Faster and Higher Fidelity Qubit Readout with Machine Learning

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Introduction

Instead of being in either a 0 or 1 binary state as in a classical bit, a qubit exists in a superposition of both states. These unique properties are key to the promised potential of quantum computing. Quantum computers' unique properties have led to theoretical results that show potentially exponential speedup over classical computers in certain applications such as number factoring [2]. Qubit readout, which refers to the process of determining the state of a qubit, is critical for allowing us to make sense of the results from a quantum computation.

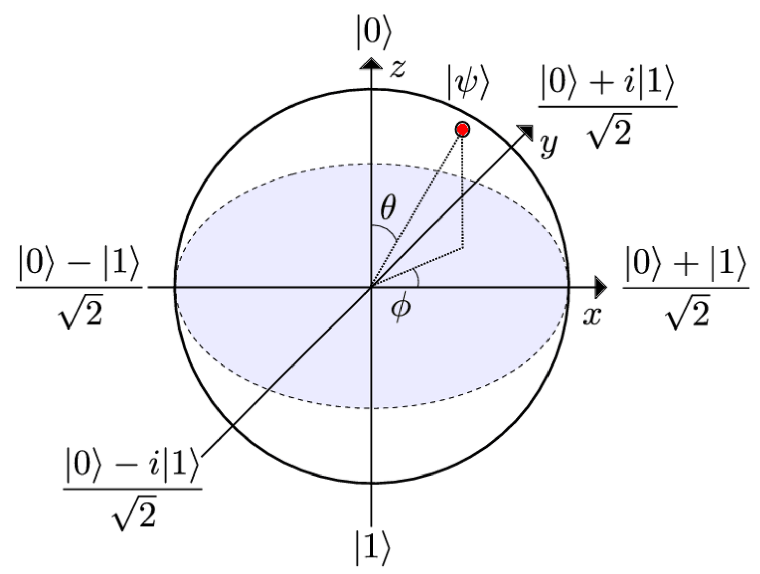

Fig. 1: A bloch sphere representation of a qubit. Qubits can exist in superpositions of the 0 and 1 states.

Problem Statement

Traditional methods for qubit state differentiation, such as the threshold cutting method and the matched filter method, rely on hand-crafted heuristics and give low accuracies [1]. Although advances in hardware technology is still very much crucial to building more functional quantum computers, there is also opportunity to achieve higher readout fidelity using only software methods, specifically machine learning methods.

Additionally, quantum computers currently face a serious challenge called qubit decoherence. Decoherence refers to the phenomenon in which a quantum system reverts back to classical, and is caused by interactions with the environment, which decay or eliminate the quantum behaviour of particles. Different qubit implementation technologies have different decoherence times. The decoherence time places an inherent limit on the window of time in which we can perform qubit readout. For this reason, a short readout time is crucial to ensure that a qubit is able to retain its the quantum information during the readout, lest it collapses from interaction with the environment before the readout is completed.

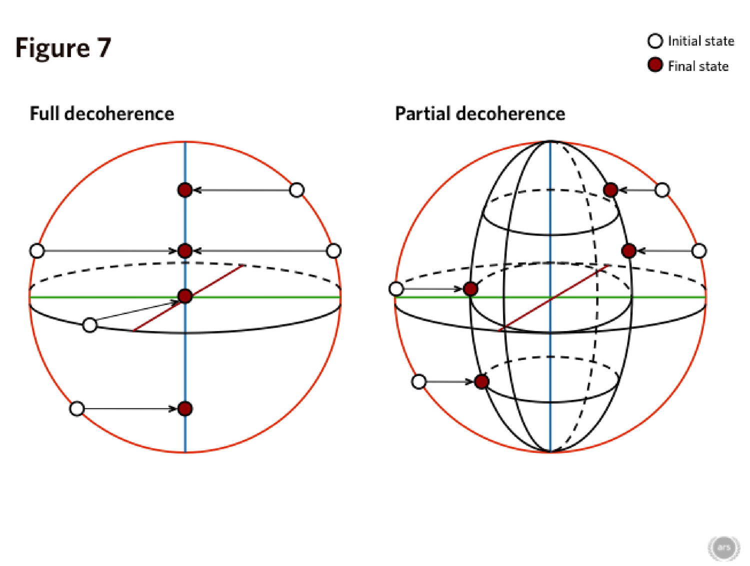

Fig. 2: A bloch sphere representation of a qubit decoherence phenomenon. This process is triggered by interaction with the environment.

Data

Our data comes from a 2-qubit superconducting experiment setup from Professor Andrew Houck's group at Princeton. We collect single shot voltage readout traces from the superconducting quantum bits for various combinations of readout power and sampling frequency. The goal is to predict from a qubit's voltage trace whether it is in the ground state or the excited state.

The ground truth of the dataset is obtained based on the assumption that we are able to prepare a qubit in the ground state and apply a quantum `NOT` gate, both with perfect fidelity.

The entire dataset is collected at 36 power levels and 31 frequencies, for a total of 1,116 subdatasets. Each subdataset contains 16,384 ground and excited traces each, and corresponds to a particular combination of power and frequency. Each individual trace is a measurement of the voltage along channel I and channel Q for 2,048 time steps, giving us a 2 by 2,048 dimensional time series data example. An example trace is shown in Figure 3.

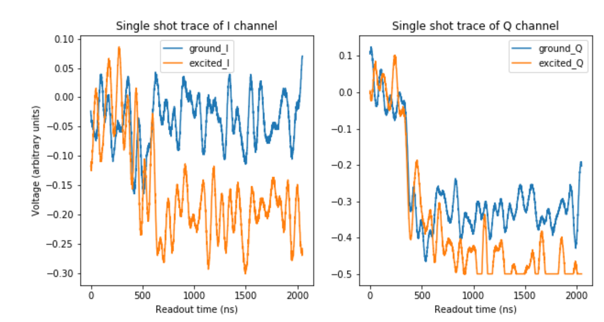

Fig. 3: An example single shot trace for the I and Q channels.

In order to better visualize the readouts, we can remove effect of system noise by simply averaging the 16,384 ground and excited state traces in a subdataset. Figure 4 shows an example of an averaged trace, in which we can clearly observe three distinct stages of the readout process. During the initialization stage, the initial 310 timesteps of both channels are almost identical for the ground and excited states. This stage carries essentially no physical information and is simply cropped from the data during preprocessing. The second stage is the integration stage, where the voltage starts to build towards the stable limit. The final stage is the stable stage, where the ground and excited voltage readouts are expected to saturate and separate from each other.

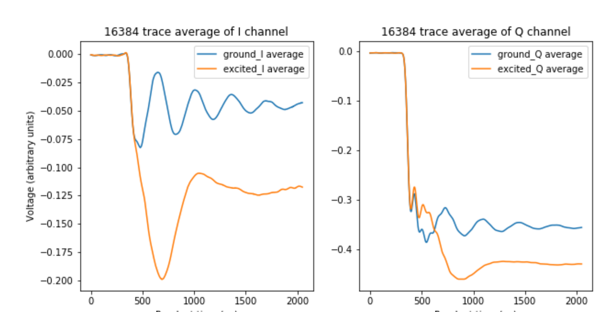

Fig. 4: Average of 16,384 traces for a particular subdataset.

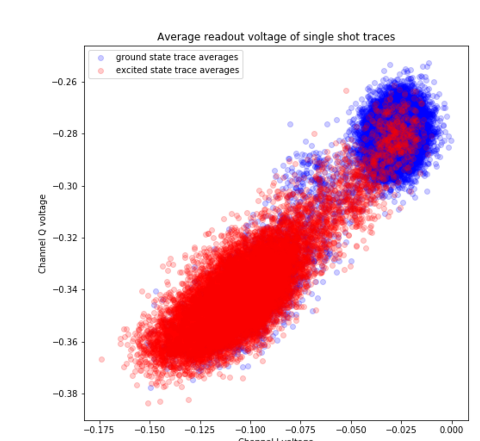

Fig. 5: Voltage averages for each individual single shot trace. Each point in the plot corresponds to channel I and channel Q voltage coordinates of an individual single shot trace.

Results

Traditional methods of qubit readout compute the average voltages for each individua trace. The I and Q channels hence form 2-dimensional coordinates for each individual Figure shows a scatter plot of the ground state and excited state qubits in the IQ volt for a particular subdataset.

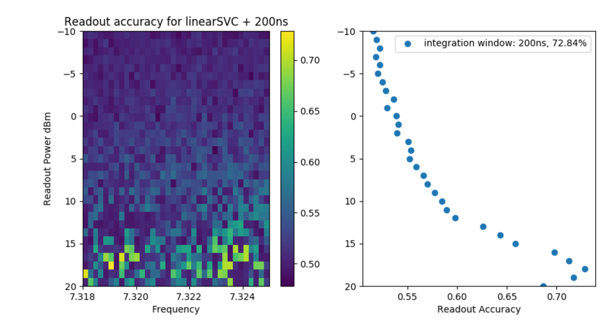

Fig. 6: Traditional methods use the trace average to perform linear SVM classification.

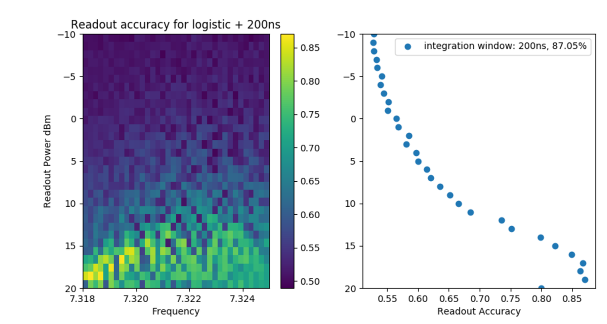

Fig. 7: For the same readout time, we are able to achieve higher accuracy.

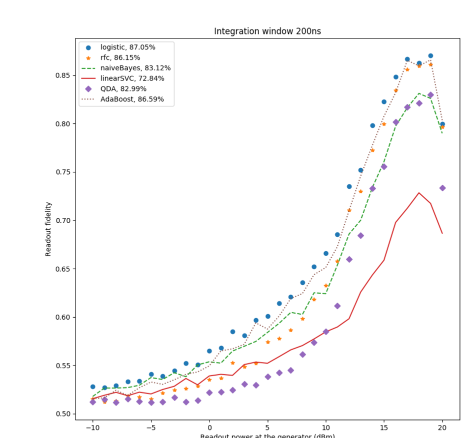

Fig. 8: For shorter readout time, we are able to improve the readout fidelity by about 15%.

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