Design of a Generalized Quantum Arithmetic Logic Unit Using QFT and Multiplexed Unitaries

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Abstract

We propose a modular and generalized Quantum Arithmetic Logic Unit (QALU) architecture capable of performing essential arithmetic and logical operations using quantum gates, quantum Fourier transform (QFT), and a quantum multiplexer. Our design includes QFT-based addition and subtraction, quantum logical XOR and AND operations, and a dynamic operation selector using quantum multiplexing of unitaries. This architecture supports reprogrammability and general-purpose computation, making it a candidate for the ALU core in scalable quantum processing units (QPUs).

1 Introduction

Quantum computation offers speedups in several domains, yet most existing quantum circuits are designed for specific algorithms. A generalized, programmable architecture akin to the classical Arithmetic Logic Unit (ALU) is missing. We present a design for such a unit using well-defined quantum operations and modular selection using multiplexed unitaries.

2 QFT-Based Arithmetic Units

2.1 QFT Adder

Given a quantum state $|\psi\rangle$ and a constant a, we apply a QFT to the register:

$$R|\psi\rangle = \sum e^{2\pi i(x+a)y/N}|y\rangle$$

$$\mathrm{IQFT}(R|\psi\rangle) = \sum |x+a\rangle$$

2.2 QFT Subtractor

Analogously,

$$R|\psi\rangle = \sum e^{2\pi i(x-a)y/N}|y\rangle$$

$$\mathrm{IQFT}(R|\psi\rangle) = \sum |x - a\rangle$$

3 Logical Operators

3.1 Quantum XOR

Implemented using the CNOT gate:

$$\mathrm{CNOT}|\psi\rangle = |x \oplus a\rangle$$

3.2 Quantum AND

Implemented using the Toffoli (CCNOT) gate:

$$\mathrm{Toffoli}|\psi\rangle = |x \cdot a\rangle$$

4 Quantum Multiplexed Unitaries (QMU)

The control register selects the operation by choosing one of several unitary blocks U_z:

$$m = \sum |z\rangle\langle z| \otimes U_z$$

Operation Table

Index	**Unitary**	**Operation**
00	U1	Addition
01	U2	XOR
10	U3	AND
11	U4	Subtraction