Dirac-DaVinci: Quantum Optimization for Art

Figure 1. Community-sourced artwork from iQuHack participants.

Introduction For the 2023 iQuHack challenge posed by IonQ, we were given a seemingly simple task: “use a quantum computer to *generate* something new.” We took this as a challenge to find an exciting use for a quantum computer that hasn’t been explored in the past. Traditionally when we think of a use for a NISQ quantum computer, we think of a computational subroutine with the potential to speed up an algorithm. To someone who hasn’t studied the intricacies of computer science, many of the current (and naturally explored) avenues for a so-called “quantum advantage” may seem meaningless. It is for this reason that we chose to interpret “use” in a non-traditional way. We wanted to leverage the quantum nature of IonQ’s devices to give us a new usage that can speak to anyone, regardless of their background.

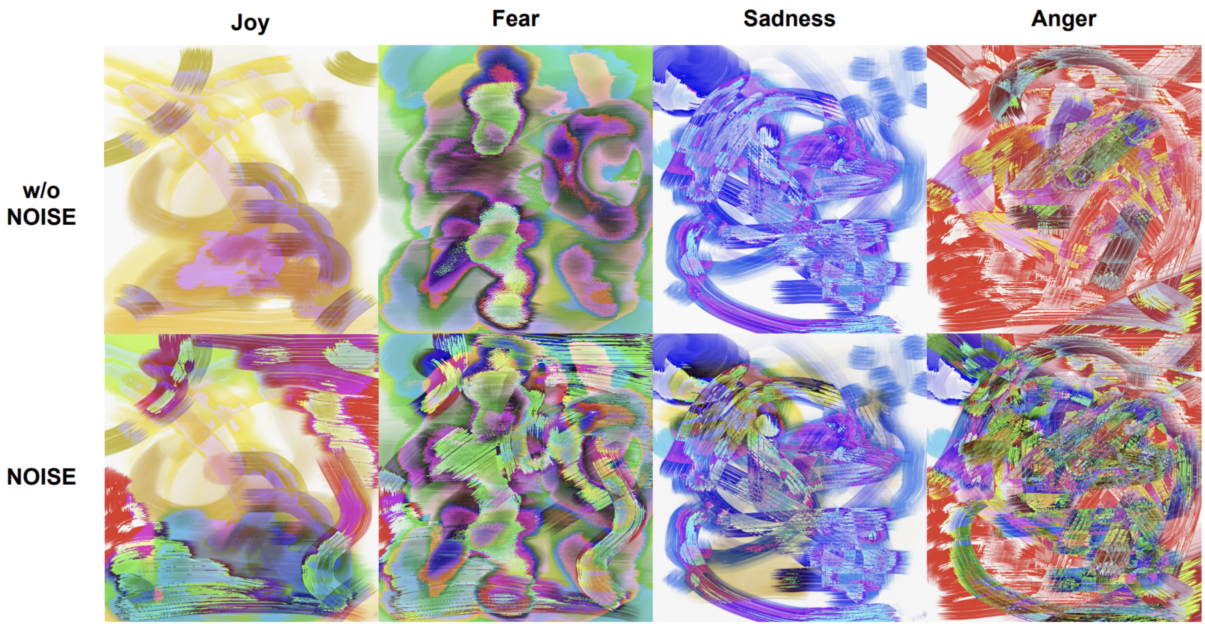

Figure 2. Combination of community developed art (top) without noise (bottom) with noise.

To us, this means art. Thus, we took on the challenge of creating a quantum painter: a “Mensing Monet”, a “Poincare Picasso,” a “Dirac Da Vinci,” if you will. Specifically, we created a hybrid quantum algorithm that generates an abstract work of art based on the desired mood of the user. We hope that by connecting the beauty of painting with the complexity of the quantum universe, we were able to produce a product that everybody can appreciate.

Our approach The Grover search is oftentimes thought of as a searching algorithm, however this line of thinking can lead one astray from the true nature of the method (i.e. amplitude amplification). Using Grover iterations, we employ constructive and destructive interference to maximize and minimize the probabilities of measuring the state of interest. Using Grover's Algorithm with a tunable oracle, we found that we can optimize the parameters of the oracle to encourage the amplitude amplification subroutine to converge on a particular subspace of the Hilbert space. Setting up the problem in this way enables a classical optimization over approximately O(N^2) parameters (where n is the number of qubits) to isolate an ideal subspace of the 2^n, dimensional Hilbert space using nearly any cost function.We optimize over the angles in two-qubit CZ entangling gates, using a naive reinforcement learning approach. We perform gradient descent towards the desired subspace and accept angle updates that move the quantum state closer to the desired subspace. Variational angle updates also act as a filter towards certain subspaces that “kick” our search state out of local minima in the energy landscape.

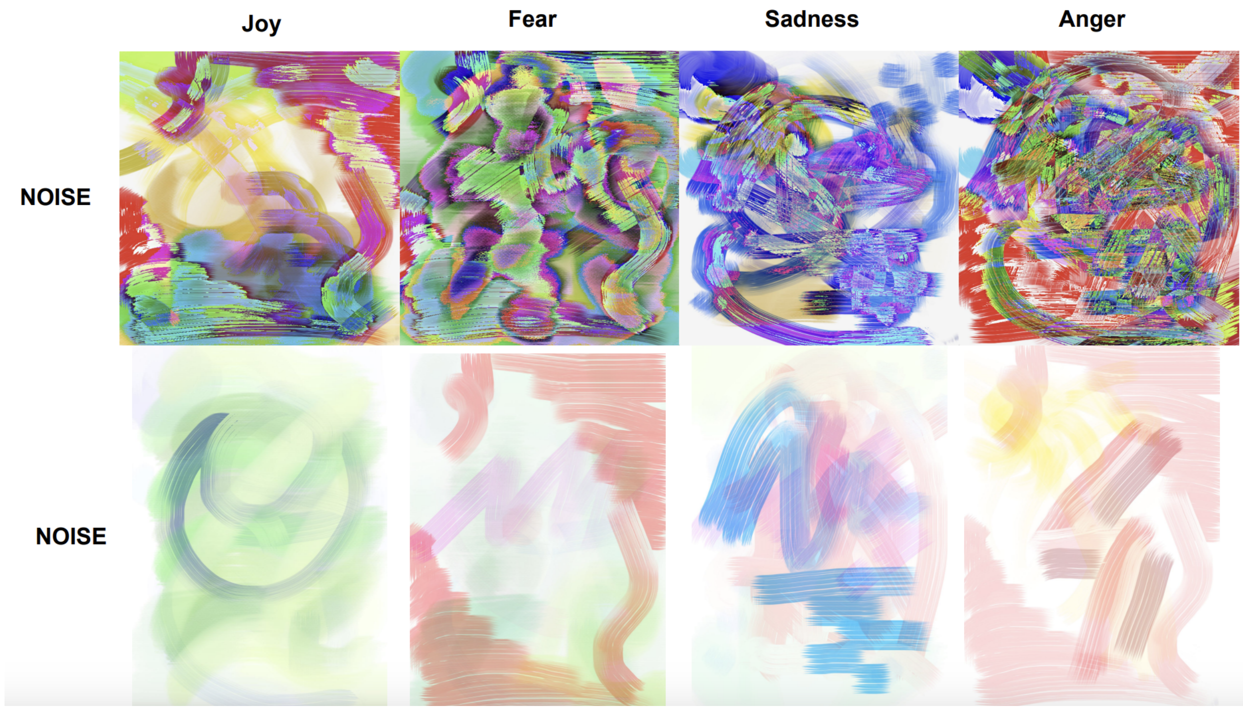

Figure 3. Algorithmically generated artwork on simulator with added noise.

For our own application of art generation, we optimized our solution space to produce artistic features corresponding to a given human emotion. By dividing the Hilbert space into subspaces that represented different emotions or moods, we captured sentiment associated with a work of art to construct new images based on a probability distribution of the algorithm's ability to land in the subspace. Finally, by adjusting the parameters of the grover search, we could reliably enter these different subspaces and seed our art generation with quantum data. We included a combination of hand drawn art from the community in and around the iQuHack competition, and art developed algorithmically based on the output parameters of the circuit.

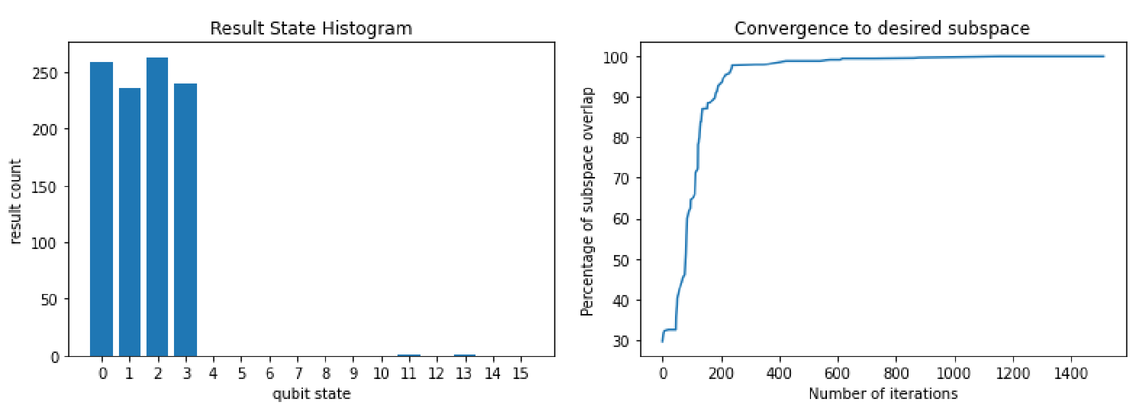

Figure 4. (left) State histogram result on the basis eigenstates. (right) Percentage of the subspace overlap over *classical* iterations.

For the painting generation itself, we collected samples of painting splotches from the iQuHack community, asking them to express their emotion through their small piece of art. We then grouped those splotches into subspaces of our quantum Hilbert space, and trained our quantum algorithm to isolate the subspace corresponding to the user requested mood. The groupings include: Joy, Sadness, Anger, and Fear. After collecting a small number of samples from the quantum computer, we overlay the various splotches on top of one another to generate an artistic render of the emotions felt during the hackathon of 2023.

Future work What started out as a humble attempt to create unique artwork turned into a new approach to categorize a data set using a quantum computer. Given the limited time frame of iQuHack 2023, we were not able to verify how our algorithm compares to existing variations of Grover's algorithm. An important step for future work is to determine if this optimization routine is in fact a novel idea. Our algorithm could be further optimized with advanced classical or potential quantum optimization techniques. While our algorithm identified the correct subspace with up to 99.9% accuracy for small numbers of qubits (i.e., small Hilbert basis), future work could scale this algorithm to identify subspaces for higher numbers of qubits. We found challenges running on IonQ's real trapped ion device, although we found large amounts of success running the algorithm on a classical simulator with a random noise model. Before this can be truly useful, however, it must be further optimized to improve performance on real noisy hardware.