Quantum Supersampling

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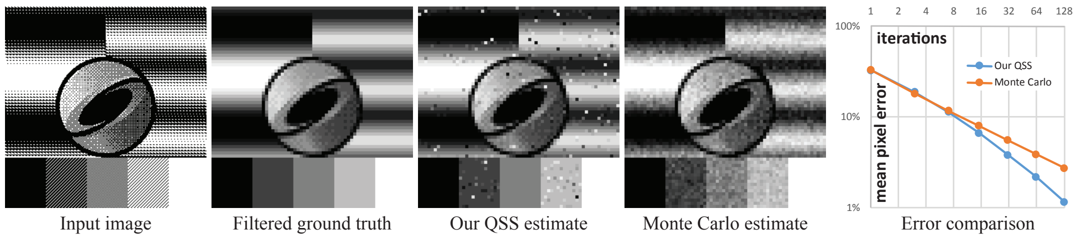

Figure 1: *Our quantum supersampling (QSS) method reduces mean pixel error, and changes the noise distribution substantially.*

Keywords: quantum, qubit, photonics, image sampling

Concepts: •**Computing methodologies** → *Image manipulation;*

With a focus on practical use of near-future quantum logic devices in computer graphics [Lanzagorta and Uhlmann 2005], we implement a qubit-based image supersampling technique with advantages over Monte Carlo estimation. In addition to applying the technique in a quantum computation device simulator, we implement a simplified version as a waveguide design for physical fabrication as an integrated photonic device.

The problem of supersampling consists of computing a pixel value as a finite sum over subpixels. A common classical solution is Monte Carlo, which computes a stochastic estimate of this sum by averaging the evaluations at randomly chosen subpixel locations.

In contrast, our *quantum supersampling* (QSS) method places the complete set of possible subpixel locations into quantum superposition, allowing their parallel simultaneous evaluation. In this configuration, a single quantum evaluation produces a phase-encoded solution for all subpixels. However, direct measurement of the resulting quantum state would produce a useless random value. To extract a useful result, we perform a transformation to produce a state that upon measurement will collapse into a value estimating the sought answer. This transformation involves repetition of the subpixel evaluation, followed by phase-based probability amplification, repeated once for each value of a qubit-based iteration counter. At the end, we apply inverse quantum Fourier transform (QFT) to the counter and read the result, collapsing it into a value corresponding to the estimated sum with a well-defined error probability.

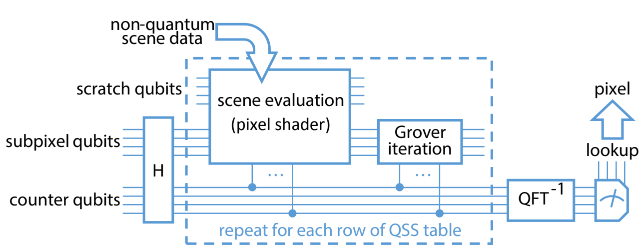

Figure 2: *Quantum logic components for sum estimation.*

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Quantum sum estimation. Sum estimation is performed using a few well-known quantum algorithms with known probability of correctness based on the number of iterations performed. Prior to subpixel evaluation we use a Hadamard transform to place all possible subpixel locations into superposition, enabling their simultaneous evaluation.

The subpixel evaluation performs selective phase inversion, similar to a Grover database search [Grover 1996]. Our example evaluation in this case returns a single bit per subpixel, so for each non-zero subpixel result, the corresponding state is phase-shifted by π radians. These phase differences become amplitude variations, with a period dependent on the sum we intend to estimate. We find the period by performing an inverse QFT on the iteration counter, finally reading it to produce a value that we use to look up the estimated sum in a pre-calculated table. The process is illustrated schematically in Figure 2. The look-up table is generated by running QSS on known source data and recording correlations between counter values and actual subpixel sums. This is an important byproduct of this technique, providing features not available with Monte Carlo.

Advantages over Monte Carlo. Key advantages of this technique over Monte Carlo estimation include lower average pixel error for the same number of subpixel evaluations, and a substantially increased number of error-free pixels, as seen in Figure 1. The QSS table provides a per-pixel indication of the probability of error, as well as next-most-likely pixel values, used to correct errors without performing further subpixel evaluation.

Practical implementation. The complexity of the quantum computation device required depends on the desired number of subsamples per pixel as well as on the desired bit depth of the output image, but not on its resolution. As a result, we are able to simulate the entire quantum computation required to produce output images, and even scale the device down for physical implementation as a quantum photonic waveguide [Carolan et al. 2015].

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