Quantum Fourier Transform

A new era of Signal Processing?

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Original Value Proposition

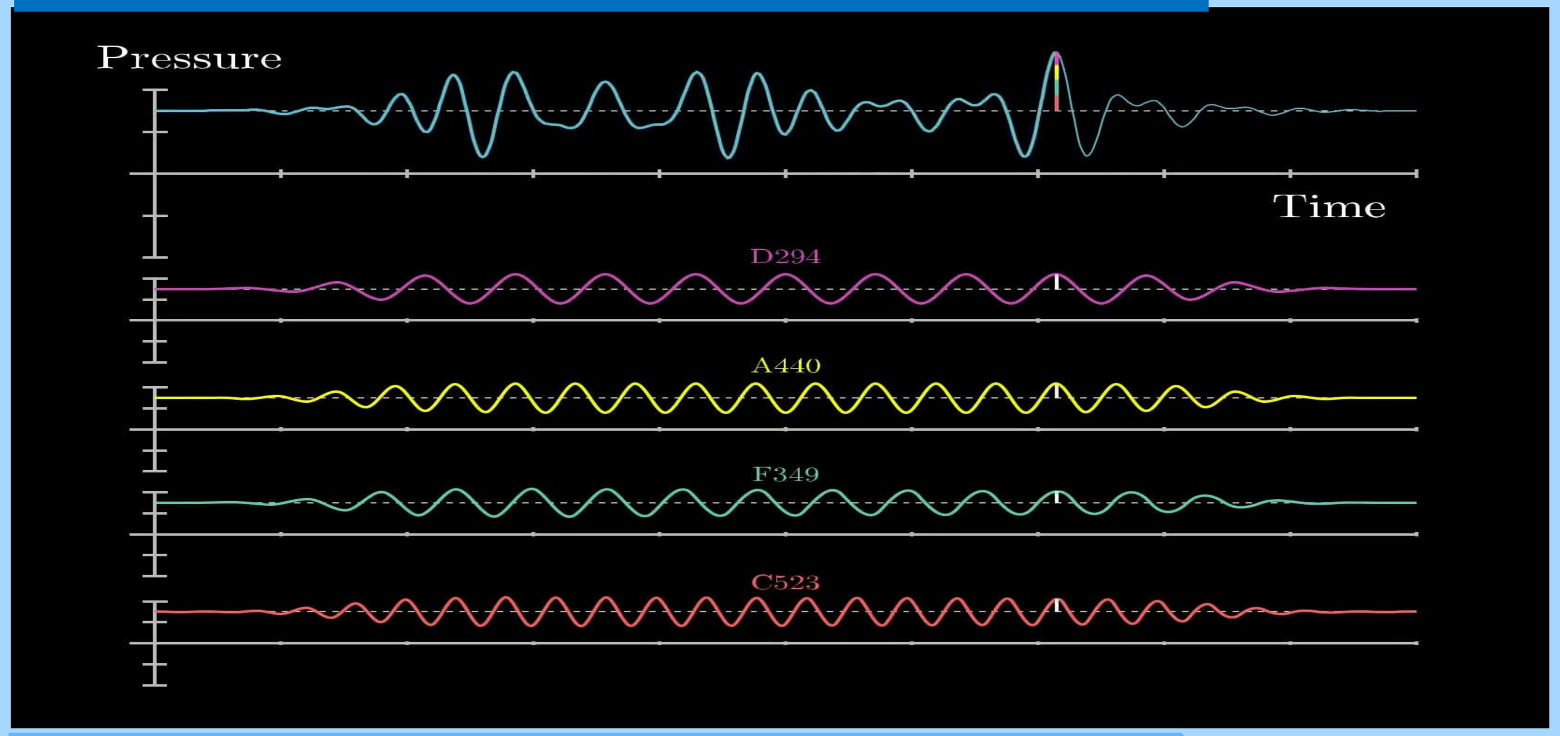
Common Misconceptions about Quantum Computing

- Quantum Computers will make Classical Computers obsolete

Potential Impacts on Signal Processing

- Quantum algorithms will replace Classical algorithms for common signal processing use cases, such as Wi-Fi and seismometers to revolutionize signal processing.

FT Visual - Grant Sanderson



Background

Fourier Transform

- Group of Mathematical Transformation functions
- Represent complex analog signal as set of sinusoids of distinct frequency (IEEE).
- 1807 Publication by Jean Baptiste Joseph Fourier (IEEE).
- Key pillar of signal processing
- Popular implementations are Discrete Fourier Transform (DFT) and Fast Fourier Transform (FFT) (Dr. Derek Muller).

Classical vs Quantum Computing

- NOT just another incremental improvement over Classical Computers.
- Bits containing 0s and 1s vs Quantum Bits, or Qubits, containing a combination of amplitudes for states 0 or 1.
- While quantum computers CAN perform traditional computing tasks by performing only a specific set of controlled rotations on these Qubits, many more advanced calculations are unlocked by exploring all other possible transformations of the 3d Block sphere.
- By exploiting what we know about Quantum Mechanics, such as properties of Entanglement, Superposition, Decoherence, Interference (IBM), these Quantum Computers can provide significant speedup for some optimized algorithms.
- The outputs of Quantum calculations encode information about the probability of any Qubit being in any given state, therefore providing a much more thorough result compared to classical computers which can provide only 1 output for a given input (IBM).

Research Methodology and Limitations

The Move to Quantum

What this means for our Fourier Transforms. FTs have already been leveraged with Quantum Computers to perform essential operations on these Qubit fields, as they allow us to quickly convert Quantum Phases to a binary output.

Experiment

- Simulate QFT on available hardware
- Encode a variety in of complex waves in a Superposition of Quantum States.
- Analyze Results with a focus on Scalability and Practicality.

Experiment Methodology

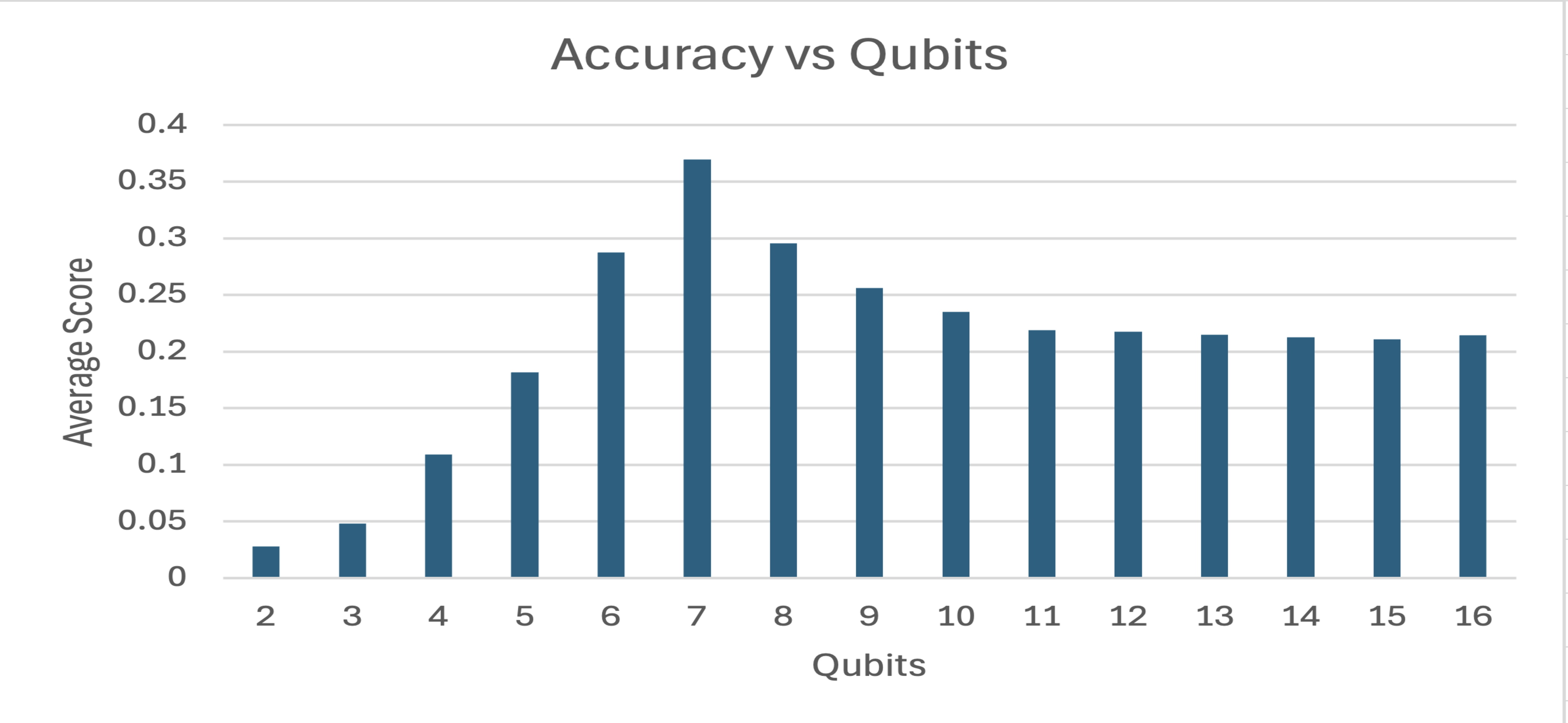
- Encode combinations of 2, 3, 5, 8, 13, 21, 34, 55, 89, 144 distinct sine waves as a Quantum Superposition, and simulate QFT to derive input frequencies.
- Frequency range from 1/1000 to 1
- Perform benchmark on several simulation containing 2-16 Qubits.
- Repeat benchmark 20 times to get more holistic data.
- Analyze simulation output for accuracy.
- Determine minimum Qubits needed to accurately process various signals.
- Derive trends, estimate quantum computational requirements of classic signal processing tasks.

Limitations on Experiments Performed

- Running all desired benchmarks on actual Quantum Hardware was not feasible for this experiment as I wanted to test more than 3 free circuits provided by IBM.
- Time cannot be used in results as simulation runs at a variable speed depending on the host and does not scale in a similar way to actual Quantum Computation
- These limitations do not impact the results as the aim was to derive trends in the amount of data that can feasibly be encoded and processed by todays Quantum Hardware, not to provide a timing benchmark compared to classical computing.

References

Experiment Data



Preliminary Findings

Experiment Results

- Decode accuracy rapidly diminishes until around 10 frequencies when it levels out
- Decode accuracy was highest with 7 Qubits, regardless of frequencies present.
- Experiment does not support claims that QFT can replace FFT for complex signal processing tasks, as data does not show exceptional decode accuracy even for simple analog signals.

Common Misconceptions Debunked

- Quantum Computers only excel at very specific tasks where Quantum Phenomena such as Entanglement and Superposition can be taken advantage of.
- Quantum Computers are not optimized for household computing tasks, such as high fidelity signal processing.

Impacts on Signal Processing

- The FFT algorithm that has been used for almost a century is still the best way to approach these tasks. Building Quantum computers is still too expensive to feasibly replace existing infrastructure.

Experiment Data