Naval Force Health Protection Program Review 2021

Pixel to Mesh (PTM)
Pixel to Geometry (PTG)

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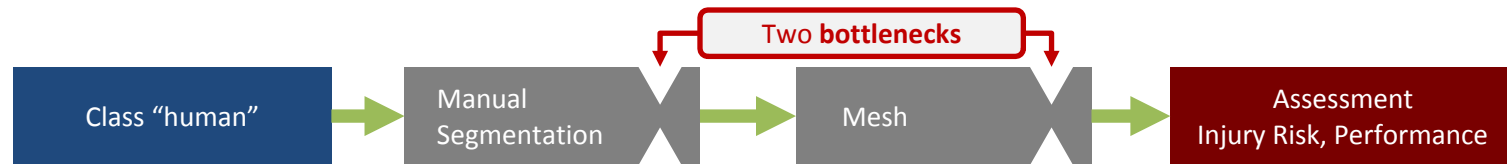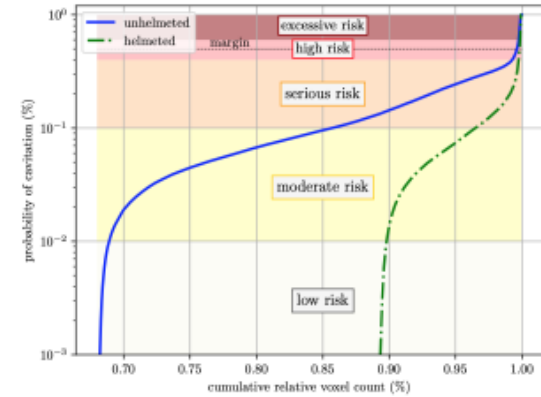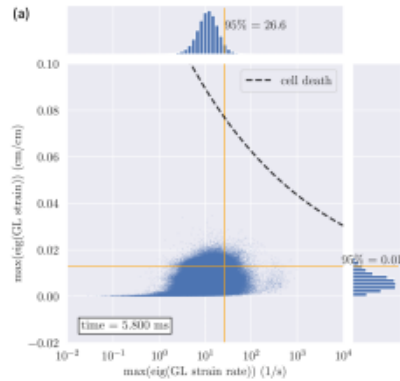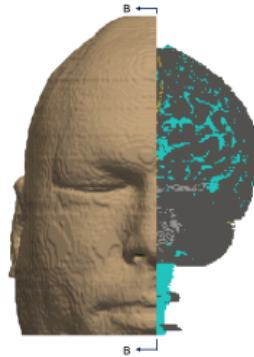
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9/30/20 to 9/30/21

Two **bottlenecks**

| Class "human" | → | Manual Segmentation | → | Mesh | → | Assessment Injury Risk, Performance |
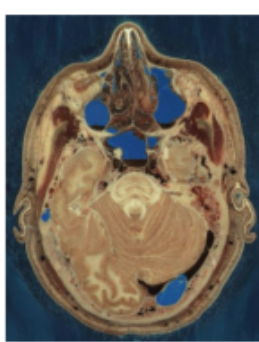
Class "male, female" "S, M, L, XL" … now 8x the bottlenecks as previously, the current approach <u>does not scale</u>.

Photo credit: US Marine Corps

manual   machine

(a) medical image

(b) ground truth   (c) machine prediction
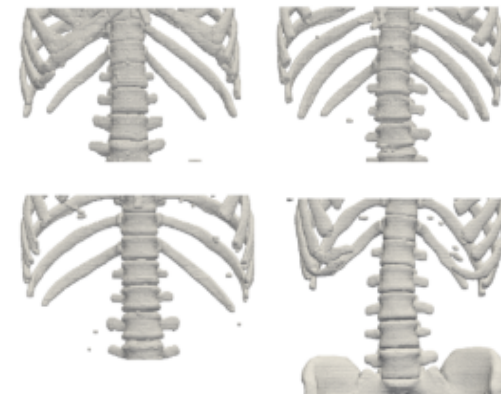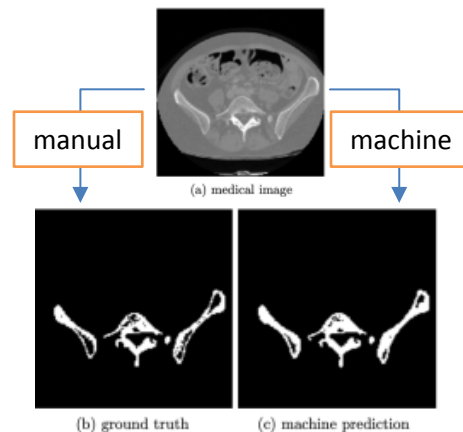
OBJECTIVE

- Automate the pixel to mesh workflow to allow scale.
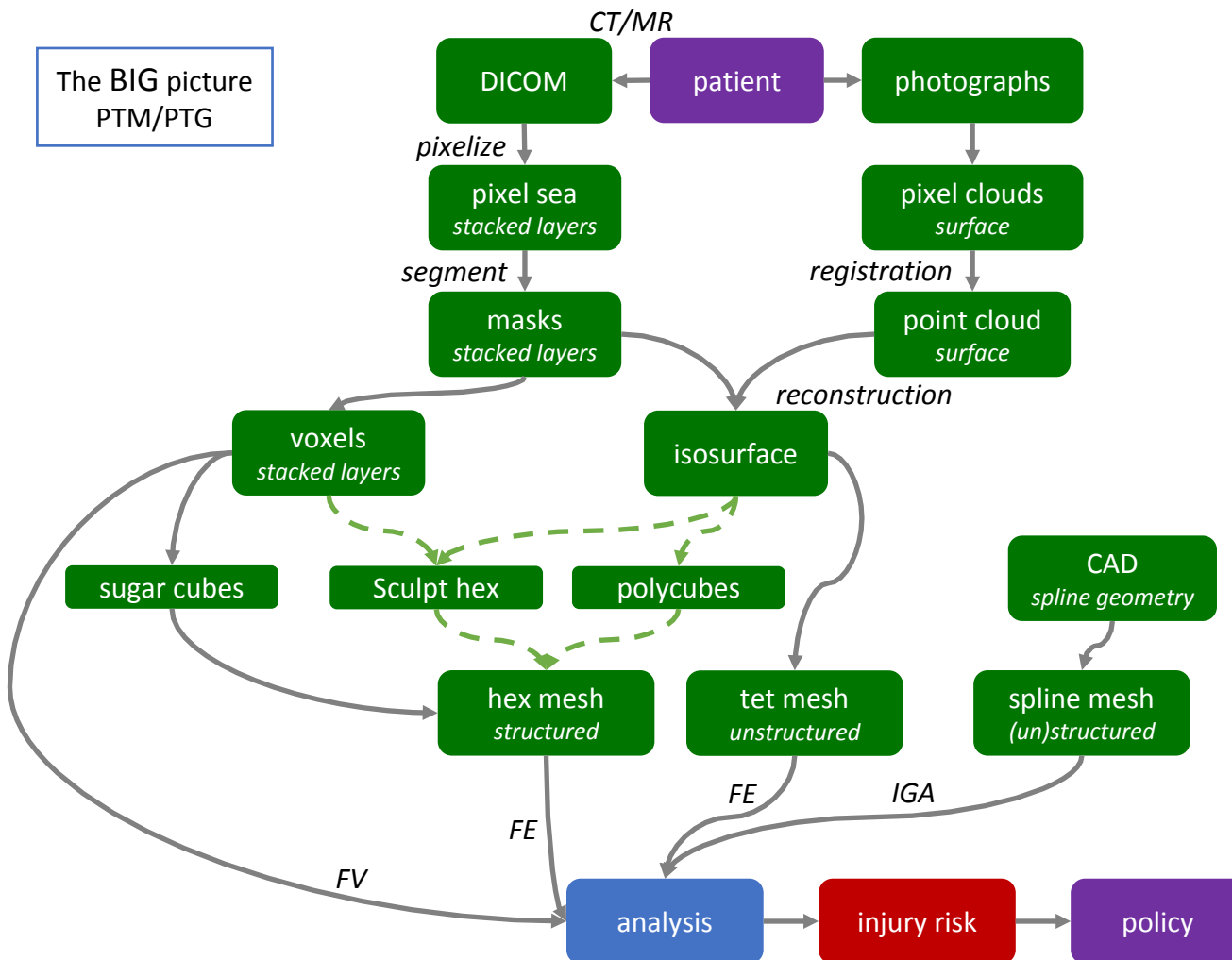
- We are currently investigating spline-based down-sampling techniques that can give rise to an alternative analysis methodology known as isogeometric analysis (IGA). We call this workflow approach Pixel to Geometry (PTG).
- Within this context, we are investigating avenues to automatically recover finite element meshes to support legacy analyses methods.
- B-spline-based approaches are ubiquitous in CAD/CAM aero/auto applications. Their utility for computational biomechanics is less clear.
- Risk: splines may require manual interaction, which counteracts automation.

ACCOMPLISHMENTS

- Implementation of Geometry Engine for Bézier and B-spline curves, surfaces, and volumes.
  - Open source: https://github.com/sandialabs/sibl
  - Python 3.8 object-oriented (OOP) and functional (FP) design
  - Research code as professional grade software:
    - Automated continuous integration (CI)
    - Proof of code quality (currently > 140 tests)
    - Code coverage watermarks
    - Standards-compliant Black code style
- Demonstrated geometry creation and unit test point (pixel) down-sampling.
- Extensive, high-quality $\LaTeX$ documentation on mathematical methods.

Success Stories
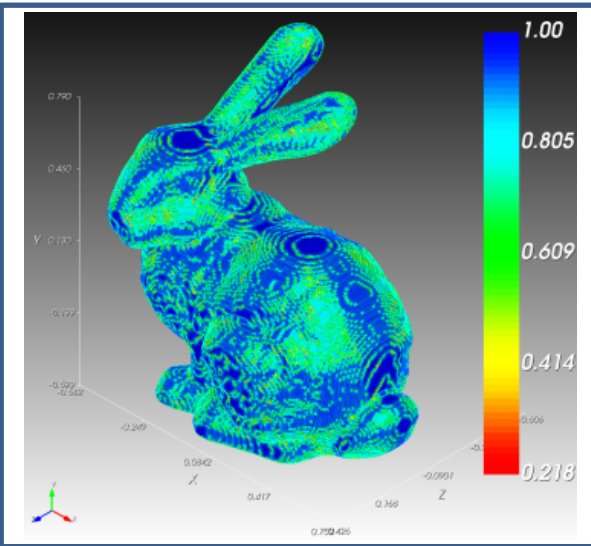
Automated Hex-Based Baseline

We have established an automated workflow that converts bitmap masks and STL data to 100% hex-based finite elements. Nearly 90% of all hexes have scaled Jacobian measures of between 0.89 and 1.00.

This incumbent workflow will serve as the basis of comparison with B-spline methods, measured not only in terms of element quality measures, but also in terms of time-to-mesh, refinement-to-convergence profile, and human-in-loop requirements.
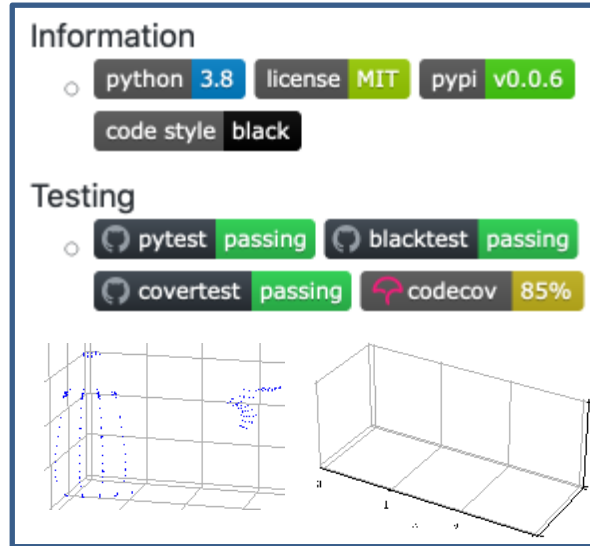
Open Platform with Proven Quality

We have implemented a Geometry Engine for Bézier and B-spline curves, surfaces, and volumes, with user-selectable p-refinement and h-adaptivity.

The open-source code base uses state-of-the-art object-oriented (OOP) and functional (FP) principles to ensure quality, reliability, and extensibility.

Automated quality testing assures reliability with proof of implementation correctness.
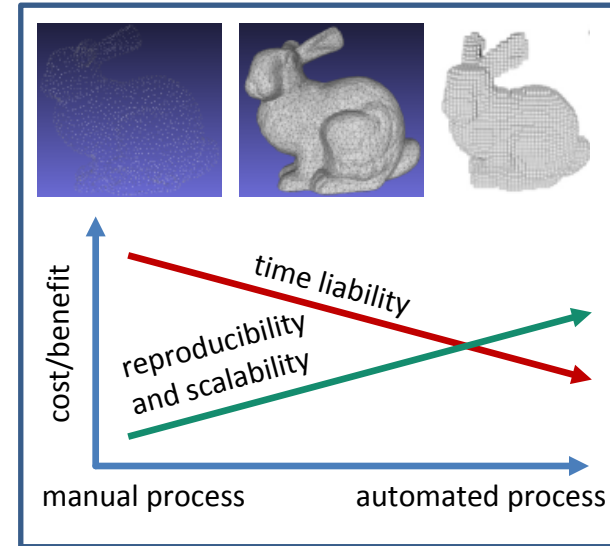
Roadmap for Injury Risk Assessment

While B-spline and Isogeometric Analysis (IGA) approaches have demonstrated significant advantages aero/auto applications, the lack of a CAD/CAM starting point for biomechanical applications may impose non-trivial manual workflow interactions.

The forthcoming exercise of our PTG workflow will objectively evaluate to what degree the workflow can be automated, and whether the workflow differences are material to injury risk predictions.

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CONCLUSIONS

- Manual workflows can produce injury risk assessment for singleton data (e.g., for a specific person at a specific time).
- Automated workflows are required to scale.
  - Populations, time-evolutions, length-scale resolution.
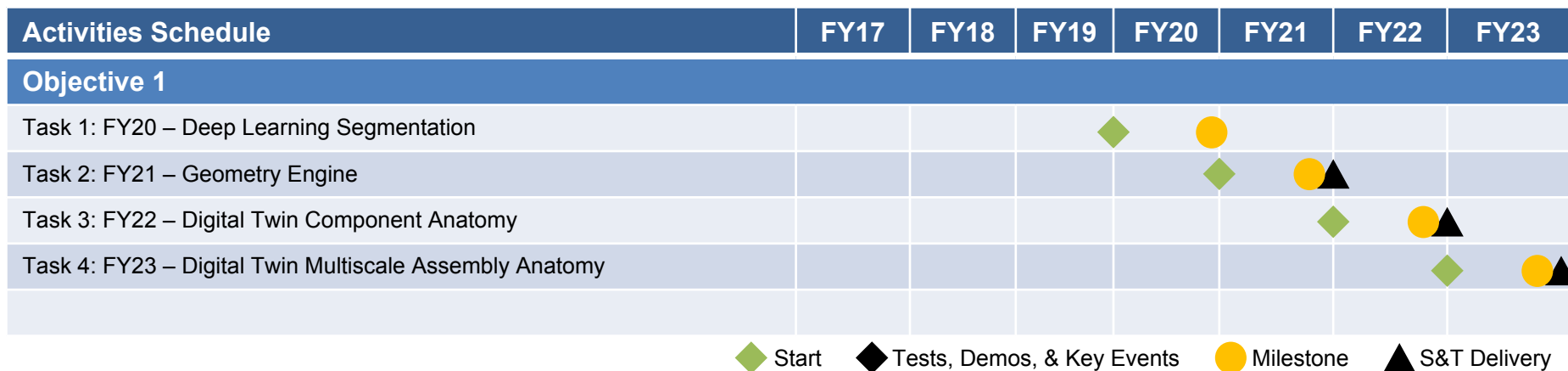
Geometry is patient-specific.

Geometry is patient-specific and can be time-specific too.
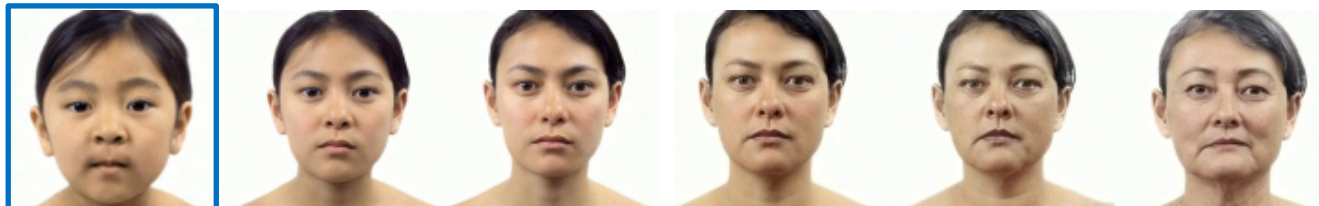
Reference: Cerniello, Anthony. Filmmaker uses digital wizardry to age face in five minutes. SBS News, February 26, 2015.

PATH FORWARD

Activities Schedule	FY17	FY18	FY19	FY20	FY21	FY22	FY23
Objective 1							
Task 1: FY20 – Deep Learning Segmentation			◆	●			
Task 2: FY21 – Geometry Engine				◆	●▲		
Task 3: FY22 – Digital Twin Component Anatomy					◆	●▲	
Task 4: FY23 – Digital Twin Multiscale Assembly Anatomy						◆	●▲

◆ Start　　◆ Tests, Demos, & Key Events　　● Milestone　　▲ S&T Delivery

- *Submitted to Military Medicine*

Head Impact Modeling to Support a Rotational Combat Helmet Drop Test

- Ryan Terpsma, M.S., Sandia National Laboratories
- Rika Wright Carlsen, Ph.D., Robert Morris University
- Ron Szalkowski, M.Eng., Team Wendy LLC
- Sushant Malave, M.S., Team Wendy LLC
- Alice Lux Fawzi, B.S.E., Brown University
- Christian Franck, Ph.D., University of Wisconsin-Madison
- Chad Hovey, Ph.D., Sandia National Laboratories

COOPERATIVE DEVELOPMENT

- The current work builds on:

  - Selected Python infrastructure and platform developments created in the PANTHER and C2B2 programs.

COLLABORATION & DISCUSSION

- There is potential for collaboration with other ONR performers who are focused on manual segmentation.
- We have ongoing constructive discussions with Rika Wright Carlsen of RMU and PANTHER.