Recent Advances in Automatic and Parallel Mesh Generation

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Abstract

Mesh generation is recognized as the main performance bottleneck in simulations involving complicated geometric definitions and/or complex physical behaviors. Automatic generation of high-quality meshes remains a challenging issue. Besides, many simulations are now demanding meshes consisting in hundreds of millions of elements or more. It could be very difficult and inefficient to create such big meshes by sequential algorithms due to the bottlenecks of memory usage and computing time.

Three technologies developed by the authors' group recently are presented in this talk, as key parts of their efforts to develop a completely automatic and parallel meshing system for real-world simulations. These technologies are:

- *Automatic creation of a feature-aware and gradient-limited sizing function.* Accurate sizing functions are crucial for efficient generation of high-quality meshes, but to define the sizing function is often the bottleneck in complicated mesh generation tasks due to the tedious user interaction involved. We present a novel algorithm to automatically create high-quality sizing functions for unstructured mesh generation. First, the tessellation of a CAD model is taken as the background mesh, in which an initial sizing function is defined by considering geometrical factors and user-specified parameters. Then, a convex nonlinear programming problem is formulated and solved efficiently to obtain a smoothed sizing function that corresponds to a mesh satisfying necessary gradient constraint conditions and containing a significantly reduced element number. Finally, this sizing function is applied in unstructured mesh generation. Meshing experiments of some very complicated geometry models are presented to demonstrate that the proposed sizing-function approach enables accurate and fully automatic unstructured mesh generation
- *Automatic generation of high-quality boundary layer elements.* A typical mesh configuration for viscous flow simulations is to create prismatic elements in boundary layers by marching the surface triangulation on viscous walls along certain directions. The quality of resulting elements and the reliability of the meshing procedure thus highly depend on the computing strategy of marching directions. We propose to compute a field of marching directions governed by a vector-form Laplacian equation. This new approach could ensure the smooth transition of marching directions, thereby leading to more desirable element shapes. Besides, the possible intersections of boundary layer elements growing from opposite sides of a narrow region could be identified by analyzing vector field. With respect to the solution of the governing equation, the boundary element method (BEM) is preferred because of its advantage in solution accuracy. Meanwhile, since the BEM needs an input of the surface triangulation only, there is no need to create a volume background mesh. Following the above idea, we develop a new hybrid prismatic meshing method, and the capability of this method is demonstrated by performance comparisons with commercial products using meshing experiments on models with complex geometries.
- *Distributed parallel mesh generation and mesh quality improvement.* A novel domain decomposition approach is developed for parallel generation and improvement of unstructured meshes. It simplifies a background mesh by analyzing its dual graph. The decomposition of the simplified mesh yields inter-domain boundaries containing no features that might negatively impact element quality. Therefore, the subsequent parallel procedures of mesh generation and improvement are efficient because they could treat sub-domains individually without compromising element quality. Apart from parallel surface mesh generation, this approach has been extended for parallel meshing and improvement of volume meshes, which enables us to build up a complete parallel

preprocessing pipeline. One billion unstructured elements for real aerodynamics simulations can now be generated in less than 7 minutes by using 256 computer cores.

The above technologies have been included into an in-house meshing tool set. Given a CAD model and a few user parameters, high-quality and large-scale unstructured hybrid meshes suitable for viscous flow simulations could now be created in a highly automatic and parallel fashion. Meshing examples are selected to show that the developed technologies are applicable to configurations of a complication level experienced in industry.

Keywords: Mesh generation, parallel algorithm, automatic mesh generation, mesh adaptation, boundary layer

References

[1] Yao Zheng, Jianjun Chen, *Unstructured Mesh Generation: Theories, Algorithms and Applications* (in Chinese), the 1st Edition, ISBN 978-7-03-047283-0, Science Press, Beijing, China, March 2016.

[2] Jianjun Chen, Zhoufang Xiao, Yao Zheng, Jianjing Zheng, Chenfeng Li, Kewei Liang. Automatic Sizing Functions for Unstructured Surface Mesh Generation, *International Journal for Numerical Methods in Engineering*, 2017, 109(4): 577-608.

[3] Dawei Zhao, Jianjun Chen, Yao Zheng, Zhengge Huang, Jianjing Zheng. Fine-Grained Parallel Algorithm for Unstructured Surface Mesh Generation. *Computers & Structures*, 2015, 154:177-191.

[4] Jianjun Chen, Dawei Zhao, Zhengge Huang, Yao Zheng, and Desheng Wang. Improvements in the Reliability and Element Quality of Parallel Tetrahedral Mesh Generation, *International Journal for Numerical Methods in Engineering*, 2012, 92(8): 671-693.