ARC-HPC Cluster Report on Research in 2024-2025

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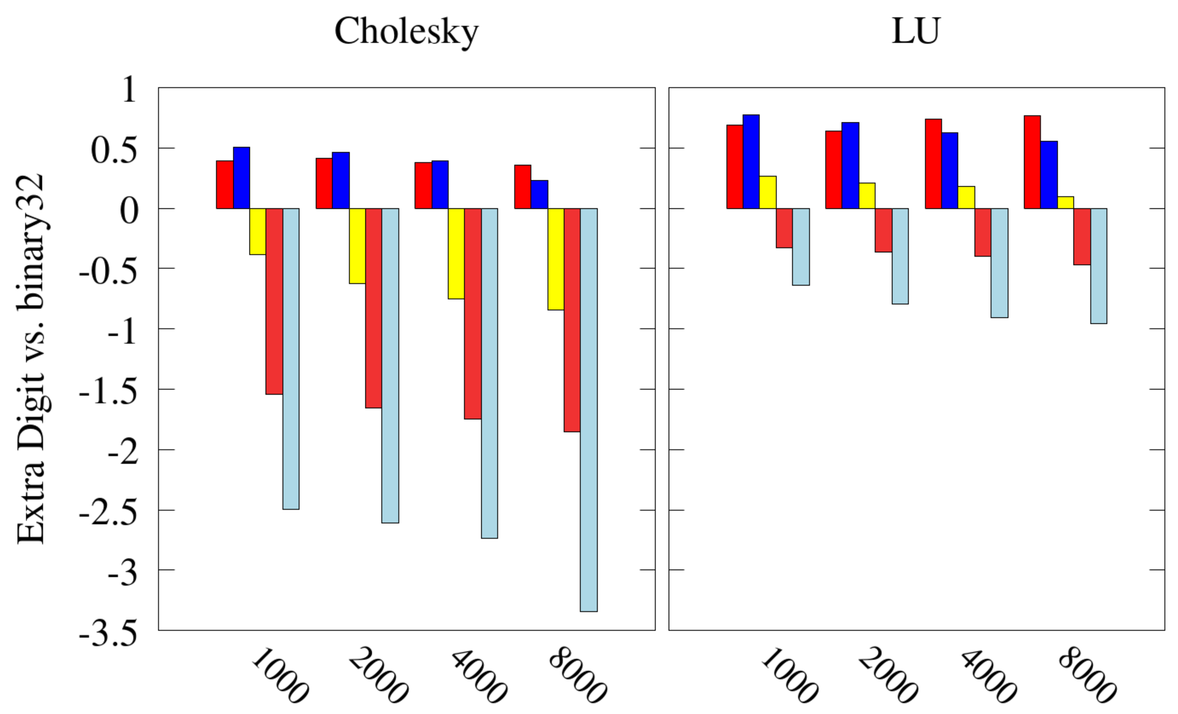
Evaluation of various FP formats in GEMM operations on FPGA

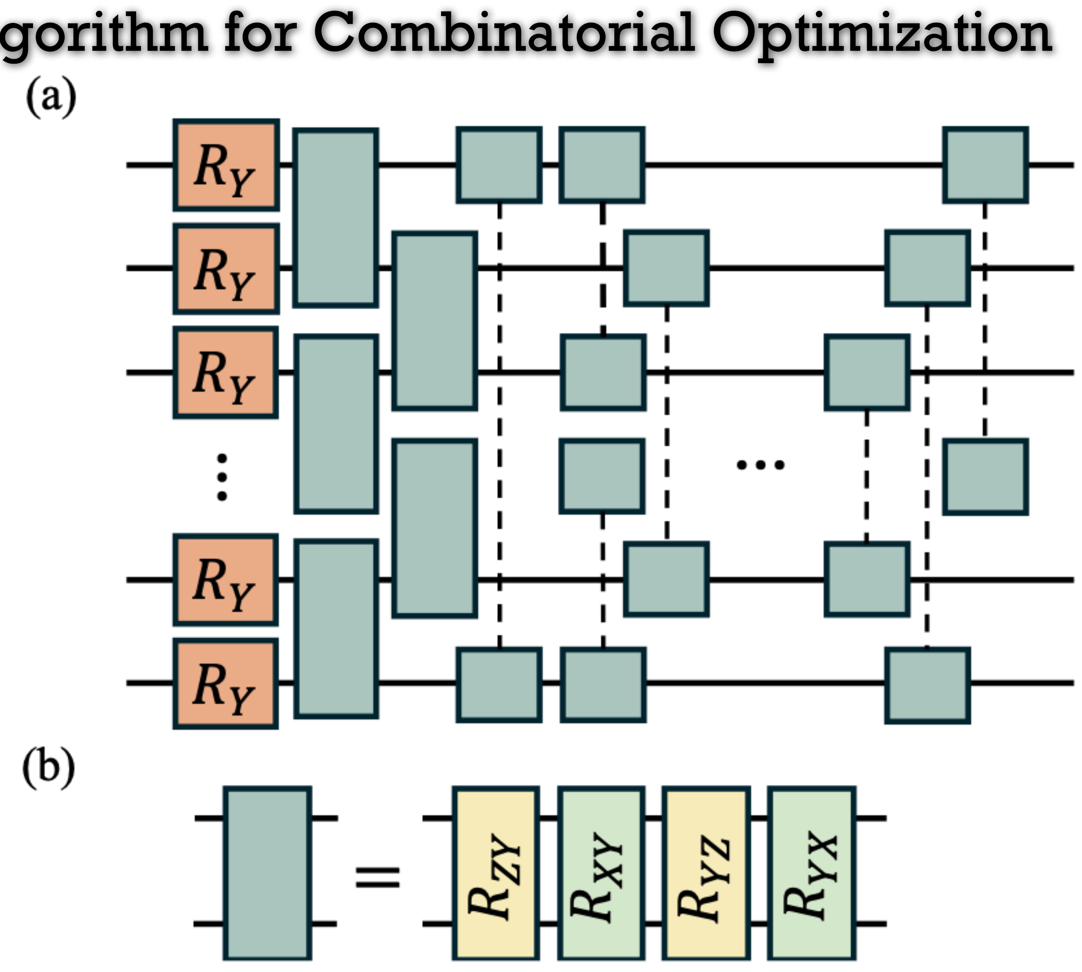
We have conducted a comparative analysis of our matrix-multiplication (GEMM) accelerator in binary32, binary128, and 32-bit/64-bit Posit formats. Posit is a variable-precision floating-point(FP) format proposed by Gustafson & Yonemoto (2017). In contrast to the standard IEEE 754 FP format, such as binary32, the Posit format has a sign, a regime, an exponent, and a fraction. To perform an arithmetic operation, we first decode these three parts. After the operation, we then encode the result. Accordingly, the Posit operation takes more steps than the IEEE 754 format. In all cases, our GEMM accelerators on FPGAs have 8x16 processing elements. The following table presents the synthesis results for our GEMM accelerators. The binary32 design exhibits the lowest resource utilization, while the other designs require more ALUTs and DSP blocks. A comparison of the binary128 and 64-bit Posit designs reveals that the logic utilization is approximately equivalent. However, the binary128 design requires roughly two times more number of DSP blocks as the 64-bit Posit design. The figure presents an analysis of numerical errors with binary32 and 32-bit Posit for two matrix decomposition algorithms.

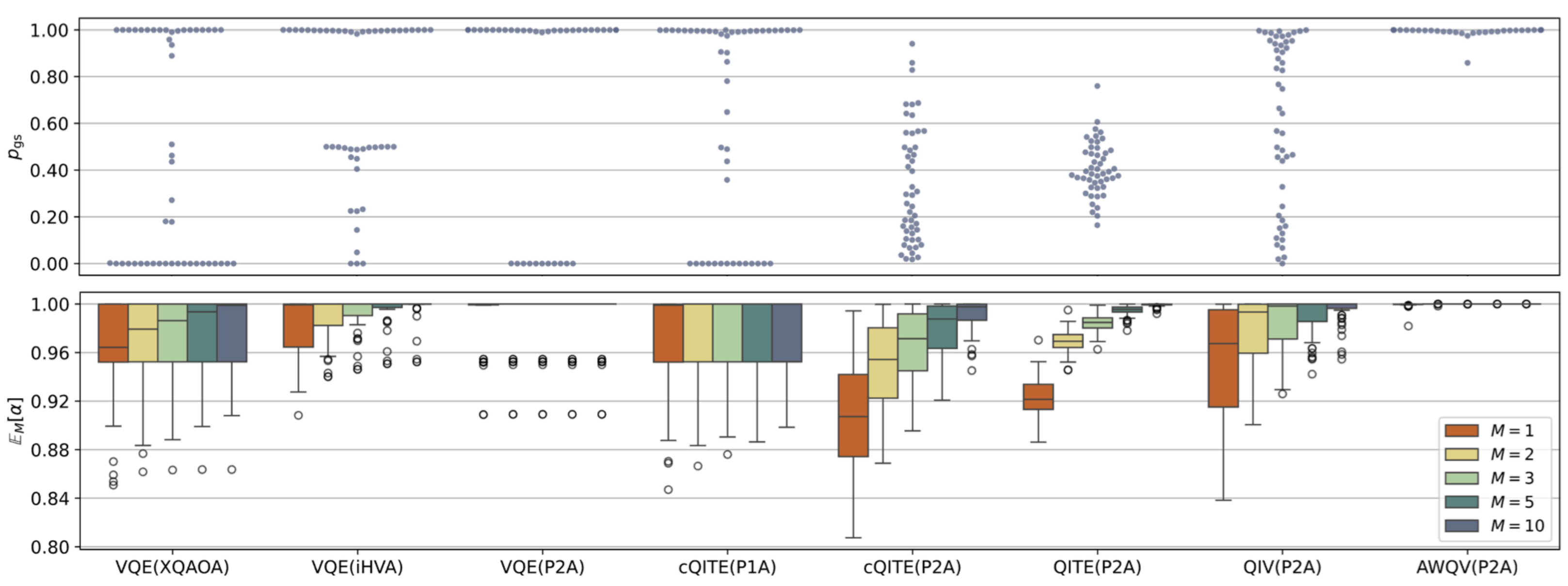
	binary32	binary128	Posit(32,2)	Posit(64,2)
ALUTs	145,903	614,483	305,196	618,428
Registers	359,222	1,045,018	537,193	929,997
Logic utilization	205,368 (22%)	528,543 (57%)	295,058 (32%)	470,141 (50%)
DSP blocks	142 (2%)	2,062 (36%)	270 (5%)	910 (16%)
Memory bits	15,219,936 (6%)	80,952,480 (34%)	15,219,488 (6%)	20,869,344 (9%)
RAM blocks	962 (8%)	4,179 (36%)	963 (8%)	1,227 (10%)
Kernel fmax	354.6	149.56	292.48	254.32



Quantum Computing (An Adaptive Weighted QITE-VQE Algorithm for Combinatorial Optimization

The variational quantum eigensolver (VQE) is an algorithm for finding the ground states of a given Hamiltonian. Its application to binary-formulated combinatorial optimization (CO) has been widely studied in recent years. However, typical VQE approaches for CO problems often suffer from local minima or barren plateaus, limiting their ability to achieve optimal solutions. The quantum imaginary time evolution (QITE) offers an alternative approach for effective ground-state preparation but requires large circuits to approximate non-unitary operations. Although compressed QITE (cQITE) reduces circuit depth, accumulated errors eventually cause energy increases. To address these challenges, we propose an Adaptive Weighted QITE-VQE (AWQV) algorithm that integrates the VQE gradients with the cQITE updates through an adaptive weighting scheme during optimization. In numerical simulations for MaxCut on unweighted regular graphs, AWQV achieves near-optimal approximation ratios, while for weighted Erdős-Rényi instances, it outperforms the classical Goemans-Williamson algorithm.





Astrophysical Simulations

Understanding the formation of galaxies, stars, and planetary systems cannot rely on astronomical observations alone. The evolutionary timescales of astrophysical objects span millions to billions of years, whereas observations capture only a single moment in the present Universe. Numerical simulations therefore play a crucial role in bridging this gap.

We use high-performance supercomputers to run large-scale simulations that follow the fundamental physical equations governing the motions of stars and interstellar gas. By modeling gravitational dynamics, hydrodynamical gas flows, and energetic processes such as supernova explosions, we aim to reproduce a realistic Milky Way Galaxy inside a computer. With these simulations, we investigate where and how our Solar System formed 4.6 billion years ago, how it has migrated through the Galaxy over cosmic time, and what kind of Galactic environment it currently inhabits.