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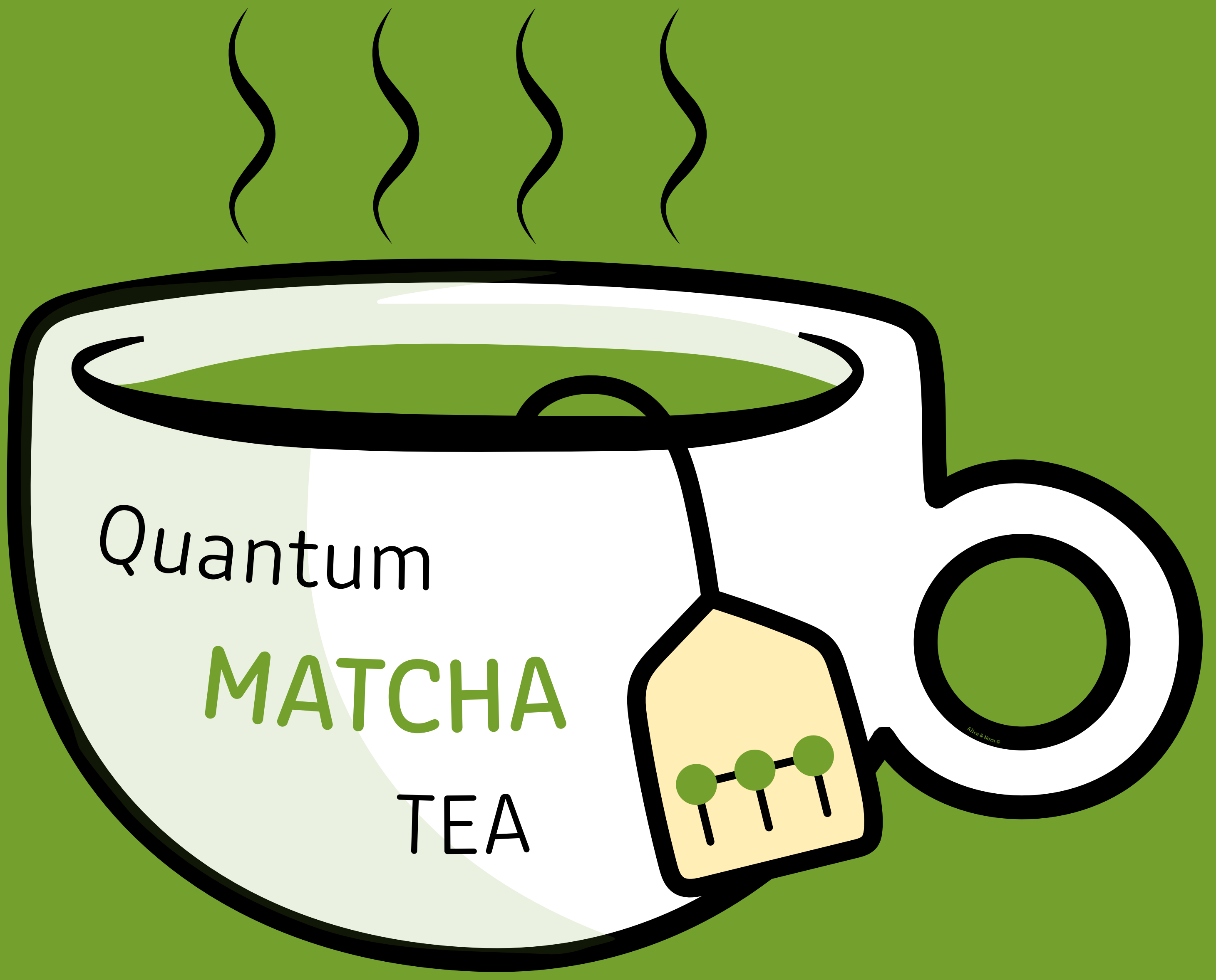
CENTER

QCSC Lecture
March 21 2023

Introduzione all’emulatore di calcolatore quantistico HPC

Quantum Matcha Tea

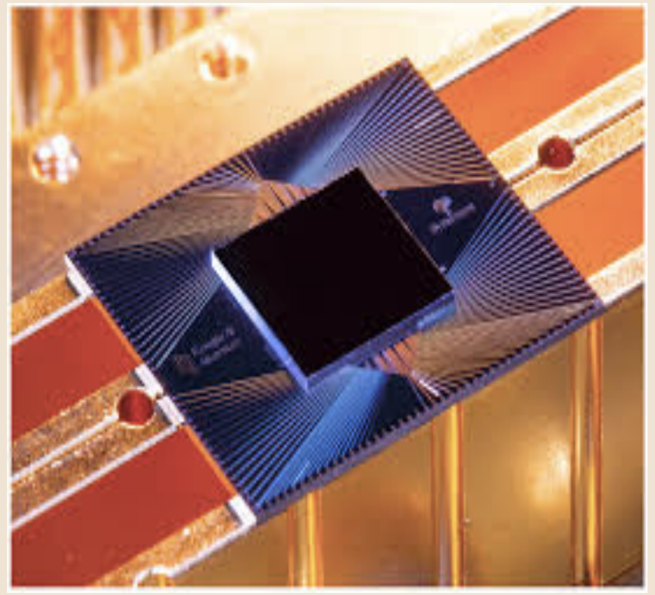


Marco Ballarin
Università degli studi di Padova

Running quantum algorithms

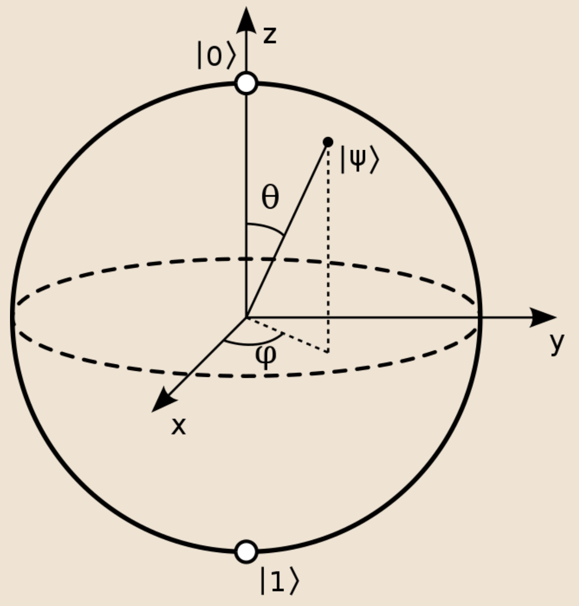
Also algorithms prepared for a quantum simulator can be digitised in quantum circuits

Quantum algorithm



+ Real hardware
- Noisy
- Limited number of qubits

Quantum hardware



+ Access to exact state
- Limited # of qubits

Exact simulator

Tensor Network simulator

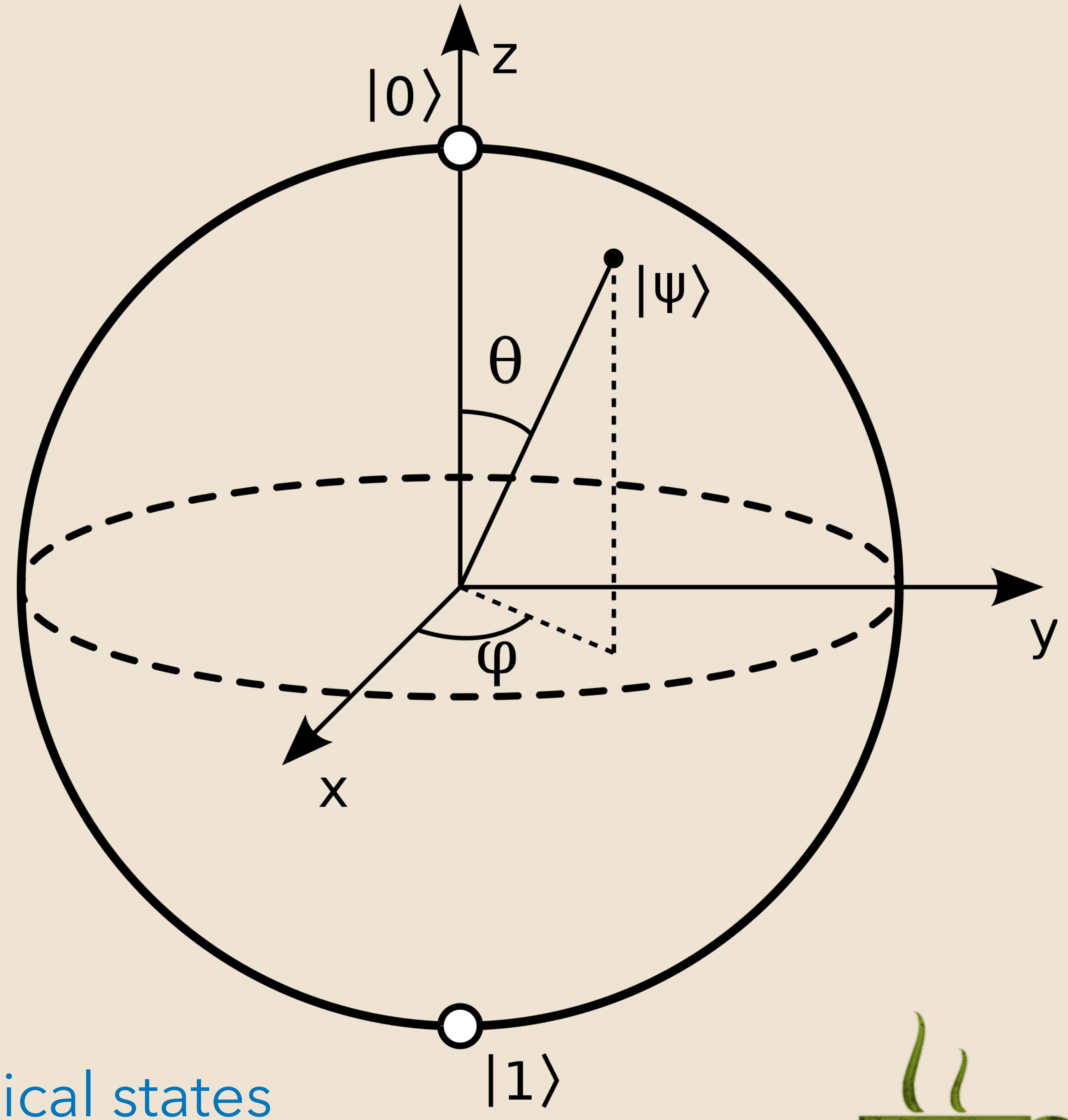
+ High # of qubits
- Limited entanglement

Quantum computation recap

QUBIT

Fundamental unit of quantum information

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \qquad \alpha, \beta \in \mathbb{C}, \quad |\alpha|^2 + |\beta|^2 = 1$$



Two qubit states

Number of coefficients scales as 2^n, n number of qubits

$$|\psi\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \eta|11\rangle$$

↓ Entangled states

$$|\psi\rangle = \alpha|00\rangle + \beta|11\rangle$$

Cannot be written as classical states

⇒ display quantum correlation

Entanglement and compression

We can represent a subset efficiently

Memory requirement $\propto 2^n$

?

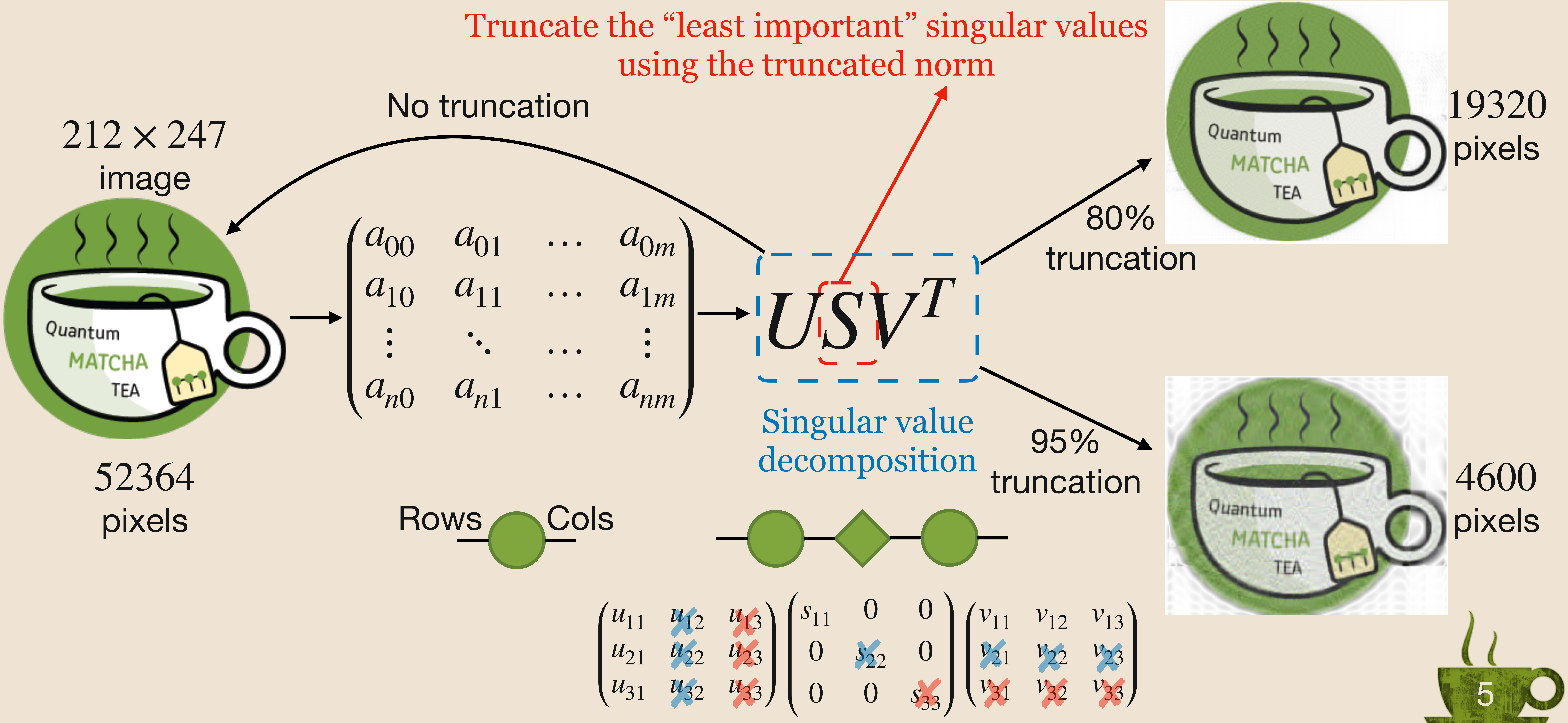
Possible compression quantified by Shannon entropy

Classical bit string

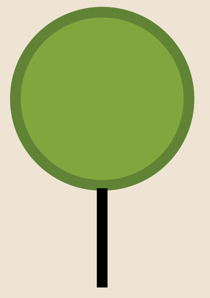
	0000	0011	RANDOM
	Optimal Compression	Here we can compress something. The quantum state is **entangled**, it cannot be written as classical state	No compression possible without approximations
Quantum state	$\|0000\rangle$	$\frac{1}{\sqrt{2}}\left(\|0000\rangle + \|1111\rangle\right)$	$\|\text{RANDOM}\rangle$

Possible compression quantified by Von Neumann **entanglement** entropy

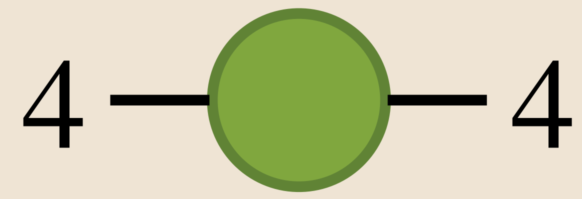
Image compression through SVD

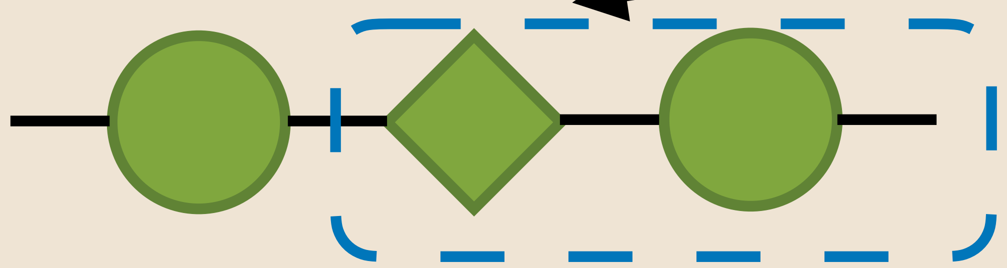


Compressing a 4-qubits state



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



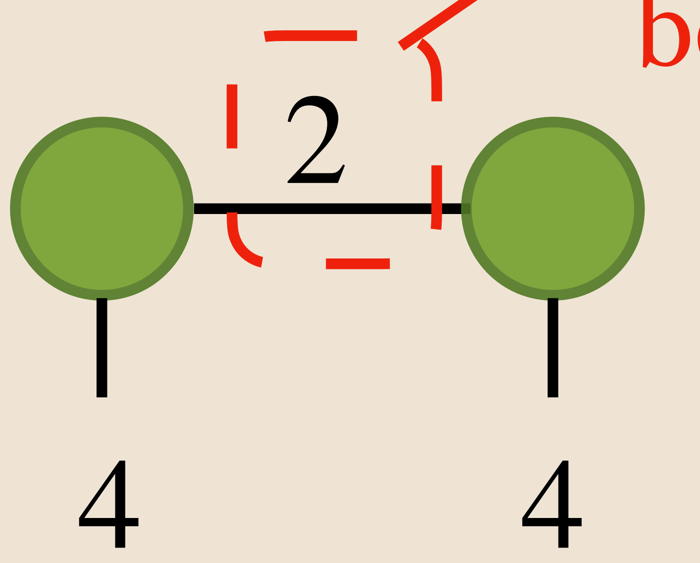


Matrix multiplication

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

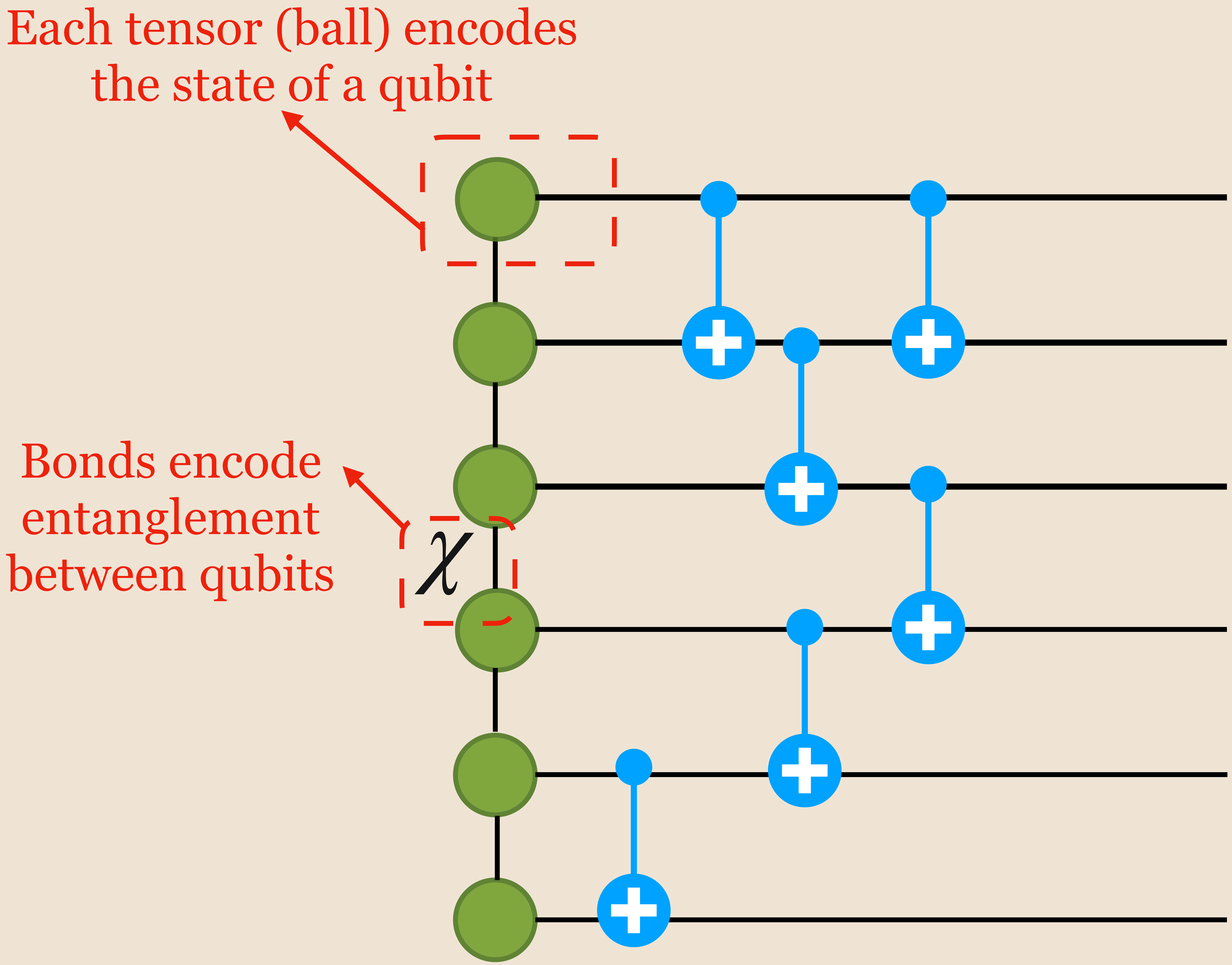
$4 \rightarrow 2$

$\longrightarrow$



Bond dimension encode entanglement between qubits

Matrix product states

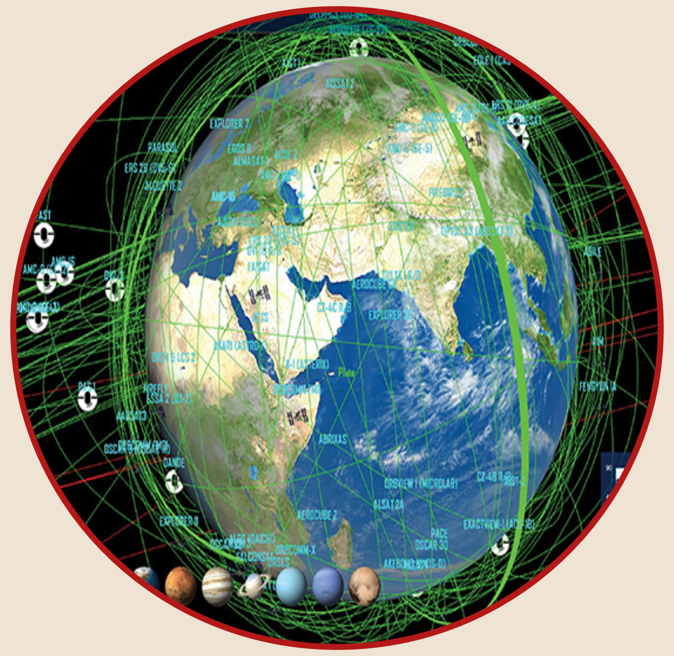


Memory requirements

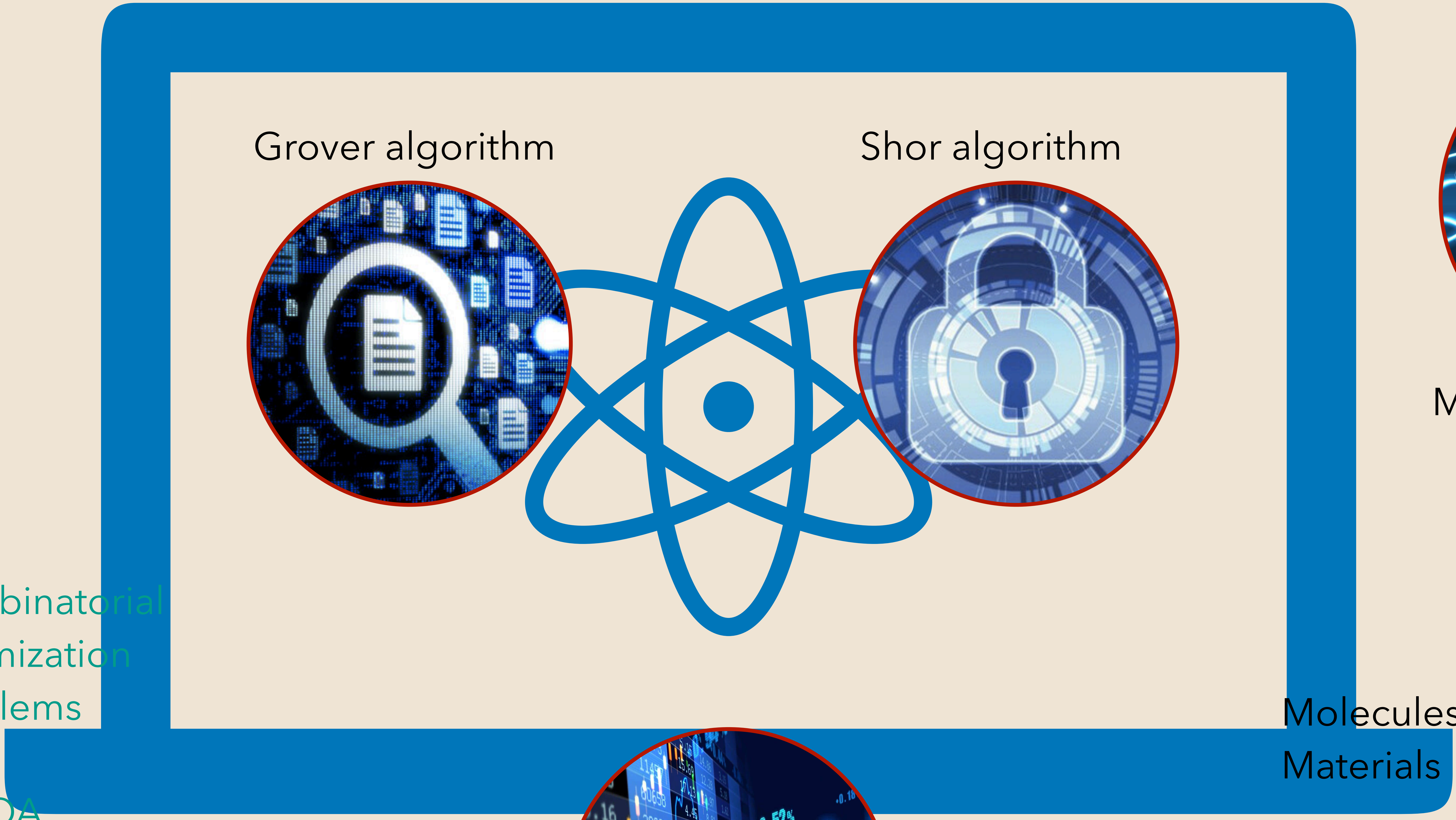
$$O(2^n) \rightarrow O(2n\chi^2)$$

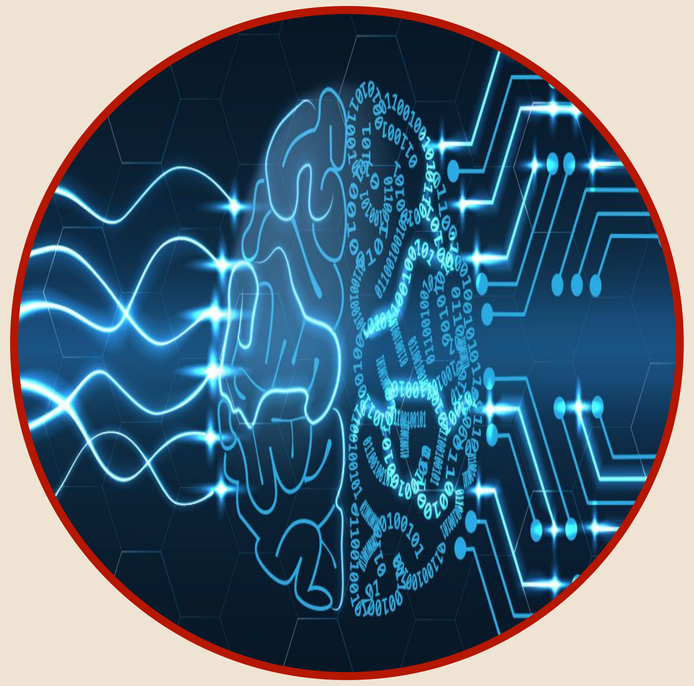
MPS SIMULATIONS ARE NOT LIMITED BY THE NUMBER OF QUBITS BUT BY THE ENTANGLEMENT

Quantum algorithms



Earth Observation





Machine Learning

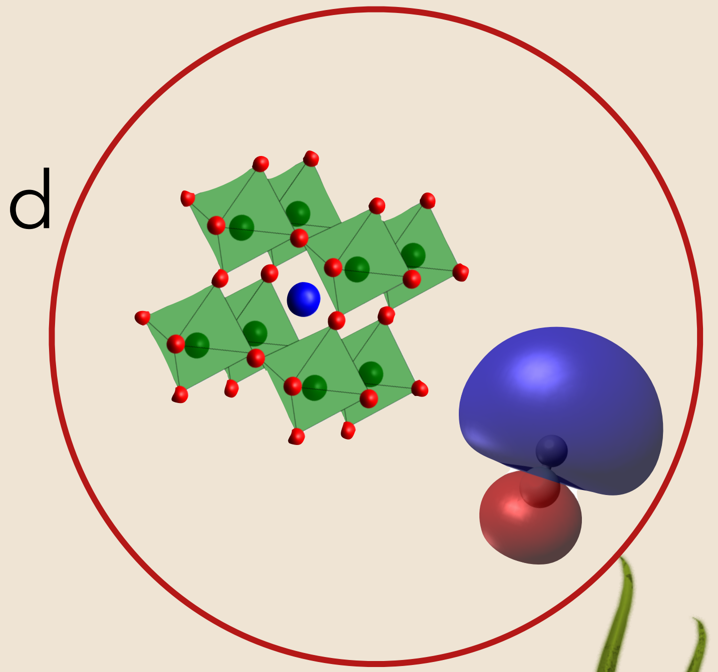
Traffic

Combinatorial optimization problems

(QAOA, quantum annealing, …)

Portfolio optimization

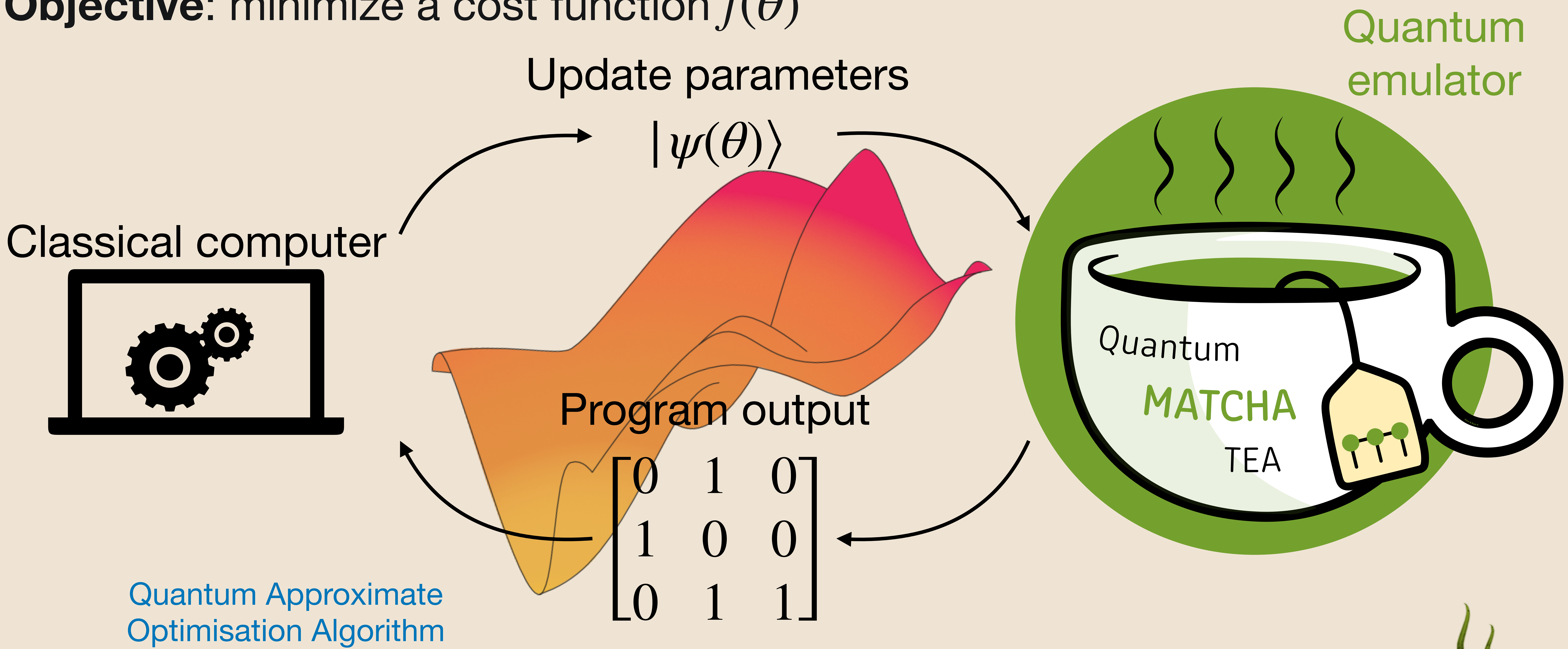
Molecules and Materials



(VQE, quantum deflation, …)

Hybrid quantum optimisation algorithms

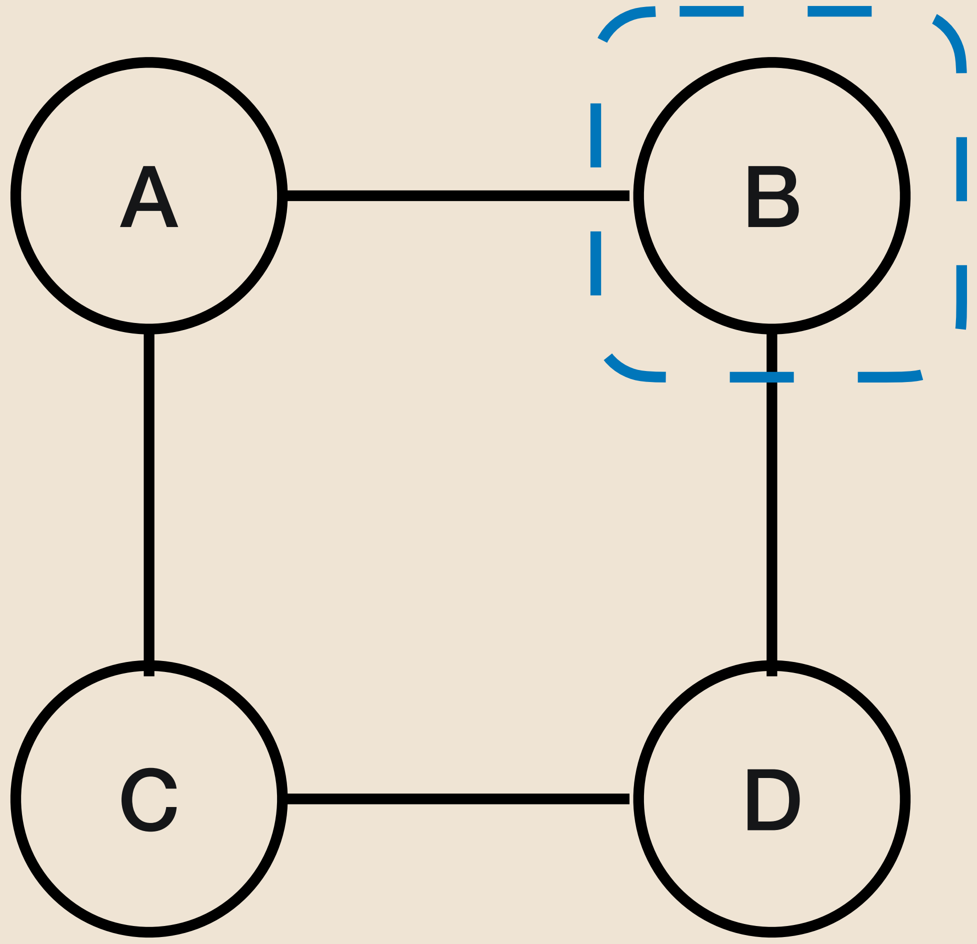
- **Objective**: minimize a cost function $f(\theta)$



- **Example**: QAOA, inspired by Quantum Annealing (see DWave lecture)

Graph colouring problem

- Assign a color to each node
- Connected nodes should have different colours



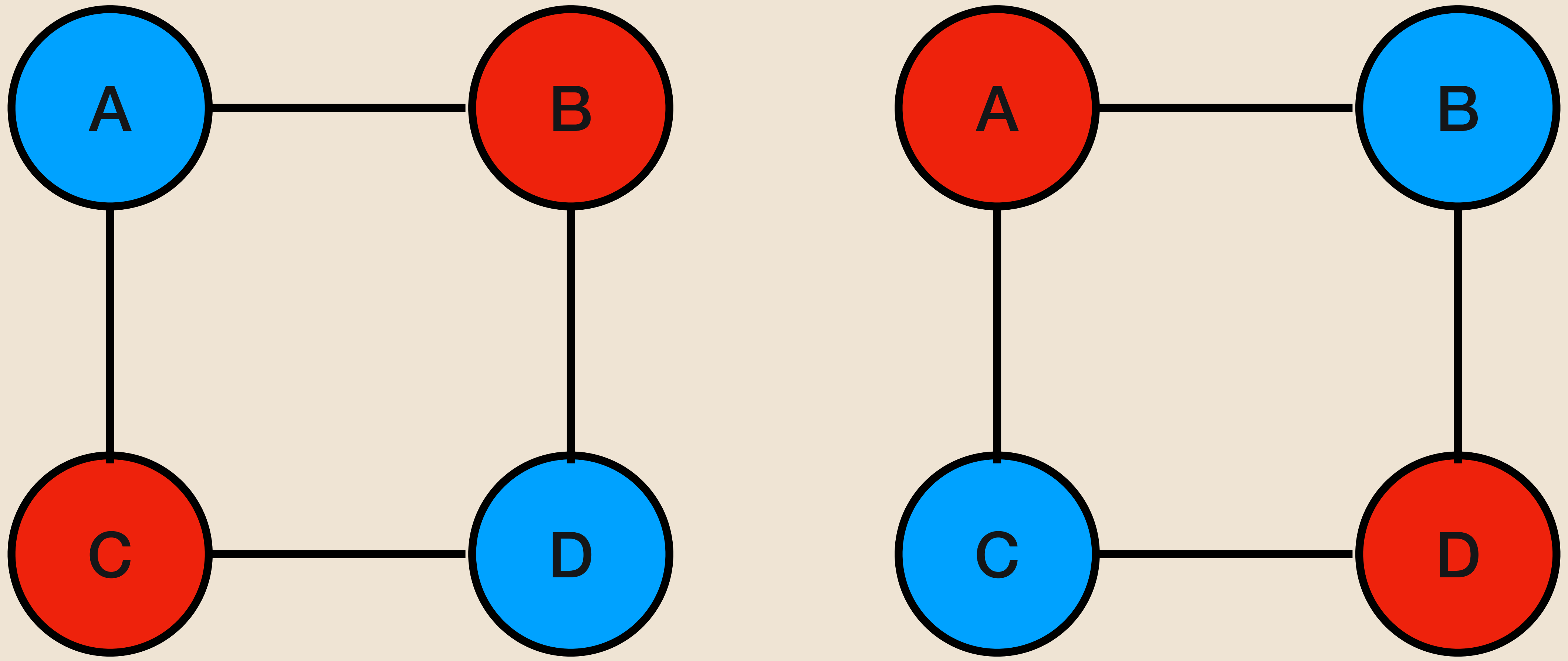
Each node is represented with binary variables:

- $|10\rangle$ blue
- $|01\rangle$ red

(One hot encoding)

Example task: colouring maps

Solutions

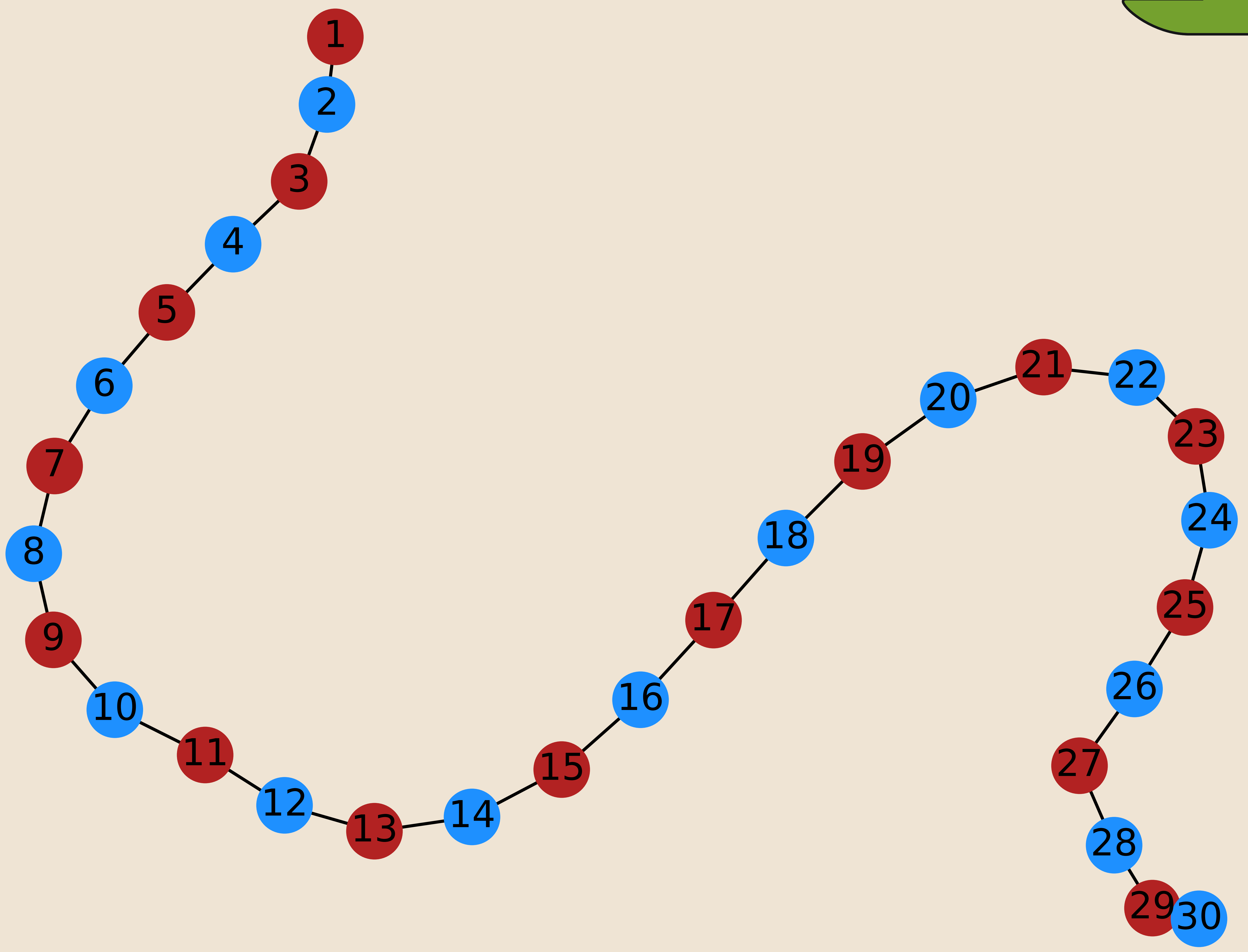


Conclusions

MPS simulations are not limited by the number of qubits but by the entanglement

Easy-to-use python frontend and fast HPC-ready backend (Both GPU and CPU)

Error analysis tools and efficient computations of observables optimised for the MPS representation



Thanks for your attention

Dipartimento di Fisica e Astronomia Galileo Galilei

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QUANTUM COMPUTING AND SIMULATION CENTER

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World Quantum Day
in Padova

14 Aprile 2023
Centro Universitario
Via Zabarella 82

Edizione 1

PROGRAMMA

DALLE 14:00
FROM
ALLE 19:30
TO

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LABORATORIO D'ARTE
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...AND MORE

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WQD APRIL 14