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RPPR Final Report
as of 31-Aug-2021

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Date Received: 30-Aug-2021
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Title: Enhance GPU/CPU Hybrid Parallel Computation for Parachute Simulation with Machine Learning
Begin Performance Period: 01-May-2020
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Report Term: 0-Other
Submitted By: Xiaolin Li
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STEM Degrees:
STEM Participants:

Major Goals: Please see the uploaded report.

Accomplishments: Please see uploaded report.

Training Opportunities: A training session was provided by Advanced Cluster Inc to faculty and graduate students in our group on the operating system of the added component of the parallel cluster.

Results Dissemination: Please see uploaded report.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Xiaolin Li
Person Months Worked: 12.00
Funding Support:
Project Contribution:
National Academy Member: N

Participant Type: Co PD/PI
Participant: Hongshik Ahn

RPPR Final Report
as of 31-Aug-2021

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Partners

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ARO–DURIP: W911NF-20-1-0159

Award Report

Enhance GPU/CPU Hybrid Parallel Computation for Parachute Simulation with Machine Learning

Principal Investigator: Xiaolin Li
Co-Principal Investigator: Hongshik Ann
Stony Brook University

Reporting Period:
August 1, 2020 – July 31, 2021

Recipient:
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Unexpended Funds: $0.00 (0.0%)
Exceeds 10% of available funds: No

Technical Report on the Transitional “Intruder” Cluster

August 30, 2021

The DURIP grant W911NF-20-1-0159 ”Enhance GPU/CPU Hybrid Parallel Computation for Parachute Simulation with Machine Learning” awarded by the Army Research Office strengthens the computing power for the numerical computation and software development of the parachute simulation platform. In addition, it provides the computational resource to several other research projects associated with our research team.

With this grant, we purchased two ACTblade x210, each with 4x nodes as configured below

- **Base system**: Dual socket Xeon SP blade system with 1x 2.5” drive bay
- **Processor**: 2x Intel 22 Core Xeon Gold 6238 2.1Ghz
- **Memory**: 96GB-6x16GB DDR4 2933 Mhz
- **Storage configuration**: 1x2.5” drive bay, 1x42nn M.2 1x80mm M.2
- **Networking**: 2xRJ45 10Gb ethernet ports
- **Expansion slot**: ConnectX-4 VPI adapter card, FRD IB (56Gb/s) and 40/56GbE, single-port QSFP28, PCIe3.0x8.

We added balanced ACT serv x2280c GPUs system with detailed configuration as follows:

- **Base system**: 2U Dual Intel Skylake w/16x skts, 4xGPU capable.
- **Processors**: 2x Intel 22-Core Xeon Gold 6238 2.1GHz
- **Memory**: 192GB 12x16GB DDR4 2933MHz
- **Storage**: 240GB Value Data Center SATA 2.5” Solid State Drive
- **GPU expansion slots**: NVDIA Tesla V100 PCI-E 32GB GDDR5 Passive Single GPU
- **Networking**: 2x RJ45 1GB ethernet ports
- **Expansion slots**: ConnectX-4 VPI adaptor card, FDR IB (56Gb/s) and 40/56GbE, single port GSFP28, PCIe3.0x8

We also purchased five work stations from Advanced Cluster (ACTstation x250) for faculty and students in our research team. Among them, three are equiped with an extra GPU node. Each workstation has 20 CPU cores and 1T storage. The auxilary system, include four 49” curved monitor were purchased from Dell Inc. Due to the price reduction since we wrote the proposal, there is a fraction of fund left after the purchase of the cluster. The remaining fund was used to purchase several MacBooks and PC laptops used by graduate students and faculty members.

The software environment consists of the CentOS 8.4 operating system; the SLURM parallel management tool, the Intel OpenMPI compiler for MPI-based applications; Sun Grid Engine 2011.11p1 as the job scheduler, PETSc3.6 for solution of linear system of equations; FronTier with computational fluid dynamics applications, and the ODE solver for the dual-stress spring-mass fabric model.

Our cluster shows excellent strong scaling for hyperbolic and parabolic partial differential equations. For elliptic equations, we tested from 1 to 1024 processors for Poisson equation using the Petsc solver. The results are shown by Figure 1. The result also suggests that the speedup declined when the machine is nearly fully occupied. On the weak scaling test, we used the FronTier to solve 2-D Riemann problem with the MPI library. The base size for each processor is set to be 100×100, 200×200, 400×400 and 800×800. The efficiency is measured by T_1/T_N, where N is the number of processors occupied. The results are displayed in Figure 2 which implies that an efficiency over 50% can be achieved up to 256 cores when the base size is smaller than 400×400 while the efficiency decreases to 20% when the base size is 800×800. The third experiment tests the GPU acceleration on the cloth simulator. The GPU code is implemented with CUDA library, which is a parallel computing platform created by NVIDIA. We compare the computational time of solving spring model for different parachute types using or without using GPU device and calculate the speedup. As shown in Table 1, using GPU device can achieve at least 16 times and up to 21 times speedup for cloth simulation.

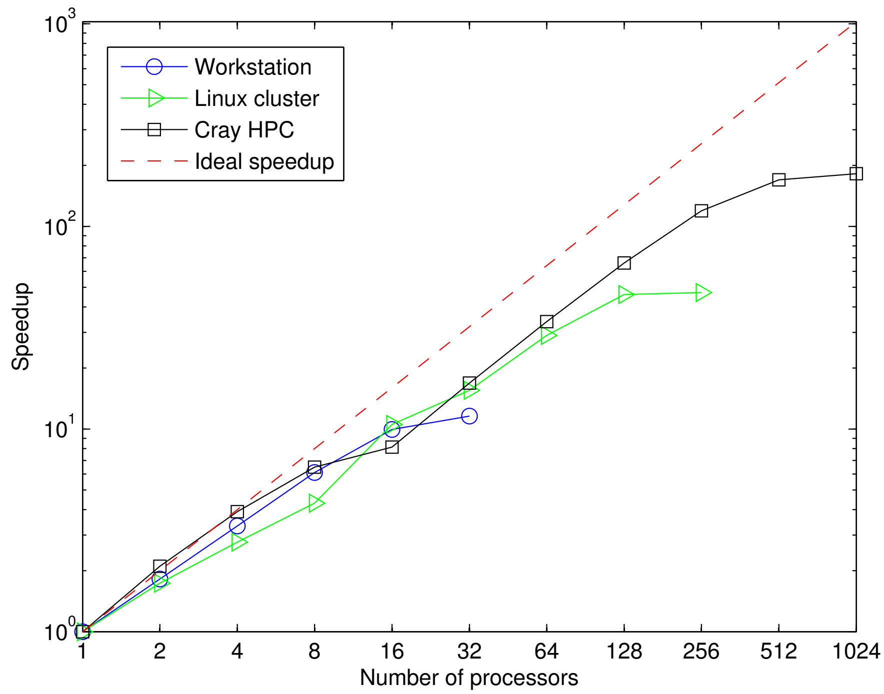

Figure 1: The figure displays the speedup of linear solver solving the 2-D Poisson equation with domain size (4096×4096) on different machine: workstation, linux cluster and Cray supercomputer.

The computational equipment will be used for the research of parachute simulation and several other projects lead by the PI and Co-PI. We summarize them in the following.

Parachute Simulation We will build the extended computational platform for parachute simulation. We will develop both incompressible fluid solver for low speed parachute and compressible fluid solver for high speed and supersonic parachute. This capability will enable the simulation of cargo deployment from high speed airplane and even to study the parachute in supersonic flow such as the re-entry vehicles. We also propose the study of fluid interaction with suspension lines and risers, an important component neglected by many previous researchers in parachute study. We will use the Dirac delta function for thin lines and the impulse action-reaction algorithm to model the fluid-riser interaction. For both incompressible and compressible fluid solvers, we will complete the implementation and testing of the turbulence modeling. We

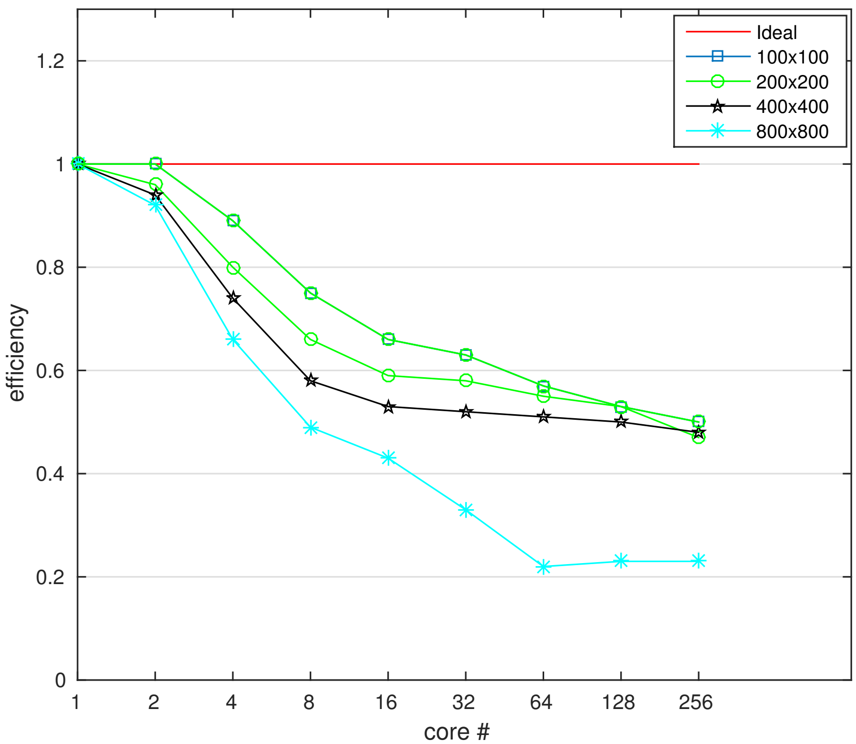

Figure 2: This figure shows the weak scaling test on 2d Riemann problem. The efficiency is calculated with T_1/T_N, where N is the number of processors used. The results implies that 50% efficiency has been achieved when mesh size per processor is smaller than 400×400.

Parachute type	CPU/GPU	Time(s)	Avg time per step(s)	Speedup
C9	CPU	2805.85	3.39	1.00
	GPU	131.90	0.16	21.2
G11	CPU	5101.47	5.41	1.00
	GPU	243.18	0.26	20.81
Intruder	CPU	1252.65	2.00	1.00
	GPU	69.67	0.11	18.18
T10	CPU	5540.02	5.99	1.00
	GPU	282.74	0.36	16.64
T11	CPU	6791.9	5.12	1.00
	GPU	352.07	0.29	17.66

Table 1: A comparison of computational time between different parachute type on CPU or GPU. The speedup is calculated based on the computing time by CPU.

will work on the parallelization of the fabric collision functions. Also in the new phase of the proposed research, we will emphasize the adaptation of our computational platform to the DOD software ecosystem and develop an API easy to be used by scientists and engineers in the DOD research laboratories. We will continue to enhance the order of accuracy in the coupling of different computational components in the system and to combine the OpenMP and GPU system for efficient parallelization and load balancing of the computational software.

Machine Learning Method in Computational Fluid Dynamics As a basic research component, we will extend our research to new methods for solving the fluid equations (Euler and Navier Stokes equations). One of the proposed study is the deep learning method for computational fluid dynamics. We will build a neural network to study two and three dimensional Navier-Stokes equation with both fixed and free boundaries. We will continue the development of the *FronTier++* library by adding more robust algorithms in geometrical optimization and topological bifurcation. We hope that this package will serve the broader academic community.

Covid-19 Batch Testing Although not directly funded by the ARO, our computational equipment will facilitate the research on the batch testing method for infectious diseaese. During the year of 2020, as the nation shares the pain and suffering of the Covid-19 pandemic, we dedicated our mathematical and computational skills to design a batch testing model. Our model is based on probability theory to optimize COVID-19 testing by a multi-step batch testing approach with variable batch sizes. This model and simulation tool dramatically increases the efficiency and efficacy of the tests in a large population at a low cost, particularly when the infection rate is low. We have recommended this model to the Stony Brook University and applied to the Covid-19 testing for students in campus.

Other project Our parallel cluster is also shared with faculty members in other SUNY campus (South Hampton). Prof. J.D'Ambroise leads a team on the study of Bose-Einstein condensation (BECs) in dilute atomic gases. The BEC phenomena has been observed on various underlying geometries such as optical lattices with varying shapes and symmetries, rings, cylinders, cones and the surface of a torus. From a mathematical perspective it is particularly interesting to explore how the various dark and bright nonlinear waves interact with the underlying geometric properties of the various background spaces in which they lies. Their recent work has been published in Phys. Lett, A. They are extending the work to the defocusing case in order to discover vortex and dark soliton structures satisfying the nonlinear Schrodinger equation on the surface of the torus.