Project Checkpoint Presentation

Group 10: Cross Modality Medical Image Synthesis and Registration through Machine Learning

Team member: Ping-Cheng Ku (pku1@jh.edu)

Mentors: Mehran Armand, Alejandro Martin Gomez

LABORATORY FOR Computational Sensing + Robotics

JOHNS HOPKINS UNIVERSITY

Background – Osteonecrosis of the Hip

- Core Decompression for Osteonecrosis
  - Drilling several holes into the femoral head to relieve pressure in the bone and create channels for new blood vessels to nourish the affected areas of the hip
  - X-rays provides images of dense structures (like bones) and intraoperative x-ray shots are taken to monitor the surgical procedure.

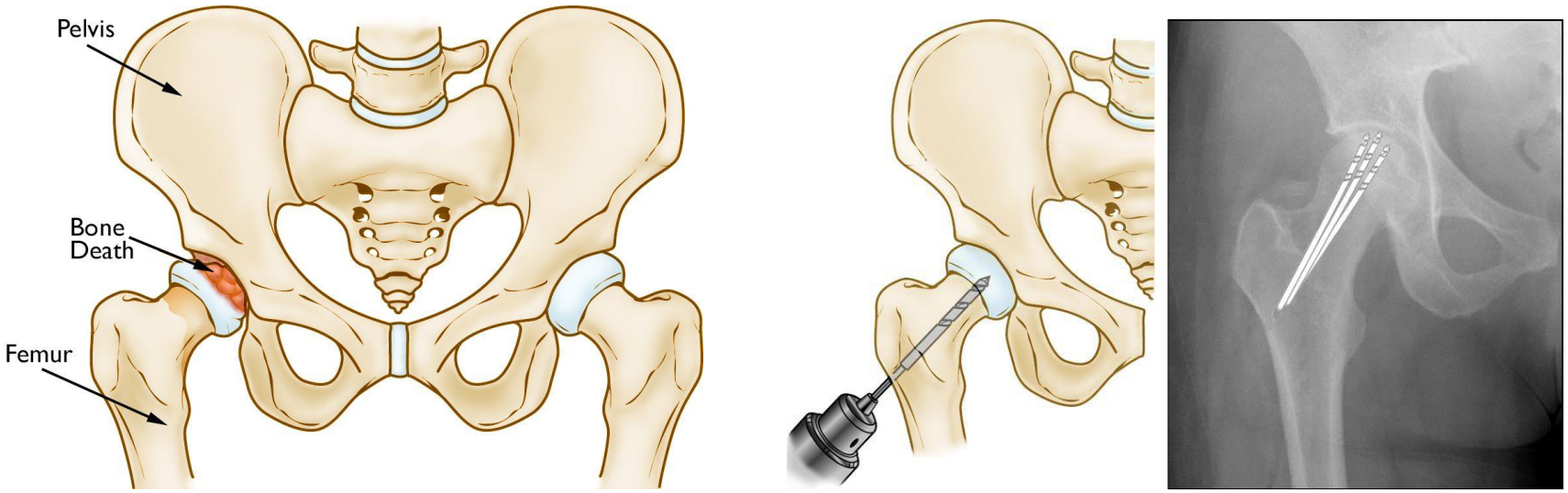
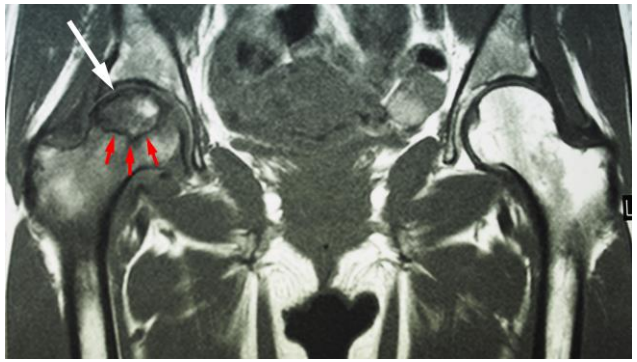


Image source (Left and right image): [1] orthoinfo - aaos. Retrieved February 16, 2021

Motivation and Project Goal

- Motivation
  - Surgeons also rely on preoperative MR scans for tool trajectory planning for core decompression surgery, but there is no easy way for them to visualize the planned paths in the intra-operative X-ray shots
- Project Goal
  - We would like to convert the annotations of segmentation of the necrotic tissues and the drill insertion paths from preoperative MR images to intraoperative x-rays would be helpful for surgeons.



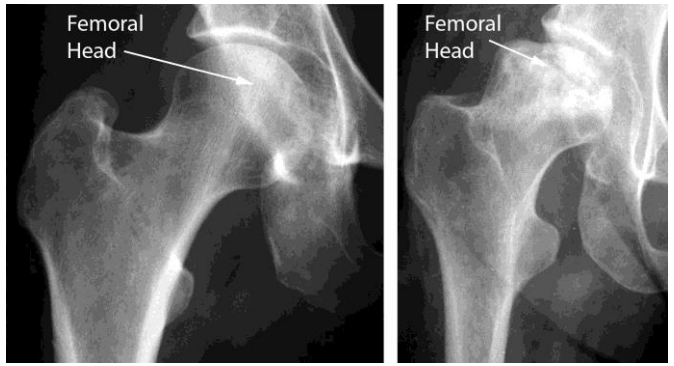


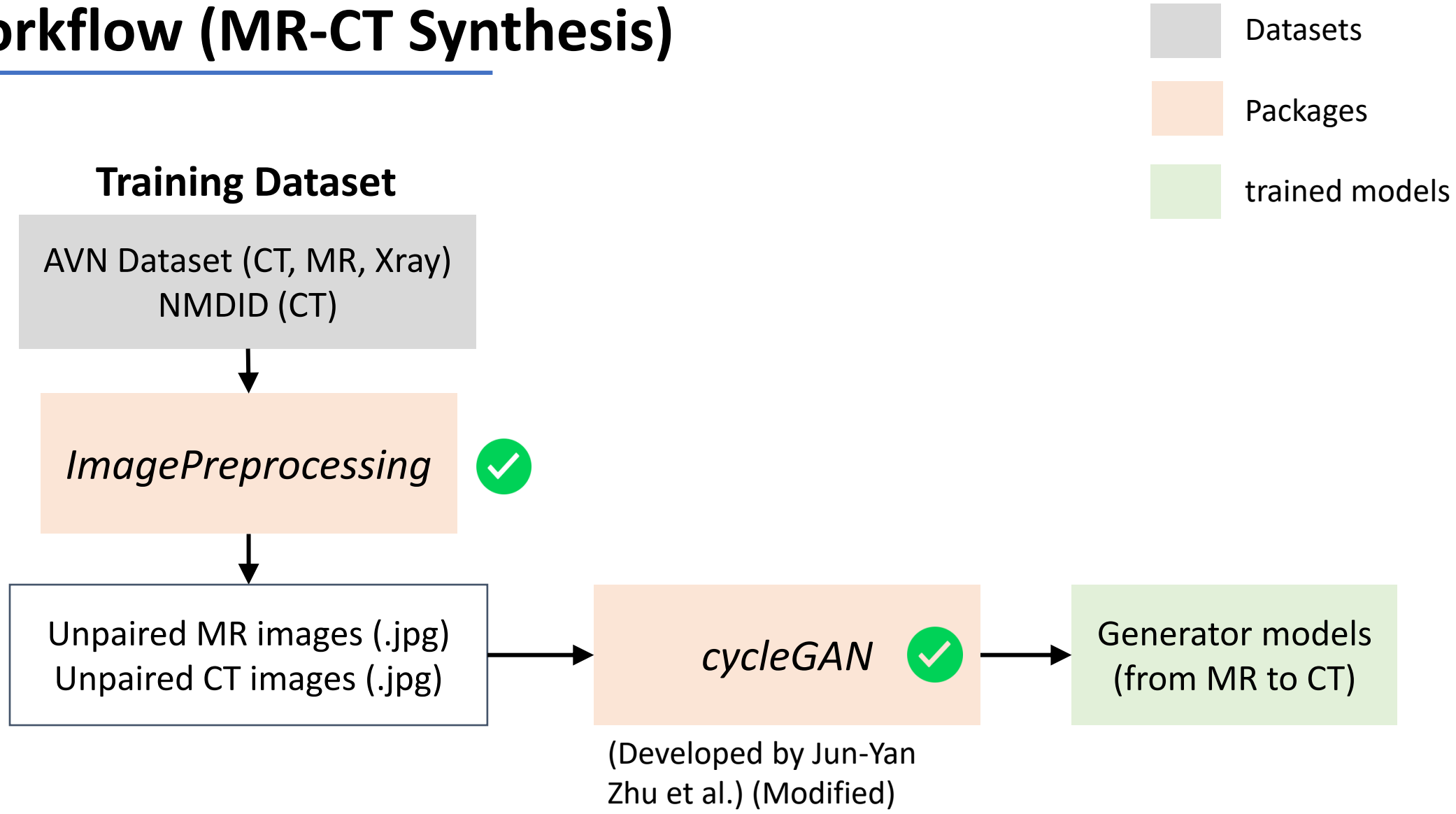
Image source (Left and right image): [1] orthoinfo - aaos. (n.d.). Retrieved February 16, 2021

Approach

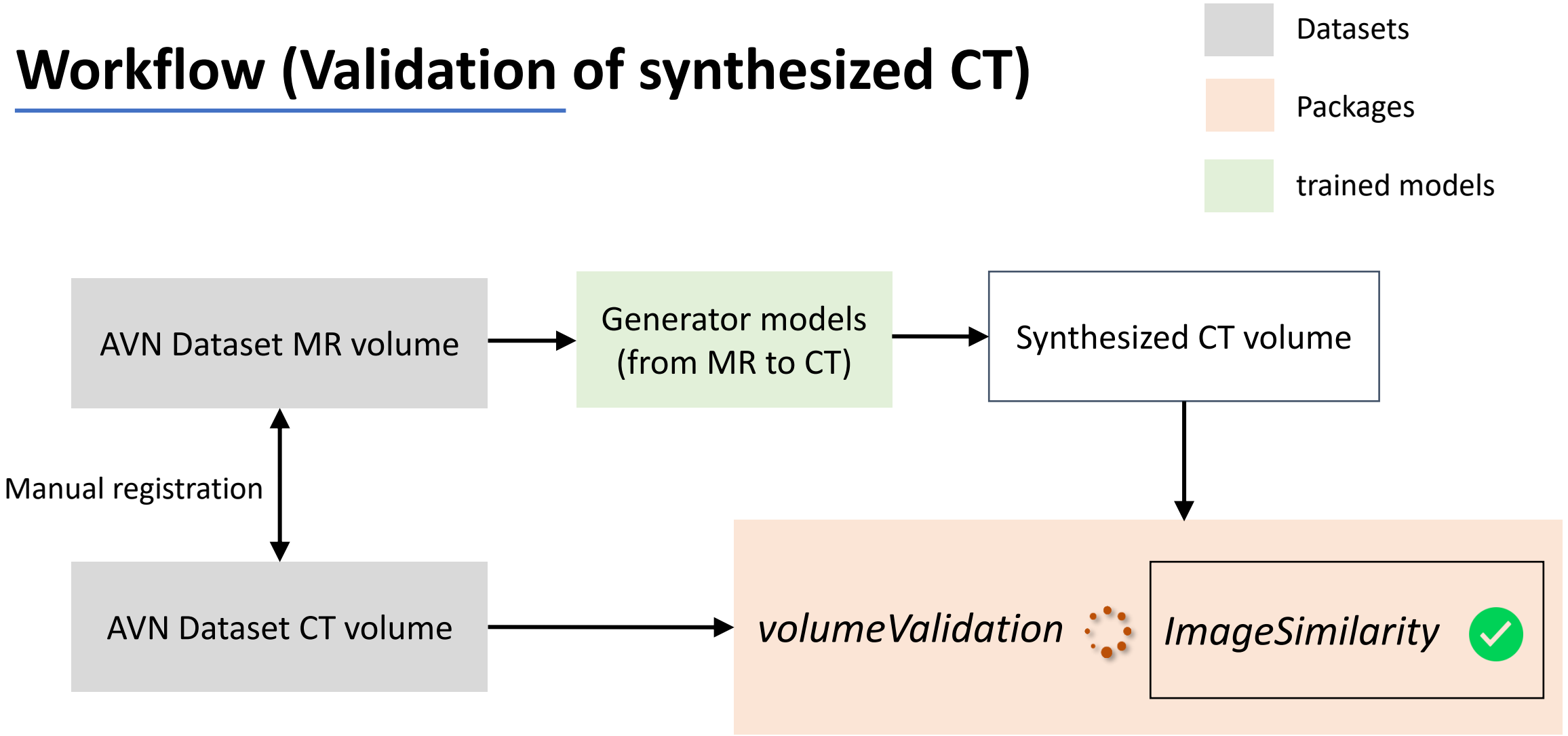
- MR-Xray registration issue:
  - Direct registration between MR and X-ray is difficult due lack of cross-modality information between MR and X-ray

- Indirect approach to achieve this goal:
  - 1. MR-CT synthesis
  - 2. Validation of synthesized CT
  - 3. CT-Xray registration
  - 4. ~~Annotated path projection from MR to X-ray~~ (removed)

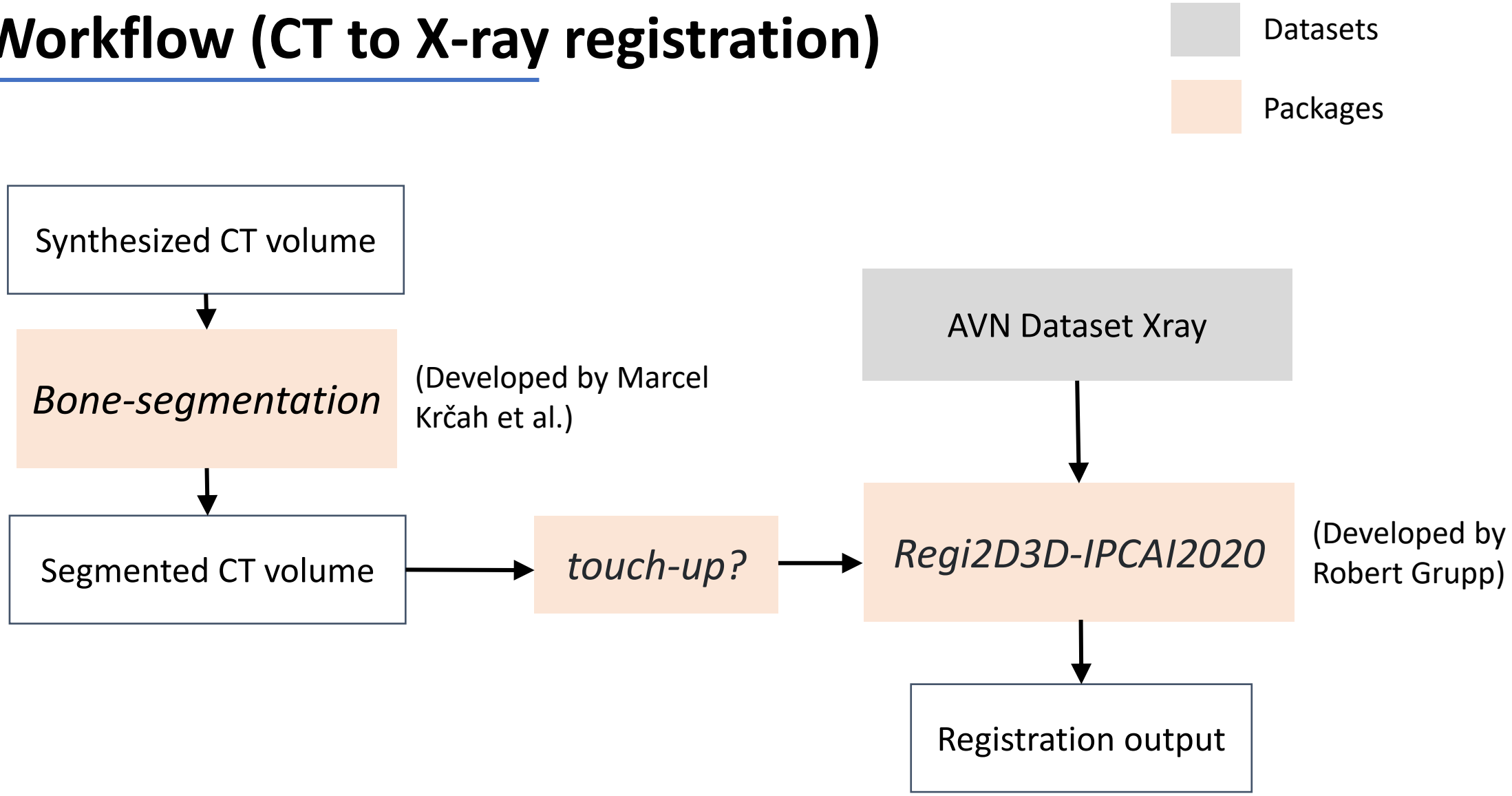
Workflow (MR-CT Synthesis)



Workflow (Validation of synthesized CT)



Workflow (CT to X-ray registration)



Dependencies Update

Dependency	Plan	Estimated time	Current Status
GPU resource access for network training	Talk to Dr. Armand to get access to MARCC	~~2/26~~ 3/25	Resolved on 3/16. Allocation to MARCC has been acquired.
	(alternative) Lab GPU resource (thin6), Google cloud	Resolved	Access to thin6 has been acquired.
Access to CT dataset for additional training images	Request access to New Mexico Database	2/26	Access to images of 24 additional patients submitted on 2/22, acquired on 2/26
	(alternative) Raise the issue during the 3/2 weekly meeting with Dr. Armand.	3/2	N/A
Acquire tool path annotations in MR images	Check with Alejandro if we can get collect annotated MRs from surgeons	3/18	Discussed during 3/1 meeting with Alejandro. Going for the alternative approach below.
	(alternative) Generate simulated tool paths ourselves	3/20	I have access to Imfusion Suite which allows simple path annotations to be made (two points that forms a line). The method to extract the paths out from the software still needs to be figured out.

Deliverables (by 4/5)

	Task	Date	Status
Minimum	Generate reasonable synthesized CT images from unpaired MR images.	3/15	Completed by 3/15
	Validate the performance of registration between synthesized CT and the x-ray images.	~~4/6~~ 4/20	CT to X-ray registration is still work in progress
	Proper code documentation and repository publishment.	5/6	Already started building up repository and documentation for multiple packages.
Expected	Code optimization and generation of best trained network models and ideal parameters.	~~4/15~~ 5/6	Trained with different parameters, will be running the training for improvements
	(NEW) Implementation of similarity metrics for network performance validation	3/30	Completed by 3/30
	(NEW) Manual registration between existing MR and CT images, and validation of the robustness of cycleGAN generator performance.	4/11	Manual registration completed, need to export the results and run validation
	~~Validate the registration workflow by registering manually annotated paths from MR to x-ray images.~~	4/20	Manually annotated MRs completed, but the registration to X-ray is **removed**.
Maximum	~~Improve workflow and combine networks for loss optimization.~~	4/29	**Removed**
	~~Develop a direct MR to x-ray registration method.~~	4/29	**Removed**
	Annotation projection from MR to X-rays	5/6	Most likely will not be implemented

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Progress Update (MR-CT Synthesis)

- *ImagePreprocessing*
  - Data loading (Support different datasets and formats (AVN and NMDID))
  - Data augmentation (random rotation, random cropping, intensity shift)
  - Dataset generation (training, validation and testing sets)
- *CycleGAN (Jun-Yan Zhu et al.)*
  - Modifications: adjusted loss function to take structural loss into consideration

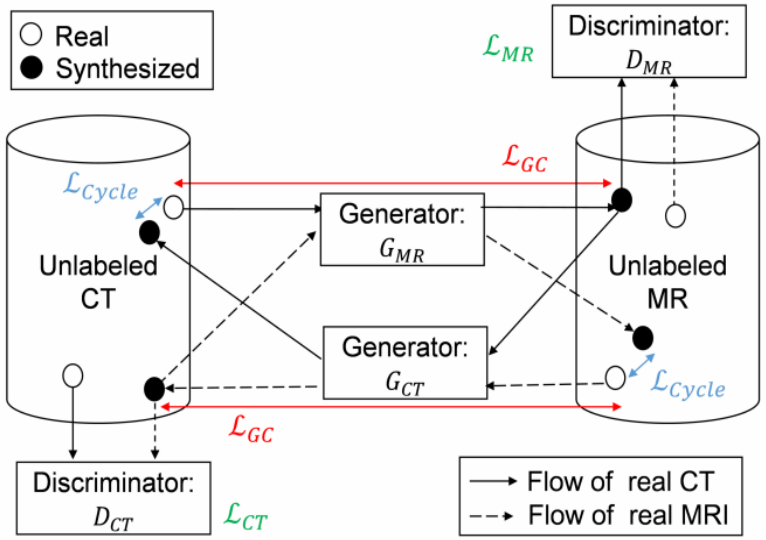
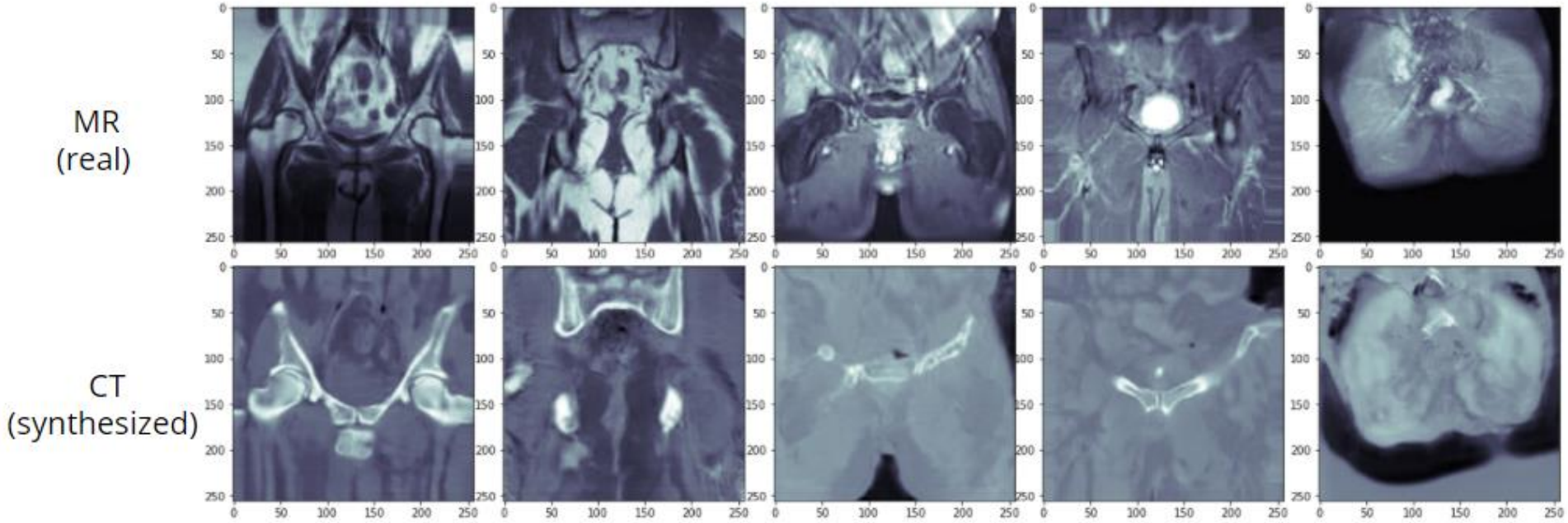


Image Reference: [5] Hiasa, Y et al.

Progress Update (MR-CT Synthesis)

- *CycleGAN (Jun-Yan Zhu et al.)*
  - Training dataset: 3000 CT from 12 patients (AVN and NMDID), 3000 MR images from 15 patients (all AVN)
  - Testing dataset: CT volumes from 3 patients (AVN and NMDID) and MR volumes from 3 patients (AVN)
  - Generator from MR to CT (G_{CT}): (epoch = 200)

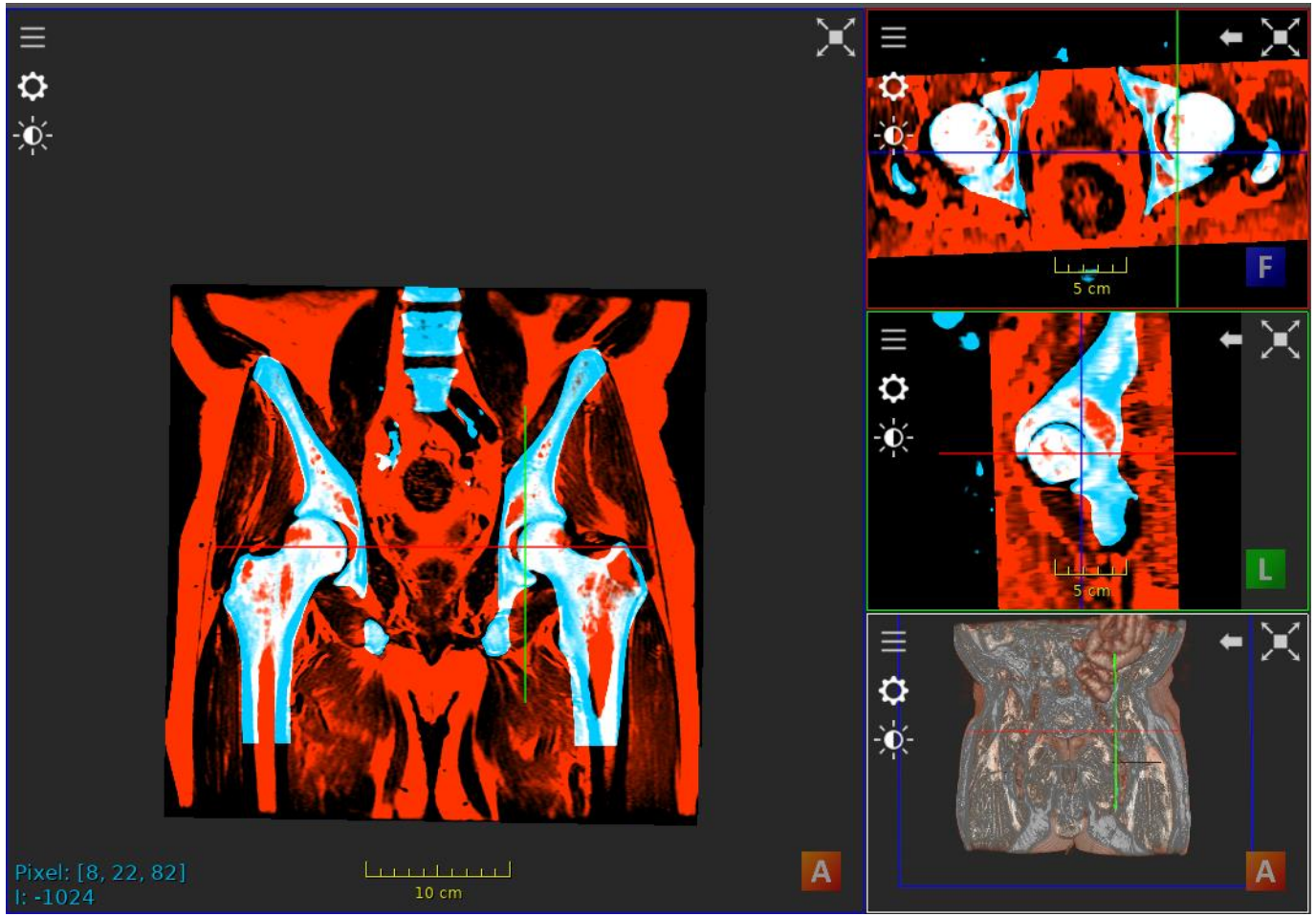


Progress Update (Validation of synthesized CT)

- *Manual registration between paired MR and CT images in AVN dataset*
  - *8 MR and CT pairs in AVN dataset (completed)*
- *volumeValidation (70% completion)*
  - Reads the entire MR and CT volumes as input
  - Converts volumes to tensors and run them through CT generator in cycleGAN
  - Calculation of image similarity between ground truth CT and synthesized CT
- *ImageSimilarity*
  - *Image quality metrics implementation:*
    - Mean square error(MSE),
    - Peak Signal to Noise Ratio (PSNR),
    - Structural similarity index(SSIM)

Progress Update (Validation of synthesized CT)

- *Manual registration (Imfusion Suite)*

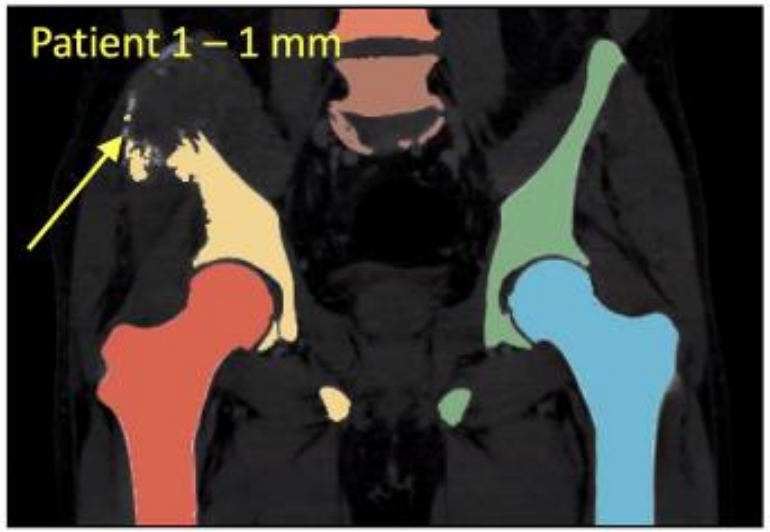


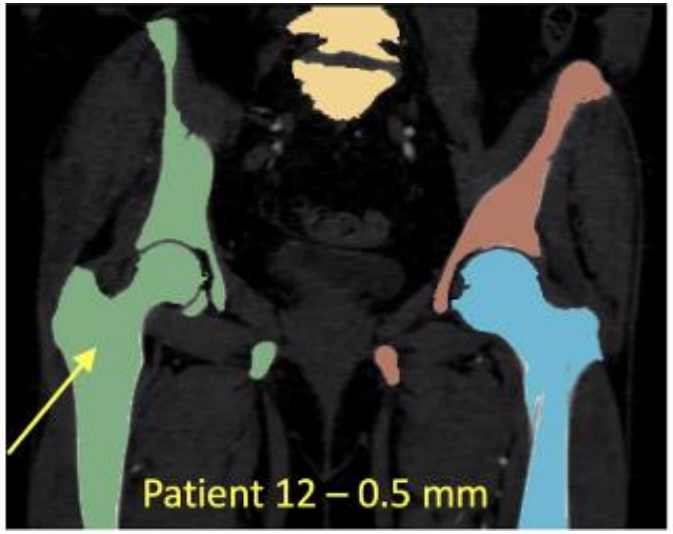
Progress Update (Validation of synthesized CT)

- *volumeValidation*
  - *Issue: Generated CT seem to have low resolution and have much thinner volumes (around 15 slices)*

Progress Update (CT to X-ray registration)

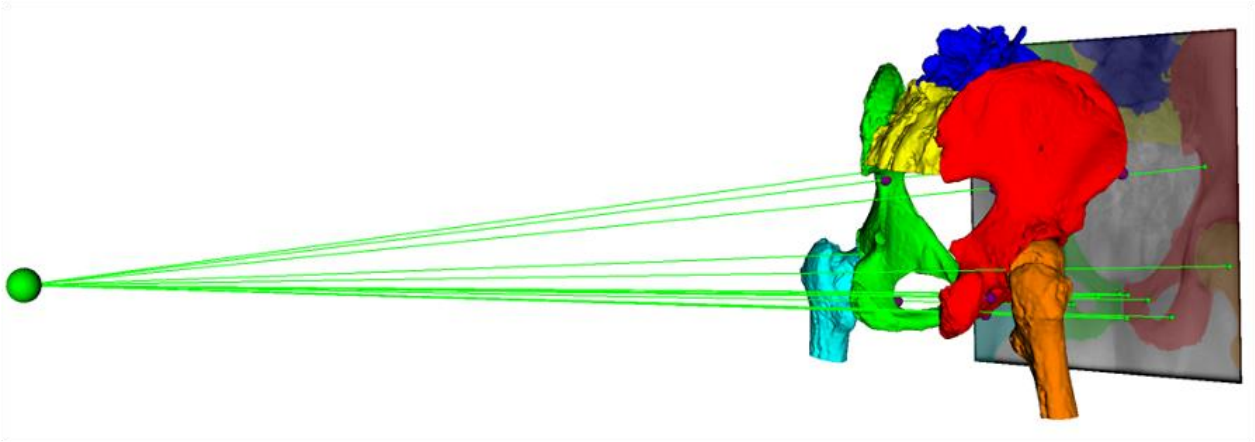
- *Bone-segmentation (Developed by Marcel Krčah et al.)*
  - *Black-box segmentation method for hip CT*
  - *Not 100% accurate, requires manual adjustments*
  - *Test result on **real CT images** in AVN dataset (**NO tested result on synthesized CT yet** , the results will be worse due to the thinner volume and less accurate CT, which may require implementation of additional post-processing packages)*





Progress Update (CT to X-ray registration)

- *Regi2D3D-IPCAI2020 (Developed by Robert Grupp)*
  - 2D/3D registration process between fluoroscopy images and CT images
  - ***NO tested results yet***
  - I can directly discuss with Robert if I run into trouble working on implementation and modification of this package.



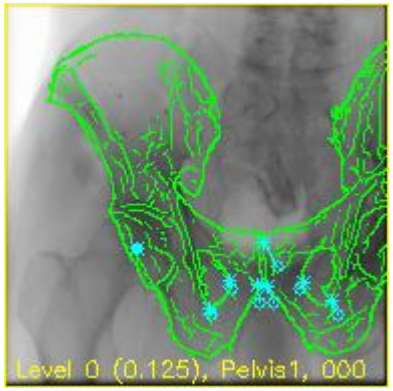
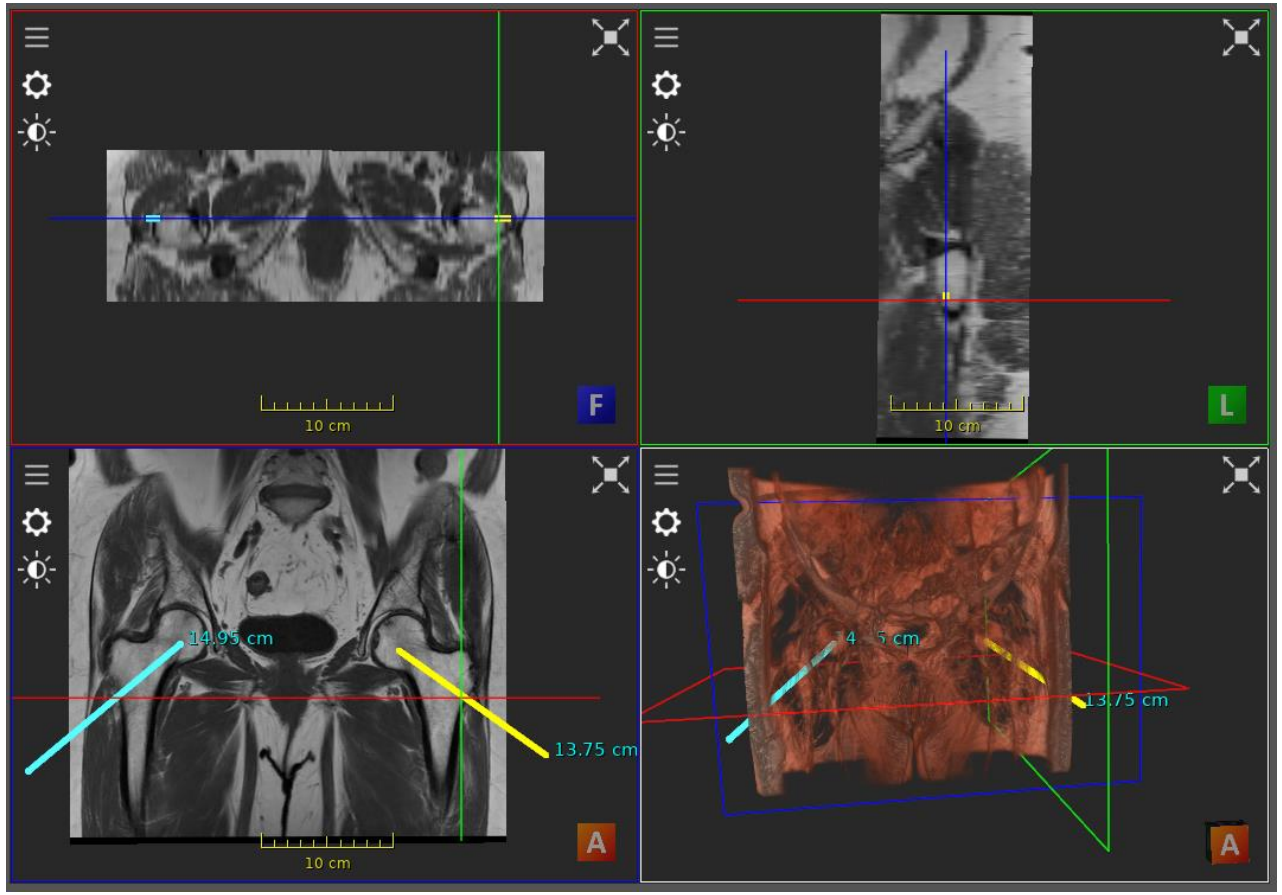


Image reference: [6] Grupp, R

Registration of annotated paths (removed)

- Core decompression drilling path planning in Imfusion Suite
- Exporting the annotated path



Project Milestones

Tasks	Expected Date	Completion Date	Status
MR to CT synthesis - Dataset collection	2/15	2/22	**Completed**
MR to CT synthesis - Dataset preprocessing	2/18	3/01	**Completed**
MR to CT synthesis - CycleGAN network architecture design	3/08	3/08	**Completed**
MR to CT synthesis - Network performance improvement	3/15	3/23	**Completed**
MR to CT synthesis - Validation and debugging	~~3/21~~ 4/11		70% complete. TODO: exportation of manually registered MR-CT pairs, volume test
CT to X-ray reg. - Model dependency setup	~~3/21~~ 3/30	3/30	**Completed**
CT to X-ray reg. - Model training and evaluation	4/18		Main focus in the next few weeks
~~Code optimization - Combination of model loss~~	~~4/29~~		
Code optimization - Code cleanup & documentation	4/29		Github repository is now up

Responsibility & Management plans

- Responsibility
  - The Team:
    - Ku Ping-Cheng: Takes the responsibilities for all tasks
  - Mentors:
    - Mehran Armand (Mehran.Armand@jhuapl.edu)
    - Alejandro Martin Gomez (alejandro.martin@jhu.edu)

- Meetings:
  - Weekly meeting with Mehran Armand and Robert Grupp on Tuesday
  - Weekly meeting with Alejandro on Friday

- Code: repository hosted on Github (https://github.com/AxDante/MR_Xray_registration)
- Reports and writeups: Overleaf

Reference

1. Osteonecrosis of the hip - orthoinfo - aaos. (n.d.). Retrieved February 16, 2021, from https://orthoinfo.aaos.org/en/diseases--conditions/osteonecrosis-of-the-hip
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6. Grupp, R. B., Unberath, M., Gao, C., Hegeman, R. A., Murphy, R. J., Alexander, C. P., . . . Taylor, R. H. (2020). Automatic annotation of hip anatomy in FLUOROSCOPY for robust and efficient 2D/3D REGISTRATION. *International Journal of Computer Assisted Radiology and Surgery, 15*(5), 759-769. doi:10.1007/s11548-020-02162-7