DEPARTMENT OF INFORMATION ENGINEERING

Quantum programming Lab

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Part of the course in

Quantum Computing and Quantum Internet

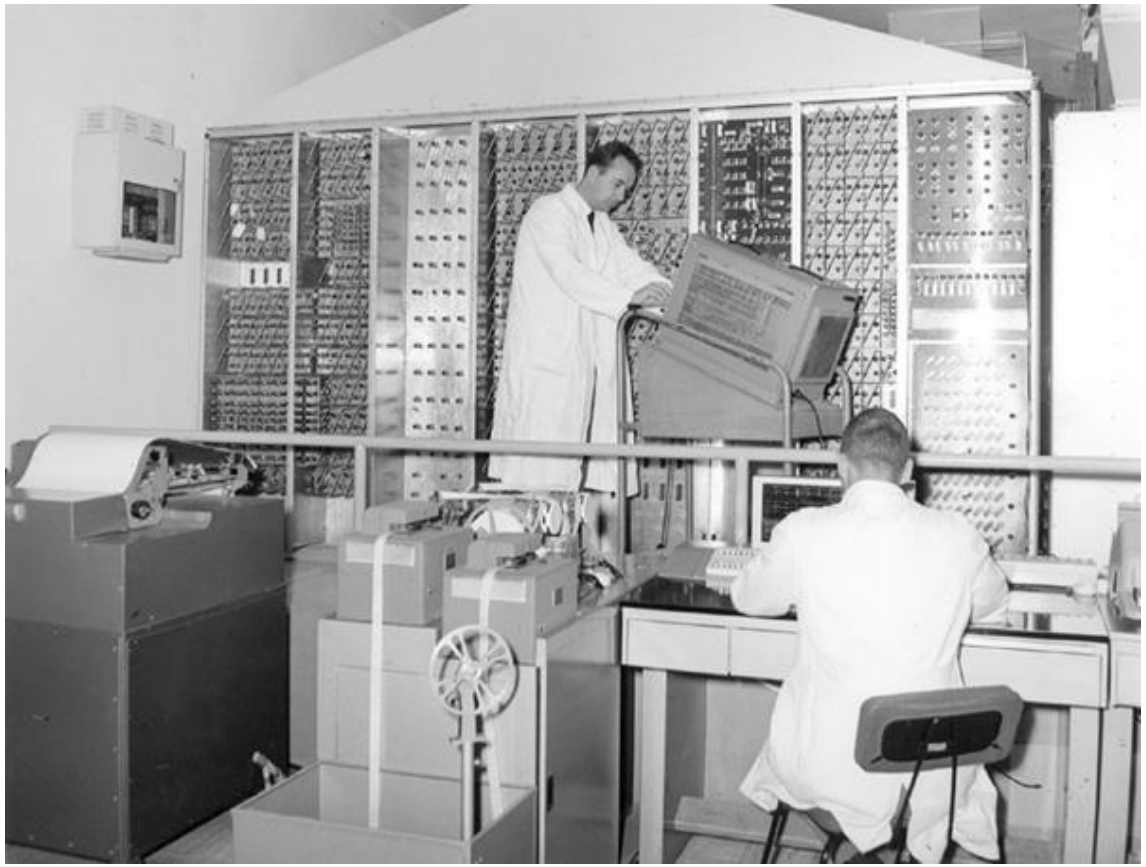
held by Prof. Luciano Lenzini

Quantum programming?

What is a quantum computer?

- A quantum computer is a machine that performs calculations based on the laws of quantum mechanics instead of the laws of classical physics.
- As the **bit** is the computational unit of a classical computer, the **qubit** is the computational unit of a quantum computer.
- The logical operations that a classical computer can perform on bits (e.g. AND, OR, NOT, NAND, …) are mapped by its **instructions set**.
- Current operating systems abstract this low-level API and provide users with applications and advanced programming languages.

We are back to the ‘60s



Calcolatrice Elettronica Pisana – 1961.

- Quantum computers have an instructions set composed of quantum gates (e.g. {H, Z, X, Y QNOT, CX, SWAP, MEASURE}).
- They can be seen as mainframes which execute an ordered list of instructions on a set of qubits and output some measurement results.

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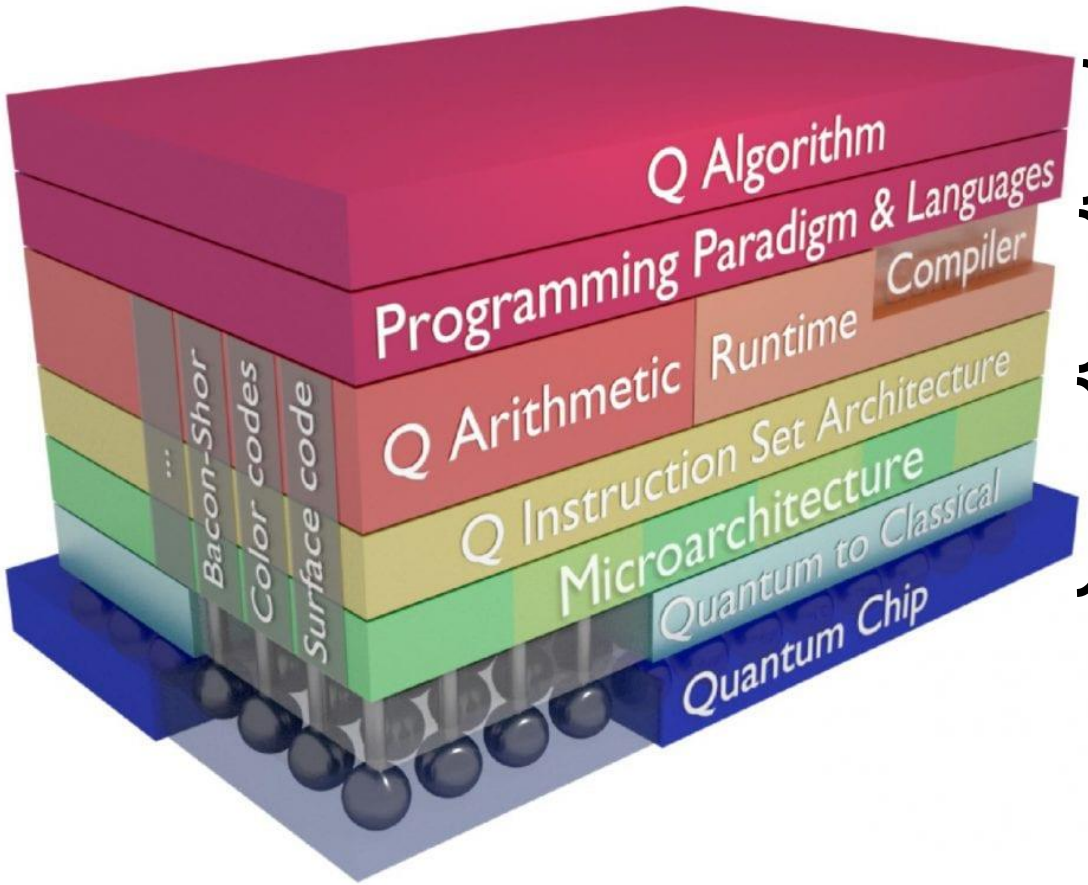
The Quantum Computing Software Stack



Where we work (e.g., Qiskit)

Middleware (Operating System)

Strongly hardware-dependent

Source: https://qutech.nl/research-engineering/quantum-computing/

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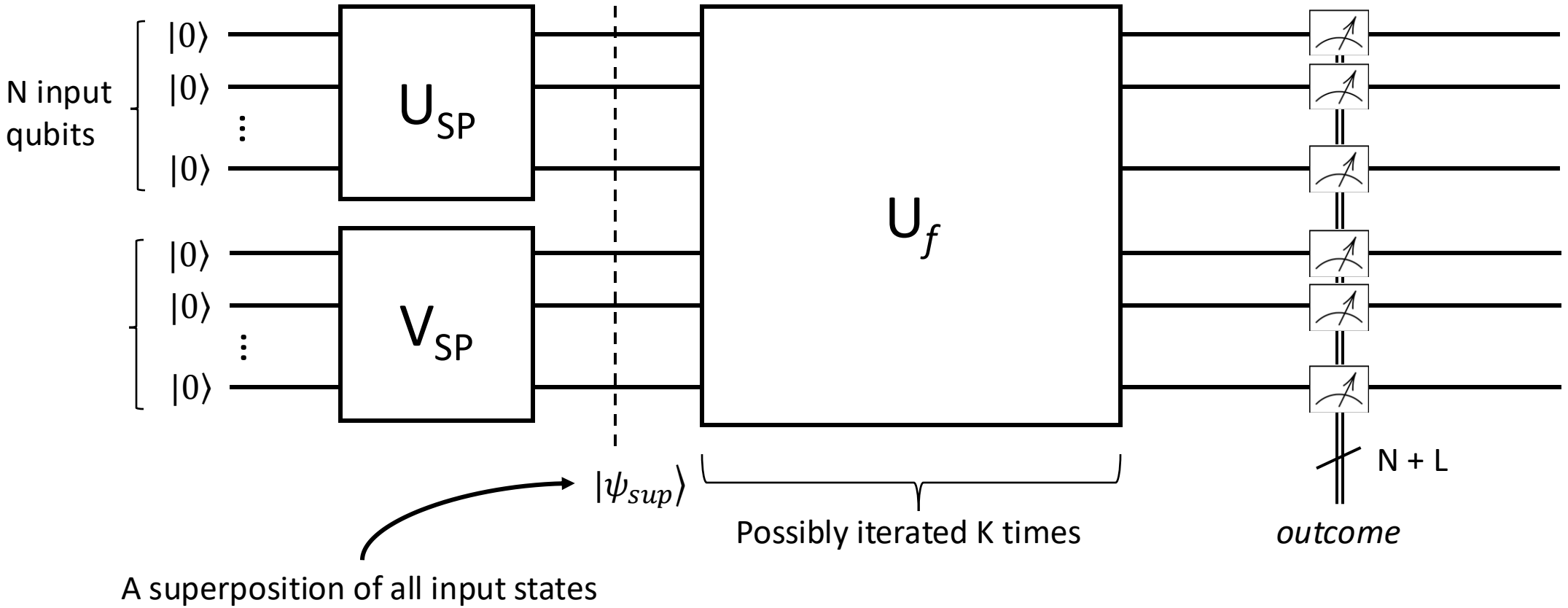
What does a quantum algorithm look like?

- Spoiler alert!!! (this will make sense in the future)



Motivations

- What problems are efficiently solved by quantum algorithms?
- As a rule of thumb, quantum algorithms are much more efficient than classical algorithms when the problem is to **determine a global property of an input function** $f: \{0,1\}^N \rightarrow \{0,1\}^M$

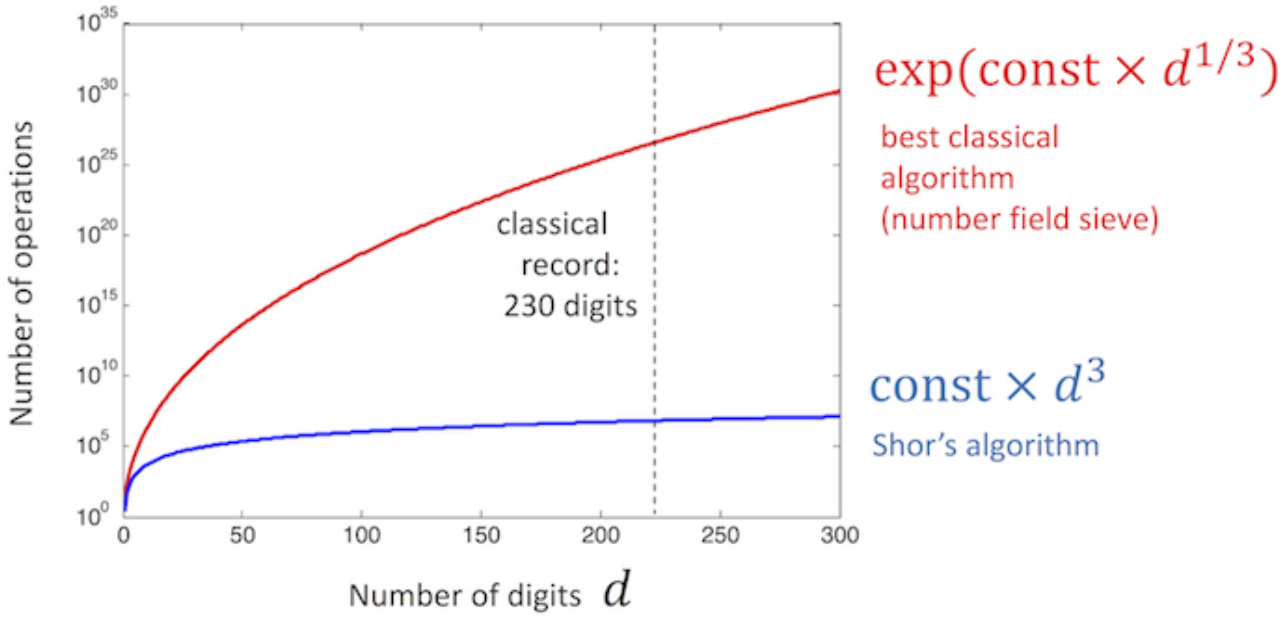
- Examples:
  - ✓ Problem: is *f* constant or balanced? -> Deutsch-Josza algorithm
  - ✓ Problem: what is the period of *f*? -> Period finding algorithm

Motivations (2)

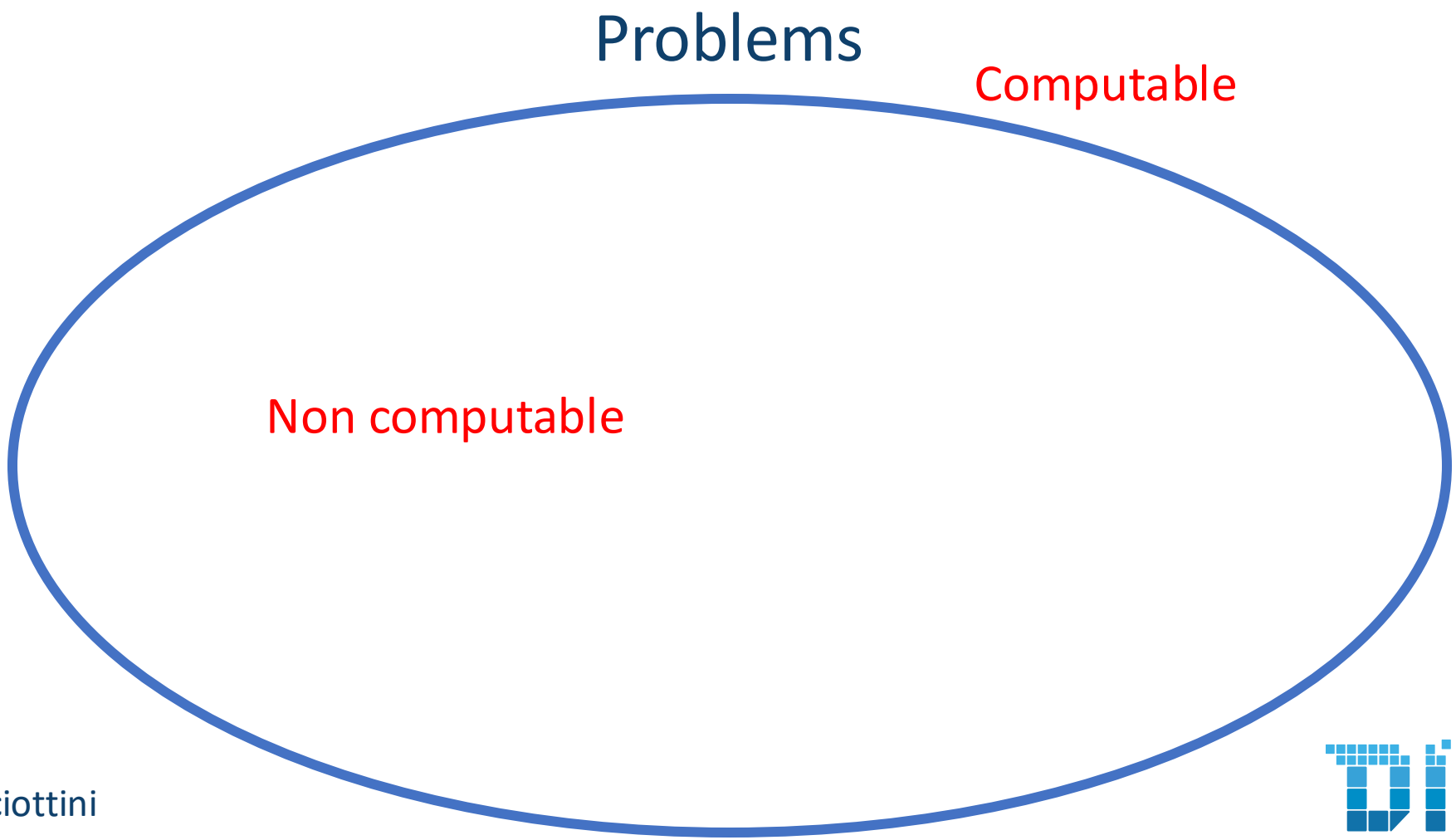
- Question:

  What is the advantage of quantum algorithms?

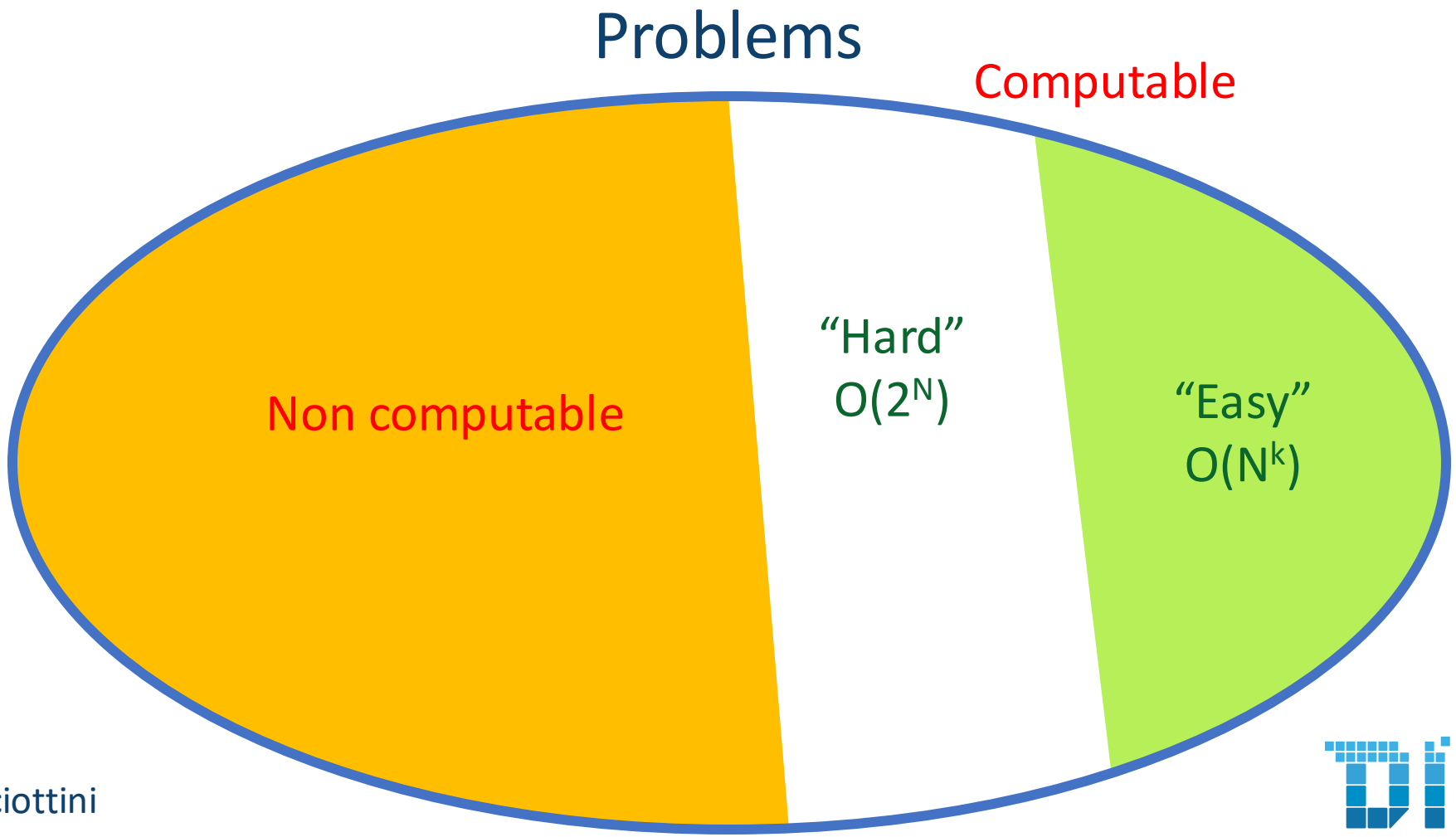
Shor's algorithm performances (IBM)



Church-Turing Thesis



Church-Turing Thesis



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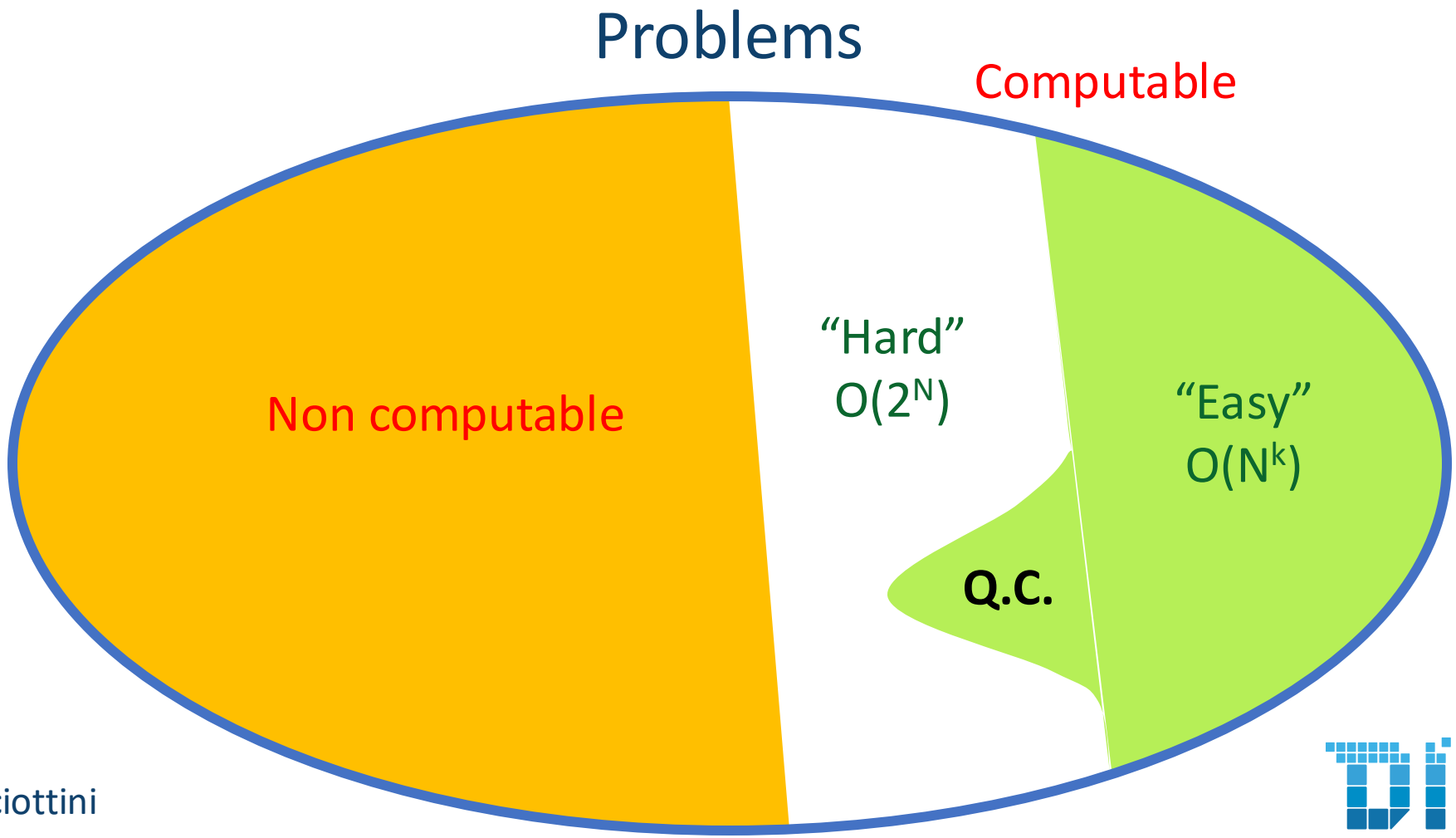


Qiskit

What is Qiskit

- Qiskit is an open-source software framework (on Python) for working with quantum computers at the level of circuits, operators, and primitives.
- It also allows to build domain specific APIs on top of its modules abstracting the underlying complexity.
- It's built on top of *OpenQASM*, the most popular **assembly language** for quantum computers (I told you they are like mainframes!).
- IBM quantum computers can be accessed directly from Qiskit.

Qiskit installation guide

- Qiskit is a Python framework. To ensure modularity and isolation we will install it into a virtual environment.
- First of all, install Miniconda (a lightweight version of Anaconda) following the instructions in the official website (here).
- At this point we create a new conda environment:

```
conda create -n qiskitEnv python=3
```

- We will install Qiskit inside this environment.

Qiskit installation tutorial (2)

- Activate the new environment with:

```
conda activate qiskitEnv
```

- If the command has been executed, you should now see (qiskitEnv) at the beginning of your prompt line. Every package installed will be confined to this environment.
- On Windows or Linux:

```
pip install qiskit[visualization]
```

- On MacOS:

```
pip install 'qiskit[visualization]'
```

Also install these packages

```
pip install qiskit-aer
```

```
pip install jupyter
```

```
pip install qiskit-ibm-runtime
```

It’s a surprise tool that will help us later!

Qiskit installation tutorial (3)

- If you have any issues during the installation, check the official Qiskit installation page [1], a guide about conda environments such as [2], or send me an email explaining your problem.

[1] https://docs.quantum.ibm.com/guides/install-qiskit
[2] https://towardsdatascience.com/manage-your-python-virtual-environment-with-conda-a0d2934d5195

Programming environment

- We can use Qiskit from any IDE, but a very useful tool to program is to use Jupyter Notebooks.
- Create a new folder in which you will save your Qiskit programs.
- Open the conda prompt, cd into the new folder and activate the virtual environment (qiskitEnv).
- Then, enter the following command:

```
jupyter notebook
```

- It will start a jupyter server and it will open your default browser. Do not close the terminal!

Example

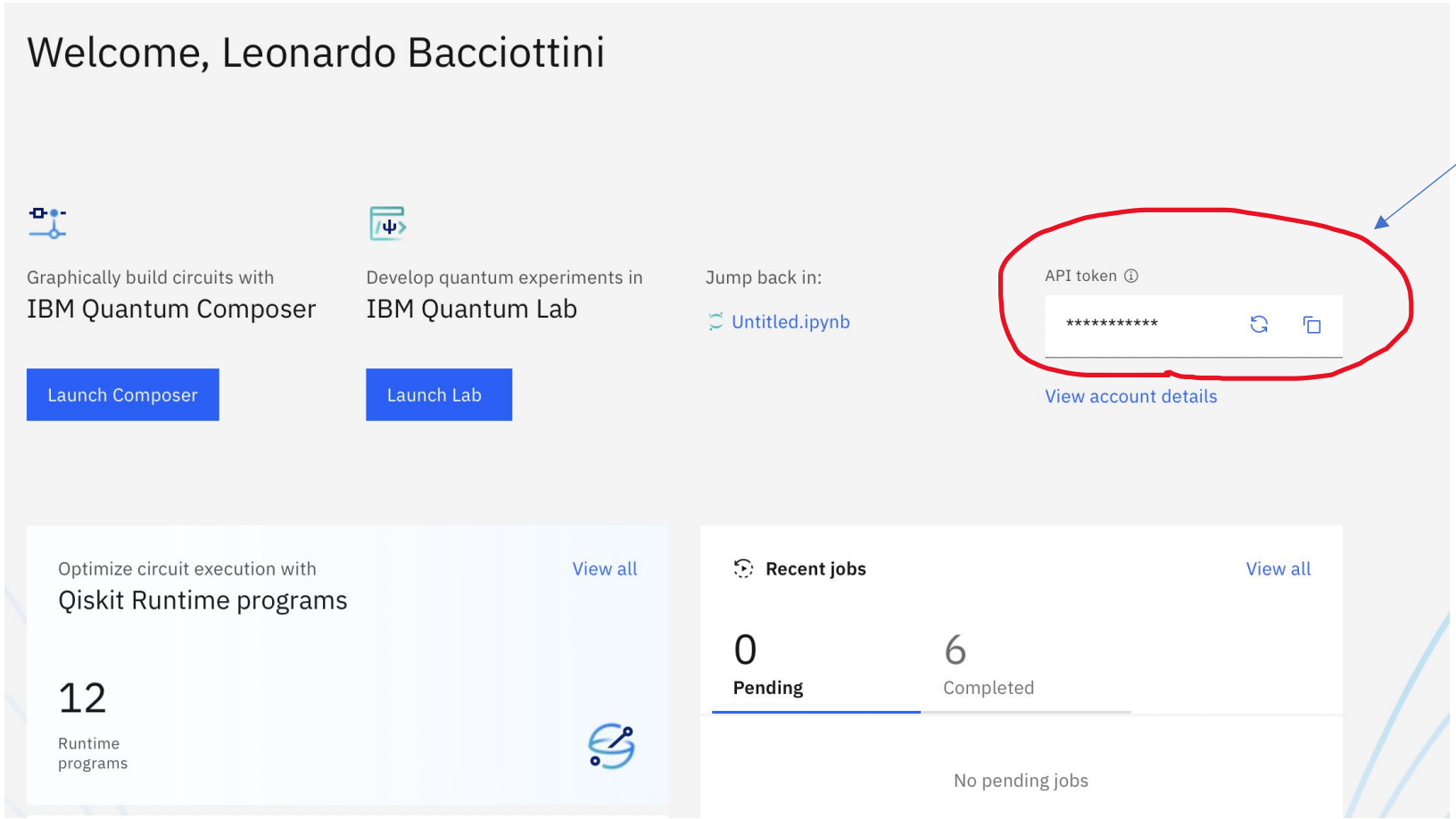
```
[baccios$ cd ./temp_jup
[baccios$ conda activate qiskitEnv
[(qiskitEnv) baccios$ jupyter notebook
 [I 12:43:37.147 NotebookApp] Serving notebooks from local directory: /Users/b
accio/Desktop/temp_jup
 [I 12:43:37.147 NotebookApp] Jupyter Notebook 6.4.11 is running at:
 [I 12:43:37.147 NotebookApp] http://localhost:8888/?token=76a45d4b064908e96e3
522088f0635abe100dc9a2ce627ec
```

Example: a new notebook

Register to IBM-Q

- Finally, to use IBM-Q devices, we have to sign up to their system.
- Go to https://quantum-computing.ibm.com and follow the instructions to create an IBMid account.

API Token



You will need this
To access IBM-Q
From Qiskit!

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