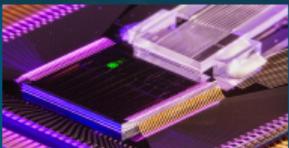




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Rapid hexahedral mesh generation with adaptivity and conformity



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Automatically generating high-quality hexahedral finite element meshes is difficult.

- Adaptivity reduces element count, but is challenging for hexahedral elements [1].
- Conformity accurately represents surfaces, but can create low-quality elements.

Analysts at Sandia and beyond need (or want) to use hexahedral finite elements.

- Plenty of Sandia analysts regular use hexes in addition to the composite tet [2].
- Most analysts outside Sandia cannot use the composite tet and typically use hexes.

`automesh` [3, 4], an open-source automatic hex-meshing tool written in Rust (CLI+Python).

- Blazingly-fast voxels-to-hexes, surface reconstruction, smoothing, and more.
- Focus here is on similarly-fast hexahedral adaptivity and progress on conformity.
- Longer term, will further improve adaptivity and conform to interior surfaces.

3 Hexahedral adaptivity



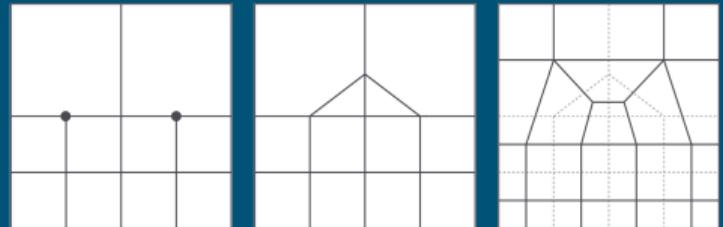
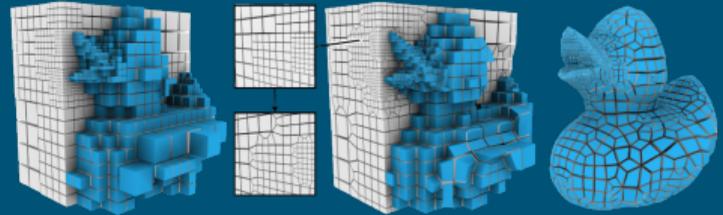
Interior mesh adaptivity via dualization [1].

- Strongly (or weakly) balanced octree.
- Cell subdivision to capture features.
- Connect hanging nodes for polyhedra.
- Centroids connect for guaranteed hexes.

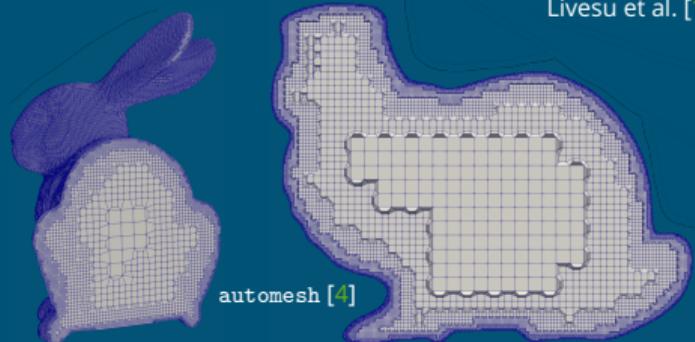
Many features make this the top choice.

- Dual schemes are unambiguously applied.
- Degrees of adaptivity are fully automatic.
- Optimal transitions for low edge valences.
- Some of the lowest element counts and fastest transitions possible [5, 6].

Recently shown that element quality can be kept somewhat high through smoothing [7].



Livesu et al. [1]



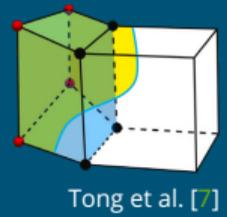
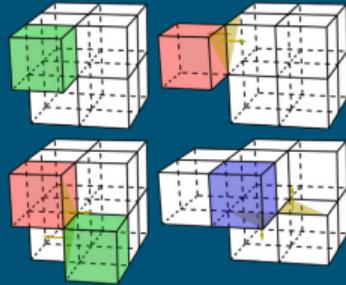
automesh [4]

4 Hexahedral conformity



Conformity to the input surface(s).

- Delete elements with nodes outside.
- Rules to clean up buffer region.
- Fill buffer with elements to surface.
- Laplacian smooth, element improvement.

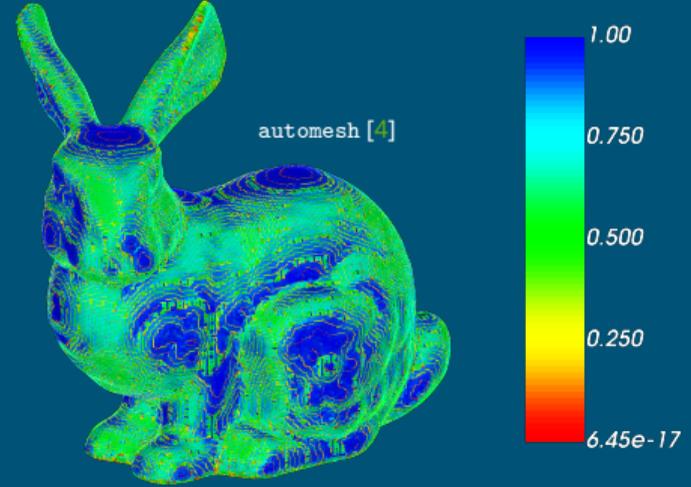


Different methods to fill buffer region.

- Strict duplication-then-projection [7].
- Multi-step process with pillowing [8].
- Closest-point projections typically.

Other aspects to consider simultaneously.

- Size via local shape diameter or curvature.
- Interior surfaces (multi-material cases).
- Snap nodes to geometric corners/edges.



5 Hexahedral adaptivity



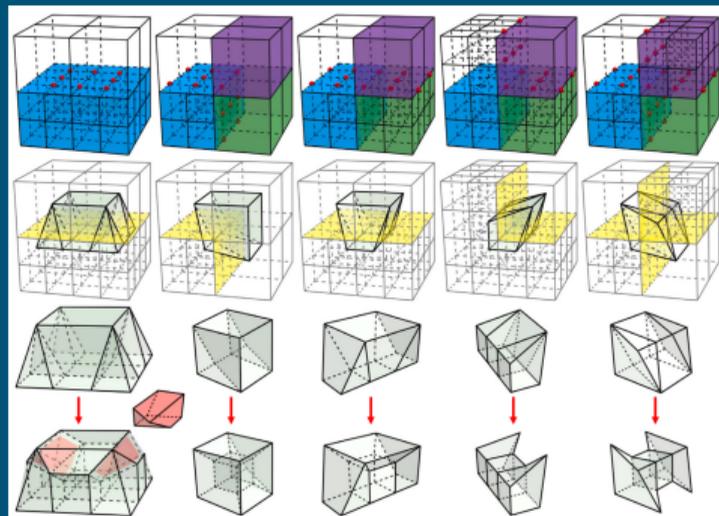
Dual schemes can be fully templated [4, 7].

- 1 face template, 4 edge templates [7].
- No need for intermediate polyhedra.
- Templates can be placed independently.
- Smoothing takes 0.258 MSJ to 0.5+ [7].

Templates can be placed wicked fast [4].

- Cell centers form indexable node map.
- Another clever map for transition nodes.
- Some number of explicit vertex templates.
- Uniform surface refinement for now.
- Eventually, weakly-balanced templates.

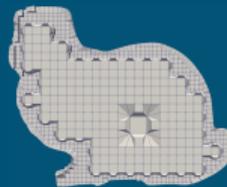
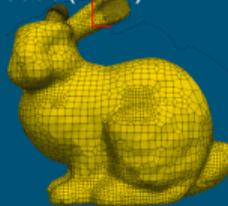
Difficult to make comparisons, but automesh could be hundreds (or thousands) times faster.



Tong et al. [7]
358 s (21.7k)

automesh [4]
182 ms (21.7k)

automesh [4]
805 s (54.7m)



6 Hexahedral conformity



Several pieces efficiently implemented.

- Outside element and node removal.
- Removal within the buffer region.
- Closest-point (and other) projections.

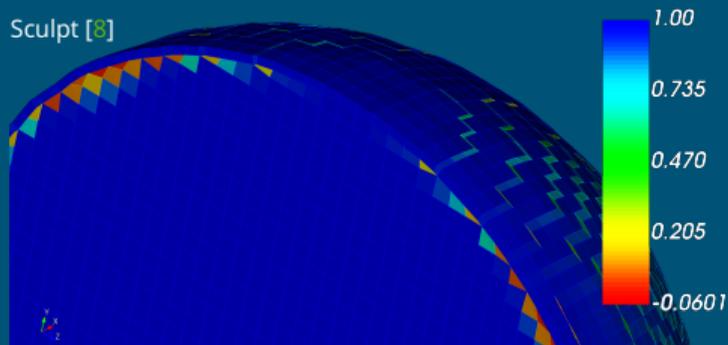
Current challenge is element improvement.

- Laplace surface & volume smoothing [8].
- General element metric improvement [9].
- Robust Jacobian-based improvement [7].
- Energetic (variational) smoothing [10].

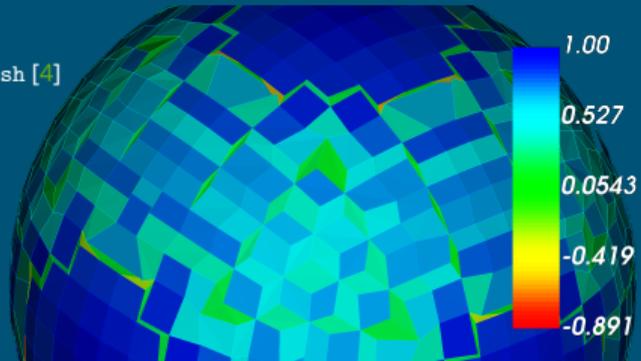
Can element quality be improved very rapidly?

- Fast/parallel treatment of limited stencils.
- Lazy enforcement of surface constraints.
- Critical thinking for new optimizations.

Sculpt [8]



automesh [4]





Major progress and current challenges.

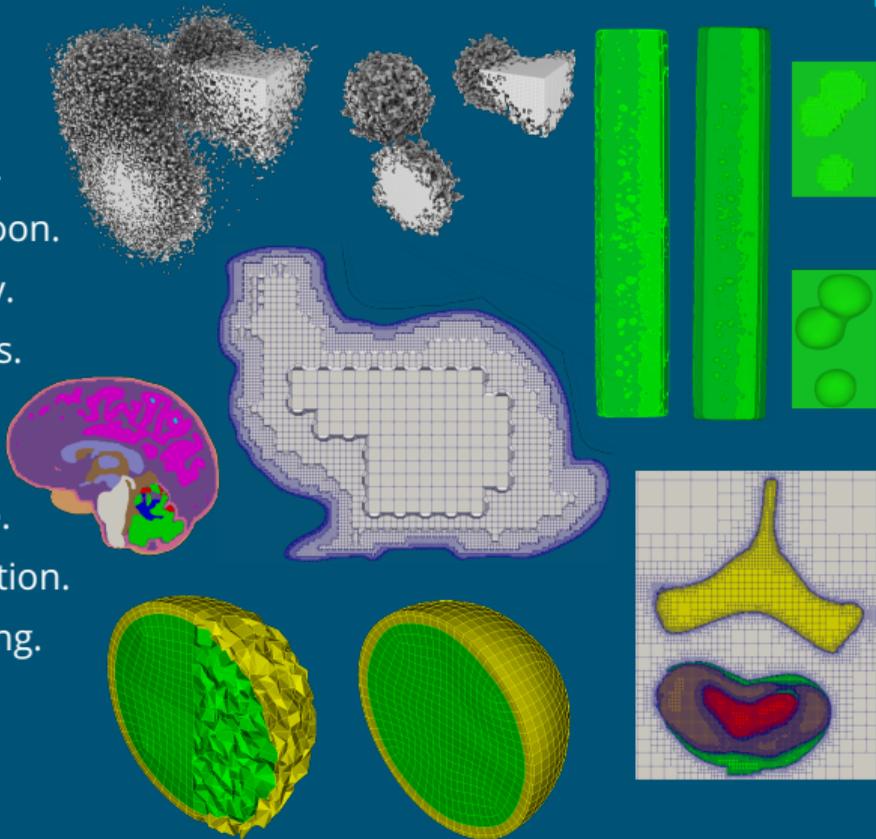
- Adaptivity is blazingly-fast and robust.
- Conformity will likely be conquered soon.
- Simple methods for surface adaptivity.
- Determine weakly-balanced templates.
- Conformity to interior surfaces and model geometry edges or corners.

Additional features [11] not discussed here.

- Voxel defeaturing, surface reconstruction.
- Taubin [12] or energetic [10] smoothing.

Outside-the-box ideas and opportunities.

- Hex-dominant meshes with VEM [13].
- Investors? Users? Possibly you!





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