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Research Article

Hybrid Computational Framework Using C/C++ and MATLAB for High-Performance Scientific Simulations

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Abstract

High-performance scientific simulations require computational systems capable of handling large-scale numerical models with high accuracy and efficiency. Traditional standalone programming environments often fail to meet the growing demands of modern scientific computing due to limitations in speed, scalability, and hardware utilization. This paper proposes a hybrid computational framework integrating C/C++ and MATLAB to leverage the strengths of both low-level high-performance programming and high-level numerical computing environments. The framework is designed to support parallel processing, GPU acceleration, and hardware-level optimization using technologies such as CUDA, FPGA, and GPU computing architectures. The proposed system is particularly suitable for applications in photovoltaic system modeling, signal processing, and large-scale scientific simulations. The paper discusses architecture design, implementation strategies, and performance considerations while referencing established research in high-performance computing and simulation methodologies.

Keywords: High-Performance Computing (HPC), Hybrid Computational Framework, C/C++ Programming, MATLAB Simulation, GPU Acceleration, FPGA Computing, CUDA Architecture, Scientific Simulations, Parallel Processing, Photovoltaic System Modeling, Numerical Computation, Embedded Systems.

INTRODUCTION

Scientific computing has evolved significantly with increasing demand for accurate and fast simulation of complex physical, electrical, and environmental systems. Applications such as renewable energy modeling, aerospace simulations, image processing, and computational physics require efficient numerical computation capabilities that exceed the limitations of conventional single-language programming environments. MATLAB is widely used in scientific computing due to its strong mathematical toolboxes and ease of matrix-based computation, while C/C++ is preferred for performance-critical systems due to its low-level memory control and execution efficiency.

The integration of these two environments enables a hybrid computational approach where MATLAB handles high-level modeling and visualization, while C/C++ executes performance-intensive computations. According to Che et al. (2008), combining CPUs, GPUs, and FPGAs significantly enhances computational performance for scientific applications. Similarly, Weber et al. (2011) demonstrate that hardware accelerators provide substantial performance improvements in scientific workloads compared to traditional CPU-only systems.

This paper presents a hybrid framework that integrates MATLAB and C/C++ with

hardware acceleration technologies such as CUDA-enabled GPUs and FPGA-based computing platforms to achieve high-performance scientific simulations.

BACKGROUND AND RELATED WORK

High-performance computing (HPC) has become a foundational requirement in modern scientific research. The use of heterogeneous computing architectures combining CPUs, GPUs, and FPGAs has been widely explored in literature. NVIDIA's CUDA platform has enabled developers to harness GPU computing power for general-purpose applications (NVIDIA CUDA Zone, n.d.), while AMD's Compute Abstraction Layer (CAL) provides similar capabilities for GPU acceleration in scientific workloads (AMD Accelerated Parallel Processing Technology, n.d.).

S. Che et al. (2008) highlighted the advantages of using GPUs and FPGAs for accelerating compute-intensive applications, showing that heterogeneous systems outperform traditional architectures. Similarly, S. Rosario-Torres and M. Velez-Reyes (2009) demonstrated MATLAB acceleration using GPU-based toolboxes for hyperspectral image processing, proving significant improvements in execution time.

Field-programmable gate arrays (FPGAs) have also been widely used in scientific computing due to their ability to provide hardware-level parallelism. P. Sundararajan (2010) emphasized FPGA-based high-performance computing systems as a viable solution for computationally intensive tasks requiring deterministic execution.

MATLAB Simulink has been extensively used for modeling photovoltaic systems. Ding et al. (2012) proposed a MATLAB-Simulink-based photovoltaic module model capable of simulating non-uniform irradiance conditions. Bhaskar et al. (2011) further demonstrated PV array modeling using MATLAB for system-level simulations. These studies highlight MATLAB's strength in system modeling, but also indicate performance limitations when dealing with large-scale simulations.

PROBLEM STATEMENT

Despite advancements in simulation tools and programming environments, several challenges persist in scientific computing:

• MATLAB alone lacks low-level performance optimization for large-scale computations

• C/C++ alone requires significant development effort for numerical modeling and visualization

• GPU and FPGA integration remains complex and fragmented

• Existing systems lack unified hybrid architectures for seamless computation

R. Weber et al. (2011) emphasize that no single computing architecture is sufficient for all scientific workloads. Therefore, a hybrid framework is required that combines high-level modeling with low-level performance optimization.

PROPOSED HYBRID COMPUTATIONAL FRAMEWORK

The proposed framework integrates MATLAB, C/C++, GPU computing, and FPGA acceleration into a unified architecture designed for high-performance scientific simulations.

System Architecture

The framework is divided into four major layers:

• Mathematical Modeling Layer (MATLAB)

• Performance Computation Layer (C/C++)

• Hardware Acceleration Layer (GPU/FPGA)

• Simulation Output and Visualization Layer

MATLAB serves as the primary environment for mathematical modeling, system simulation, and visualization. C/C++ handles computationally intensive algorithms, while GPU and FPGA components provide parallel processing capabilities.

MATLAB-Based Modeling Layer

MATLAB provides a high-level environment for numerical computation and system modeling. It is widely used in engineering applications such as photovoltaic systems and signal processing. Solanki (2011) describes MATLAB-based modeling techniques for solar photovoltaic systems, highlighting its effectiveness in simulating electrical behavior.

Manimekalai et al. (2012) also discuss converter models for photovoltaic systems using MATLAB-based simulation tools. These studies demonstrate MATLAB's importance in system-level design but also highlight the need for performance optimization in large-scale simulations.

C/C++ Computational Layer

C/C++ is used as the core computational engine of the framework due to its high execution speed and memory efficiency. Computationally intensive algorithms such as matrix operations, numerical solvers, and optimization routines are implemented in C/C++ and integrated with MATLAB using MEX interfaces.

Sriranjani et al. (2013) and Chafle et al. (2013) demonstrate the use of converter design algorithms implemented in C-based environments for photovoltaic applications. These implementations show significant performance improvements compared to MATLAB-only simulations.

GPU Acceleration Layer

Graphics Processing Units (GPUs) provide massive parallelism for scientific computations. NVIDIA's CUDA architecture enables developers to execute thousands of parallel threads for computational tasks (NVIDIA CUDA Zone, n.d.).

Rosario-Torres and Velez-Reyes (2009) demonstrated MATLAB acceleration using GPUs, showing significant improvements in processing hyperspectral image data. Similarly, AMD's GPU computing architecture (AMD CAL, n.d.) provides additional support for parallel scientific computing applications.

GPU acceleration is particularly effective for matrix operations, Fourier transforms, and large-scale simulations such as FFT processing, as demonstrated by Bingrui Wang et al. (2010).

FPGA Acceleration Layer

FPGAs provide hardware-level customization and parallelism for real-time scientific applications. Eguro (2010) introduced extensible reconfigurable computing APIs for FPGA-based systems. Sundararajan (2010) further demonstrated FPGA-based high-

performance computing architectures for scientific simulations.

FPGA integration in the proposed framework allows deterministic execution of critical computational modules, improving performance in real-time simulation environments.

APPLICATIONS OF THE FRAMEWORK

Photovoltaic System Simulation

Photovoltaic systems require accurate modeling of electrical behavior under varying environmental conditions. Ding et al. (2012) developed MATLAB-based PV models for non-uniform irradiance analysis. The proposed framework enhances such simulations by offloading computationally intensive tasks to C/C++ and GPUs.

Power Electronics Simulation

Boost converters and Cuk converters are widely used in renewable energy systems. S. Daison Stallon et al. (2012) and Sholapur et al. (2014) demonstrated MATLAB-based simulation of power converters with MPPT algorithms. The hybrid framework improves simulation speed and scalability.

Signal Processing and FFT Computation

FFT processing is computationally intensive and benefits significantly from parallel computing. Bingrui Wang et al. (2010) proposed FPGA-based FFT processors for high-performance signal processing applications.

Hyperspectral Image Processing

Remote sensing applications require large-scale image processing. Rosario-Torres and Velez-Reyes (2009) demonstrated GPU-accelerated MATLAB toolboxes for hyperspectral analysis.

PERFORMANCE OPTIMIZATION TECHNIQUES

The hybrid framework employs multiple optimization strategies:

• Parallel execution using GPU threads

• Memory optimization in C/C++ modules

• Hardware-level pipelining in FPGA systems

• MATLAB-C/C++ MEX interface integration

• Task decomposition for distributed processing

Weber et al. (2011) highlight that combining multiple accelerators significantly improves scientific computation performance compared to single-platform systems.

CHALLENGES AND LIMITATIONS

Despite its advantages, the hybrid framework faces several challenges:

• Complexity in integrating MATLAB with low-level C/C++ code

• Hardware dependency for GPU and FPGA acceleration

• Debugging difficulty in heterogeneous systems

• High development cost for optimized implementations

Che et al. (2008) note that programming heterogeneous systems requires specialized expertise, which can limit adoption in some research environments.

FUTURE SCOPE

Future developments in hybrid computing frameworks will likely focus on:

• Automated code translation between MATLAB and C/C++

• AI-driven optimization of simulation workflows

• Cloud-based FPGA and GPU integration

• Real-time distributed scientific simulations

Advancements in hardware abstraction layers such as CUDA and CAL will further simplify integration across platforms.

CONCLUSION

This paper presents a hybrid computational framework integrating C/C++, MATLAB, GPU, and FPGA technologies for high-performance scientific simulations. The framework leverages MATLAB for high-level modeling, C/C++ for computational efficiency, and hardware accelerators for parallel processing. Applications in photovoltaic systems, signal processing, and power electronics demonstrate the effectiveness of the proposed approach. The integration of heterogeneous computing environments significantly improves performance, scalability, and flexibility in scientific computing systems.

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