A Characterization of Distribution Techniques for Dynamic Adaptive Grid Hierarchies

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This paper presents a performance characterization of dynamic partitioning and load-balancing techniques for distributed adaptive grid hierarchies that underlie parallel adaptive mesh-refinement (AMR) techniques for the solution of partial-differential equations. The primary motivation for the characterization is the development of a policy driven tool for automated configuration and run-time management of distributed adaptive applications on dynamic and heterogeneous networked computing environments.

Dynamically adaptive methods for the solution of partial differential equations that employ locally optimal approximations can yield highly advantageous ratios for cost/accuracy when compared to methods based upon static uniform approximations. These techniques seek to improve the accuracy of the solution by dynamically refining the computational grid in regions of high local solution error. Distributed implementations of these adaptive methods offer the potential for the accurate solution of realistic models of important physical systems. These implementations however, lead to interesting challenges in dynamic resource allocation, data-distribution and load balancing, communications and coordination, and resource management. The overall efficiency of the algorithms is limited by the ability to partition the underlying data-structures at run-time so as to expose all inherent parallelism, minimize communication/synchronization overheads, and balance load. A critical requirement while partitioning adaptive grid hierarchies is the maintenance of logical locality, both across different levels of the hierarchy under expansion and contraction of the adaptive grid structure, and within partitions of grids at all levels when they are decomposed and mapped across processors. The former enables efficient computational access to the grids while the latter minimizes the total communication and synchronization overheads. Furthermore application adaptivity results in application grids being created, moved and deleted on-the-fly, making it is necessary to efficiently re-partition the hierarchy so that it continues to meet these goals.

Moving these applications to dynamic and heterogeneous networked computing environments introduces a new level of complexity. These environments require the selecting and configuring application components based on available resources. However, the complexity and heterogeneity of the environment make selection of a "best" match between system resources, application algorithms, problem decompositions, mappings and load distributions, communication mechanisms, etc., non-trivial. System dynamics coupled with application adaptivity makes application configuration and run-time management a significant challenge. Clearly there is a need for "smart" tools that can automate the configuration and management process.

This paper first presents an application-centric characterization of distribution mechanism for AMR applications on heterogeneous (and dynamic) cluster computing environment. It then describes the design and implementation of an automated application configuration and management system that dynamically adapts the application distribution and communication mechanisms based on current operating conditions.