A Coupled Framework for Parallel Simulation and Visualization

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1 Introduction

Critical climate applications like cyclone tracking require high-performance simulations to obtain real-time forecasts and high-resolution visualization by the climate scientists for subsequent timely analysis. "On-the-fly" visualization will enable the scientists to provide real-time guidance to decision makers. Such high-fidelity simulations and simultaneous visualization require large stable storage for storing the climate data and high-bandwidth networks for transferring data from the simulation to the visualization site. A combination of high simulation rate [1] and high I/O bandwidth [2], [3] leads to high rate of generation of gigabytes of output data onto the disk. This gives rise to the critical problem of storage limitation for long-running climate applications. The network bandwidth between the simulation and visualization site impacts the rate at which data is moved out from the simulation site and hence determines the amount of remaining disk space available for simulation output. Eventual unavailability of storage for simulations can result in either stalling of the simulations or loss of visualization of critical climate events. In this work, we have developed a framework which adaptively uses the processor space and adjusts the frequency of output based on the application and resource dynamics.

2 Related Work

Currently climate scientists analyze the output of climate simulation in an offline "post-processing" step after the simulation is completed. Yu et. al. [4] proposed strategies for *offline* visualization of earthquake simulations. However, these strategies cannot be applied for online visualization, which is very important for critical climate applications. The approaches in [5]–[7] propose tightly-coupled execution of the simulation and visualization components where simulation is followed by visualization on the same set of processors. As a result, simulation is stalled when visualization runs, which is undesirable as it lowers the simulation rate.

3 Adaptive Integrated Framework

We have developed an adaptive framework that simultaneously performs numerical simulations and continuous online remote visualization of critical climate applications in resource-constrained environments [8]. Our adaptive framework performs efficient processor allocation and robust disk-space management to handle the large amount of data produced by the simulations to enable continuous online visualization at the remote visualization engine. Our framework, shown in Figure 1, consists of the following components: *an application manager* that determines the application configuration for climate simulations based on resource characteristics, *a job handler* that coordinates the execution of climate simulations, *a simulation process* that performs climate simulations with different application configurations, *frame sender and frame receiver daemons* that deal with transport of frames from simulation to visualization sites, and *a visualization process* for visualization of the frames. For our work, we use a mesoscale numerical weather forecast model, WRF (Weather Research and Forecasting Model) [9], [10] for simulating climate events. The rate of simulations is typically high for large number of processors and large I/O bandwidth. However faster execution time and larger I/O bandwidth can lead to faster consumption of storage space by the simulations. In addition, if the network bandwidth from the simulation to the visualization end is low, then the disk may overflow soon. We have formulated a linear optimization problem that primarily attempts to maximize the simulation rate within the constraints related to continuous visualization,

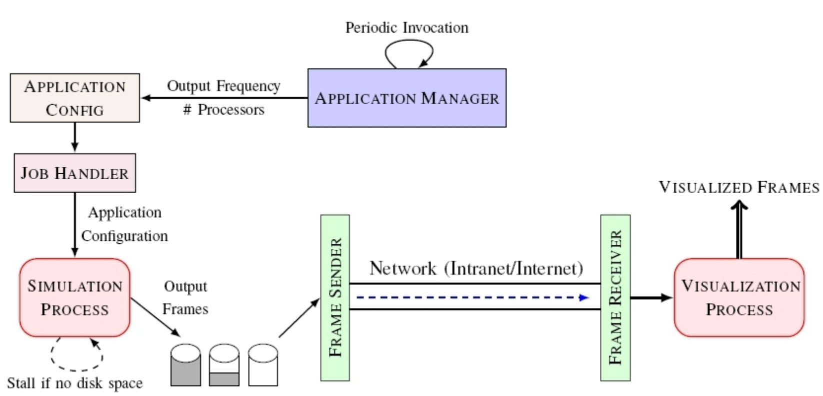


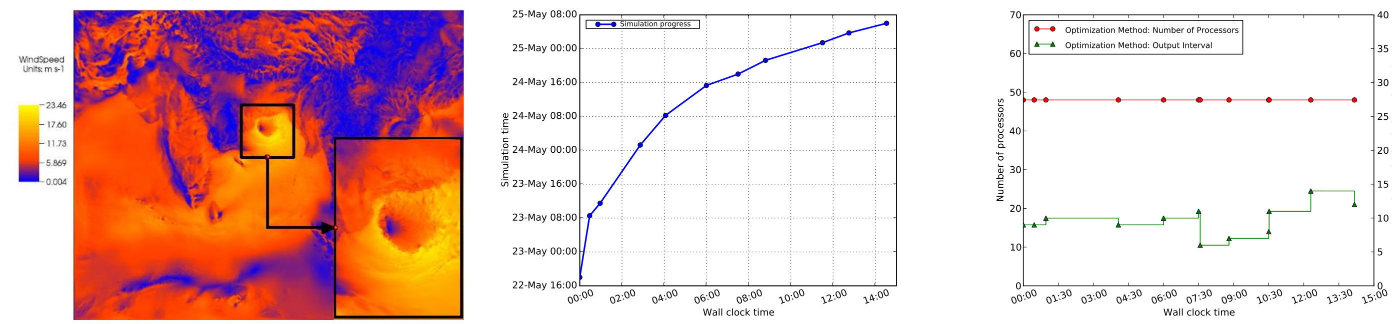
Fig. 1: Adaptive integration framework

acceptable frequency of output, I/O bandwidth, disk space and network speed. Since we want the best possible throughput of the simulation in spite of the resource constraints, we express the objective of our optimization problem as $minimize\ t$ where t is the execution time to solve a time step. This solution to this optimization problem gives us the optimal number of processors and the frequency of output for simulations. The details of the formulation can be found in [8].

4 Experiments and Results

We have used our framework for tracking a tropical cyclone in India, *Aila* [11] from May 22 to May 25 2009. We simulated Aila upto a finest resolution of 3.33 km using WRF. To track the lowest pressure region or eye of the cyclone Aila, we employ a finer resolution nest on the region of our interest inside the parent domain as shown in Figure 2(a). We have visualized the NetCDF [12] output from WRF using VisIt [13]. The resource configurations for the experiments are detailed in [8].

Our optimization method is able to complete the entire simulations for all experiments, completely avoiding disk overflow and the resulting stalling of simulations, and provides a consistent rate of visualization. Figure 2(b) shows the rate at which simulation progresses. Figure 2(c) shows the adaptation of the number of processors and the output interval of the simulations by the framework based on the application and resource configurations with the progress in execution times.



(a) Windspeed visualization in finer resolution nest inside parent domain

(b) Simulation progress rate

(c) Change in number of processors and the output interval

Fig. 2: Few results from the simultaneous simulation and visualization using our adaptive framework

5 Conclusion

We have provided an overview of our adaptive integrated framework for simulation and visualization of critical climate applications like cyclones. Our framework adapts the simulation rate and the output interval based on the disk space and network speed constraints considering the dynamics of the changing resource configurations.

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