Applications Development for a
Parallel COTS Spaceborne Computer

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Within the NASA High Performance Computing and Communications (HPCC) Program, the Remote Exploration and Experimentation (REE) project at the Jet Propulsion Laboratory (JPL) intends:

> To bring commercial supercomputing technology into space, in a form which meets the demanding environmental requirements, to enable a new class of science investigation and discovery.

Specifically, the project will:

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

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

The project consists of three initiatives: computing testbeds, system software, and applications. This talk focuses on the applications initiative. The purpose of this initiative is to demonstrate that the unique high-performance low-power computing capability developed by the project enables new science investigation and discovery. In order to do this, five Science Application Teams (SATs) were chosen to develop scalable science applications, and to port these to REE testbeds running REE system software. The needs of the applications also lead to requirements on the system software, and ensure that the hardware and system software meet the needs of the NASA spaceborne applications community.

Under the testbed initiative, an initial testbed composed of PCs running Linux connected by Fast Ethernet was built and used for initial applications demonstrations. The next testbed (the first generation embedded scalable computing testbed,) which is designed to operate at least at 30 MOPS/watt, is currently being built, and is scheduled to be delivered in November 1999. This testbed consists of 40 commodity off-the-shelf (COTS) processors connected by a COTS network fabric. Through future RFPs, the project will obtain additional testbeds that perform faster while using less power (at least 300 MOPS/watt), and are larger (at least 50 processors). Criteria that are required of the testbeds are: consistency with rapid (18 month or less) transfer of new Earth-based technologies to space, no single point of failure, and graceful degradation in the event of hardware failure.

The purpose of the system software initiative is to provide the services required to let the applications make full use of the hardware while assuring reliable operation in space and providing an easy-to-use development environment. Much like the hardware, the system software is intended to use commercial components as much as possible. The major challenge for the system software is to develop a middleware layer between the operating system and the applications which accepts that both permanent and transient faults will occur and provides for recovery from them.

The science applications will be used to test, evaluate, and validate candidate architectures and system software. They are generally MPI programs which are not replicated, and therefore, can take full advantage of the computing power of the hardware. (However, we also will support Triple Modular Redundancy (TMR) in software for smaller applications that require high reliability, as opposed to high availability.) As the processors are COTS components, they are not radiation-hardened, and will suffer from faults. (Note: memory will be error-detecting and correcting – EDAC.) Most of the transient faults will be single event upsets (SEUs). The SEUs which occur require that the applications be self-checking, or tolerant of errors.

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One part of the application initiative which addresses this requirement is research in Algorithm-Based Fault Tolerance (ABFT) techniques, and development of ABFT libraries for linear algebra and Fourier analysis tasks shared by the applications. As an example, the fine optical control application from NGST consists of three parts: phase retrieval (Misell algorithm), phase unwrapping, and actuator fitting. Approximately 70% of the CPU time spent in the phase retrieval code is used to perform FFTs. We are writing an ABFT wrapper for the version of the distributed FFT that is being used (FFTW[1]) that will allow the application to determine if this routine completed correctly, or if an SEU occurred during the calculation, in which case the FFT can be repeated.

The first round of SATs consists of the following five teams:

Gamma-ray Large Area Space Telescope (GLAST): This team, led by Prof. Peter Michelson (Stanford) and Prof. Toby Burnett (U. of Washington) will examine detection of gamma rays in a sea of background cosmic rays (about 1 in 10,000 events will be a gamma ray), and reconstruction of the gamma-ray trajectory.

Mars Rover Science: Dr. R. Steven Saunders (JPL) leads this team, which has two applications. First, texture analysis and image segmentation are used to identify various materials on Mars for further scientific analysis. Second, images obtained from a stereo camera are analyzed for use in autonomous navigation.

Next Generation Space Telescope (NGST): Led by Dr. John Mather (Goddard Space Flight Center – GSFC), this team also has two applications. The first is to perform multiple fast reads of the charge coupled devices (CCDs) which take the telescope images in order to eliminate or reduce the effect of cosmic rays which hit these CCDs during an exposure. The second is to perform fine optical control by using a wave front sensing algorithm to control a deformable mirror.

Orbiting Thermal Imaging Spectrometer (OTIS): This team is led by Prof. Alan Gillespie (U. of Washington). They are designing an application to take hyperspectral imaging data and retrieve temperature and emissivity, as well as performing spectral matching and unmixing, then image classification.

Solar Terrestrial Probe Project (STP): This team, led by Dr. Steven Curtis (GSFC), is examining using fleets of spacecraft for two applications: radio astronomical imaging and plasma moment analysis.

All of these applications take advantage of large amounts of computing, as well as performance/power ratios that are at least an order of magnitude above those available in today's spacecraft. They are attempting to implement and test new approaches to science data processing and autonomy.

The REE project will release a solicitation for new SATs in September 1999. The new teams should be on contract by March 2000. We intend the new teams to diversify our understanding of spaceborne applications, both in the type of applications (real-time processing, more general autonomy) as well as in the NASA enterprises which they effect (Space Science, Earth Science, Aeronautics, and Human Exploration and Development of Space).

The REE project is still fairly young, but our experience to this point looks promising for the future of the project. We do not see any severe problems ahead, and we are convinced that our model of moderately fault-tolerant applications on COTS computers in space will play a major role in many future NASA missions.

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[1] Fastest Fourier Transform in the West: (http://theory.lcs.mit.edi/~fftw)