

Workshop sul calcolo nell'INFN

The QuantumTEA Cloud Platform

M. Ballarin (Unipd), L. Zangrando (INFN)

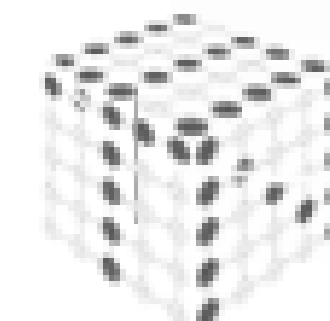
Loano 24/05/2023



QUANTUM
COMPUTING
AND
SIMULATION
CENTER



QUANTUM
Information and Matter

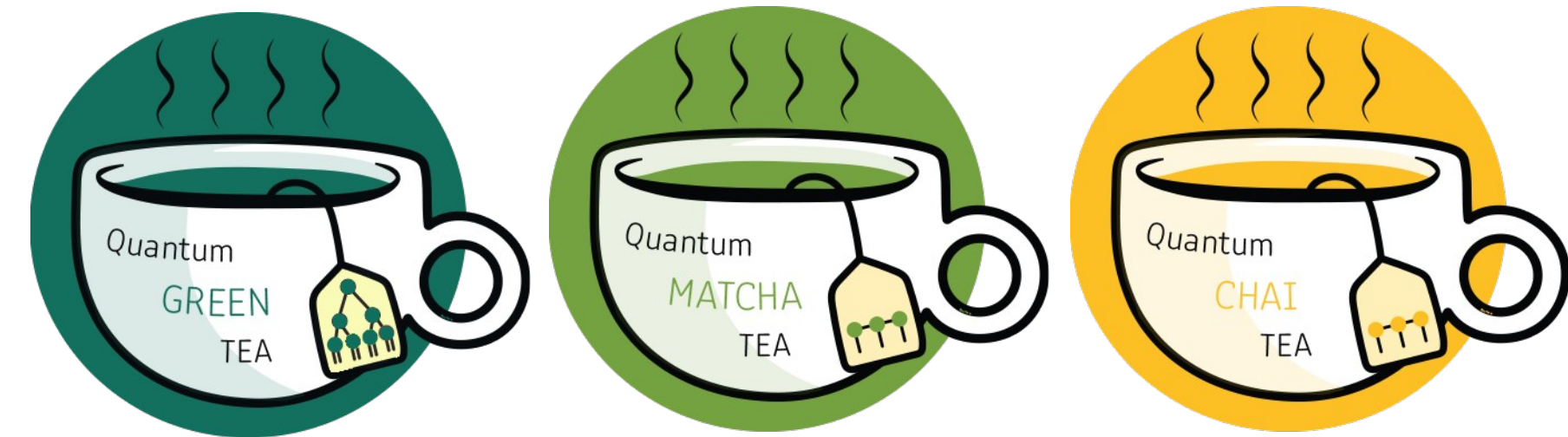


T-NISQ
Tensor Networks in Simulation of Quantum Matter



Quantum T_{ensor}-N_{etwork} E_{mulator} A_{pplications}

- Tensor network emulators for quantum systems;



-  Quantum computer emulator powered by tensor networks;

- Emulates complex quantum systems “via quantum circuits” with a large number of qubits $O(100)$;
- Run general-purpose quantum circuits (algorithms).

Quantum Computing and Simulation Center



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- QuantumTEA is developed in the context of QCSC project;
- World Class Research Infrastructures (WCRI) project of University of Padua;
- Objectives of QCSC:
 - Establish one of the first general-purpose quantum computer in Italy at the Department of Physics and Astronomy of the University of Padua;
 - Create a competence center to guide and support the development and the inclusion of quantum technologies in the Italian academic and business environment.

QCSC partners



QUANTUM
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UNIVERSITÀ
DEGLI STUDI
DI PADOVA



UNIVERSITÀ
DEGLI STUDI
DELL'AQUILA



Istituto Nazionale di Fisica Nucleare



UNIVERSITÀ
DI PAVIA

CINECA

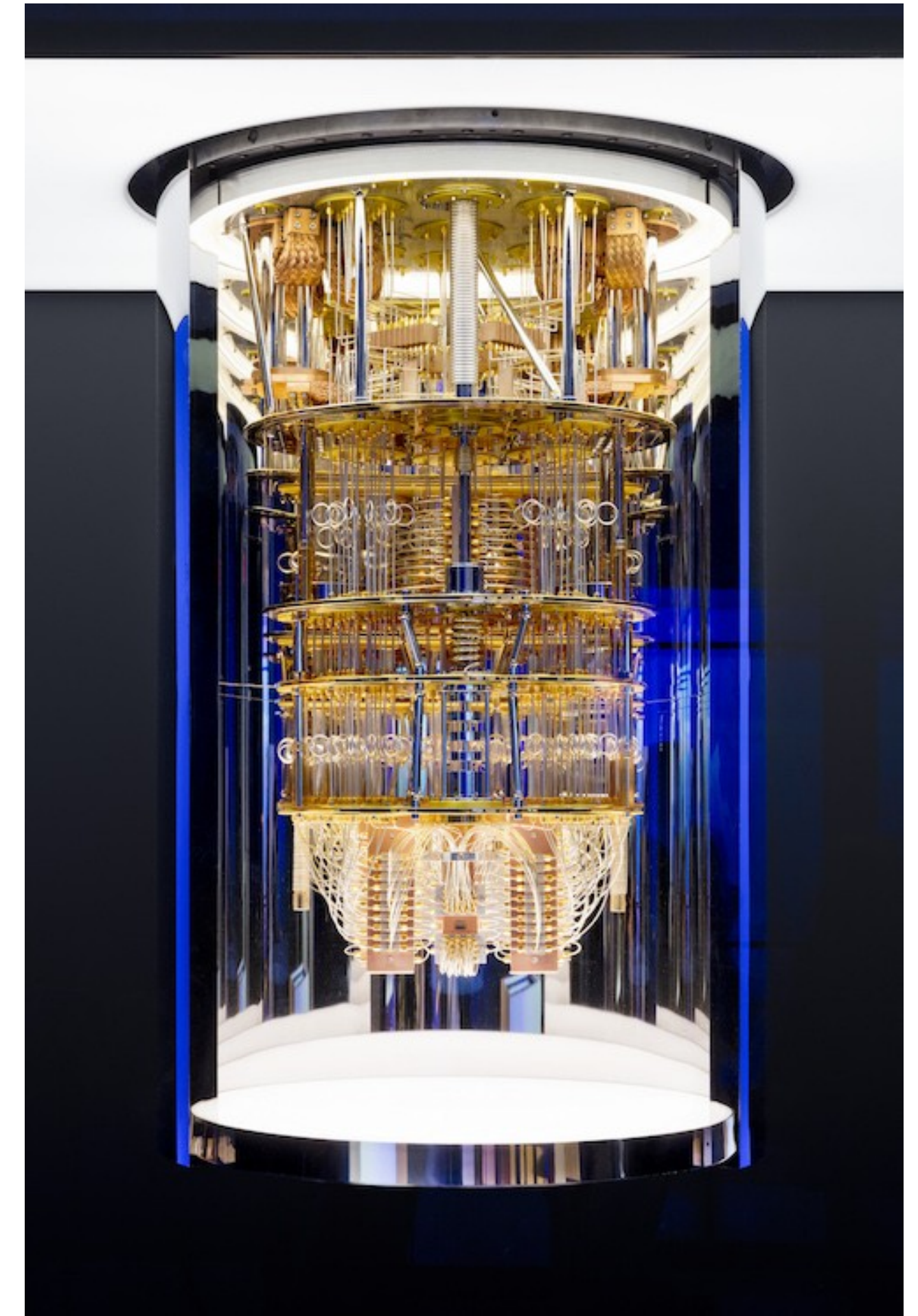


neat

Why develop a quantum emulator? (1/2)



- Quantum computers are not production-ready yet;
- Today's quantum computers are:
 - very noisy systems with a limited number of qubits;
 - difficult to control and to isolate from the surrounding environment;
- Large number of computation errors, impossible to correct with quantum error correction algorithms.

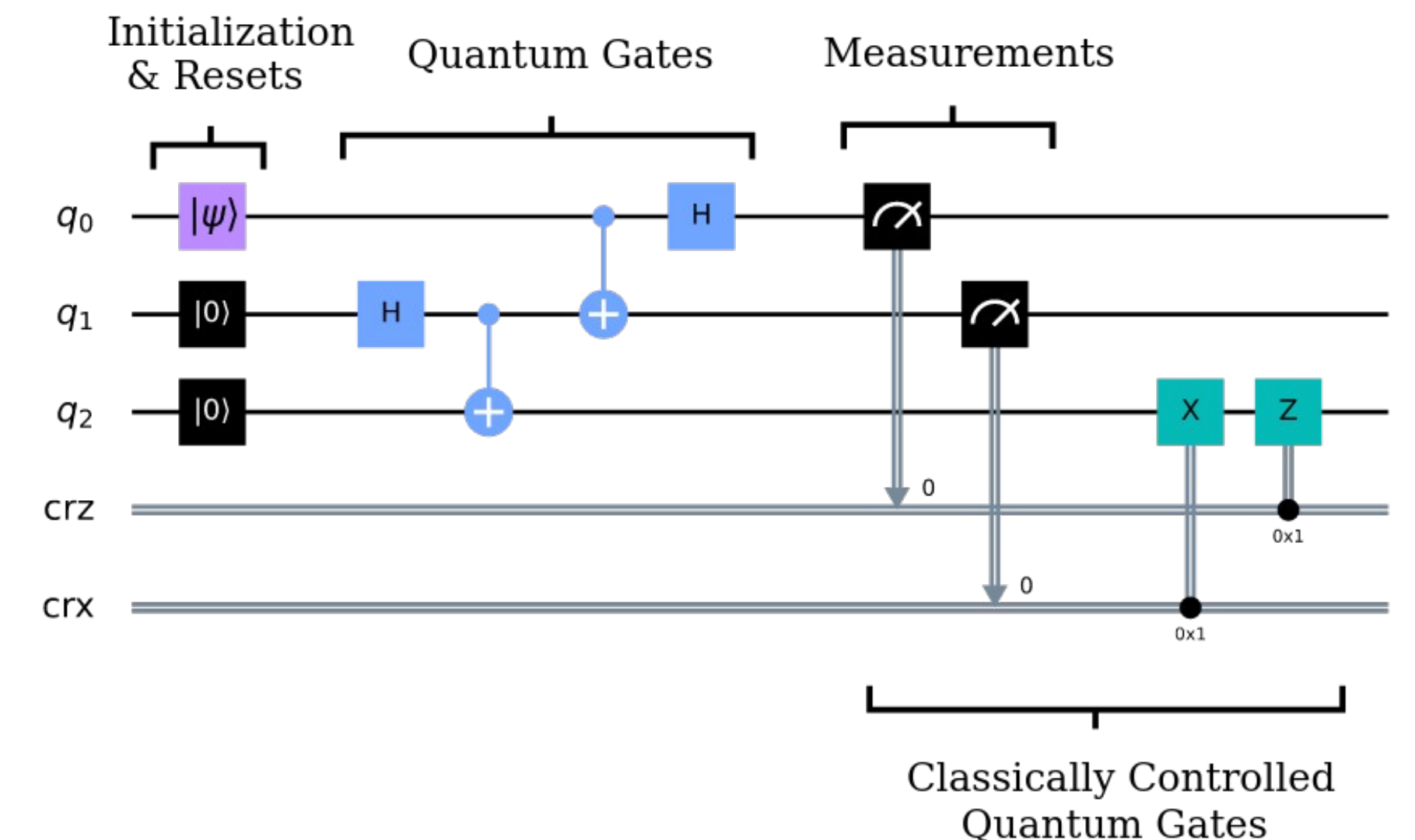


A view inside the IBM Quantum System One

Why develop a quantum emulator? (2/2)



- With emulators we can:
 - Validate the result of a real Quantum Computer (QC) computation;
 - Test and benchmark QC performances;
 - Understand when we really need a QC;
- For industry: develop solutions based on quantum algorithms for the moment QPU take off and become scalable.



The Qubit



Classical bit $b \in \{0,1\}$

The Qubit



Classical bit $b \in \{0,1\}$



quantum qubit $|\psi\rangle \in \mathcal{H}, \dim(\mathcal{H}) = 2$

$$|\psi\rangle = \cos \theta |0\rangle + e^{i\phi} \sin \theta |1\rangle$$

The Qubit

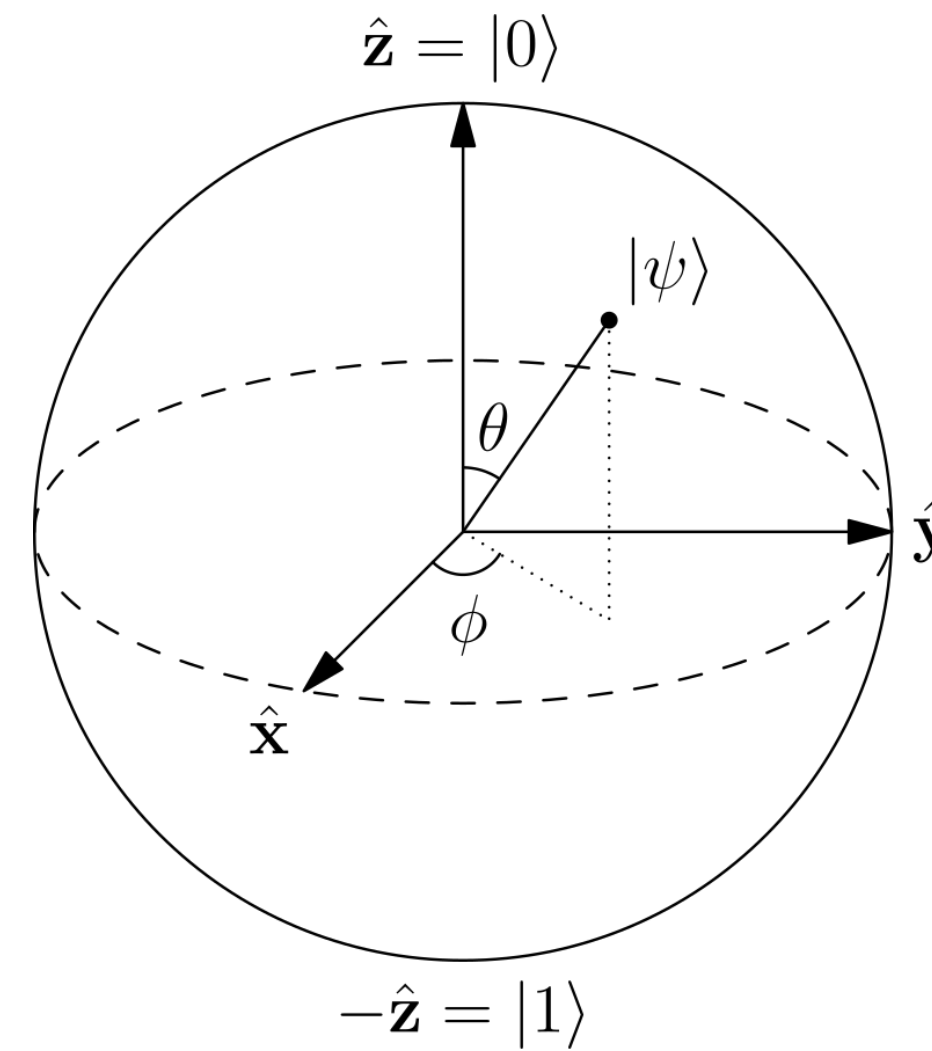


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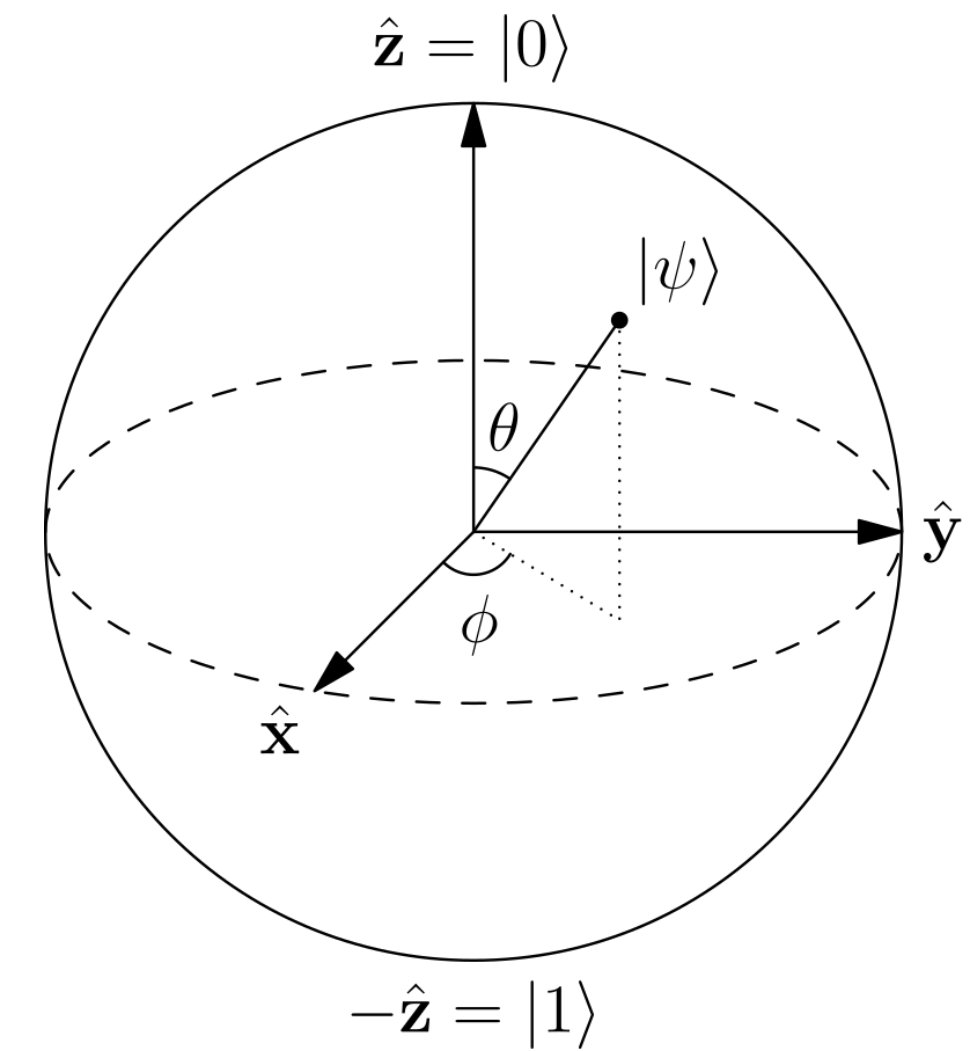
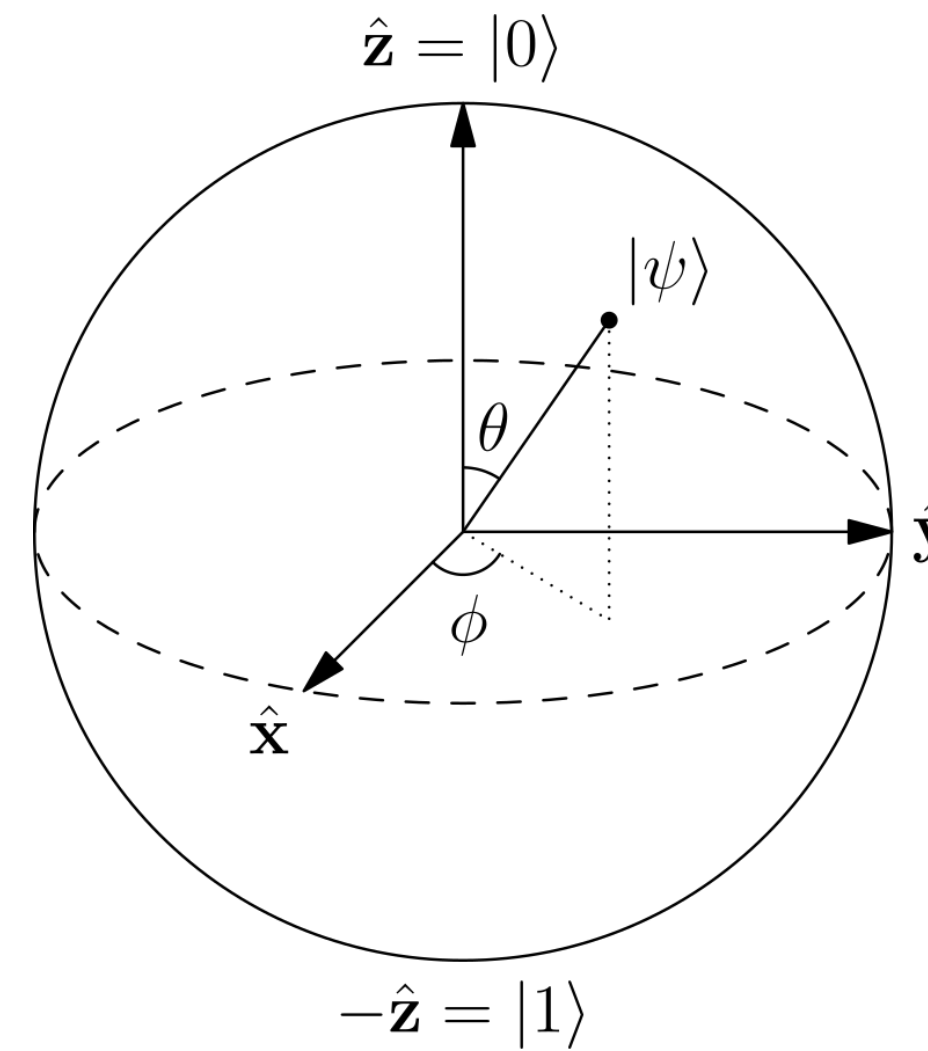


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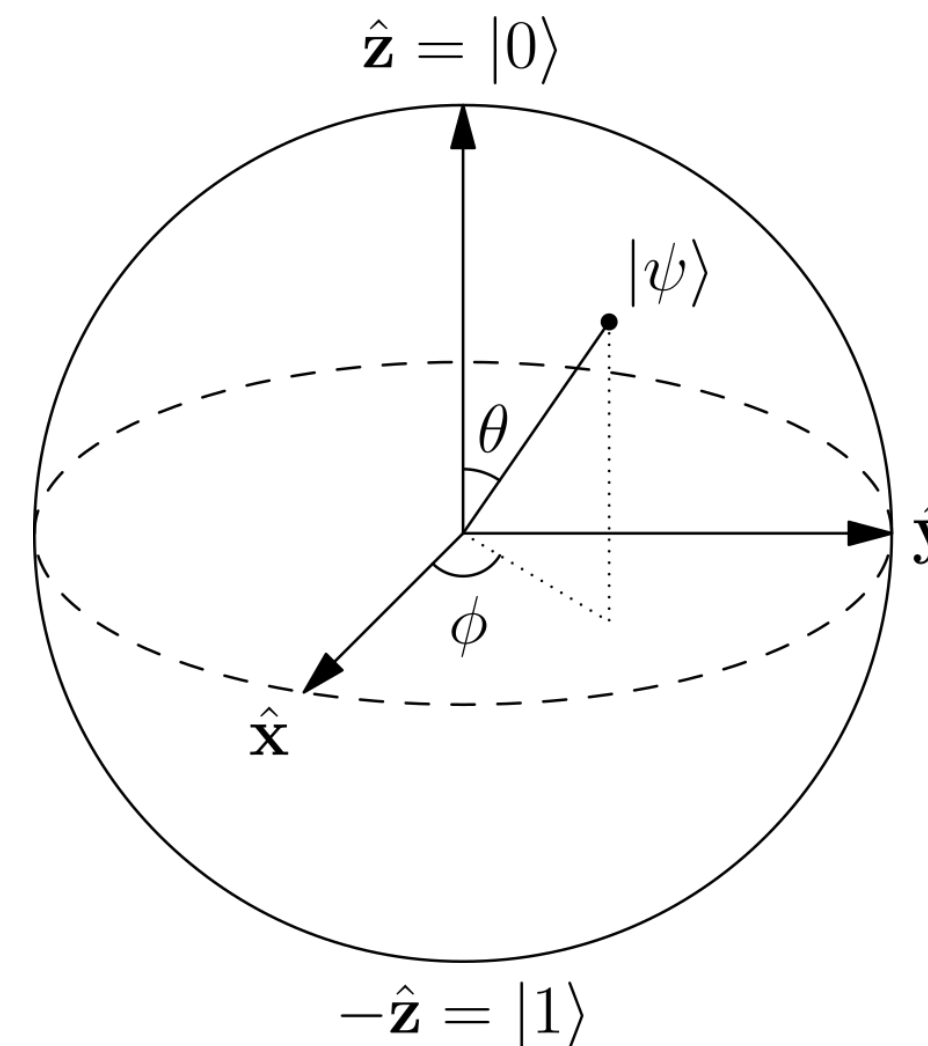
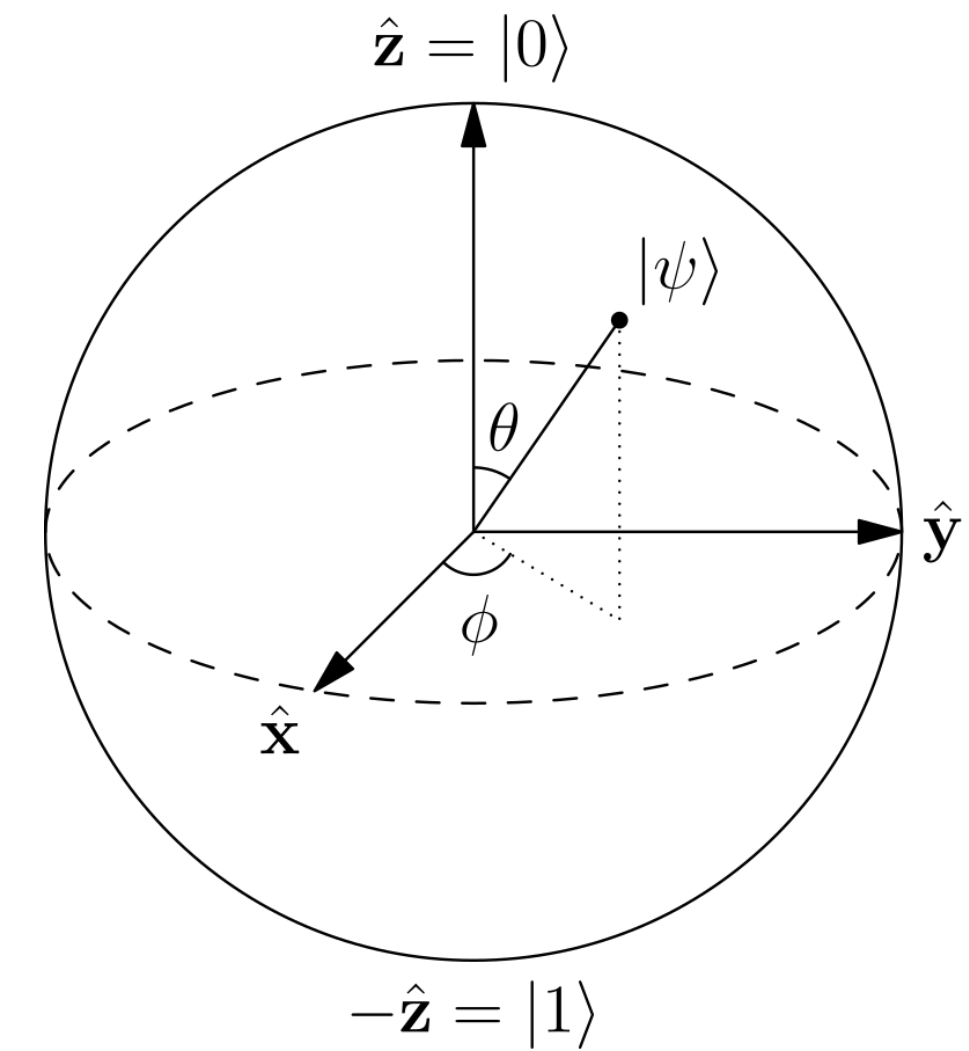
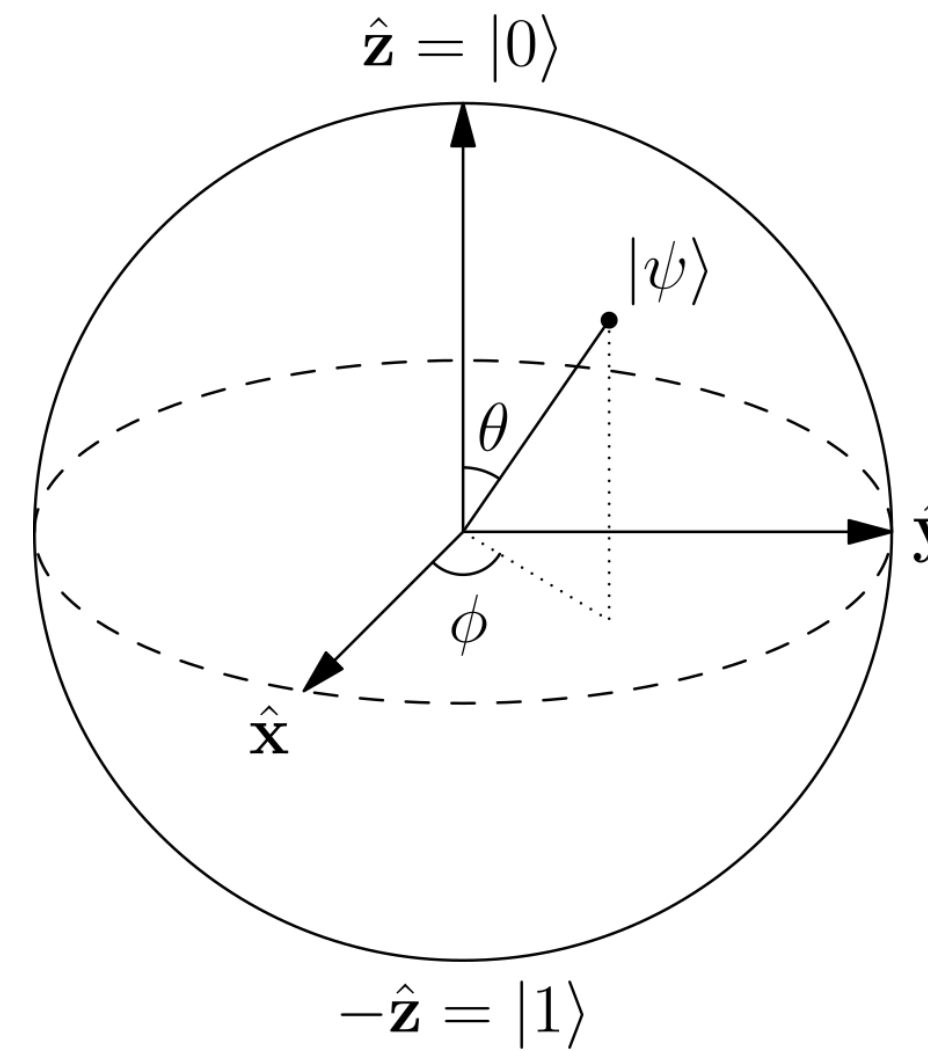


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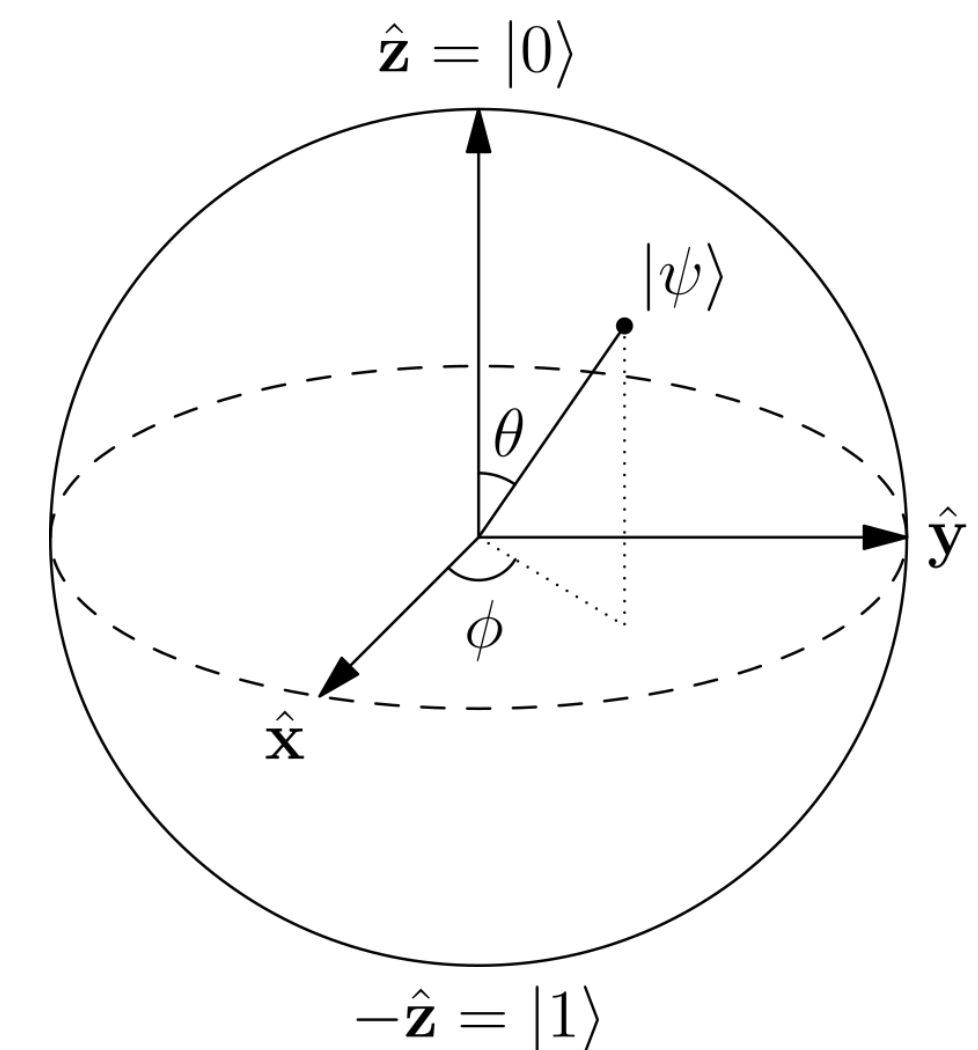
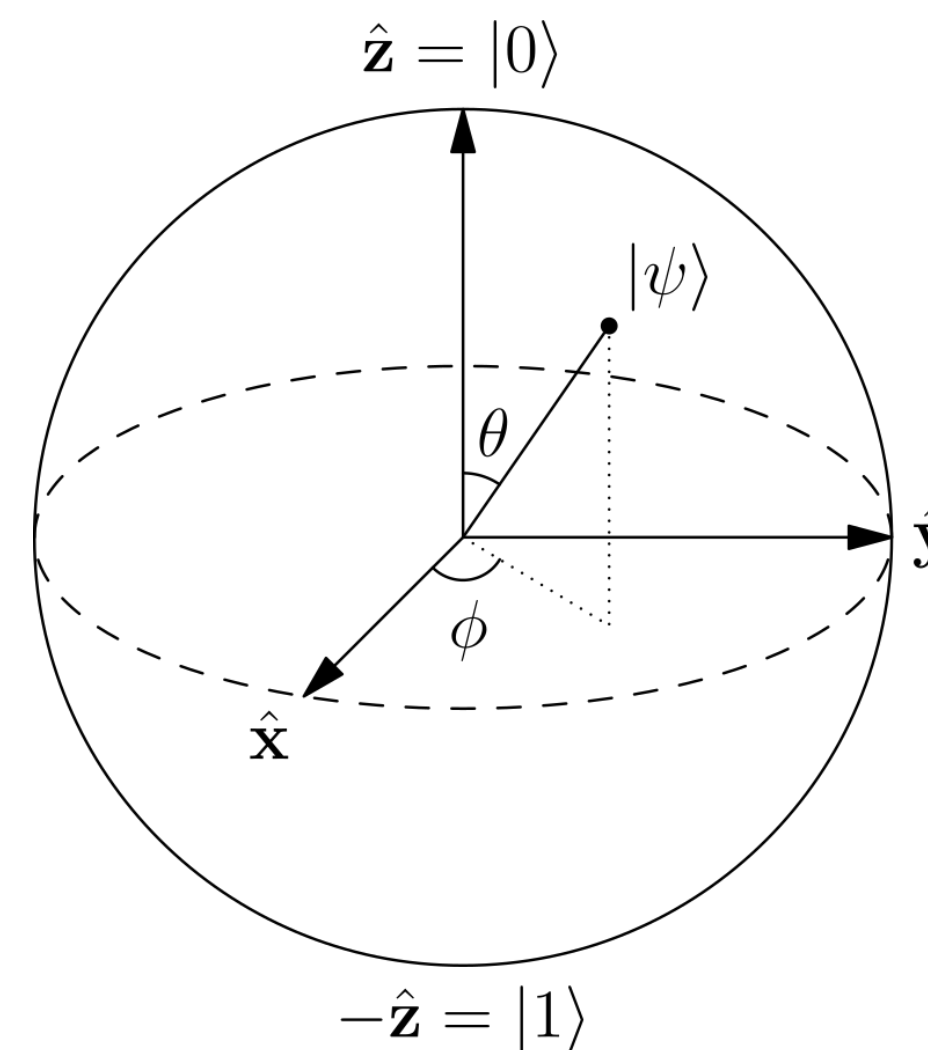
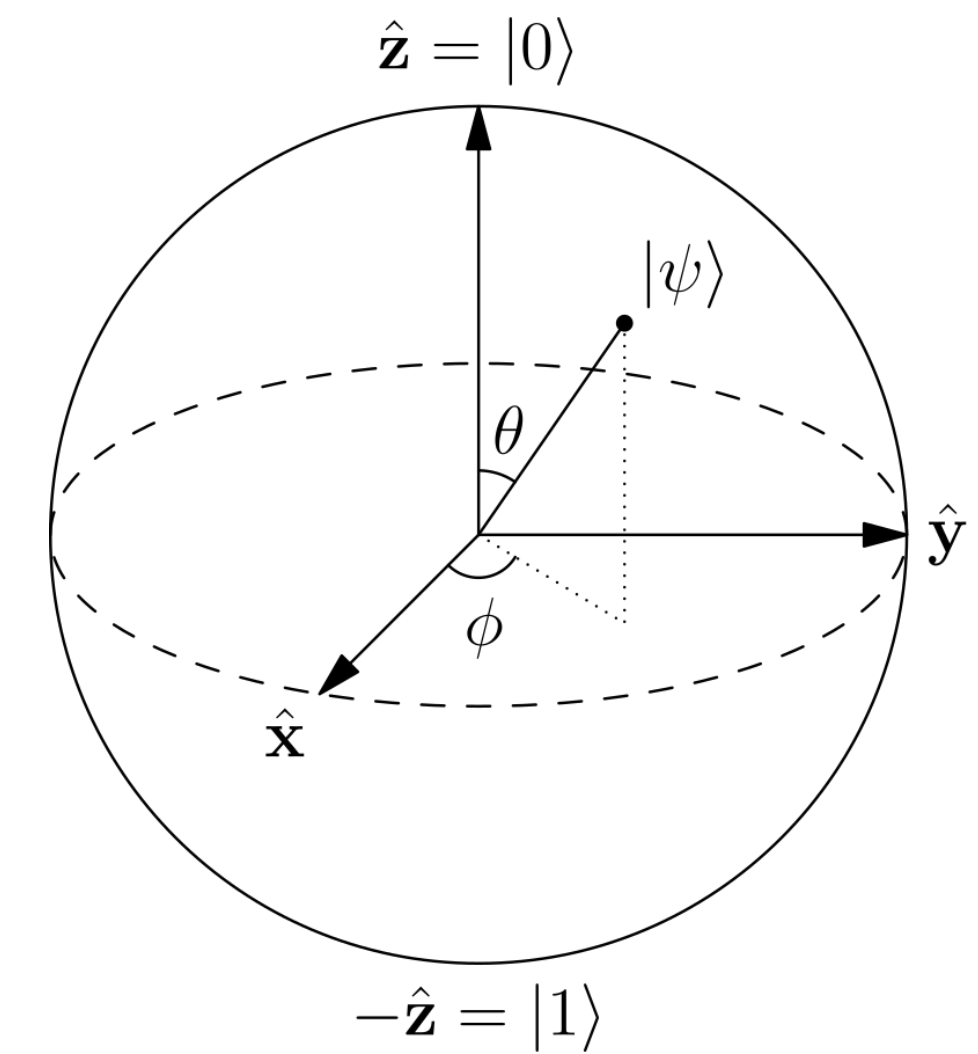
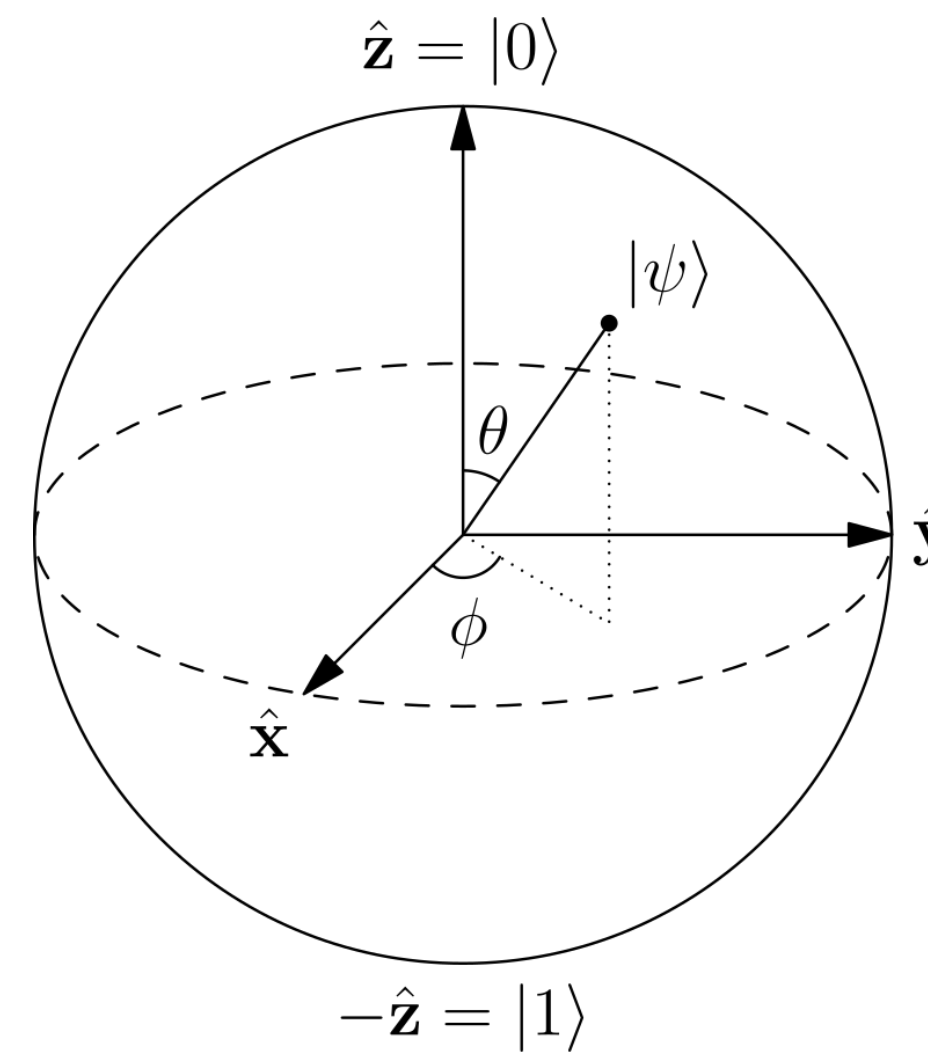


Classical bit $b \in \{0,1\}$



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The Qubit

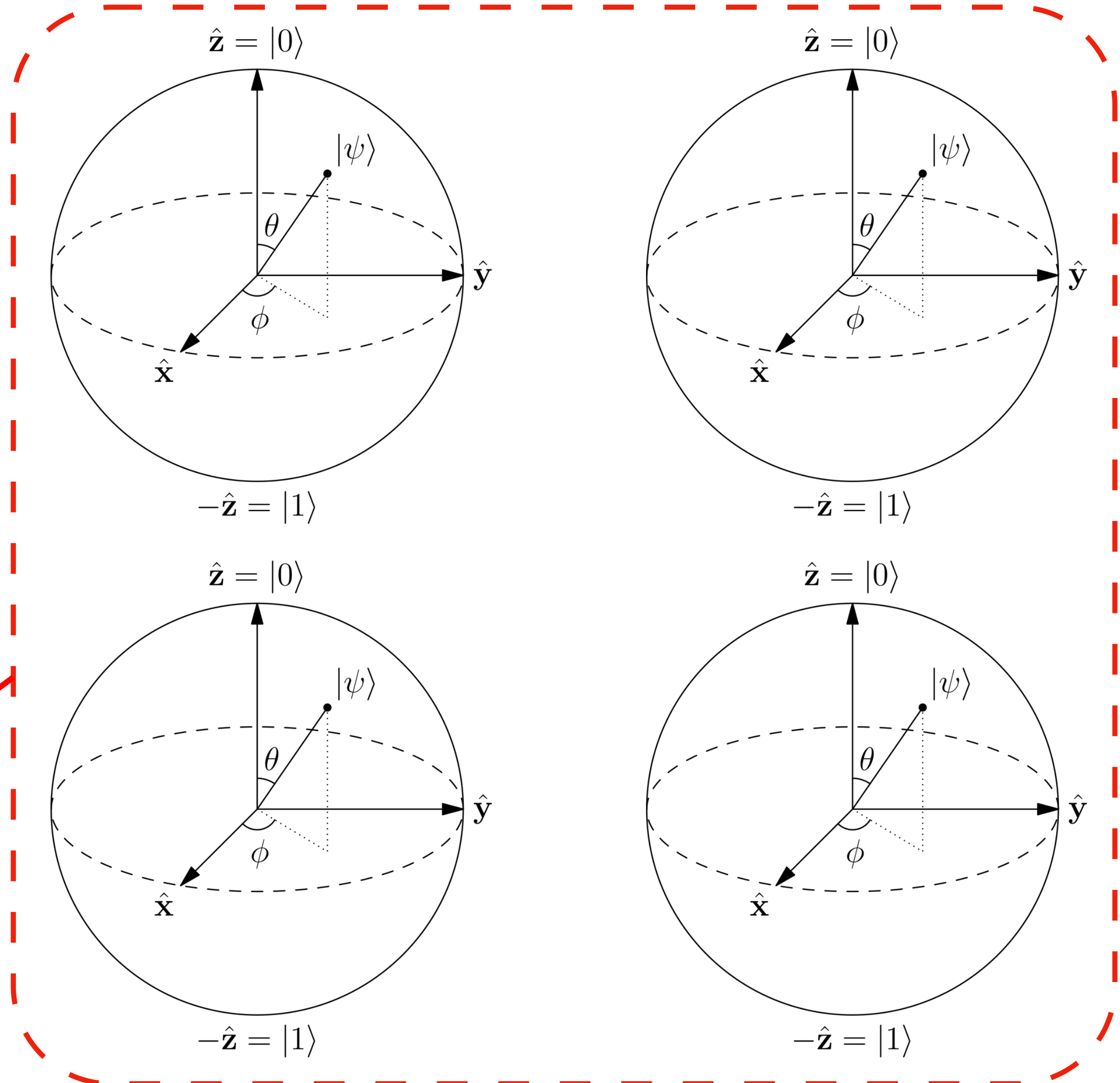


Classical bit $b \in \{0,1\}$



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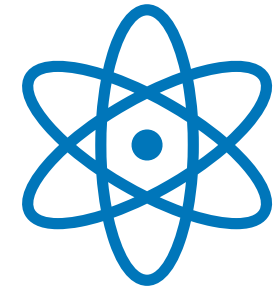


For 4 qubits you need a $2^4=16$ coefficients.
For 50 qubits you would need $2^{50}=10^{15}$

Running quantum algorithms



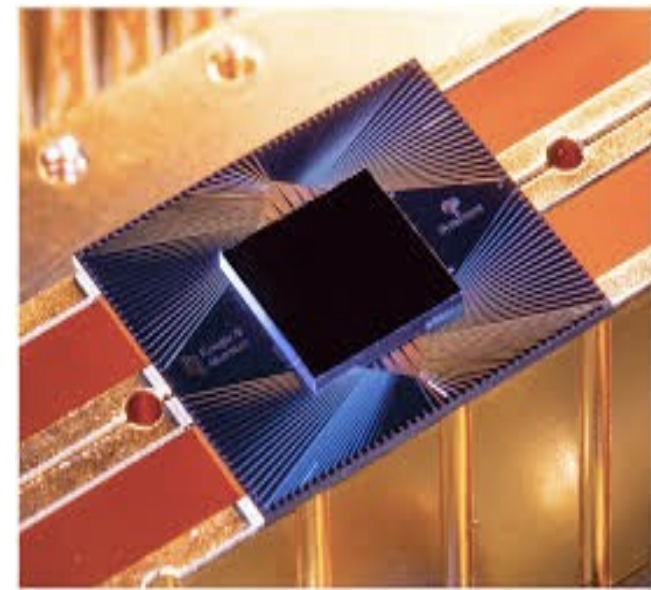
Quantum algorithm



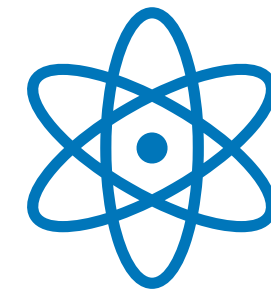
Running quantum algorithms



Quantum algorithm



- + Real hardware
- Noisy
- Limited number of qubits

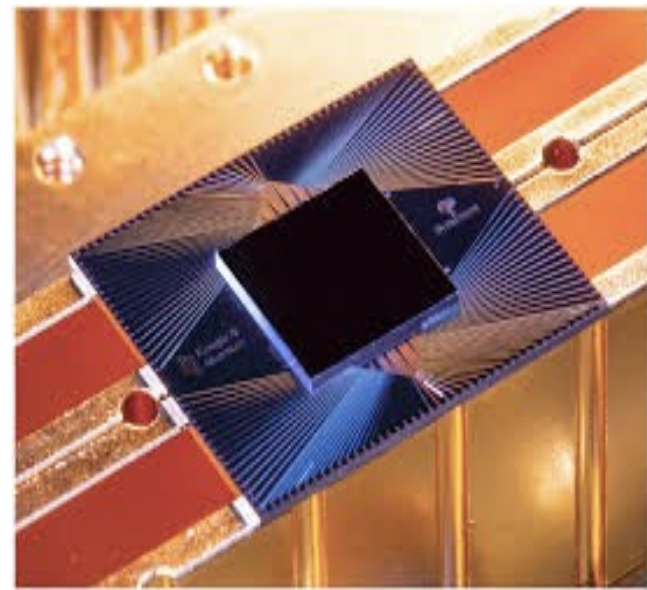


Quantum hardware

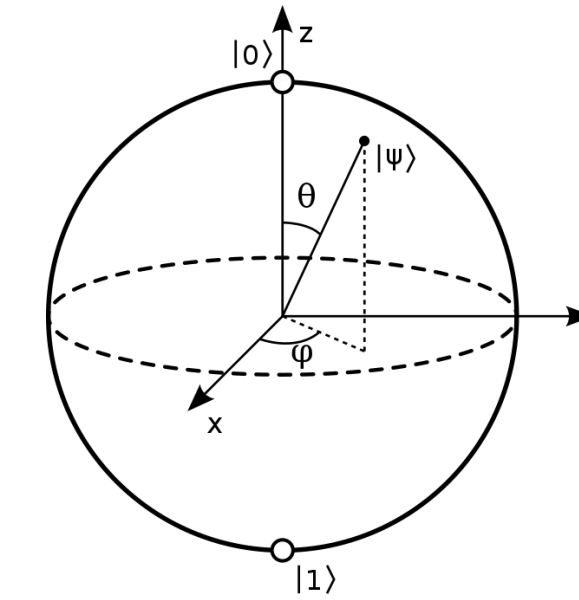
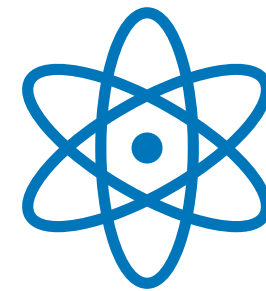
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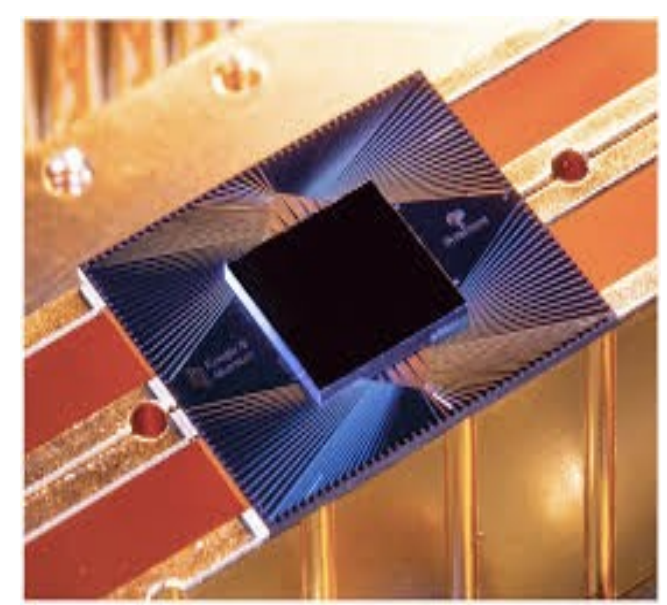


- + Access to exact state
- Limited number of qubits

Exact simulator

Quantum hardware

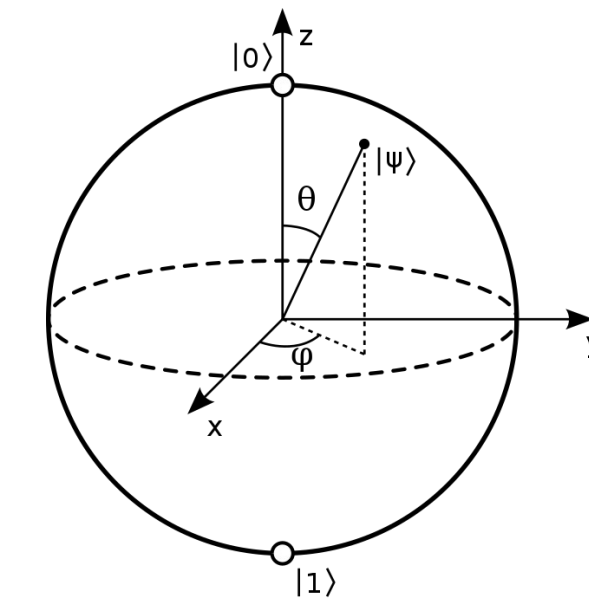
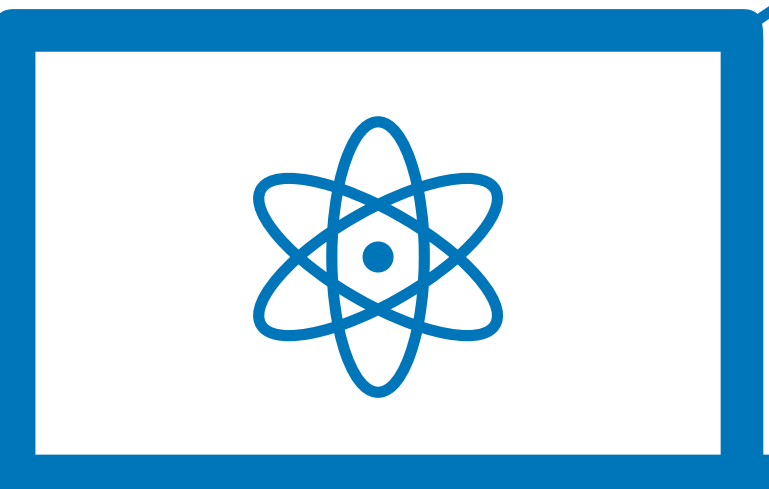
Running quantum algorithms



Quantum hardware

- + Real hardware
- Noisy
- Limited number of qubits

Quantum algorithm



Exact simulator

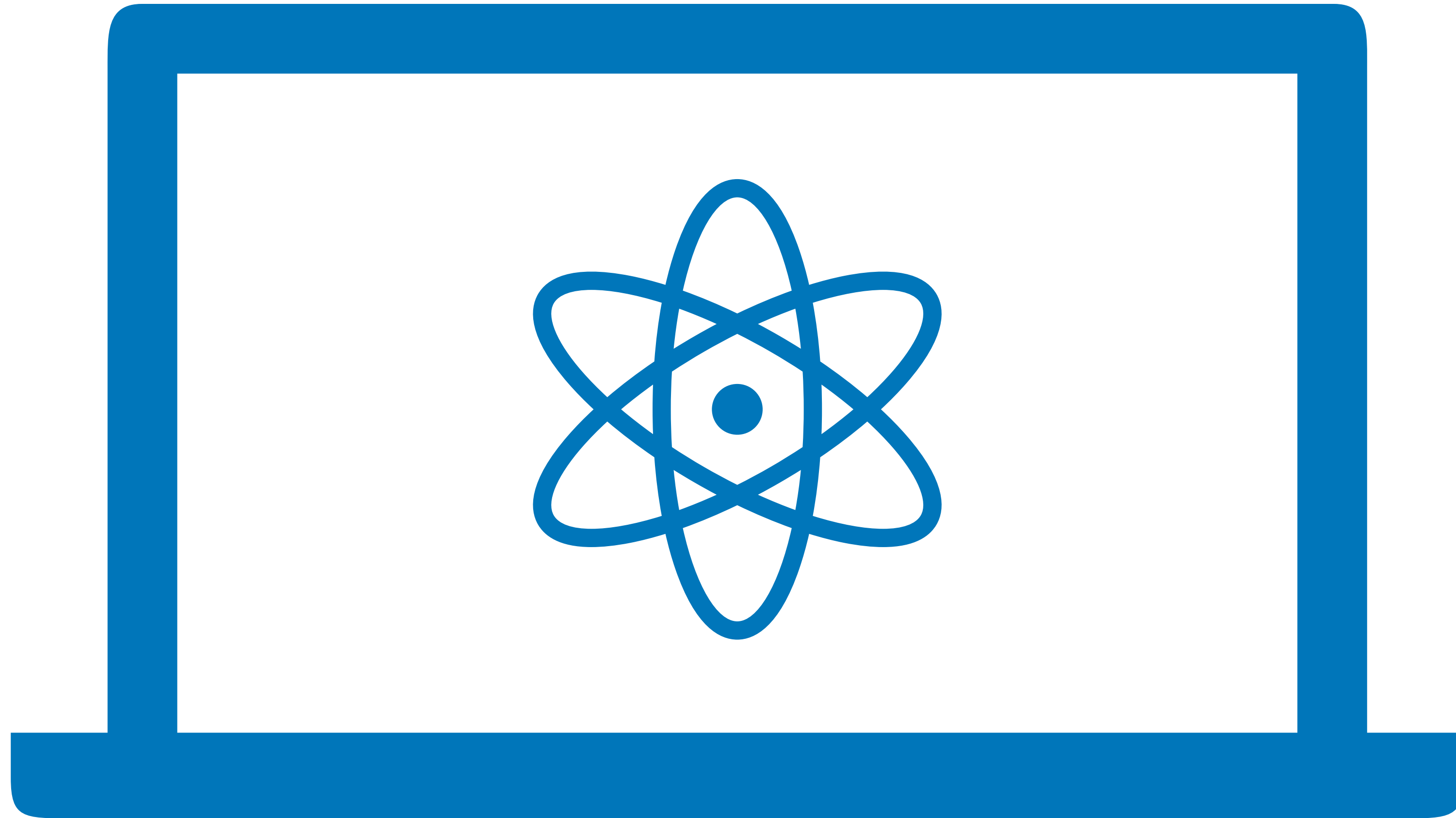
- + Access to exact state
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Tensor Network simulator

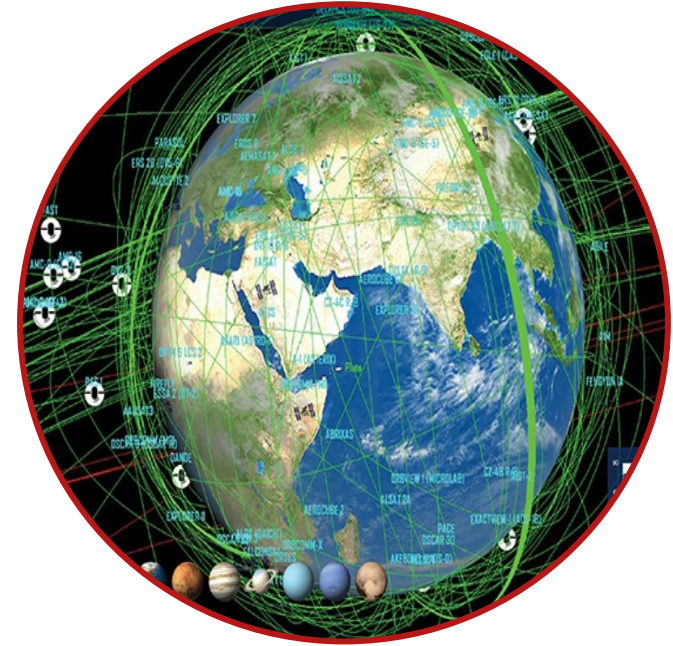


- + High number of qubits
- Limited entanglement

Quantum algorithms



Quantum algorithms



Earth
Observation

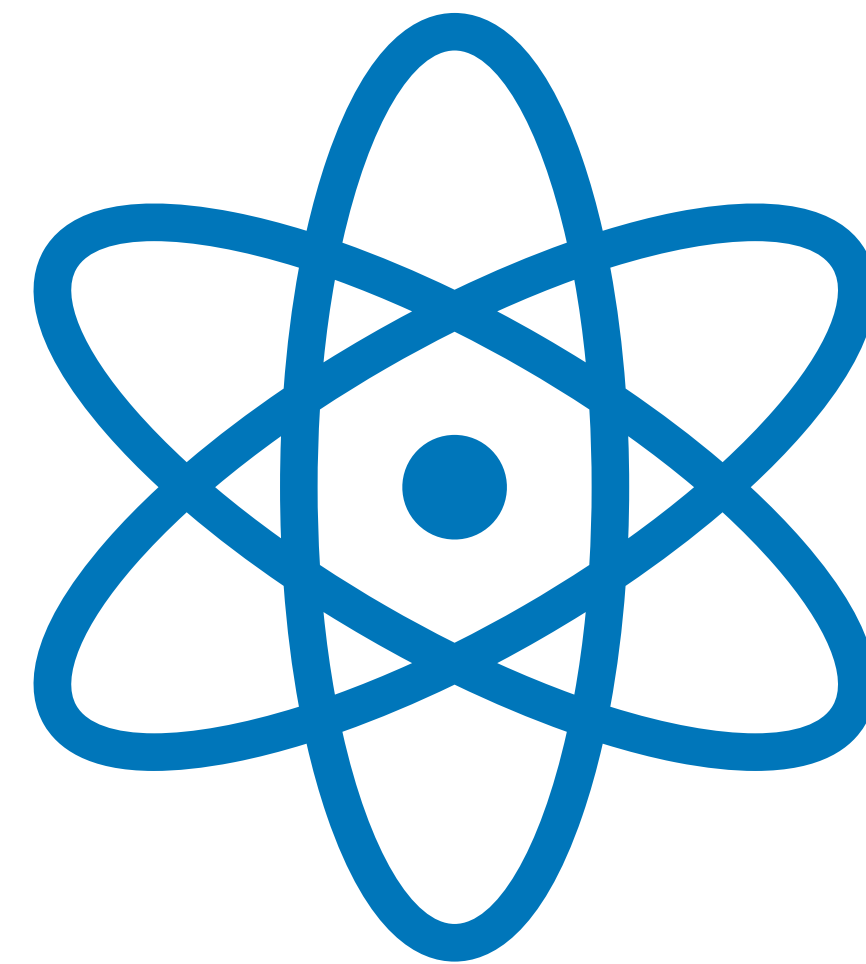


Traffic

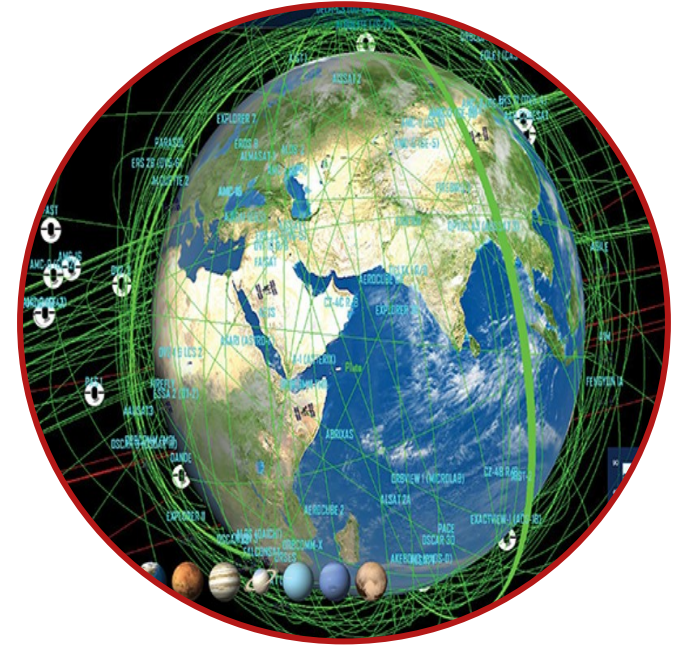
Combinatorial
optimization
problems

(QAOA, quantum
annealing, ...)

Portfolio
optimization



Quantum algorithms



Earth Observation



Traffic

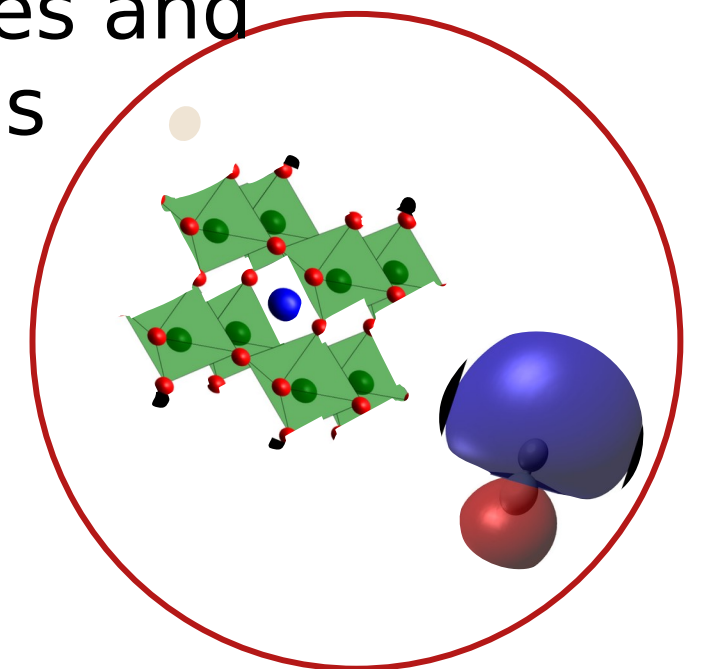
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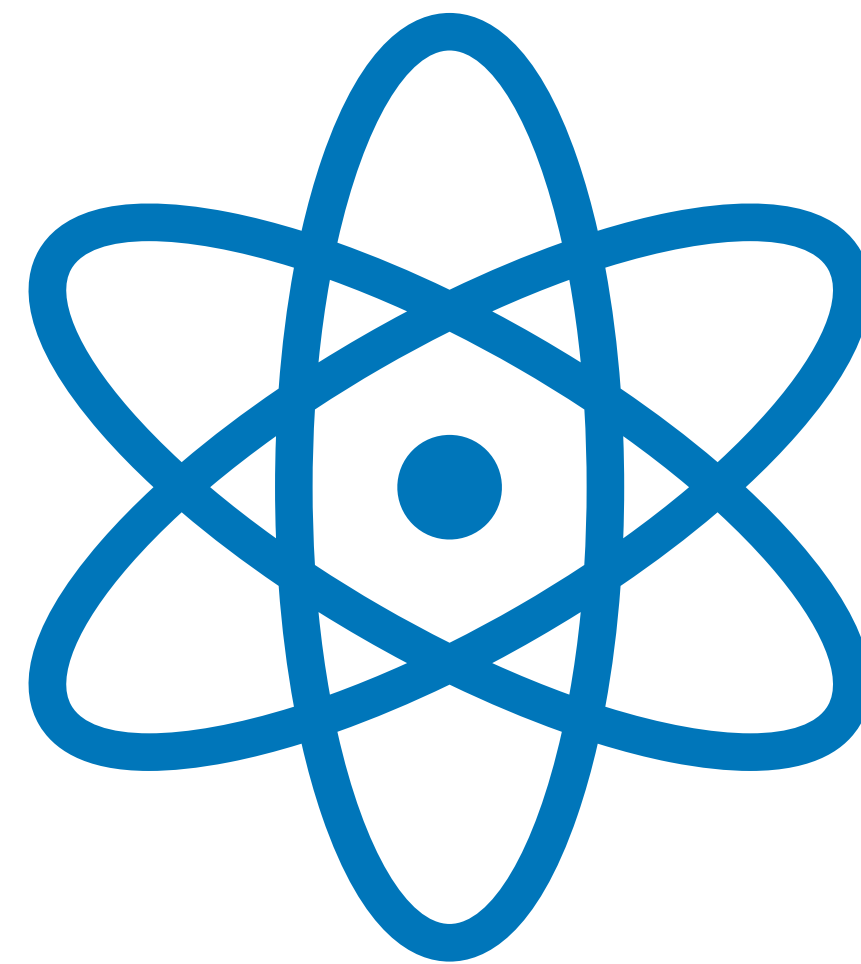
Portfolio optimization



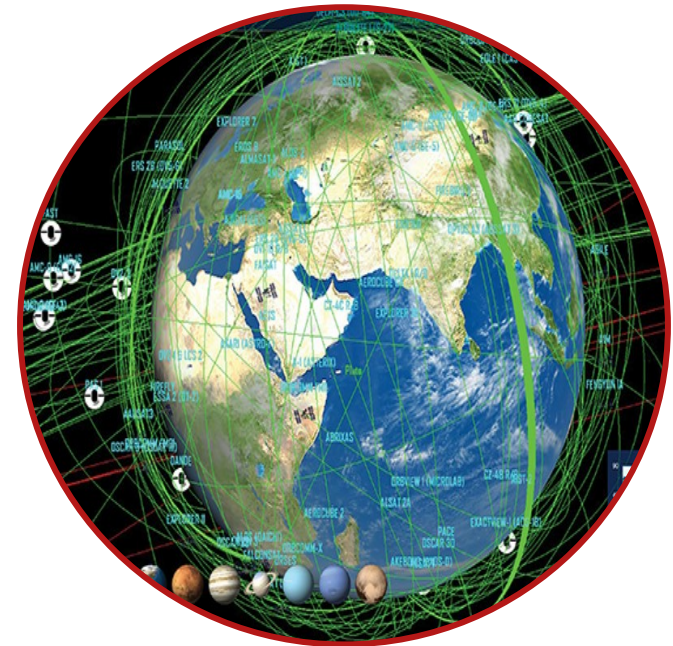
Molecules and Materials



(VQE, quantum deflation, ...)



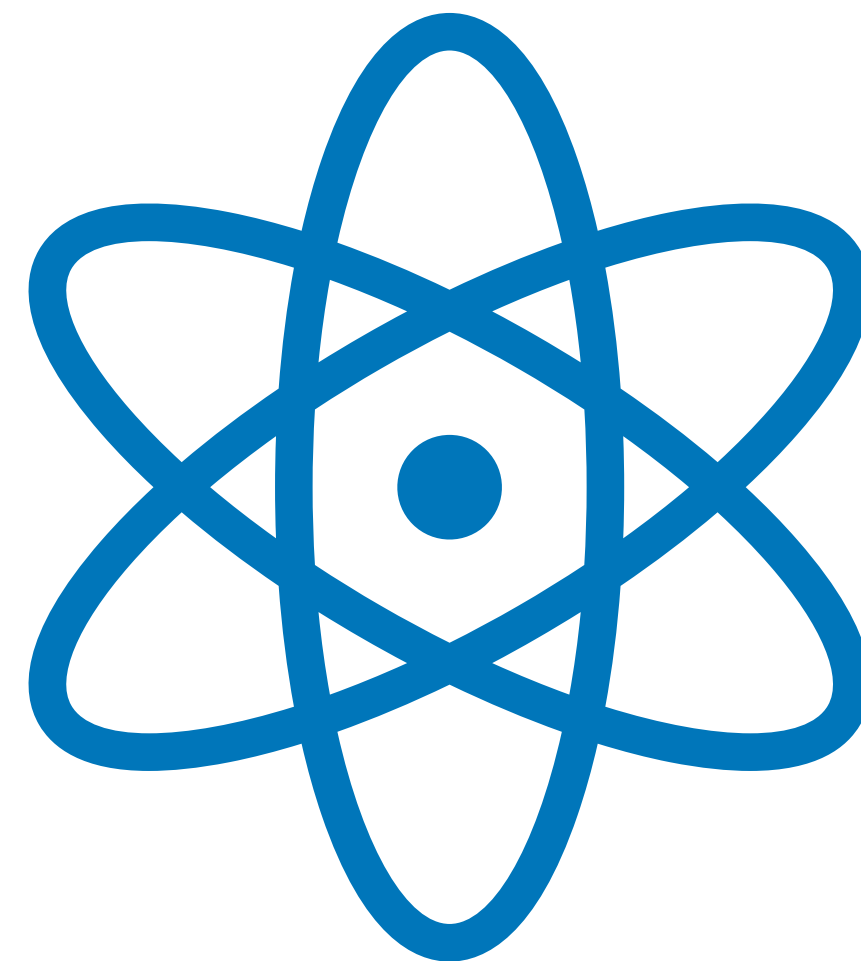
Quantum algorithms



Earth Observation



Machine Learning



Traffic

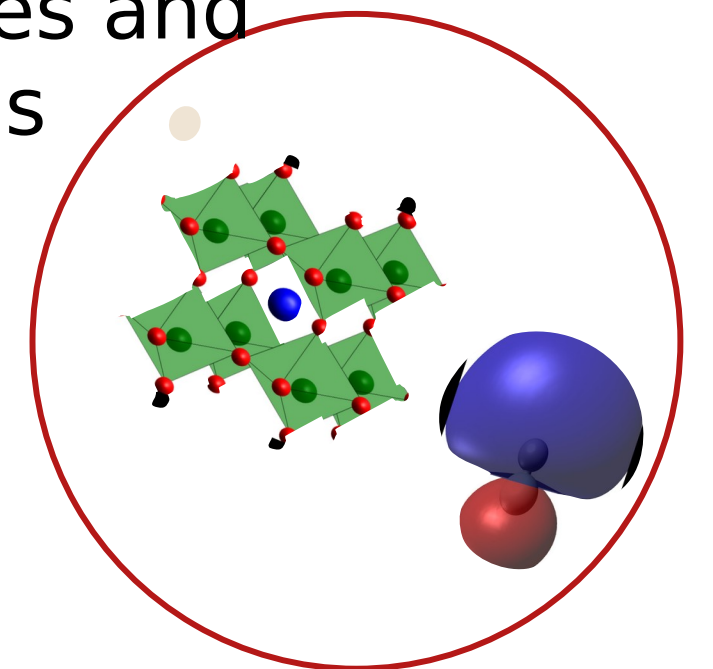
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Portfolio optimization

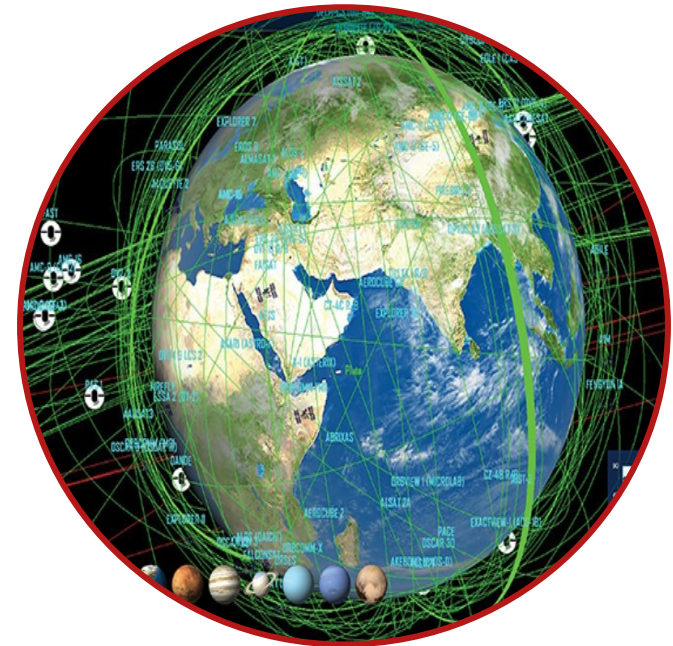


Molecules and Materials



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Quantum algorithms



Earth Observation



Traffic

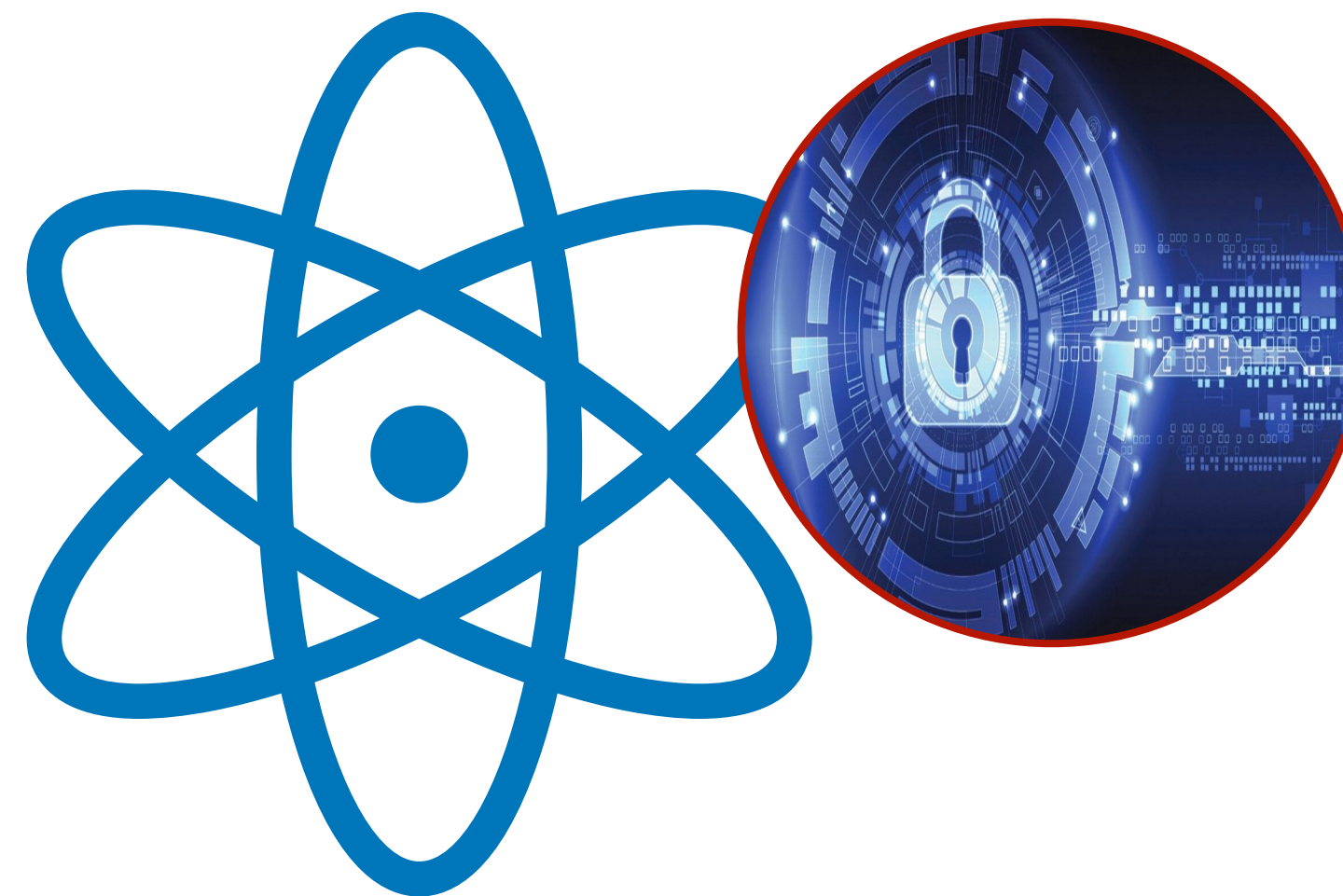
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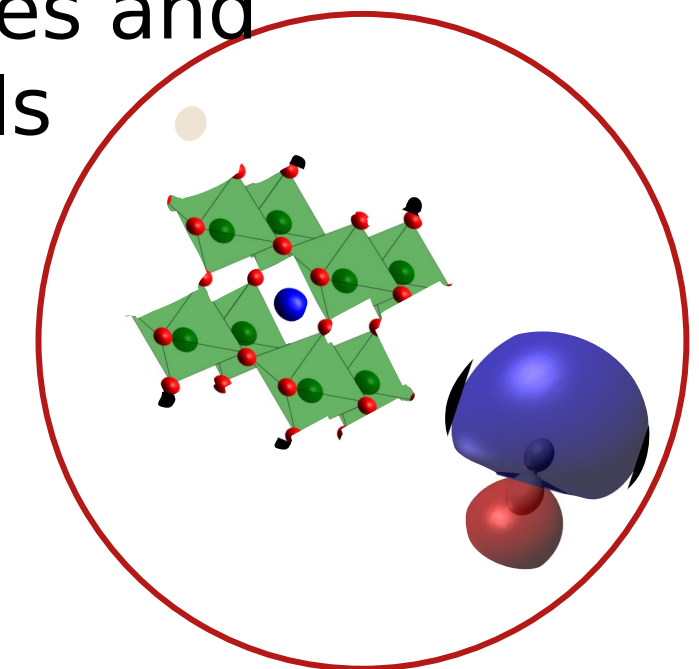


Shor algorithm



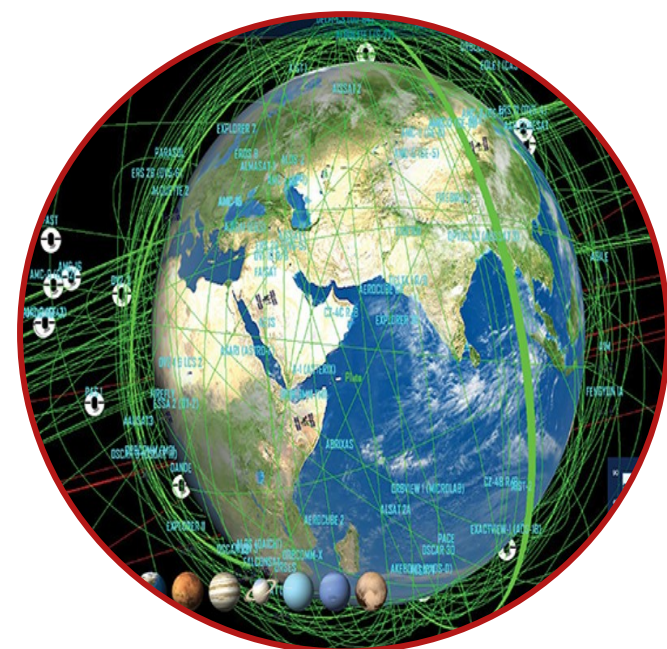
Machine Learning

Molecules and Materials



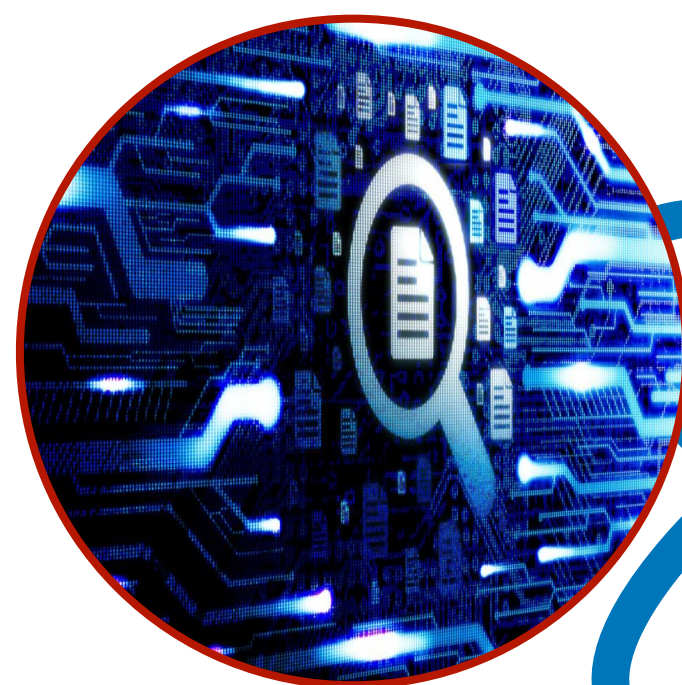
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Quantum algorithms

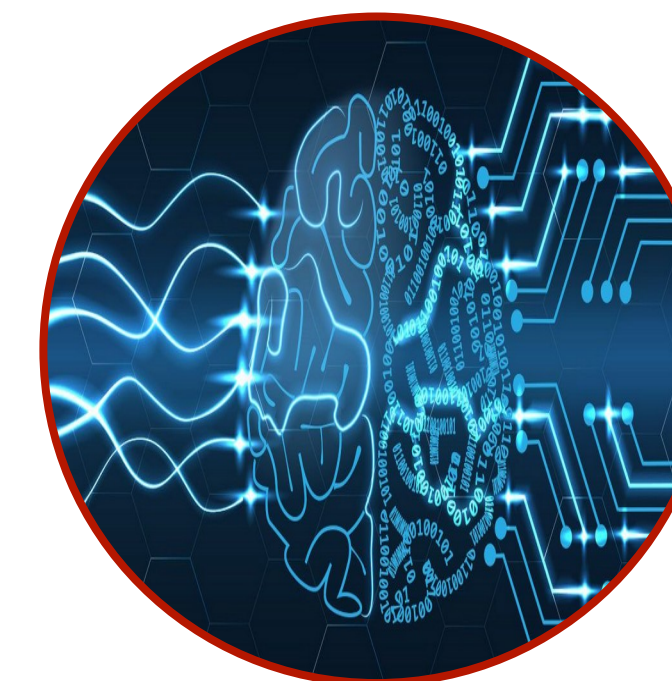
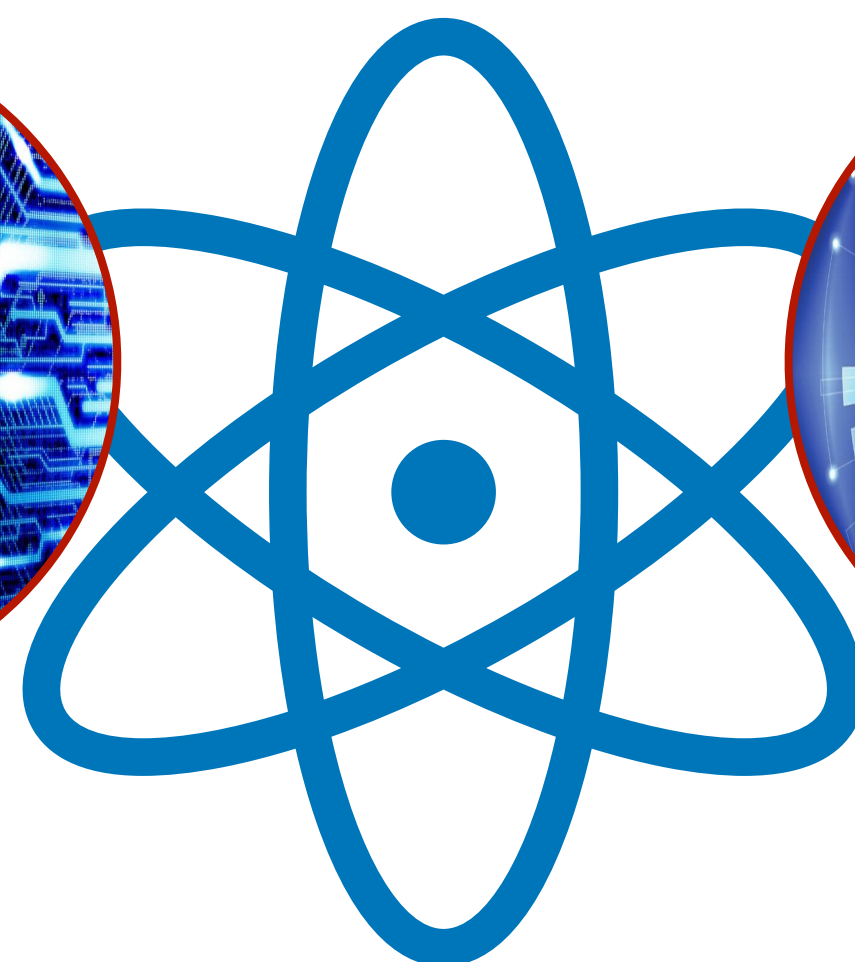


Earth Observation

Grover algorithm



Shor algorithm



Machine Learning



Traffic

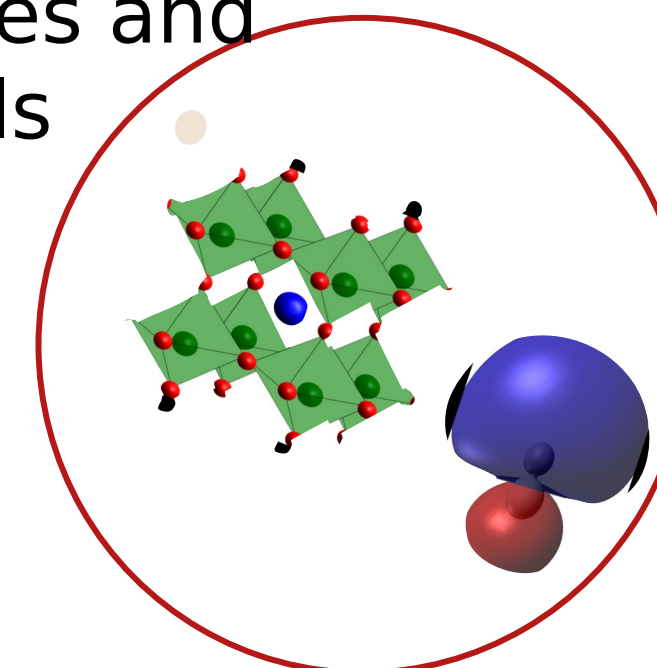
Combinatorial optimization problems

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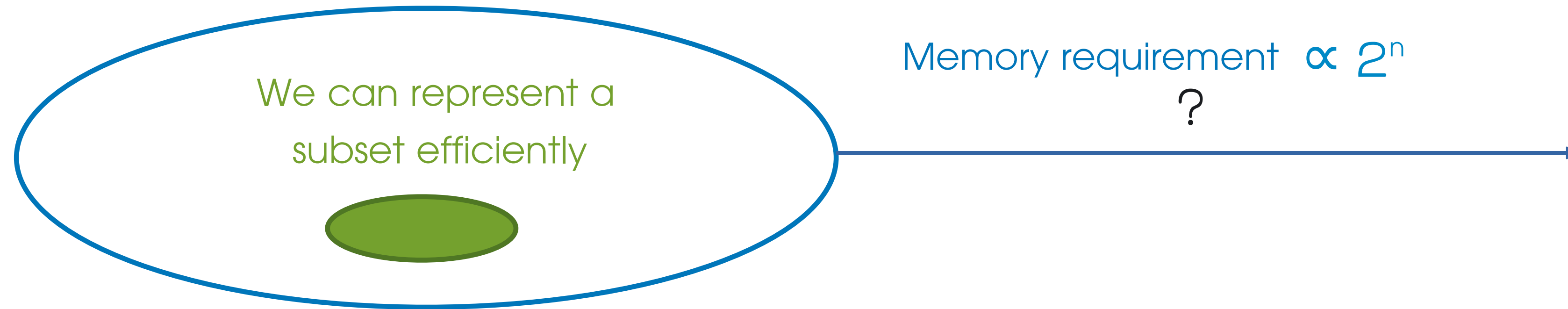


Molecules and Materials

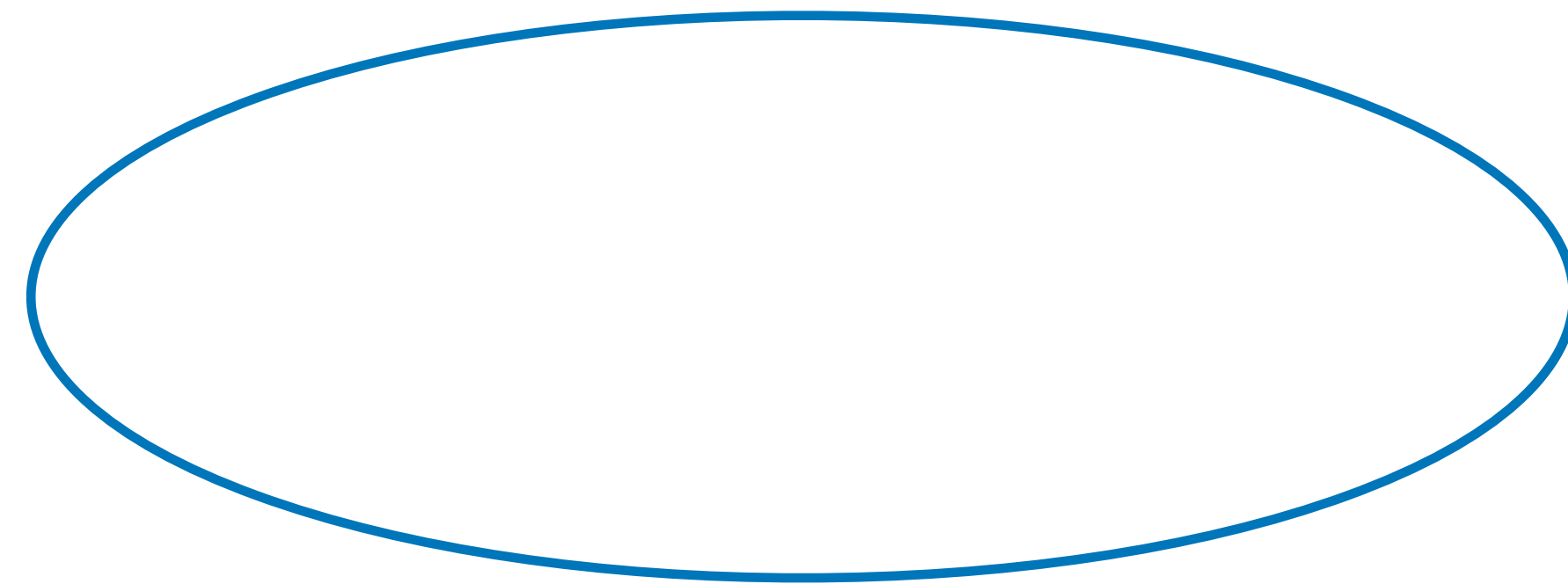


(VQE, quantum deflation, ...)

Entanglement and compression



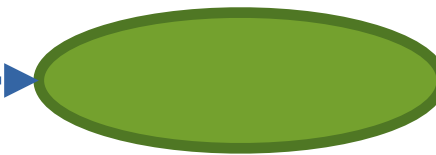
Entanglement and compression



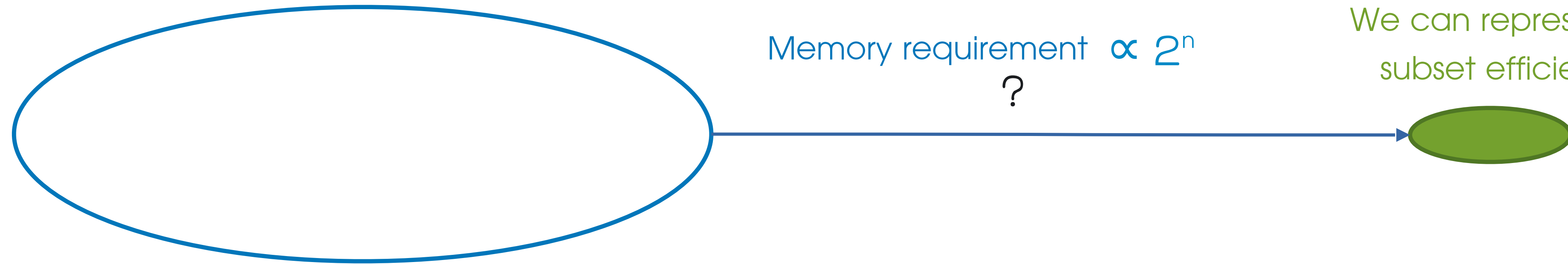
Memory requirement $\propto 2^n$
?



We can represent a
subset efficiently



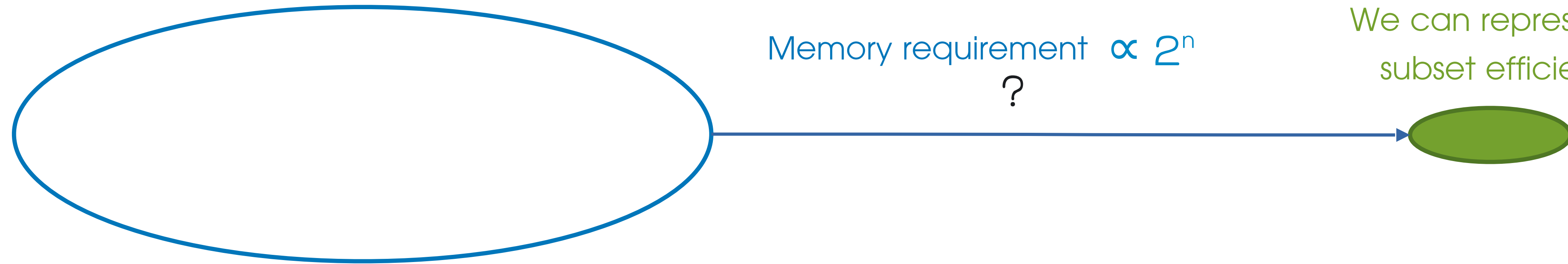
Entanglement and compression



Classical
bit string

0000

Entanglement and compression



Memory requirement $\propto 2^n$
?

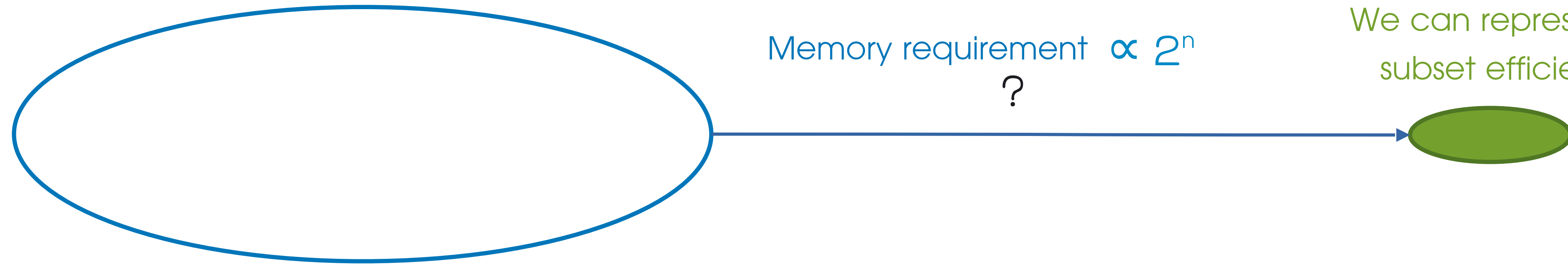
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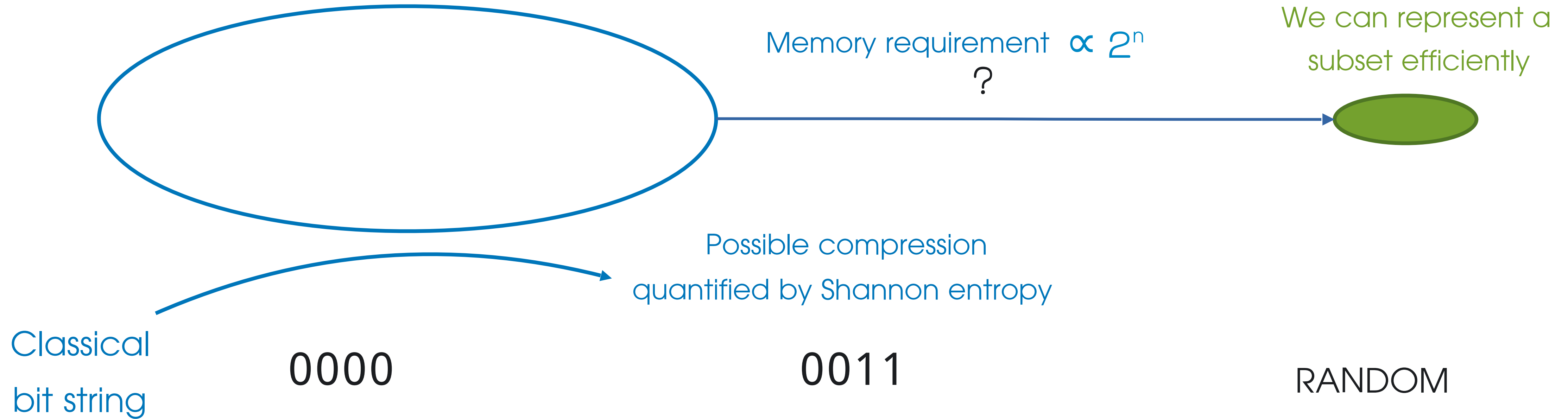
Classical
bit string

0000

0011

RANDOM

Entanglement and compression

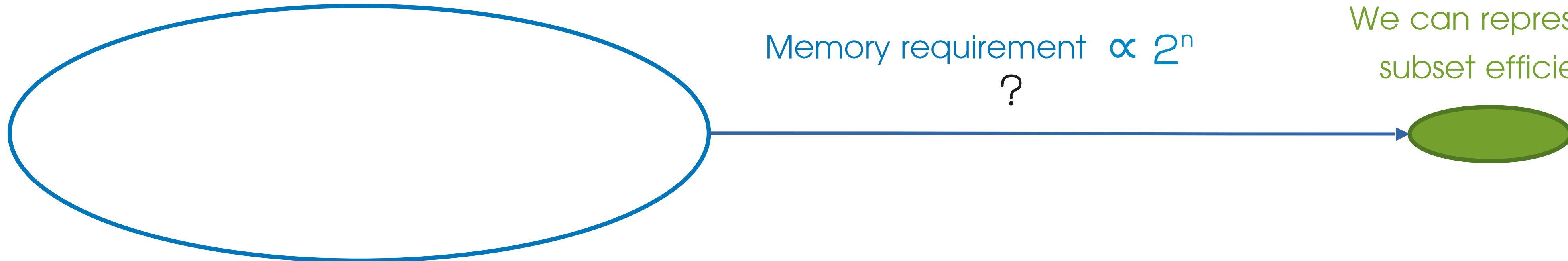


Entanglement and compression



Memory requirement $\propto 2^n$
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Possible compression
quantified by Shannon entropy

Classical
bit string

0000

0011

RANDOM

Optimal
Compression

Quantum
state

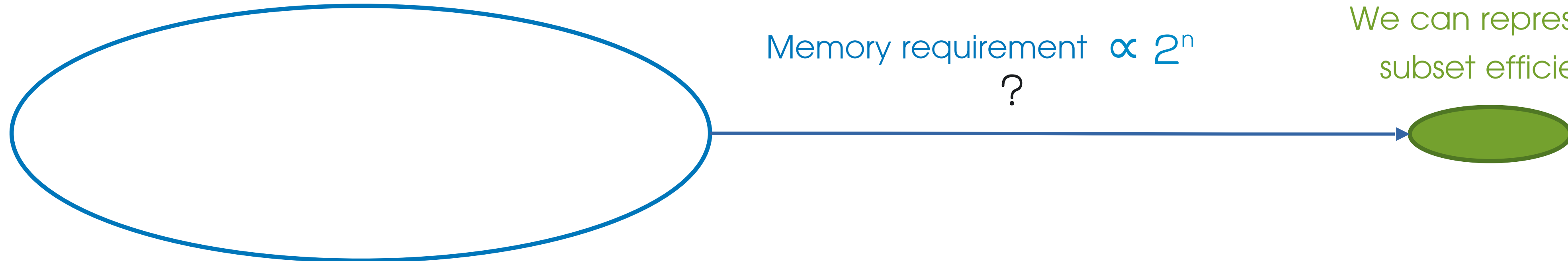
$|0000\rangle$

Entanglement and compression



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Possible compression
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0000

Optimal
Compression

$|0000\rangle$

0011

Here we can compress something.

The quantum state is **entangled**, it cannot be written as classical state

$$\frac{1}{\sqrt{2}} (|0000\rangle + |1111\rangle)$$

RANDOM

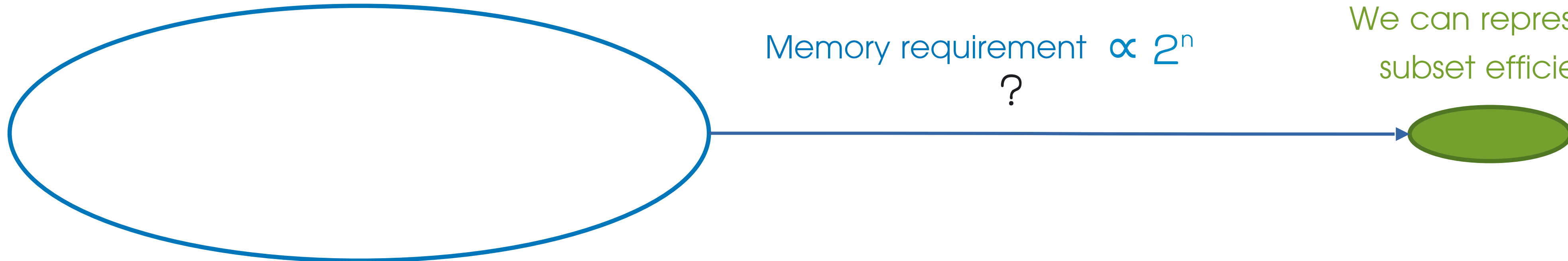
Quantum
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$$\frac{1}{\sqrt{2}} (|0000\rangle + |1111\rangle)$$

RANDOM

No compression possible without approximations

$|RANDOM\rangle$

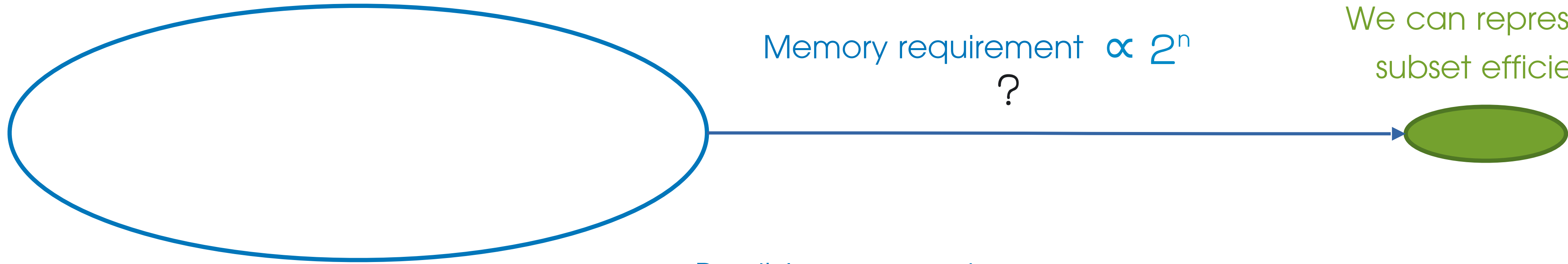
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RANDOM

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$|RANDOM\rangle$

Possible compression

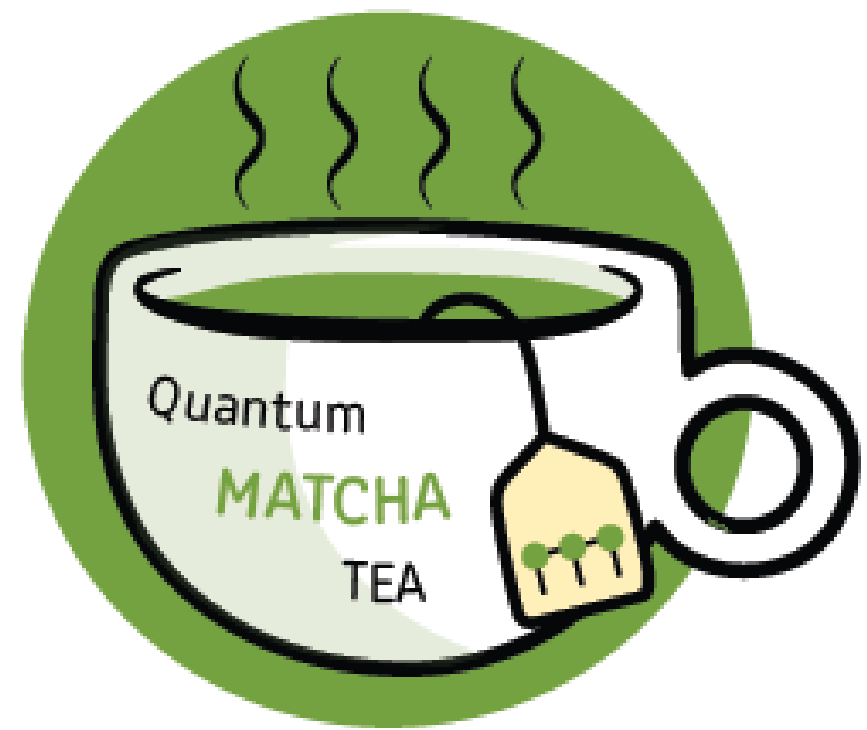
quantified by Von Neumann **entanglement** entropy

Quantum
state

Image compression through SVD



212 × 247
image

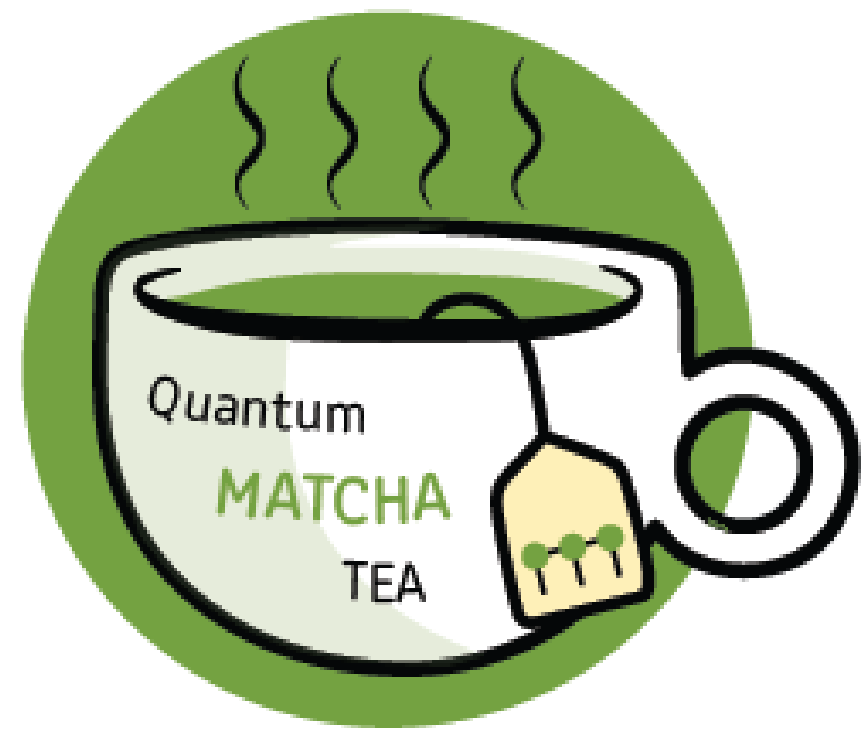


52364
pixels

Image compression through SVD



212 × 247
image



52364
pixels

$$\begin{matrix} \rightarrow & \left(\begin{array}{cccc} a_{00} & a_{01} & \dots & a_{0m} \\ a_{10} & a_{11} & \dots & a_{1m} \\ \vdots & \ddots & \dots & \vdots \\ a_{n0} & a_{n1} & \dots & a_{nm} \end{array} \right) & \rightarrow & U S V^T \end{matrix}$$

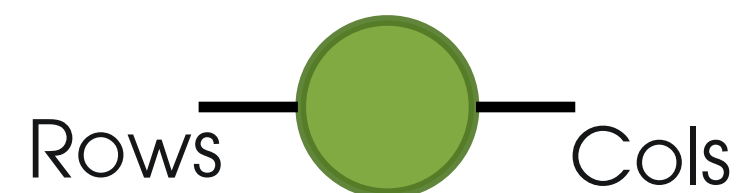


Image compression through SVD

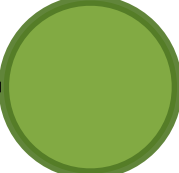


212 × 247
image



52364
pixels

$$\begin{pmatrix} a_{00} & a_{01} & \dots & a_{0m} \\ a_{10} & a_{11} & \dots & a_{1m} \\ \vdots & \ddots & \dots & \vdots \\ a_{n0} & a_{n1} & \dots & a_{nm} \end{pmatrix} \rightarrow U S V^T$$

Rows  Cols

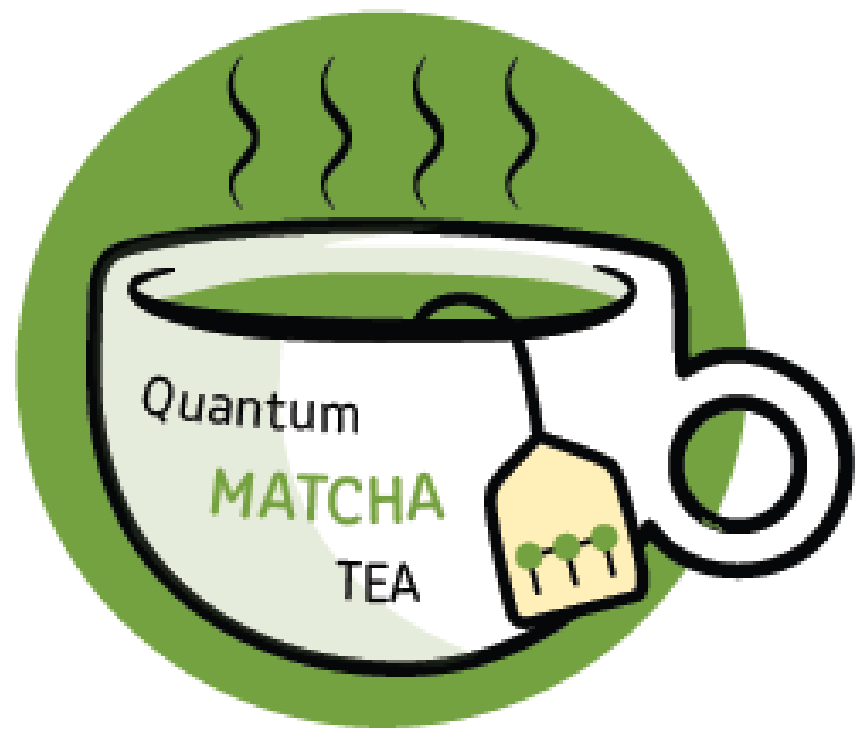
  

$$\begin{pmatrix} U_{11} & U_{12} & U_{13} \\ U_{21} & U_{22} & U_{23} \\ U_{31} & U_{32} & U_{33} \end{pmatrix} \begin{pmatrix} s_{11} & 0 & 0 \\ 0 & s_{22} & 0 \\ 0 & 0 & s_{33} \end{pmatrix} \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{pmatrix}$$

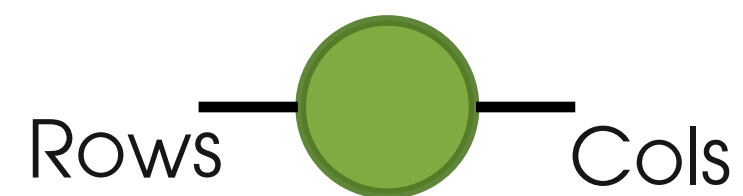
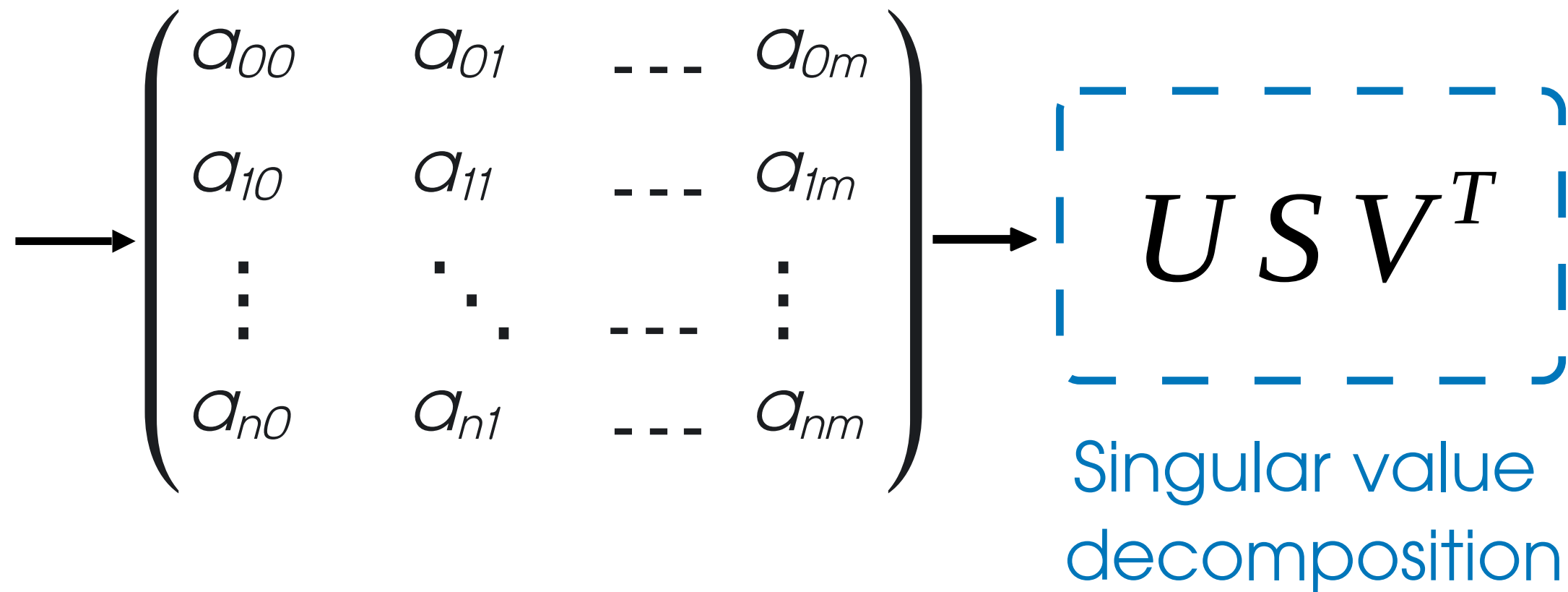


Image compression through SVD

212 × 247
image



52364
pixels



$$\begin{pmatrix} U_{11} & U_{12} & U_{13} \\ U_{21} & U_{22} & U_{23} \\ U_{31} & U_{32} & U_{33} \end{pmatrix} \begin{pmatrix} s_{11} & 0 & 0 \\ 0 & s_{22} & 0 \\ 0 & 0 & s_{33} \end{pmatrix} \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{pmatrix}$$

Image compression through SVD



212 × 247
image

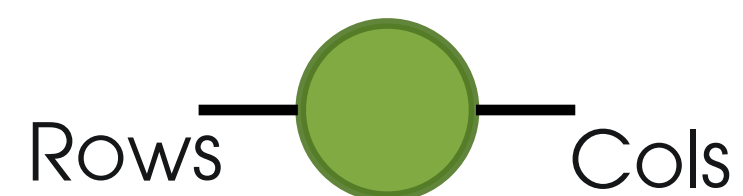
No truncation

$$\begin{pmatrix} a_{00} & a_{01} & \dots & a_{0m} \\ a_{10} & a_{11} & \dots & a_{1m} \\ \vdots & \ddots & \dots & \vdots \\ a_{n0} & a_{n1} & \dots & a_{nm} \end{pmatrix}$$

$$U S V^T$$

Singular value
decomposition

52364
pixels



$$\begin{pmatrix} U_{11} & U_{12} & U_{13} \\ U_{21} & U_{22} & U_{23} \\ U_{31} & U_{32} & U_{33} \end{pmatrix} \begin{pmatrix} s_{11} & 0 & 0 \\ 0 & s_{22} & 0 \\ 0 & 0 & s_{33} \end{pmatrix} \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{pmatrix}$$

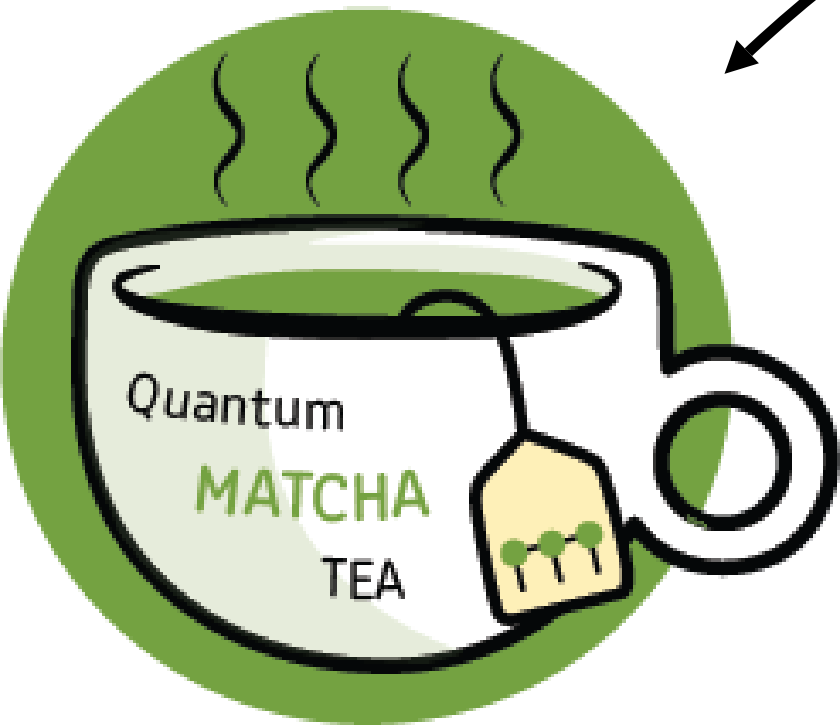


Image compression through SVD

Truncate the “least important” singular values using the truncated norm

212 × 247 image

No truncation

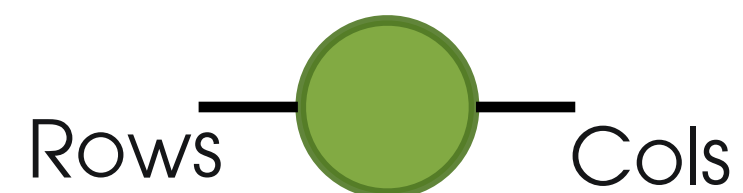


52364 pixels

$$\begin{pmatrix} a_{00} & a_{01} & \dots & a_{0m} \\ a_{10} & a_{11} & \dots & a_{1m} \\ \vdots & \ddots & \dots & \vdots \\ a_{n0} & a_{n1} & \dots & a_{nm} \end{pmatrix}$$

$$U S V^T$$

Singular value decomposition



$$\begin{pmatrix} U_{11} & U_{12} & U_{13} \\ U_{21} & U_{22} & U_{23} \\ U_{31} & U_{32} & U_{33} \end{pmatrix} \begin{pmatrix} s_{11} & 0 & 0 \\ 0 & s_{22} & 0 \\ 0 & 0 & s_{33} \end{pmatrix} \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ V_{31} & V_{32} & V_{33} \end{pmatrix}$$



Image compression through SVD

Truncate the "least important" singular values using the truncated norm

212 × 247 image

No truncation

$$\begin{pmatrix} a_{00} & a_{01} & \dots & a_{0m} \\ a_{10} & a_{11} & \dots & a_{1m} \\ \vdots & \ddots & \dots & \vdots \\ a_{n0} & a_{n1} & \dots & a_{nm} \end{pmatrix}$$

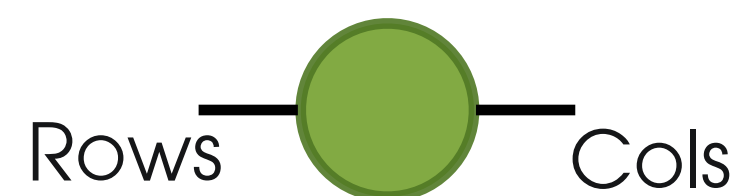
$$U S V^T$$

Singular value decomposition

80% truncation

19320 pixels

52364 pixels



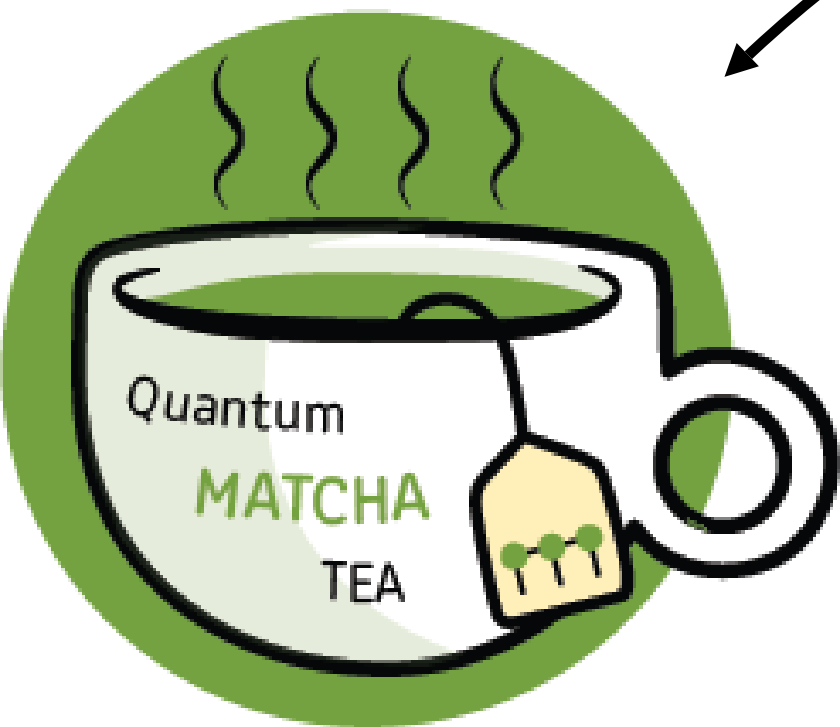
$$\begin{pmatrix} U_{11} & U_{12} & \cancel{U_{13}} \\ U_{21} & U_{22} & \cancel{U_{23}} \\ U_{31} & U_{32} & \cancel{U_{33}} \end{pmatrix} \begin{pmatrix} s_{11} & 0 & 0 \\ 0 & s_{22} & 0 \\ 0 & 0 & \cancel{s_{33}} \end{pmatrix} \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ V_{21} & V_{22} & V_{23} \\ \cancel{V_{31}} & \cancel{V_{32}} & \cancel{V_{33}} \end{pmatrix}$$



Image compression through SVD

Truncate the "least important" singular values using the truncated norm

212 × 247 image



52364 pixels

No truncation

$$\begin{pmatrix} a_{00} & a_{01} & \dots & a_{0m} \\ a_{10} & a_{11} & \dots & a_{1m} \\ \vdots & \cdot & \dots & \vdots \\ a_{n0} & a_{n1} & \dots & a_{nm} \end{pmatrix}$$

$$U S V^T$$

Singular value decomposition

80% truncation

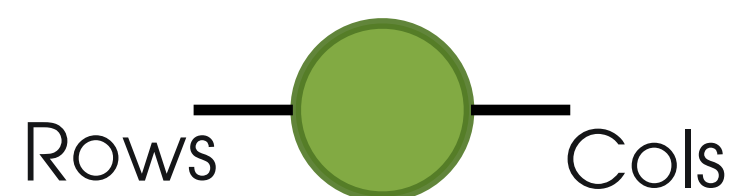


19320 pixels

95% truncation



4600 pixels



$$\begin{pmatrix} U_{11} & \cancel{U_{12}} & \cancel{U_{13}} \\ U_{21} & \cancel{U_{22}} & \cancel{U_{23}} \\ U_{31} & \cancel{U_{32}} & \cancel{U_{33}} \end{pmatrix} \begin{pmatrix} s_{11} & 0 & 0 \\ 0 & \cancel{s_{22}} & 0 \\ 0 & 0 & \cancel{s_{33}} \end{pmatrix} \begin{pmatrix} V_{11} & V_{12} & V_{13} \\ \cancel{V_{21}} & \cancel{V_{22}} & \cancel{V_{23}} \\ \cancel{V_{31}} & \cancel{V_{32}} & \cancel{V_{33}} \end{pmatrix}$$

Compressing a 4-qubits quantum state

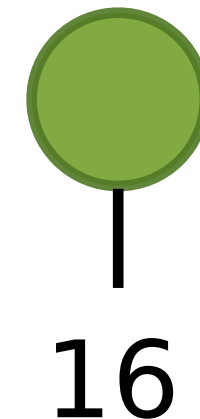
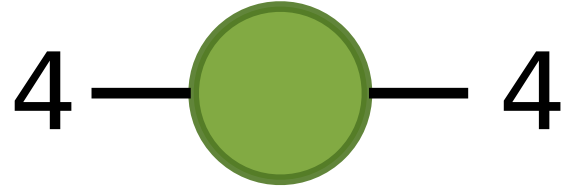


●
|
16

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix}$$

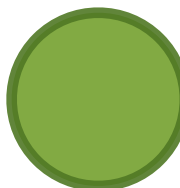
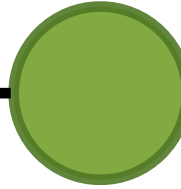
Compressing a 4-qubits quantum state



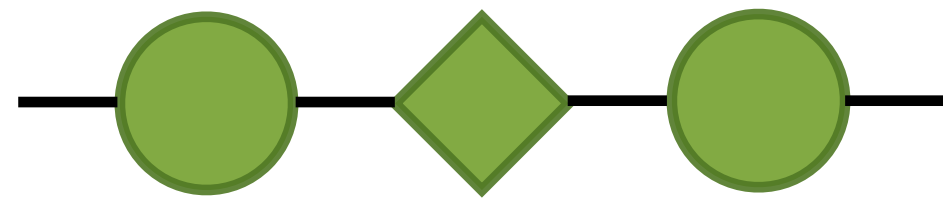
 $|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{matrix} 4 \\ 4 \end{matrix}$ 



Compressing a 4-qubits quantum state

 | $|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$ 

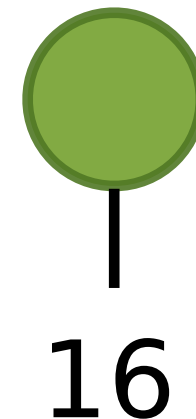
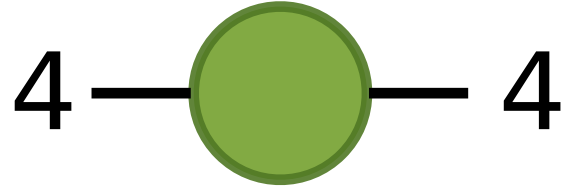
16 4 — 4

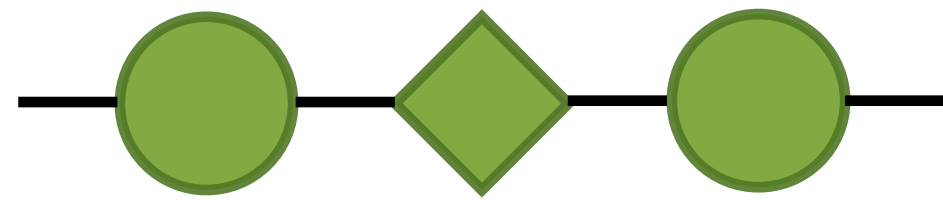


$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$



Compressing a 4-qubits quantum state


 $|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$


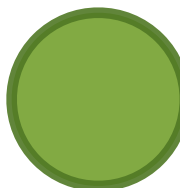
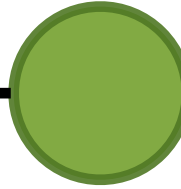


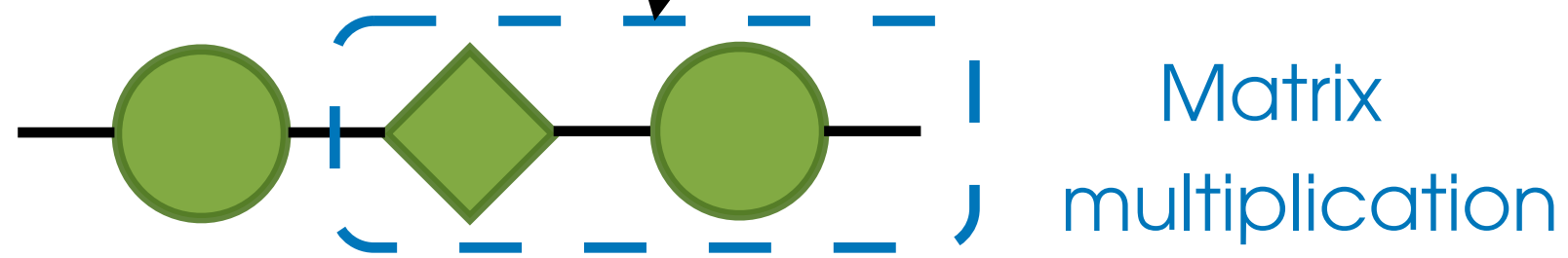
$$\begin{pmatrix} 1 & 0 & \cancel{0} & \cancel{0} \\ 0 & 0 & \cancel{1} & \cancel{0} \\ 0 & 0 & \cancel{0} & \cancel{1} \\ 0 & 1 & \cancel{0} & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cancel{0} & 0 \\ 0 & 0 & 0 & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ \cancel{0} & \cancel{1} & \cancel{0} & \cancel{0} \\ \cancel{0} & \cancel{0} & \cancel{1} & \cancel{0} \end{pmatrix}$$

4 → 2



Compressing a 4-qubits quantum state


 $|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$


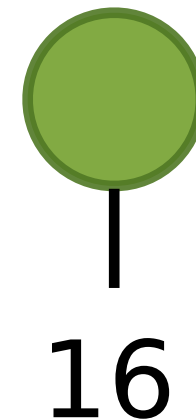


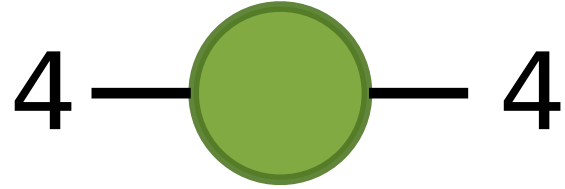
$$\begin{pmatrix} 1 & 0 & \cancel{0} & \cancel{0} \\ 0 & 0 & \cancel{1} & \cancel{0} \\ 0 & 0 & \cancel{0} & \cancel{1} \\ 0 & 1 & \cancel{0} & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cancel{0} & 0 \\ 0 & 0 & 0 & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ \cancel{0} & \cancel{1} & \cancel{0} & \cancel{0} \\ \cancel{0} & \cancel{0} & \cancel{1} & \cancel{0} \end{pmatrix}$$

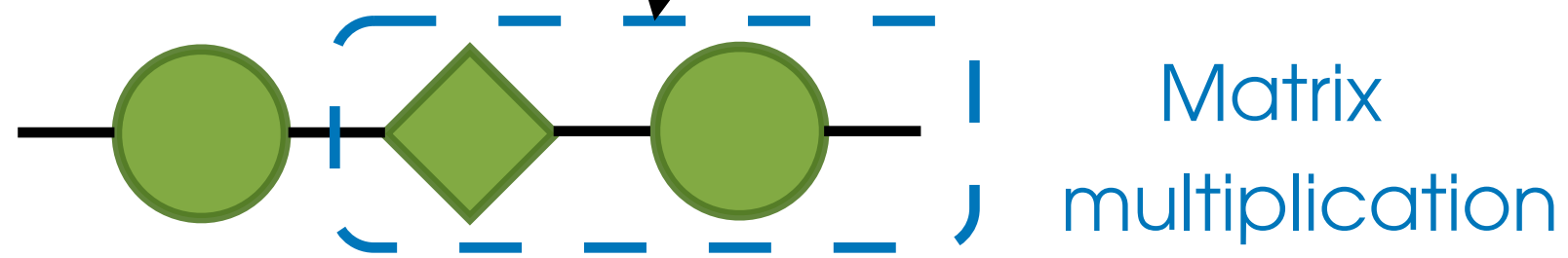
4 → 2



Compressing a 4-qubits quantum state

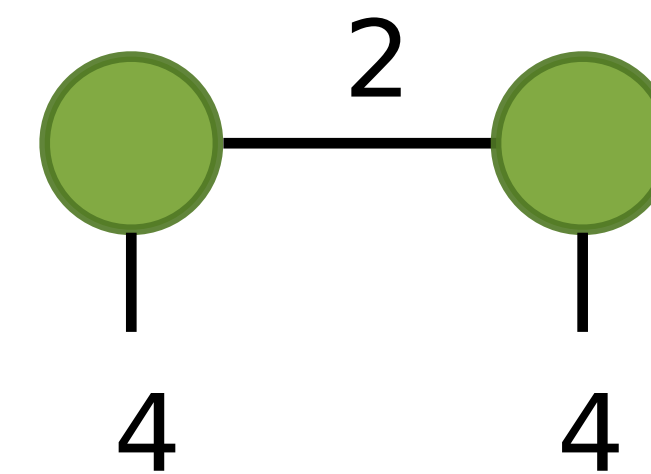


$$|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$




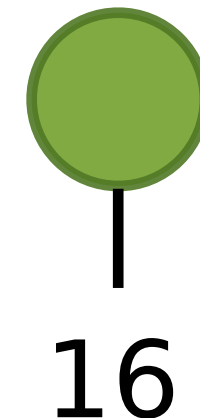
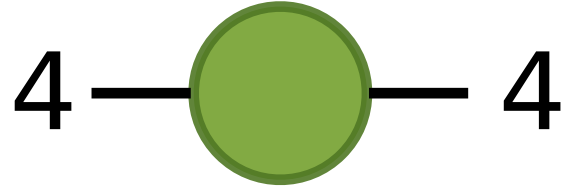
$$\begin{pmatrix} 1 & 0 & \cancel{0} & \cancel{0} \\ 0 & 0 & \cancel{1} & \cancel{0} \\ 0 & 0 & \cancel{0} & \cancel{1} \\ 0 & 1 & \cancel{0} & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cancel{0} & 0 \\ 0 & 0 & 0 & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ \cancel{0} & \cancel{1} & \cancel{0} & \cancel{0} \\ \cancel{0} & \cancel{0} & \cancel{1} & \cancel{0} \end{pmatrix}$$

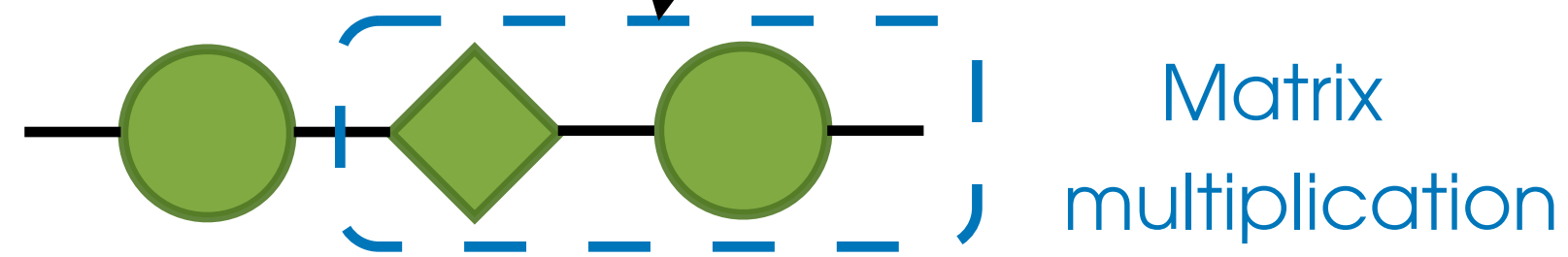
4 → 2





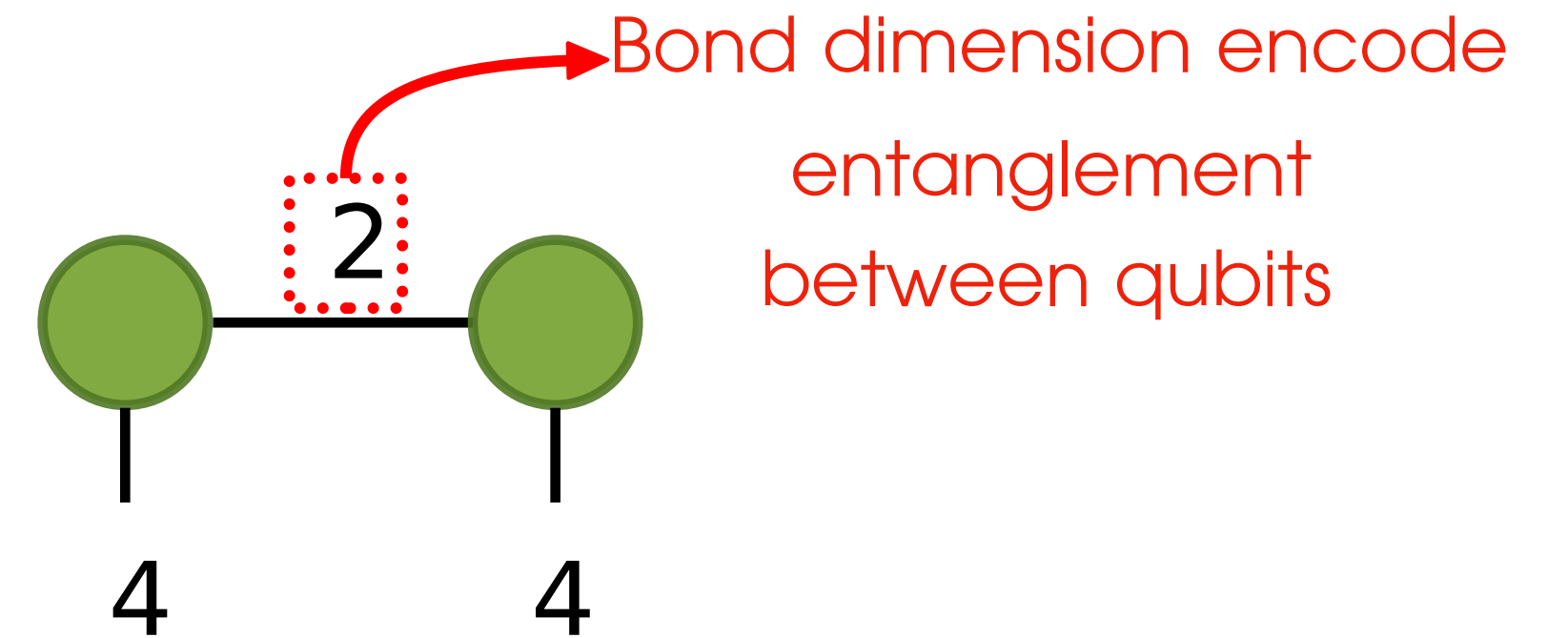
Compressing a 4-qubits quantum state


 $|\psi\rangle = \frac{1}{\sqrt{2}}(|0000\rangle + |1111\rangle) = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \\ 1 \end{pmatrix} \longrightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$


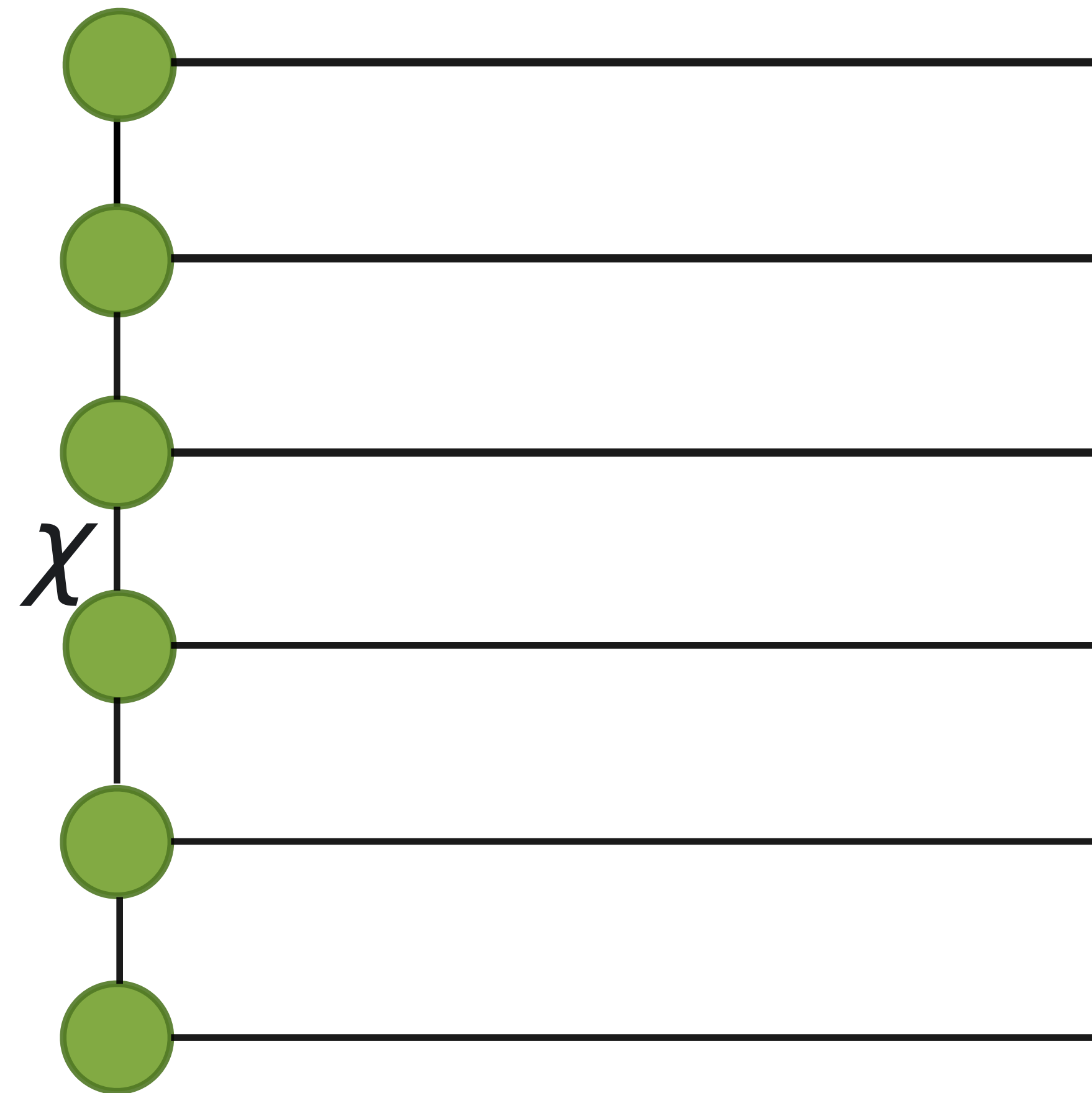


$$\begin{pmatrix} 1 & 0 & \cancel{0} & \cancel{0} \\ 0 & 0 & \cancel{1} & \cancel{0} \\ 0 & 0 & \cancel{0} & \cancel{1} \\ 0 & 1 & \cancel{0} & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cancel{0} & 0 \\ 0 & 0 & 0 & \cancel{0} \end{pmatrix}
 \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ \cancel{0} & \cancel{1} & \cancel{0} & \cancel{0} \\ \cancel{0} & \cancel{0} & \cancel{1} & \cancel{0} \end{pmatrix}$$

4 → 2



Matrix Product States

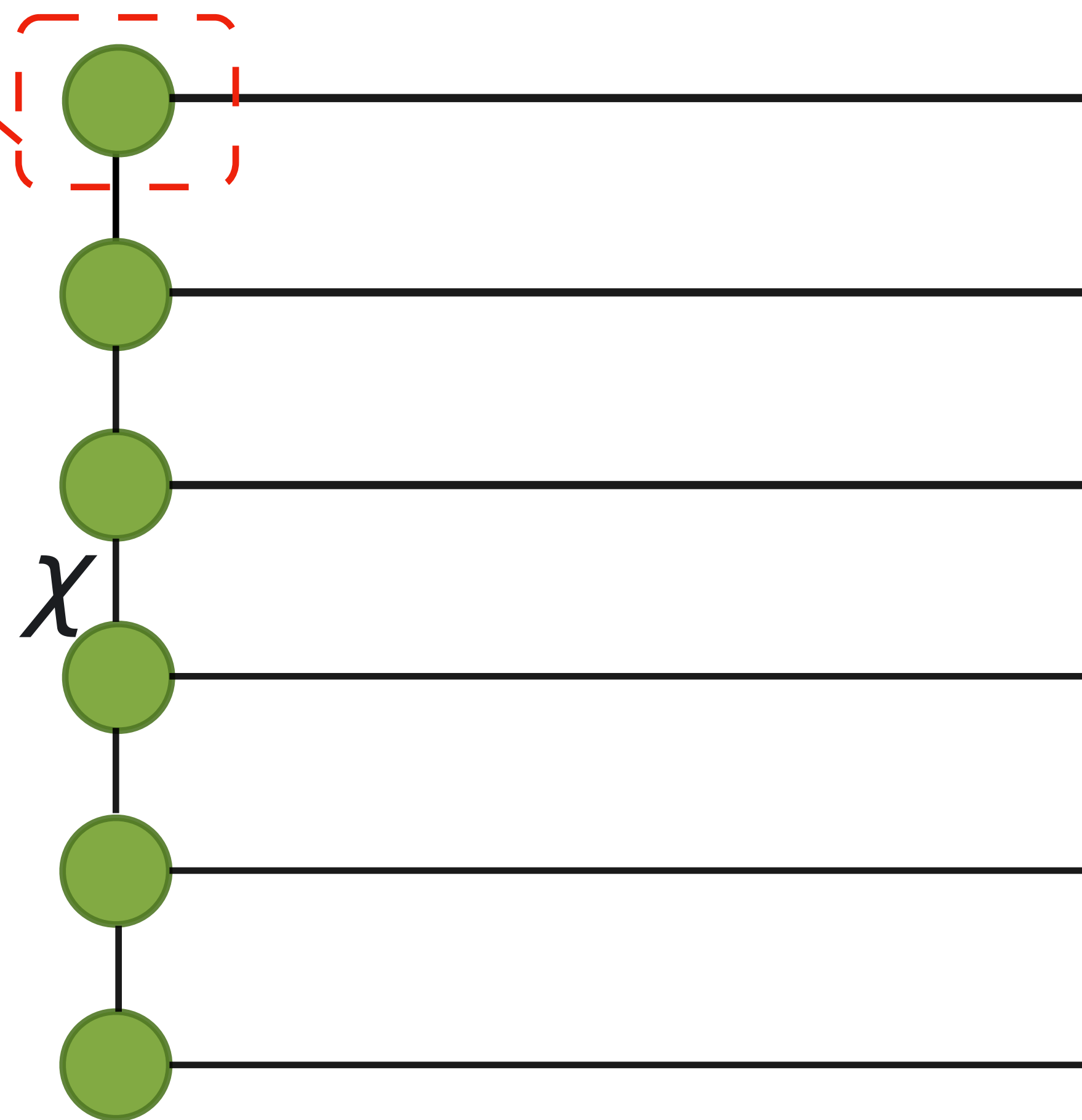


Memory requirements
 $O(2^n) \rightarrow O(2n \chi^2)$

Matrix Product States



Each tensor (ball) encodes
the state of a qubit



Memory requirements

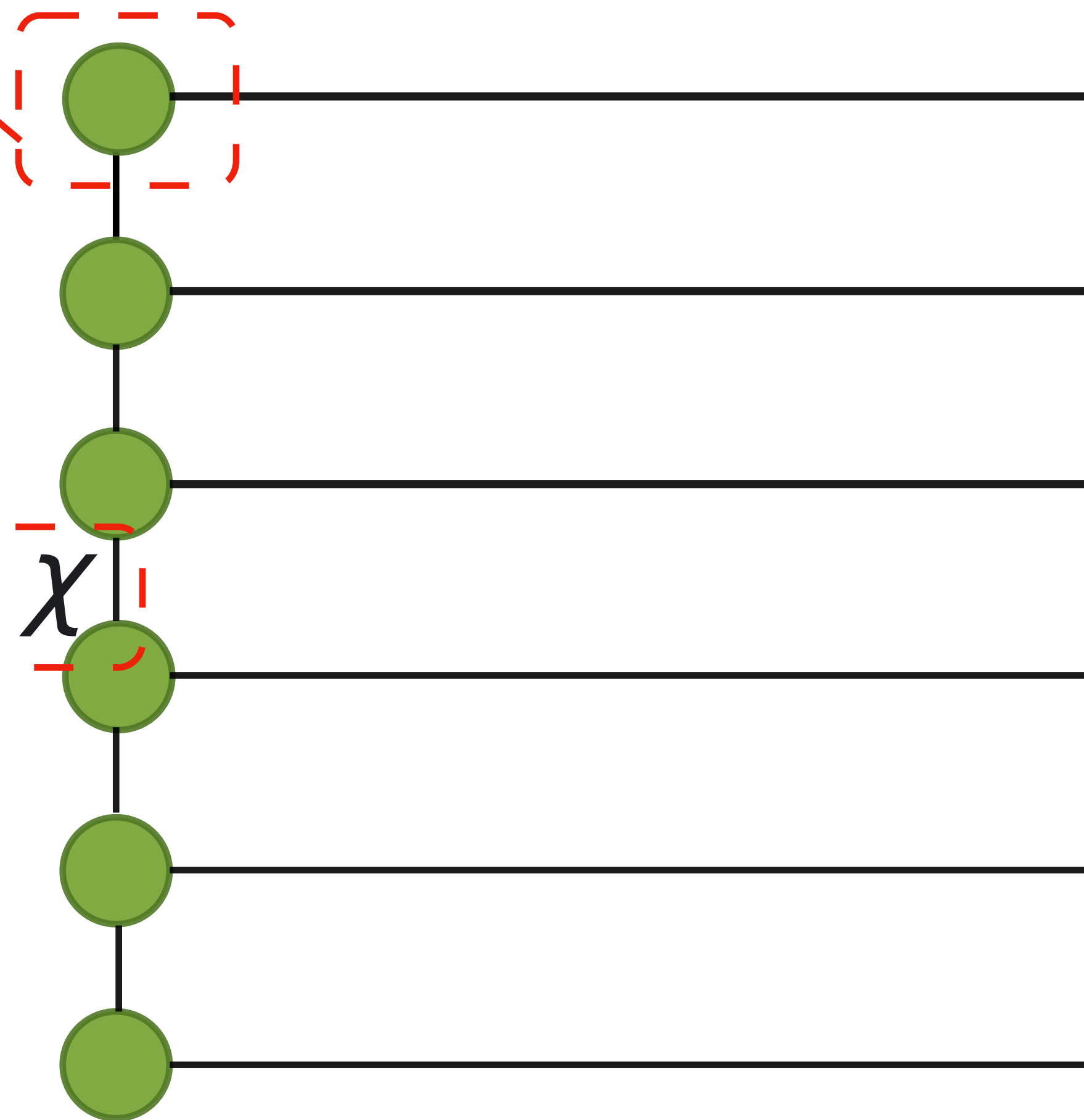
$$O(2^n) \rightarrow O(2n \chi^2)$$

Matrix Product States



Each tensor (ball) encodes the state of a qubit

Bonds encode entanglement between qubits



Memory requirements

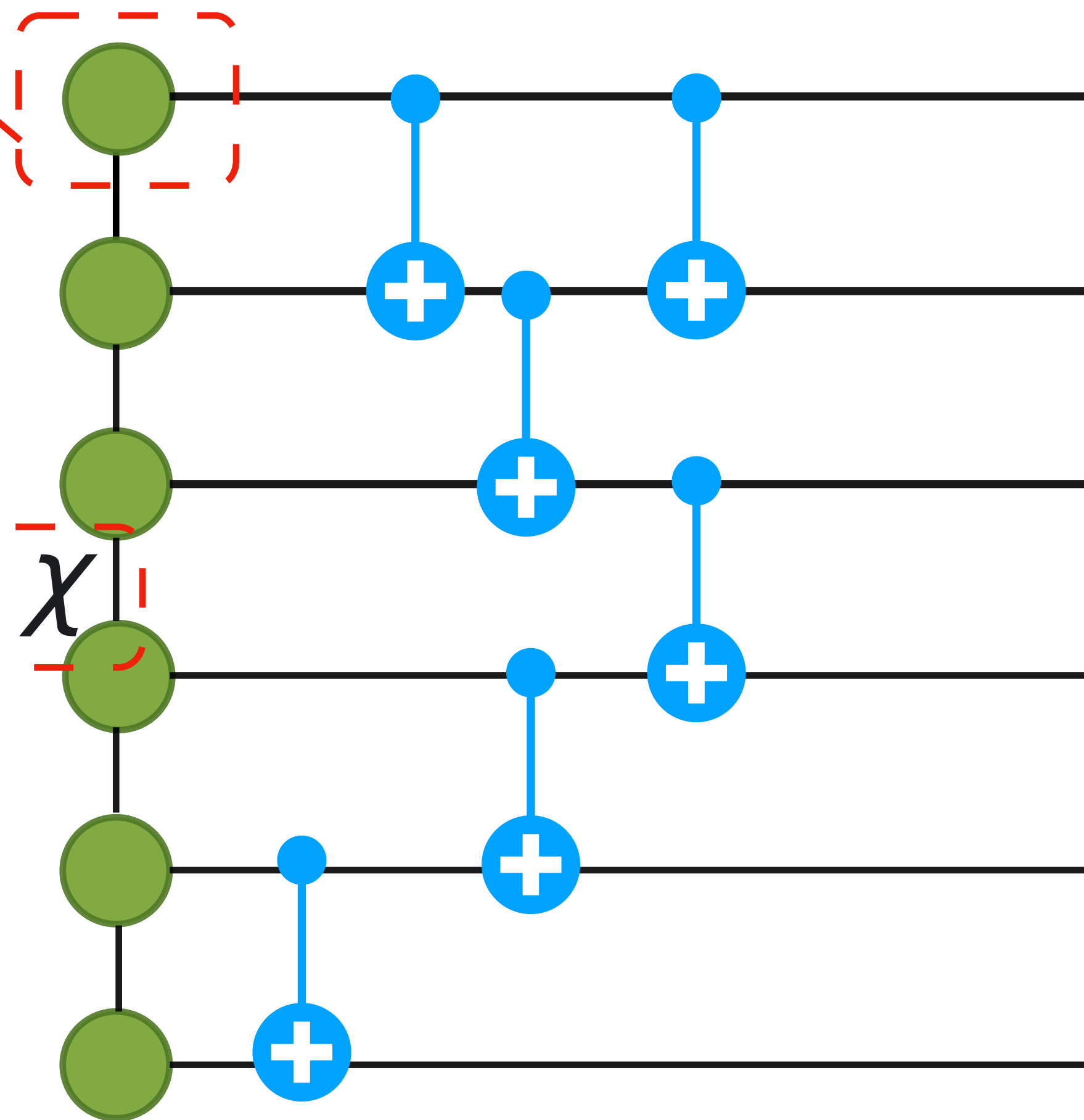
$$O(2^n) \rightarrow O(2n \chi^2)$$

Matrix Product States



Each tensor (ball) encodes the state of a qubit

Bonds encode entanglement between qubits



Memory requirements

$$O(2^n) \rightarrow O(2n \chi^2)$$

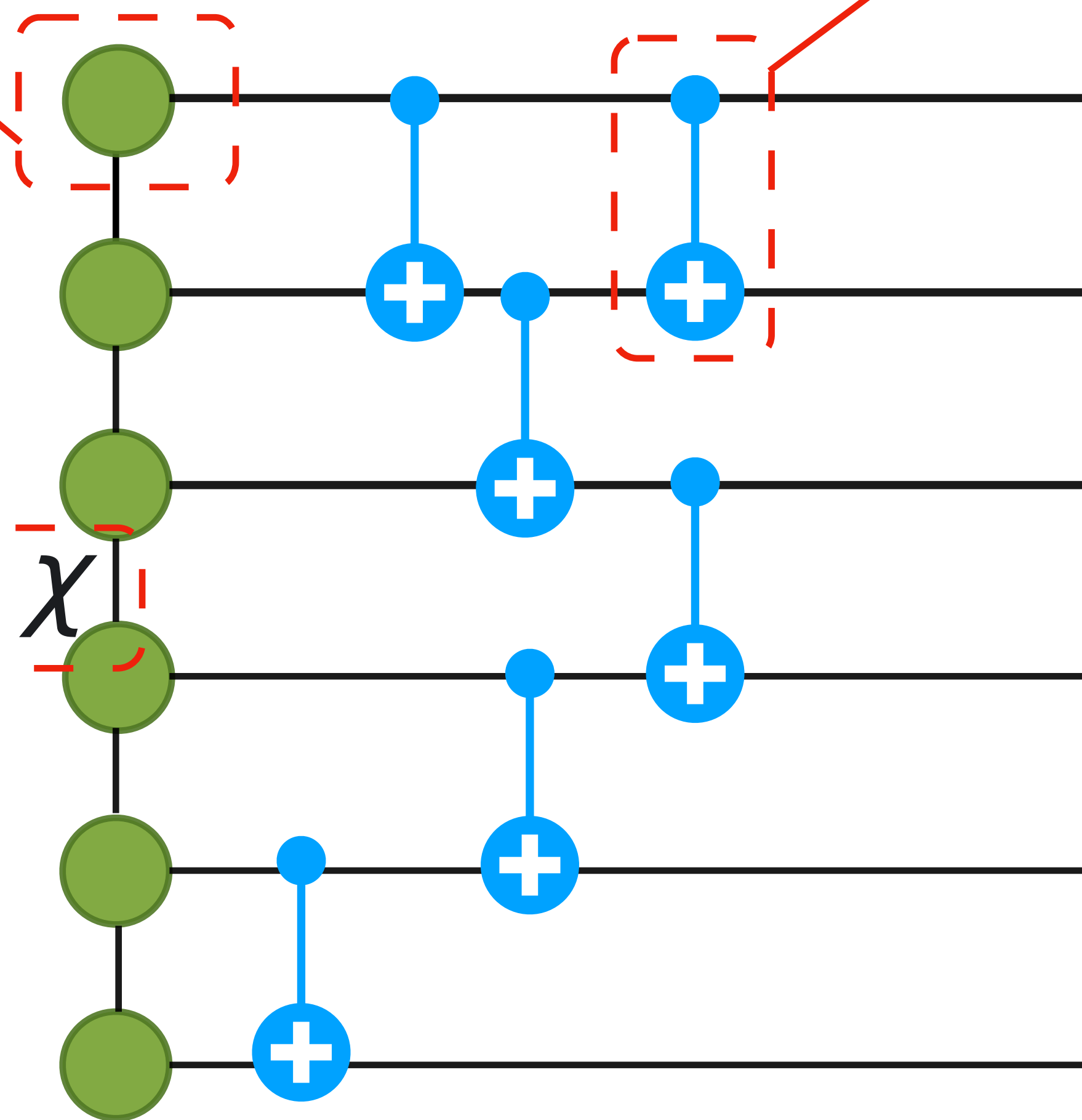
Matrix Product States



Each tensor (ball) encodes the state of a qubit

Quantum gate

Bonds encode entanglement between qubits



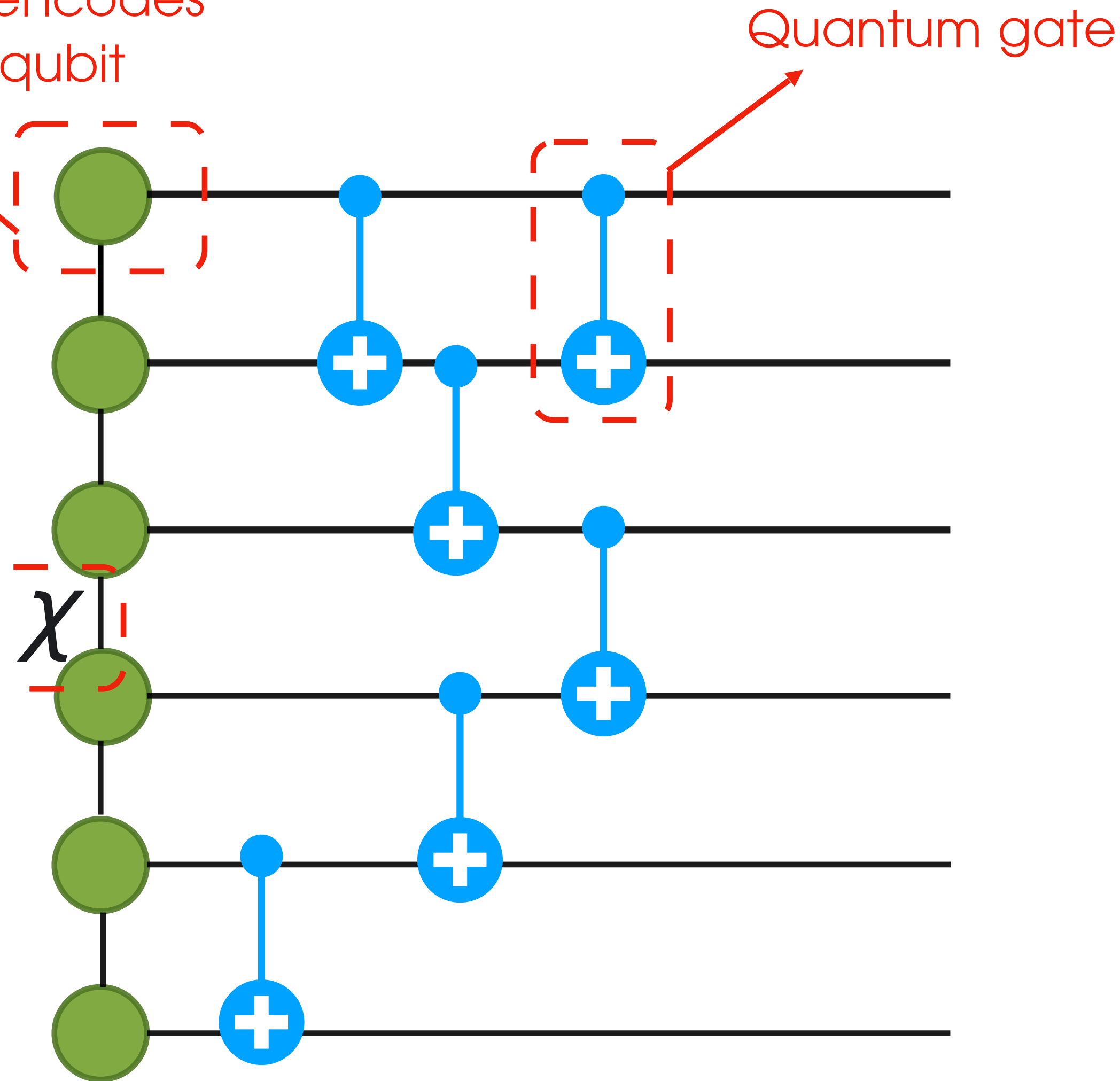
Memory requirements
 $O(2^n) \rightarrow O(2n \chi^2)$



Matrix Product States

Each tensor (ball) encodes the state of a qubit

Bonds encode entanglement between qubits

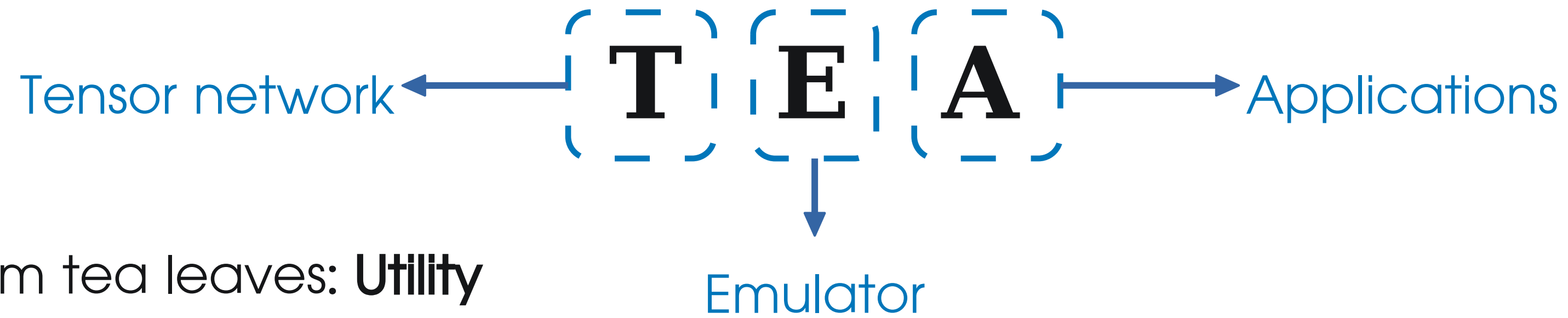


Memory requirements

$$O(2^n) \rightarrow O(2n \chi^2)$$

MPS SIMULATIONS ARE NOT LIMITED BY THE NUMBER OF QUBITS BUT BY THE ENTANGLEMENT

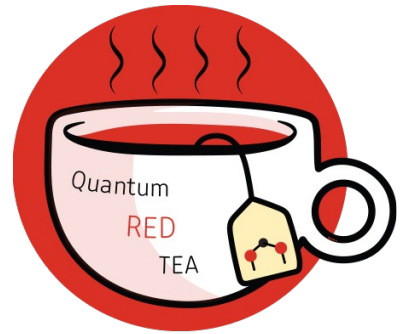
QuantumTEA distribution



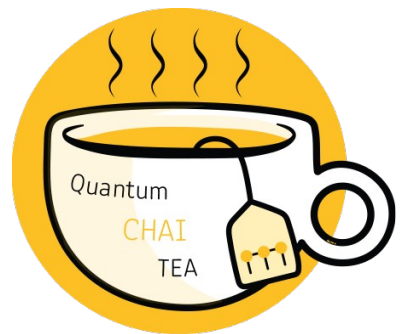
Quantum tea leaves: **Utility**



Quantum matcha tea: **quantum circuit HPC simulations**



Quantum red tea: **tensor handling**

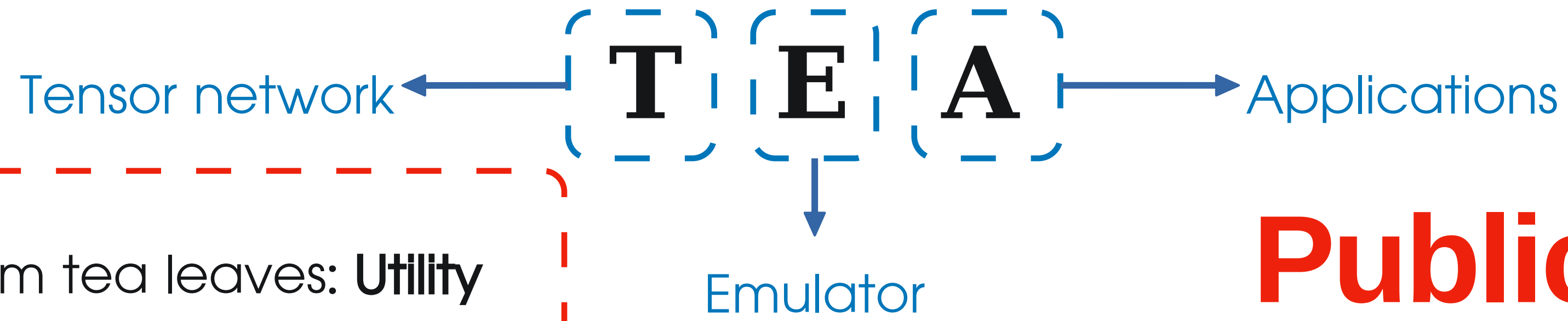


Quantum chai tea: **AI and ML with tensor networks**

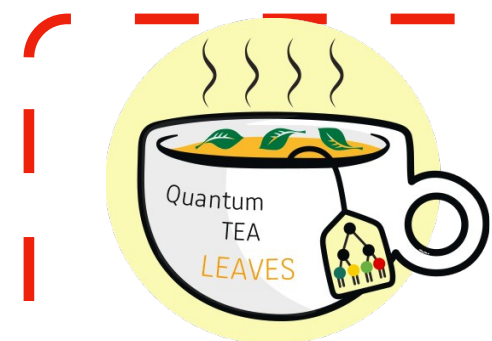


Quantum green tea: **Schrödinger equation solution for many-body states**

QuantumTEA distribution



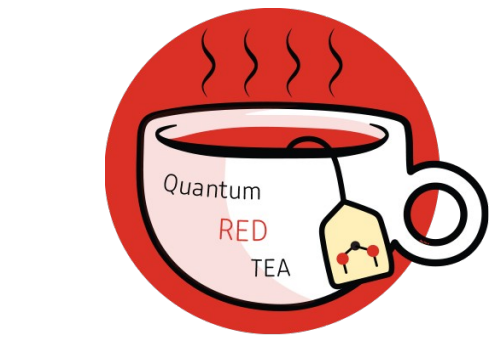
Public!



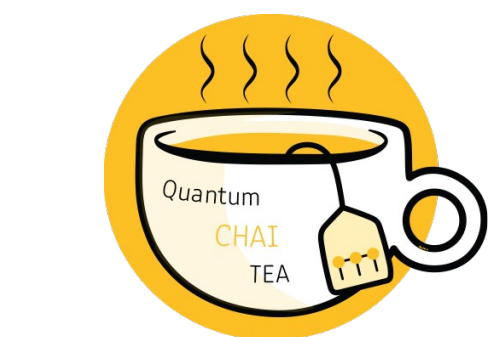
Quantum tea leaves: **Utility**



Quantum matcha tea: **quantum circuit HPC simulations**



Quantum red tea: **tensor handling**



Quantum chai tea: **AI and ML with tensor networks**

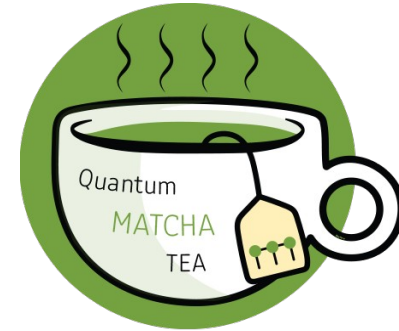
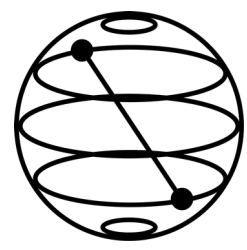


Quantum green tea: **Schrödinger equation solution for many-body states**

Quantum Matcha TEA workflow



Quantum circuit

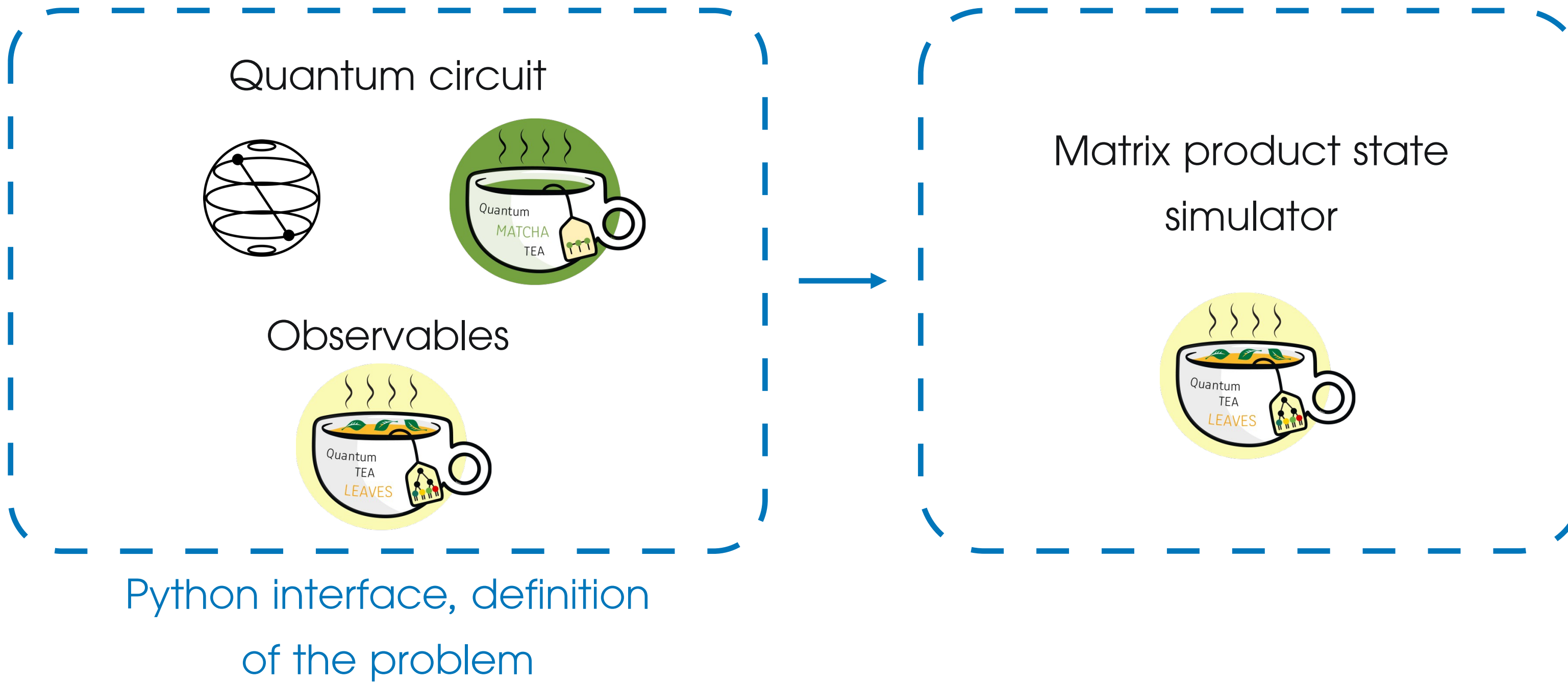


Observables

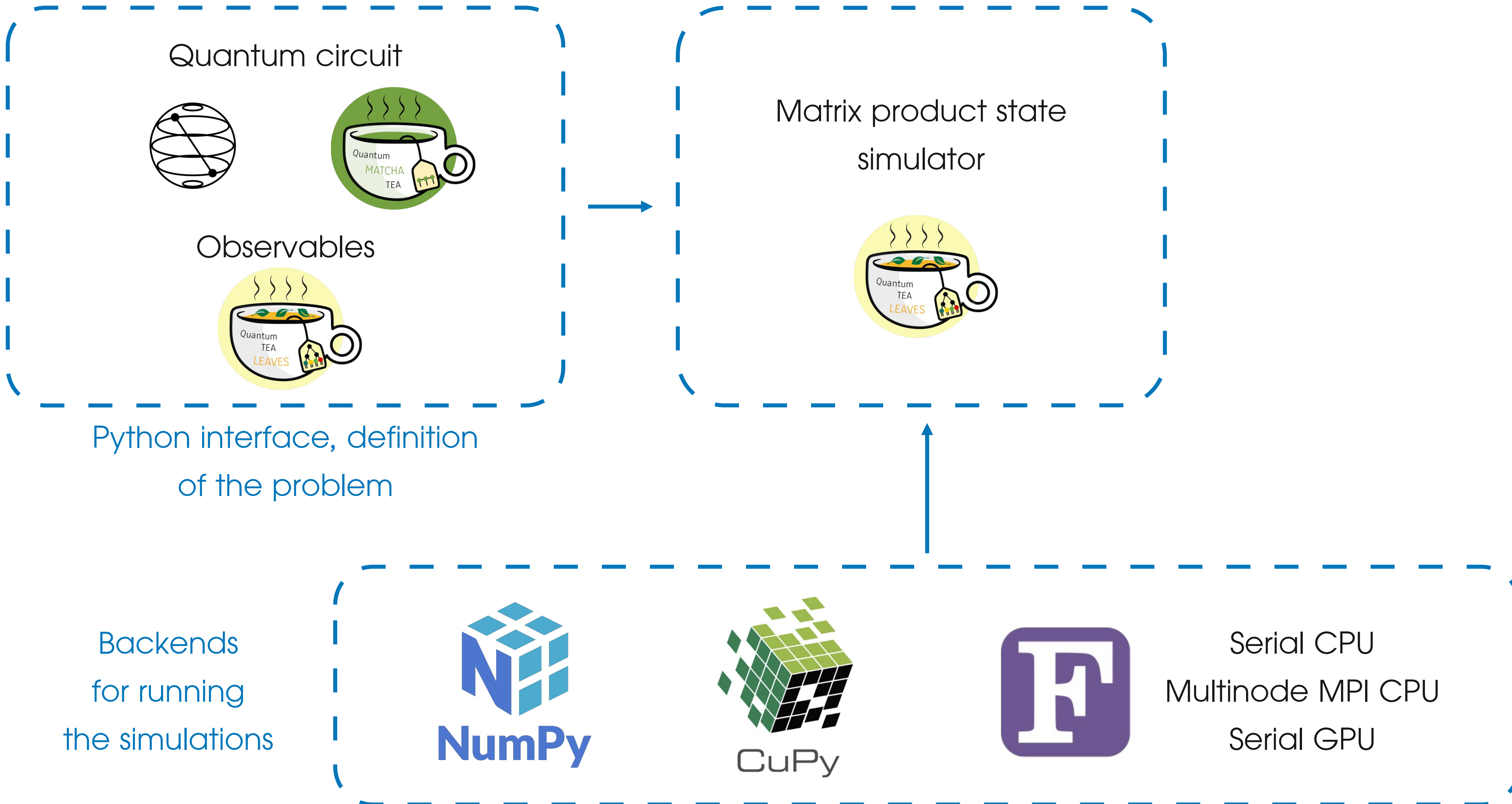


Python interface, definition
of the problem

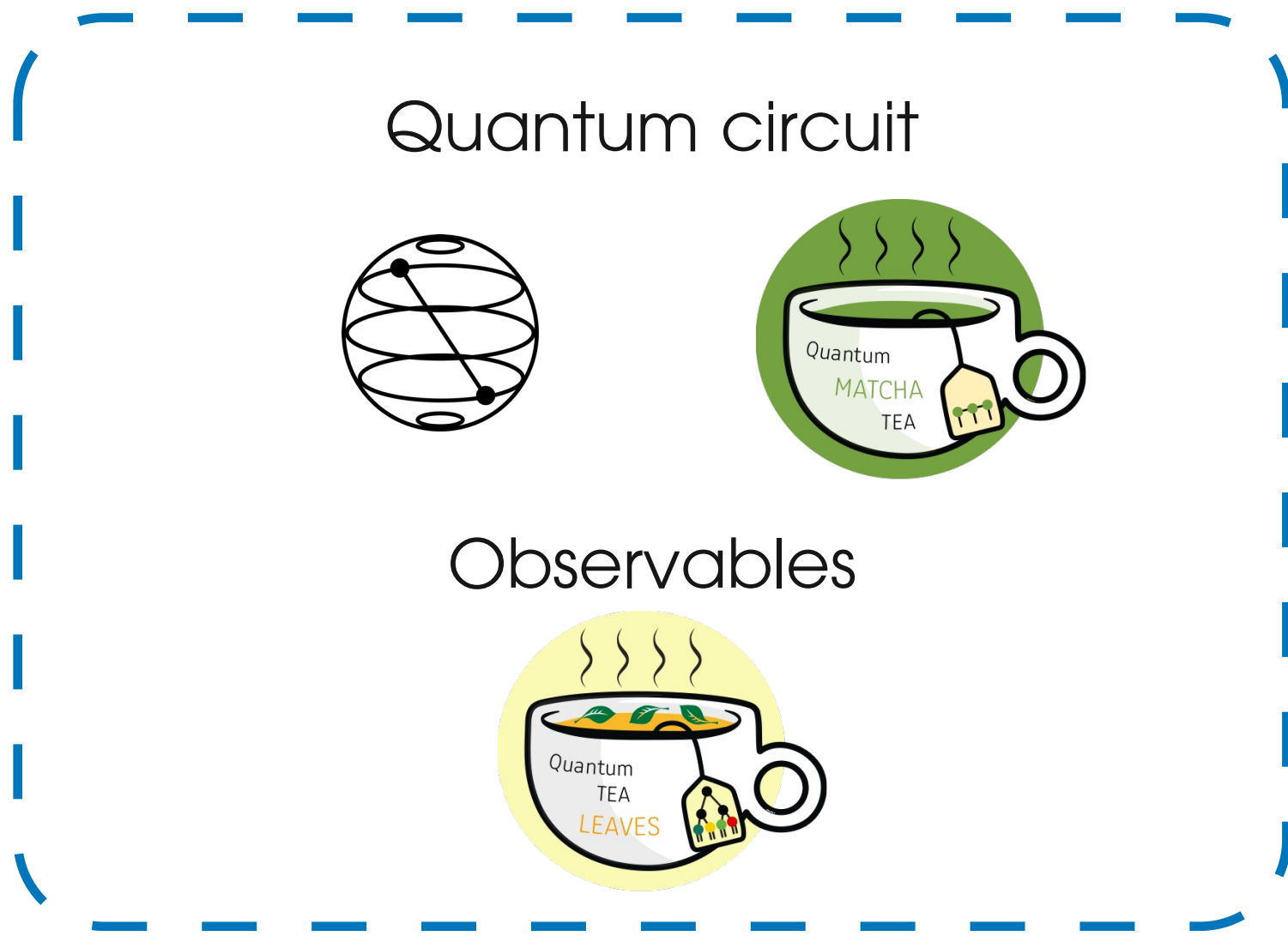
Quantum Matcha TEA workflow



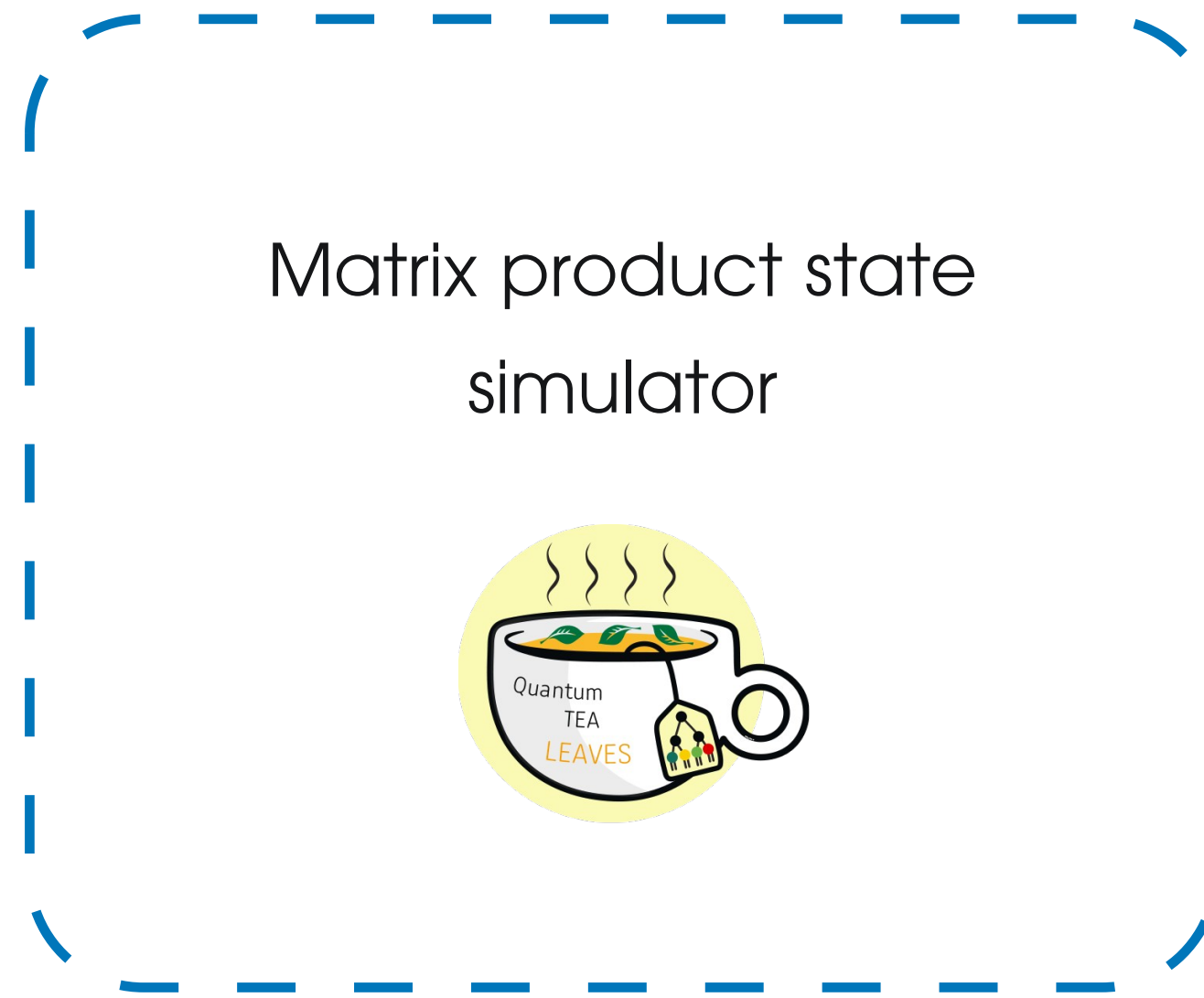
Quantum Matcha TEA workflow



Quantum Matcha TEA workflow



Python interface, definition of the problem



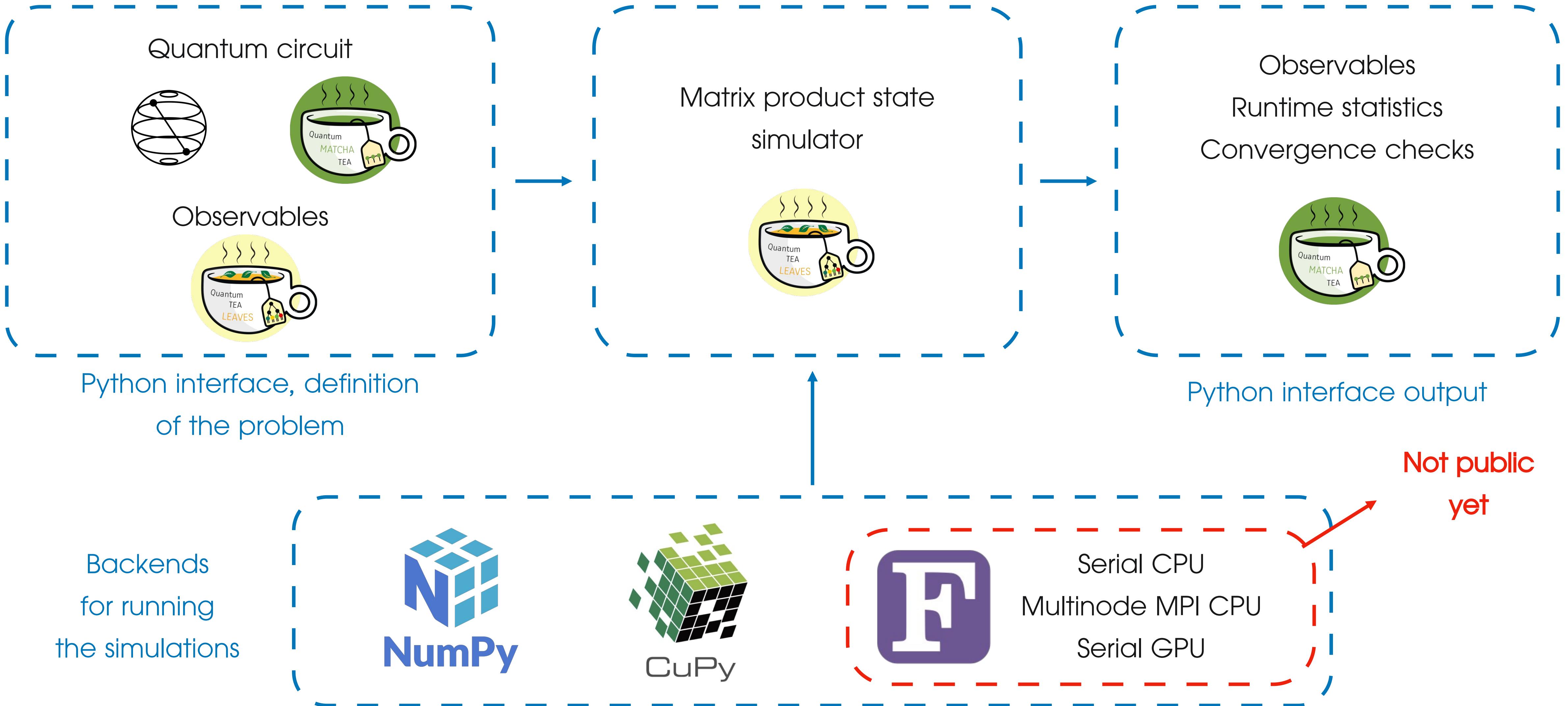
Backends for running the simulations



Serial CPU
Multinode MPI CPU
Serial GPU

Not public yet

Quantum Matcha TEA workflow

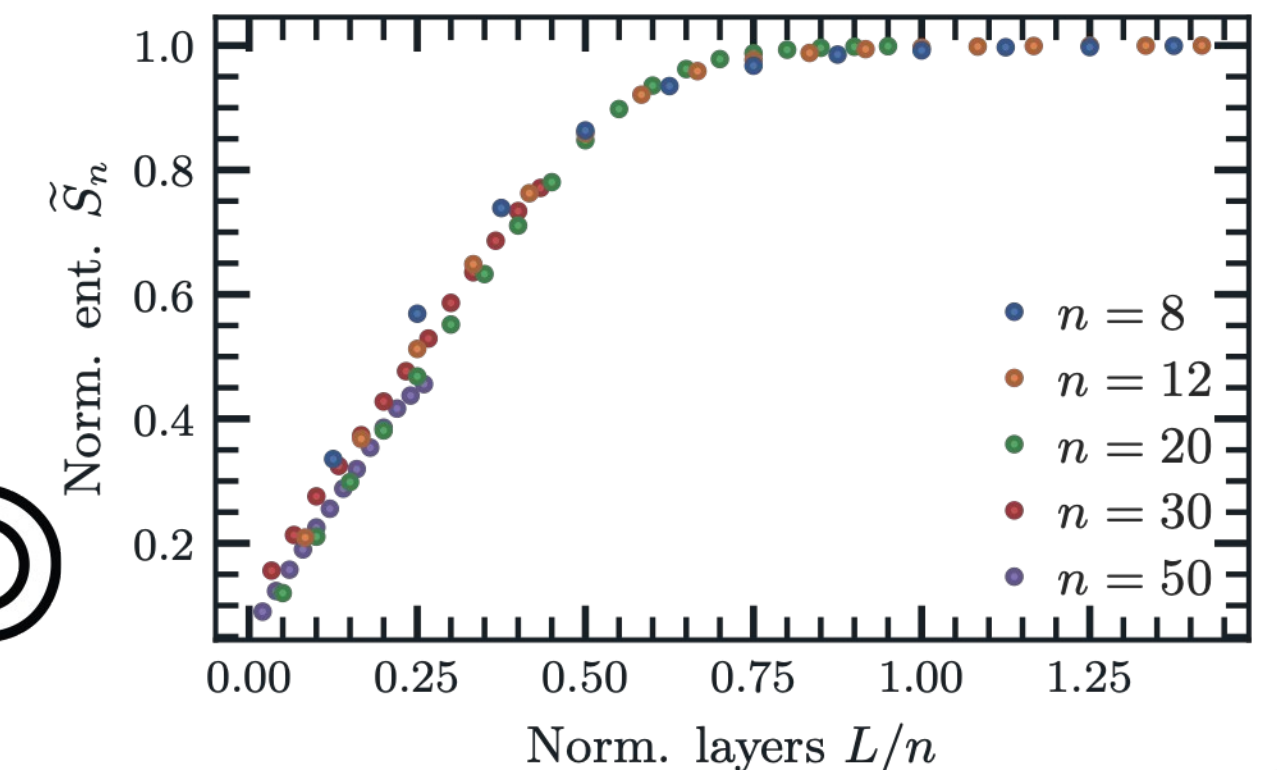




Entanglement entropy production in QNN

Ballarin, Marco, et al. arXiv:2206.02474

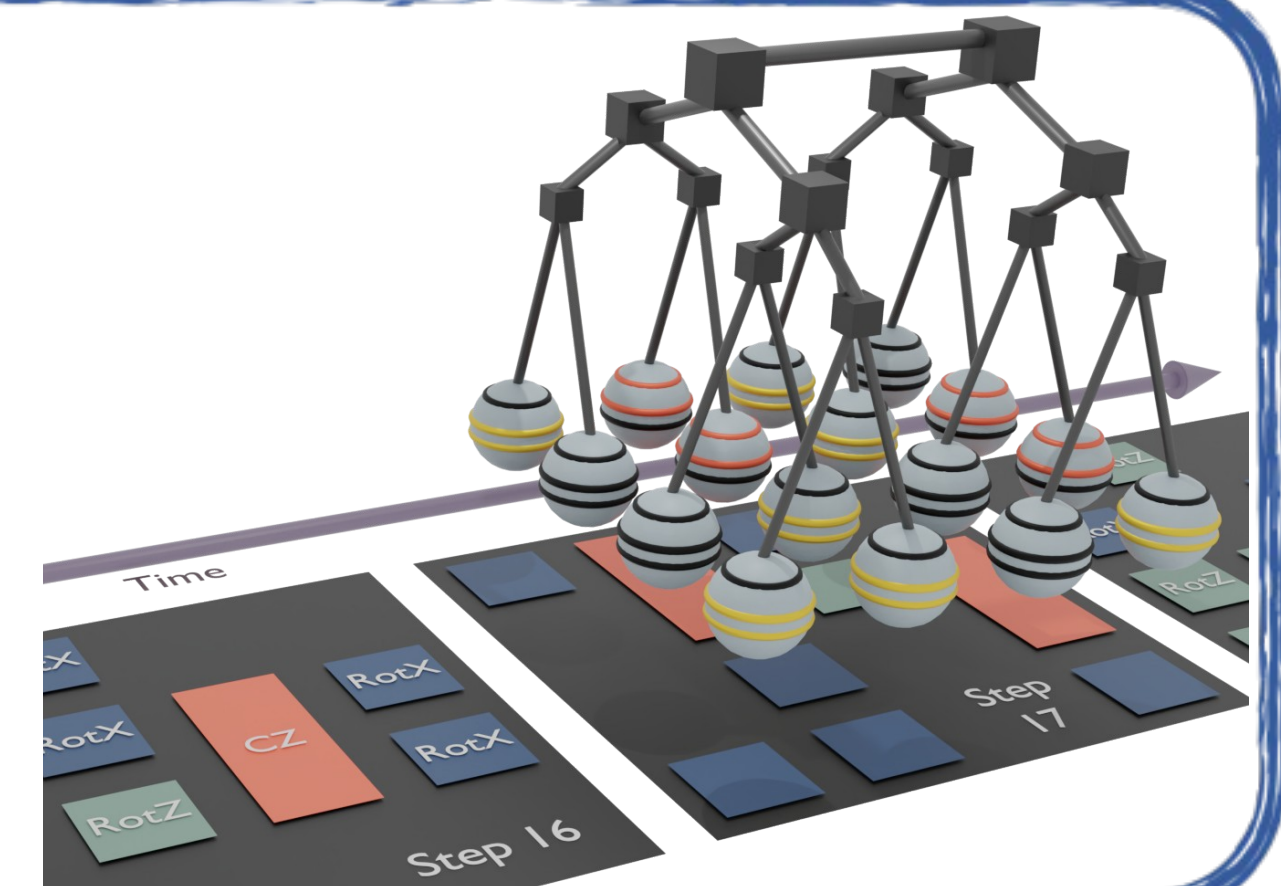
- Simulations up to 50 qubits
- Bond dimension of 4096
- 11h of runtime on Galileo100



Ab initio two-dimensional digital twin for quantum computer

Jaschke, Daniel, et al. arXiv:2210.03763

- Use of the unbiased sampling
- Quantum matcha tea simulations used as target state to compute the fidelity of a simulation with crosstalk



QuantumTEA Cloud Platform



- Prototype that provides the QuantumTEA's capabilities as Cloud Service
 - QuantumTEA-as-a-Service
 - based on Kubernetes running at CloudVeneto
- It is meant to be easily accessible
- It allows users to run quantum circuits with QuantumTEA without specific cloud computing skills

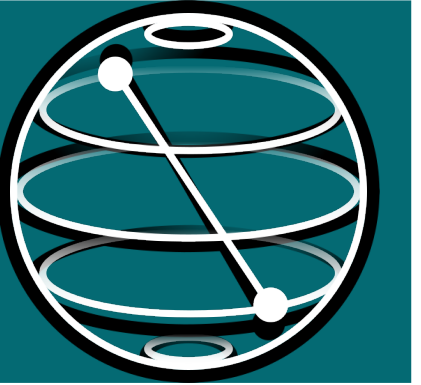


Quantum computing standards and Qiskit



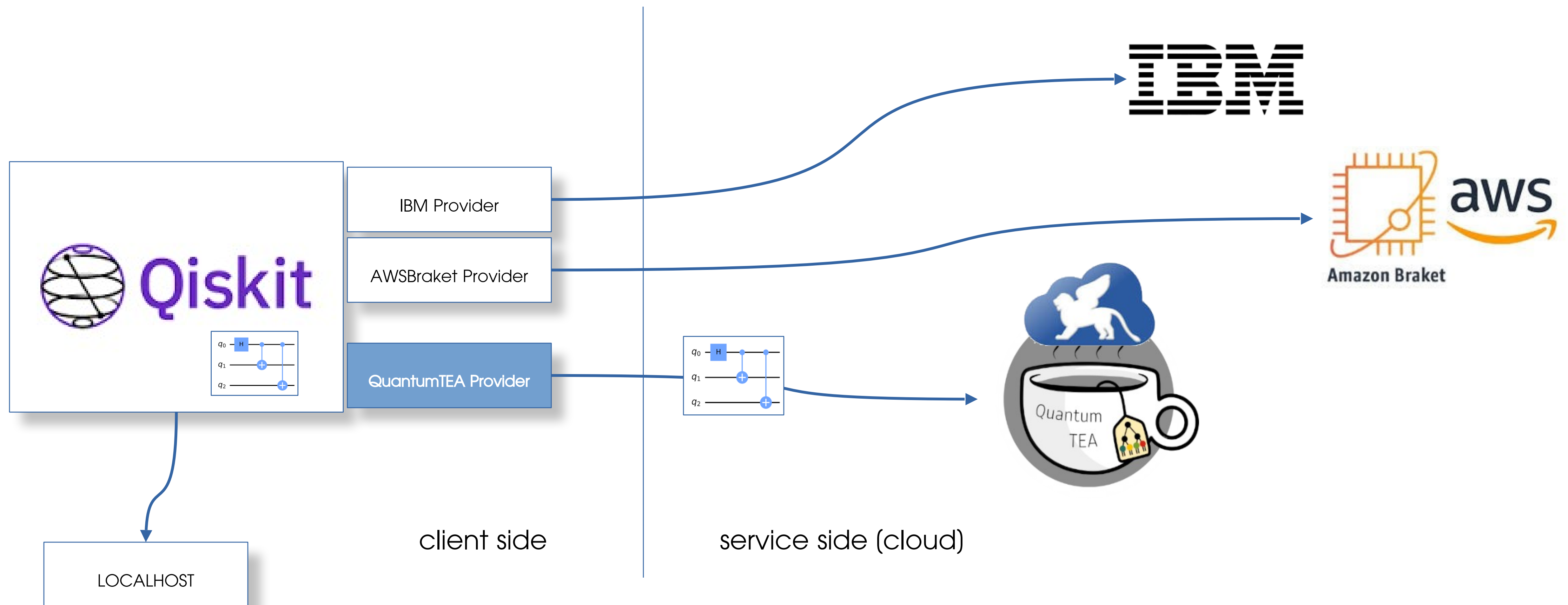
- No quantum computing standards exists
 - several technologies, APIs, provider specific
- **Qiskit** open source Python SDK developed by IBM
 - Qiskit provides tools for creating and manipulating quantum programs
 - and running them on
 - real quantum computers
 - simulators on a local computer or on a remote cloud service





Qiskit high level architecture

Users can take their existing algorithms written in Qiskit and, with a few lines of code, run them directly on different cloud platform including our QuantumTEA



QuantumTEA Qiskit provider implementation

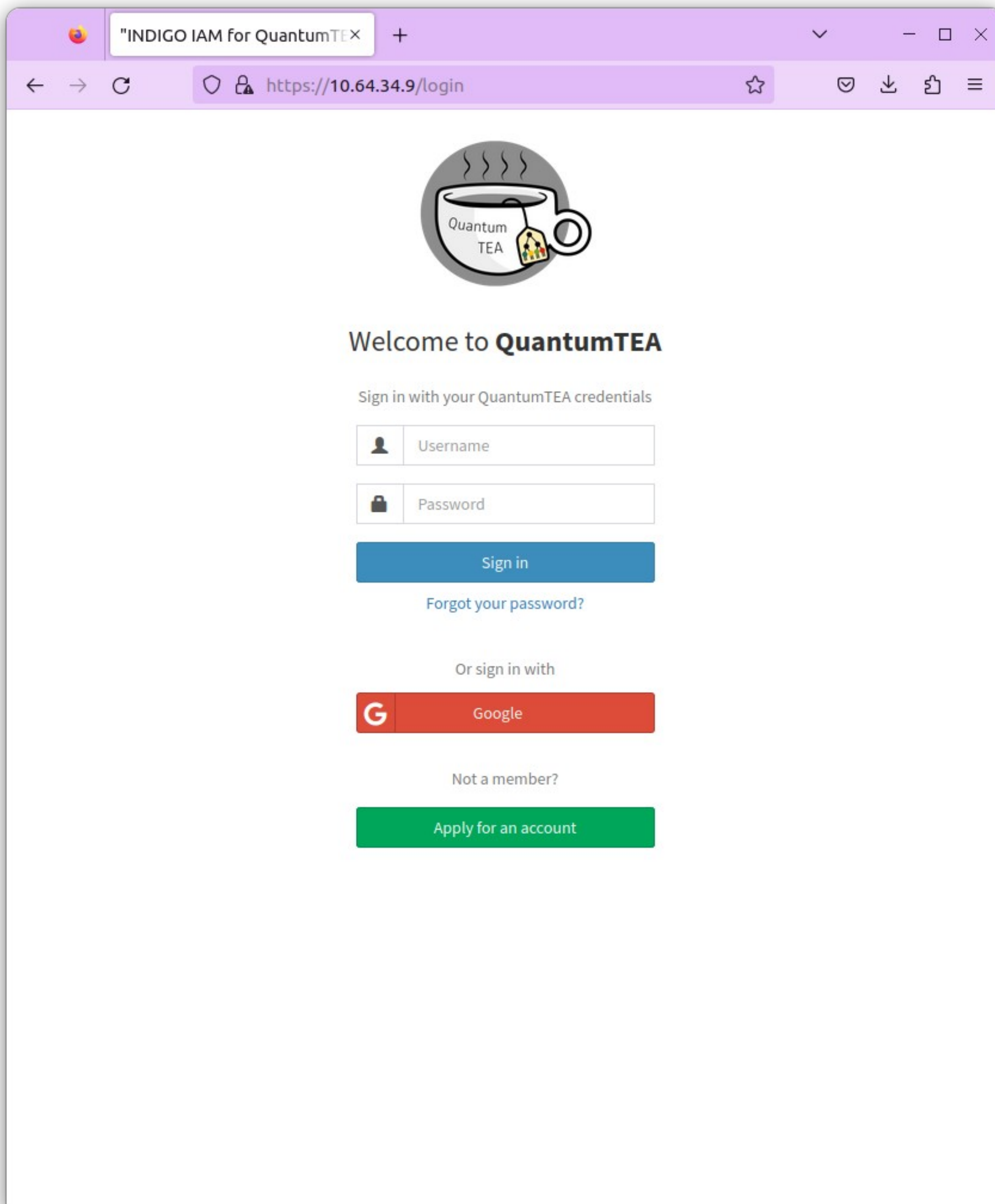
- QuantumTEA-qiskit-provider implements a set of Qiskit interfaces (qiskit.providers Python APIs)
 - **Provider** subclass that handles access to the backend(s)
 - handles backend objects that enable executing circuits on a device or simulator (initialization, authentication, etc)
 - **Backend** subclass and its run() method
 - provide the interface between Qiskit and the hardware or simulator that will execute circuits
 - run() method handles submitting the circuits to the backend to be executed and returning a Job object (involves serialization (JSON), low level communication layer (REST))
 - **Job** subclass that handles interacting with a running job
 - the output from the run() method

QuantumTEA Qiskit provider implementation

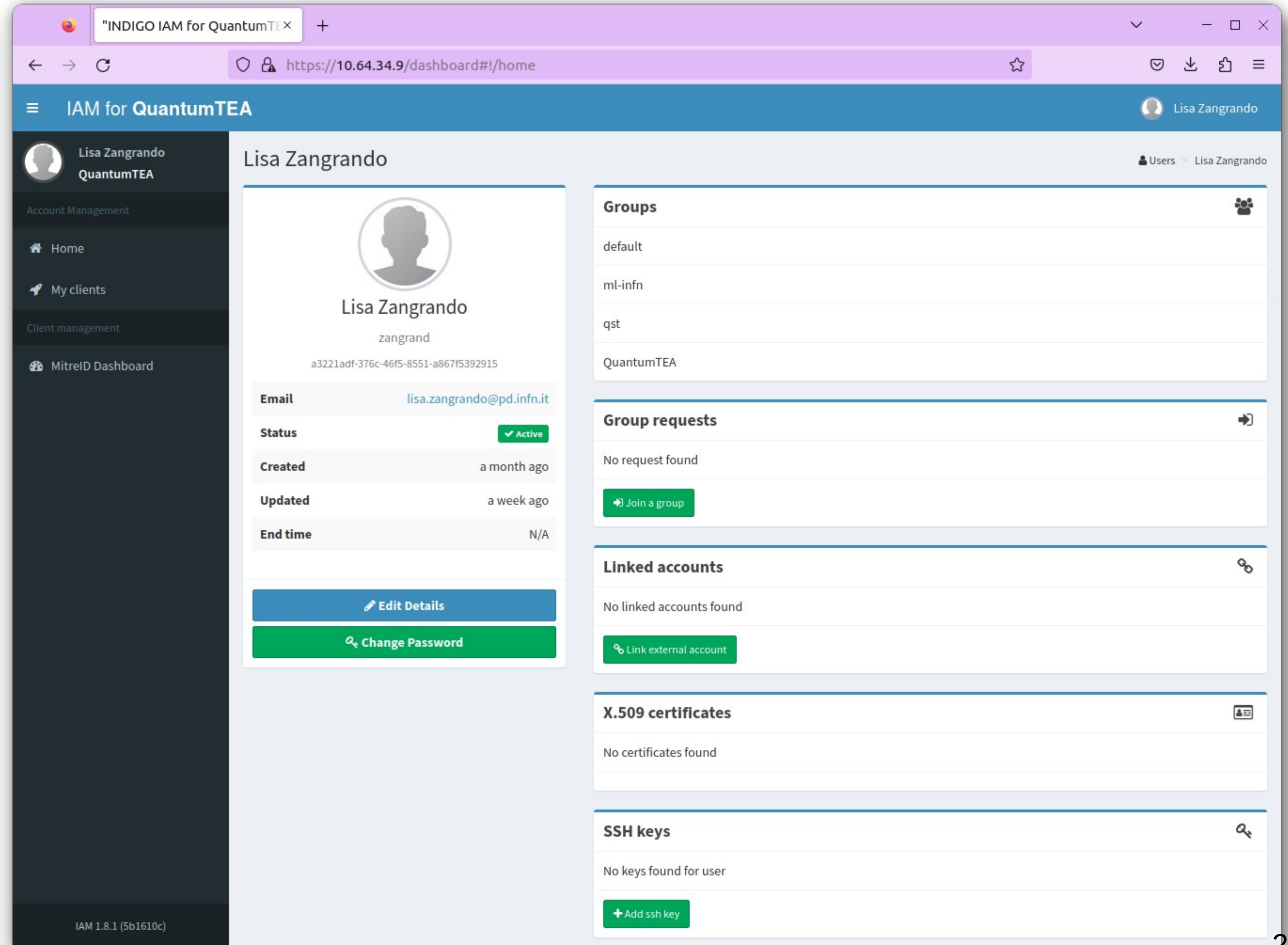
```
from qiskit import QuantumCircuit
from qt_provider import QuantumTeaProvider
# Create a Quantum Circuit acting on the q register
circuit = QuantumCircuit(2, 2)
# Add a H gate on qubit 0 and a CX (CNOT) gate on control qubit 0 and target qubit 1
circuit.h(0)
circuit.cx(0, 1)
# Map the quantum measurement to the classical bits
circuit.measure([0, 1], [0, 1])
# Create a new QuantumTeaProvider instance
qt_provider = QuantumTeaProvider(TOKEN)
# Get the "KubernetesBackend" backend
qt_backend = qt_provider.get_backend(name="QuantumMatchaTEA")
# Execute the circuit on the QuantumTea Cloud Platform
job = qt_backend.run(qc)
# Grab results from the job
result = job.result()
```

To access the QT service you need an
ACCESS TOKEN (IAM or Keystone)

Access Token from IAM

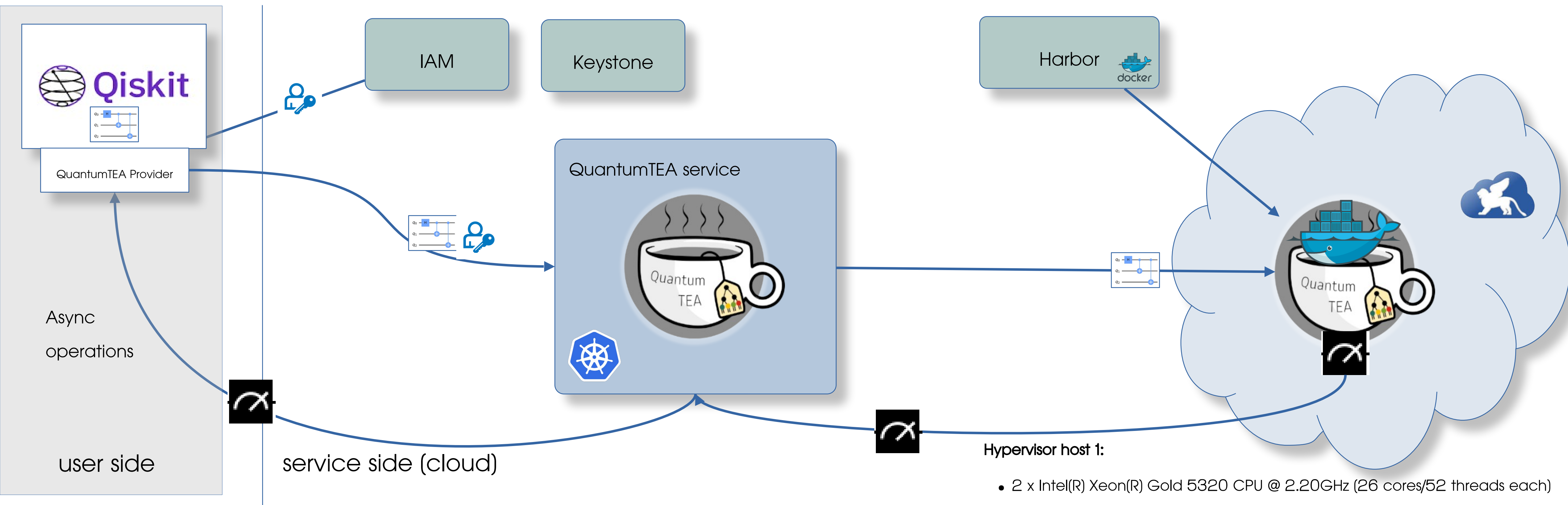


The screenshot shows the login page for QuantumTEA. At the top, there is a logo of a teacup with a tea bag and the text "Quantum TEA". Below the logo, it says "Welcome to QuantumTEA". There is a sign-in form with fields for "Username" and "Password", a "Sign in" button, and a link for "Forgot your password?". Below the form, there is a section for "Or sign in with" with a "Google" button. At the bottom, there is a link for "Not a member?" and a "Apply for an account" button. The browser address bar shows "https://10.64.34.9/login".



The screenshot shows the user dashboard for Lisa Zangrando. The page title is "IAM for QuantumTEA". The user's name "Lisa Zangrando" and email "zangrand" are displayed. The dashboard is divided into several sections: "Groups" (listing default, ml-infn, qst, and QuantumTEA), "Group requests" (No request found), "Linked accounts" (No linked accounts found), "X.509 certificates" (No certificates found), and "SSH keys" (No keys found for user). There are buttons for "Join a group", "Link external account", and "Add ssh key". The user's profile information includes a status of "Active", creation date of "a month ago", and update date of "a week ago". The browser address bar shows "https://10.64.34.9/dashboard#!/home".

QuantumTEA Cloud Platform high level architecture



Hypervisor host 1:

- 2 x Intel(R) Xeon(R) Gold 5320 CPU @ 2.20GHz (26 cores/52 threads each)
- 512 GB RAM
- 1 GPU NVIDIA A30

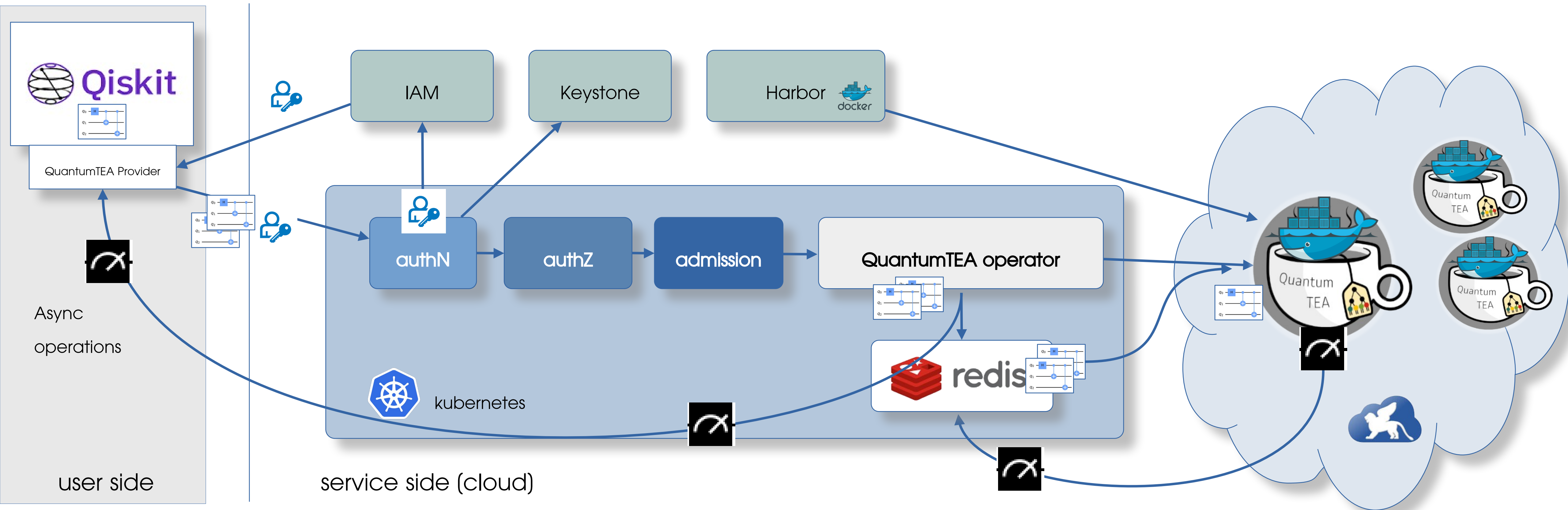
Hypervisor host 2:

- 2 x Intel(R) Xeon(R) Gold 6230R (26 cores/52 threads each)
- 512 GB RAM
- 1 GPU NVIDIA RTX A4000

QuantumTEA service

- validate the the user request (multiple circuits support)
- estimate the resources (RAM) needed by the docker container
- instantiate containers from our QuantumTEA docker image on K8s nodes (i.e. CloudVeneto Vms)
- monitor the execution and collect the results

QuantumTEA Cloud Platform architecture



QuantumTEA operator

- Implemented in GO
- QuantumTEAJob Custom Resource Definition (CRD)
- AuthN webhook: added support to IAM

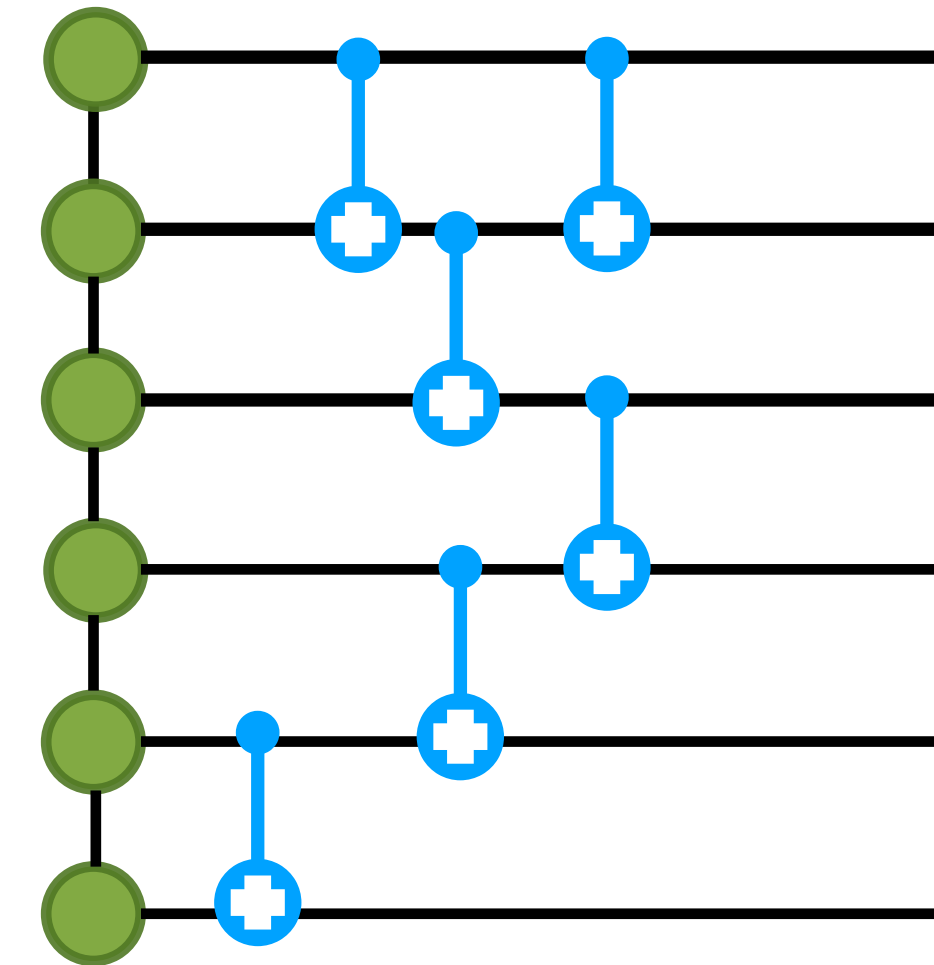
Redis datastore

- QuantumCircuit queue (one per job)
- Allow the execution of M circuits by N containers in parallel ($M \geq N$)
- Collect the results

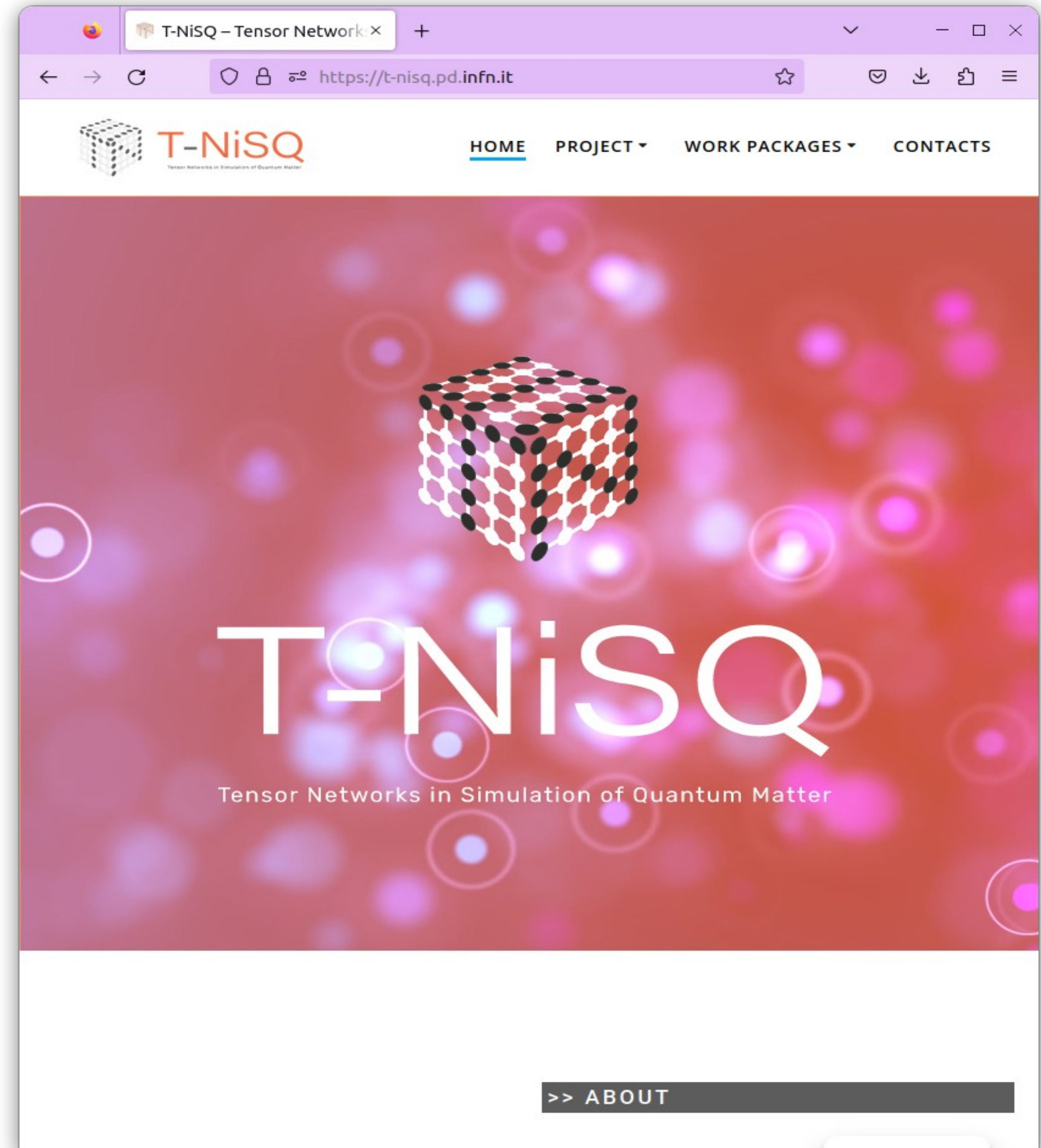
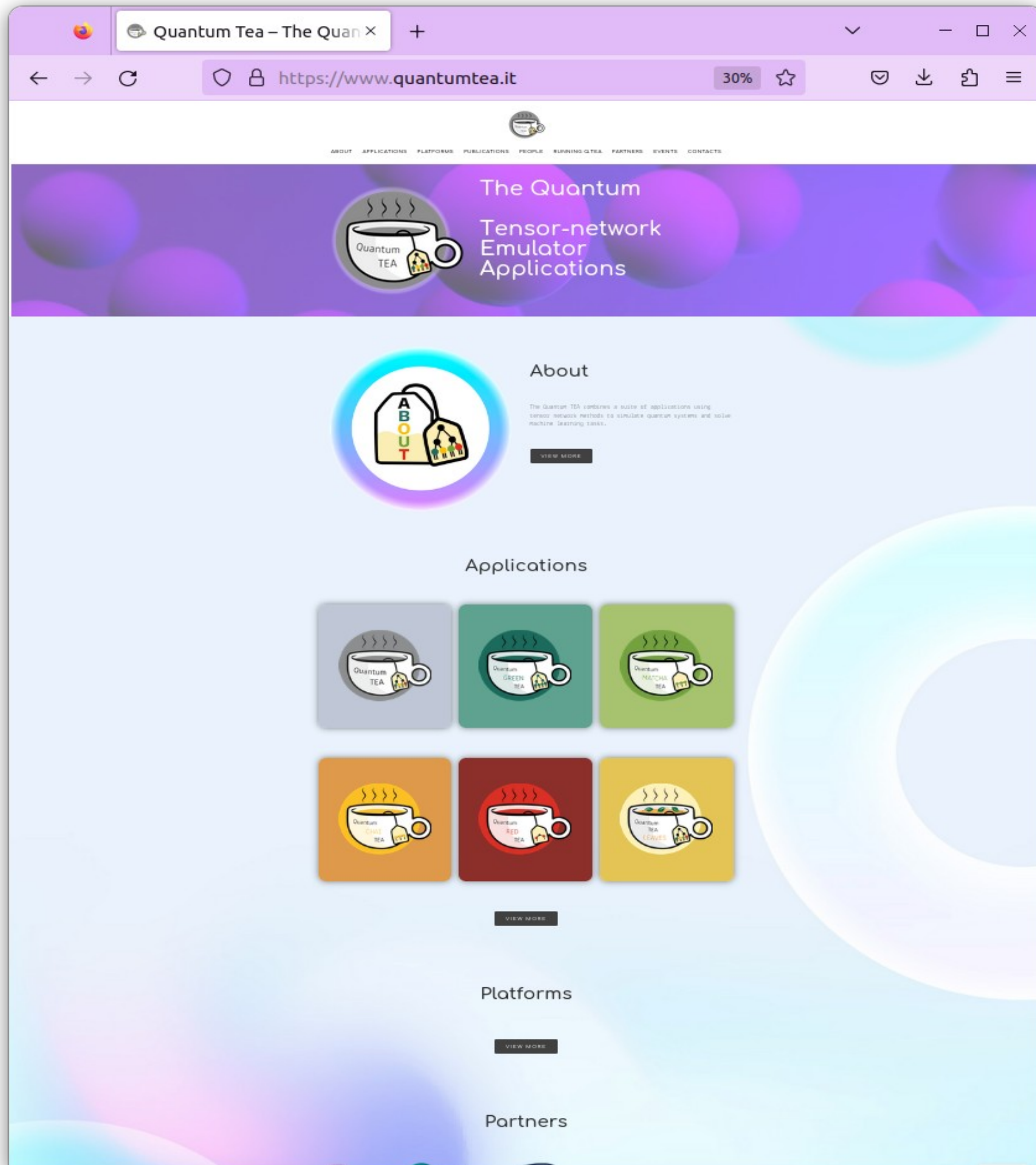
Outlook and next steps



- **QuantumTEA emulator:**
 - New tensor network ansatzes for the simulation;
 - Introduce and emulate noisy processes.
- **QuantumTEA Cloud Platform:**
 - Service not yet available to be tested by external users;
 - To move from prototype to production ready:
 - Improvement the user request validation;
 - simplify getting the token from IAM and test the integration;
 - user guide and units test;
 - stress tests with real use cases (complex circuits).



Our websites 1/2



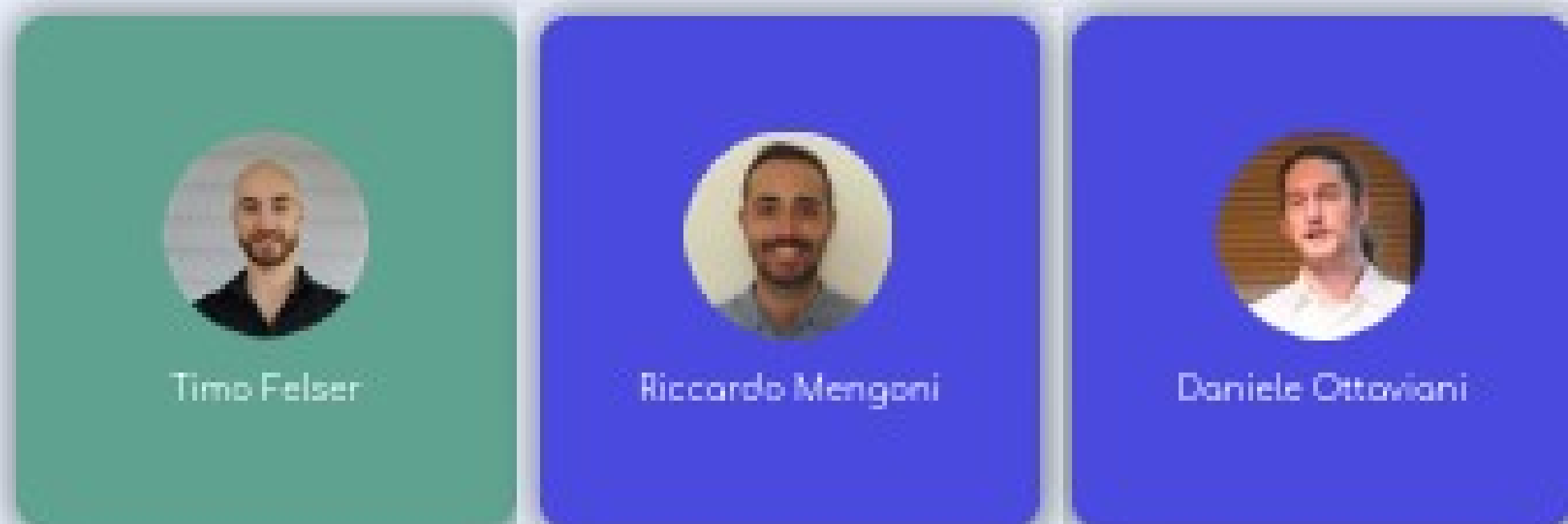
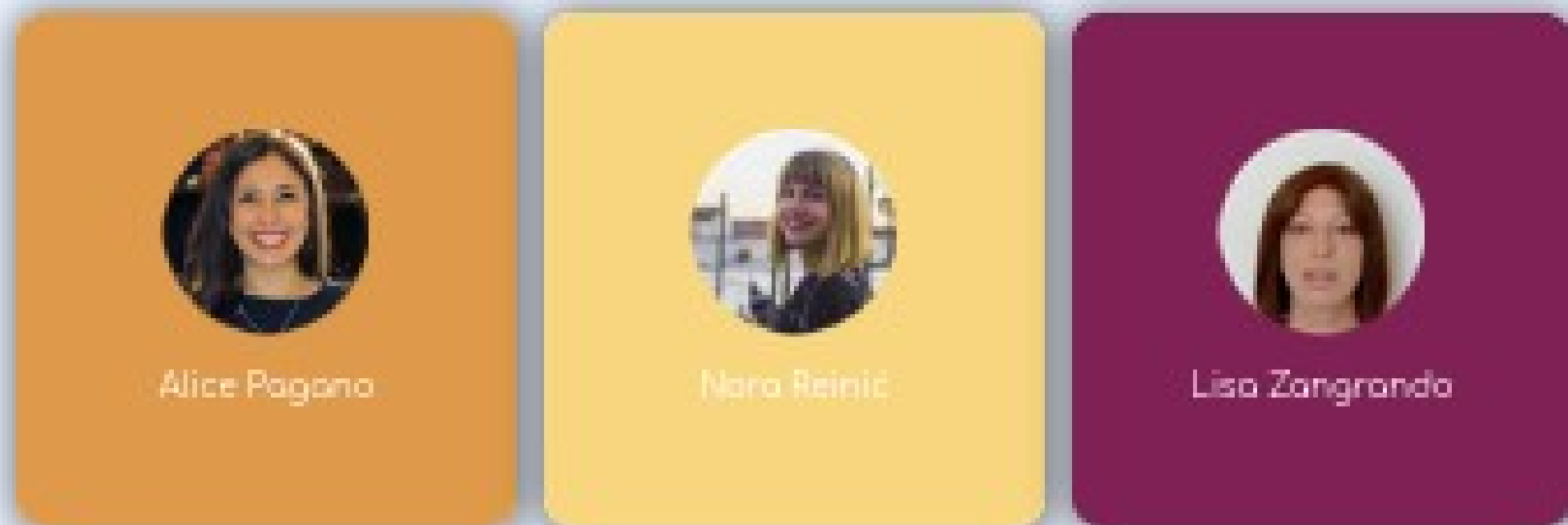
Our websites 2/2



The screenshot shows the homepage of the Quantum Computing and Simulation Center. The browser address bar displays <https://qsc.dfa.unipd.it>. The navigation menu includes Home, About, Partners, Governance, Working Groups, Activities, Resources, and Contacts. The main header features a large stylized 'Q' logo and the text "Quantum Computing and Simulation Center". Below this is an "About" section with a circular image of a quantum device and a "VIEW MORE" button. A "News" section follows, displaying four event cards: "TG2 – Weekend | Interview with Professor Montangero", "World Quantum Day 14 APRILE 2023", "Incontri introduttivi al Quantum Computing", and "Preliminary call for quantum computing projects".

The screenshot shows the homepage of the Quantum Information and Matter website. The browser address bar displays <https://quantum.dfa.unipd.it>. The navigation menu includes Home, About, Partners, Governance, Working Groups, Activities, Resources, and Contacts. The main header features a large stylized 'Q' logo and the text "Quantum Information and Matter". Below this is a "// UNIVERSITY OF PADUA" banner and a "Quantum Information and Matter" title. A sub-header reads "We develop and explore the applications of novel numerical and theoretical methods to quantum science and technologies." Below this are four navigation buttons: "publications", "seminars", "people", and "research". A "// news" section follows, with the text "Group activities, new members, publications and more" and four small images representing various activities.

Conclusions



QuantumTEA developers

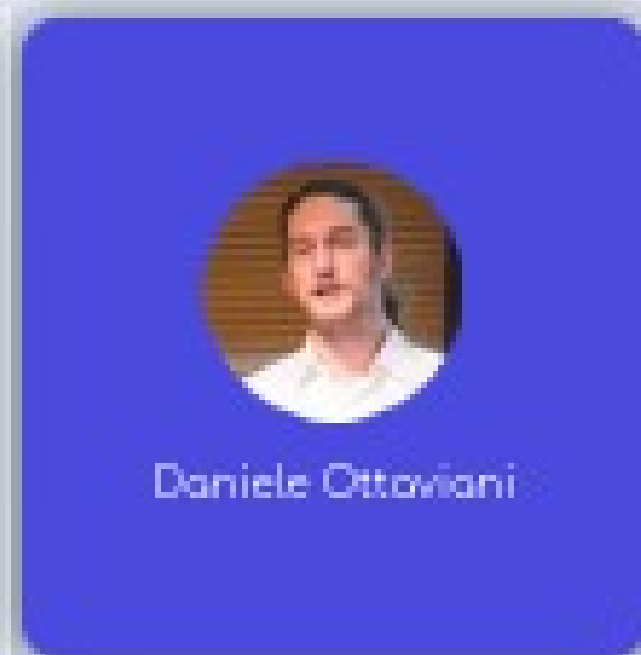
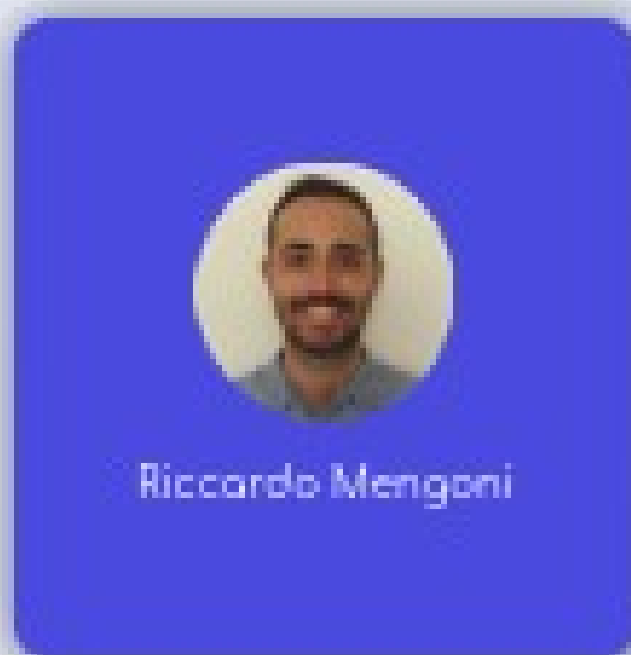
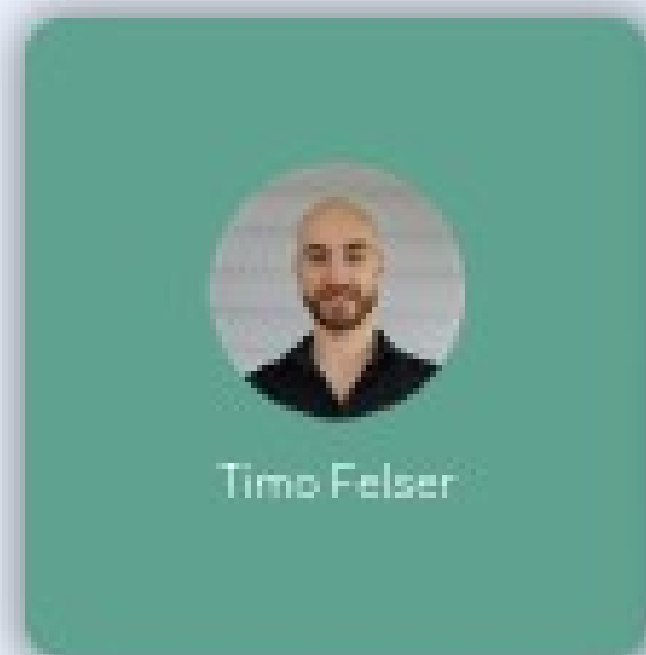
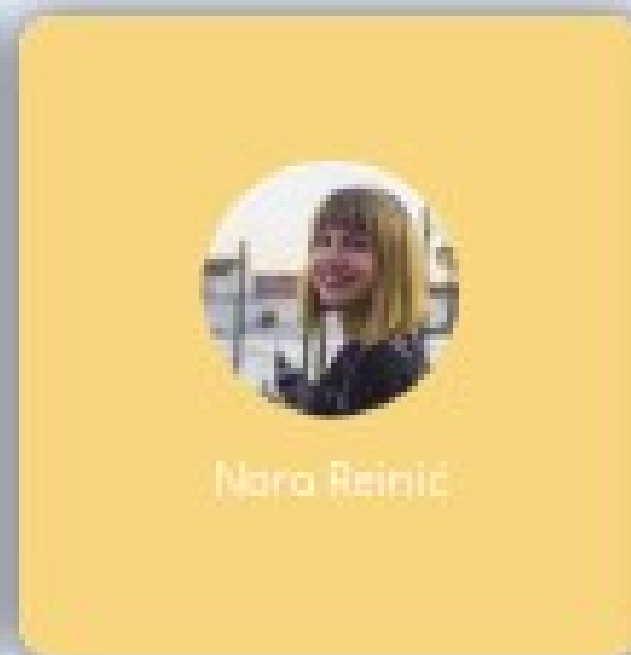
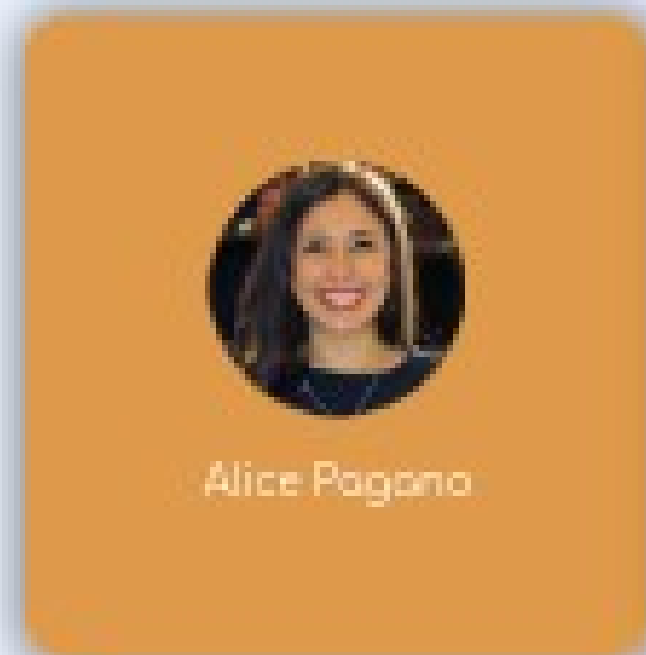
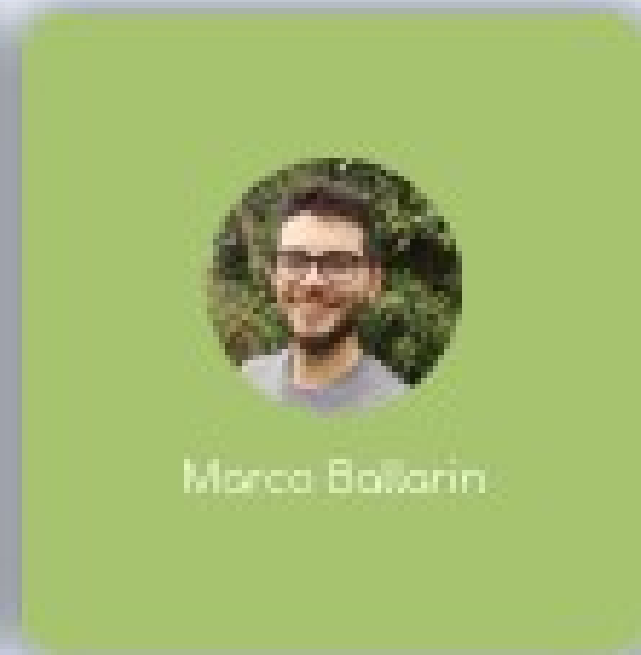
Documentation and source code on baltig.infn.it



Contact us:

- quantumtea@lists.infn.it
- quantumcomputer@dfa.unipd.it

Thank you!



QuantumTEA developers

Documentation and source code on baltig.infn.it



Thank you !



Contact us:

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Questions



QuantumTEA developers

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