Quantum Machine Learning

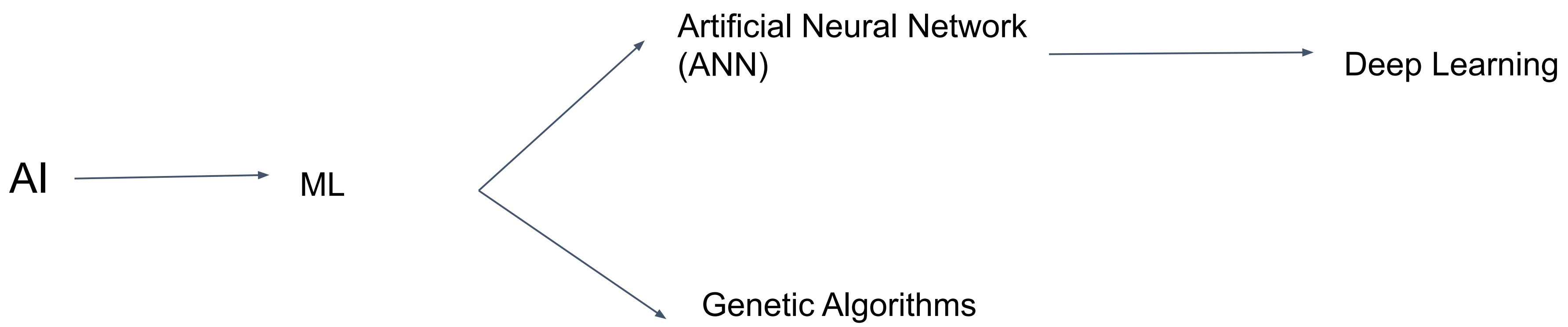
Guo Zheng

Aug 10, 2018

Outline

- Overview
  - Classical Machine Learning (CML)
  - Quantum Machine Learning (QML)
- Sample Algorithms & Applications
  - SVM
  - Other applications
    - Deep quantum learning
- Summary
  - Major challenges
  - Future development

CML overview



Using statistical techniques to progressively improve performance on a specific task.

QML

- Quantum algorithms are the ones that can be applied on quantum computers.

- Examples: Shor’s algorithm (integer factorization), Grover’s algorithm (search)

QML

Generally, two approaches:

1. Implements the computationally expensive subroutines of classical machine learning algorithms on a quantum computer.
2. Uses classical machine learning algorithms on a quantum information, to speed up performance of the algorithms.

For the first one, the classical data should be mapped to quantum mechanical states before using the QML algorithms.

QML

The most straightforward one is analysing quantum data using QML:

- Compared with CML, $O(N^2)$ to $O((\log N)^2)$
- Available through smaller and simpler quantum computers
- Can be made practical in the next several years

QML

- Quantum RAM (qRAM) & Quantum Basic Linear Algebra Subroutines (qBLAS) (Exponential speedup)
    - Fourier transform
    - Finding eigenvectors and eigenvalues
    - Solving linear equations (HHL algorithm)
- Example: HHL algorithm for solving linear equations

HHL algorithm

$$A\overrightarrow{x} = \overrightarrow{b}$$

- Techniques used
  - Hamiltonian simulation techniques used to apply e^iAt to |b>
  - Decompose b into eigenbasis of A and find corresponding eigenvalues using quantum phase estimation.
- The final results is the expectation value of <x|M|x>, where M is a linear operator.
  - Restriction: not getting all values of x, but knowing normalization, weights in different parts of the state space, and moments.
- Complexity: O(N^0.5) while classical O(N)

QML - deep learning

- Does not require a large, general purpose quantum computer
  - Well suited for special purpose information processors (quantum annealers and programmable photonic circuits)
- Improvements are expected to be at the learning stage
  - Thanks to quantum entanglement the weight adjustments can be done in parallel

Application - deep quantum learning

- Quantum annealers have been applied to more than a thousand spins (D-Wave).
- Quantum Boltzmann Machine still in design stage
  - More general tunable couplings, and capable of implementing quantum logic gates

Major Challenges

1. Input
   a. Process of reading data still takes a certain amount of time, which might be a restriction on the complexity of the algorithm
2. Output
   a. Expressing quantum solutions of the algorithms needs exponential number of classical bits relative to quantum bits. (Can be potentially overcome by reading the summary statistics of the solution states)
3. Costing
   a. Complexity-wise, QML is less than CML but it’s hard to determine the number of quantum gates needed for the a certain amount of data (hard to determine the crossover point).
4. Benchmarking
   a. Difficult to say QML is more efficient than all CML. Need to make more test of QML to determine it’s lower bounds etc compared to CML.

Major challenges

- Construction of qRAM
  - Principle demonstration of qRAM has been made, but constructing large arrays of quantum switches are still a large technical problem.

Future developments

- Quantum hardwares are needed to perform QML
  - Small quantum computers, general purpose quantum computers, quantum annealers, quantum simulators etc
- Can perform QML on quantum data first and use the results to design next generation processors as CML did

References

1. Jacob Biamonte. Quantum machine learning. https://arxiv.org/pdf/1611.09347.pdf
2. Krishnakemarsekar. Awesome quantum machine learning. https://github.com/krishnakumarsekar/awesome-quantum-machine-learning#quantumai
3. Cristian Romero Garcia. Quantum Machine Learning.
4. Carlo Ciliberto. Quantum machine learning: a classical perspective. http://rspa.royalsocietypublishing.org
5. Quantum Algorithms for linear systems of equations. Wikipedia. https://en.wikipedia.org/wiki/Quantum_algorithm_for_linear_systems_of_equations
6.