Title: Acceleration of Unsteady Hydrodynamic Simulations
Using the Parareal Algorithm

Author: Araz Eghbal Andrew G. Gerber Eric Aubanel

PII: S1877-7503(16)30498-7
DOI: http://dx.doi.org/doi:10.1016/j.jocs.2016.12.006
Reference: JOCS 595

To appear in:

Received date: 13-6-2016
Revised date: 27-11-2016
Accepted date: 17-12-2016

Please cite this article as: Araz Eghbal, Andrew G. Gerber, Eric Aubanel, Acceleration of Unsteady Hydrodynamic Simulations Using the Parareal Algorithm, *<![CDATA[Journal of Computational Science]]>* (2016), http://dx.doi.org/10.1016/j.jocs.2016.12.006

Acceleration of Unsteady Hydrodynamic Simulations Using the Parareal Algorithm

Araz Eghbal[a,*], Andrew G. Gerber[a], Eric Aubanel[b]

[a]*Department of Mechanical Engineering, University Of New Brunswick, Fredericton, Canada E3B 5A3*
[b]*Faculty of Computer Science, University Of New Brunswick, Fredericton, Canada E3B 5A3*

Abstract

The parareal algorithm is used to obtain temporal parallelization added to the parallelism obtained from the conventional spatial domain decomposition techniques for hydrodynamic problems. Parareal solution becomes unstable at high Reynolds numbers where the non-linear convection term in the Navier-Stokes equations becomes much larger than the diffusion term. A new framework that allows using parareal for unsteady high Reynolds number hydrodynamic problems is proposed where parareal coarse and fine time integration operators are incorporated with coarse and fine spatial grids respectively and RANS or DES turbulence models are employed with a blended filter that can be tuned for the stability of the method.

This framework is composed of three solution stages where parareal serves as a transitional stage that bridges a coarse grid solution to a fine grid one. While in lower Reynolds number problems parareal solution can serve as a final solution, in higher Reynolds number problems with high degree of non-linearity parareal provides a shorter path to the final solution. Anticipating a parareal stage in a transitional sense allows a looser convergence requirement which leads to high speedup gains in that stage. On the other hand improved initial values at the beginning of the last stage yields a shorter final fine stage solution.

A windowing technique is employed in this methodology to further control the parareal instabilities by keeping the parareal corrections smaller while still being able to cover an arbitrary simulation time with given computational resources. Application of this methodology has been illustrated with a fully turbulent vortex shedding from a cylinder and a flow from the Grand Passage tidal zone in the Bay of Fundy. It is concluded that a tuned turbulence model may sufficiently stabilize the parareal methodology for many practical problems such that it becomes applicable in the initialization process if not accurate enough as a final solution.

MPI and OpenMP programming paradigms are used for temporal parallelism introduced by parareal and data parallelism obtained via spatial domain decomposition methods respectively. Also all computational tasks are accelerated using CUDA compatible GPGPUs.

Keywords: Parareal, Domain Decomposition, Vortex Shedding, RANS, DES, LES, GPGPU

---

1. Introduction

Simulation of practical hydrodynamic problems, using Computational Fluid Dynamic (CFD) techniques, is very time consuming and hence it is important to investigate and incorporate new methods to expose additional solution parallelism and take full advantage of high-performance computing resources. Traditional spatial domain decomposition exposes significant parallelism but increasing the number of subdomains, in order to utilize all the available computational resources, does not necessarily translate to computational speedup. This is due to the fact that communication and synchronization becomes more and more costly as the number of subdomains increases.

Extension of parallelization to the temporal domain of evolution problems is interesting and have been studied for a long time. One of these methods that has gained significant attention during the past decade is the parareal algorithm [1]. Parareal is an iterative scheme and can be defined under multiple shooting[2], multi-grid or PITA[3] formalisms. Parareal employs two types of time integration operators i.e. coarse and fine propagators with which it performs a series of prescribed correction steps and approach convergence through an iterative process. Performance of parareal critically depends on the choice of these coarse and fine propagators. Coarse propagators should be computationally fast which can be achieved by using simpler physical models, larger time steps but at the same time they should be accurate enough to avoid divergence of numerical solvers. So the right balance of precision and speed is very critical for parareal performance.

The communication between the propagators within the parareal framework is small (occurring only at the end of a propagator solution) so it is scalable and highly suitable for the MPI parallel computing paradigm. Therefore

---

*Corresponding author
Email address: `araz.eghbal@unb.ca` (Araz Eghbal)