485495
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https://1qbit.com/whitepaper/optimal-feature-selection-in-credit-scoring-classification-using-quantum-annealer/

Application of Quantum Computing

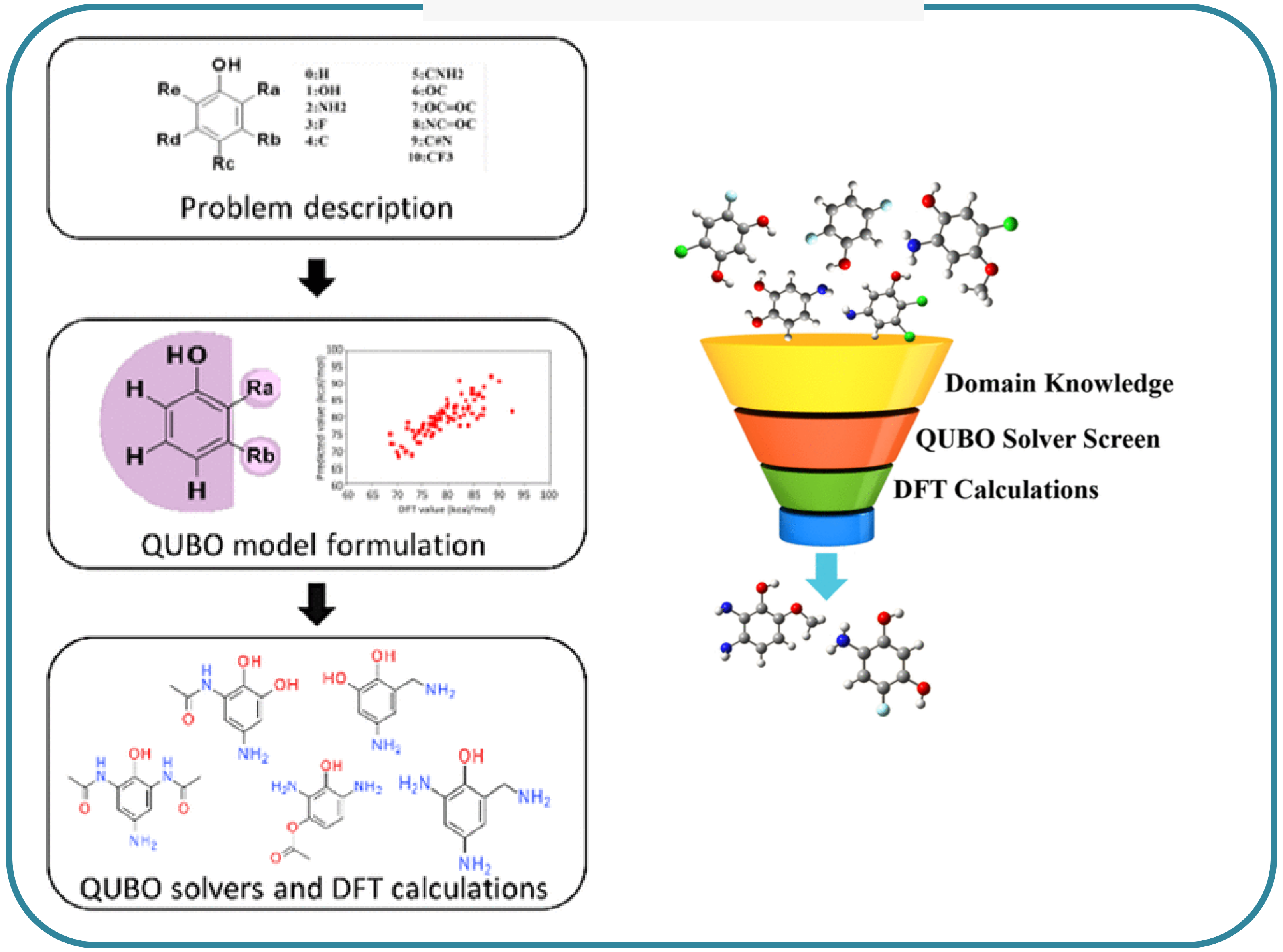
Material & Drug Finding

數位退火模擬量子電腦演算 台塑篩選材料時間加速10倍

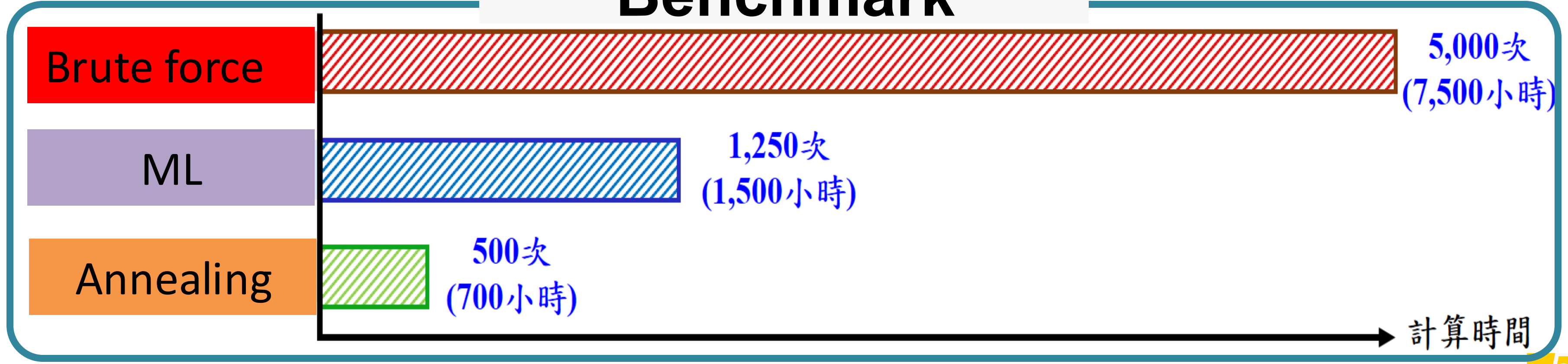
2024/05/02 18:43

Efficient Exploration of Phenol Derivatives Using QUBO Solvers with Group Contribution-Based Approaches,Chien-Hung Cho, et al., *Industrial & Engineering Chemistry Research* **2024** *63* (10), 4248-4256

Workflow



Benchmark



Thanks for listening