High Performance Computing Software Applications for Space Situational Awareness

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ABSTRACT

The High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA) has completed its first full year of applications development. The emphasis of our work in this first year was in improving space surveillance sensor models and image enhancement software. These applications are the Space Surveillance Network Analysis Model (SSNAM), the Air Force Space Surveillance Fence System simulation (SimFence), and Physically Constrained Iterative De-convolution (PCID) image enhancement software tool. Specifically, we have demonstrated order of magnitude speed-up in those codes running on the latest Cray XD-1 Linux supercomputer (Hoku) at the Maui High Performance Computing Center. The software applications improvements that HSAI-SSA has made have had significant impact to the warfighter and have fundamentally changed the role of high performance computing in SSA.

1. INTRODUCTION

The mission of the High Performance Computing Software Applications Institute for Space Situational Awareness (HSAI-SSA) is to support SSA needs of stakeholders by developing high performance computing (HPC) software applications for SSA. The Institute's Strategic Goals (SG) include:

- SG 1: Astrodynamics for Characterization of Space Objects
  - Develop HPC products and tools to enable the development of a space-track test bed:
    - Represent the satellite population accurately and precisely
    - Enhance space surveillance network architecture analysis and modeling
    - Evaluate new algorithms in "apples to apples" comparison between new and standard approaches

- SG 2: Image Enhancement
  - Automate top-performing image enhancement algorithms
  - Increase the fidelity of the image products
  - Develop high-speed parallel versions using HPC assets

- SG 3: Non-imaging Space-Object Identification (SOI)
  - Characterize the material composition, mission, health, status, and ownership of space objects through non-imaging techniques such as multi-spectral analysis, photometry and polarimetry

- SG 4: Data Fusion / Data Repository

– Create HPC software that synthesizes and analyses large amounts of data from multiple sensors and databases in near-real-time and automatically generates distilled conclusions for the operators and decision makers

The Institute collaborates directly with experts and end users in the Joint Space Control mission area in order to identify those “leverage points” at which HPC can be applied to make a strategic difference in how the mission is performed. The HSAI-SSA has had a successful period of performance thus far during FY06, working with multiple software applications. Highlights of our results as well as a brief description of space situational awareness are captured below.

2. WHAT IS SSA?

Space situational awareness, or SSA is the foundation of the space control mission area which is responsible for protecting space assets, preventing damage to space assets, and negating any potential action (manmade or natural) against space assets. SSA encompasses a very broad range of technical disciplines, and includes the surveillance of space and maintenance of the satellite catalog, intelligence on space objects of interest, assessment of the space environment, and data fusion for integrated joint command and control.

Space surveillance encompasses the detection, track, and orbit prediction of 12,000+ objects of greater than 10 centimeters in size in Earth orbit at present. This mission will only grow in complexity when new sensors come on line because it is estimated that that there are 100,000+ objects presently in Earth orbit that are at least 5 centimeters or greater in size. Collecting intelligence on space objects of interest can be through a variety of means such as imaging of large, near Earth objects or analyzing photometric and spectral measurements of objects too small or too far away to be resolved by normal imaging sensors. The purpose of this mission area is to characterize the physical nature of space objects (e.g., class, size, mass, configuration, capability, attitude motion, etc.), characterize the behavior of payloads (e.g., mission, status, intent, strategy, etc.), and detect changes in the characterization. Assessing and monitoring the natural space environment is important in order to distinguish between natural and artificial phenomena. This also enables the development of models and simulations of the Earth’s space environment that can then be used to predict environmental conditions for space-dependent operations. Finally, all of the information and data from the surveillance, intelligence collection, and environmental monitoring must be fused together at various levels in order to effectively manage (or command and control) our space resources.

3. PROJECT UPDATES

There are currently three applications that the Institute is helping to develop; two in Strategic Goal 1 (Astrodynamics) and one in Strategic Goal 2 (Image Enhancement). All three applications now run on the Maui High Performance Computing Center (MHPCC) newest Cray XD-1 Linux super cluster call Hoku (or star in Hawaiian). The two astrodynamics projects are the Space Surveillance Network Analysis Model (SSNAM) and SimFence (Simulation of the Air Force Space Fence). SSNAM is used by Air Force Space Command to analyze the performance of the global space tracking network (Space Surveillance Network or SSN), and is being re-engineered to run as a scalable, parallel process. It consists of three main functions: tasker, loop, and evaluate. The tasker function determines which satellites will be assigned to which sensor in the SSN for observations; the loop function cycles through the simulation (which is usually 90 simulation days), and the evaluate function collects the results of each simulation day and evaluates its correctness. Of the three, the loop function is most amiable to parallel processing. There are however, some major parts of the tasker function that also allows for parallel processing. We have demonstrated to date about a 3-fold overall speedup and up to a 6-fold speedup to date in the load balanced Loop processing for SSNAM (see Figure 1) when comparing 50 processors (25 nodes) on Hoku (Hoku 50) and a cluster of 8 PCs in Colorado Springs (COS 8).

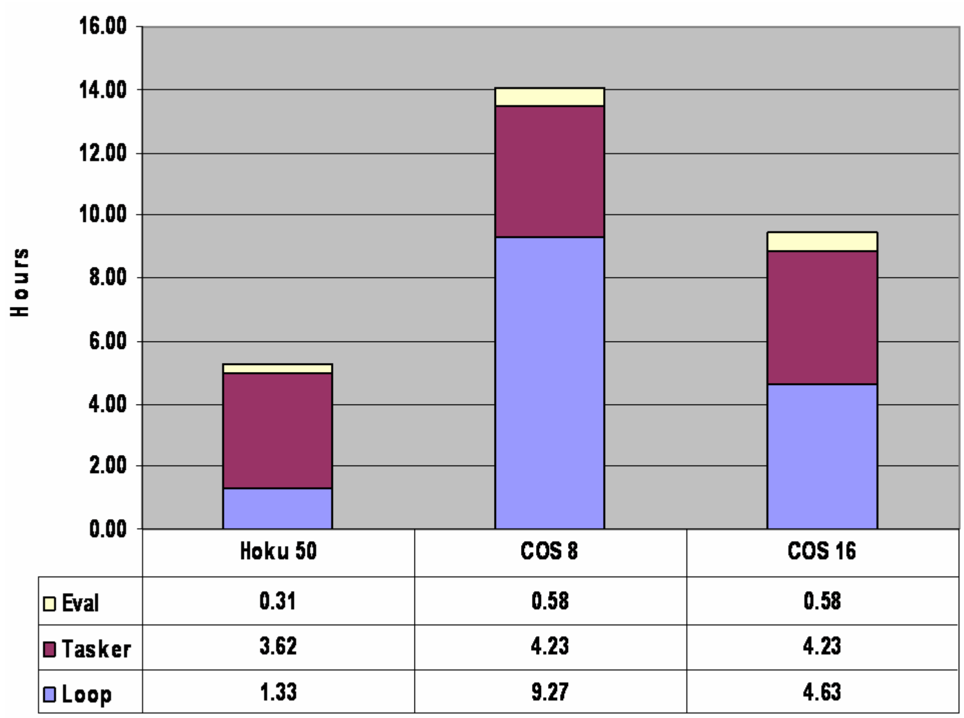

Fig. 1. MHPCC improvements to SSNAM show overall speedup of approximately 3x and loop speedup > 6x.

SimFence [1] is a detailed physical model of the Air Force Space Fence, a unique, multi-static, continuous-wave surveillance radar. This radar system is a network of sensors in its own right and accounts for nearly half of all radar detections of space objects being made by the global space surveillance network. SimFence is complex because the system has thousands of separate but precisely phased radiating elements in antenna arrays that total more than 12 miles in length. HPC techniques have improved the runtime of this model by nearly two orders of magnitude (greater than 97-fold initial speedup) which is well beyond the capability stipulated for the original goal. A further 8-fold speedup was also achieved recently through parallelization enhancements, specifically load-balancing the worker processors so that they all complete their assignments in roughly the same time. Figure 2 is a schematic illustrating the load-balancing.

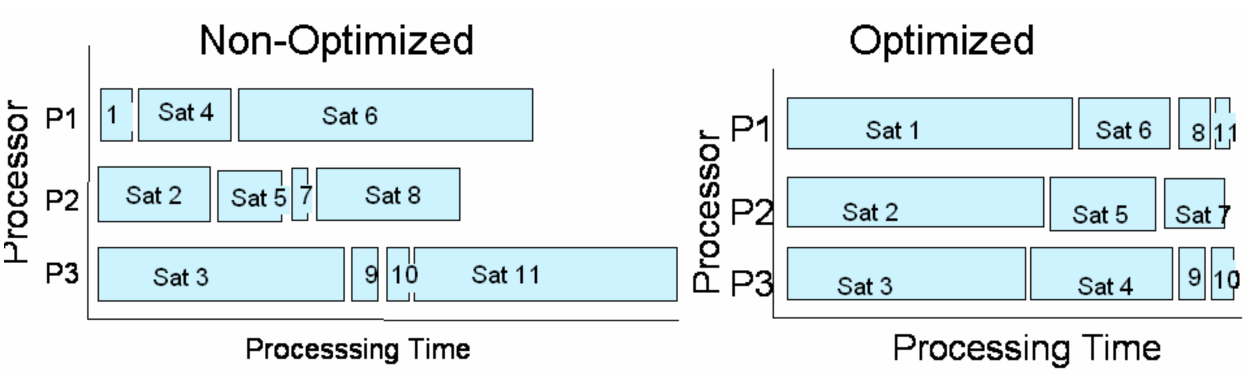

Fig. 2. Load-balancing in SimFence allows all processors to complete their work in roughly the same time.

Strategic Goal 2 (Image Enhancement) applications attempts to improve the resolution of images obtained from existing electro-optical sensors by applying a state-of-the-art new image processing algorithm. The Physically Constrained Iterative Deconvolution (PCID) algorithm, when applied to a sequence of images of the same object, achieves the theoretically optimum gain in image resolution, beyond which no method of any type can improve upon. PCID is one version of a Multi-Frame Blind Deconvolution (MFBD [2]) algorithm. Moreover, it provides a measure of how close to optimum a particular image reconstruction has come. Other image processing algorithms can run faster, but none can do better in reconstructing the image. The MHPCC team has done extensive profiling of PCID and identified the Fast Fourier Transfer (FFT) process as the "long-pole-in-the-tent." Parallelizing and optimizing the FFT implemented in PCID (called FFTW) down to row level has helped the team achieve about a 20-fold speed up when using 64 processors (see Figure 3).

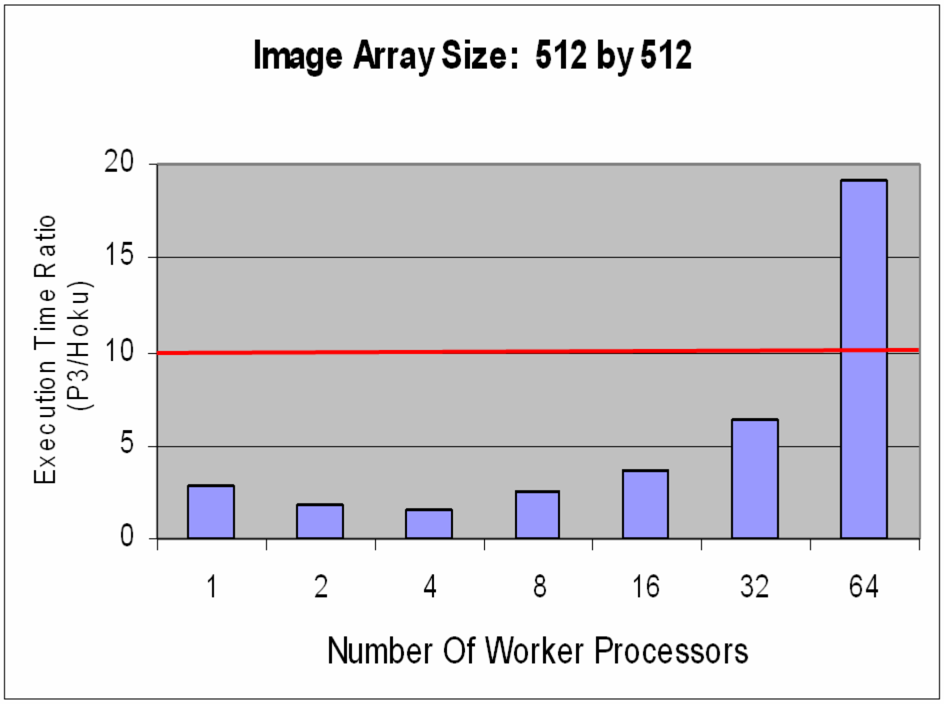

Fig. 3. MHPCC improvements to PCID implementation shows speedup >10x.

4. CONCLUSION

With a rather modest funding effort, the HSAI-SSA has, in its first full year, made significant progress in developing HPC SSA applications for the warfighter. We've been able to demonstrate order of magnitude speed-up in space surveillance models and image enhancement software. We've employed proven software engineering practices to demonstrate scalability and to identify the "knee" in the performance curve. In short, HSAI-SSA is well-focused and bringing the right technical expertise together with the right computing resources to develop, test and transition Department of Defense HPC software applications in this critical area.

5. REFERENCES

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