

Quantum Machine Learning (QML)

January 19th, 2022

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Content

- Classical Machine Learning
- Quantum Machine Learning
- Quantum Computing
- Amplitude Encoding
- 1st generation QML
- 2nd generation QML
- Discussion

Machine Learning



ML Algorithms

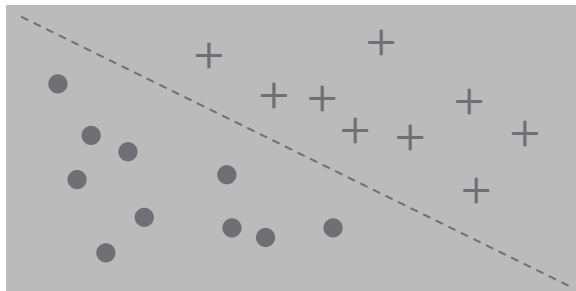
Supervised learning

Support Vector Machine

K Nearest Neighbors

Neural Networks

...



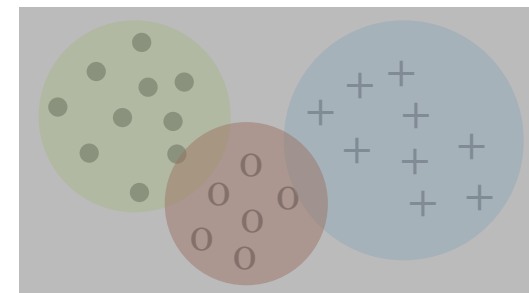
Unsupervised learning

Principal Component Analysis

K Means Clustering

Neural Networks

...



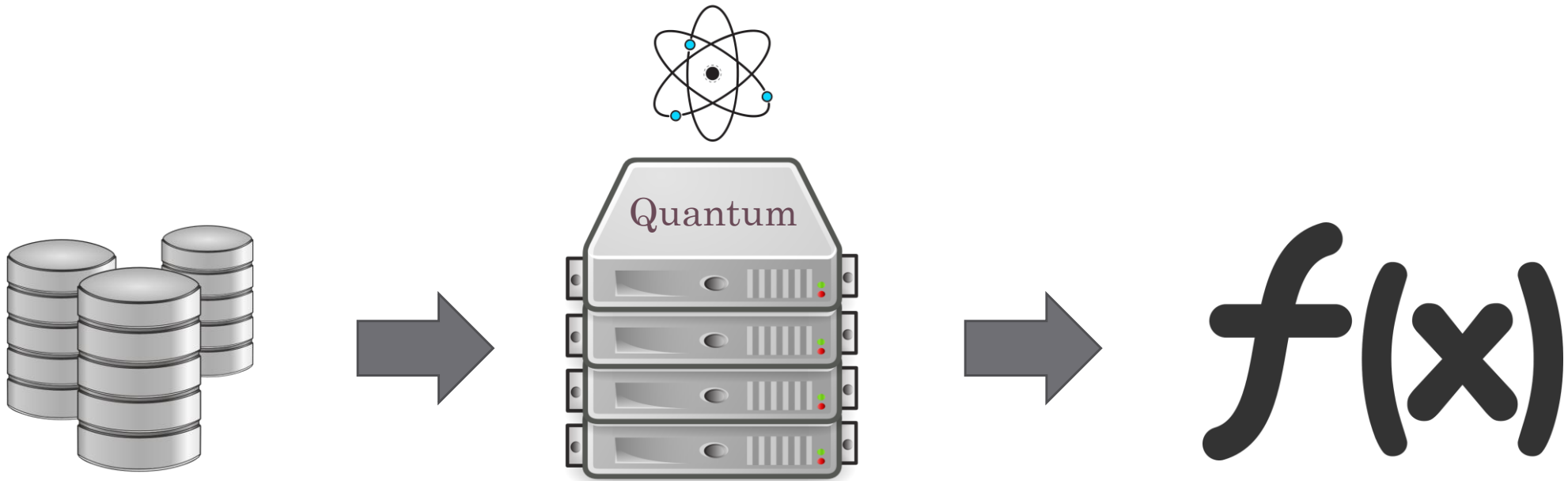
Quantum Machine Learning

		Type of Algorithm	
		classical	quantum
Type of Data	classical	CC	CQ
	quantum	QC	QQ

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Quantum Machine Learning



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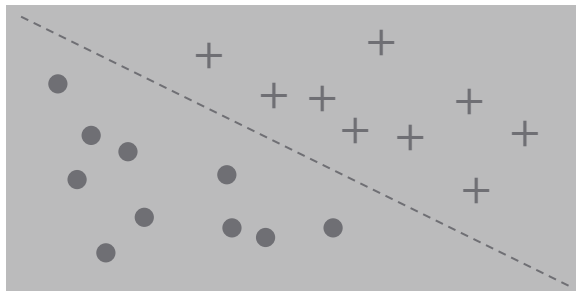
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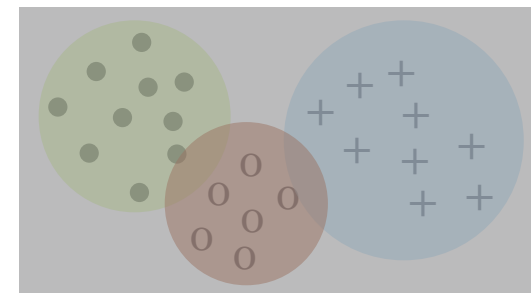
Unsupervised learning

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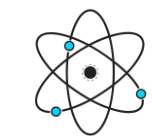
Neural Networks

...



QML Algorithms

Supervised learning



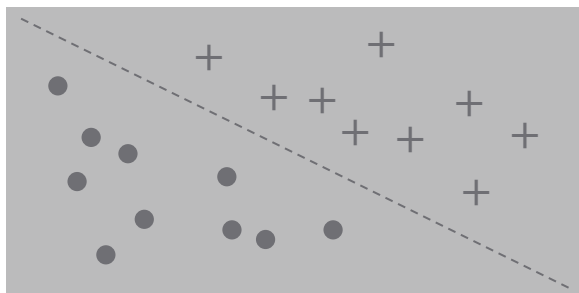
QUANTUM

Support Vector Machine

K Nearest Neighbors

Neural Networks

...



Unsupervised learning



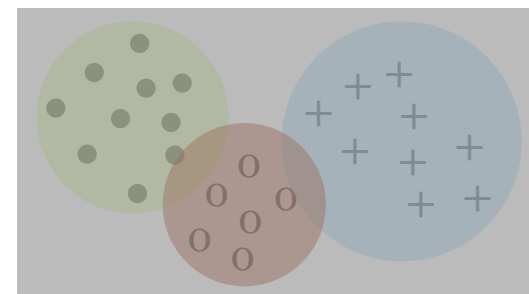
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QML Algorithms

Supervised learning



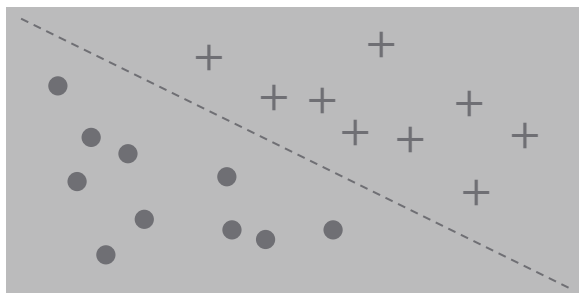
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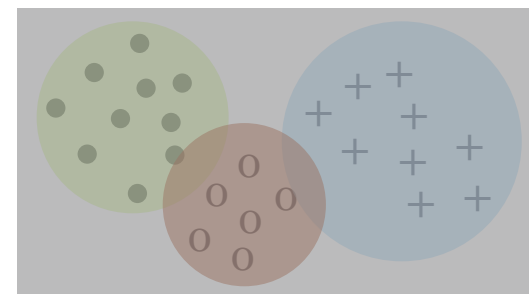
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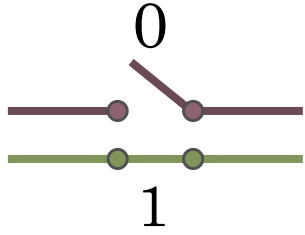
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Exponential speed-up → QML became a hype!

Classical

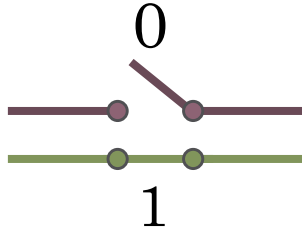
Bit



Quantum

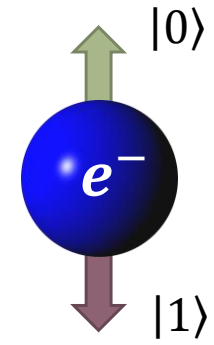
Classical

Bit



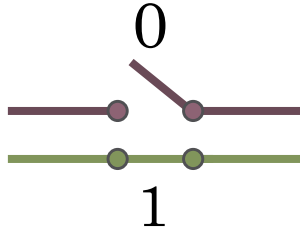
Quantum

Qubit



Classical

Bit



n -bit register $\rightarrow 2^n$ values

$00 \rightarrow 0$

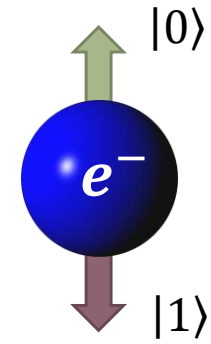
$01 \rightarrow 1$

$10 \rightarrow 2$

$11 \rightarrow 3$

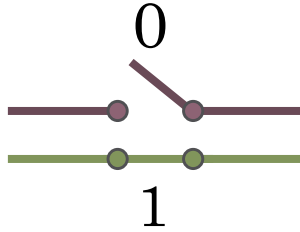
Quantum

Qubit



Classical

Bit



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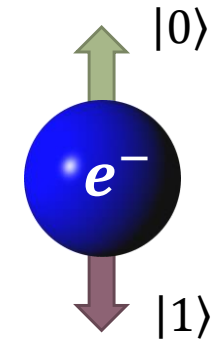
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Quantum

Qubit



n -bit q-register $\rightarrow 2^n$ values

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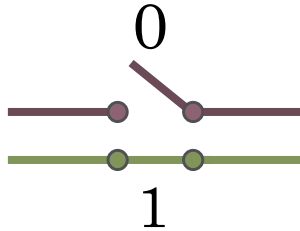
$|01\rangle \rightarrow |1\rangle$

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Classical

Bit



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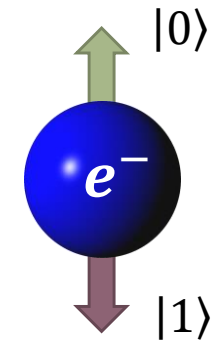
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Quantum

Qubit



n -bit q-register $\rightarrow 2^n$ values

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$|01\rangle \rightarrow |1\rangle$

$|10\rangle \rightarrow |2\rangle$

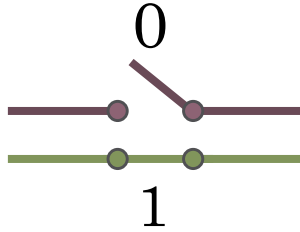
$|11\rangle \rightarrow |3\rangle$

Superposition!

$$a_0|0\rangle + a_1|1\rangle + a_2|2\rangle + a_3|3\rangle$$

Classical

Bit



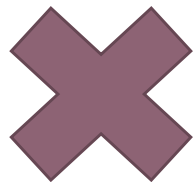
n -bit register $\rightarrow 2^n$ values

$00 \rightarrow 0$

$01 \rightarrow 1$

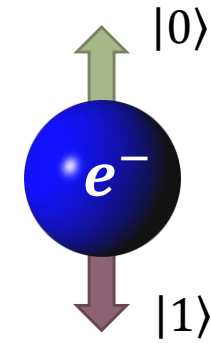
$10 \rightarrow 2$

$11 \rightarrow 3$



Quantum

Qubit



n -bit q-register $\rightarrow 2^n$ values

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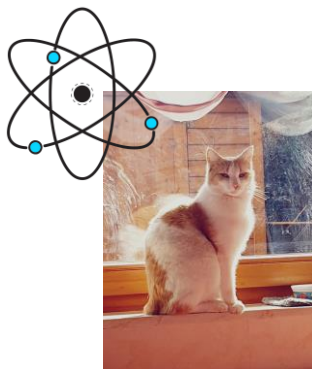
Amplitude Encoding


$$\rightarrow \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ \vdots \\ x_{n-1} \end{bmatrix} \in \mathbb{R}^n$$

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$$\rightarrow |x\rangle = x_0 |0\rangle + \cdots + x_{n-1} |n-1\rangle$$

Amplitude Encoding




$$\rightarrow \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ \vdots \\ x_{n-1} \end{bmatrix} \in \mathbb{R}^n$$

$O(n)$ bits

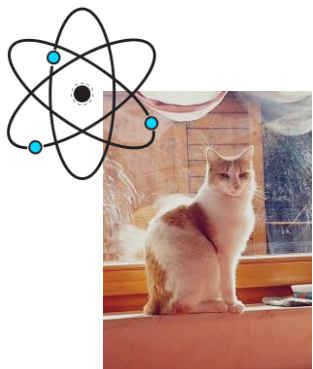


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Amplitude Encoding



$$\rightarrow \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ \vdots \\ x_{n-1} \end{bmatrix} \in \mathbb{R}^n \quad O(n) \text{ bits}$$



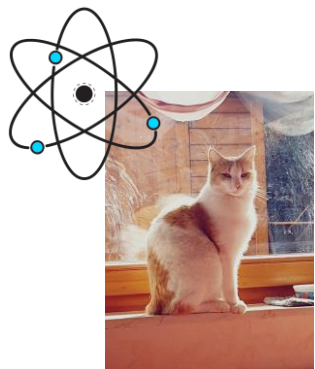
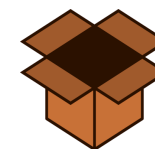
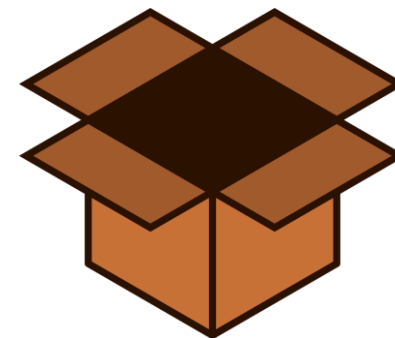
$$\rightarrow |x\rangle = x_0 |0\rangle + \cdots + x_{n-1} |n-1\rangle \quad O(\log_2 n) \text{ qubits}$$

Amplitude Encoding



$$\rightarrow \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ \vdots \\ x_{n-1} \end{bmatrix} \in \mathbb{R}^n$$

$O(n = 2^d)$ bits



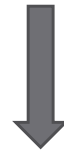
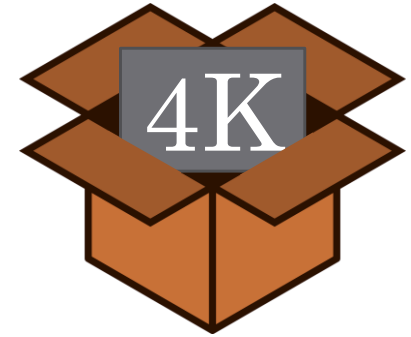
$$\rightarrow |x\rangle = x_0|0\rangle + \cdots + x_{n-1}|n-1\rangle \quad O(d) \text{ qubits}$$

Amplitude Encoding

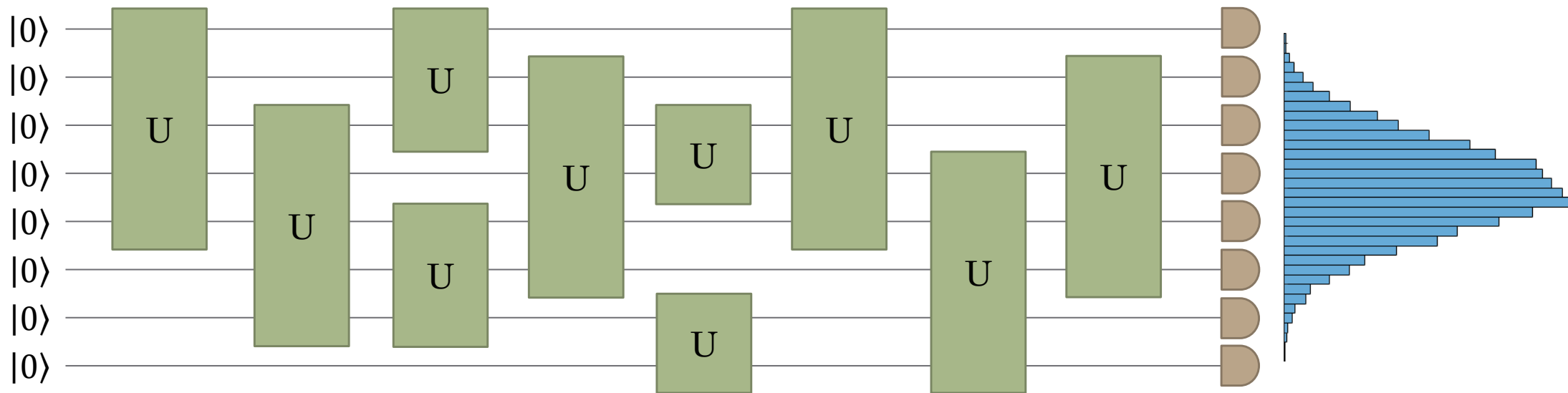
4K movie \approx 100 GB



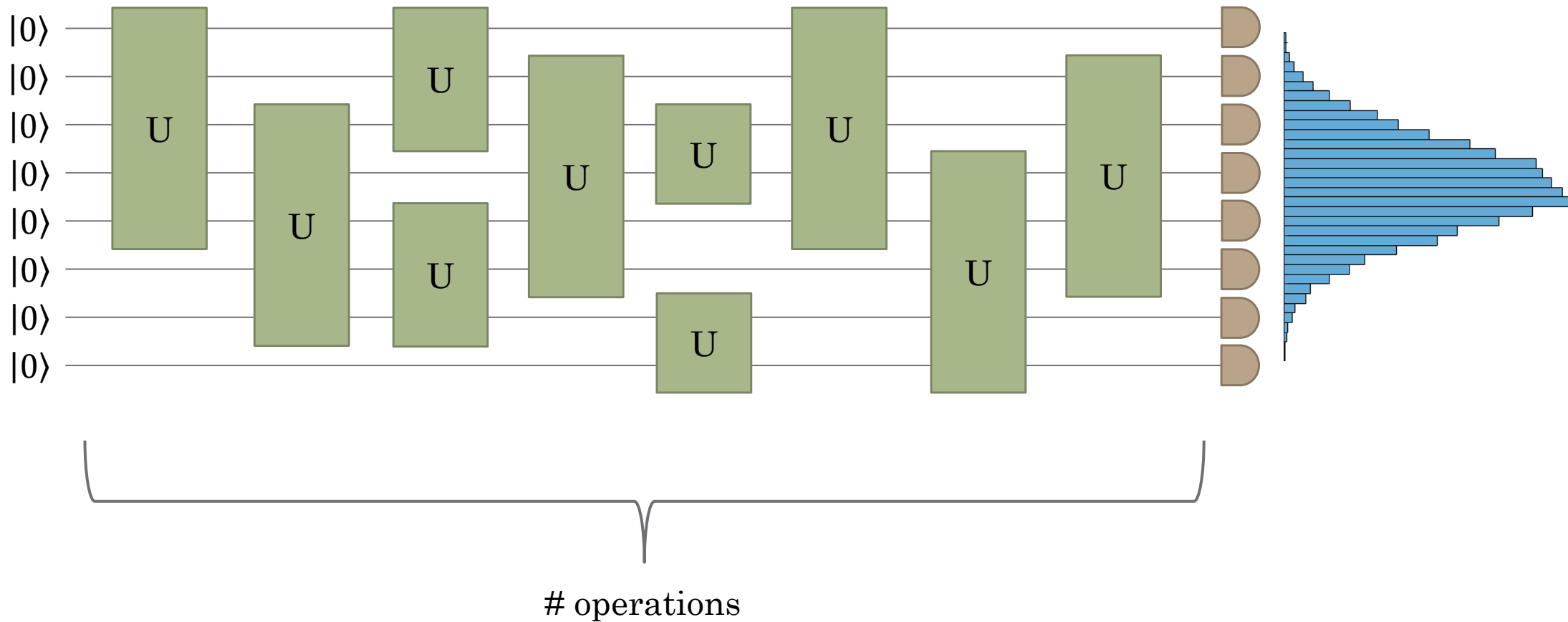
40 qubits



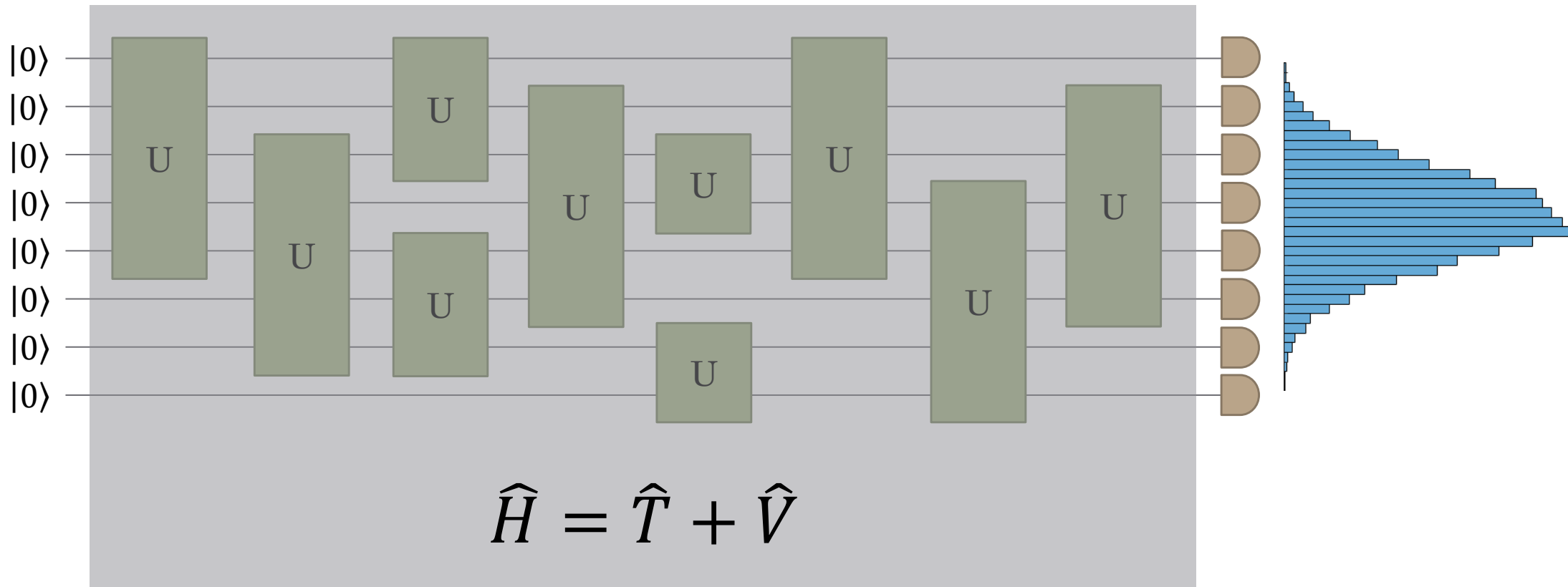
Quantum Circuits



Quantum Circuits

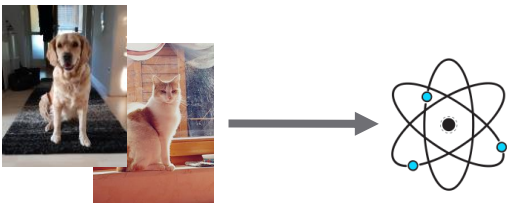
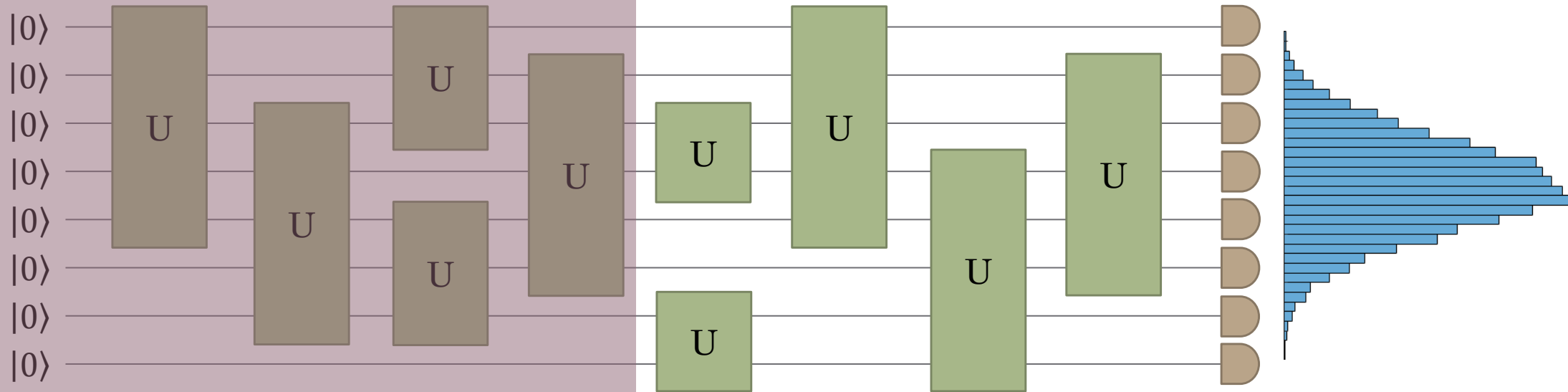


Quantum Circuits

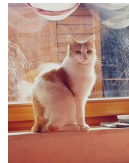
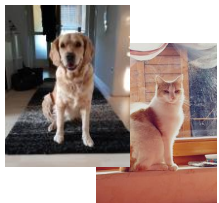
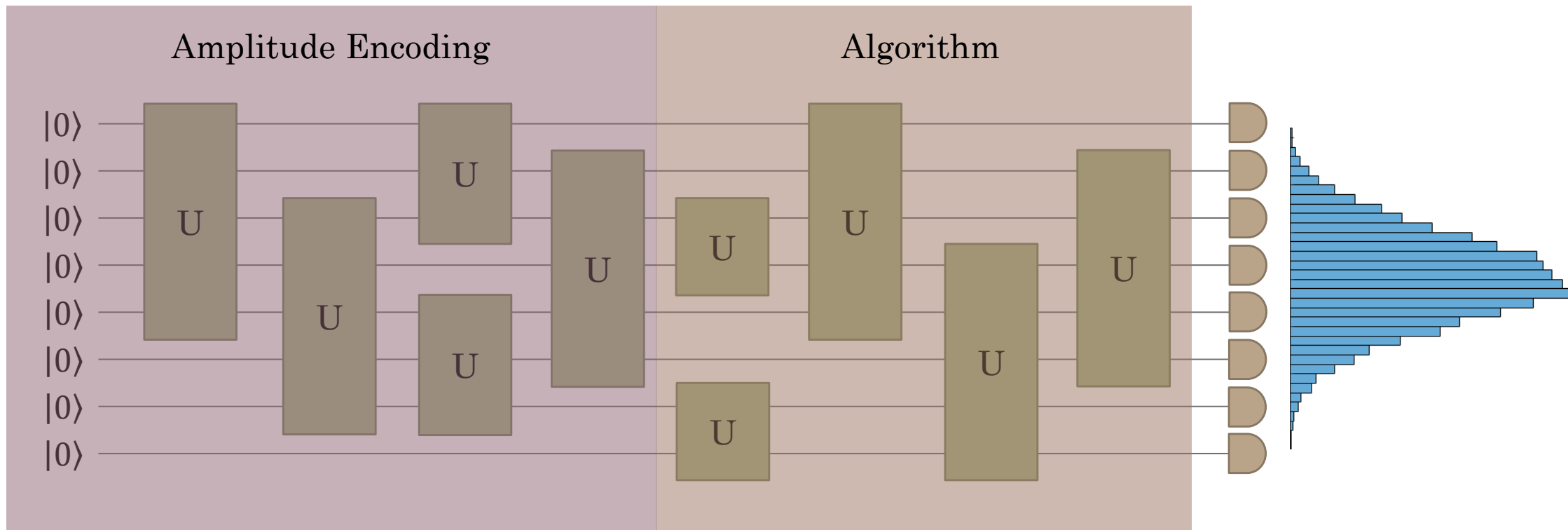


Quantum Circuits

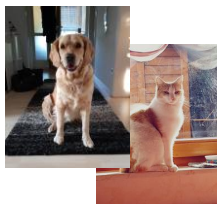
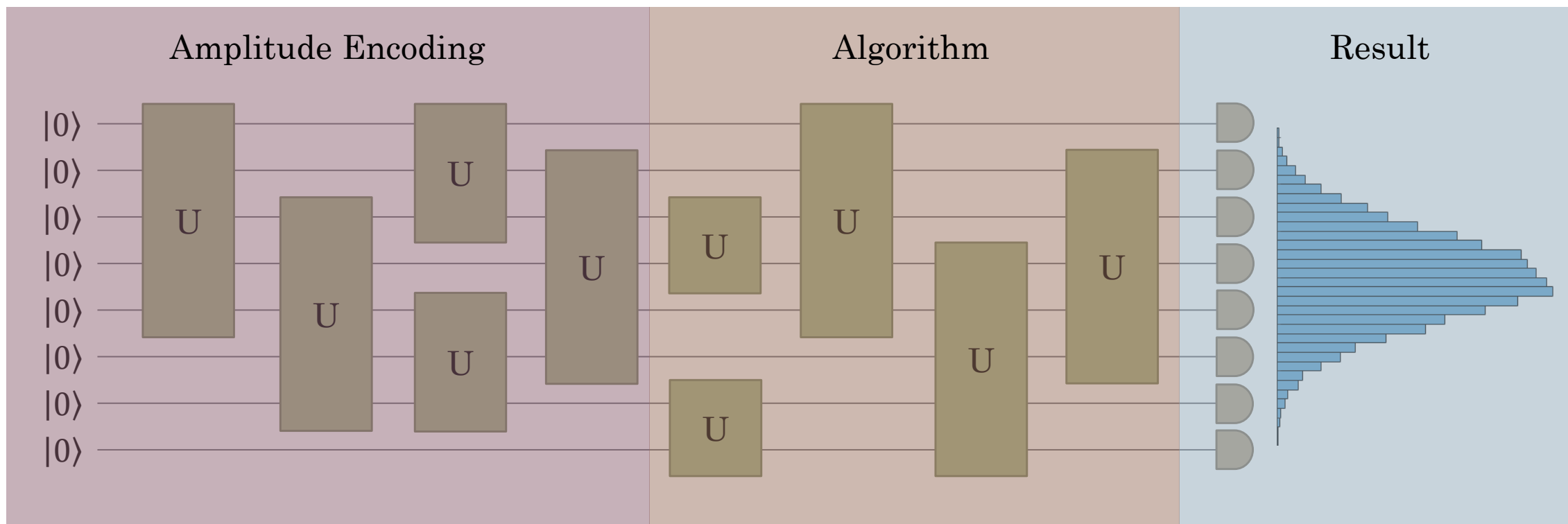
Amplitude Encoding



Quantum Circuits

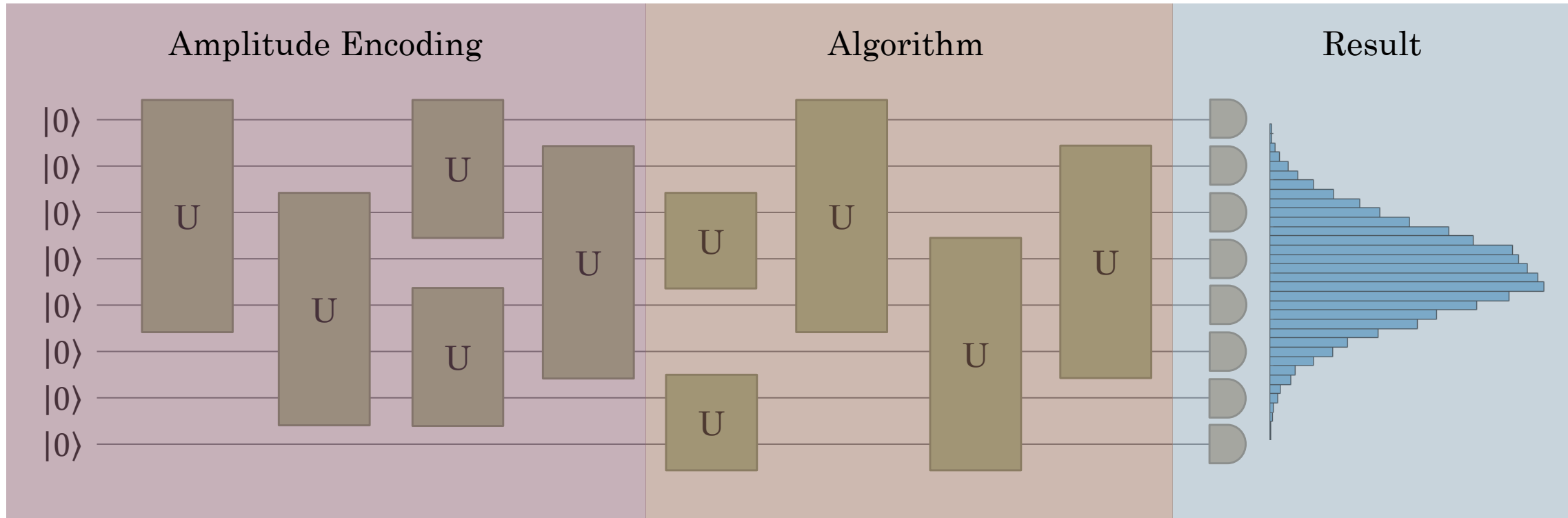


Quantum Circuits

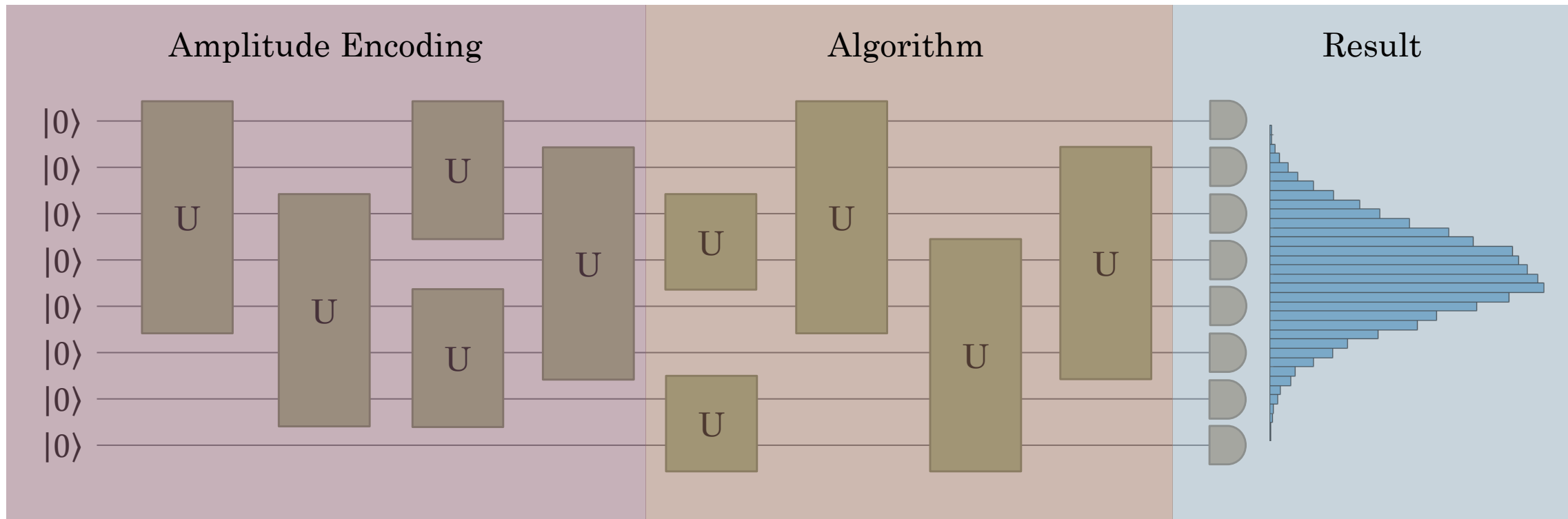


$$P(\text{cat}) = 90\%$$

1st Generation

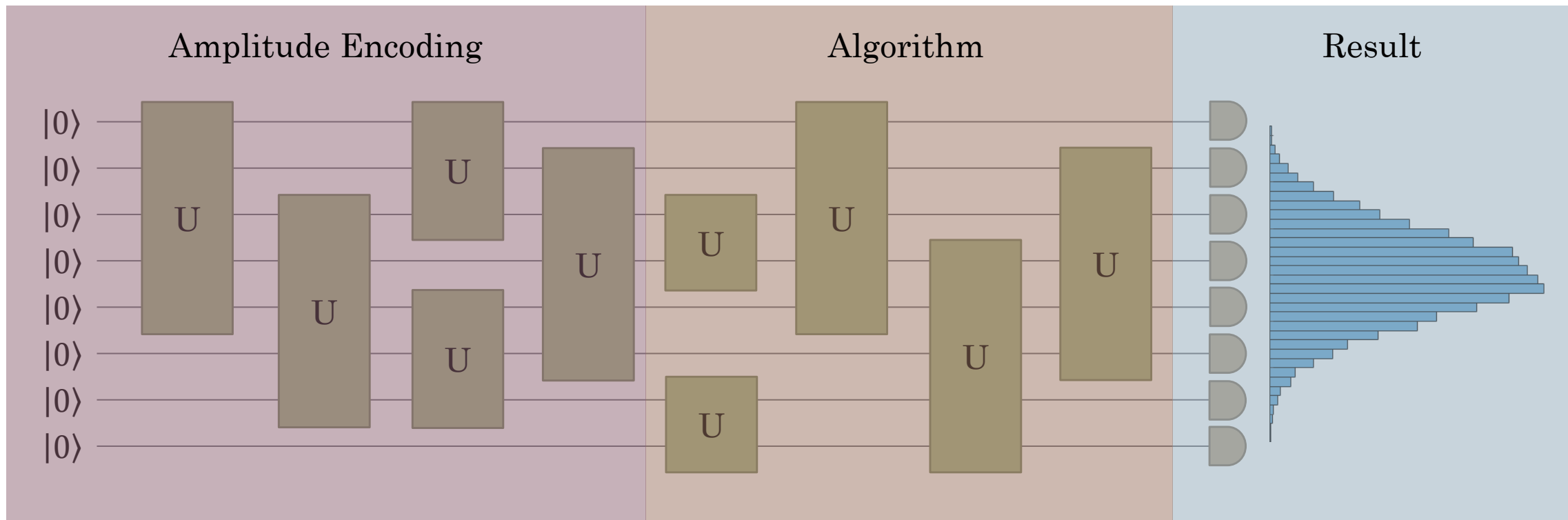


1st Generation



gates is low

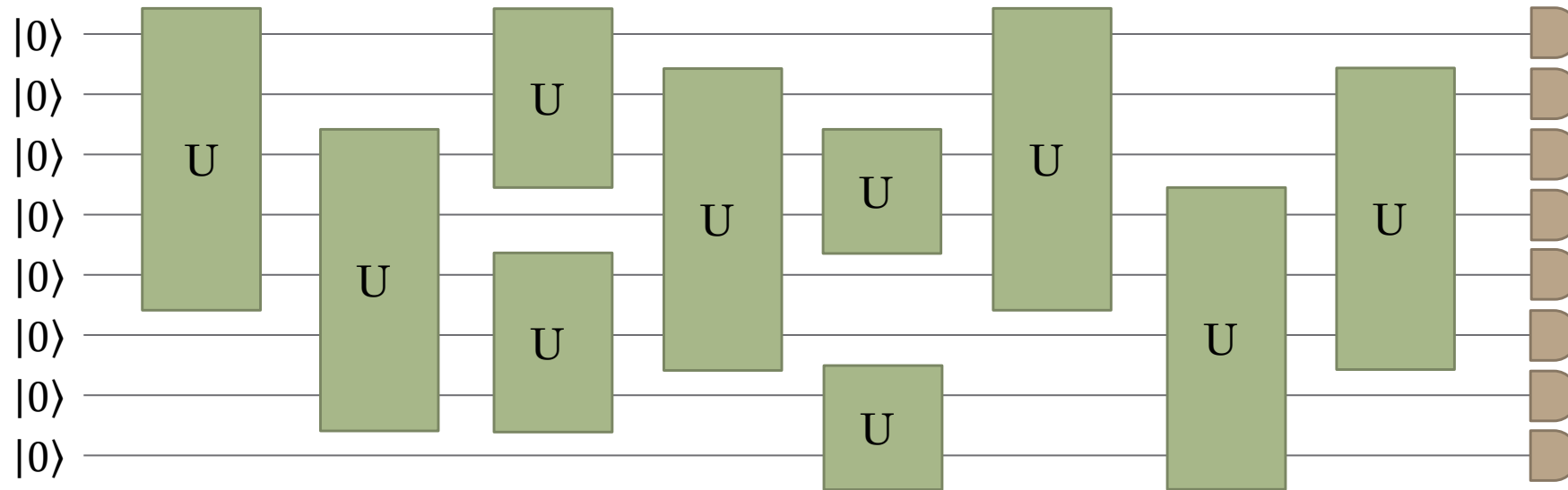
1st Generation



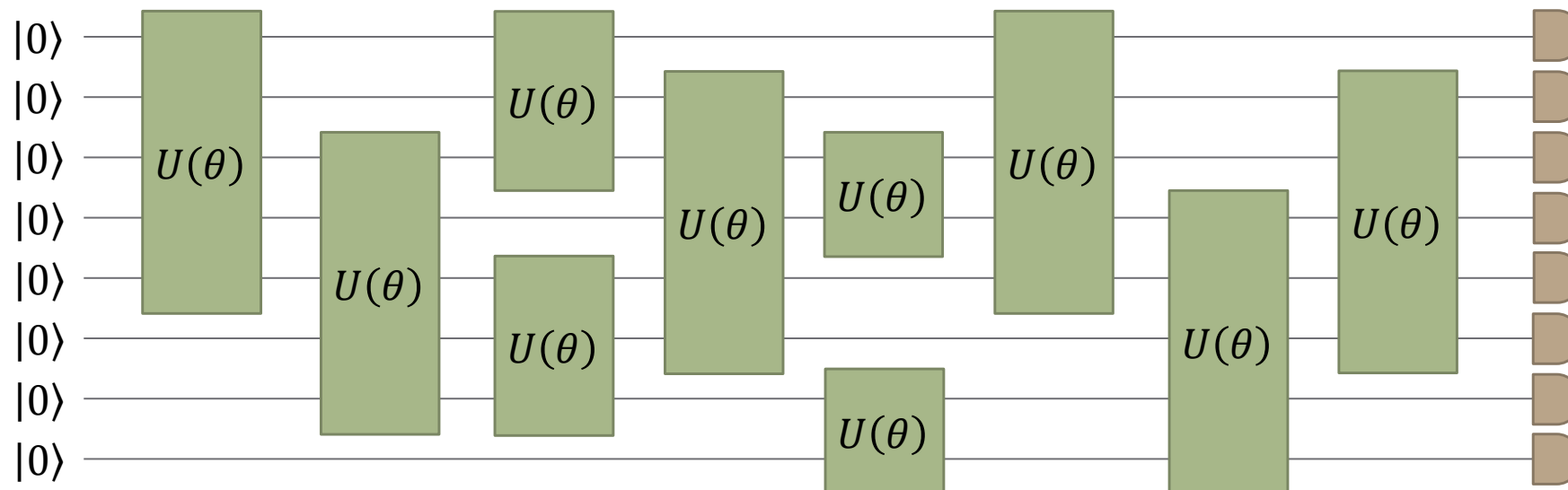
gates = $O(2^n)$

gates is low

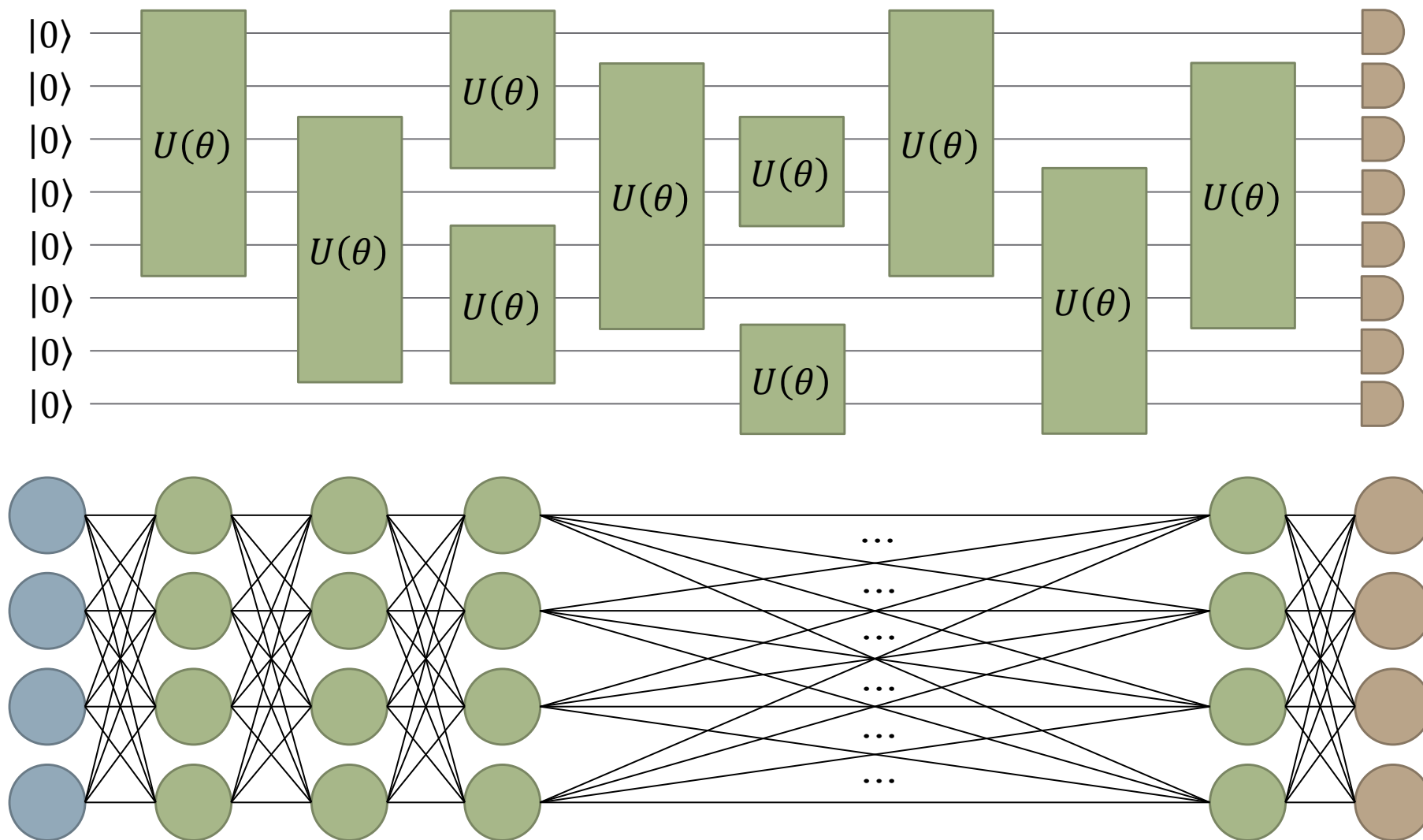
1st Generation



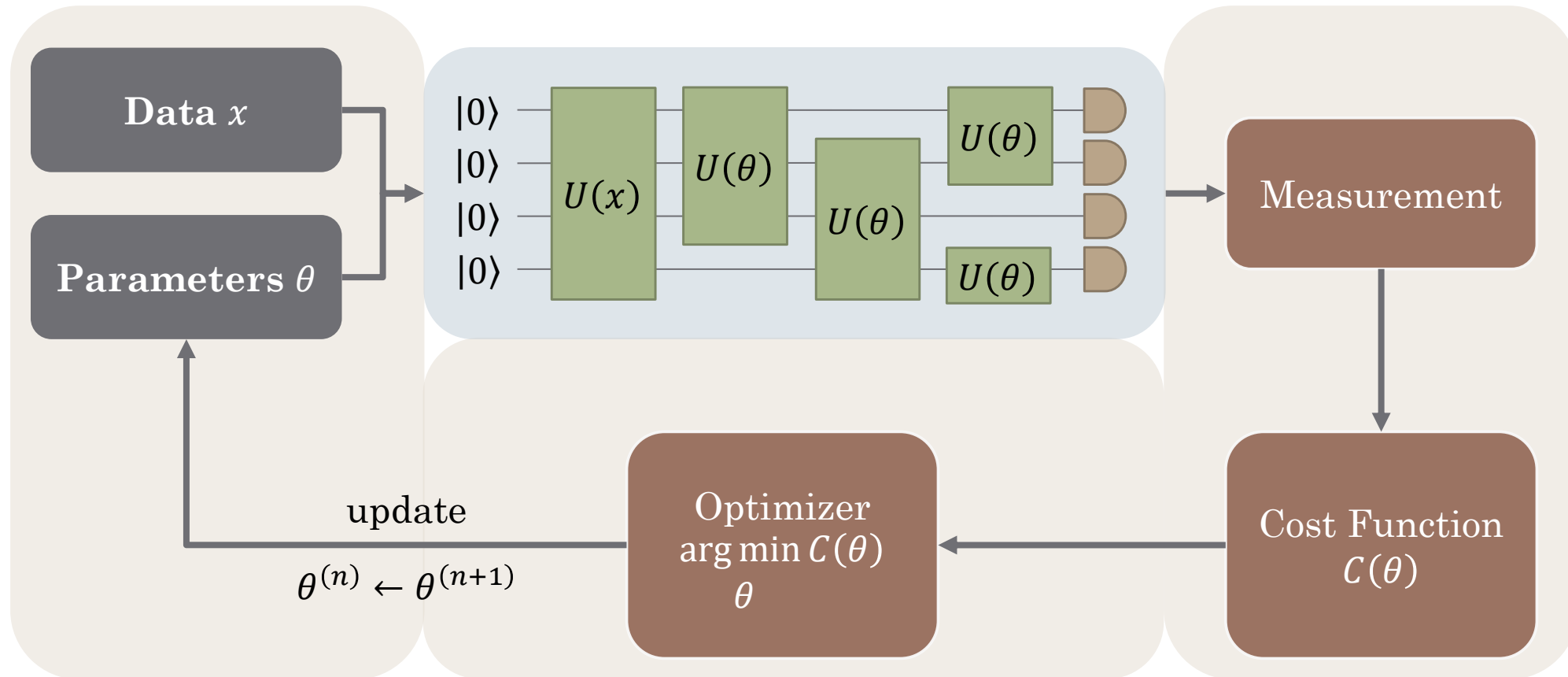
2nd Generation



2nd Generation



Parameterized Quantum Circuits (PQCs)



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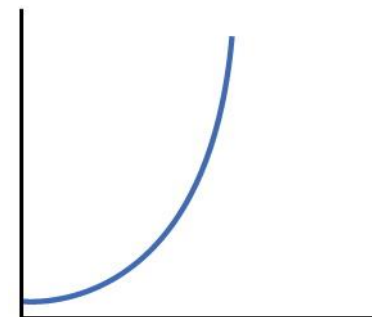
- PQCs can be highly expressive
 - Benedetti et al., arXiv:1906.07682, 2019

$$f(x, \theta)$$

Parameterized Quantum Circuits (PQCs)

- PQCs can be highly expressive
 - Benedetti et al., arXiv:1906.07682, 2019
- PQCs can be trained faster
 - Abbas et al., arXiv:2011.00027, 2020

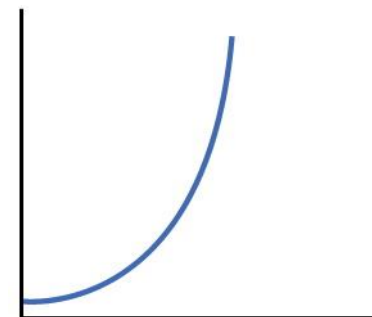
$$f(x, \theta)$$



Parameterized Quantum Circuits (PQCs)

- PQCs can be highly expressive
 - Benedetti et al., arXiv:1906.07682, 2019
- PQCs can be trained faster
 - Abbas et al., arXiv:2011.00027, 2020
- PQCs are scalable with the hardware

$$f(x, \theta)$$



Further Literature

- Qiskit – <https://qiskit.org>
- PennyLane – <https://pennylane.ai>
- IBMQ – <https://quantum-computing.ibm.com>
- Quantum Computation and Quantum Information
 - Michael Nielsen, Isaac Chuang, ISBN: 978-1-107-00217-3, 2000
- Supervised Learning with Quantum Computers
 - Maria Schuld, Francesco Petruccione, ISBN: 978-3-030-07188-2, 2018
- Talks on YouTube

Thank you very much!

Questions and discussions are highly welcome!