Performance Evaluation of SVM with Multiple Quantum-inspired Annealers

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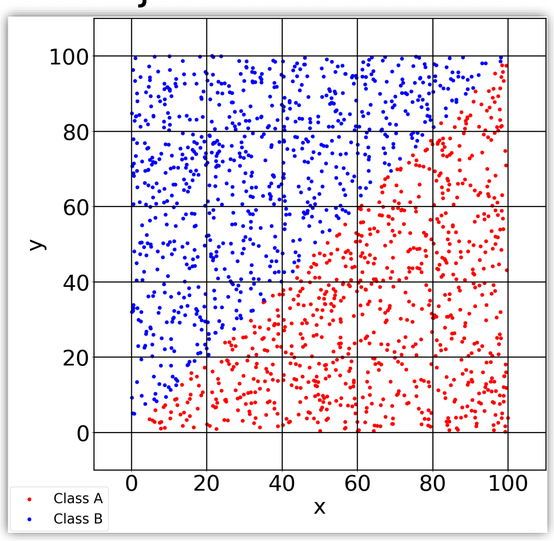
Introduction

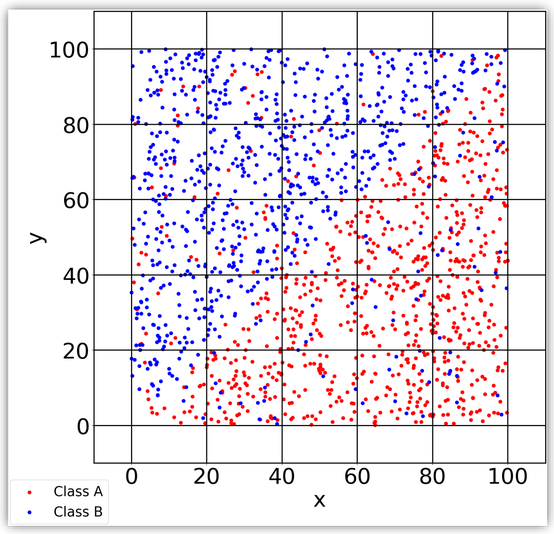
Quantum annealing faces challenges regarding qubit scalability and cooling requirements. To address these, semiconductor-based Quantum-inspired (QI) annealers have been developed to emulate annealing on classical hardware, enabling large-scale optimization at room temperature. However, performance evaluations of QI annealers on machine learning algorithms, specifically Support Vector Machines (SVM) [1], remain insufficient. This study evaluates the classification accuracy of SVMs across three mainstream cloud-based QI annealers (Amplify AE, Toshiba SQBM+, and Fujitsu DA) using datasets with varying noise levels. We demonstrate that QI annealers achieve results comparable to classical computing environments, exhibiting particular robustness in noisy conditions.

Experimental Settings

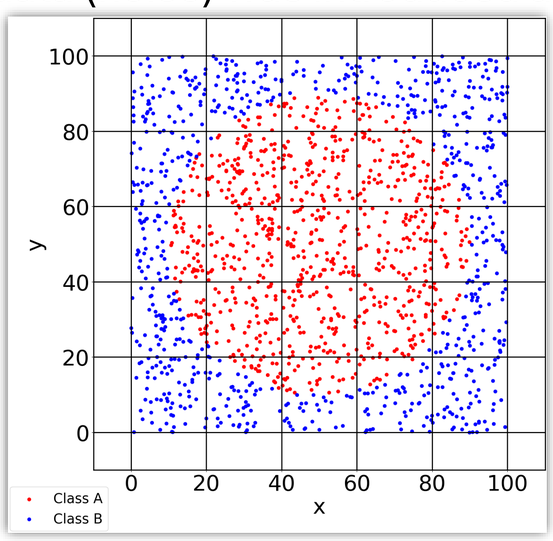
- Dataset Generation: Synthetic 2D datasets were generated to simulate binary classification tasks.
- Problem Types: Experiments focused on two structures: linearly separable and non-linearly separable.
- Noise Injection: To simulate real-world conditions, mislabeled data (noise) was introduced at rates ranging from 0% to 20%.



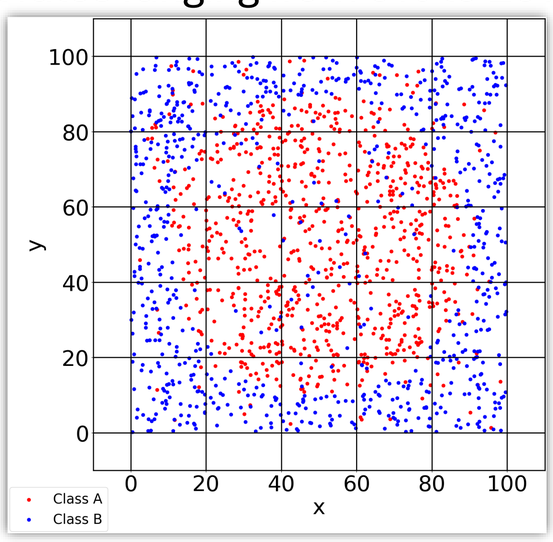
Linearly Separable (Noise: 0%)



Linearly Separable (Noise: 10%)



Non-Linearly Separable (Noise: 0%)



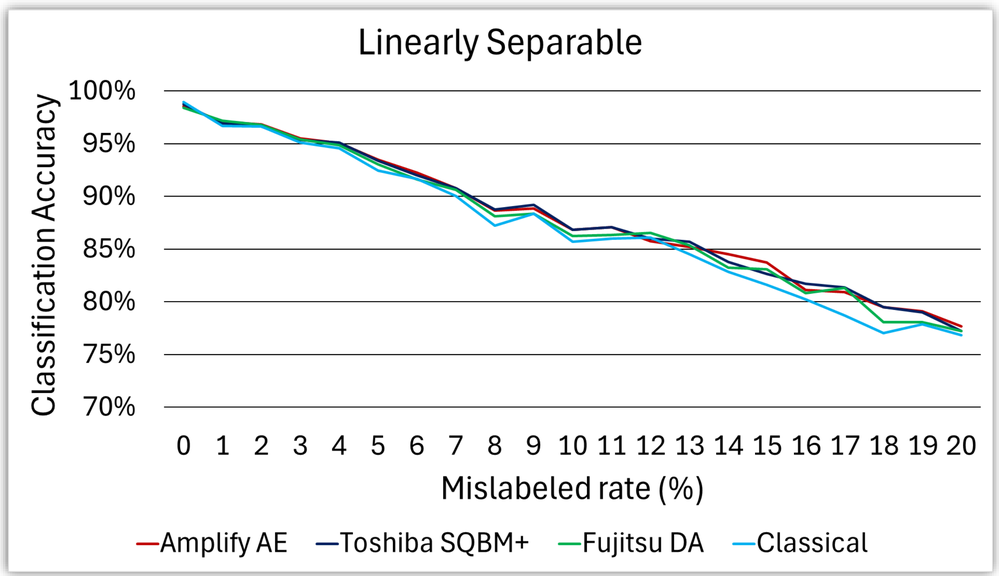
Non-Linearly Separable (Noise: 10%)

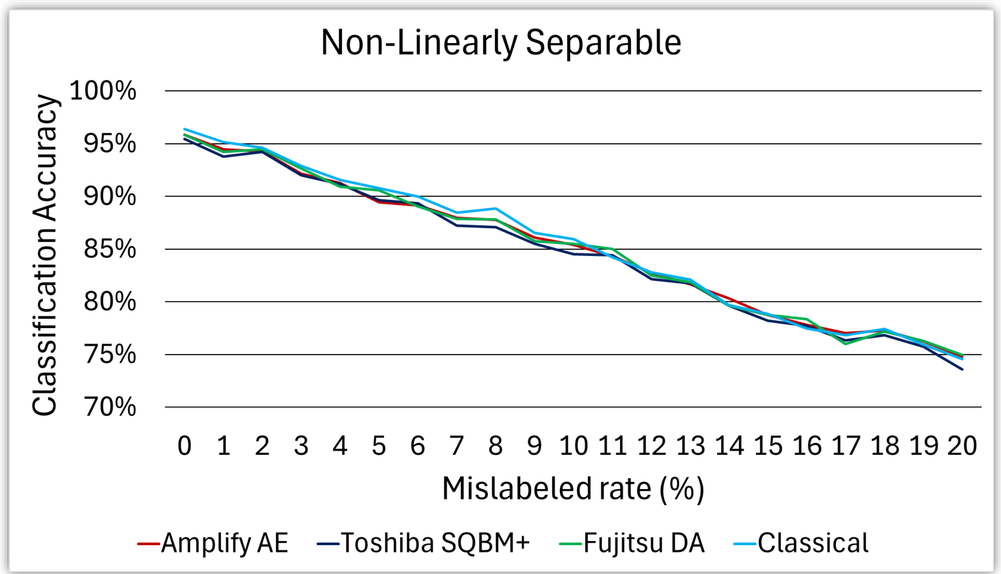
Experimental Procedures

1. Data Splitting: A total of 1,600 data points were divided into 100 training, 1,000 validation, and 500 test points.
2. Normalization: Min-Max scaling ([0, 1]) was fitted on the training set and applied to validation/test sets.
3. Training: A classifier was created using the 100 training data points.
4. Tuning: Hyperparameters were optimized on the validation set using Optuna (TPE sampler) for Bayesian optimization.
5. Testing: The final accuracy was calculated by applying the top 10 optimized classifiers to the test data. The reported result is the average across 5 independent datasets.

Results

- Overall, SVMs executed on QI annealers achieved classification accuracy comparable to that of the classical computing environment.
- In linearly separable problems, QI annealers outperformed the classical baseline in certain high-noise conditions.
- Conversely, for non-linearly separable problems, the classical approach generally yielded the highest accuracy.





Conclusion

- SVMs executed on QI annealers achieved classification accuracy comparable to classical baselines, demonstrating particular robustness in noisy environments.
- Despite comparable accuracy, classical solvers currently provide shorter execution times for small-scale problems compared to QI annealers.
- However, since recent studies [2] suggest that quantum approaches may gain execution-time advantages as dimensionality increases, our future work will investigate the scalability of QI annealers in high-dimensional feature spaces.

References
[1] V. N. Vapnik, The Nature of Statistical Learning Theory.
New York: Springer, 1995.
[2] D. J. Woun and P. Date, "Adiabatic Quantum Support Vector Machines," 2023 IEEE International Conference on Quantum Computing and Engineering (QCE), 2023.

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