Quantum Image Processing

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Focus of the seminar

- Fast encoding of images and filters
- Efficient quantum convolutions
- Fully quantum image manipulation algorithms

Image Processing

- Applications
- Techniques
- Problems

Some Applications

Medical Imaging

Astronomy

Microscopy

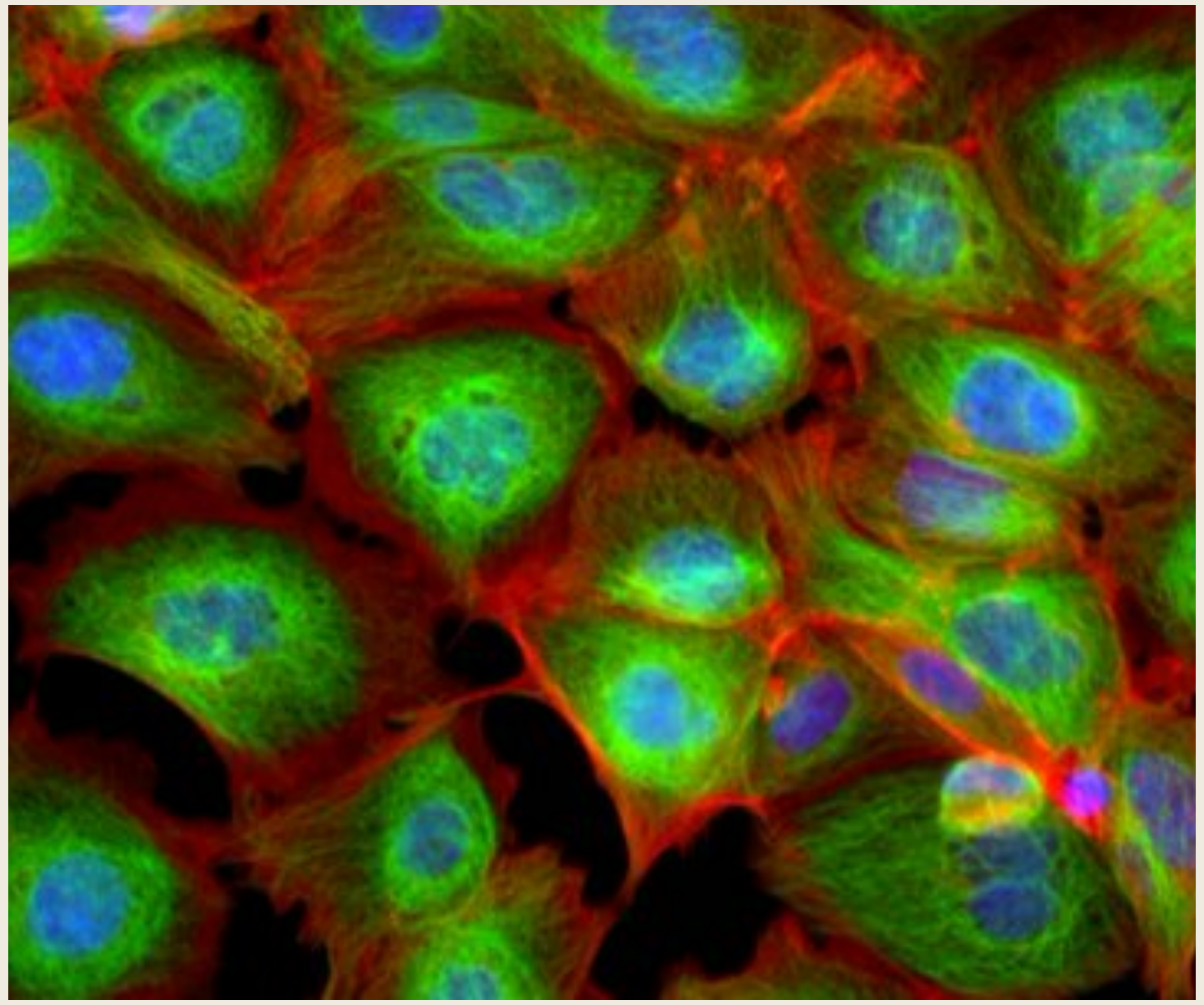
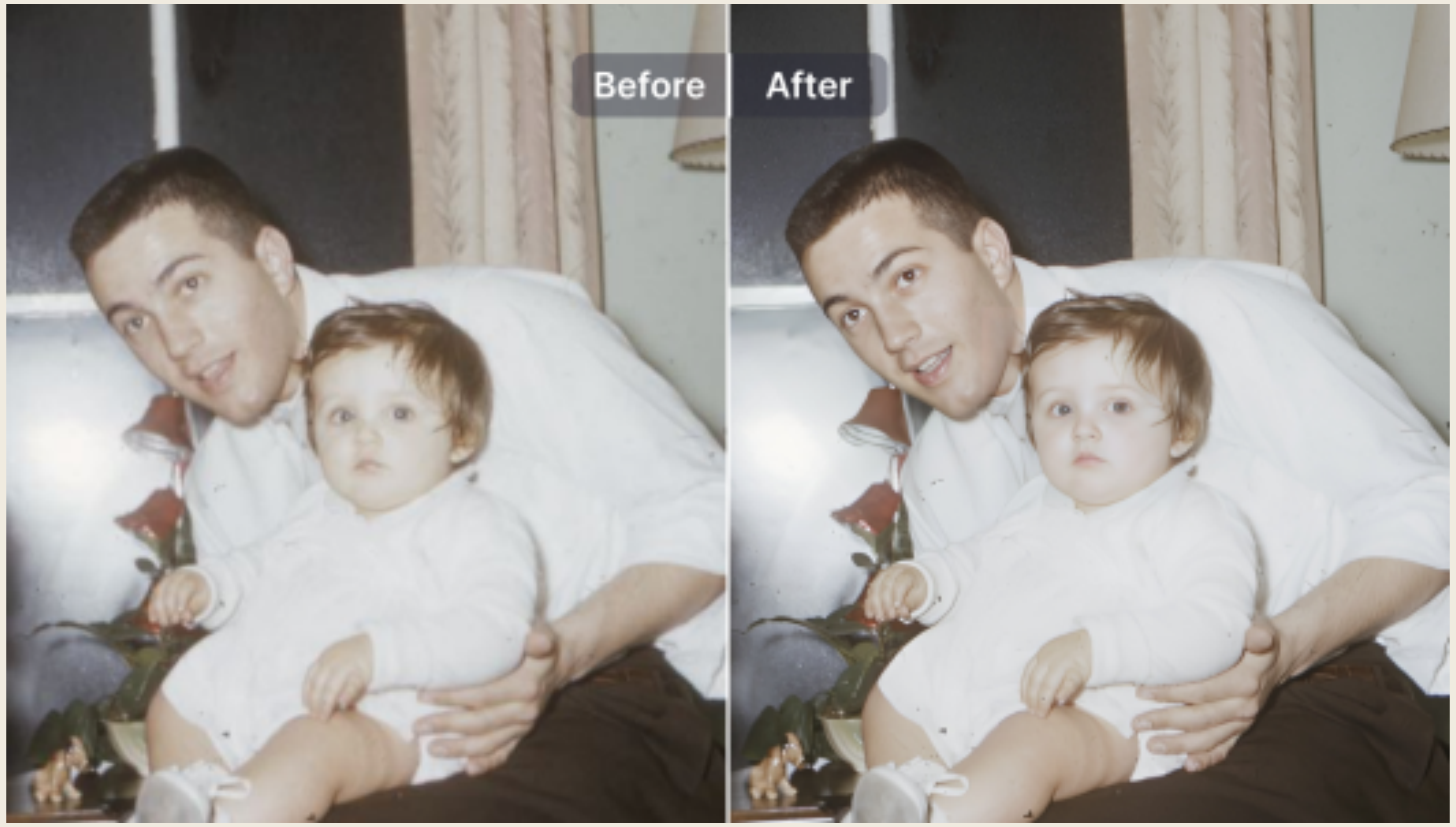


Image Processing

- Applications
- Techniques
- Problems

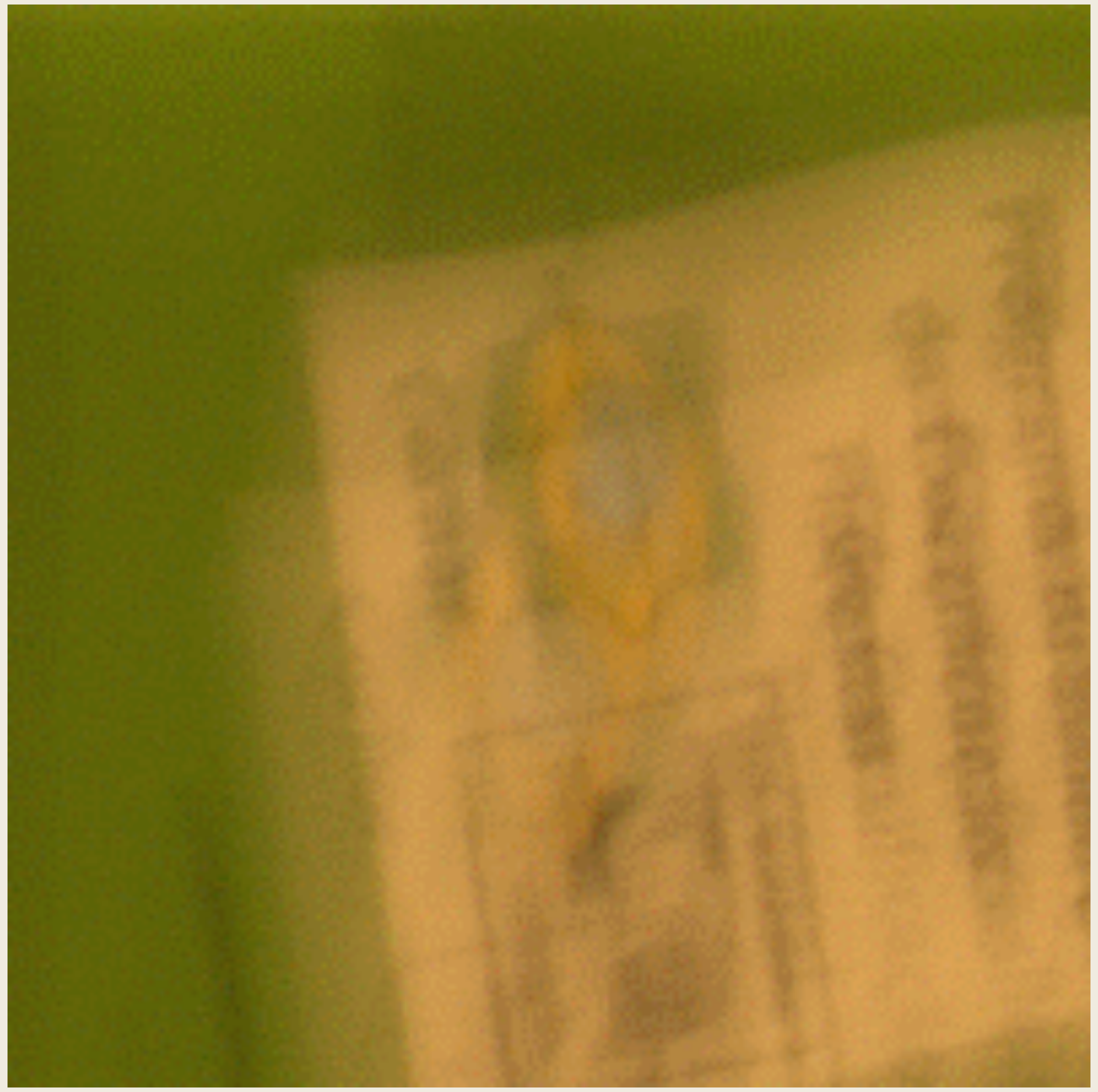
Techniques

Image Enhancement



Techniques

Image Restoration: Deblurring



Techniques

Edge Detection

Image Processing

- Applications
- Techniques
- Problems

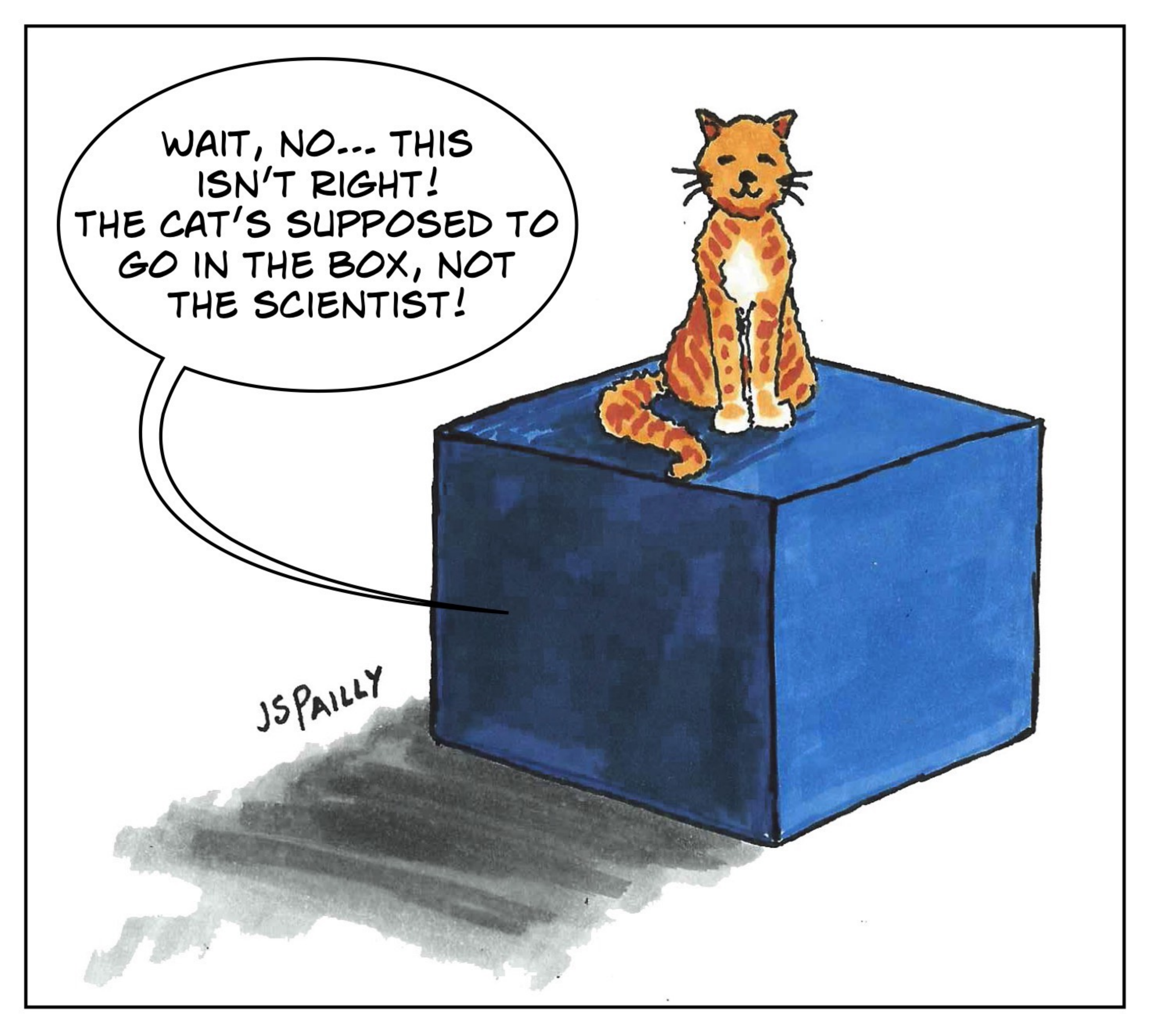
Problems

Space

Time

55 million rendering hours

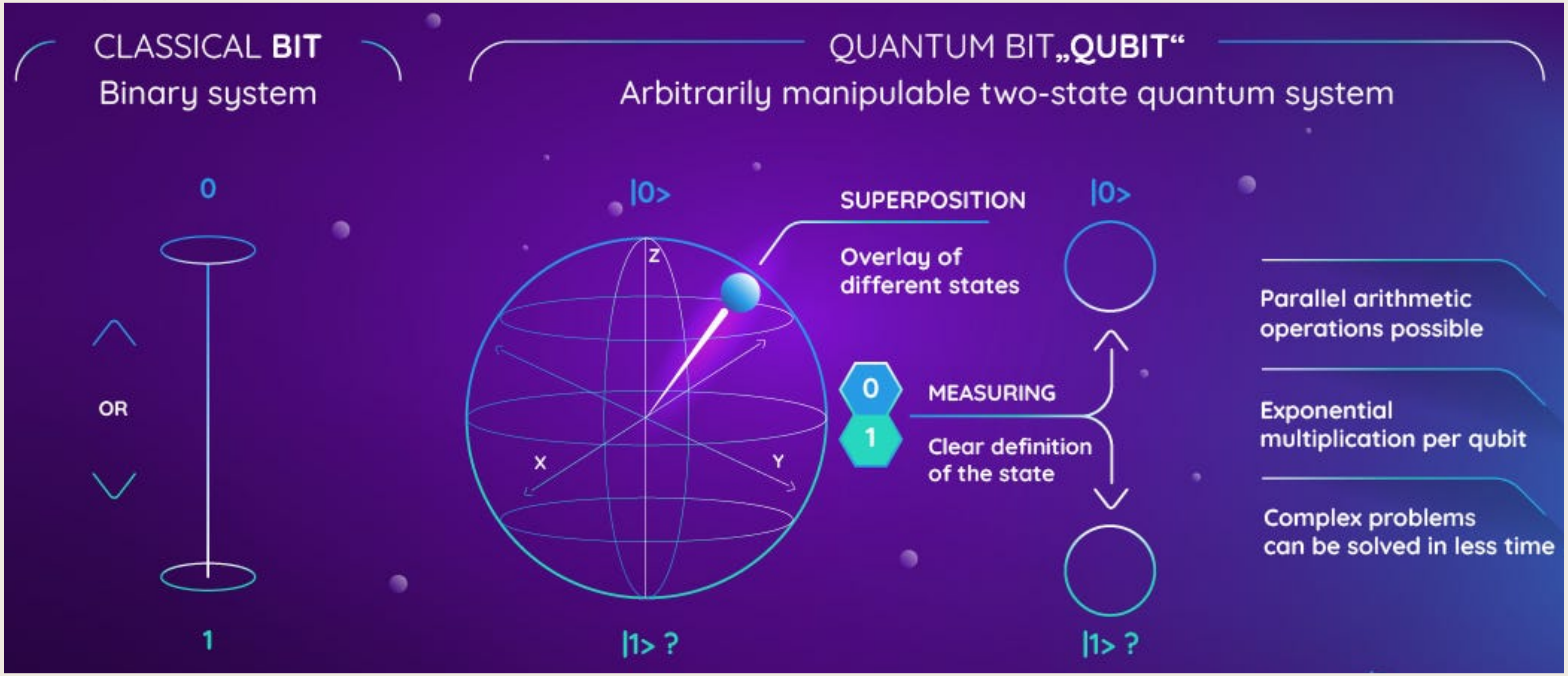
Let's think outside the box!

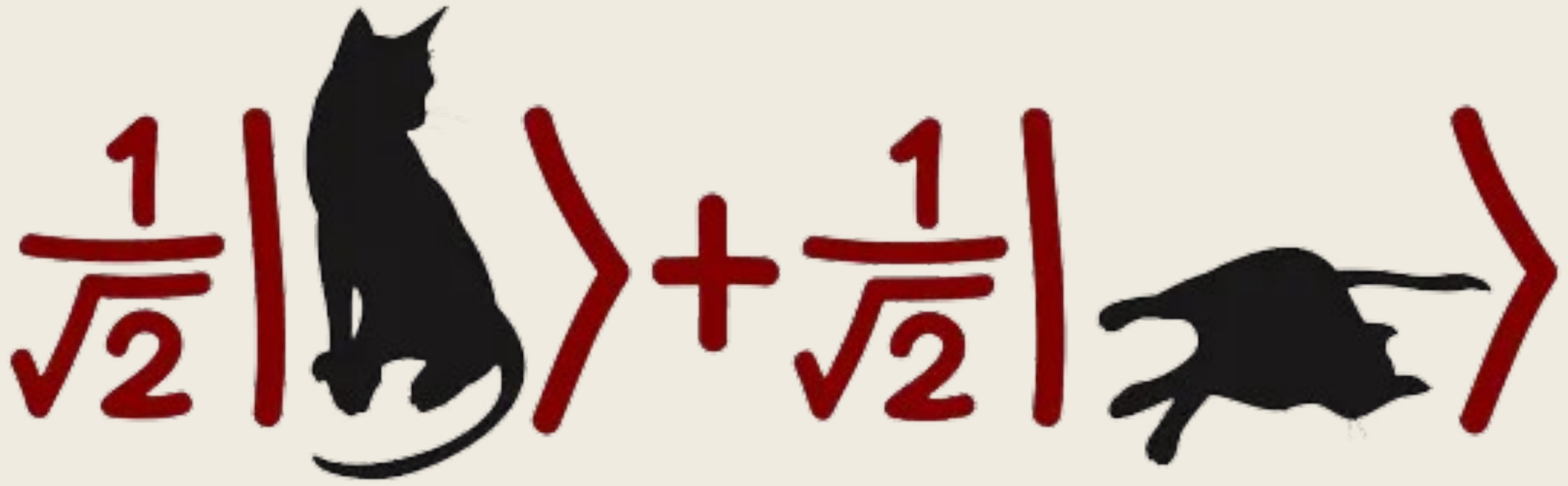


Quantum Computing

- Quantum Foundations
- Quantum Speedup

Quantum Foundations





Quantum Speedup

Constant Balanced Problem

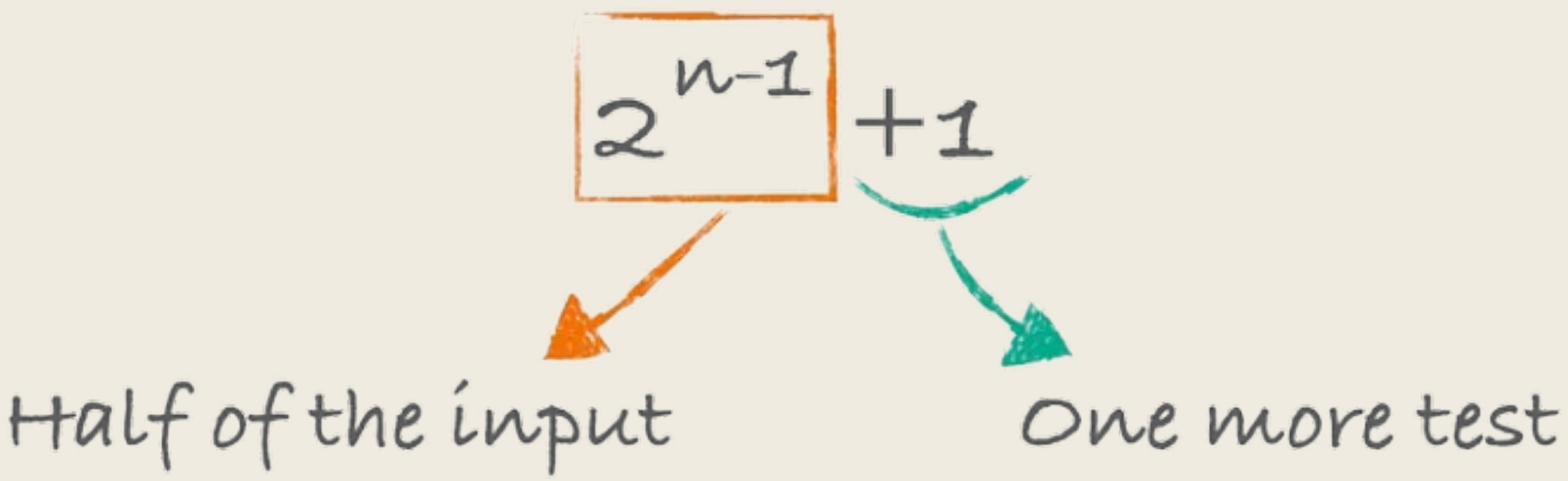
$$f: \{0,1\}^n \rightarrow \{0,1\}$$

Function	x	$f(x)$	Type
$f(x) = 0$	0 1	0 0	Constant
$f(x) = 1$	0 1	1 1	Constant
$f(x) = x$	0 1	0 1	Balanced
$f(x) = x \oplus 1$	0 1	1 0	Balanced

Quantum Speedup

Classical Solution

$$f : \{0,1\}^n \rightarrow \{0,1\}$$

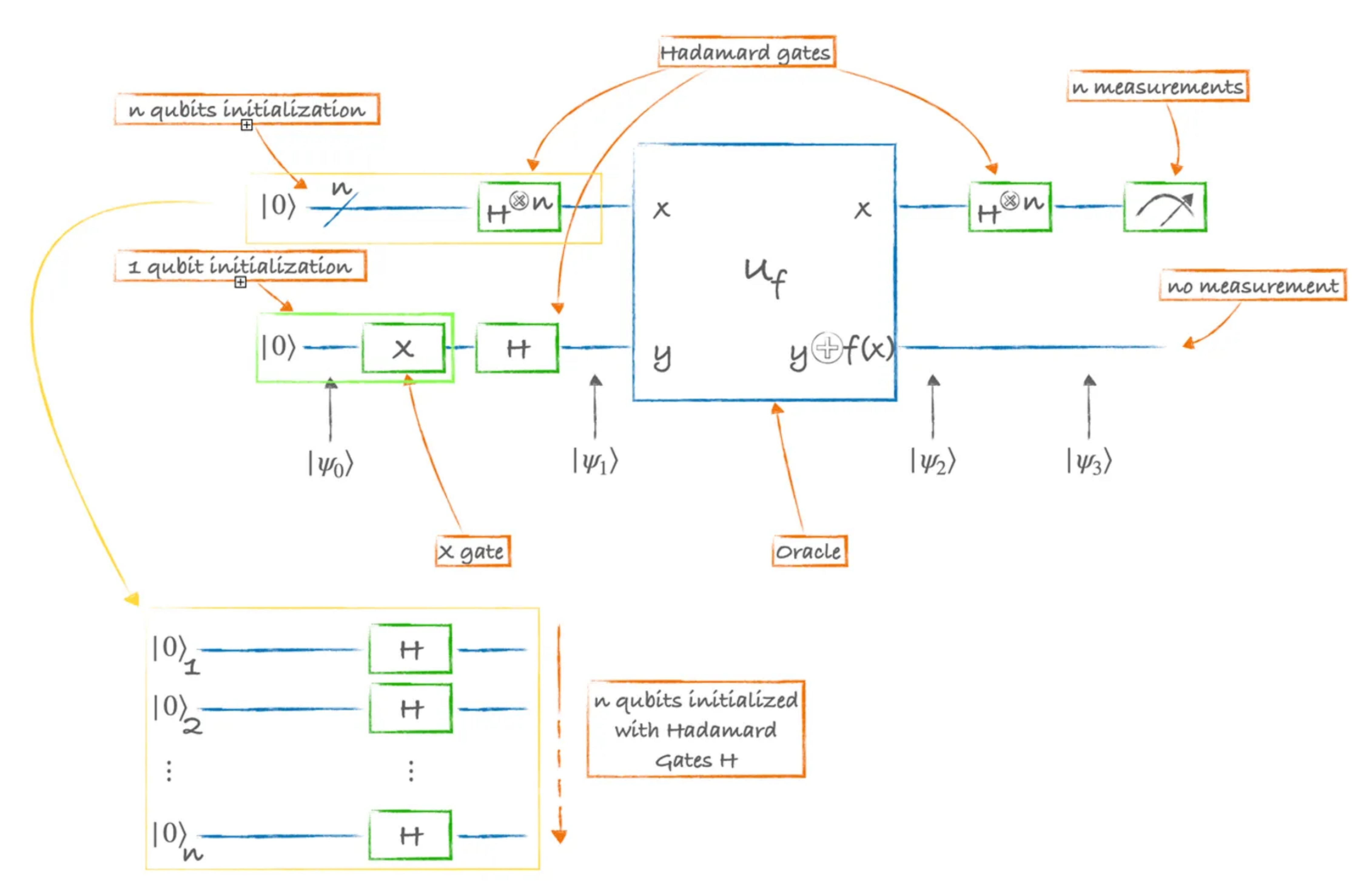


$O(2^n)$

Quantum Speedup

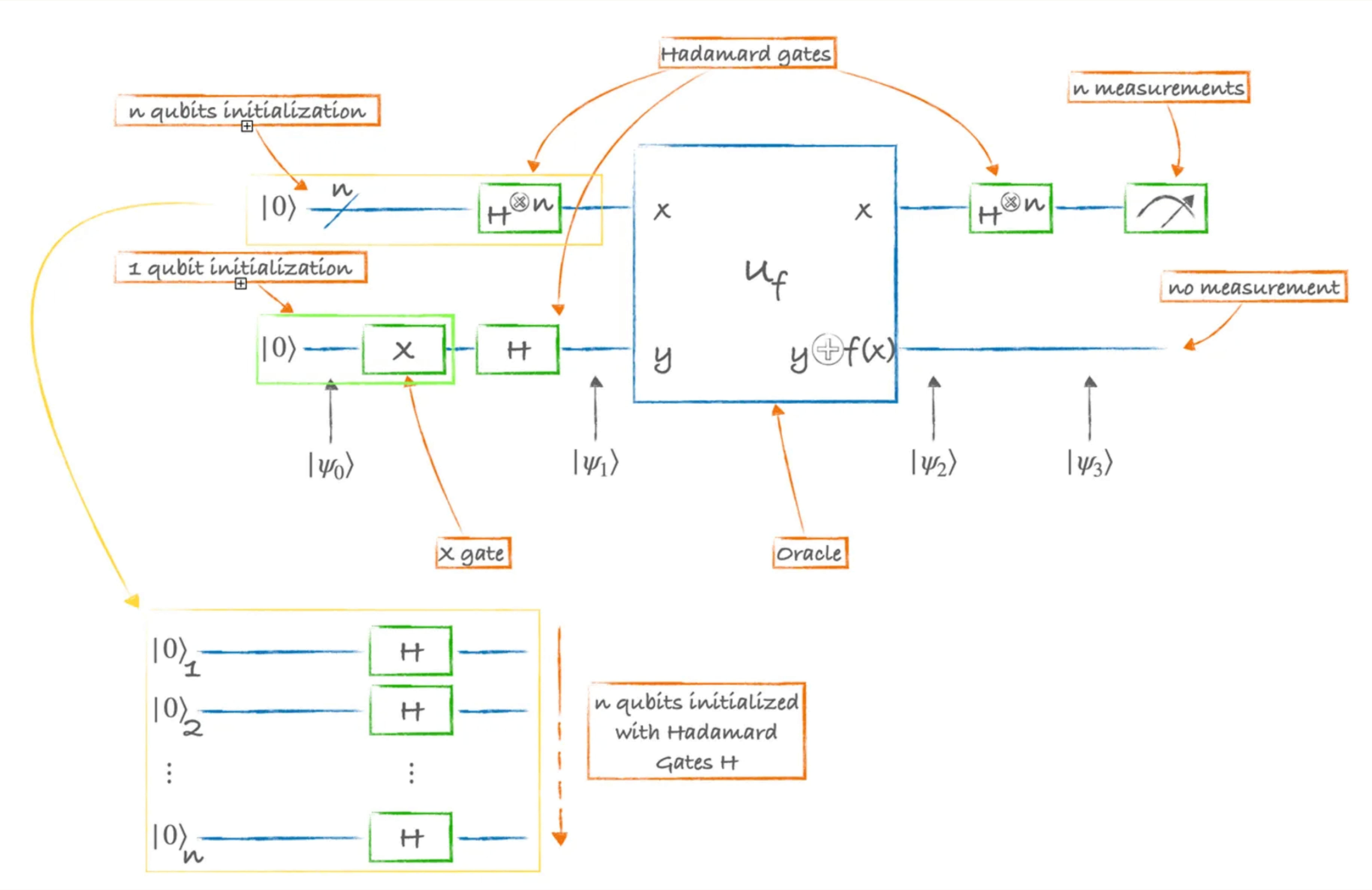
Deutsch-Josza Algorithm

$f:\{0,1\}^n \rightarrow \{0,1\}$



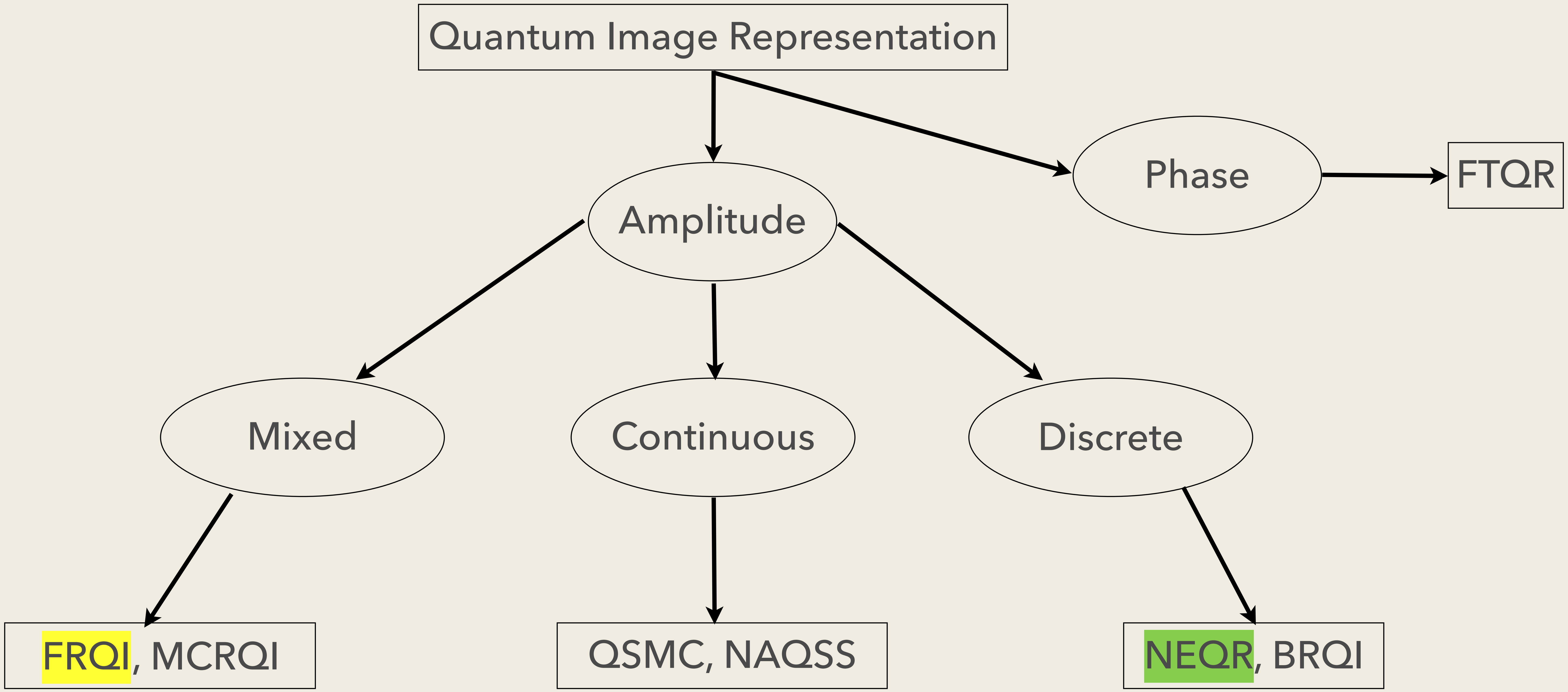
O(1)

Quantum Speedup



Open Problems

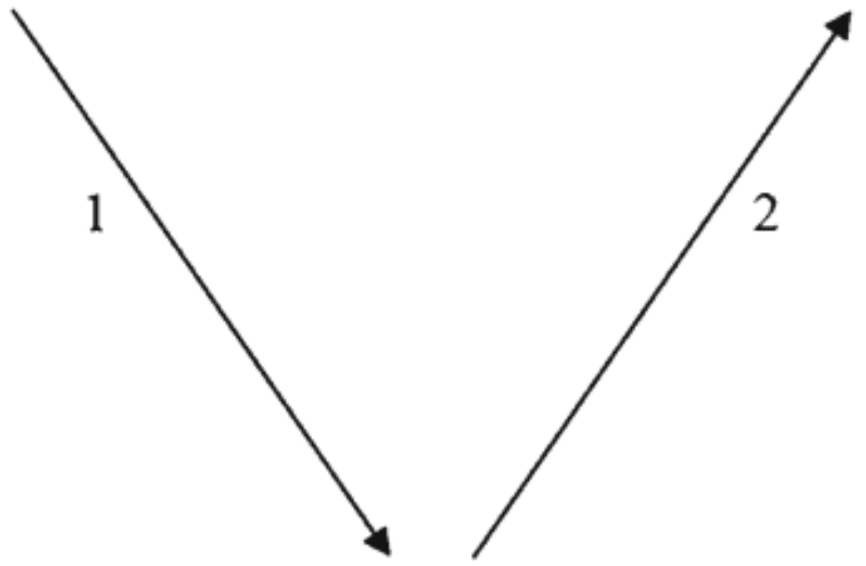
Data Encoding



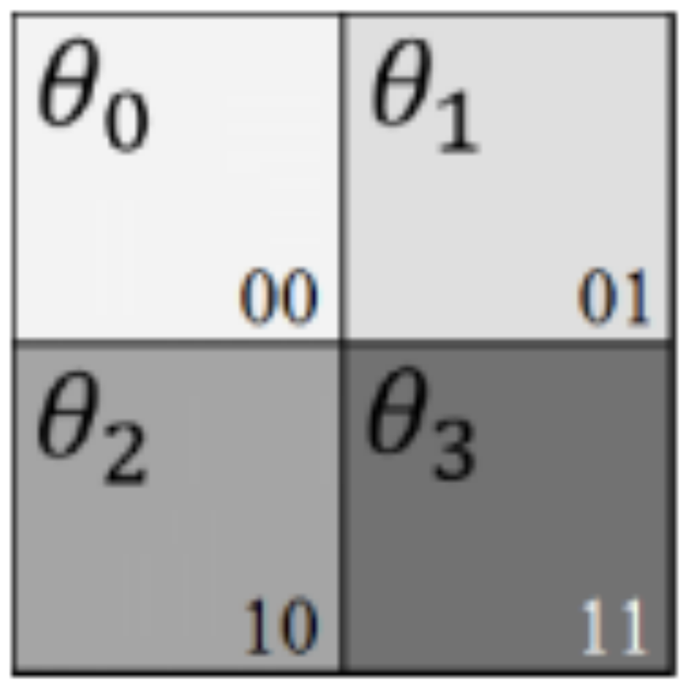
Data Encoding

FRQI

$$|0\rangle^{\otimes 2n+1} \xrightarrow{\mathcal{P}} |I(\theta)\rangle = \frac{1}{2^n}\sum_{i=0}^{2^{2n}-1}\left(\sin\theta_i|0\rangle + \cos\theta_i|1\rangle\right)\otimes|i\rangle$$



$$|H\rangle = \frac{1}{2^n}|0\rangle \otimes \sum_{i=0}^{2^{2n}-1}|i\rangle$$



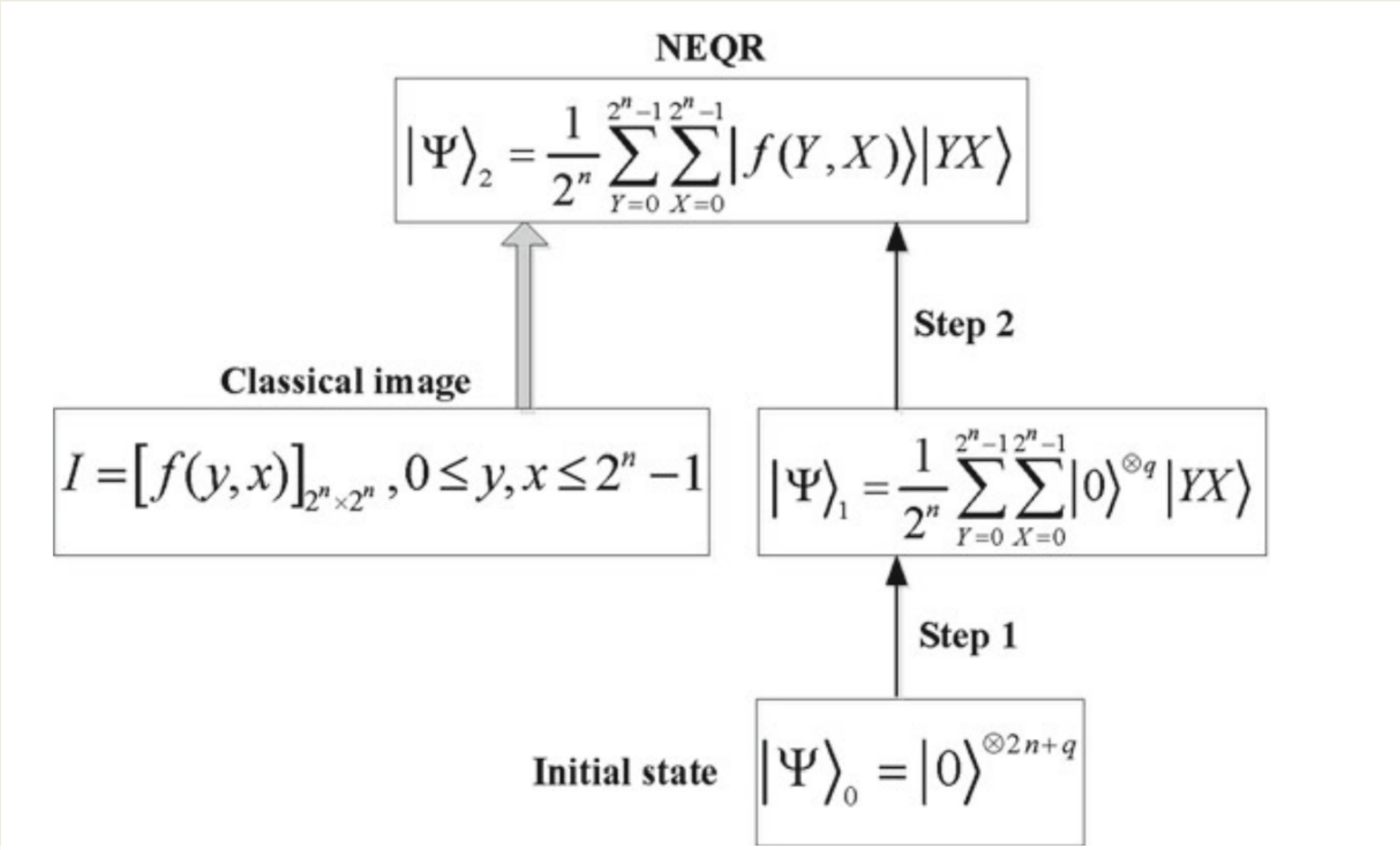
$$|I(1)\rangle = \frac{1}{2}[(\cos\theta_0|0\rangle + \sin\theta_0|1\rangle) \otimes |00\rangle + (\cos\theta_1|0\rangle + \sin\theta_1|1\rangle) \otimes |01\rangle$$
$$+(\cos\theta_2|0\rangle + \sin\theta_2|1\rangle) \otimes |10\rangle + (\cos\theta_3|0\rangle + \sin\theta_3|1\rangle) \otimes |11\rangle]$$

NEQR

Data Encoding

FRQI

NEQR



$$|I\rangle = \frac{1}{2}(|0\rangle\otimes|00\rangle + |100\rangle\otimes|01\rangle + |200\rangle\otimes|10\rangle + |255\rangle\otimes|11\rangle)$$

$$= \frac{1}{2}(|00000000\rangle\otimes|00\rangle + |01100100\rangle\otimes|01\rangle$$

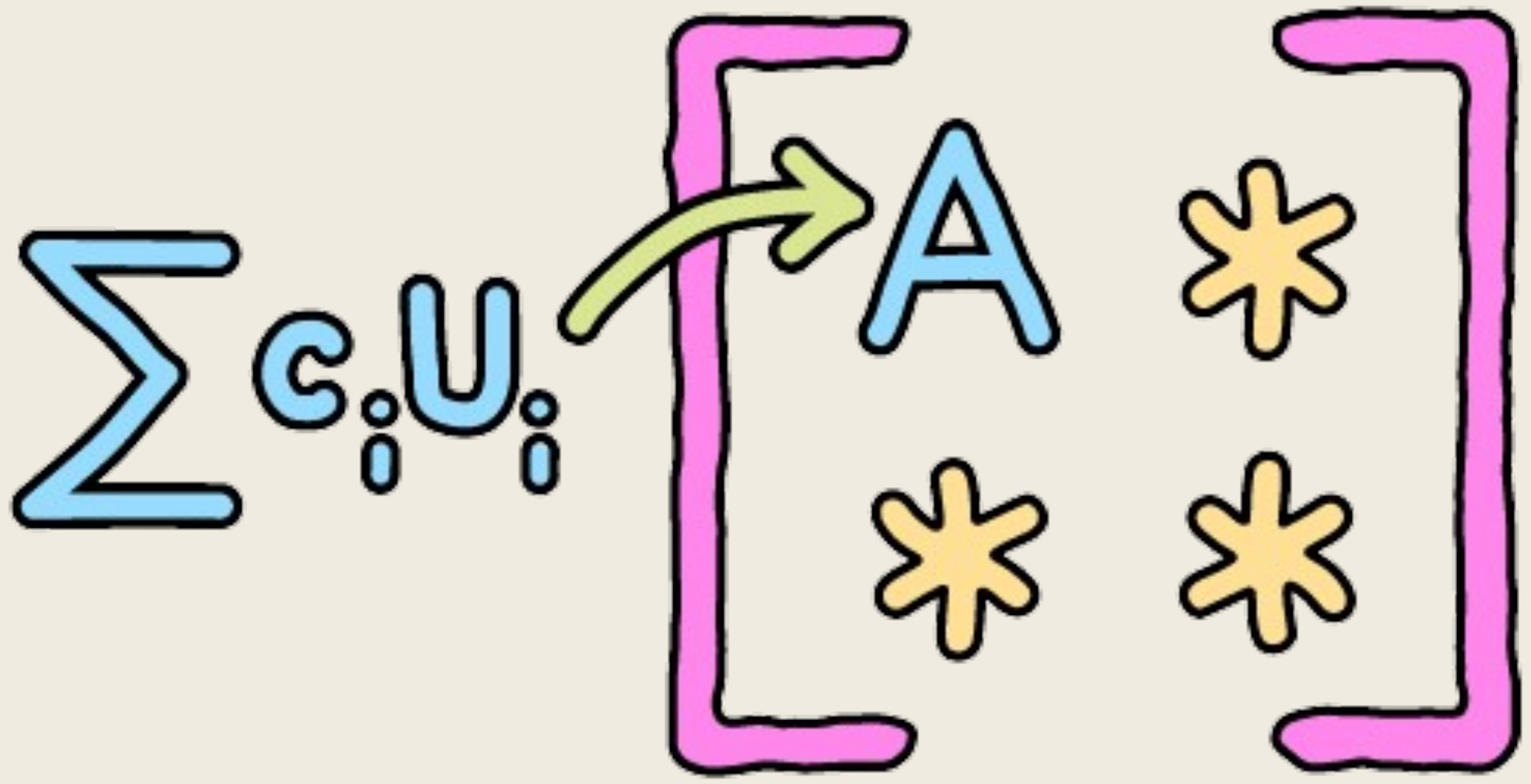
$$+ |11001000\rangle\otimes|10\rangle + |11111111\rangle\otimes|11\rangle)$$

Data Encoding

Is there another way?

How can we do it efficiently?

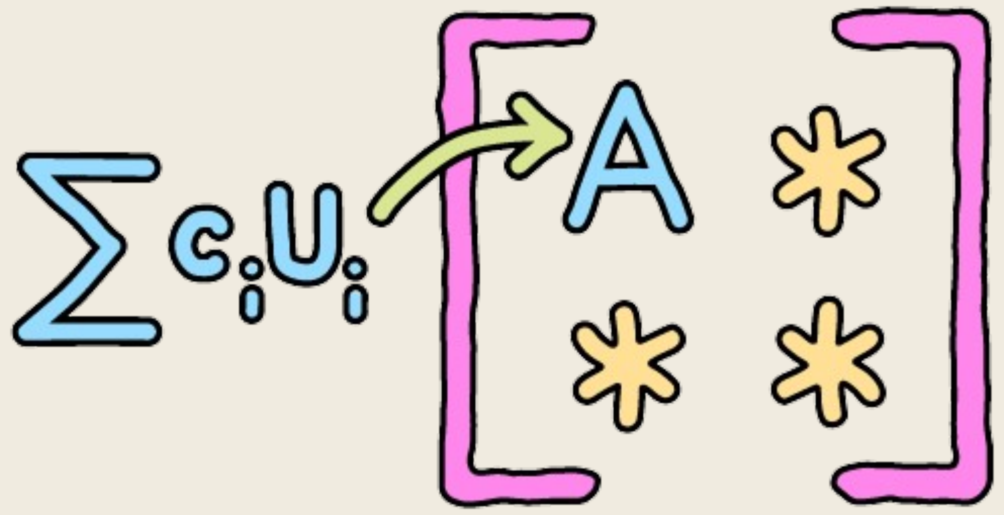
Block Encoding



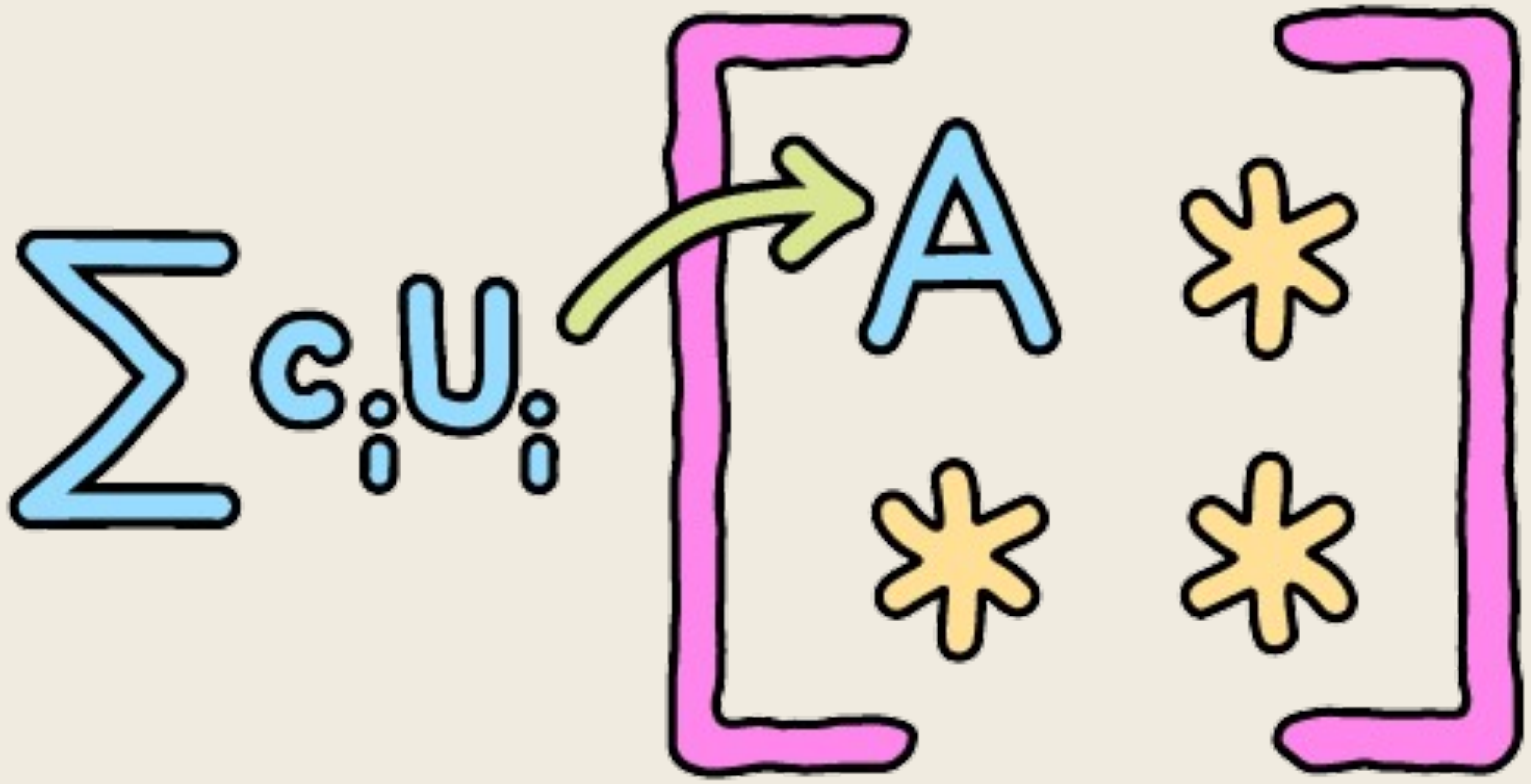
Block Encoding

Definition 1 (Block-encoding [GSLW18, Definition 43]). *Suppose that A is an n-qubit matrix, $\alpha, \varepsilon \in \mathbb{R}_+$, and $a \in \mathbb{N}$. Then, we say that the $n + a$-qubit unitary operation U is the (α, a, ε)-block-encoding of A if*

$$\left\| A - \alpha(\langle 0^a | \otimes I_n) U (|0^a\rangle \otimes I_n) \right\| \leq \varepsilon. \tag{3}$$



Block Encoding

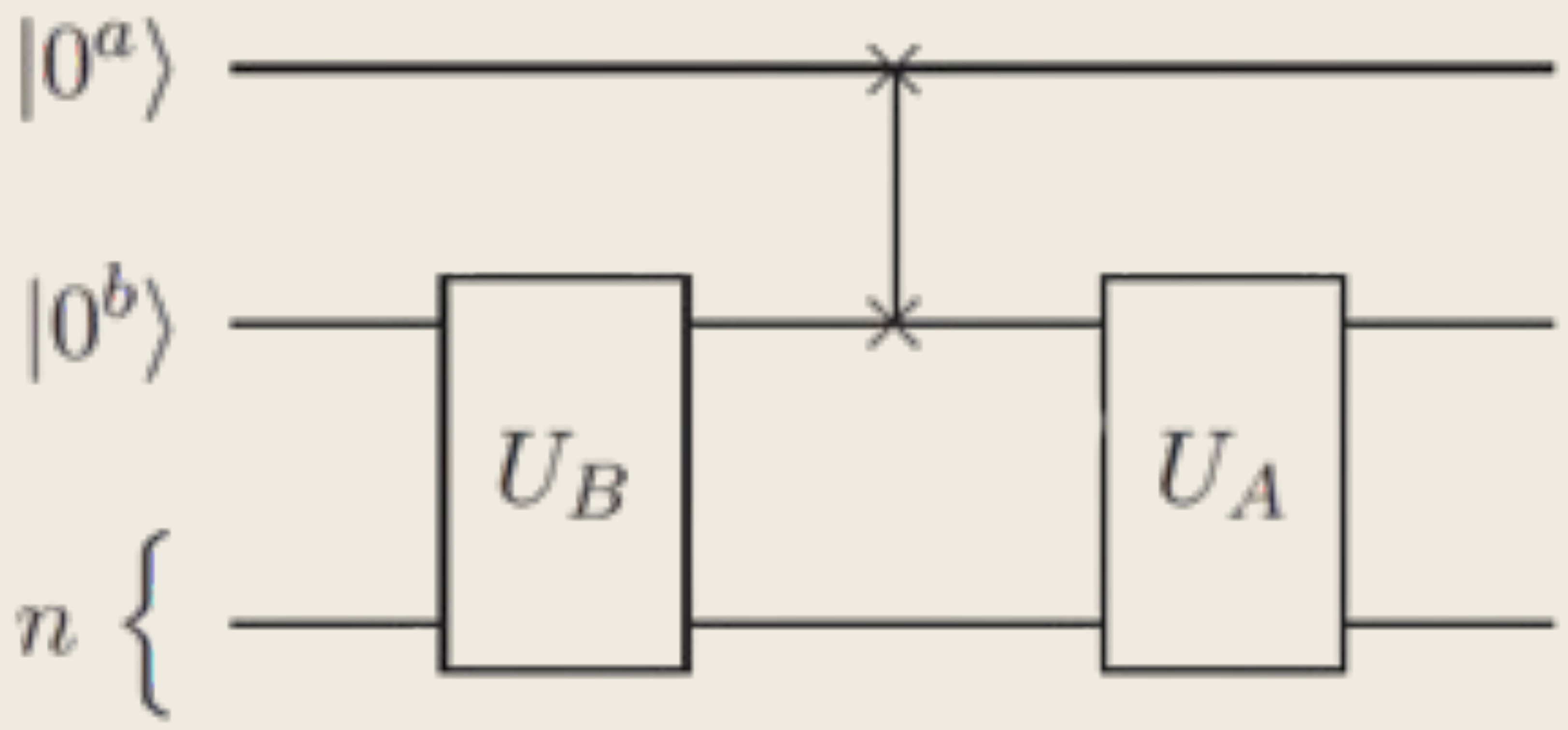


FABLE method

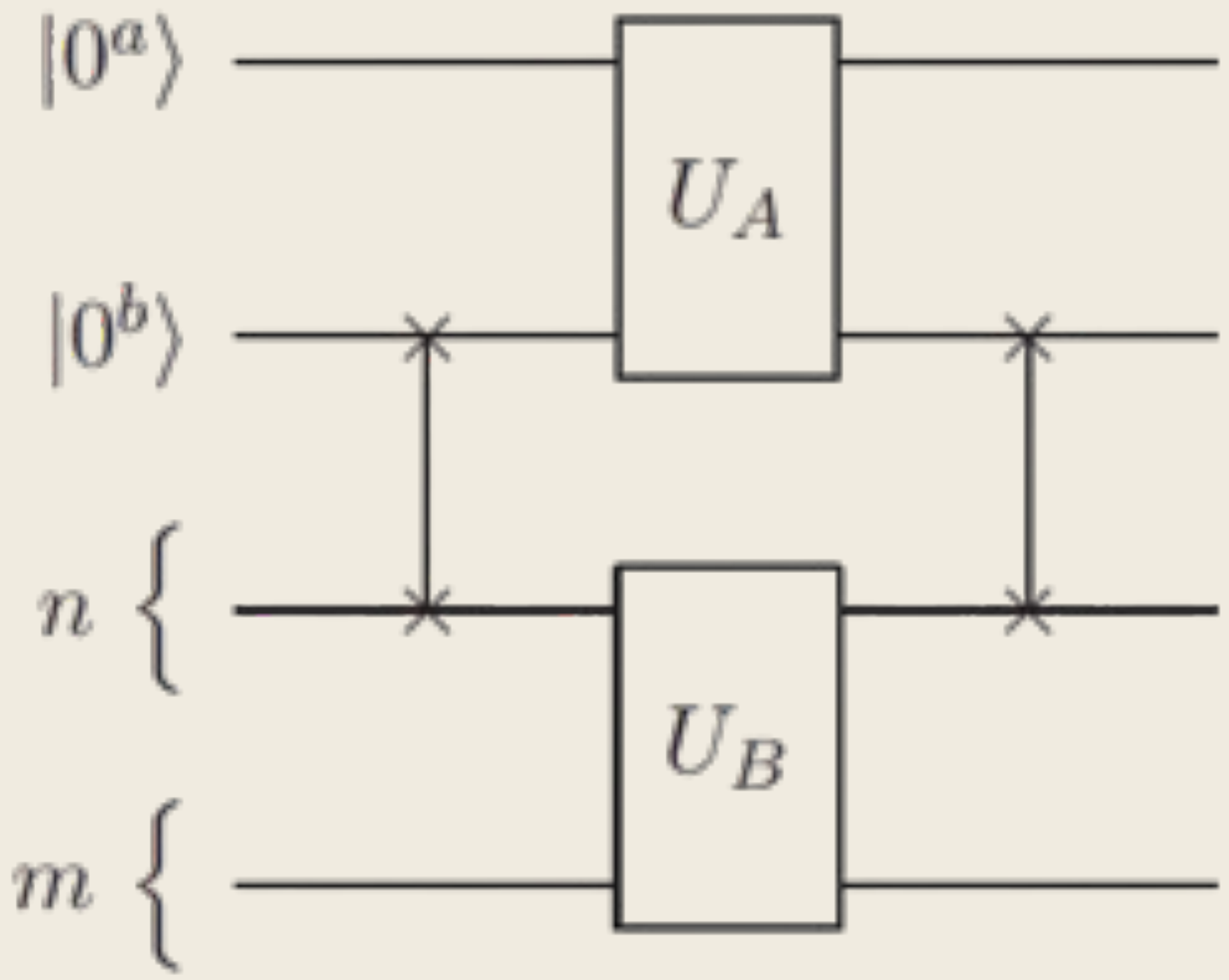
Hamiltonian Simulation method

Linear combination of Unitary matrices

Block Encoding Algebra

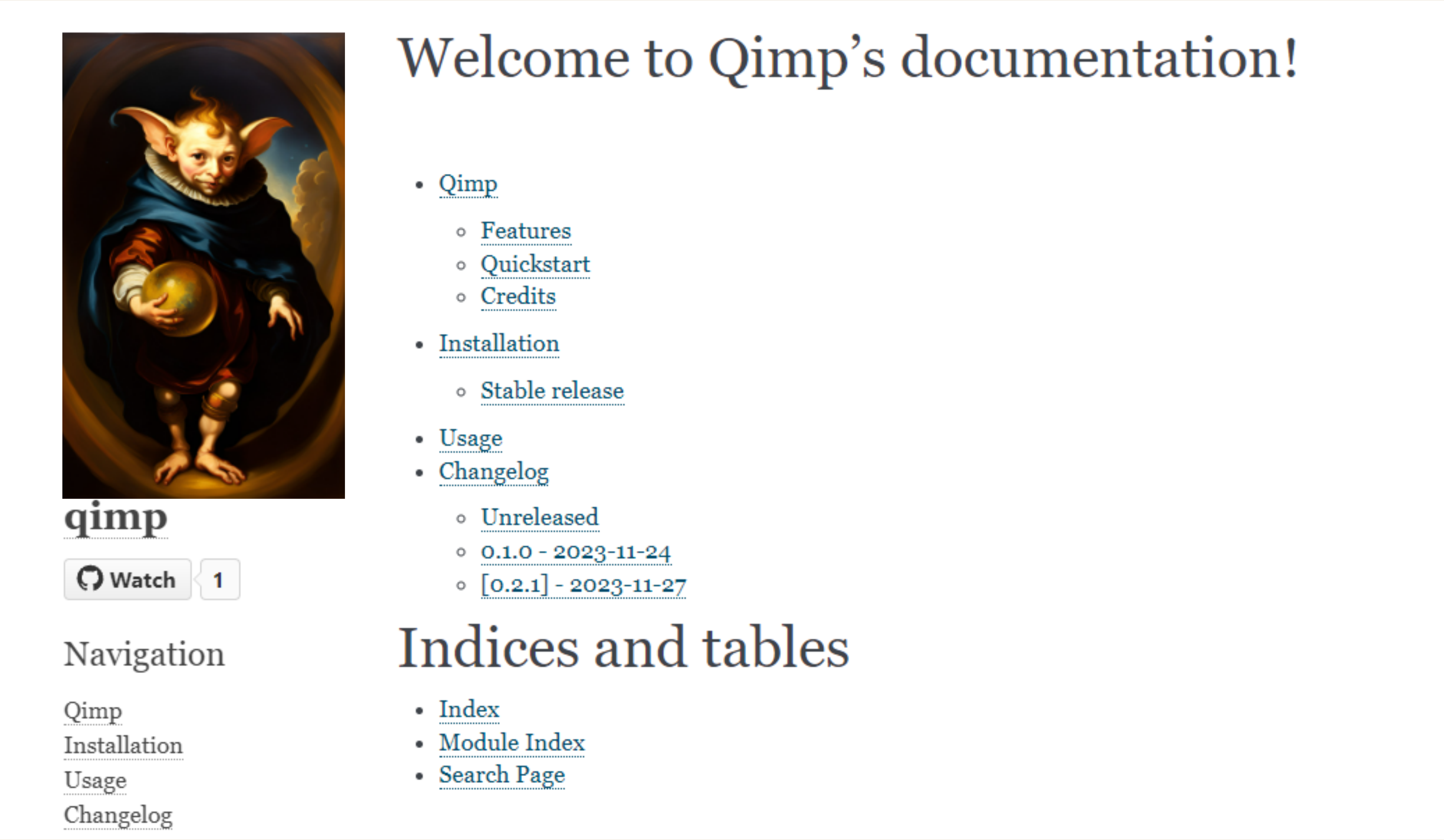


(a) $(\alpha\beta, a+b, \alpha\varepsilon_B + \beta\varepsilon_A)$-block-encoding of n-qubit matrix AB.



(b) $(\alpha\beta, a+b, \alpha\varepsilon_B + \beta\varepsilon_A)$-block-encoding of nm-qubit matrix $A \otimes B$.

QImP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[0.2.1] - 2023-11-27
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QImP Milestones

- Implement different data loading techniques
- Implement image restoration algorithms
- Implement object detection techniques
- Implement image classification algorithms
- Keep the quantum advantage

Research Group Milestones

- Study how to encode structured matrices
- Study how to efficiently perform matrix algebra with these matrices
- Exploit matrices properties for image manipulation (e.g. QSVD, QDCT, ...)