SAND2020-7205PE
SAND2020-5287 PE

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

PI: Chad Hovey
Co-I: Anirudh Patel, Ryan Terpsma
Sandia National Laboratories
chovey@sandia.gov

9/30/19 to 9/30/20

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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.

Background

Manual Segmentation

Section A-A

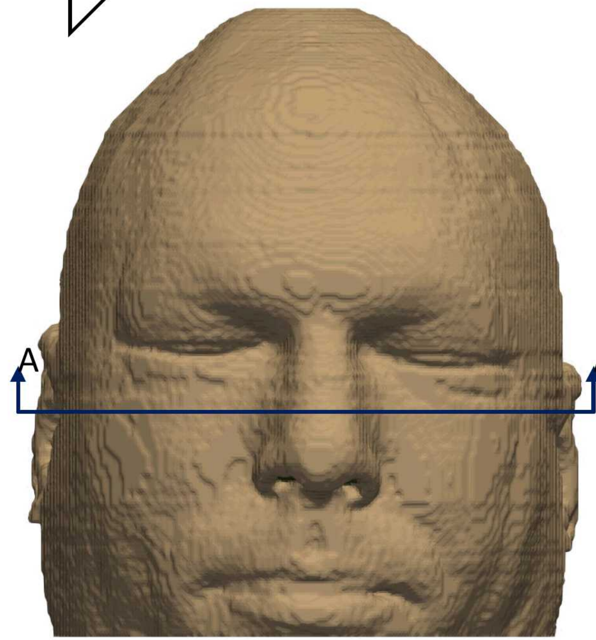
NIH U.S. National Library of Medicine

CT and digital photography scan entire body

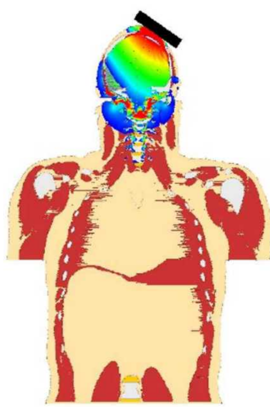
- full body 1,871 axial slices at 1 mm intervals
- CT: 512 x 512 pixels; 12 bit gray
- Photo: 4,096 x 2,700 pixels; 24 bit color

MR head and neck

- axial slices at 4 mm intervals
- 256 x 256 pixels; 12 bit gray

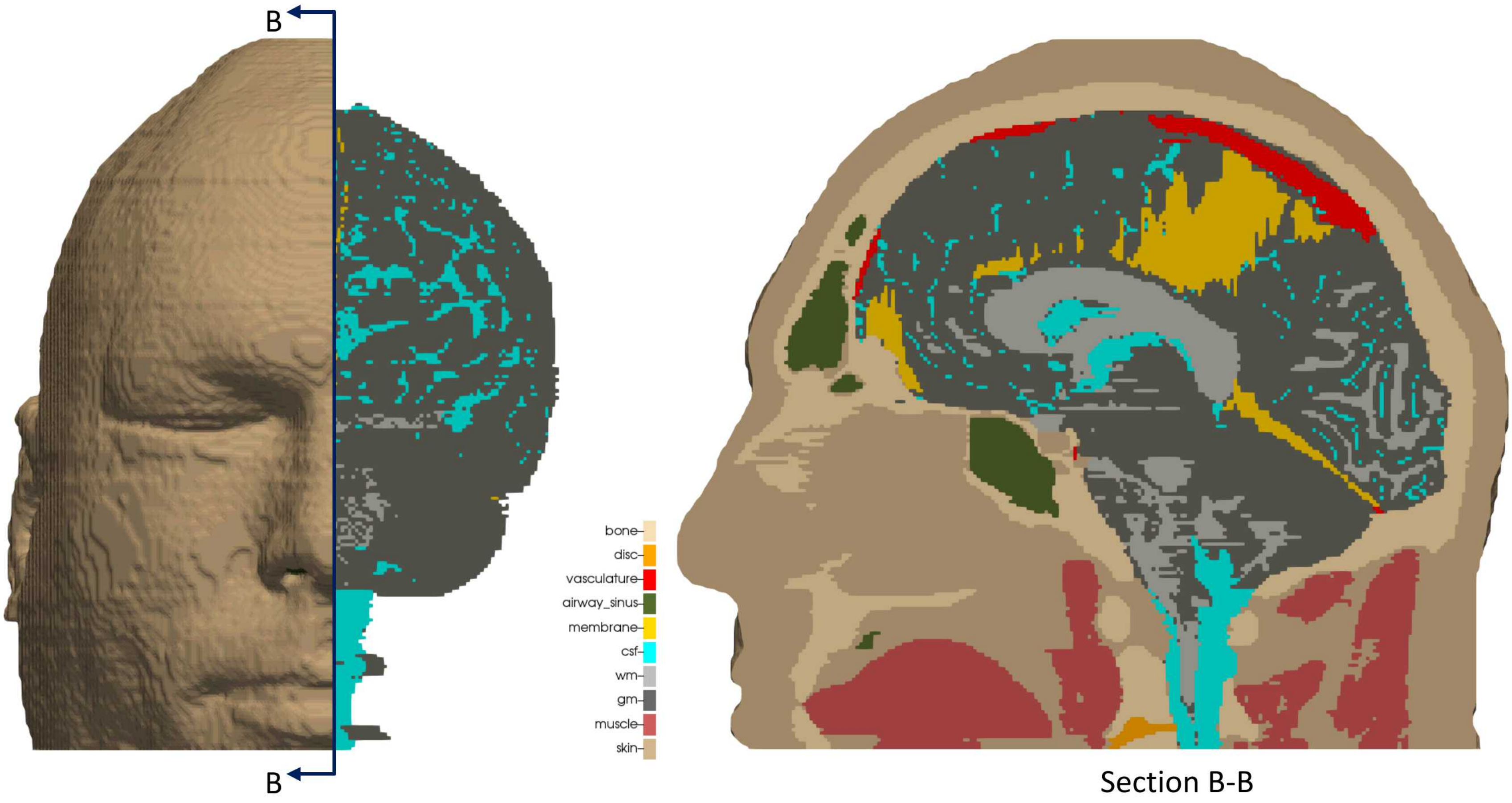


Sandia Injury Biomechanics Laboratory (SIBL) 5-kg head model ("**Bob**")



Background

SAND2020-5287 PE



Background

SAND2020-5287 PE

Manual Segmentation

Months to develop a single model.

Reproducible by one engineer.

Engineer contributes tedium.

Accurate segmentation.

Machine Segmentation

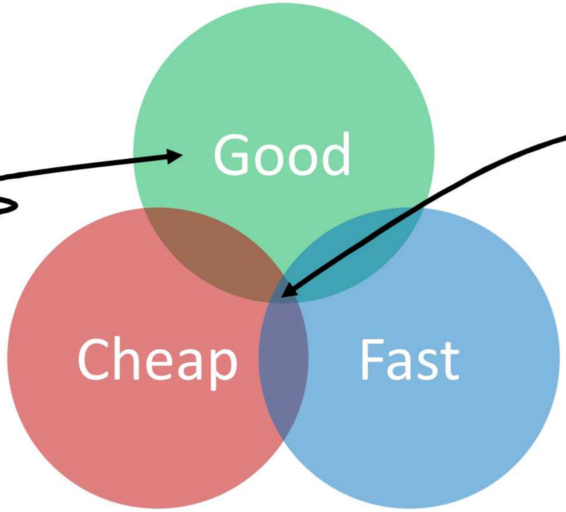
Minutes to develop a single model.

Reproducible by many engineers.

Engineer contributes insight.

Just as accurate segmentation.

Pick any one
(as long as you pick "good").

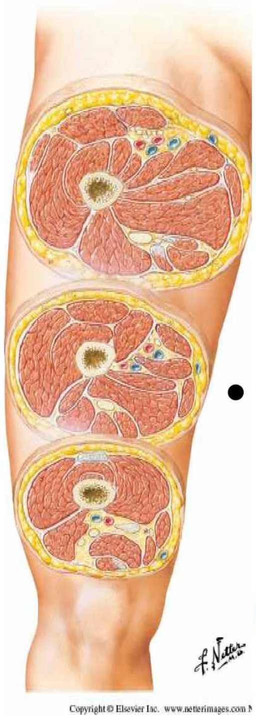


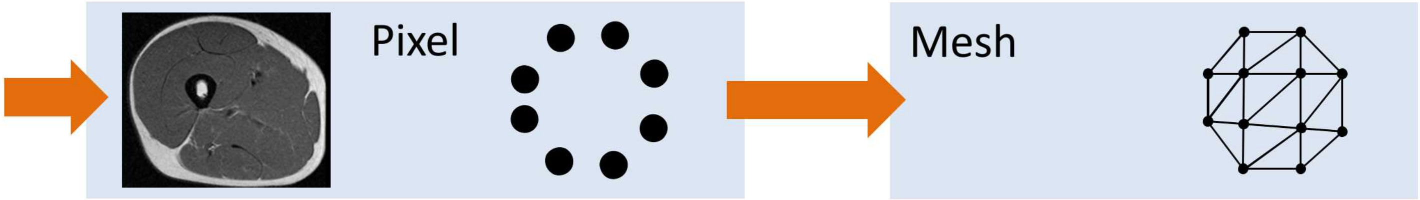
Pick any three.

OBJECTIVE

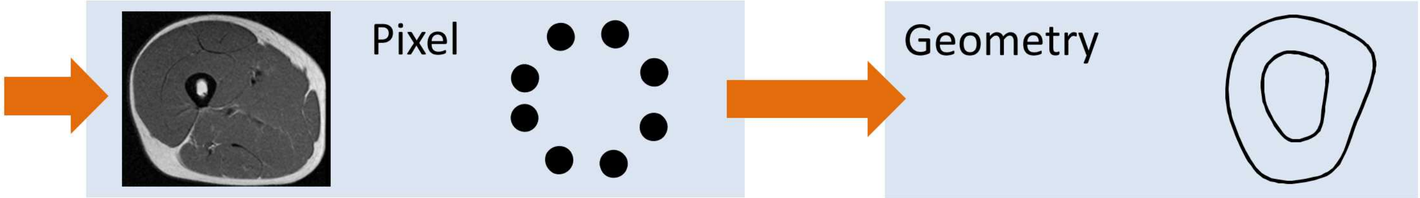
SAND2020-5287 PE

- 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

SAND2020-5287 PE

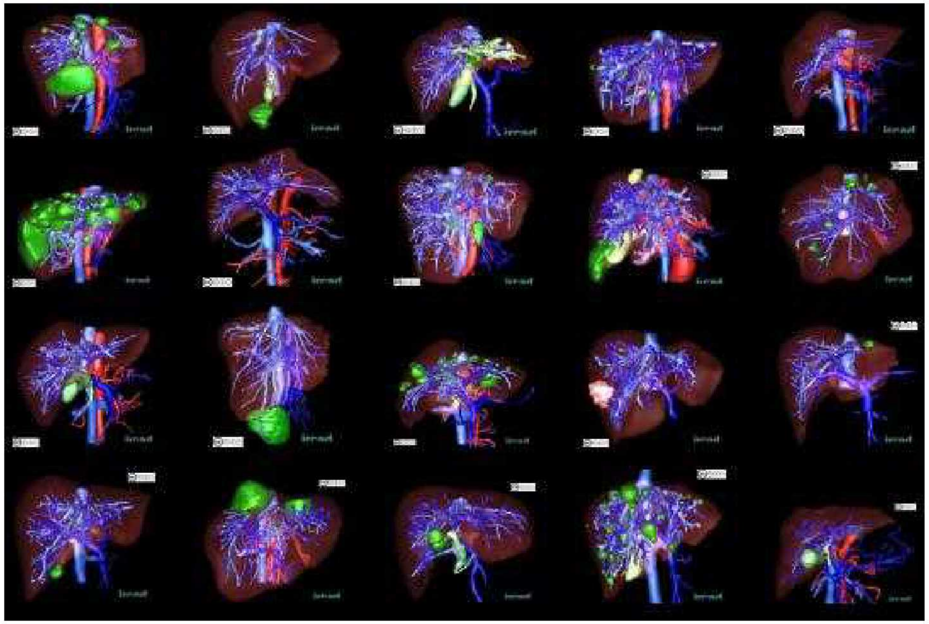
- Leverage existing labeled data from IRCAD France, containing 10 male and 10 female subjects.
- Leverage the U-Net deep learning algorithm to teach a machine to recognize bone and soft tissue in axial CT images.
- From the machine’s pixel data output, create a patient database (n=20) containing 3D finite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

TECHNICAL APPROACH

SAND2020-5287 PE

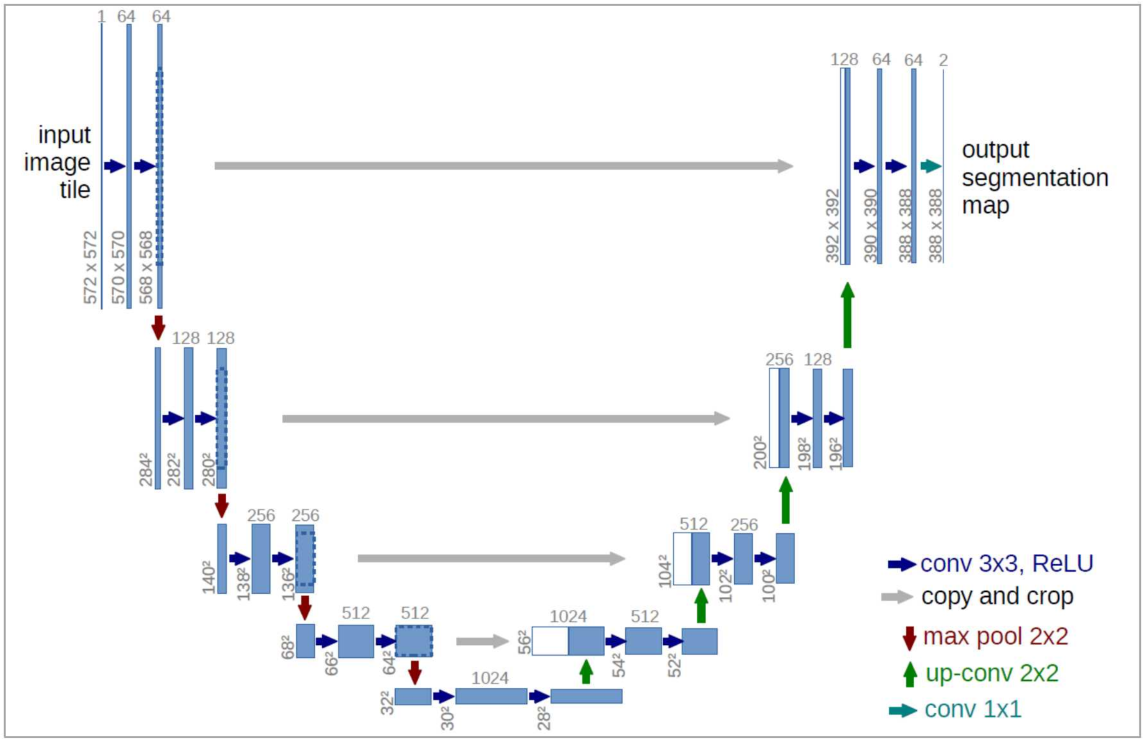
The 3D-IRCADb-01 database contains 3D CT scans of 10 males and 10 females with hepatic tumors in 75 percent of the cases. Patient-specific data follows, which is an extraction from the source table.

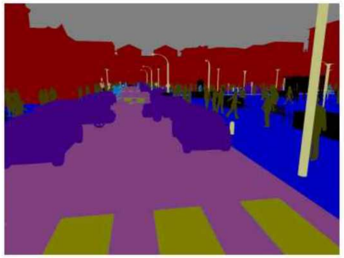
Patient No.	Sex	DOB	Voxel Size (mm, mm, mm)	Image Size (px, px, slice)
1	F	1944	0.57, 0.57, 1.6	512, 512, 129
2	F	1987	0.78, 0.78, 1.6	512, 512, 172
3	M	1956	0.62, 0.62, 1.25	512, 512, 200
4	M	1942	0.74, 0.74, 2.0	512, 512, 91
5	M	1957	0.78, 0.78, 1.6	512, 512, 139
6	M	1929	0.78, 0.78, 1.6	512, 512, 135
7	M	1946	0.78, 0.78, 1.6	512, 512, 151
8	F	1970	0.56, 0.56, 1.6	512, 512, 124
9	M	1949	0.87, 0.87, 2.0	512, 512, 111
10	F	1953	0.73, 0.73, 1.6	512, 512, 122
11	M	1966	0.72, 0.72, 1.6	512, 512, 132
12	F	1973	0.68, 0.68, 1.0	512, 512, 260
13	M	1951	0.67, 0.67, 1.6	512, 512, 122
14	F	1970	0.72, 0.72, 1.6	512, 512, 113
15	F	1946	0.78, 0.78, 1.6	512, 512, 125
16	M	1950	0.70, 0.70, 1.6	512, 512, 155
17	M	1942	0.74, 0.74, 1.6	512, 512, 119
18	F	1958	0.74, 0.74, 2.5	512, 512, 74
19	F	1970	0.70, 0.70, 4.0	512, 512, 124
20	F	1949	0.81, 0.81, 2.0	512, 512, 225

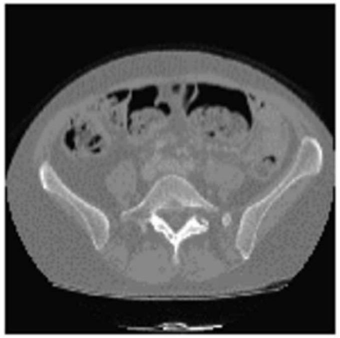


Reference: IRCAD France, https://www.ircad.fr/research/3d-ircadb-01/, accessed August 29, 2019.

TECHNICAL APPROACH







Reference: Ronneberger O, Fischer P, Brox T. U-net: Convolutional networks for biomedical image segmentation. In *International Conference on Medical image computing and computer-assisted intervention* 2015 Oct 5 (pp. 234-241). Springer, Cham; and Heinrich, Greg, Image Segmentation Using DIGITS 5, NVIDIA Developer Blog, 2016 Nov 10, https://devblogs.nvidia.com/image-segmentation-using-digits-5/.

ACCOMPLISHMENTS

SAND2020-5287 PE

- Sourced a labeled dataset (D-IRCADb-01) sufficient for use with U-Net.

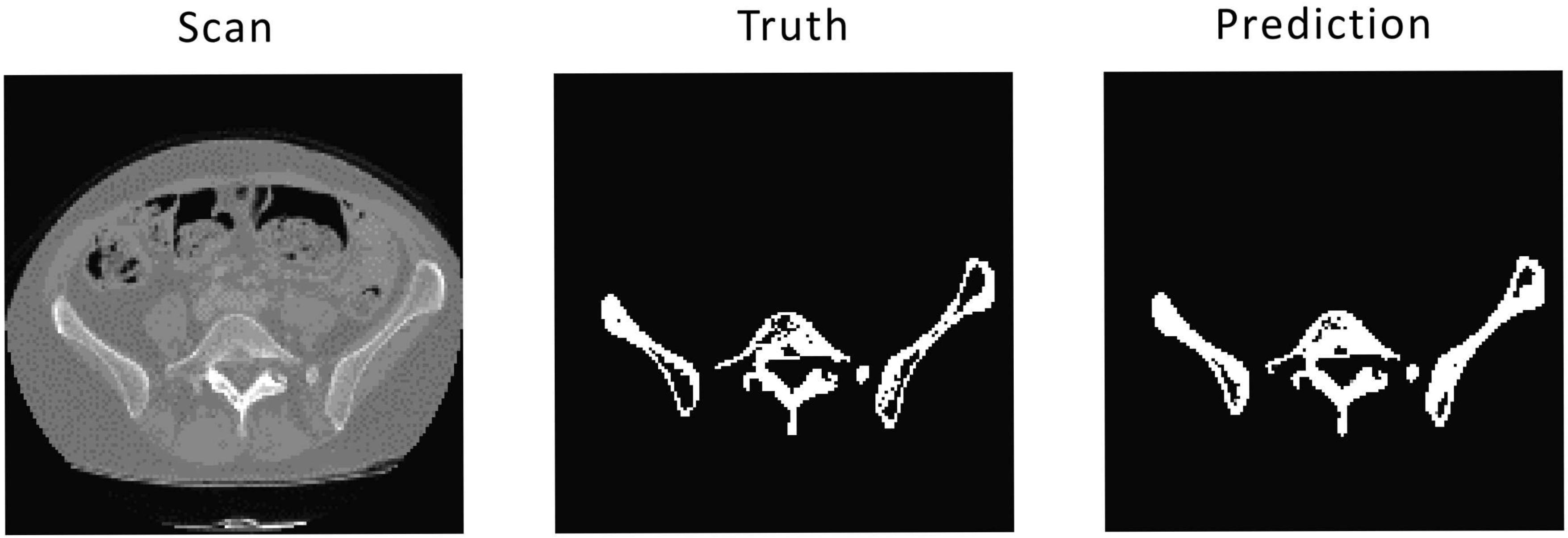
- Created a U-Net implementation, which has demonstrated the concept of automated segmentation with quality that is competitive to manual segmentation.

- Demonstrated the ability to use pixel segmentation to create finite element meshes, the PTM workflow.

- Started the PTG workflow.

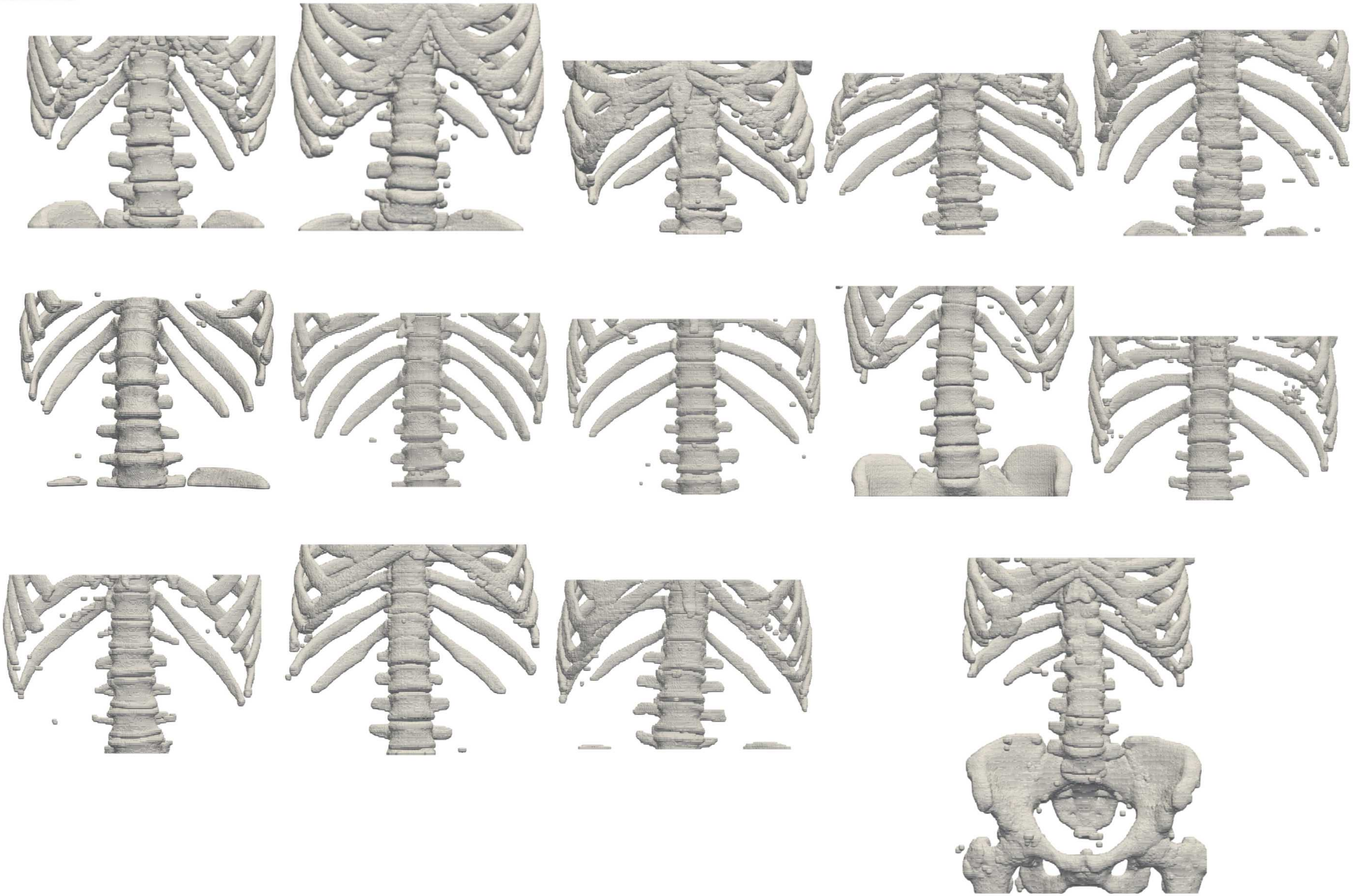
ACCOMPLISHMENTS

SAND2020-5287 PE



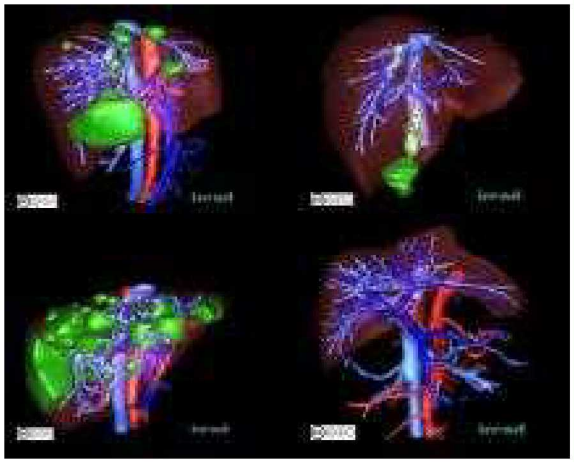
ACCOMPLISHMENTS

SAND2020-5287 PE



Success Stories

SAND2020-5287 PE

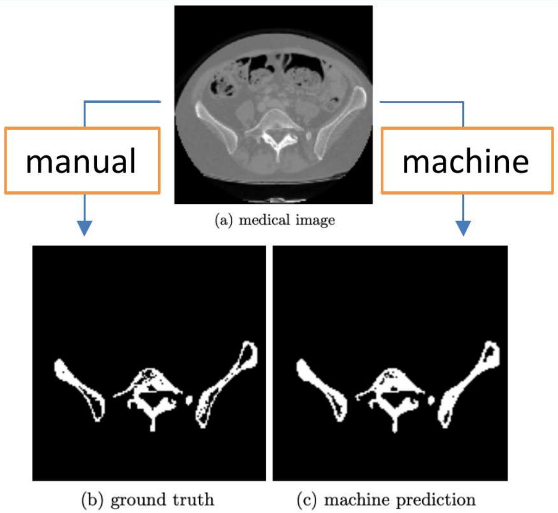


Leverage existing scans and algorithms

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.

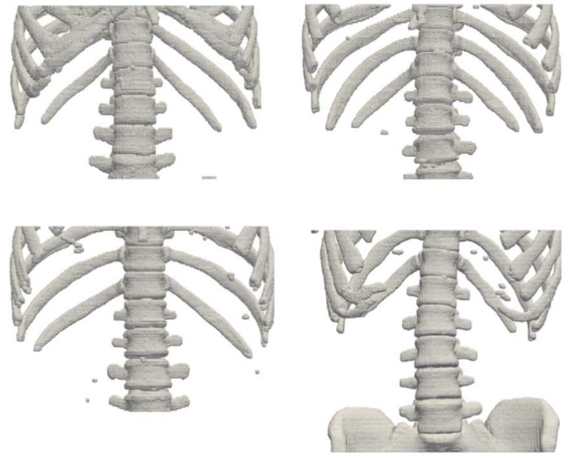


Bone Recognition

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.

Benefits and Impact

SAND2020-5287 PE

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.

CONCLUSIONS

SAND2020-5287 PE

- 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

SAND2020-5287 PE

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

SAND2020-5287 PE

- Work in progress: SAND report.

COOPERATIVE DEVELOPMENT

SAND2020-5287 PE

- The current work builds on:
  - Selected Python infrastructure and platform developments created in the PANTHER and C2B2 programs.

COLLABORATION & DISCUSSION

SAND2020-5287 PE

- There is potential for collaboration with other ONR performers who are focused on manual segmentation.