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Dualization for Automatic Mesh Generation in the Pixel to Mesh Workflow

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Sandia National Laboratories

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Award Period 9/30/21 to 9/30/22

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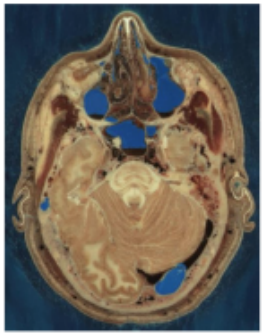
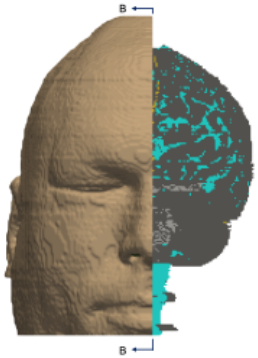
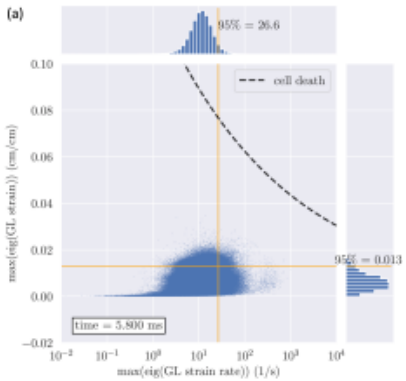
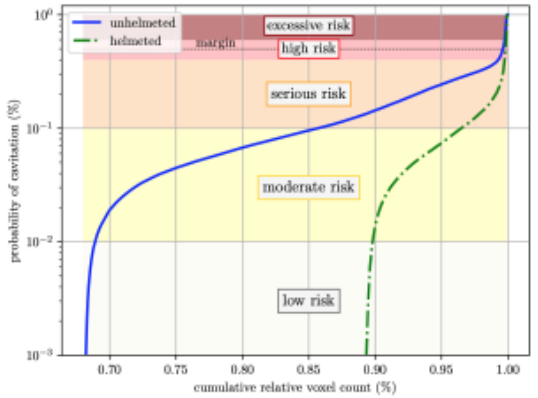
Background







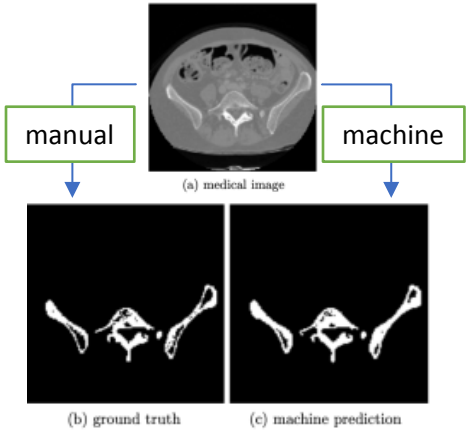


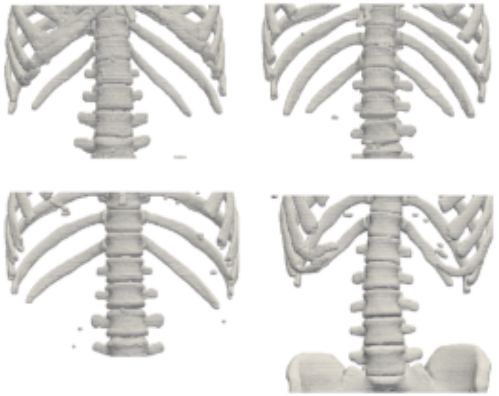
Two **bottlenecks**

Human → Manual Segmentation → Mesh → Assessment Injury Risk, Performance

Models "M/F" "S, M, L, XL" → … now 8x the bottlenecks as previously, the current approach <u>does not scale</u>.

Photo credit: US Marine Corps

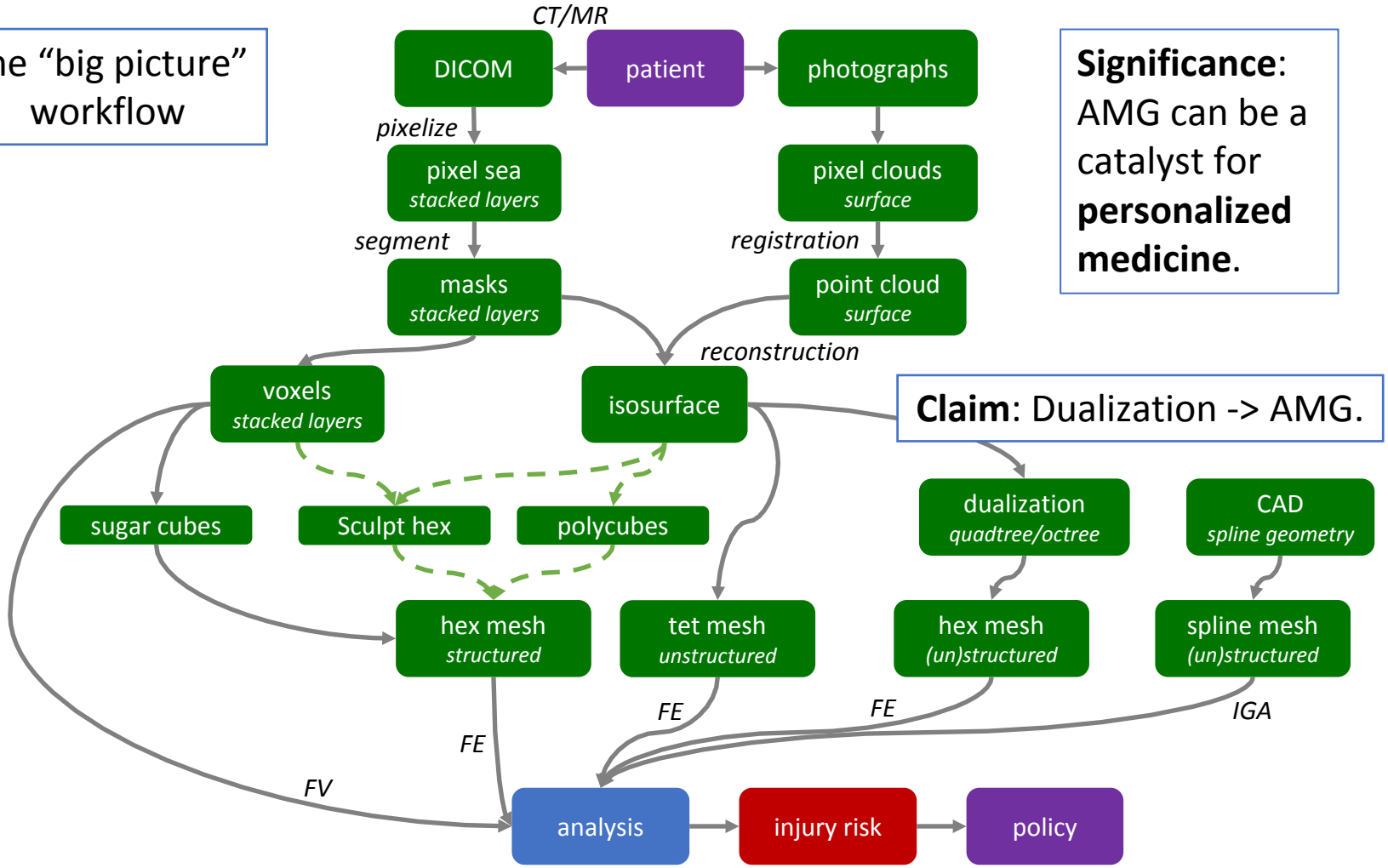




Objective

- Automate the pixel to mesh workflow to allow scale.

The "big picture" workflow



Significance: AMG can be a catalyst for **personalized medicine**.

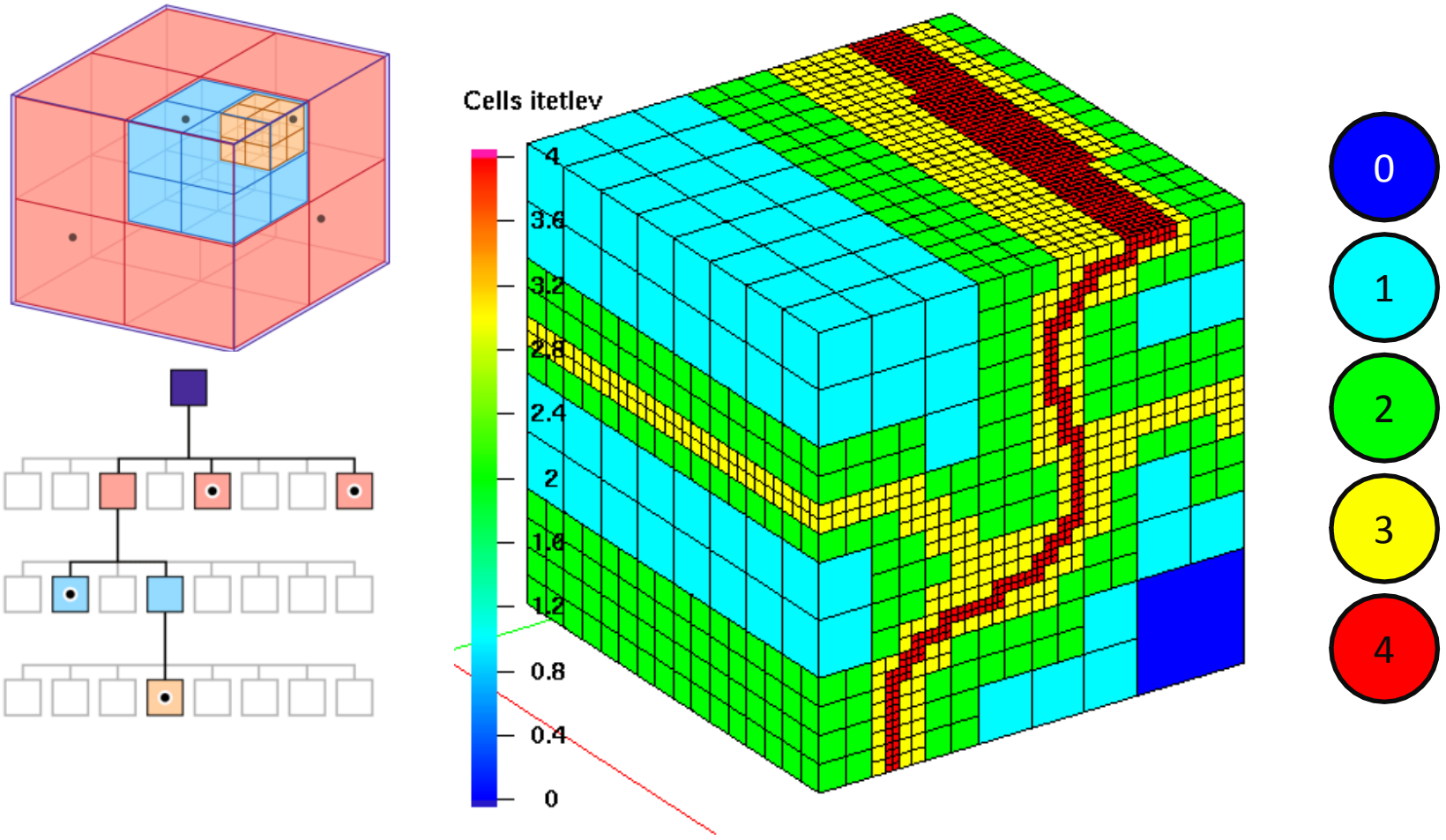
Claim: Dualization -> AMG.

Technical Approach – Risks

- B-spline-based approaches are ubiquitous in CAD/CAM aero/auto applications.
  - Risk: splines may require **manual interaction**, which counteracts automation.
  - Human model encoded with pixels, not CAD.

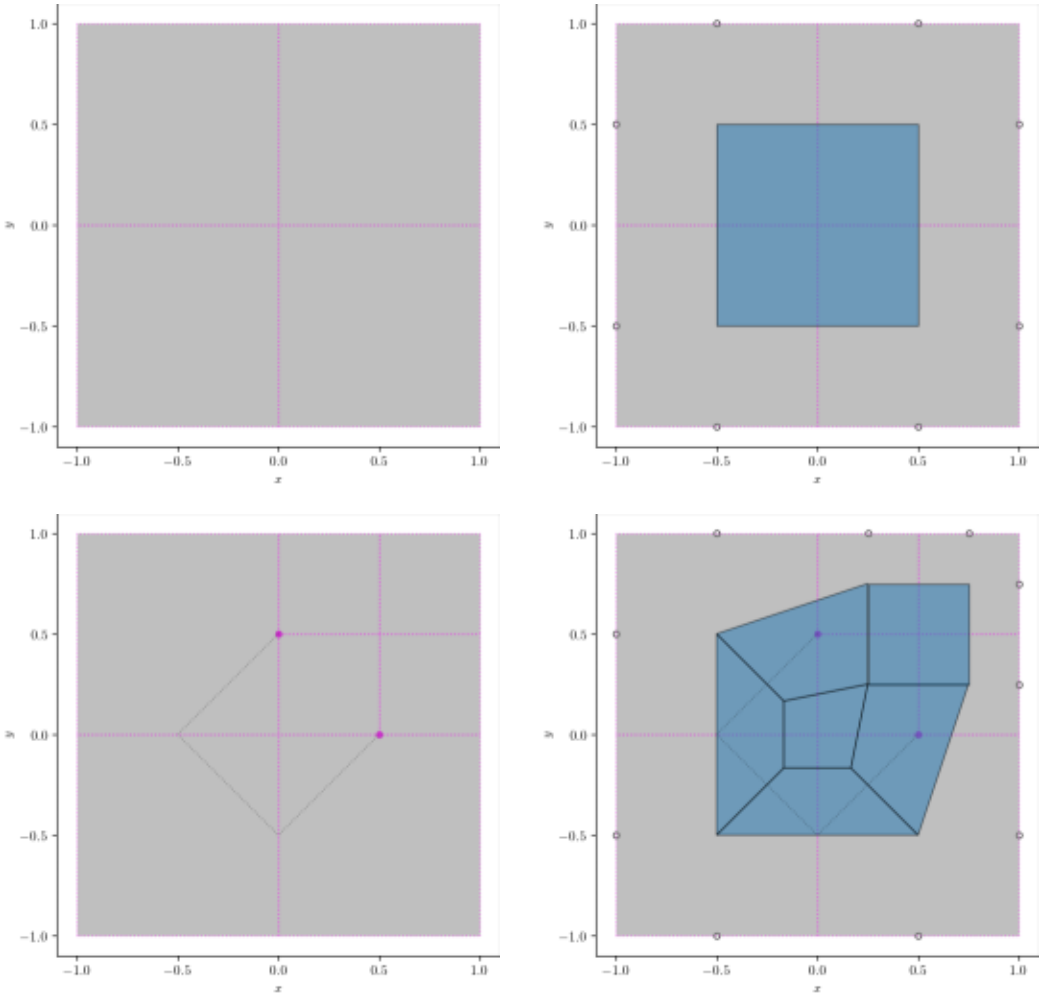
- Mitigation:
  - Pivot from IGA toward dualization methods.

Technical Approach – Octree



Reference: https://docs-assets.developer.apple.com/published/183088f967/octree_2x_d5ec086e-6563-4f2b-99a2-4e1762919c72.png and LaGriT Example: Octree Refine Hex, Intersect Object https://meshing.lanl.gov/proj/examples/ex_octree_refine_intersect_object/index.html.

Technical Approach - Dualization



Reference: Hovey C. Sandia Injury Biomechanics Laboratory Library. Sandia National Lab.(SNL-NM), Albuquerque, NM (United States); 2020 Jan 27. https://github.com/sandialabs/sibl.

Technical Approach - Dualization

Balance	Total	Non-Unique	Unique
Strong	16 = 2^4	10	**6**
Weak	4	3	**1**
	20	13	**7**

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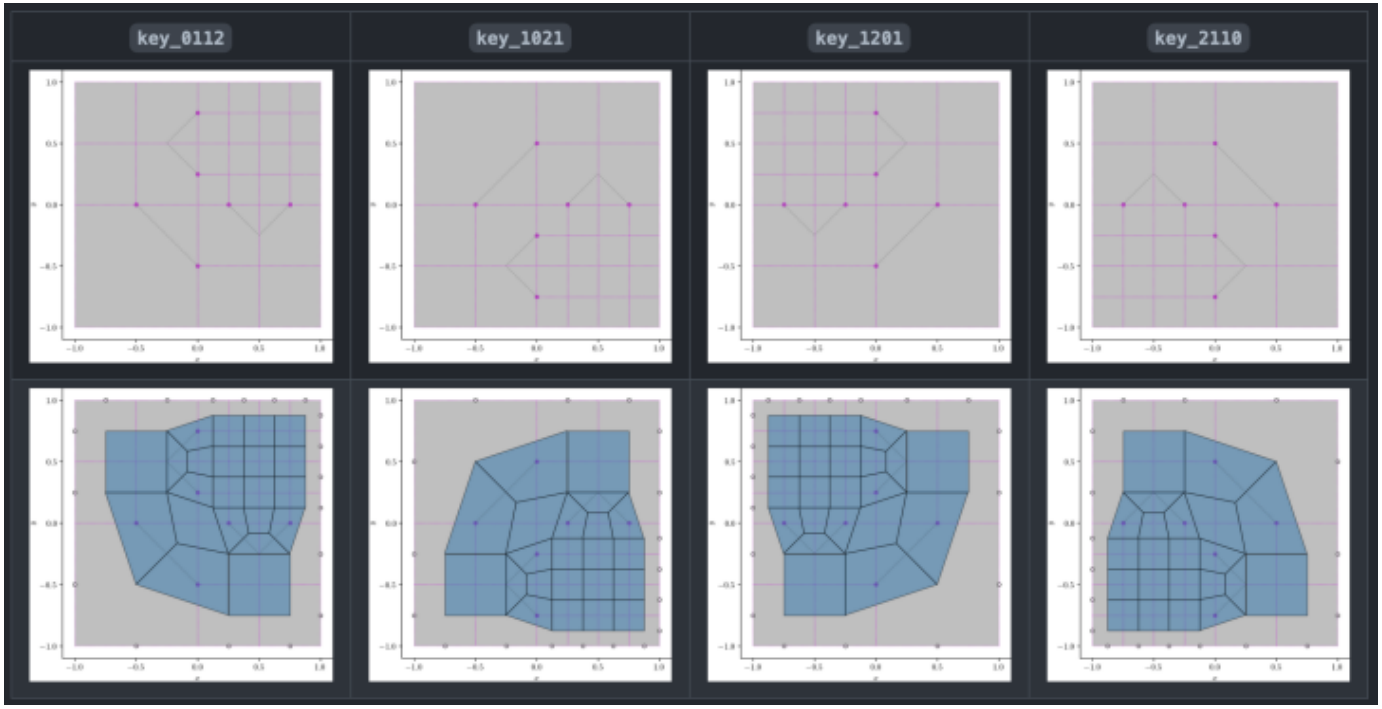

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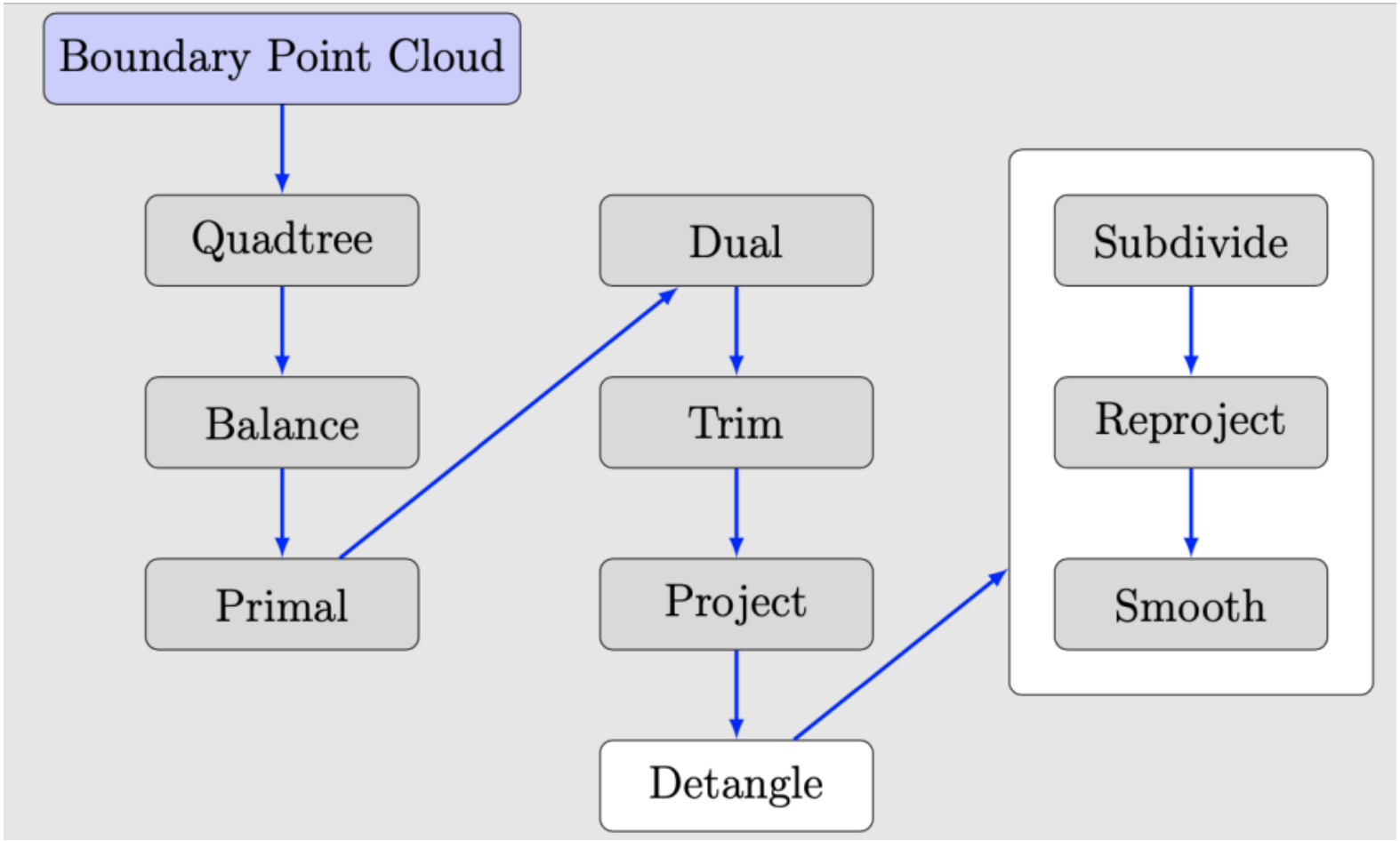

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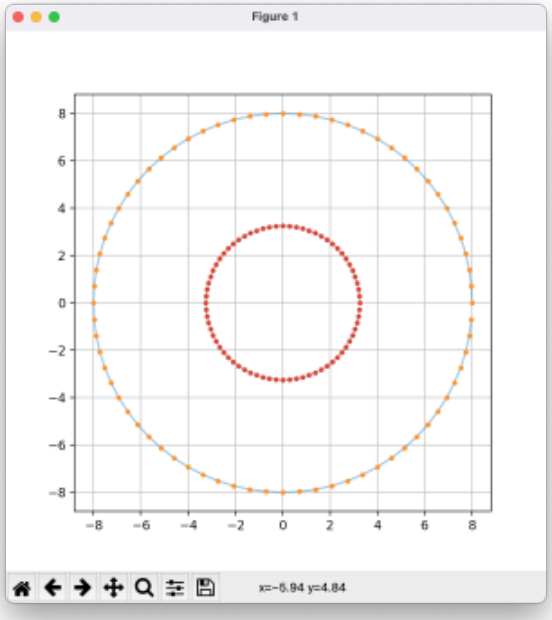

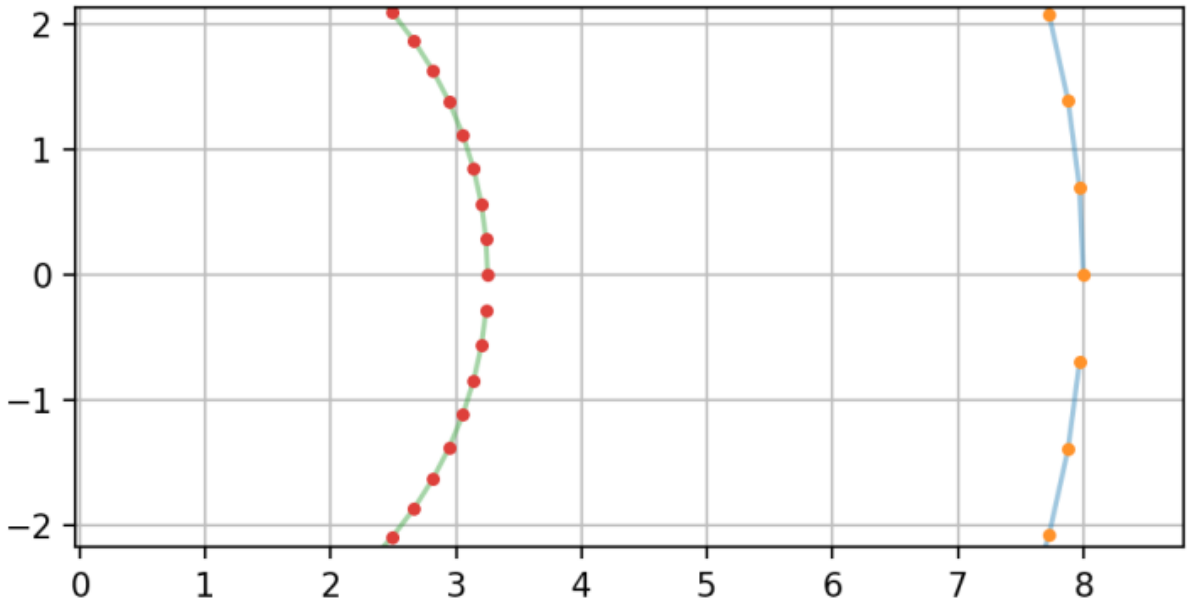

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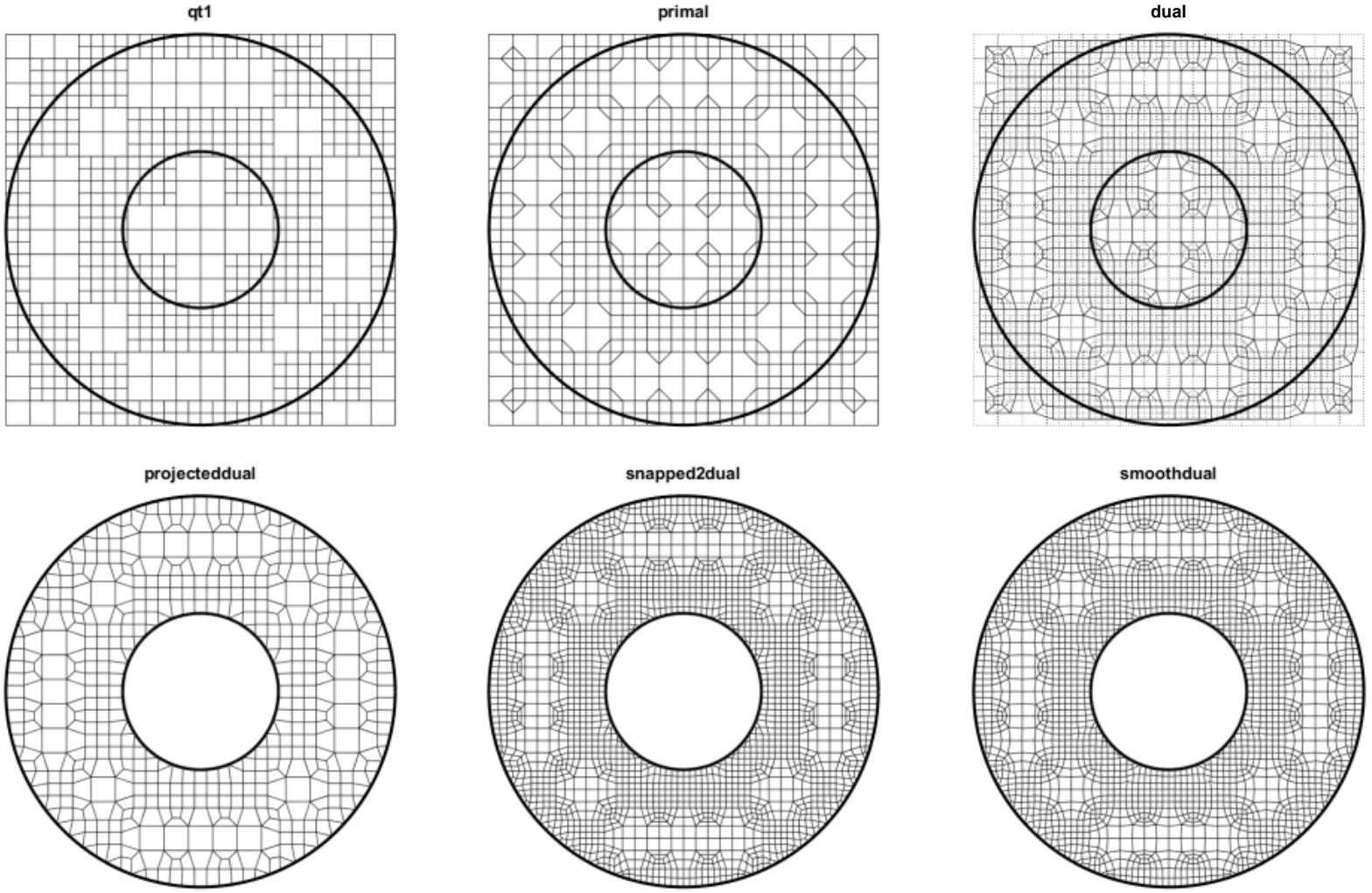

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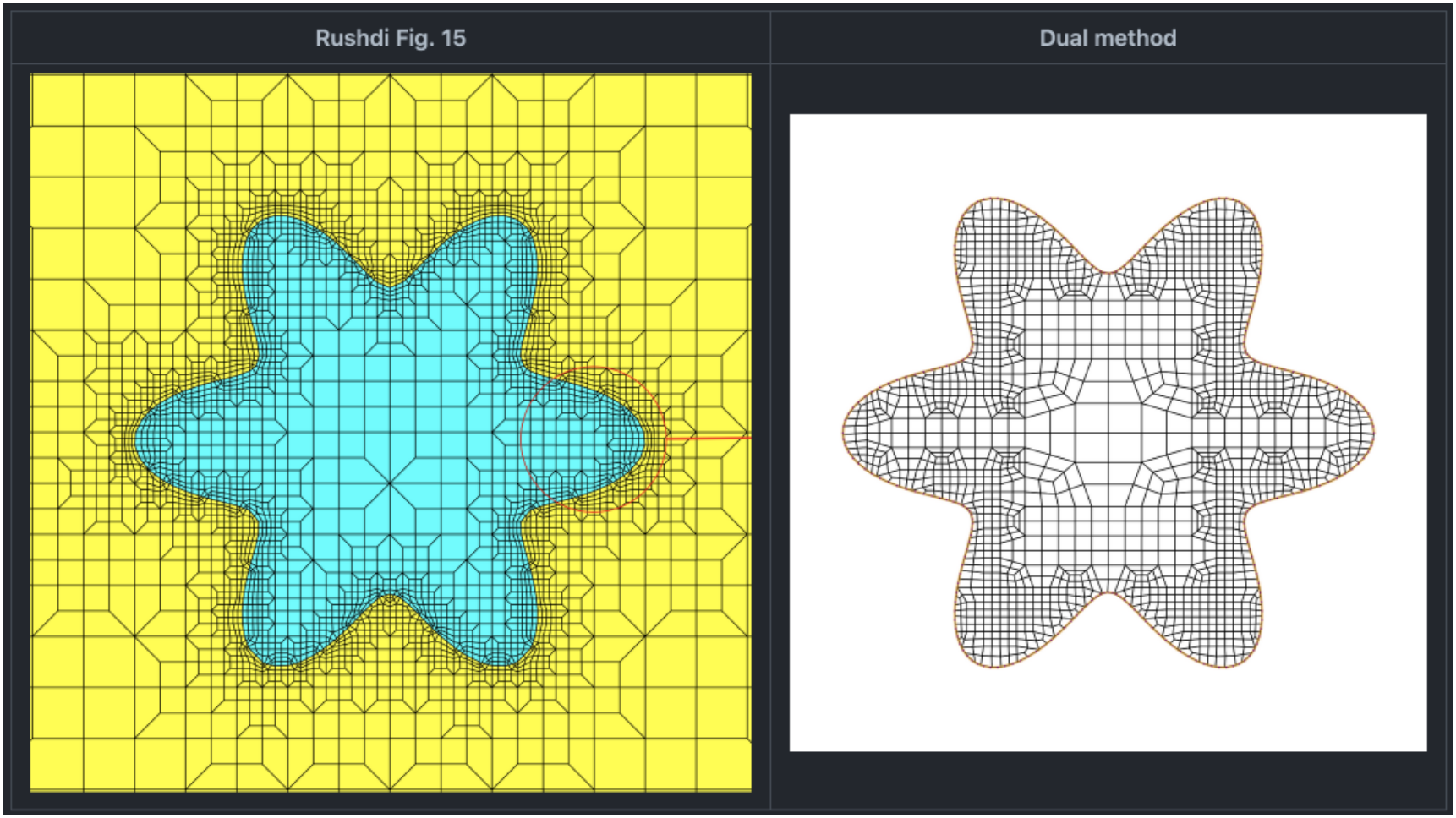

Reference: Rushdi AA, Mitchell SA, Mahmoud AH, Bajaj CC, Ebeida MS. All-quad meshing without cleanup. Computer-Aided Design. 2017 Apr 1;85:83-98;
Hovey C. Sandia Injury Biomechanics Laboratory Library. Sandia National Lab.(SNL-NM), Albuquerque, NM (United States); 2020 Jan 27. https://github.com/sandialabs/sibl and A. Sokolow SIBL mesh engine.

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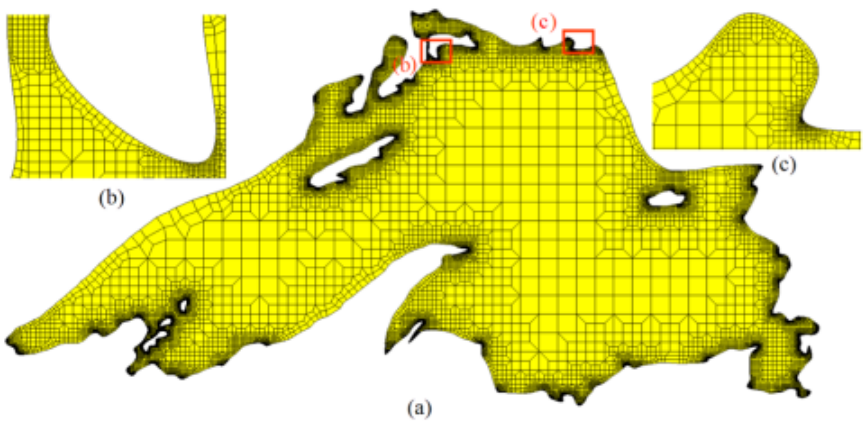
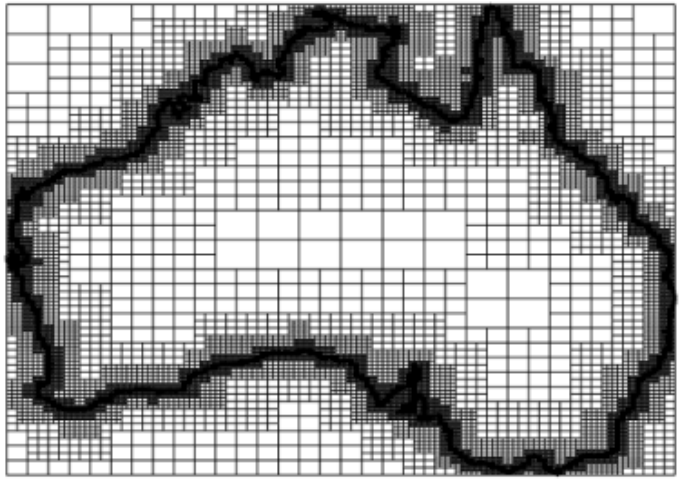


Fig. 10. The Lake Superior map. (a) Final guarantee-quality all-quad mesh with all angles $\in [43°, 135°]$; and (b-c) Zoom-in pictures of (a).

Reference: Liang X, Ebeida MS, Zhang Y. Guaranteed-quality all-quadrilateral mesh generation with feature preservation. Computer Methods in Applied Mechanics and Engineering. 2010 Jun 1;199(29-32):2072-83; Hovey C. Sandia Injury Biomechanics Laboratory Library. Sandia National Lab.(SNL-NM), Albuquerque, NM (United States); 2020 Jan 27. https://github.com/sandialabs/sibl and A. Sokolow SIBL mesh engine.

Technical Approach - Dualization

qt1



smoothdual

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Technical Approach – Risks

- Current libraries may be proprietary, forcing a "build" over "buy" approach.

- Mitigation:
  - Propose to vendors that Sandia and ONR are non-commercial entities.
  - Build a 2D workflow first; a 3D workflow second.

Accomplishments

- Collaboration – RMU/PANTHER
- Communication – publication, conference, web
- Development – SIBL open-source GitHub repo
  - **Fully automated 2D workflow** from boundary representation to quadrilateral mesh,
  - DevOps environment for continuous integration and continuous deployment (**CI/CD**),
  - **Impact**: open-source collaboration with **proven quality** that is **reproducible** and **responsive**.

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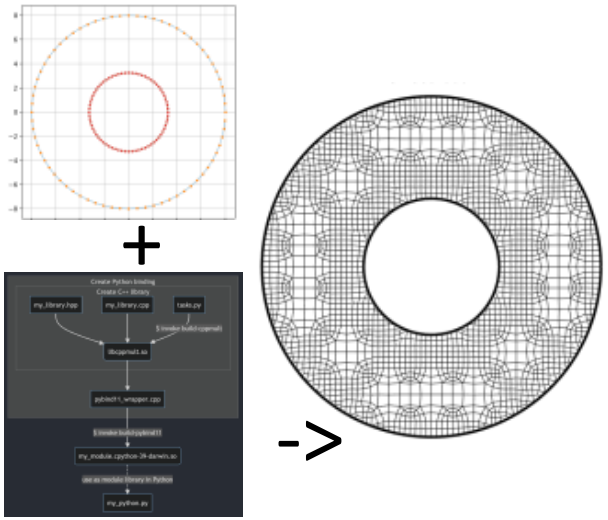
Success Stories

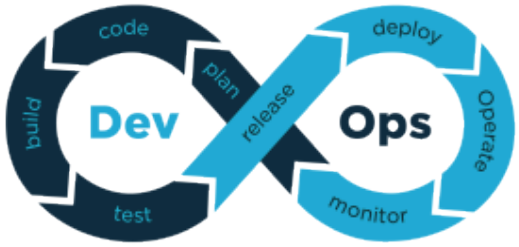


Fully Automated 2D Workflow Boundary to Dualized Quadrilaterals

We have created and demonstrated a fully automated 2D workflow, taking a discrete boundary representation into a fully quadrilateral mesh *without human interaction in the workflow.*

Other 2D strategies (e.g., paving, *etc.*) do not have a 3D analog. In contrast, dualization in 2D via quadtree has a direct 3D analog in via an octree.

We have a promising path forward.

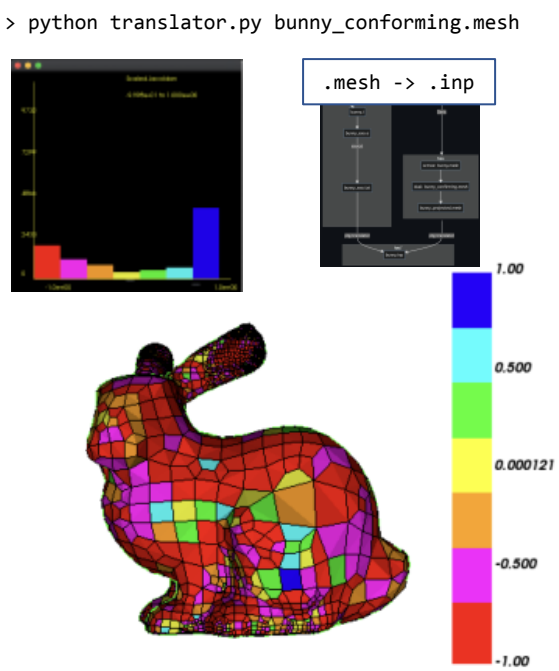


Success with Software Service Delivery

DevOps Culture of of Continuous Integration Continuous Deployment (CI/CD).

- Changes are **automatically built**, **validated**, and **tested**.
- Code is **always deployable**.
- **Real-time feedback** loop from stakeholders.
- Developers are **more productive**, workflows are **repeatable**.
- Updates are small and frequent -> failures are rare -> **software stability**.

Reference: Microsoft Azure, Continuous Delivery versus Continuous Deployment, https://tinyurl.com/5dx5etr2, accessed 23 May 2022.



Success with RMU/PANTHER Collaboration

The collaboration with Robert Morris University and the PANTHER team has been produced three concrete deliverables:

(1) *Military Medicine* publication,
(2) MHSRS 2022 acceptance,
(3) Python code integration into SIBL GitHub repository with Sushan Nakarmi.

Issues

- Technical Issues:
  - None.
- Resource Issues:
  - Departure of three collaborators Patel, Sokolow, and Terpsma.

Conclusions

- **Mesh generation** remains a serious bottleneck in the **personalized medicine** workflow.
- When modeling **incompressible materials** (e.g., the brain), quad/hex meshes are mandatory for both performance and convergence.
- AMG is known for quad and tri/tet elements, but only **emerging** for **hex** meshes.
- We have created and demonstrated AMG via dualization in 2D and a path forward for 3D.
- AMG 3D aims to **unlock** the current mesh **bottleneck** and be a **catalyst** for **personalized medicine**.

Path Forward

Activities Schedule	FY20	FY21	FY22	FY23	FY24	FY25	FY26
Objective 1							
Complete SIBL Geometry Engine 2D Dualized Automatic Mesh Generation							
Assess existing 3D dualization library (e.g., CinoLib, Gena)							
SIBL Geometry Engine 3D Dualized Automatic Mesh Generation							
Pixels (CT/MR) to Mesh Generation							
Digital Twin Component Anatomy							

Publications, Patents, Presentations, & Awards

Peer Reviewed Publications

A-7. Terpsma R, Carlsen RW, Szalkowski R, Malave S, Fawzi AL, Franck C, Hovey C. Head impact modeling to support a rotational combat helmet drop test. Military medicine. 2021 Sep 11. Link to Terpsma 2021 and Download (3.3 MB).

A-6. Miller ST, Cooper CF, Elsbernd P, Kerwin J, Mejia-Alvarez R, Willis AM. Localizing Clinical Patterns of Blast Traumatic Brain Injury Through Computational Modeling and Simulation. Frontiers in Neurology. 2021;12. Link to Miller 2021 and Download (4.2 MB).

- Abstract accepted to the MHSRS 2022
  - Semi-automated patient-specific modeling workflow,
  - SNL in collaboration with RMU.

Reference: https://www.sandia.gov/biomechanics/

Cooperative Development

- Ongoing collaborations with Rika Wright Carlsen and her research team.

- Potential for collaboration with other ONR performers who have **manual segmentation** in their workflow.
- Current works **builds on** C2B2, PANTHER, and Special Studies **past investments**.

Collaboration & Discussion

- Continued collaboration with RMU/PANTHER.
- Nascent collaboration with CNR-IMATI.

Optimal Dual Schemes for Adaptive Grid Based Hexmeshing

MARCO LIVESU, CNR IMATI
LUCA PITZALIS, University of Cagliari and CRS4
GIANMARCO CHERCHI, University of Cagliari

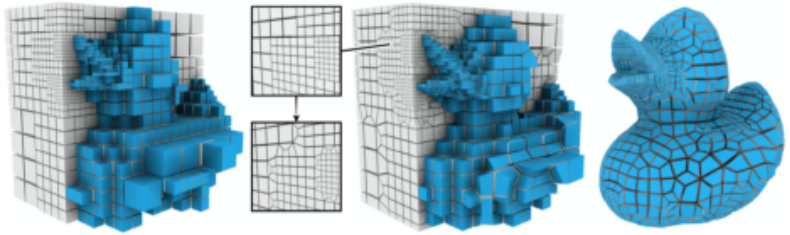


Fig. 1. We propose a novel set of dual schemes to turn an adaptively refined grid into a conforming hexahedral mesh. Compared with prior methods, our schemes allow to process a broader class of input grids, and produce coarser hexahedral meshes with a simpler singular structure.

- Python and/or Julia developer with experience in Solid Mechanics and DevOps.

Reference: Livesu M, Pitzalis L, Cherchi G. Optimal dual schemes for adaptive grid based hexmeshing. ACM Transactions on Graphics (TOG). 2021 Dec 6;41(2):1-4.