Dynamic mesh optimization based on the spring analogy

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The quality of the mesh is decisive for the convergence of computational fluid dynamics (CFD) simulations and for the quality of the results. In this paper I revisit the idea of the spring analogy for mesh optimization [1] and report on an implementation in OpenFOAM. The applications that are of interest here are structured meshes for wind energy problems, namely flow meshes over complex terrain and around wind turbine blades.

The dynamic spring system is obtained by treating mesh points as point particles and mesh edges as springs connecting them. Usually this system is reduced to a linear matrix system, representing Hook's law [1–4]. Stabilization issues that are related to dynamical cell volume inversion can then be solved by introducing torsional springs [3,4], for which the spring stiffness is a function of cell volume and cell face areas.

Here I present a different approach, based on the fully transient simulation of the coupled spring system, including mass and friction fields for the dynamic mesh points. Also the spring stiffness and the desired spring length are treated as fields, and they may be subject to additional diffusion equations. This allows for the controlled generation of inhomogeneous and anisotropic meshes that are in dynamical equilibrium. The implemented boundary conditions for the points are fixed value, freely moving, or tangential slide conditions on the given boundary surface.

For the solution of the edge, face or cell collapse problem I introduce additional springs into the system, connecting face centres with face vertices and cell centres with cell vertices. They are set up in a way that they favor symmetric faces and cells, by means of identical distances of all associated vertex points to the respective centre point. In addition they are equipped with core regions which provide smoothly diverging expansion forces, if the danger of face area or cell volume inversion arises. Similarly, the edge springs have a core region that prevents edge collapse.

All parameters are conveniently settable by the user via OpenFOAM dictionaries. Examples for three-dimensional meshes around an airfoil and above an artificial hill are shown in Figures 1 and 2, respectively. This demonstrates the usefulness of the tool: It allows one to set up a simple mesh without worrying about cell quality or the boundary layer resolution, and then, as a pre-processing step, automatically optimize the mesh for the subsequent CFD simulation.

Note that the tool is by no means restricted to structured meshes, since the applied principles and the implementation are completely general and support arbitrary face and cell shapes.

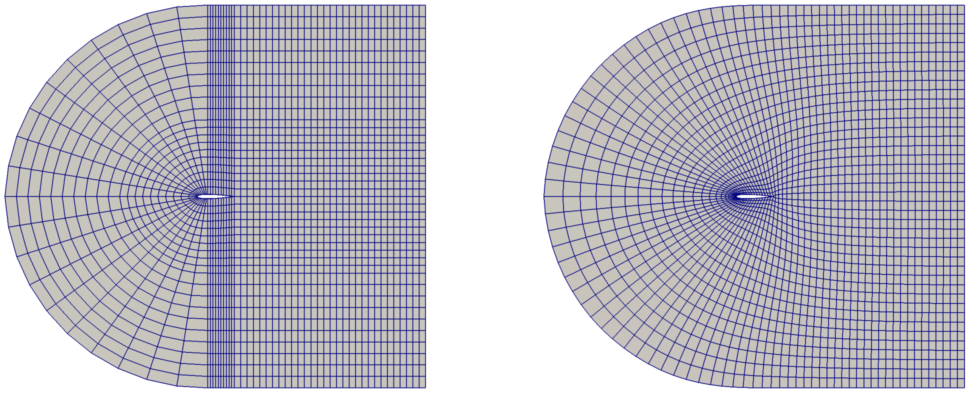

Figure 1: The initial mesh around the airfoil (left panel), and the converged optimized mesh (right panel). Notice the effect of the increased spring constant near the airfoil mesh boundary.

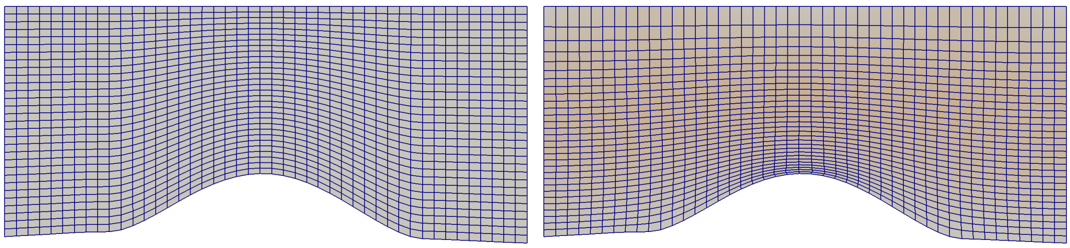

Figure 2: The initial mesh above an artificial hill (left panel), and the dynamically optimized mesh featuring inhomogeneous spring stiffness (right panel). Notice the resulting grading in the height direction.

References

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