Astronomical Data Analysis Software and Systems IX
ASP Conference Series, Vol. 216, 2000
N. Manset, C. Veillet, and D. Crabtree, eds.

On-Board Supercomputing for NGST and NASA's Remote Exploration and Experimentation Project

M. A. Nieto-Santisteban, R. J. Hanisch

Space Telescope Science Institute, 3700 San Martin Drive, MD 21218

J. D. Offenberg, D. J. Fixsen, R. Sengupta

Raytheon/ITSS Corporation, 4400 Forbes Blvd, Lanham, MD 20706

J. C. Mather

NASA Goddard Space Flight Center, Greenbelt, MD 20771

Abstract. The Next Generation Space Telescope (NGST) is one of the applications selected by the Remote Exploration and Experimentation (REE) project as a candidate to demonstrate the benefit of having on-board supercomputing power. The REE capabilities would improve NGST science by enabling on-board data processing that would allow much more efficient use of the limited downlink bandwidth.

Specifically, the NGST Image Processing Group (IPG)[1] is developing cosmic ray rejection and data compression algorithms for parallel processors. Real-time cosmic ray rejection would enable us to reduce the downlink data volume by as much as two orders of magnitude by combining multiple read-outs on the spacecraft rather than downlinking them separately. The combined read-outs can be further reduced in size by applying either lossy or lossless data compression algorithms. This paper describes these algorithms, their implementation and optimization for a parallel, fault-tolerant computing environment, and their relationship with the REE project.

1. Remote Exploration and Experimentation Project

The Remote Exploration and Experimentation (REE) Project[2] is a component of NASA's High Performance Computing and Communications (HPCC) program. The project is intended to use mostly commercial-off-the-shelf (COTS) technology and develop low-power, scalable, fault-tolerant, high-performance computing for use in space. The primary goals of REE are:

- Demonstrate a process for rapidly transferring commercial high-performance computing technology into ultra-low power, fault-tolerant architectures for space.

[1] `http://www-ree.jpl.nasa.gov`

[2] `http://ngst.gsfc.nasa.gov/cgi-bin/iptsprodpage?Id=14`

- Demonstrate that high-performance onboard processing capabilities enables a new class of science investigation and highly autonomous operation.

The translation of HPCC technology into space requires the Project to address issues of mass, power, fault tolerance, and reliability which are different from the concerns of ground based computing. REE will validate computing efficiencies on the order of 300–1000 MOPS per watt in a multiprocessor architecture that can scale from 1 to 100 watts, depending on the specific mission needs. Software Implemented Fault Tolerance (SIFT) will be developed to use COTS (i.e., non-radiation hardened) components in space without compromising reliability or efficiency.

2. NGST in Deep Space

NGST will be placed in deep space (L2 halo orbit) where radiation will affect both computers and collected data. In principle, radiation hardening is required to protect systems and applications.

Radiation affects the reliability of conventional electronic components so hardware faults are likely to happen. Hardening a microprocessor requires either expensive basewafers, more power than equivalent non-hard circuits, or more chip area. The process involves a number of tradeoffs which include radiation tolerance, cost, chip area, electrical performance, and power dissipation that make it very expensive.

REE intends to lower the cost by using COTS technology combined with SIFT algorithms. A major challenge will be to develop a fault detection and recovery schema that assures system reliability without compromising the performance of applications over the intended NGST operation period of 10 years.

In a baseline of $10^3 s$ exposure, about 5% of the data in the field-of-view will be lost due to cosmic ray hits. To optimize NGST data quality, we should read the detector frequently and discard only suspected cosmic ray events, keeping as much good data as possible. However, the capacity of the current baseline NGST-to-ground communications link (5–6 GB/day) is several orders of magnitude lower than the volume of raw data (320–640 GB/day) required to perform cosmic ray removal on the ground (Fixsen et al. 2000).

3. How REE can Improve the NGST Science

NGST will be optimized for deep, very sensitive observations. We anticipate that most observations will take several hours, a day, or even more for a single field. Although long exposures maximize the signal to noise, we are not able to integrate indefinitely due to the effects of cosmic rays and detector saturation. Without cosmic ray removal and saturation detection, long integrations will be accomplished by executing several short observations, which will be co-added later.

We are focusing on two onboard processing approaches, *Fowler sampling* without cosmic ray rejection (NGST Integrated Science Instrument Module (ISIM) baseline) and *uniform sampling* with cosmic ray rejection (NGST IPG).

Both of them are based in the non-destructive readout capability of detectors as well as the combination of all readouts in one single final image (Fixsen et al. 2000). As it is presented in the cited paper, uniform sampling with cosmic ray removal is good for integration times as long as $2000s$ or even longer. Long observations are desirable because they both maximize the signal to noise ratio and reduce the number of images to be downlinked from the spacecraft.

The ISIM baseline design is for two redundant, flight-qualified computers, each with three 150 MHz PowerPC CPUs. We estimate that the cosmic ray rejection and compression code can run on one of these computers (three CPUs) concurrently with planned house-keeping and management tasks with up to 32 readouts for a baseline of $10^3 s$ exposures (approximately 1 readout per $30s$). Although the results on this baseline of 32 readouts seem to be satisfactory, REE would provide us with the computational power necessary to process 64 readouts in $1000s$ so the read-noise can be properly reduced. Additionally, appropriate on-board cosmic ray detection followed by either lossless or "wise" lossy compression (Nieto-Santisteban et al. 1999) would allow us to downlink not only processed images without cosmic rays but also the whole ramp of suspect pixels. The cost in bandwidth would be the same or even less than the cost of downlinking differences of averaged Fowler samples having cosmic ray contamination.

4. Parallel Processing

Using the Message-Passing Interface (MPI), we have integrated and implemented in a single package the cosmic ray rejection and compression algorithms for on-board parallel processing. The application creates one master and P slave processes. Such processes are run in different machines connected by a network. The master process reads all N readouts, splits them up into M segments, and distributes them among the slaves as they become free. Thus, each slave will remove cosmic rays, prescale the data and compress the results using the Rice lossless compression algorithm (CCSDS 1997). Once the segments are compressed they are sent back to the master which will properly assemble them in one single image to downlink (Figure 1).

5. Software-Implemented Fault Tolerance

REE's global objective is to enable high-performance, reliable, low-power, parallel computation for space applications by using mostly COTS components. REE intends to achieve this goal by using SIFT techniques that will perform fault detection, isolation and recovery in a transparent manner without compromising reliability or performance.

In order to gain experience with SIFT techniques, several generations of testbeds are being built to perform fault tolerant experiments. These testbeds will be provided with a SIFT middleware layer residing between the operating system and the applications, and between the operating system and the hardware. A software fault injector for simulating of radiation faults has been also generated to test the system and study its performance. The NGST IPG's contribution to these tests has been the development of parallel code for cosmic ray

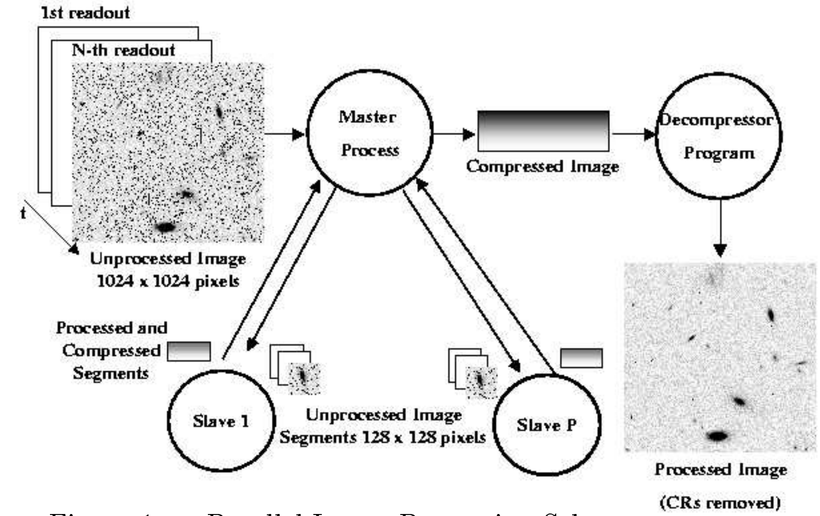

Figure 1. Parallel Image Processing Schema.

rejection and compression to be run on the testbed under a radiation induced fault environment.

6. Conclusions

NGST and the REE project share common interests and can mutually benefit. Both projects look for the return of the greatest science at the lowest cost.

- Cosmic Ray rejection can increase science throughput of NGST data and reduce the downlink requirements,
- The combination of COTS and SIFT can dramatically lower the cost,
- NGST could take advantage of the computational systems research that is already under way,
- NGST may provide a new flight opportunity in the year 2008. (REE intends to have the first flight opportunity in 2002.)

Acknowledgments. These studies are supported by the NASA Remote Exploration and Experimentation Project (REE), which is administered at the Jet Propulsion Laboratory under Dr. Robert Ferraro, Project Manager.

References

Consultative Committee for Space Data System 1997, CCSDS120.0-G-1 Green Book.

Fixsen, D. J., Offenberg, J. D., Stockman, H. S., Hanisch, R. J., Nieto-Santisteban, M. A., Sengupta, R., & Mather, J. C. 2000, this volume, 539

Nieto-Santisteban, M. A., Fixsen, D. J., Offenberg, J. D., Hanisch, R. J., Stockman, H. S. 1999, in ASP Conf. Ser., Vol. 172, Astronomical Data Analysis Software and Systems VIII, ed. David M. Mehringer, Raymond L. Plante, & Douglas A. Roberts (San Francisco: ASP), 137