A Glimpse into Quantum-enhanced Machine Learning Solutions

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Amadeus Knowledge Sharing Session

Who are we?

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Three Computer Engineering and Data Science students from PoliTO, mainly interested in Machine Learning and High-performance Computing, who recently got fascinated by Quantum Computing.

Outline

1. Motivation

2. Quantum Computing Foundations

3. Qlearnkit

   Quantum Support Vector Machines

   Quantum Long-Short Term Memory

4. Conclusion

Motivation

Why going Quantum ?

Until now, we've relied on supercomputers to solve most problems. These are very large classical computers, often with thousands of classical CPU and GPU cores. However, supercomputers aren't very good at solving certain types of problems, which seem easy at first glance.

Why going Quantum ?

Imagine you want to seat 10 fussy people at a dinner party, where there is only one optimal seating plan out of all the different possible combinations. How many different combinations would you have to explore to find the optimal?

Can you guess how many combinations?

Why going Quantum ?

For 2 people

2 Total combination.

Why going Quantum ?

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2 Total combination.

For 5 people

120 Total combination.

Why going Quantum ?

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For 5 people

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For 10 people

Over 3 Million of total combination!!!

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- Supercomputers don't have the working memory to hold the myriad combinations of real world problems.

Why going Quantum ?

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- Supercomputers don't have the working memory to hold the myriad combinations of real world problems.
- Supercomputers have to analyze each combination one after another, which can take a long time.

Quantum Computers

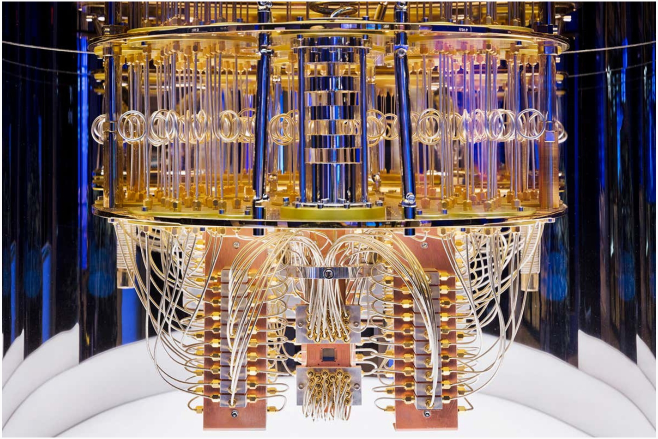


Figure 1: IBM's Quantum Computer

What are Quantum Computers good at ?

cose da dire:

- Linear Algebra
- Optimization
- Sampling
- Research Algorithms

A Growing Interest in the field

cose da dire:

- tanti framework (qiskit, pennylane, cirq, tensorflow quantum, ...)
- tanti paperi (con plot della crescita 2012-2021)
- tutti (Microsoft, Google, IBM, NVidia ...) hanno/vogliono un computer quantistico
- tanta ricerca nel settore Quantum Programming Languages

Quantum Computing Foundations

Bra-ket notation

Useful for representing quantum systems

Bra = Row

$$\langle A| = \begin{bmatrix} a_0 & a_1 & a_2 & \cdots \end{bmatrix}$$

Ket = Column

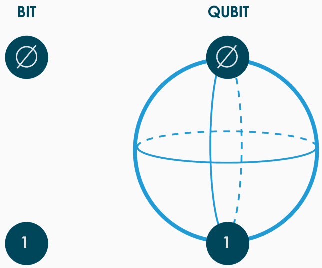
$$|B\rangle = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ \vdots \end{bmatrix}$$

Properties & operations:

- Scalar product $= \langle A|B\rangle = [a_0, a_1, a_2, \cdots] \cdot [b_0, b_1, b_2, \cdots]^T$
- Norm $= \langle A|A\rangle = |A|^2$

What is a qubit?

- Building block for quantum computers
- 2-state quantum system (photon, electron, Schrodinger's cat, ...)
- 0, 1, both at the same time (superposition)
- Can be manipulated (quantum circuits)
- Can form more complex quantum systems (multi-quibit systems)
- Can be observed causing its collapse (measurement)



What is a qubit?

- What does it mean to be 0 and 1 simultaneously?
  It's a matter of probability during measurement
- Bra-ket qubit representation:

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \qquad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \qquad |\psi\rangle = \begin{bmatrix} \psi_0 \\ \psi_1 \end{bmatrix}$$

- Probability measurement:

$$P(|\psi\rangle = 0) = |\psi_0|^2$$

$$P(|\psi\rangle = 1) = |\psi_1|^2$$

- Probability distribution: $\langle\psi|\psi\rangle = |\psi|^2 = 1 \ \forall \ \psi$

Multi-qubit system and entanglement

How can we represent 2 or more qubits with bra-kets?

With tensor products and longer vectors

$$|AB\rangle = \begin{bmatrix} a_0 \\ a_1 \end{bmatrix} \otimes \begin{bmatrix} b_0 \\ b_1 \end{bmatrix} = \begin{bmatrix} a_0 b_0 \\ a_0 b_1 \\ a_1 b_0 \\ a_1 b_1 \end{bmatrix}$$

By stacking n qubits we can represent 2^n infinite precision numbers

$$P(A = 0, B = 1) = |a_0 b_1|^2$$

Multi-qubit system and entanglement

How can we represent state $|00\rangle + |11\rangle$ with a tensor product?

We can't as there is no set of values for a_0, a_1, b_0, b_1 that allows it.

$$|AB\rangle = \begin{bmatrix} a_0 b_0 \\ a_0 b_1 \\ a_1 b_0 \\ a_1 b_1 \end{bmatrix}$$

However, we can still create this state with quantum circuits. The resulting state is said to be entangled as measuring one qubit immediately tells us the state of the other.

$$|00\rangle + |11\rangle = \begin{bmatrix} 1/\sqrt{2} \\ 0 \\ 0 \\ 1/\sqrt{2} \end{bmatrix}$$

Qlearnkit

References

Some references to showcase [allowframebreaks] [4, 2, 5, 1, 3]

Conclusion

Summary

All the material used for this presentation is available at the following link:

`https://github.com/mspronesti/talk-qml-amadeus`

Thanks for you attention!

Any Question ?

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