Accelerating Finite-Element Structural Elastic Dynamic Analysis Using GPU Computing

NHERI Computational Symposium
2024
February 1-2
Los Angeles, California

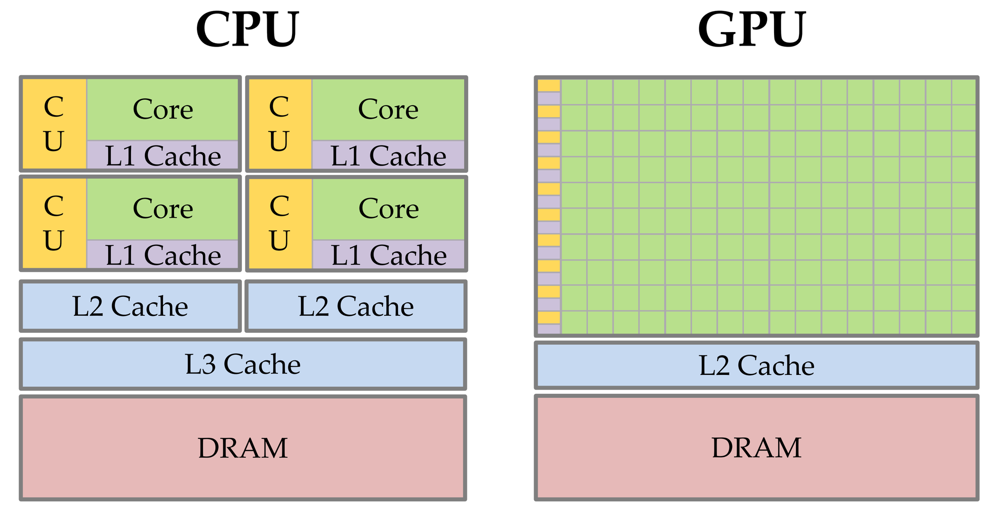
Gustavo A. Araújo R.[1], Barbara G. Simpson[1], Minjie Zhu[2], and Michael H. Scott[2]
[1]Stanford University, [2]Oregon State University

GPU-accelerated elastic finite element analyses (FEA) achieve a **115x speedup** compared to CPU-driven analysis with **10^6 degrees of freedom (dofs)**. **Assembly** and **domain update** stages experienced **significant acceleration**, but the **solver remains a bottleneck.**

Scan QR code to download **Full Paper**

Introduction

- **Computational limitations** in FEA impact **modeling fidelity** and **run time**[1].
- **CPU parallel processing** quickly achieves **performance plateaus** with increasing number of cores.
- **GPUs** offer an alternative for accelerated FEA, using **thousands of cores** and **massive parallelization**.



CPU	GPU
• Sequential tasks • Low latency • Multiple instruction	• Parallel tasks • High throughput • Multiple data

Figure 1. CPU vs GPU architecture.

Methods

A pilot program was built in CUDA[2] to fully GPU-accelerate a linear-elastic dynamic analysis. Compared to previous implementations, all major tasks (assembly, solver and domain update) were ported to the GPU[3].

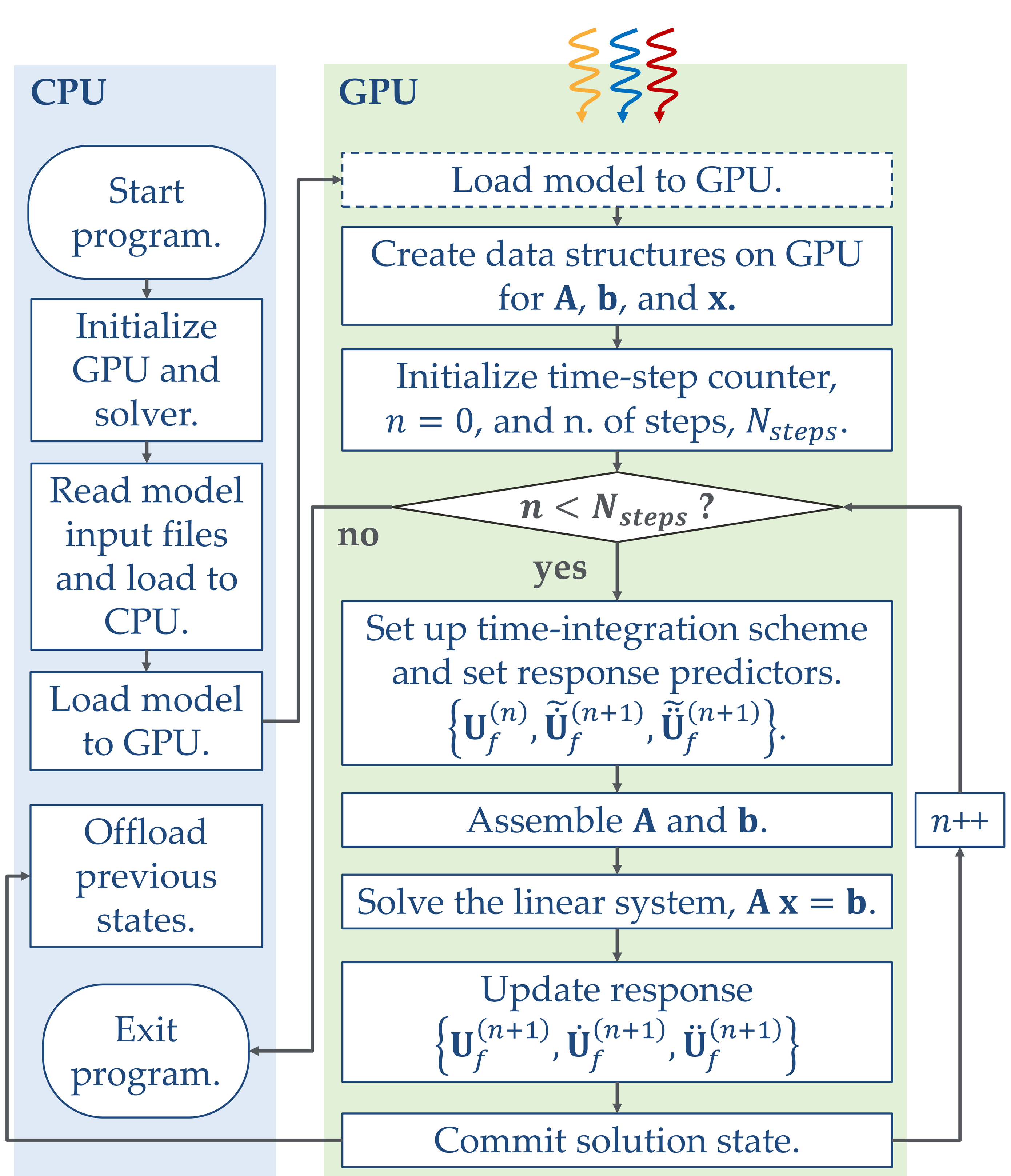


Figure 2. Fully GPU-accelerated elastic FEA.

Solver:
AmgX[3] with PCG method.

Assembly:
Threads add element contributions; duplicates from shared dofs are later summed and reduced.

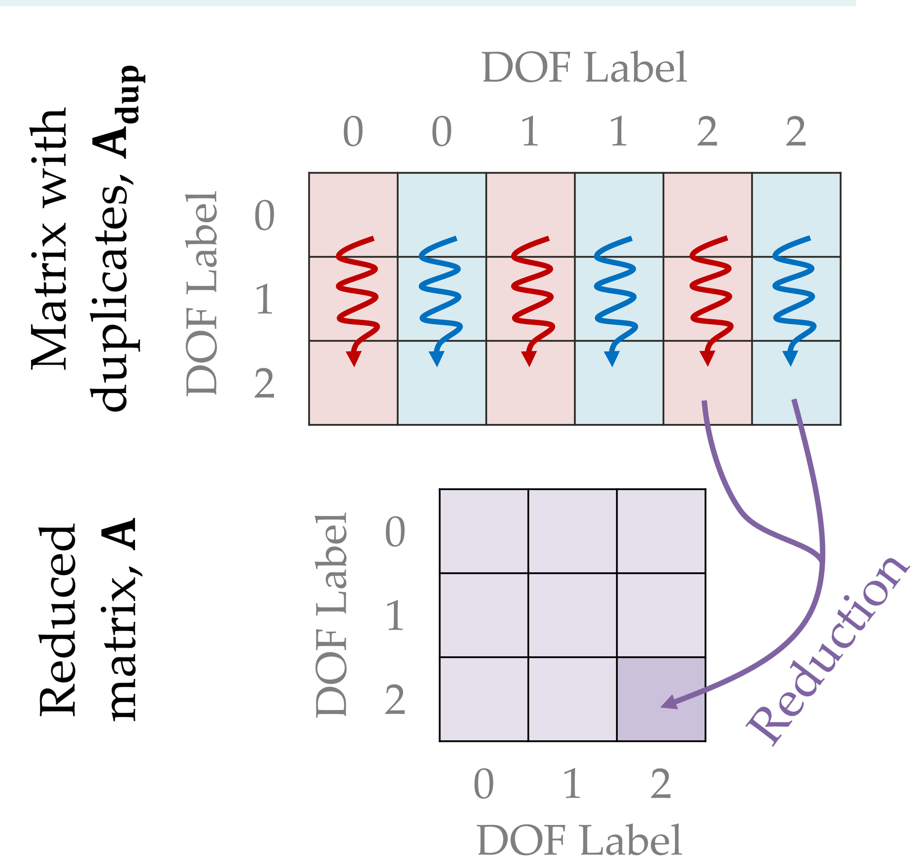


Figure 3. GPU-accelerated assembly.

CUDA programming model

- **CUDA threads** on NVIDIA® GPUs execute tasks in **parallel** by **collectively** running a specific **kernel function**.
- Threads are organized in **blocks and grids.**

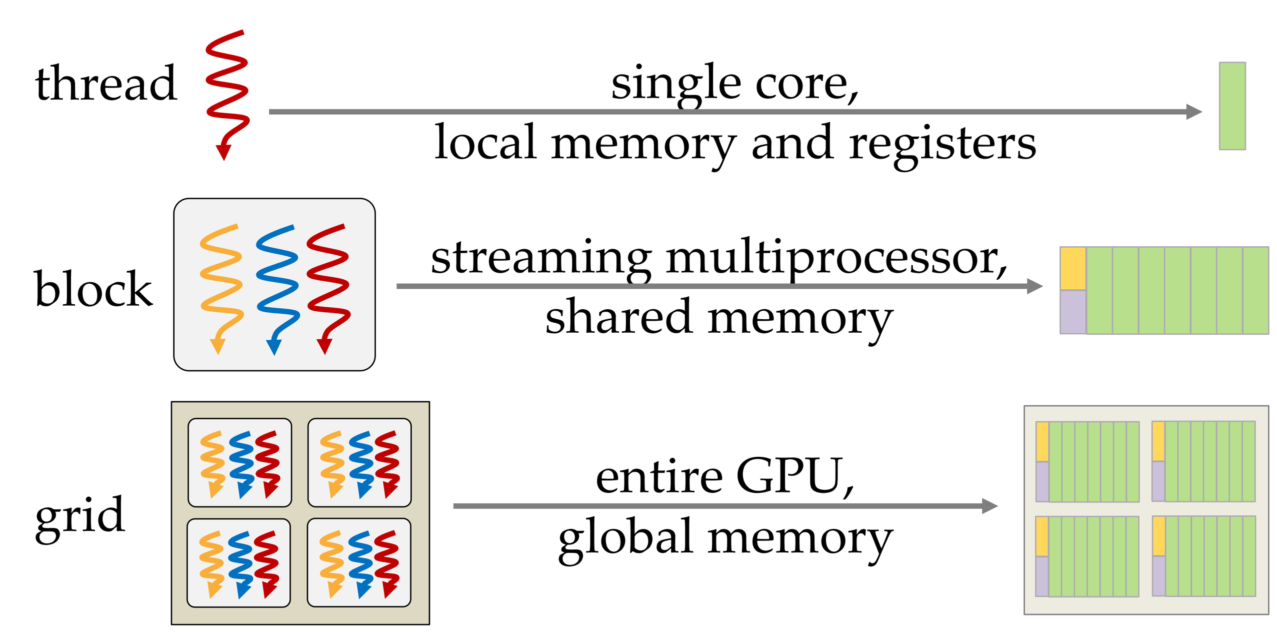
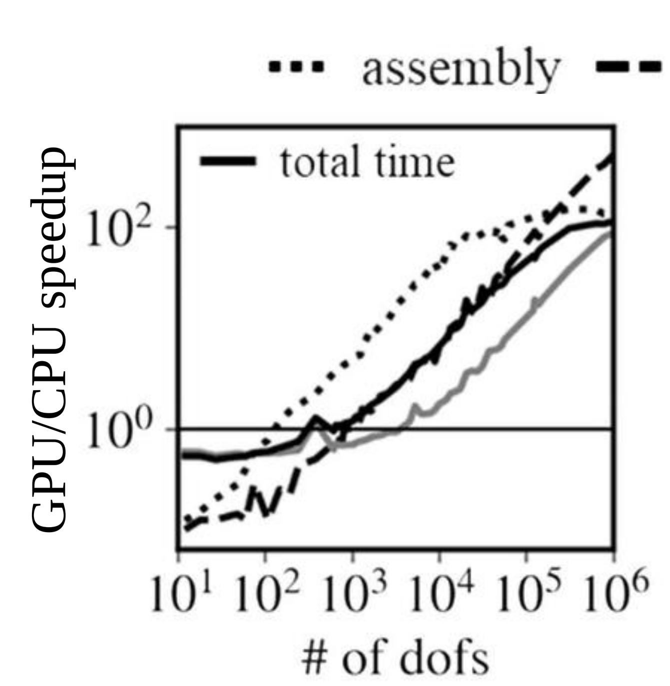


Figure 4. CUDA programming and memory model[2].

Results



Speedups of more than 100x! More evident in assembly stage.

Figure 5. Speedups for a single analysis time step[4].

Conclusions

- Feasibility of fully GPU-accelerated linear-elastic analysis.
- Finer discretization does not necessarily increase GPU run time for assembly and update steps.
- Speedup in solver stage depends on DOFs.

References

1. Lu, X. and Guan, H. (2017), Earthquake Disaster Simulation of Civil Infrastructures: From Tall Buildings to Urban Areas, 1st ed., Springer Singapore, doi: https://doi.org/10.1007/978-981-10-3087-1.
2. NVIDIA. (2017a), "CUDA Toolkit 9.0", NVIDIA, September.
3. NVIDIA. (2017b), "AMGX Reference Manual", NVIDIA, October.
4. Simpson, B.G., Minjie, Z., Seki, A. and Scott, M. (2023), "Challenges in GPU-Accelerated Nonlinear Dynamic Analysis for Structural Systems", Journal of Structural Engineering, American Society of Civil Engineers, Vol. 149 No. 3, p. 04022253, doi: 10.1061/JSENDH.STENG-11311.

Acknowledgements

This research was supported by National Science Foundation (NSF) under grant number CMMI-2145665, titled CAREER: Accelerating Real-time Hybrid Physical-Numerical Simulations in Natural Hazards Engineering with a Graphics Processing Unit (GPU)-driven Paradigm. The findings, opinions, recommendations, and conclusions in this study are those of the authors alone and do not necessarily reflect the views of others, including the sponsors