ISO Presentation

Quantum Programming

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6 May 2020

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Plan

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Quantum Computing applied to Machine Learning

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Real-world problem overview

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- Can we predict whether user j will like product k? Can we **recommend** a product to this user?

Mathematical description

Binary recommendation system

Let $\mathbf{P} \in \{0\,;\,1\}^{m \times n}$, whose coefficients are known with a given probability. A quantum recommendation system, given $\hat{\mathbf{P}}$ the incomplete representation of $\mathbf{P}$ and an user j, predicts k such that $\mathbf{P}_{j,k} = 1$ with high probability.

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Problem statement

How does the real-world implementation of the Quantum Recommendation System algorithm differs from its theoretic implementation?

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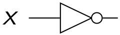

(a) NOT gate

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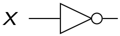

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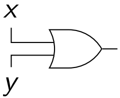

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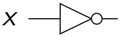

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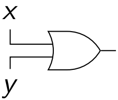

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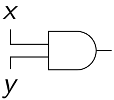

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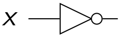

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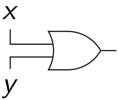

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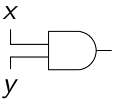

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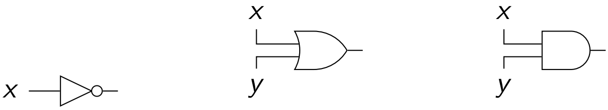

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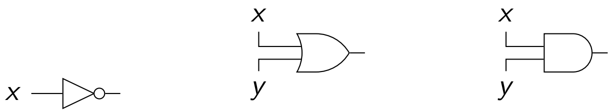

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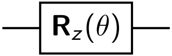

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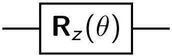

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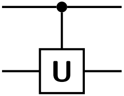

(b) A controlled gate

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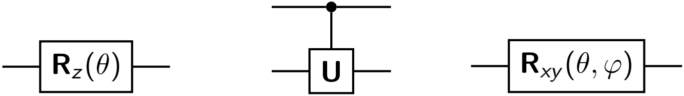

(a) The $\mathbf{R}_z(\theta)$ gate **(b)** A controlled gate **(c)** The $\mathbf{R}_{xy}(\theta, \varphi)$ gate

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A qubits-string is called a **quantum register**.

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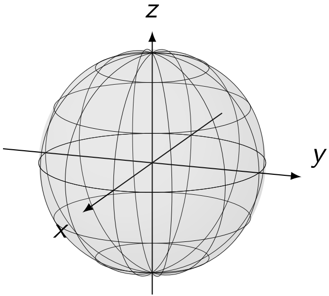

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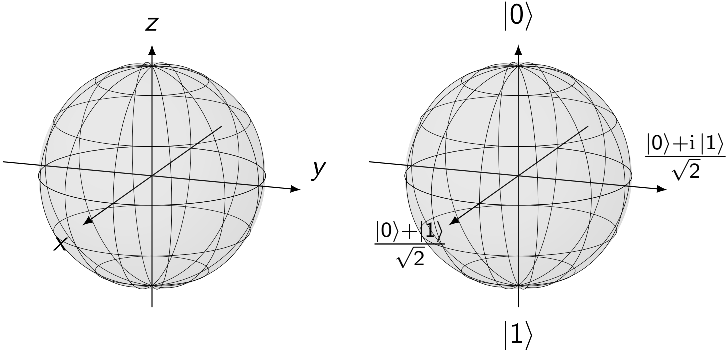

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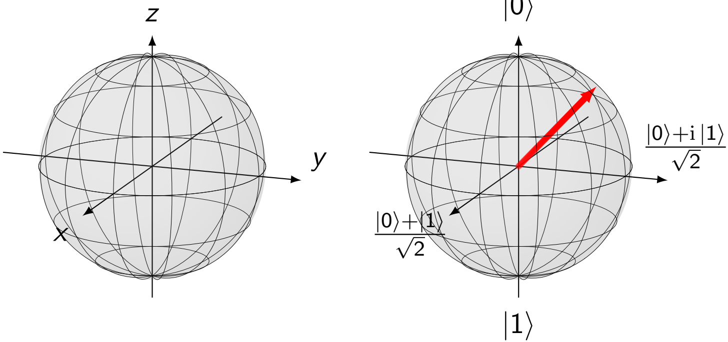

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- Possibility to get a probabilistic view of a qubit at the price of forcing it into a certain state. Measurement destroys information.

Plan

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Let $\mathbf{x} \in \mathbf{R}^n$ be a normalized vector. Then, its associated quantum state is:

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Loading $\mathbf{x}$ means creating $|x\rangle$ from $|0\rangle^{\otimes \lceil \log_2(n) \rceil}$ with a polylogarithmic number of gates in n[3].

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QRAM[4]

A QRAM is a binary tree whose leaves store the coefficients of a vector $\mathbf{x}$ and whose nodes stores the sum of its leaves values.

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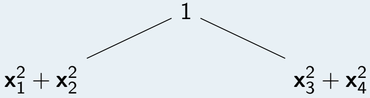

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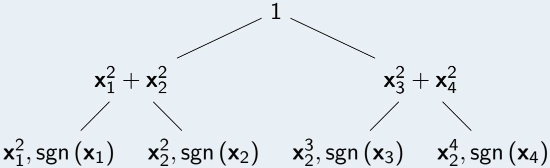

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Parallel execution

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$$\mathbf{L}\ |\theta_k\rangle\ |x\rangle\ |\text{target}\rangle = \begin{cases} |\theta_k\rangle\ |x\rangle\ \mathbf{R}_y\left(\theta_k\right)|\text{target}\rangle & \text{if } |x\rangle = |k\rangle \\ |\theta_k\rangle\ |x\rangle\ |\text{target}\rangle & \text{otherwise} \end{cases}.$$

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Parallel execution of rotations

It is possible to get the state $|\theta\rangle \, \mathrm{e}^{\mathrm{i}\,\theta} \, |x\rangle$ from the state $|\theta\rangle \, |x\rangle$

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The z-rotation

Given an angle θ, the rotation around the z-axis of the Bloch sphere is given by the gate:

$$\mathbf{R}_z(\theta) = \begin{pmatrix} 1 & 0 \\ 0 & \mathrm{e}^{\mathrm{i}\,\theta} \end{pmatrix} .$$

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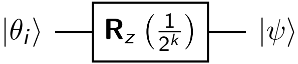

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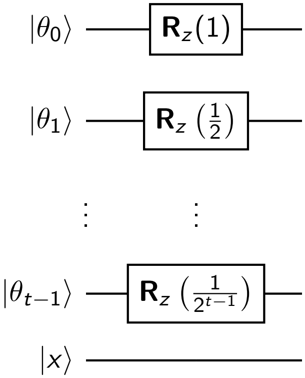

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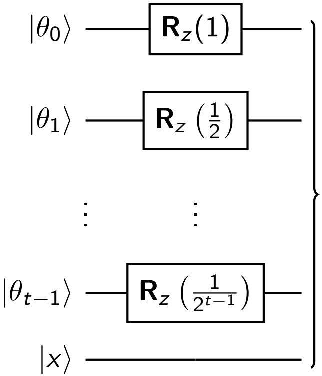

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Parallel execution of controlled z-rotations

As a recall:

> *Parallel execution of controlled rotations consists in applying on the target qubit a rotation around the y-axis of angle θ_k only if the first quantum register is in state $|k\rangle$ in time constant with respect to n.*

Parallel execution of controlled z-rotations

As a recall:

> *Parallel execution of controlled rotations consists in applying on the target qubit a rotation around the y-axis of angle θ_k only if the first quantum register is in state $|k\rangle$ in time constant with respect to n.*

Applying the z-rotation gates in the previous circuit applies a rotation on the target qubit around the z-axis of angle θ_k in time $O(1)$.

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> *Parallel execution of controlled rotations consists in applying on the target qubit a rotation around the y-axis of angle θ_k only if the first quantum register is in state $|k\rangle$ in time constant with respect to n.*

Applying the z-rotation gates in the previous circuit applies a rotation on the target qubit around the z-axis of angle θ_k in time $O(1)$.

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Is it possible to transform a y-rotation into a z-rotation of the same angle?

Converting a z-rotation to a y-rotation

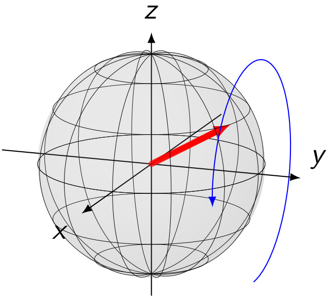

Figure: An example of a transformation of a y-rotation into a z-rotation

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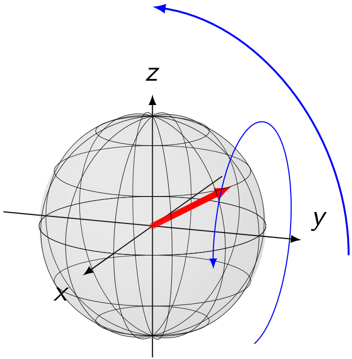

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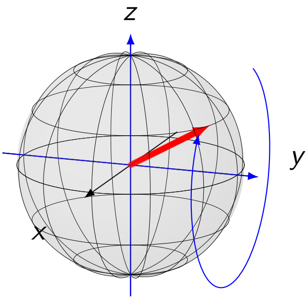

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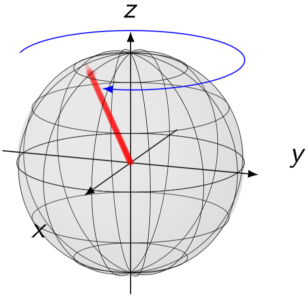

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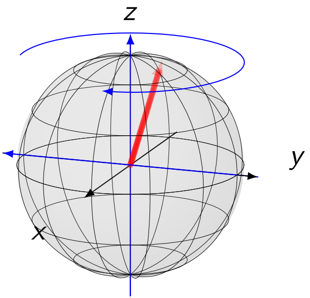

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Plan

Errata

- It **is** possible to apply Quantum Phase Estimation without measuring

Errata

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Plan

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Conclusion

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- Error-correction, number of qubits, $\cdots$

References I

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