CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

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Project Number

S1405

Project Title

An Optimized Multigrid Algorithm for Enabling Efficient Physical Simulations on Realistic Geometries

Abstract

Objectives

Partial differential equations (PDEs) are used in physics to mathematically describe the workings of the universe. Using computers to solve these equations allows scientists and engineers of all disciplines to create realistic simulations of real-life phenomena such as the distribution of stress across a support beam in a building to ensure its safety; the diffusion of calcium through a heart cell to improve medical knowledge and save lives; or the Einstein field equations around a black hole to understand how it generates gravitational waves. However, the physics of the real world is very complex, and as a result, when solving such PDEs to accurately represent reality, existing solution methods can exhibit prohibitively long computation times. In this project an improved PDE solver algorithm is developed to enable more efficient creation of physical simulations.

Methods

In most PDE solver schemes, discretized models of real geometries, referred to as geometric meshes, can be used to approximate physical objects and the equations that govern their behavior. Unlike the best existing methods, which discard information about this underlying geometric mesh, the proposed algorithm creates a hierarchy of multiresolution meshes, retaining geometric information on a multiscale level. This allows for a more faithful and efficient simulation of reality, capable of adapting to differing speed and resolution criteria. The developed algorithm utilizes the GAMer software package to generate the geometric meshes used in simulation, FEniCS software to discretize the PDEs, and the PETSc libraries for essential linear algebra functions.

Results

The computation time of the algorithm was tested against other established PDE solver methods by solving sample PDEs to a target accuracy. Experimental results show that the developed algorithm is faster than most available methods, and is competitive with the fastest of them.

Conclusions

The algorithm here proposed is capable of reaching a solution to the tested PDEs at a rate competitive with the fastest available methods, indicating it is highly computationally efficient. It additionally provides increased flexibility due to its use of an adaptive multilevel approach. This enables faster generation of computer simulations of reality through the solution of physical equations, making it possible to model very large-scale real-world problems.

Summary Statement

A superior numerical algorithm is developed for solving partial differential equations across three-dimensional geometries, better enabling the fast and efficient generation of physical simulations of reality.

Help Received

I developed and tested the software presented independently. I used computational resources provided by the lab of Dr. Rommie Amaro, at the University of California, San Diego. I consulted with, and received advice from, Dr. Christopher Lee at the University of California, San Diego.