Report for the Dissertation Advisory Committee Meeting

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1 Current Research

In section I will first define the key concepts and terms that are commonly used in my research. Later, I'll describe my current research in more depth.

Flow Visualization: Flow visualization is a prominent branch of scientific visualization that enables visualization and analysis of fluid dynamics phenomena. This usually involves a computational fluid dynamics simulation which outputs the data into a mesh and associated fields. Flow visualization is employed the study of aerodynamics, climate modeling, combustion, etc. Domain scientist use the visualization to capture and highlight regions of interest to better understand the fluid behavior. Most common technique to perform flow visualization is by using *particle advection*.

Particle Advection: Particle advection is the process of moving massless particles through a flow field, where the velocity of the particle is calculated using the fields on the problem mesh. This process can be mathematically described by the following equation:

$$P_{i+1} = P_i + h \times v(t_i,\ P_i) \tag{1}$$

Equation 1 mathematically defines how this process is performed. In the equation, P_i is the instantaneous position for the particle at time t_i and P_{i+1} is the next position of the particle. The term $v(t_i,\ P_i)$ represents the velocity at position P_i. Finally, h represents the duration of the displacement with the evaluated velocity information. Particle advection is the basis over which various flow visualization techniques are built.

Computationally modeling Equation 1 has many implicit components associated with it. For each step of a particle, we need to be able to *locate* the containing cell for the particle in the problem mesh. After locating the correct cell, we need to be able to *interpolate* the fields on the problem mesh to calculate the velocity of the particle. Finally, we need to use Equation 1 to *integrate* the trajectory of the particle over a series of steps. Equation 1 is also known as the Euler integration scheme, which is a first order scheme and requires only one locate and interpolate operation. Higher order integration scheme require more locate and interpolate operations, which can be determined my the order of the integrator, but in exchange offer better accuracy. This process needs to be repeated for all particles over the number of steps each particle needs to take before termination. Hence, it is apparent that particle advection can be a very computationally expensive operation. This fact is compounded by some other explicit factors like — volume of data, number of particles required for analysis, initial distribution of particles, and nature of the flow field.

My current research focuses on better understanding of all these factors that affect the performance of particle advection. Currently I am working on my area exam which comprehensively surveys the particle advection related works that improve or study the performance of particle advection while addressing or or more of the above implicit or explicit factors. I am also studying the shared memory performance of particle advection through the use of the *roofline model*. This study involves understanding the direct impact of various parameters on the performance of the algorithm.

Finally, my objective of studying the performance characteristics of particle advection is to develop a exascale ready flow visualization system. Such a system needs to be highly configurable, extensible and efficient. It needs to be able to handle the analysis requirements from various domains. This system will become a major part of my dissertation, and I plan to demonstrate its usefulness for the flow analysis needs of the ECP community.

Apart from this my research also involves contributing code to the VTK-m library, but for the sake of brevity I have left that out from this report.

2 Publications

1. A. Yenpure, H. Childs, and K. Moreland, "Efficient Point Merging Using Data Parallel Techniques," in *Eurographics Symposium on Parallel Graphics and Visualization* (H. Childs and S. Frey, eds.), The Eurographics Association, 2019
2. D. Pugmire, A. Yenpure, M. Kim, J. Kress, R. Maynard, H. Childs, and B. Hentschel, "Performance-Portable Particle Advection with VTK-m," in *Eurographics Symposium on Parallel Graphics and Visualization* (H. Childs and F. Cucchietti, eds.), The Eurographics Association, 2018

3 Potential Future Publications

1. Boundary Termination Optimization for Lagrangian Basis Flows
   w/ Sudhanshu Sane
2. Distributed Memory Particle Advection Bake-off
   w/ Roba Binyahib
3. Particle Advection with Device Targeting for Better Performance
   w/ Kristi Belcher
4. Analysis of Particle Advection Performance using the Roofline Model

4 Activities

Internship

Sandia National Laboratories: *Summer 2019*
This internship involved a self-defined project where I worked towards building the foundations of my flow visualization system. During this period I also contributed the Finite Time Lyapunov Exponent (FTLE) calculation filter to VTK-m. The filter helped Sudhanshu Sane in his efforts to perform a qualitative comparison of Lagrangian Basis Flows generated to completion to those terminated on boundaries.

Conferences

EuroVis / EGPGV 2019: *Porto, Portugal*
Presented my work on efficient point merging, which was also my DRP project.

VTK-m Code Sprint 2019: *Albuquerque, NM*
Contributed more code to VTK-m.

Supercomputing 2019: *Denver, CO*
Volunteered as a Student.

ECP Annual Meeting 2019: *Houston, TX*
Attended various session on performance profiling successes for ECP applications.

Service

Early Carrier Program Committee Member
9th IEEE Large Scale Data Analysis and Visualization (LDAV) symposium, 2019

Technical Paper Review
In Situ Visualization for Computational Science (textbook by Springer) 2020