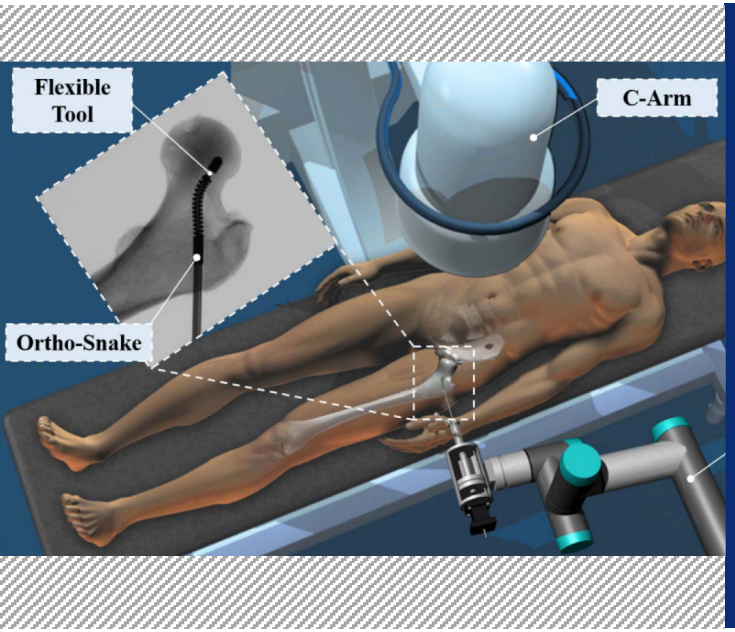

Localizing dexterous surgical tools in X-ray for image-based navigation⋆

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[*] Joint first authors.

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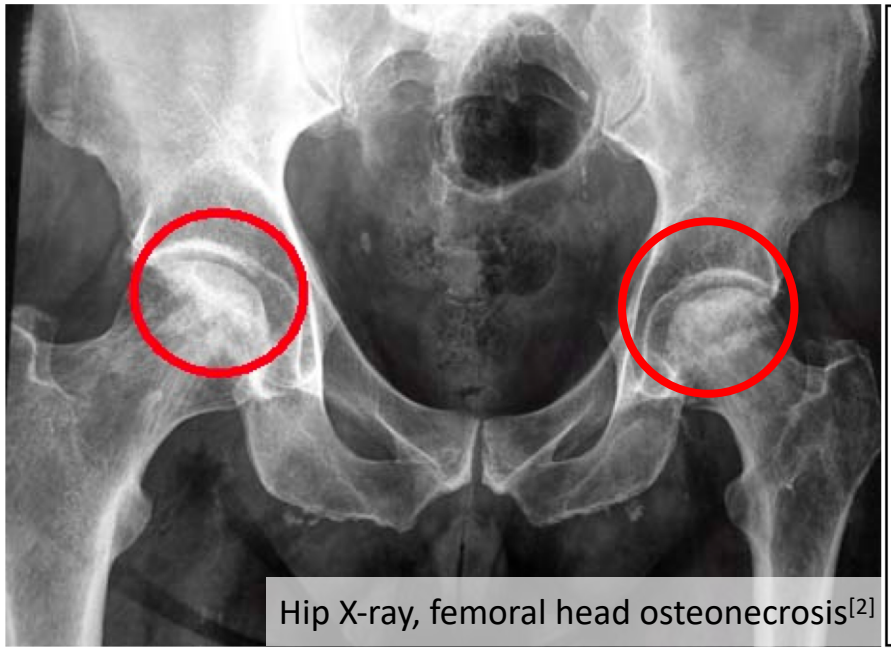
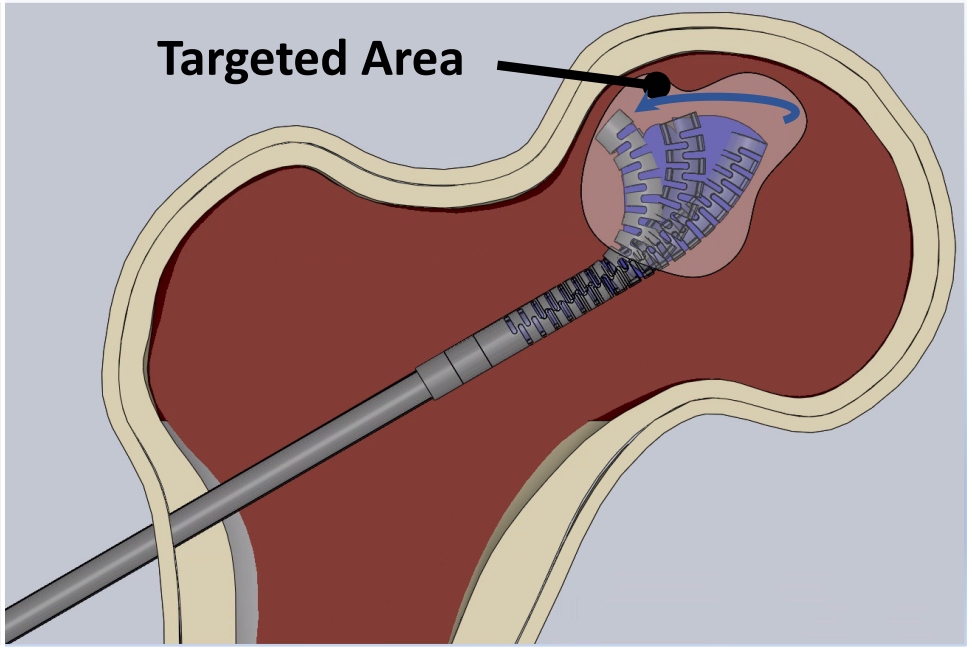
Background

- Continuous dexterous manipulators (snake-like robot) for orthopedic surgery[1]
- Applications: osteolysis, femoroplasty, osteonecrosis, etc.


Hip X-ray, femoral head osteonecrosis[2]



[1] Alambeigi, Farshid, et al. "A curved-drilling approach in core decompression of the femoral head osteonecrosis using a continuum manipulator." IEEE Robotics and Automation Letters 2.3 (2017): 1480-1487.
[2] https://www.goudelis.gr/en/content/femoral-head-osteonecrosis-avascular-necrosis

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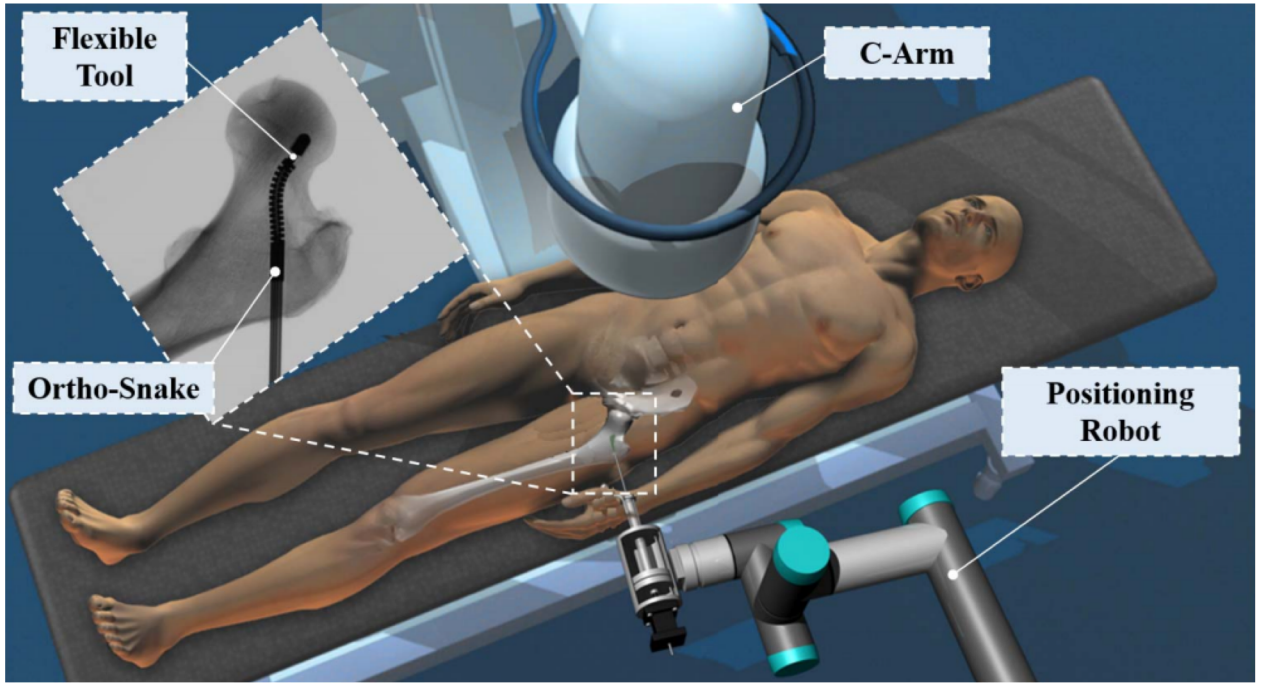
Background

- X-ray images commonly used in orthopedic procedures → fast & accurate
- X-ray image-based tool navigation



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Challenges

Snake navigation and shape estimation

Sensor based:

- Optical tracking system: limited workspace
- Fiber Bragg Grating (FBG) based shape sensing[3] : inaccurate results when touching obstacles

Image based:

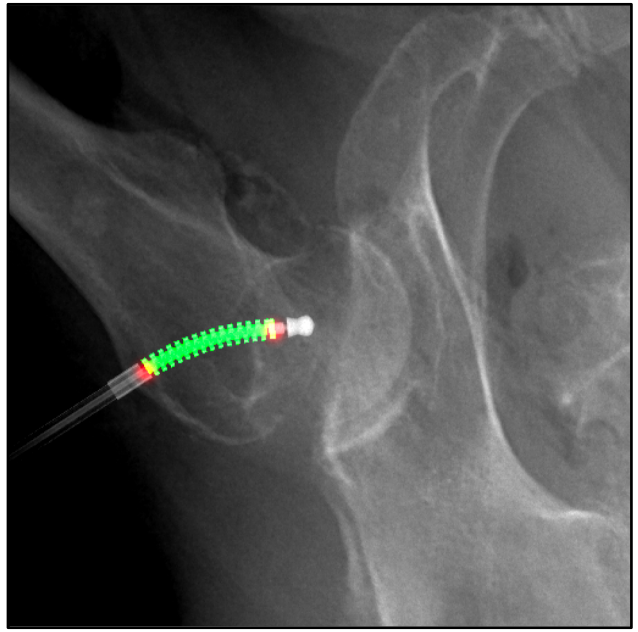
- X-ray image-based 2D-3D registration: small capture range, requires automatic and robust initialization

[3] Sefati, Shahriar, et al. "FBG-based large deflection shape sensing of a continuum manipulator: Manufacturing optimization." 2016 IEEE SENSORS. IEEE, 2016.

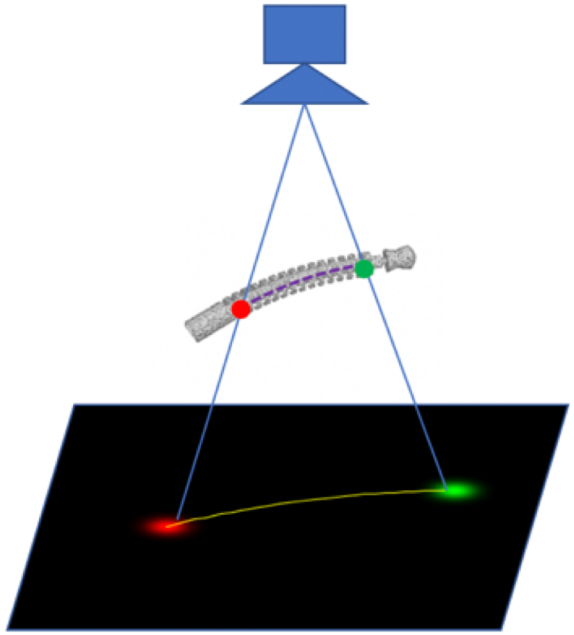
Our solution

Image-based initialization for 2D-3D registration by concurrent segmentation and localization of the snake in X-ray images

Simulation DRR



Detection result



Initialization for 2D-3D registration

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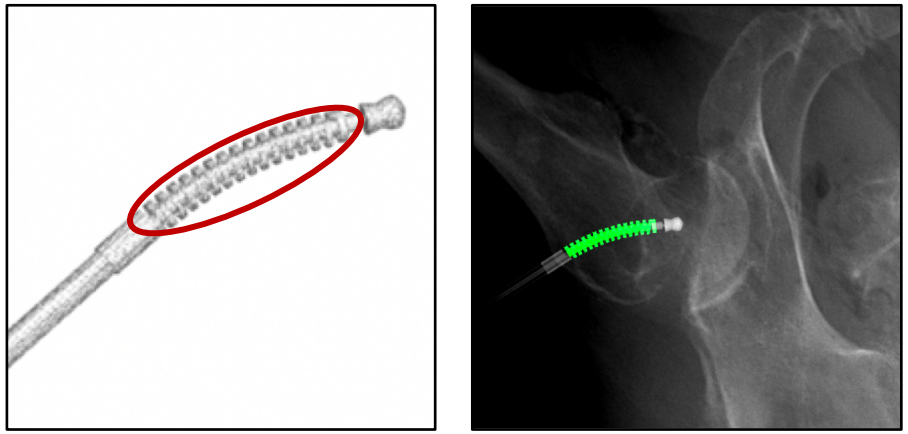
Segmentation and landmark detection

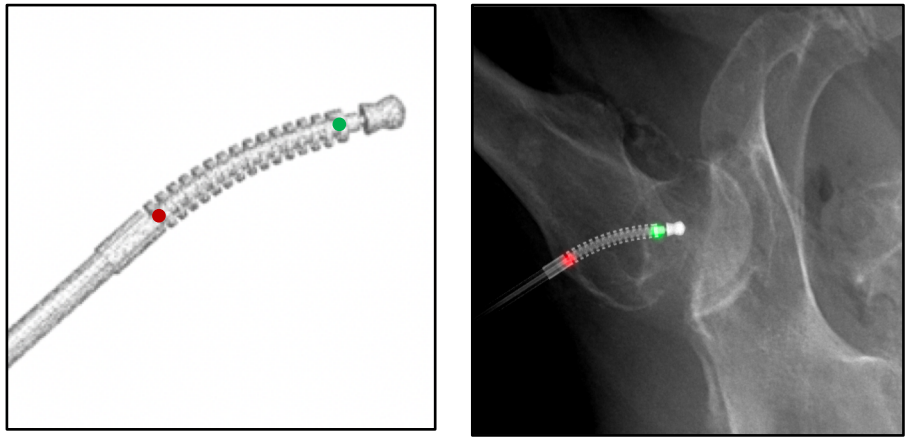
Segmentation mask:

- Region of 26 alternating notches which discerns the snake from other surgical tools



Localization landmarks:

- Middle of the 2 conjunction points between the first notch and the base
- Center of the distal plane of the last notch



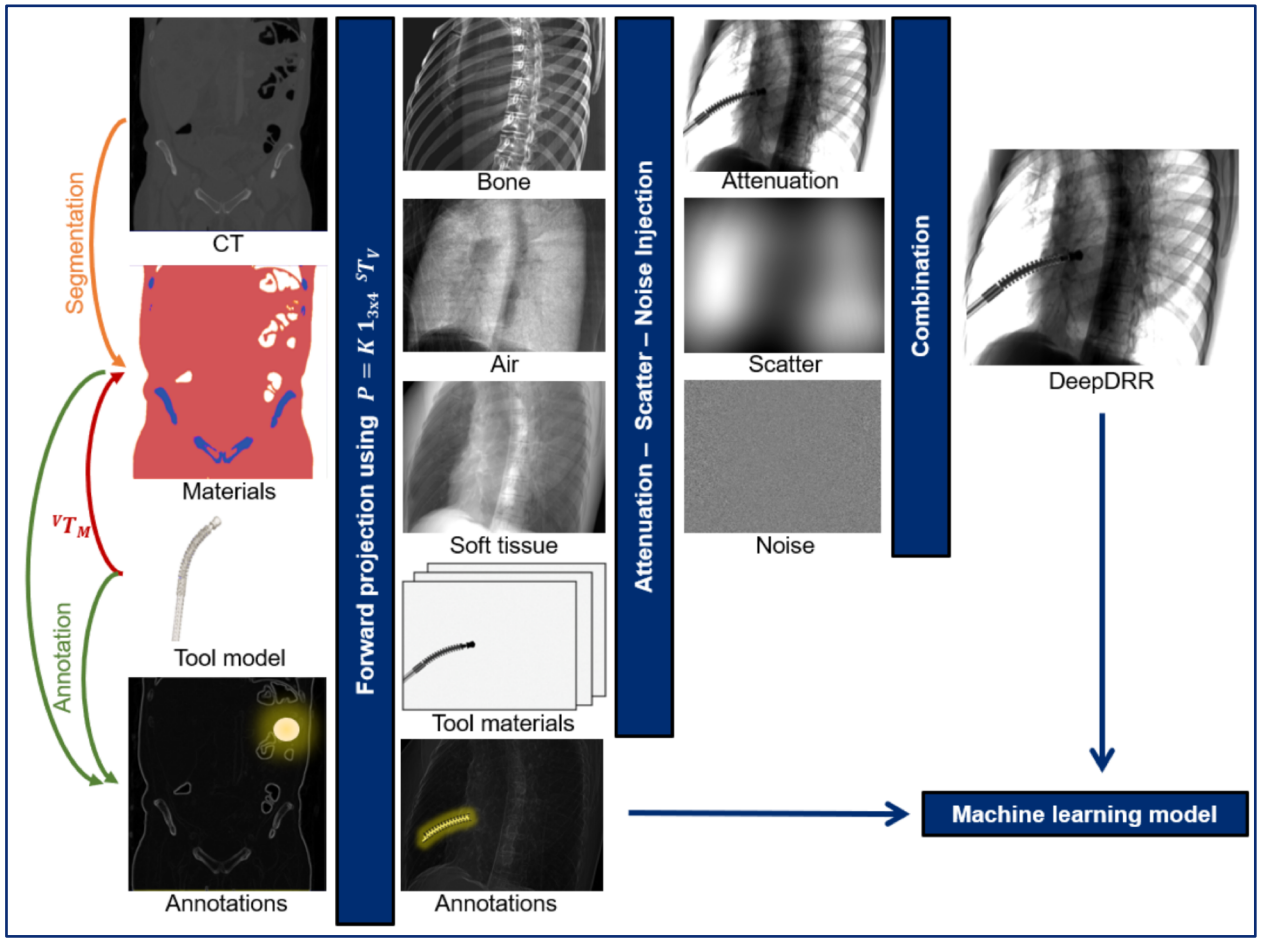
Method

Simulate X-ray images via DeepDRR[4]

CT data

Snake model

DeepDRR



[4] Unberath, Mathias, et al. "Deepdrr–a catalyst for machine learning in fluoroscopy-guided procedures." International Conference on Medical Image Computing and Computer-Assisted Intervention. Springer, Cham, 2018.

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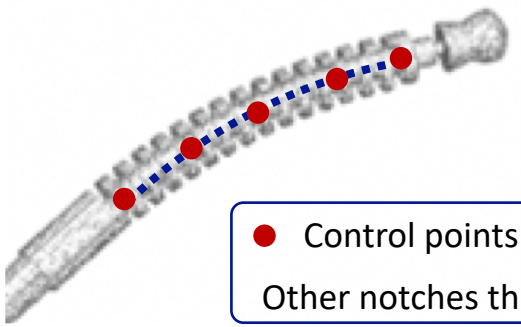
Data augmentation

*all uniform random sampling

- Source rotation:
  - LAO/RAO $\in [0°, 360°]$
  - CRAN/CAUD $\in [75°, 105°]$
- Source-to-isocenter $\in [400, 500]$ mm
- Volume translation $\in [-20, 20]$ mm in all axes

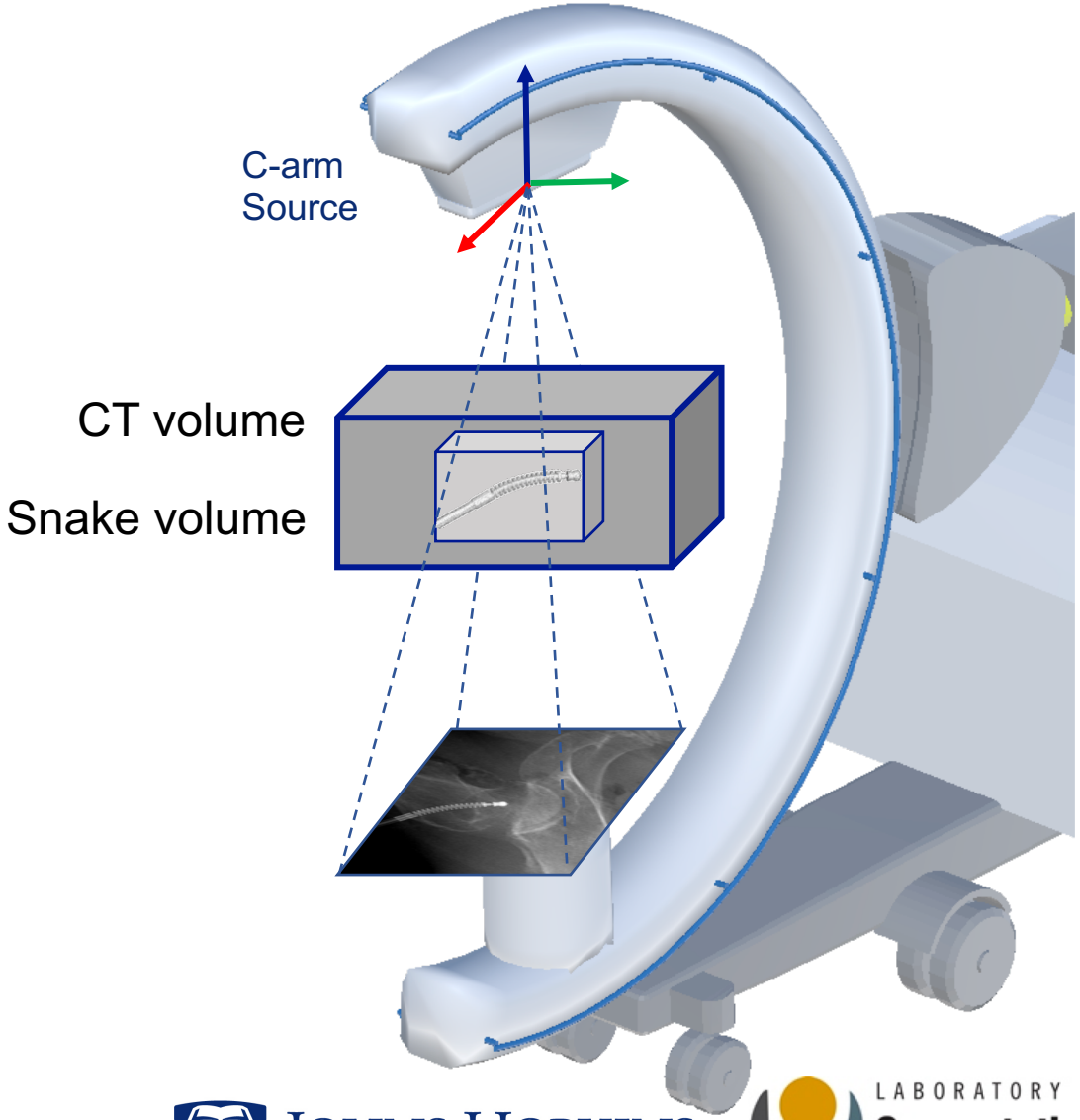
Snake shape:

- Control point angles $\in [-7.9°, 7.9°]$



Control points

Other notches through B-spline interpolation



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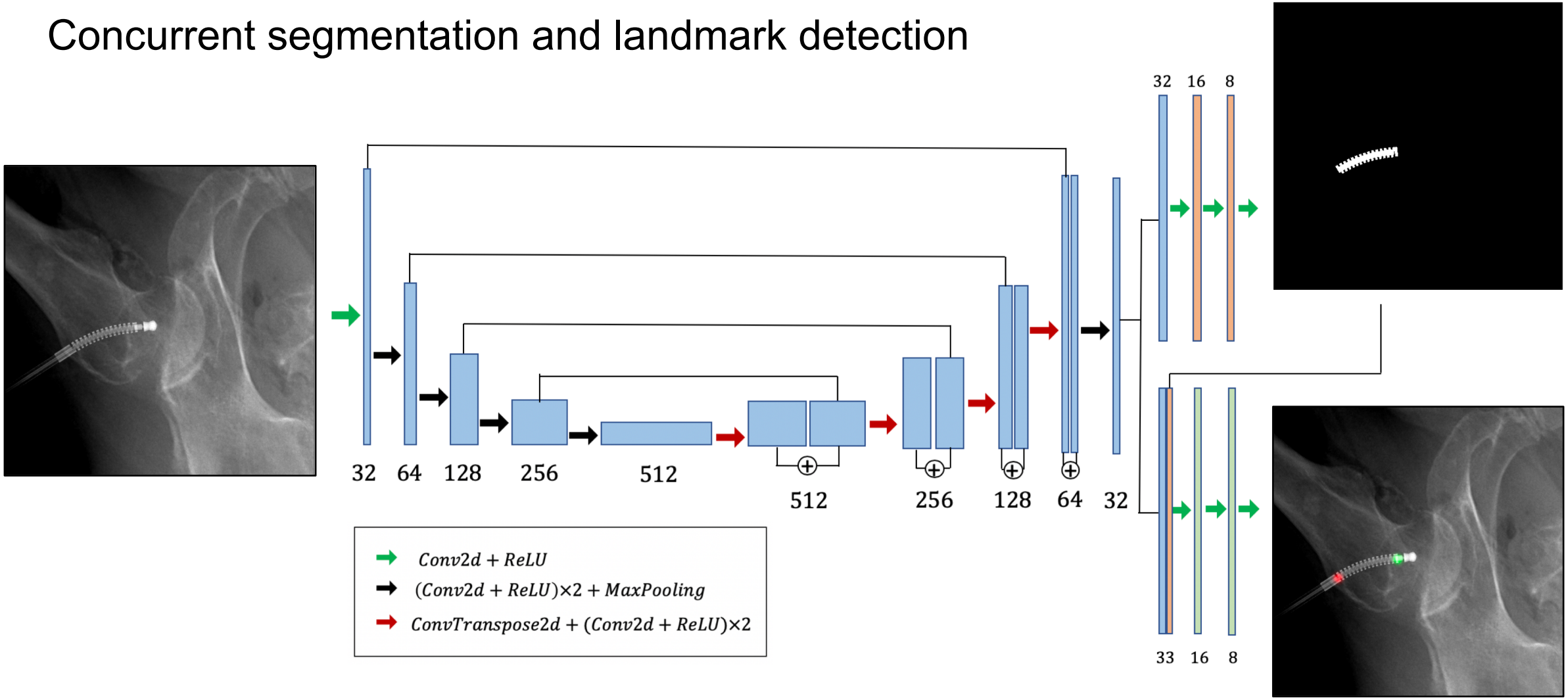
Method

Concurrent segmentation and landmark detection



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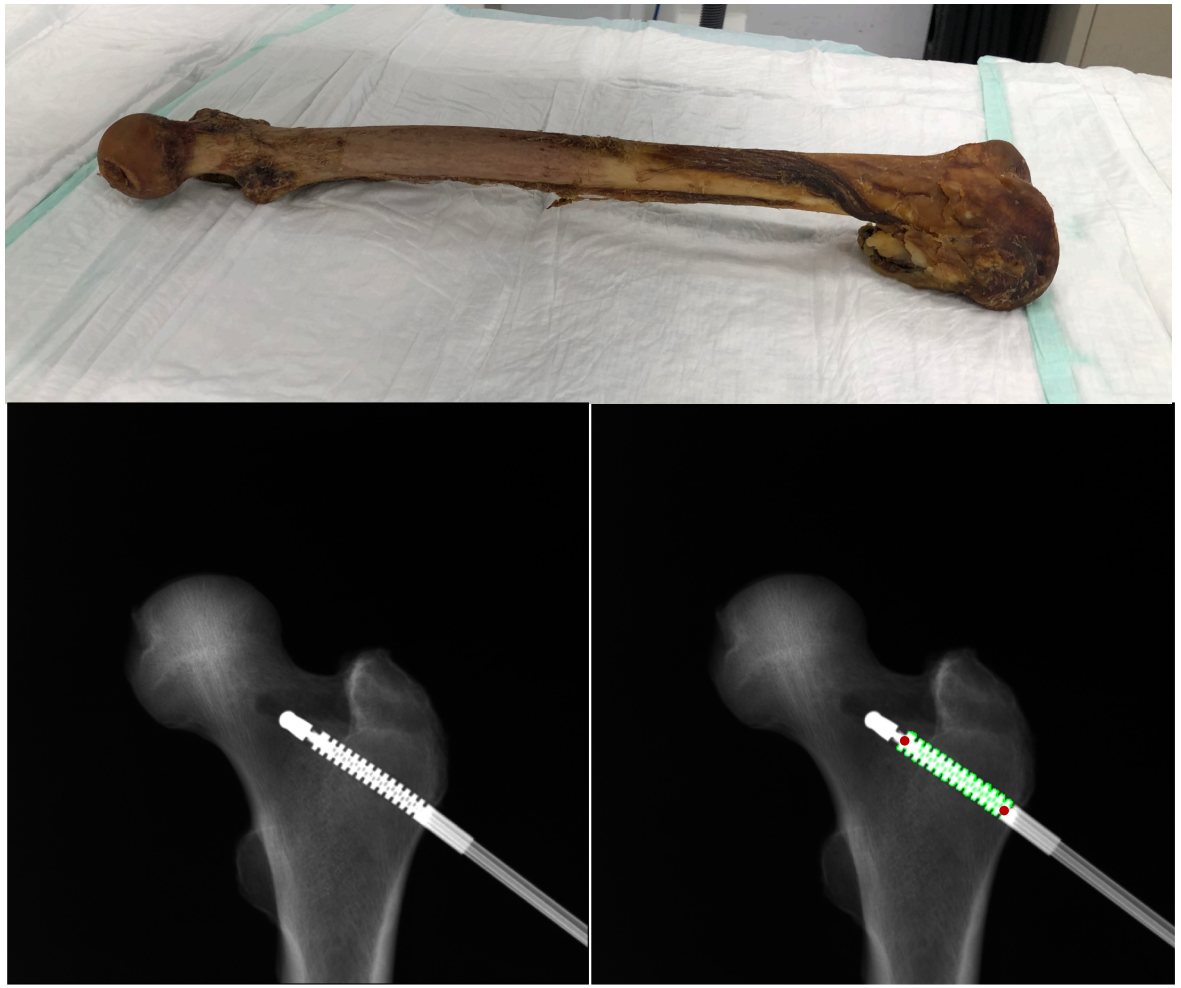
Real X-ray evaluation

- 87 *ex vivo* X-ray images acquired during curved drilling experiment of femur
- Manually annotated mask and landmarks for evaluation



Real X-ray | Manual annotation

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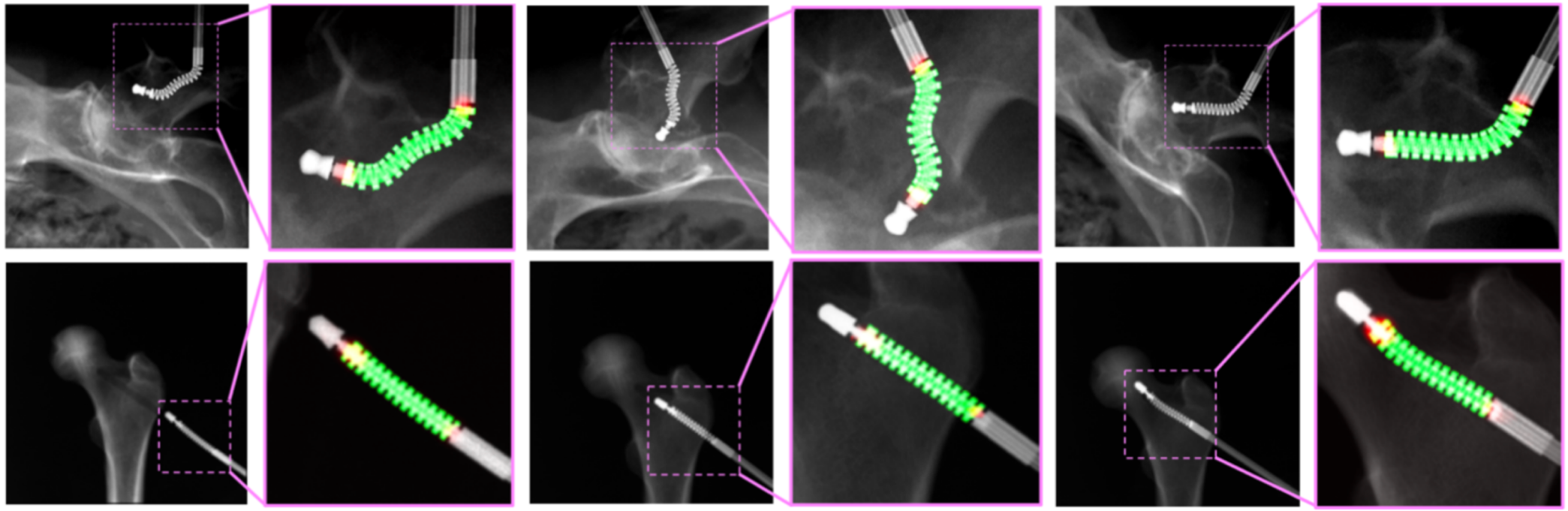
Result

	Segmentation Dice Score	Landmark Mean L2 (mm)
Synthetic	0.996 ± 0.001	0.365 ± 0.345
Real	0.915 ± 0.063	2.54 ± 0.95

Sim:

Real:



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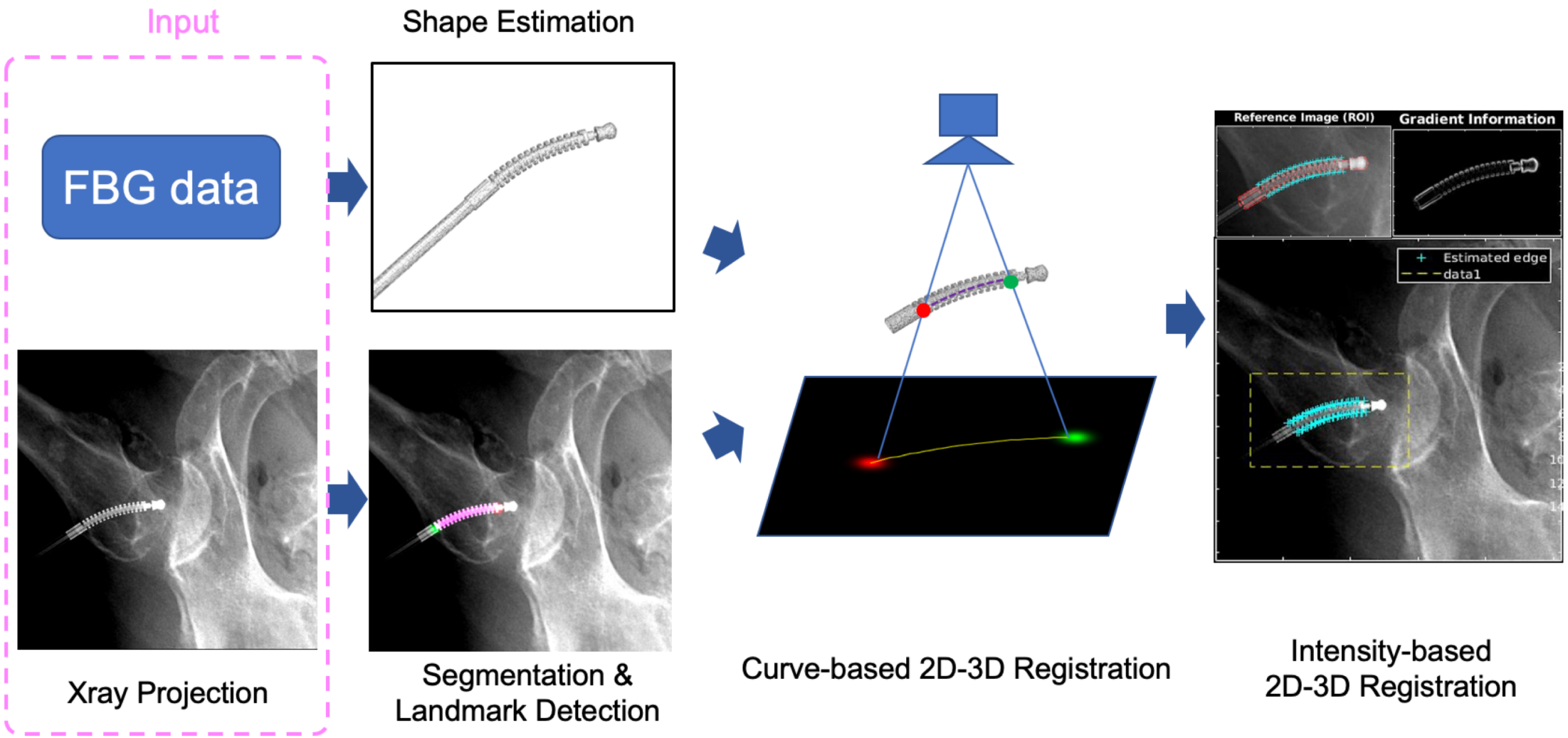
Application to Registration



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Conclusion

- Automatic image-based initialization for 2D-3D registration
  - yield overlapping structures by design
- Learning-based localization pipeline
  - simultaneously localize and segment snake in X-ray images
- Further investigation of framework robustness
  - generalize to real X-ray images

Future Work

- Train our ConvNet on a more exhaustive dataset
- Translate to other real data
- Reliably and robustly initialize image-based 2D-3D registration

Thank you!

Welcome to see our poster **LA-1**

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