Geo-Inspired Parallel Simulation (GiPC)

CHALLENGE

It is known in the field of power systems simulation that problems can be positioned (partitioned) in ways that take advantage of the geographical and physical properties of the system. However, partitioning for fast execution has many degrees of freedom in very large and complex system simulation.

Develop solutions for partitioning and solving graph-based physical simulation problems using geographic information about the physical network

CURRENT PRACTICE

There are many examples of partitioning large graph-based problems, and a base of proven and industry-accepted software tools for doing so. One such tool is METIS, and a variation known as hMETIS, which is a hypergraph partitioning tool popular in the integrated circuit design community. The output of hMETIS is determined by the weights placed on the unpartitioned graph. The specification of this weighting is ultimately tied to the speed of execution realized in the parallel-computed solution. In complex graphs, it is difficult to find partitions that optimally use the properties of the cluster computer. This issue is linked to the nature of the problem being solved. For example, improvement was shown in computational performance when a custom partitioning scheme influenced by the geographic properties of a power transmission system was used as compared to a hMETIS partition without consideration of these factors[1]. This demonstrates that performance improvement is available to partitions posed with the right link between cluster computer properties and the properties of the problem being solved.

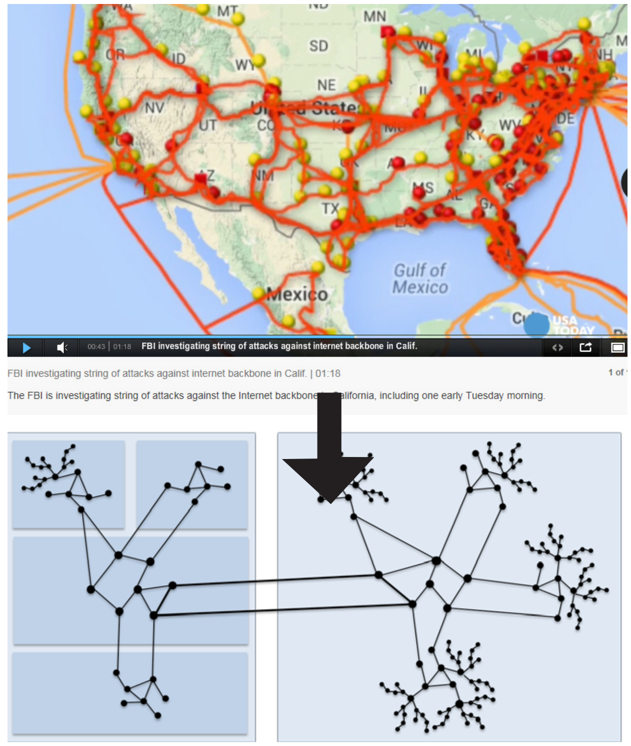
The problem with existing methods is that there is no means for automatically finding partitions of networks that optimize the similarities of the physical problem with those of the cluster computer. For example, fast dynamics need shorter simulation time steps to converge, whereas slower dynamics can get by with longer time steps. A multi-objective optimization process is needed that can discover appropriate solutions for partitioning the problem in each case required.

Geographic properties of networks serving human populations parallel the construction and efficient use of cluster computers.

TECHNICAL APPROACH

The Geo-inspired parallel computing (GiPC) software demonstrated in the second year of this task is designed to discover with a high degree of automatic operation good solutions to the partitioning problem using the similarities between the geographic and physical properties of a real system and the design and performance of a modern cluster computer. The case example is an auto-generated graph consisting of the edges and nodes of subsystems representing smaller physical networks connected together to form a final graph of millions, hundreds of millions, or potentially billions of nodes in size.

GiPC is a multi-objective optimization engine that uses hMETIS to create candidate partitions and then uses open-source software and a simulation manager framework developed by MSU students to test the partitions to compare performance against objectives. New partitions are created to improve observed performance. The framework is intended to use the Graph Engine for Multi-threaded Systems (GEMS) to search for nodes and edges with geo-tags that will produce candidate partitions with attractive properties, resulting in feasible convergence times for the optimization engine on problems differing widely in graph size. The analytical target cascading (ATC) method excels at cascading the optimization problem into sub-problems that run in parallel, thus giving the optimization process a chance to solve ever larger graph partitioning problems with larger allocations of cluster computer resources, keeping the execution time tolerable while scaling the size of the graph. An application of the software will be demonstrated with a use-case tied to the real-time simulation of cyber-attacks on the power grid.



The Internet backbone can be represented as a graph, where each relay can be seen as a node (vertex) and each branch line can be seen as a connection (edge).

IMPACT

Finding good solutions to very large and complex problems often appears impossible, and is impossible by manual means. Modern multi-objective optimization theory takes such impossible tasks and makes them tractable. GiPC relies on generalized techniques developed for parallel computing. The result is confidence that when the process is complete, a partition exhibiting good computational performance has been found that is better than the alternatives. The use of geo-inspired processes is a key to finding these alternatives with a reasonable expenditure of high-performance computing resources.

Contacts

Michael S. Mazzola
Task Lead
662.325.8757
mazzola@ece.msstate.edu

David Haglin
Chief Scientist
509.372.4707
david.haglin@pnnl.gov

David A. Dampier
Director, Distributed Analytics & Security Institute
662.325.0779
dampier@dasi.msstate.edu

[1] Wei Xue and Shanxiang Qi, "Multilevel Task Partition Algorithm for Parallel Simulation of Power System Dynamics" Y. Shi et al. (Eds.): ICCS 2007, Part I, LNCS 4487, pp. 529-537, 2007.

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