IMPACT OF HEX-MESH STRUCTURE TO SIMULATION QUALITY— A FIRST STUDY

Muhammad Naeem Akram[1], Guoning Chen[1], Yue Zhang[2]

[1]University of Houston, Houston, TX., U.S.A. chengu@cs.uh.edu, makram2@uh.edu
[2]Oregon State University, Corvallis, OR., U.S.A. zhangyue@oregonstate.edu

Motivation: It has been shown that element quality of a hexahedral (hex) mesh has direct impact to the quality of simulations performed on it [1]. However, there is little study on how the structure of a hex-mesh will impact the quality of the simulation. Understanding this will enable us to develop theory and algorithms for the generation of hex-meshes with structures better adapted to the needs of applications. Here, the structure of a hex-mesh is defined as a hexahedral partitioning strategy of the domain induced by the singularities (e.g., irregular edges and nodes) of the mesh and the separation surfaces emanating from them.

To assess how the structures of different hex-meshes of the same volume will affect the same simulation performed on them. We set up our experimental study as follows:

Mesh preparation: We generate hex-meshes of a selected model using the structure simplification technique proposed by Gao et al. [2]. For each model, a hex-mesh generated with certain technique with complex structure is used as the input. By choosing different parameters, hex-meshes with different structures but similar numbers of elements can be produced with boundary error smaller than a user-specified threshold.

Simulation evaluation: We perform two different types of simulation evaluation on the hex-meshes generated above. On the one hand, we compute several elliptic PDE problems on the mesh and measure the eigenvalue quality of the stiffness matrices involved in those PDE solving. See Gao et al. [1] for more details. On the other hand, we compute the mechanical stresses on a volume that is under deformation using finite element methods and analyze the topology of the tensor fields over the mesh. Deviation from an expected topology for a reference fine mesh will be used to gauge the quality of the mesh under investigation. See Palacios et al. [3] for more details.

Results and Discussion: Fig. 1 provides the stress tensor simulation results obtained on two hex-meshes of a Rockerarm model. The two hex-meshes, M1 and M2, have rather different structures (i.e. different numbers of hexahedral blocks – 622 for M1 and 47 for M2) but similar numbers of hex-elements (22764 for M1 with complex structure vs 20358 for the simpler one, M2) and volume boundary (both with 3% Hausdorff distance error). The visualizations of the stress tensors are generated using the technique described in [3]. From the results, we can see that the tensor fields are much smoother and well-behaved in the simulation obtained on the hex-mesh with simpler structure, represented by the contiguous and smooth neutral surface (Fig. 1b), when compared to the disconnected surface obtained from the tensor field computed on the hex-mesh with complex structure (Fig. 1a). Interestingly, M1 (with complex structure) has higher minimum scaled Jacobian than M2 (i.e. 0.633 vs 0.433). This initial study provides intriguing result that cries for a more complete and comprehensive study, which will surely impact the practice of hex-meshing.

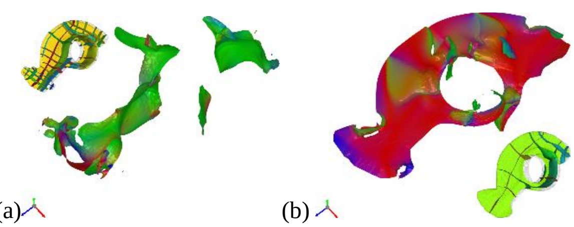

Fig. 1 Stress tensor structures obtained in hex-meshes with complex (a) and simple (b) structures (insets)

REFERENCES

[1] Xifeng Gao, Jin Huang, Kaoji Xu, Zherong Pan, Zhigang Deng, and Guoning Chen, "Evaluating Hex-mesh Quality Metrics via Correlation Analysis, " Computer Graphics Forum (SGP 2017), 36(5): 105-116, 2017.

[2] Xifeng Gao, Daniele Panozzo, Wenping Wang, Zhigang Deng, and Guoning Chen, "Robust Structure Simplification for Hex Re-meshing," ACM TOG, Vol. 36, No. 6 (SIGGRAPH Asia 2017), Article No. 185:1-185:13.

[3] Jonathan Palacios, Harry Yeh, Wenping Wang, Yue Zhang, Robert S. Laramee, Ritesh Sharma, Thomas Schultz, and Eugene Zhang, "Feature Surfaces in Symmetric Tensor Fields Based on Eigenvalue Manifold", IEEE Transactions on Visualization and Computer Graphics, Vol 22(3), 2016, pp. 1248-1260.