Project 11: 3D Segmentation of Hard and Soft Tissue for Simulating X-ray Image Formation with Deep Learning

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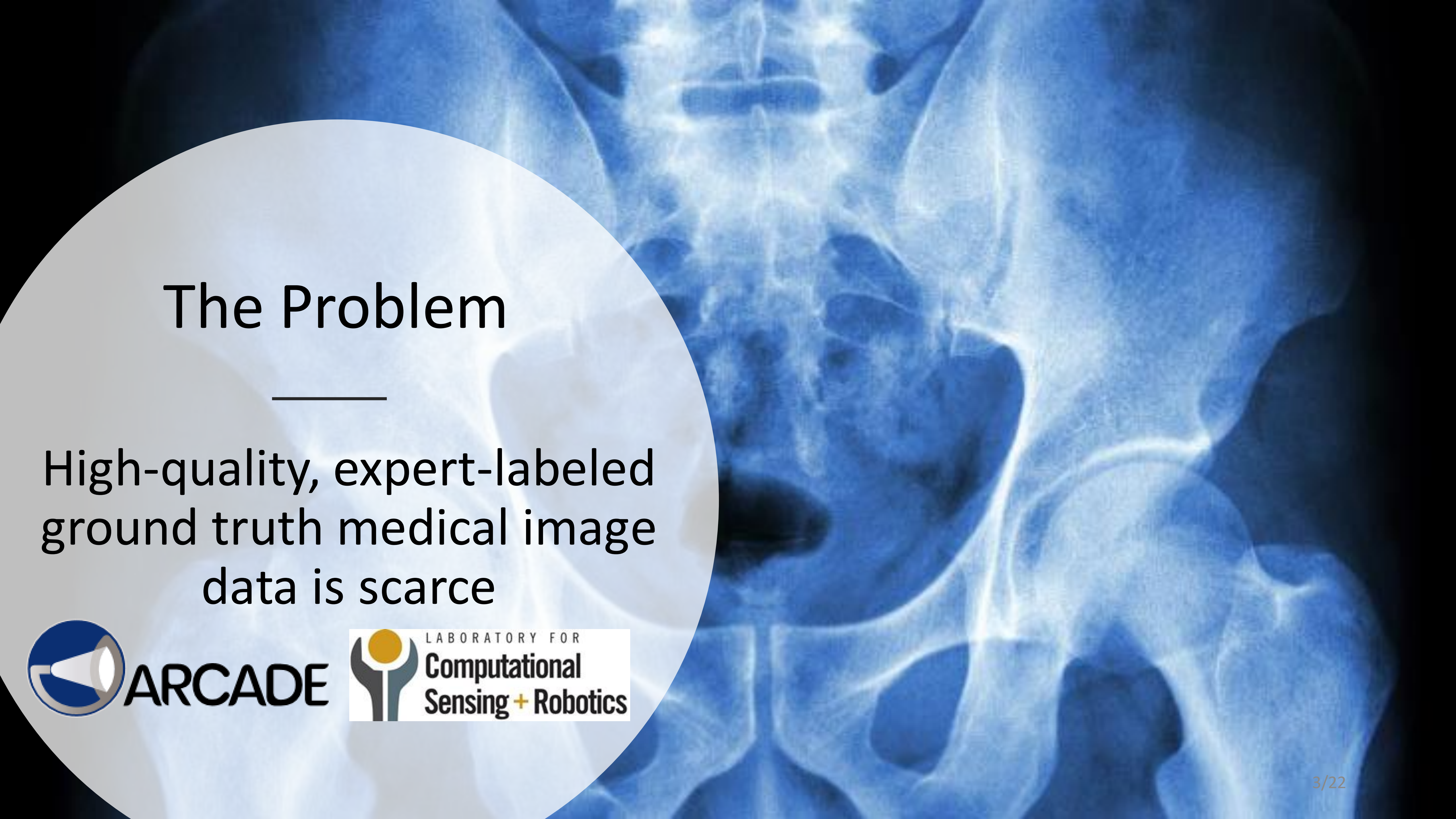
Fluoroscopy-guided Intervention

- Minimally-invasive procedures guided by continuous X-ray image (video) displayed on a monitor
- Applications in orthopedic surgery, liver biopsy, catheter insertion, enemas, angiography, urological surgery, pacemaker implantations, and more
- Rapidly growing discipline, prime for automation

Image: https://www.gehealthcare.com/products/surgical-imaging/oec-elite



The Problem

High-quality, expert-labeled ground truth medical image data is scarce

ARCADE

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The Solution: Digitally Reconstructed Radiographs (DRRs)

Computed Tomography (CT) Volume

Images:
https://dissolve.com/video/Skull-neck-blood-vessels-rotating-rights-managed-stock-video-footage/002-D30-45-586 (skull)
https://www.researchgate.net/figure/Fig-1b-3D-CT-reconstruction-of-the-initial-situation-of-the-pelvis_fig2_305343551 (pelvis)
https://github.com/arcadelab/deepdrr (DeepDRR)

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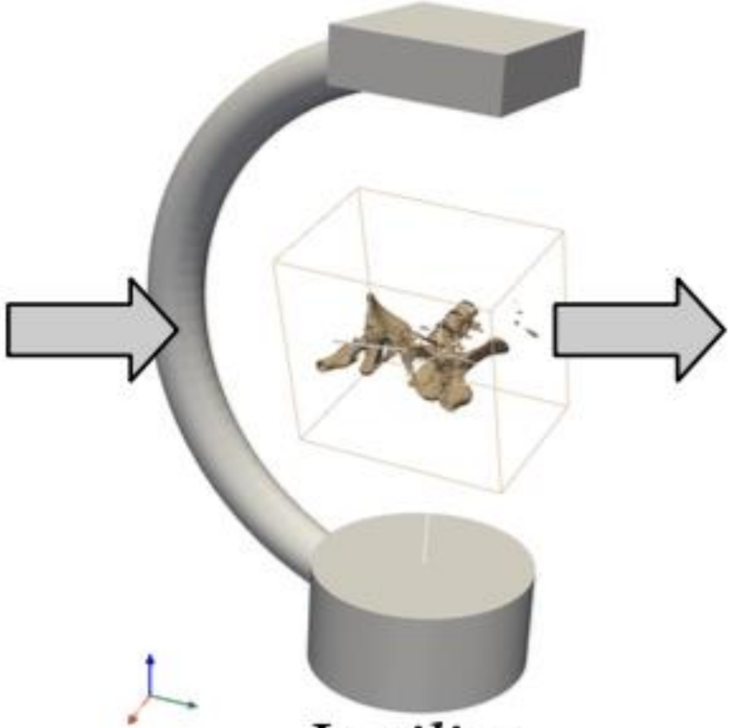

In silico projection

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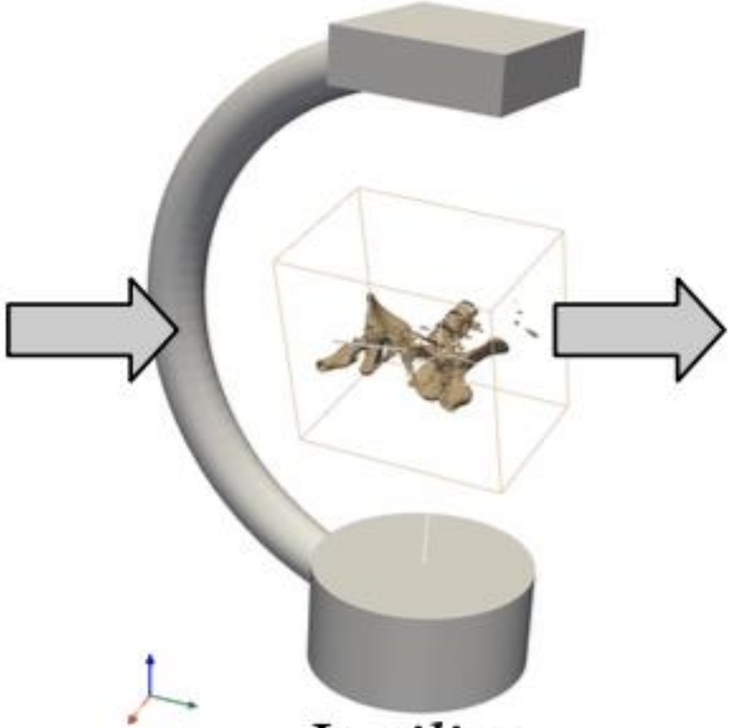

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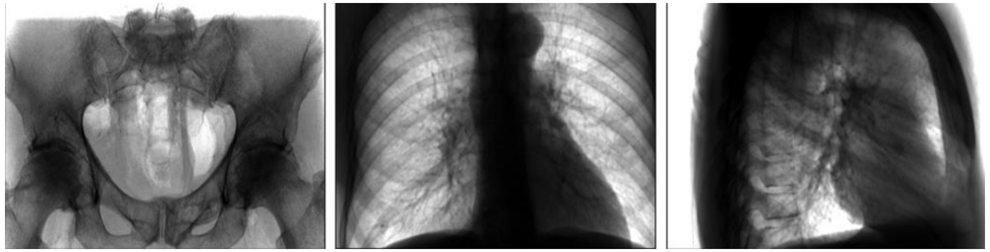

Digitally Reconstructed Radiographs (DRRs)

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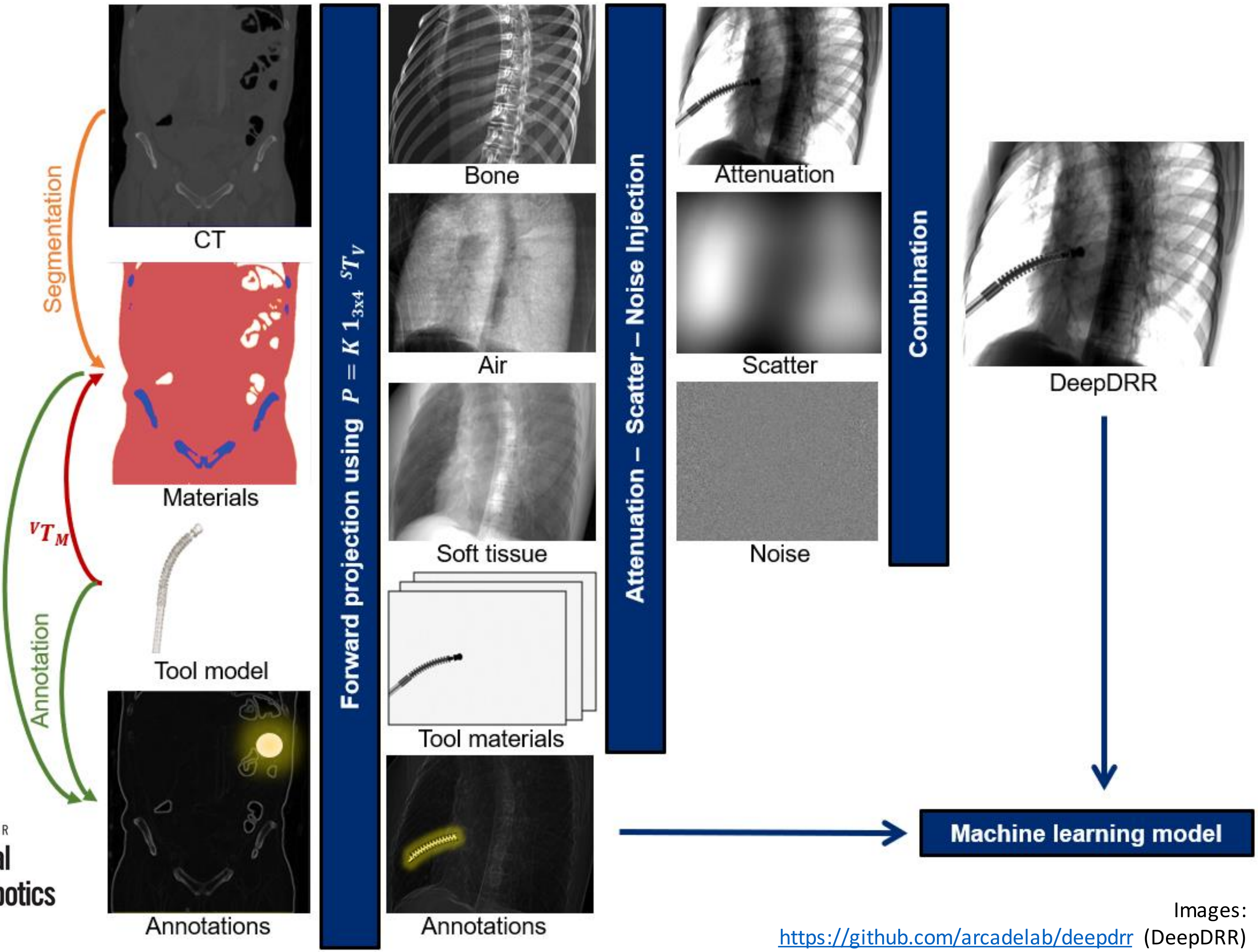
DeepDRR

- Combines machine learning models for material decomposition and scatter estimation in 3D and 2D, respectively, with analytic models for projection, attenuation, and noise injection to render quality DRRs
- Developed in-house
- Segmentation pipeline is currently limited to bone, soft tissue, and air



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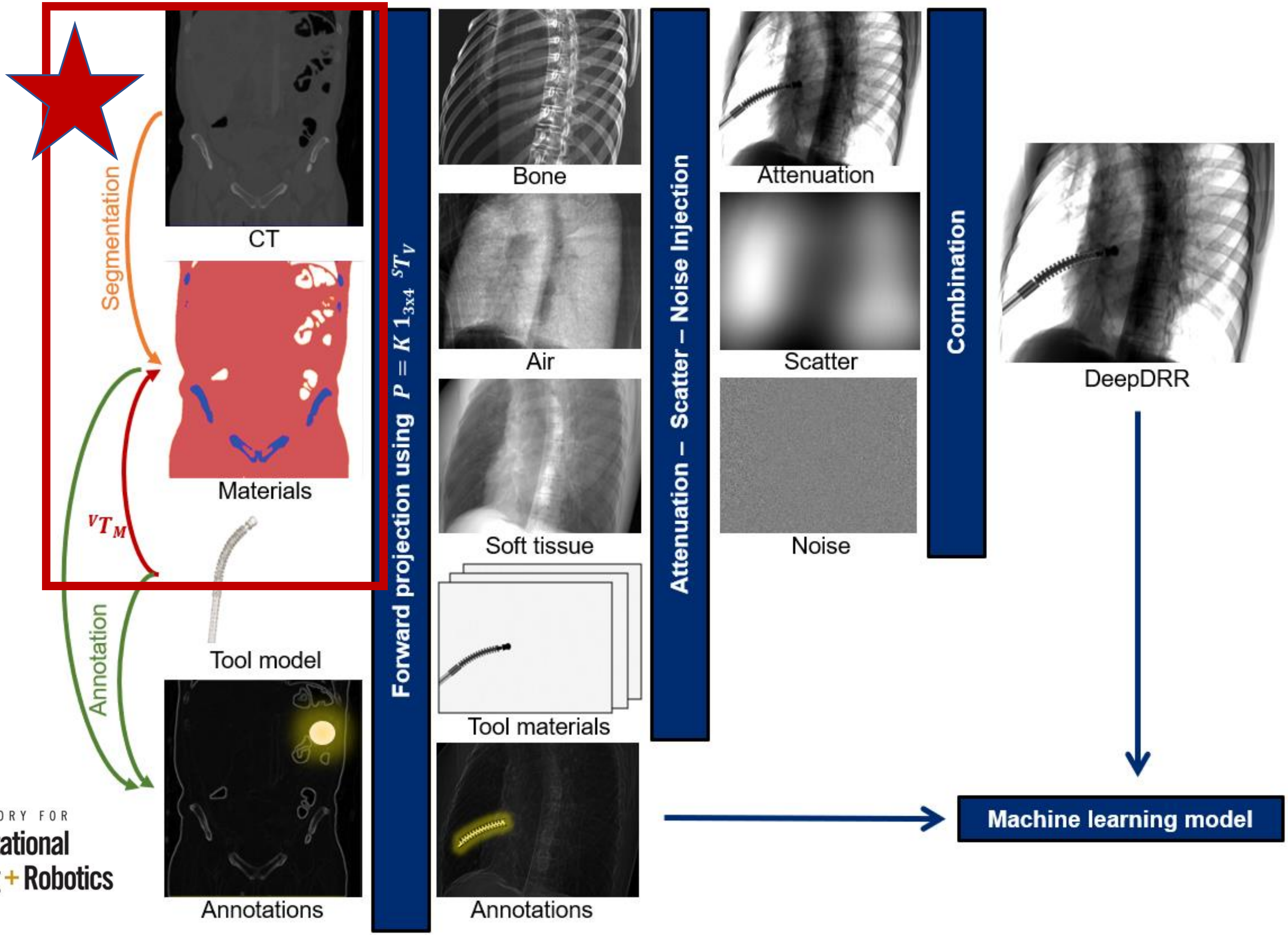

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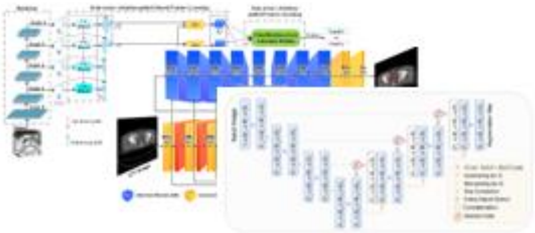
Project Goals

Build	Evaluate	Integrate
Build algorithms that automatically segment tissues of varying X-ray absorption rates from CT data.	Compare the performance of (3) different 3D segmentation model architectures on at least 2 different tissue types (cardiac, lung, liver, etc...)	Integrate our 3D segmentation pipeline with the current DeepDRR simulation system and improve DRR quality.

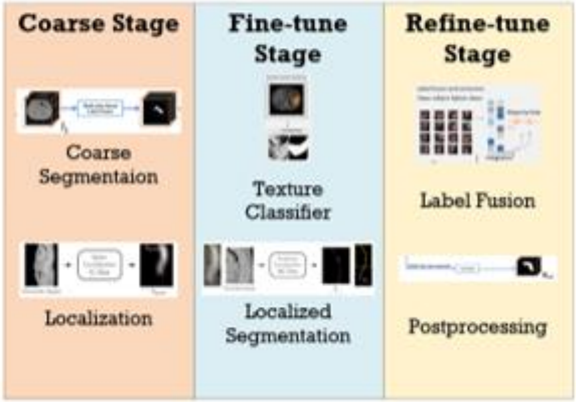
We started with a literature review...

Categories of Researches

- An End-to-End Network



- An Coarse-to-fine framework



An End-to-End Network

A network that does "everything"

Click to add text

Pros:

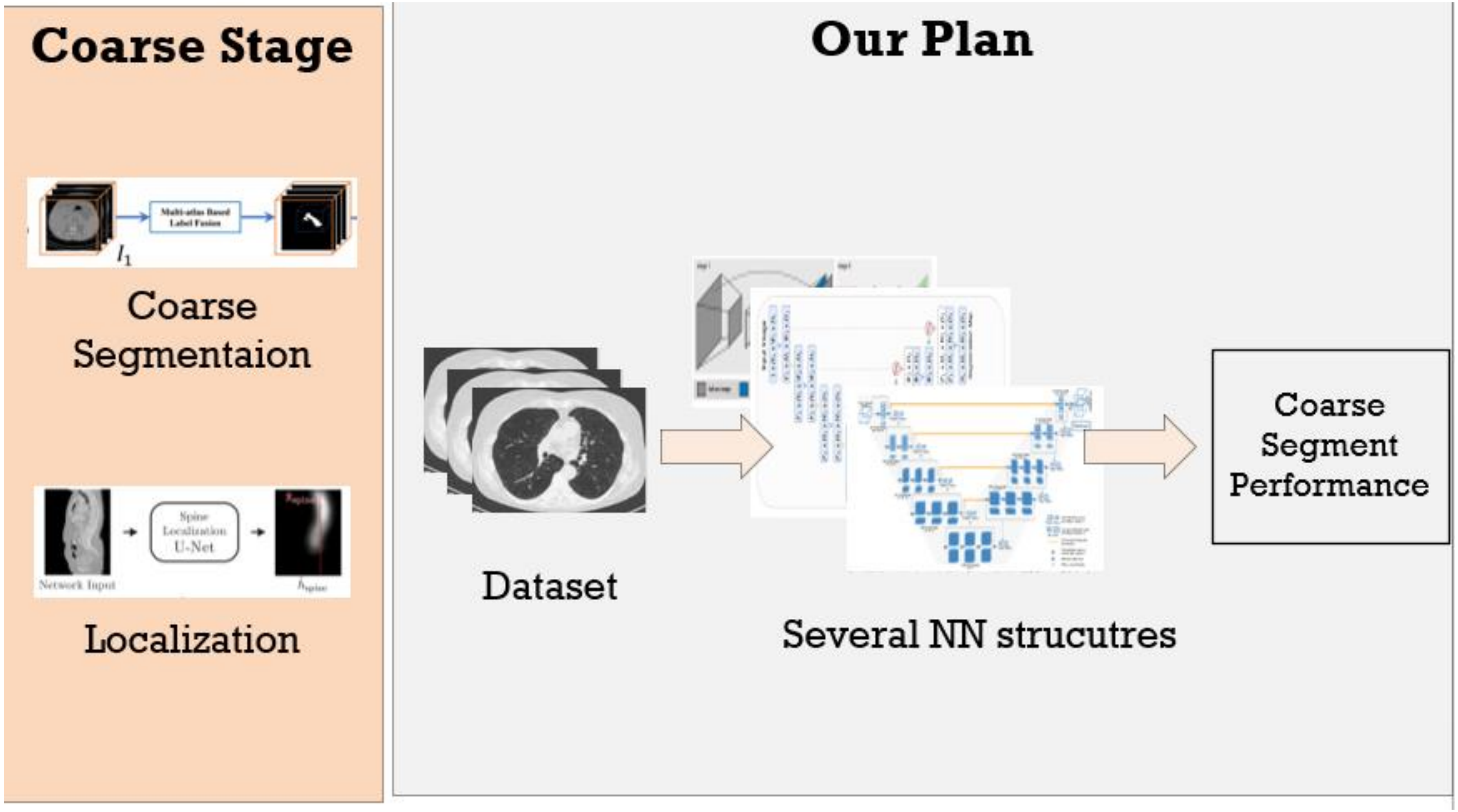
- Straightforward

Cons:

- Difficult to enhance the performance

About 4/15 paper in our review use this strategy.

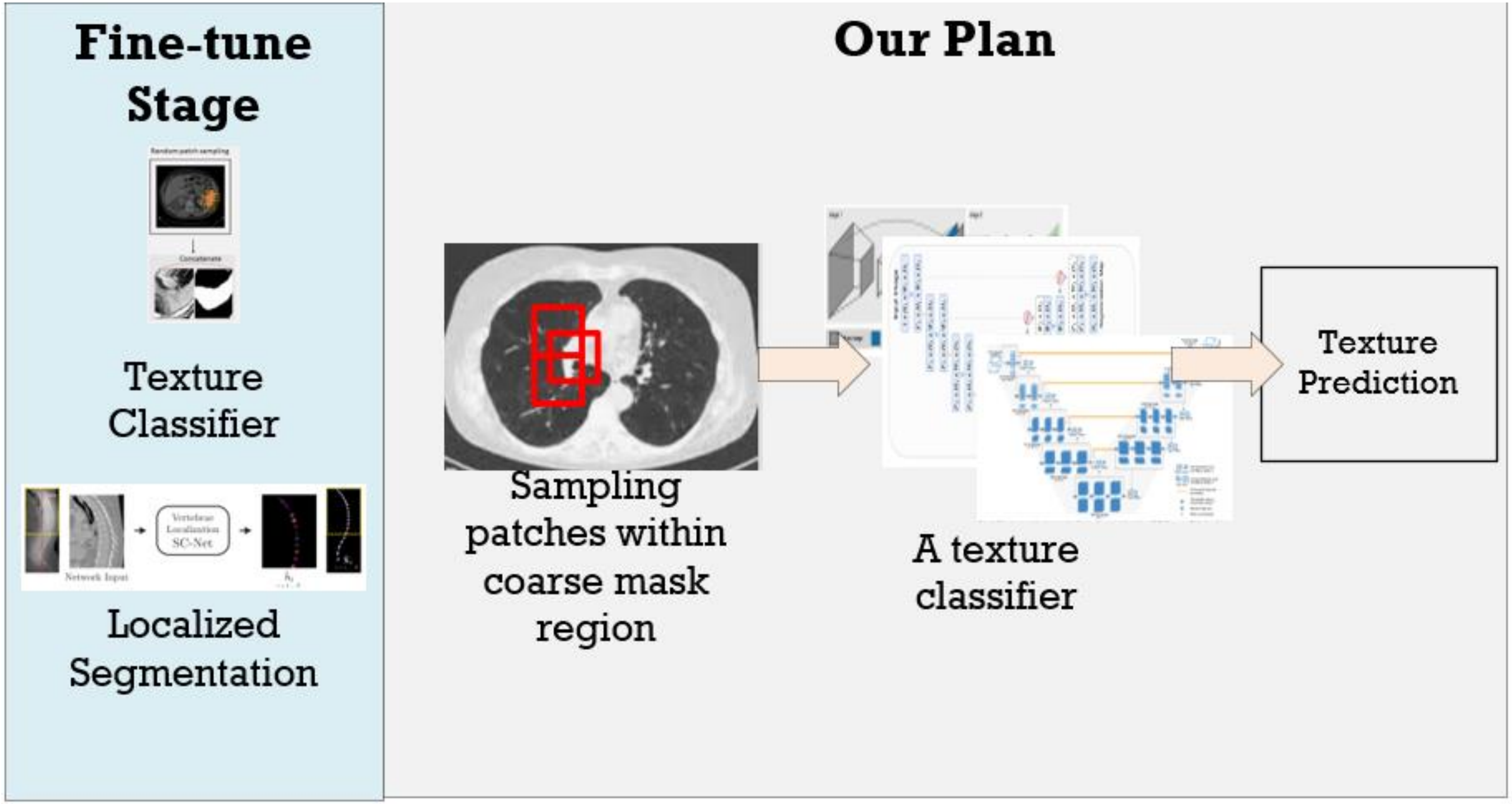
Coarse Segmentation Stage



- Take a light-weight Network with good performance!

Sketches from paper [3],[6](left),[4],[8],[11](Right), CT volume from 3D Slicer

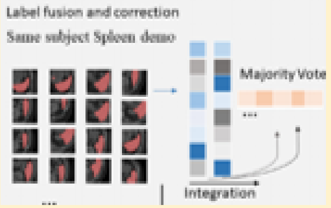
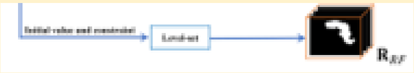
Fine Segmentation Stage



- Take a model sensitive to texture changes

Sketches from paper [3],[5](left),[4],[8],[11](Right), CT volume from 3D Slicer

Refine Segmentation Stage

Refine-tune Stage	Our Plan
 Label Fusion	Simplest one: Majority Voting Fusion
 Postprocessing	Optional: Postprocessing with classical methods

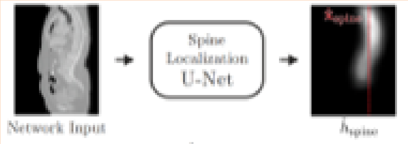
- Check performance on X-Ray Simulation

Sketches from paper [6],[7]

A Coarse-to-Fine framework

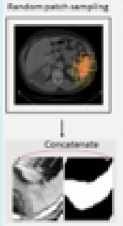
Coarse Stage

Coarse Segmentaion



Localization

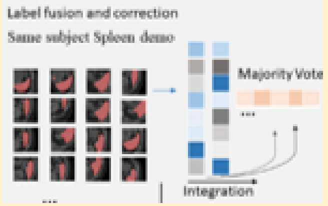
Fine-tune Stage



Texture Classifier

Localized Segmentation

Refine-tune Stage



Label Fusion

Postprocessing

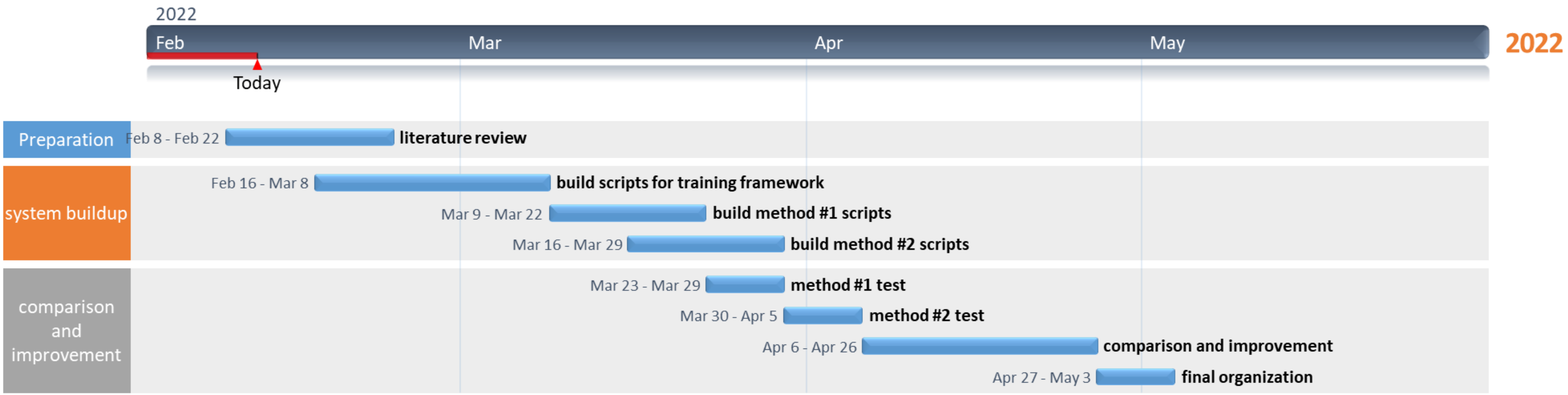
Sketches from paper [3], [5], [6],[7]

- A step-by-step process
- Easy to check progression in each time point
- Combining various methods

Project deliverables

- ➢ Minimum:
- Scripts of a validated segmentation pipeline for bone, soft tissue, and air in full-body CT.
- Comparison report of existing models on different type of tissues.
- ➢ Expected: Minimum +
- Scripts and results for segmenting lung, cardiac, liver in full-body CT.
- Integrated scripts into the DeepDRR simulation.
- ➢ Maximum: Expected +
- Validation scripts and results on full and partial CT with possible data corruptions, fractures, wounds, etc.
- Analysis report of the DRR performance using the improved segmentation pipeline.

Project timeline



Milestones

Milestones	Expected Date
Comparison report of existing models	Feb 22
Scripts for training framework	March 8
Scripts for bone, soft tissue and air segmentation	March 22
Scripts for lung, cardiac and/or liver segmentation	April 6
Report for segmentation results	April 12
Integration to deepDRR system	April 12

Dependencies

Dependencies	Needed by	Remedies
Access to the workstation for training models in Dr. Unberath's lab	Feb 28th	Run the training process on PC; pay for commercial servers.
Full body CT dataset (already have one dataset with limited cases)	Feb 28th	Use partial CT dataset for bones, soft tissue or other tissues.
Pretrained model for specific tasks(optional)	March 15th	Drop the optional task

Project management

Weekly meeting on Thursday with mentor

Additional meetings as necessary

Project group slack channel

Git repository for code management

Reading List

- Unberath, M., Zaech, J. N., Lee, S. C., Bier, B., Fotouhi, J., Armand, M., & Navab, N. (2018, September). Deepdrr–a catalyst for machine learning in fluoroscopy-guided procedures. In International Conference on Medical Image Computing and Computer-Assisted Intervention (pp. 98-106). Springer, Cham.
- Liu, P., Han, H., Du, Y., Zhu, H., Li, Y., Gu, F., … & Zhou, S. K. (2021). Deep learning to segment pelvic bones: large-scale CT datasets and baseline models. International Journal of Computer Assisted Radiology and Surgery, 16(5), 749-756.
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- Isensee, F., Jaeger, P.F., Kohl, S.A.A. *et al.* nnU-Net: a self-configuring method for deep learning-based biomedical image segmentation. *Nat Methods* **18,** 203–211 (2021). https://doi.org/10.1038/s41592-020-01008-z
- Tang Y, Gao R, Lee H H, et al. High-resolution 3D abdominal segmentation with random patch network fusion[J]. Medical Image Analysis, 2021, 69: 101894.
- Zhang Y, Wu J, Liu Y, et al. A deep learning framework for pancreas segmentation with multi-atlas registration and 3D level-set[J]. Medical Image Analysis, 2021, 68: 101884.
- Zhang Y, Li H, Du J, et al. 3D multi-attention guided multi-task learning network for automatic gastric tumor segmentation and lymph node classification[J]. IEEE Transactions on Medical Imaging, 2021, 40(6): 1618-1631.
- Schlemper J, Oktay O, Schaap M, et al. Attention gated networks: Learning to leverage salient regions in medical images[J]. Medical image analysis, 2019, 53: 197-207.

Reading List

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- Nadeem S A, Hoffman E A, Sieren J C, et al. A CT-based automated algorithm for airway segmentation using freeze-and-grow propagation and deep learning[J]. IEEE transactions on medical imaging, 2020, 40(1): 405-418.
- Milletari F, Navab N, Ahmadi S A. V-net: Fully convolutional neural networks for volumetric medical image segmentation[C]//2016 fourth international conference on 3D vision (3DV). IEEE, 2016: 565-571.