Unsupervised and Supervised Learning with Quantum Computer

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Abstract
Quantum computer has been shown to outperform classical computer in some specific tasks, due to its intrinsic quantum properties. Recently, quantum algorithms have been developed to enhance the field of machine learning – where classical computer faces challenges in data storage and computational cost. We consider two main themes: unsupervised learning, supervised learning and their quantum enhancements

Unsupervised learning
- Data have not been classified clearly
- Goal: Find the hidden structure (i.e., clusters)

K-means approach: measure distances between data instances and group closer ones
- Euclidean distance:
  \[ d(x_i, x_j) = \sqrt{\sum_{k=1}^{N} (x_{ik} - x_{jk})^2} \]
- Classical computer: with N-dimensions vector \( \rightarrow \) N steps to calculate the Euclidean distance
- Quantum computer: \( O(\log N) \) by performing SwapTest circuit
  with \( |\psi> = \frac{1}{\sqrt{2}}(|0> |x_1> + |1> |x_2> \]
  \( |\phi> = \frac{1}{\sqrt{2}}(|0> - |1> \]

Classical data as a quantum state
- Classical data: \( \tilde{x} = (x_1, x_2, ..., x_n) \)
- Quantum state: \( |\psi> = \sum a_i |i> \) where \( |i> \) is the system of qubits
- Quantum encoding: \( \tilde{x} \rightarrow |x> = \frac{1}{||\tilde{x}||} \sum_{i} x_i |i> \)

Supervised learning
- Data have been classified clearly
- Goal: train the given set of data, and use the inferences to classify new data

Support vector machine: classify data into one of two sets
- SVM can be formulated as a quadratic programming problem and classical computer solves in time \( \sim O(poly(M, N)) \)
- Quantum computer implements with \( O((\log(NM))^2) \) run time

KEY IDEAS:
- Faster evaluation of inner products
- Better performance in solving linear equations:

HHL Algorithm

Goal: solve \( A\tilde{x} = b \)
In quantum setting, the problem is quantized:\n\( A|x> \equiv |b> \) where \( |b> \) is normalized

KEY IDEA: inverting \( A \rightarrow |x> = A^{-1} |b> \)
Classical computer: \( O(N \log(N)) \)
Quantum computer: \( O((\log N)^3) \)

Quantum circuit for HHL algorithm

Conclusion
- HHL algorithm acts as a first building block for future work in quantum machine learning
- Need to address challenges in hardware and software for efficiently performance
- Prospect in quantum machine learning: quantum deep learning

References