Abstract

With the rapid advancement of GPU hardware, a trend for accelerating compute-intensive applications on massively parallel architectures has emerged. In keeping with this trend, several researchers in academia and industry are focusing their efforts on GPU-accelerated Finite Element Analysis (FEA) and its applications. Because FEA is a popular method for solving partial differential equations in a variety of engineering disciplines, any reduction in computational complexity through GPU acceleration would benefit a large portion of the scientific community. Furthermore, as problems of increasing complexity and size are introduced, the massive computational power that a modern GPU is capable of providing becomes more necessary. In a similar vein, this thesis seeks to address a number of issues concerning GPU acceleration of FEA and one of its most important applications, structural topology optimization. In the first part of this thesis, a novel three-stage GPU-based FEA matrix generation strategy is implemented with the key idea of decoupling the computation of global matrix indices and values by use of a novel data structure referred to as the neighbor matrix. The first stage computes the neighbor matrix on GPU based on the unstructured mesh. Using this neighbor matrix, the indices and values of the global matrix are computed separately in the second and third stages. The proposed method is compared to the state of the art GPU-based techniques for different element types, different benchmark problems and large-scale FEA meshes, demonstrating significant improvements in computation time and GPU performance. The second part of the thesis accelerates solid isotropic material with penalization (SIMP) method and bi-directional evolutionary structural optimization (BESO) method of topology optimization on GPU by incorporating algorithm-level and high performance computing-based modifications to the standard existing algorithms with a focus on the FEA stage. The key idea behind these implementations is to combine GPU acceleration of the entire application pipeline with a novel mesh reduction strategy that eliminates the need to compute empty voxels during the FEA stage of topology optimization. In the proposed strategy, the effective number of design variables is reduced by using the concept of active nodes and active elements in the finite element mesh. A novel mesh numbering scheme is also introduced to facilitate parallel identification of active nodes using the proposed GPU-based algorithm. The preconditioned conjugate gradient (PCG) solver is further developed using the proposed strategy and the numbering scheme. The proposed implementations of SIMP and BESO are evaluated using different benchmark problems from the literature. When compared to the standard GPU-based implementation, the proposed GPU-adapted implementations provide three key benefits: shorter execution times, lower memory consumption, and improved FEA convergence, all of which mitigate the major computational issues associated with topology optimization.