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1 Multi-Disciplinary Coupling of Earth System Models on a Hybrid Computing Architecture

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Significant advances have occurred in the development of Earth System Models (ESM's) over the last decade. The most complex models now utilize software infrastructures to synchronize exchanges of information between numerical models to achieve the dynamic coupling of multi-disciplinary components. The ultimate objective is a comprehensive earth system model providing quantitative predictive capabilities of interactions between atmosphere, oceans, biosphere and solid Earth.

Multi-disciplinary coupling provides a powerful framework for interoperating models from many scientific domains. For example, Sun-Earth models are composed of a series of interoperating physics domains, ranging from the Sun's surface to the Earth's upper atmosphere. Potential also exists to dynamically couple non-geoscience applications, such as economic models, with ESM's.

ESM's demand an enormous amount of computing resources. The climate community reports that implementing the necessary increases in spatial resolution, model completeness, new parameterizations, run length and ensemble scenarios will require an increase of between 10^{10} to 10^{12} in computing capability.

While the technology barriers in ESM's are characterized by floating point perfor-

mance, memory bandwidth, memory latency, interconnect bandwidth and interconnect latency, the specific performance constraints of individual components are not identical. By nature multi-disciplinary coupling of applications has a fragmenting effect on the computational requirements of the system as a whole. Each component brings it's own algorithmic characteristics and development history. In addition, the extension of the application to include new and possibly non-HPC communities will further fragment the characteristics of the underlying computational resource.

Hybrid architectures provide an infrastructure to support the execution of a single application across multiple processing technologies. Each processing technology offers it's own unique characteristics and opportunities that can be leveraged to meet the performance demands of various applications. While loosely coupled implementations exist based on peer-to-peer networking technologies or file based implementations, these do not address the performance requirements of earth system models.

The High Productivity Computing Systems (HPCS) program sponsored by the Defense Advanced Research Projects Agency (DARPA) in the US aims at providing economically viable high productivity computing systems for the government and industrial user communities in the 2010 timeframe. Cray's Cascade program receives funding under HPCS to develop a new generation of high-productivity computer systems capable of sustained performance in excess of one petaflop, and will deliver a hybrid architecture. Under this agreement, Cray will follow a phased approach that integrates multiple processor technologies, a new high-performance network and an innovative adaptive software layer into a single scalable platform system.

Hybrid computing will provide a revolutionary infrastructure for application developers. We present both the challenges and opportunities of a hybrid architecture for earth system modelers.