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Special Studies: Pixel to Mesh (PTM) Pixel to Geometry (PTG)

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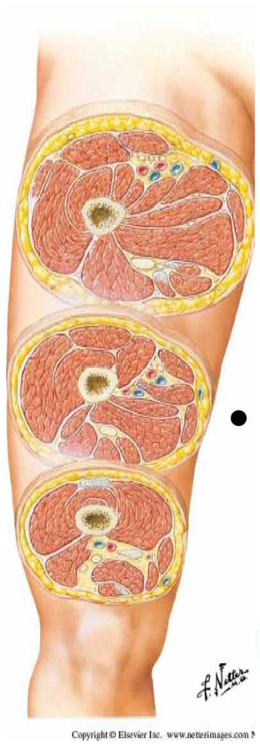
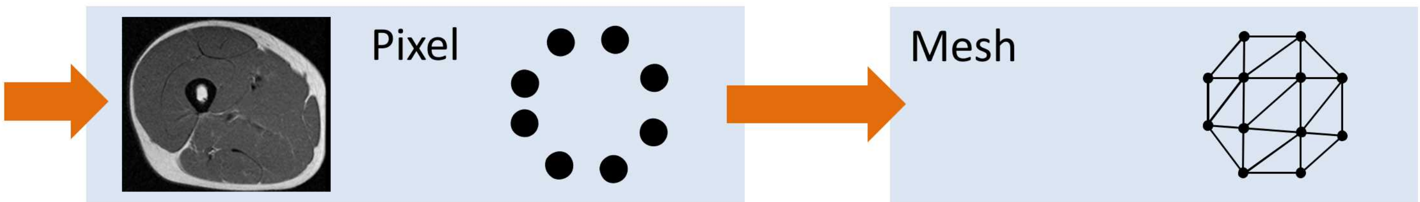
Background

- The Sandia Injury Biomechanics Laboratory (SIBL) has now successfully demonstrated that bone segmentation from axial CT images of torsos can be **automated**.
- The automation of the segmentation process is an important **breakthrough**, since it **eliminates** the need for **manual segmentation**, a significant bottleneck impeding the development of personalized human body **digital twin** based on a specific patient's medical imaging.

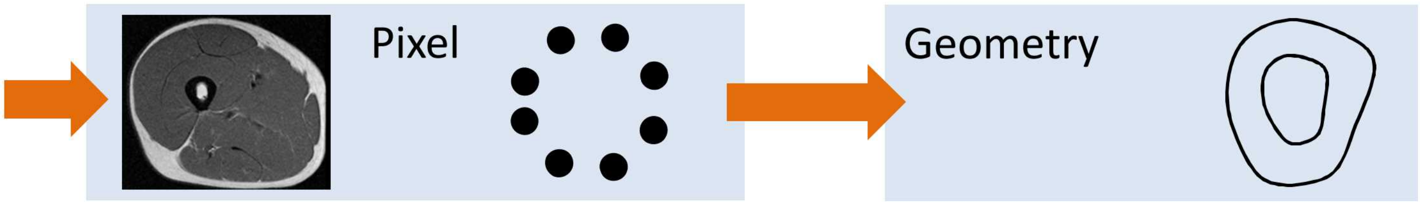
OBJECTIVE

- Develop a proof-of-concept machine learning application that automates bone segmentation.
- Pixel to Mesh (PTM)
    - Map the pixel data to a finite element mesh.





- Pixel to Geometry (PTG)
    - Eliminate the mesh bottleneck.



References: Netter Images and health-innovations.org.

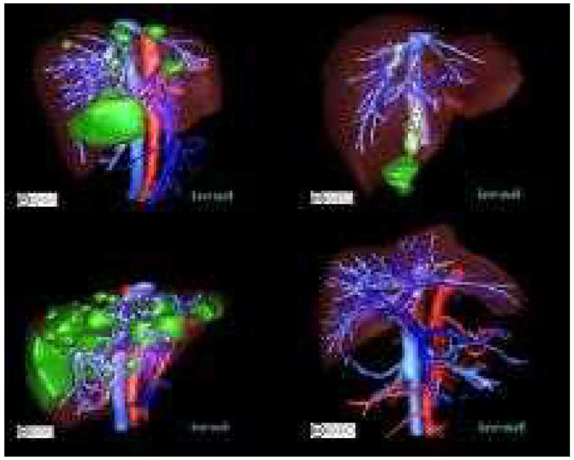
TECHNICAL APPROACH

- Leverage existing labeled data from IRCAD France, containing 10 male and 10 female subjects.
- Leverage the U-Net deep learning algorithm to teach a machine to recognize bone and soft tissue in axial CT images.
- From the machine's pixel data output, create a patient database (n=20) containing 3D finite element mesh torso bone anatomy, using the Sandia EXODUS toolset.
- Initiate PTG toward isogeometric analysis (IGA).

ACCOMPLISHMENTS

- Sourced a labeled dataset (D-IRCADb-01) sufficient for use with U-Net.
- Created a U-Net implementation, which has demonstrated the concept of automated segmentation with quality that is competitive to manual segmentation.
- Demonstrated the ability to use pixel segmentation to create finite element meshes, the PTM workflow.
- Started the PTG workflow.

Success Stories

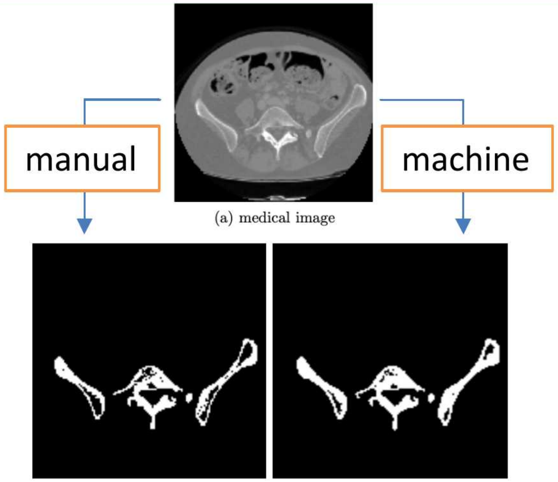


Leverage existing scans and algorithms

The 3D-IRCADb-01 database contains 3D CT scans of 10 males and 10 females. While the scans were originally created for hepatic tumor research, our laboratory was able to leverage data for use in bone and soft tissue recognition using the U-Net algorithm.

U-Net is a deep learning convolutional network for use with human image segmentation.

We created a state-of-the-art machine learning implementation building on Google TensorFlow and Keras.



(a) medical image

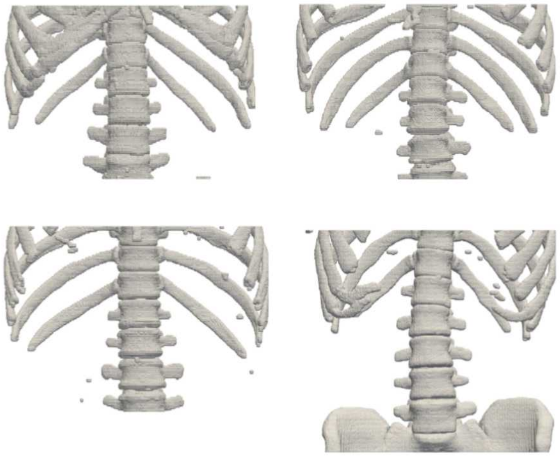
(b) ground truth (c) machine prediction

Bone Recognition

Our U-Net implementation, once trained on what is bone and what isn't, is capable of segmenting axial CT data and generating pixel maps of bone.

The resulting segmentation achieves a dice similarity score of 91.5%, indicating high level of confidence to reproduce human-level performance.

Our model is extensible, *e.g.*, from a single (bone only) to a dual (bone and soft tissue) material model, which would complete a first-order torso segmentation.



Finite Element Mesh (n=20)

We have also demonstrated successful conversion of pixels to voxels, as a proxy for finite volume or finite element meshes. We have called these two processes, taken in serial, Pixel to Mesh (PTM).

Within the PTM workflow, we found that the mesh step quickly became intractable. This motivated an alternative approach called isogeometric analysis (IGA).

We have now started to construct preliminary building blocks within the Pixel to Geometry (PTG) workflow to enable IGA.

CONCLUSIONS

- The Navy and Traumatic Brain Injury Community now has **confidence**, through our Pixel to Mesh (PTM) minimum working example (MWE) for n=20 torso skeletons, that the deep learning approach is **viable**.

- While the initial efforts have shown **promise**, significant additional **investment** is needed to develop this burgeoning technology into an application **platform** that can enjoy widespread use throughout the military medical community.

PATH FORWARD

Activities Schedule	FY17	FY18	FY19	FY20	FY21	FY22	FY23
Objective 1							
Torso subtask: 20 patient database for sternums					◆ ●		
Torso subtask: 20 patient database for ribs, clavicle, scapula						● — ▲	

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

PUBLICATIONS, PATENTS, PRESENTATIONS, & AWARDS

- Work in progress: SAND report.

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.