Title:
Adaptive Tetrahedral Mesh Generation of 3D Heterogeneous Objects

Authors:
Yaohui You, youyaohui@hku.hk, The University of Hong Kong
Xinyu Kou, kouxy@hku.hk, The University of Hong Kong
S. T. Tan, sttan@hku.hk, The University of Hong Kong

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Introduction:
In recent years, heterogeneous materials have attracted a lot of attention for their superior properties over homogeneous materials. To design, analyze, and optimize the behavior of heterogeneous materials, the finite element method (FEM) as an effective numerical method has been immensely utilized. Although tremendous efforts are devoted to finite element analysis (FEA) of heterogeneous materials in the past two decades, little attention has been focused on mesh generation, which is an essential part of the FEA procedure. For the sake of simplicity, classic mesh generation methods targeted on homogeneous objects are often directly applied into the domain of heterogeneous objects. The meshes generated by these traditional methods, however, either result in poor simulation accuracies (as they fail to characterize the material heterogeneities), or introduce denser elements than desired, significantly degrading the computational efficiency. To solve such problems, specific mesh generation methods for efficient and robust FEA of heterogeneous objects are called for.

Zhang et al. [6] proposed an automatic 3D mesh generation method for heterogeneous objects. Unfortunately, only multiple material objects, which are very primitive in terms of material heterogeneities, are taken into account. Functionally graded materials (FGMs), whose material heterogeneities vary gradually within the domain of interest, usually outperform multiple materials. Therefore, meshing strategies that concentrate on these objects warrant further exploration. Amongst the few contributions that handle the meshing problem of FGMs are [2] and [5]. These authors have paid duly attention to 2D FGM objects, yet having not touched on the 3D FGMs that are more general and complex in practice. In order to fill this gap, we propose an adaptive tetrahedral mesh generation method based on optimal Delaunay triangulation (ODT) [1] for general 3D heterogeneous objects.

Main idea:
In adaptive meshes of homogeneous objects, denser elements are usually generated in the boundary area to conform to the geometric resolution, while coarser elements are created in the interior to save computational resources. However, for heterogeneous objects where two or more different material ingredients exist, this observation is not true anymore. Besides the geometric resolution, the length scale associated with the material heterogeneity in each finite element also has a great impact on the accuracy of FEA solutions [3]. In other words, the adaptive meshing of heterogeneous objects is determined by both the material heterogeneity and the geometric complexity. Regarding that, we propose an adaptive tetrahedral mesh generation method, which naturally includes a three-step meshing process: initial mesh generation, material-oriented refinement and geometry-oriented refinement (see Fig. 1).

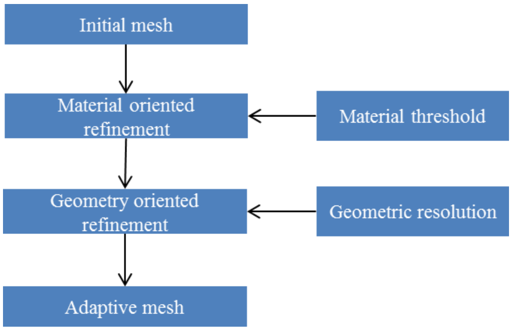

Fig. 1: The flowchart of the adaptive meshing algorithm.

Given a 3D heterogeneous model as shown in Fig. 2(a), an initial mesh, *I-Mesh* (see Fig. 2(b)), is firstly constructed by using the Delaunay-based tetrahedral mesh generation method [4]. Since the *I-Mesh* is only a coarse mesh and far away from desirable, the material-oriented refinement is consequently executed, aiming to generate a mesh that is validated in terms of a predefined material threshold. In this step, a global mesh adaptation method based on ODT is applied. Fig. 2(c) shows the *M-Mesh* after the material-oriented refinement. To satisfy the material threshold, denser elements are generated in the interior of the domain where material composition changes fast (see the material composition function shown in Fig. 2(a)), while relatively coarser elements are used in the boundary area where material composition changes relatively slowly. As only material heterogeneity information is considered in the material-oriented refinement, the *M-Mesh* shown in Fig. 2(c) does not approximate the geometry of the heterogeneous model well for coarse elements are generated in the boundary area. To solve such a problem, the geometry-oriented refinement is further applied. Fig. 2(d) shows the *G-Mesh* after the geometry-oriented refinement. Notice that finer elements are constructed in the boundary area to conform to the geometric resolution.

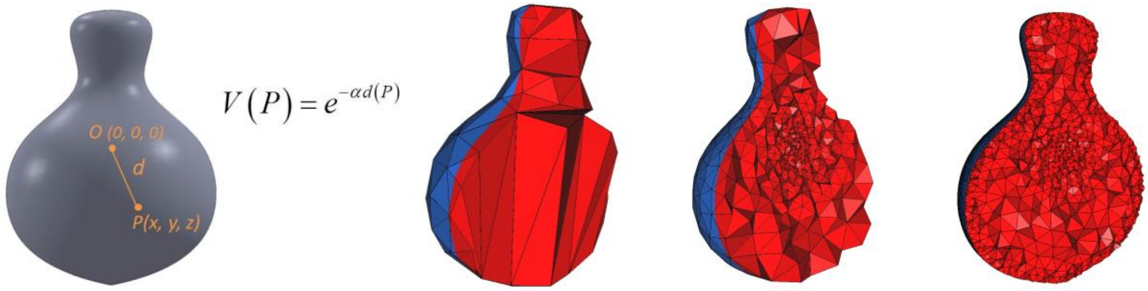

Fig. 2: An example of adaptive meshing on a heterogeneous model: (a) the geometry and material description of the heterogeneous model, here V denotes the material composition function, $d(P)$ represents the distance from an arbitrary point P to the reference point O and α is a positive constant; (b) cut view of the *I-Mesh*; (c) cut view of the *M-Mesh*; (d) cut view of the *G-Mesh*.

Conclusion:

Experiments indicate that the adaptive meshing strategy controls the mesh adaptations in terms of the material heterogeneity as well as the geometric complexity. In addition, the proposed strategy guarantees high-quality meshes. Therefore, our adaptive meshes are feasible for accurate and efficient FEA simulations of heterogeneous objects.

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References:

[1] Chen, L.; Xu, J.C.: Optimal Delaunay triangulations, Journal of Computational Mathematics, 22(2), 2004, 299-308.

[2] Chiu, W.K.; Kou, X.Y.; Tan, S.T.: Adaptive meshing of 2D heterogeneous objects using material quadtree, Computer-Aided Design & Applications, 8(2), 2011, 289-300. http://dx.doi.org/10.3722/cadaps.2011.289-300

[3] Paulino, G.H.; Kim, J.-H.: The weak patch test for nonhomogeneous materials modeled with graded finite elements, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 29, 2007, 63-81. http://dx.doi.org/10.1590/S1678-58782007000100010

[4] Rineau, L.; Yvinec, M.: Meshing 3D Domains Bounded by Piecewise Smooth Surfaces* in Proceedings of the 16th international meshing roundtable, 2008. http://dx.doi.org/10.1007/978-3-540-75103-8_25

[5] Shin, K.H.: Adaptive mesh generation for finite element analysis of functionally graded materials in American Society of Mechanical Engineers, Computers and Information in Engineering Division, CED, Orlando, FL, 2005. http://dx.doi.org/10.1115/IMECE2005-82442

[6] Zhang, Y.J.; Hughes, T.J.R.; Bajaj, C.L.: An automatic 3D mesh generation method for domains with multiple materials, Computer Methods in Applied Mechanics and Engineering, 199(5-8), 2010, 405-415. http://dx.doi.org/10.1016/j.cma.2009.06.007

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