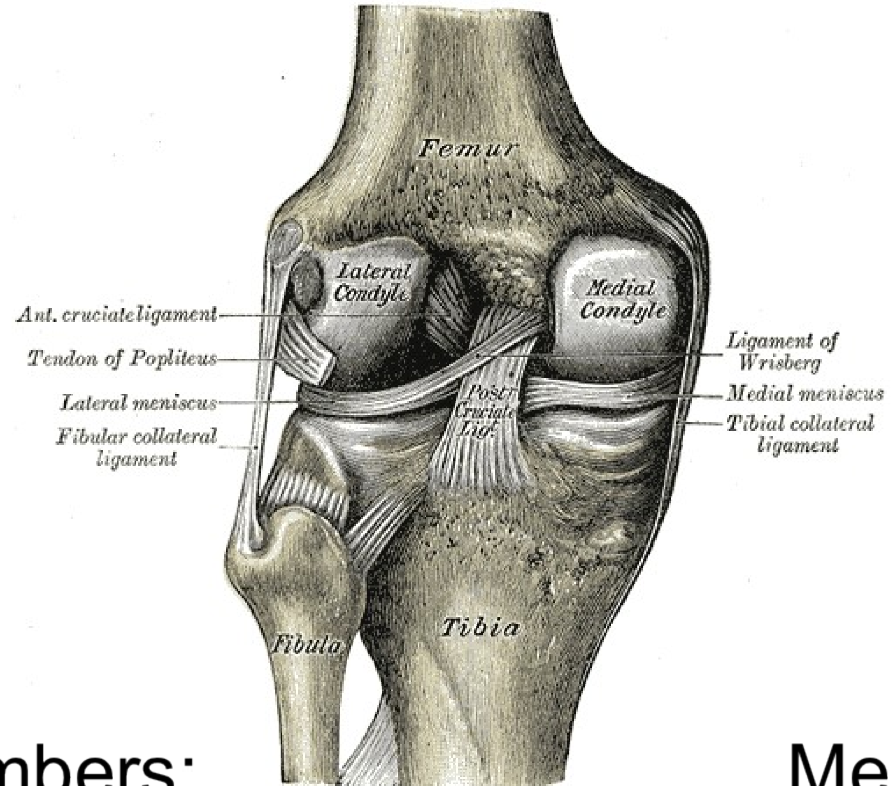
Statistical Atlas of the Knee



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Xin Kang (Ben)

Outline

- Project Update
- Paper Selection
- Summary
- Significance
- Relevance
- Algorithm Details
- Paper Evaluation
- Possible Improvements

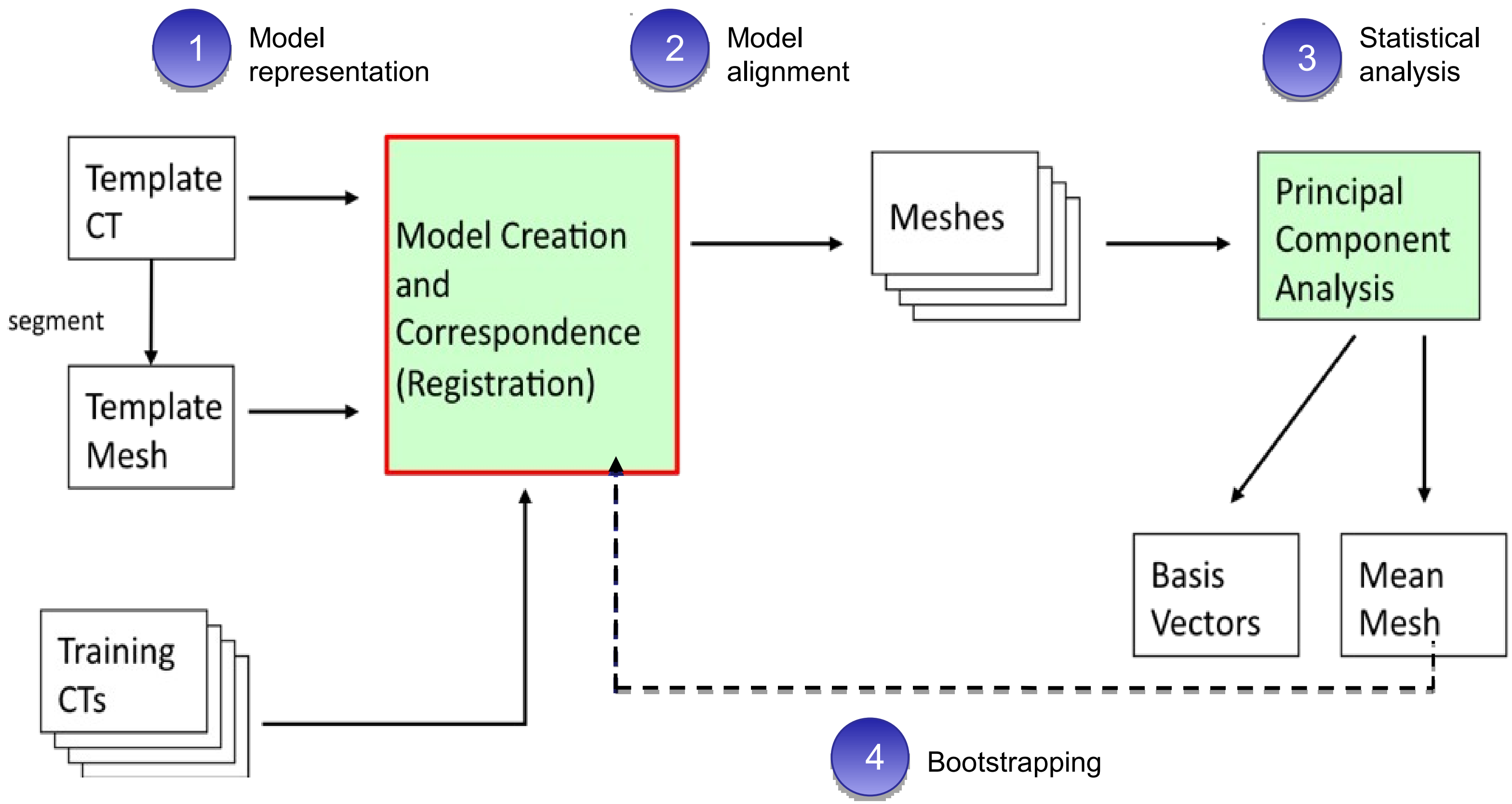
What we have done so far

- Obtain preliminary atlas using the current pipeline and existing pelvis data
  - by February 25 **Done!**
- Create a tetrahedral mesh of femur and tibia using the Hong Kong dataset
  - by March 27 (Ceylan)
- Automate the pipeline
  - by March 27 (Murat)

Paper Selection

- Yezzi, A. Zollei, L. Kapur, T. *A variational framework for integrating segmentation and registration through active contours*. Medical Image Analysis 7 (2003) 171 – 185.

Paper Relevance:
Remember Basic Atlas Construction Process



Shamelessly stolen from Dr. G. Chintalapani's PhD dissertation

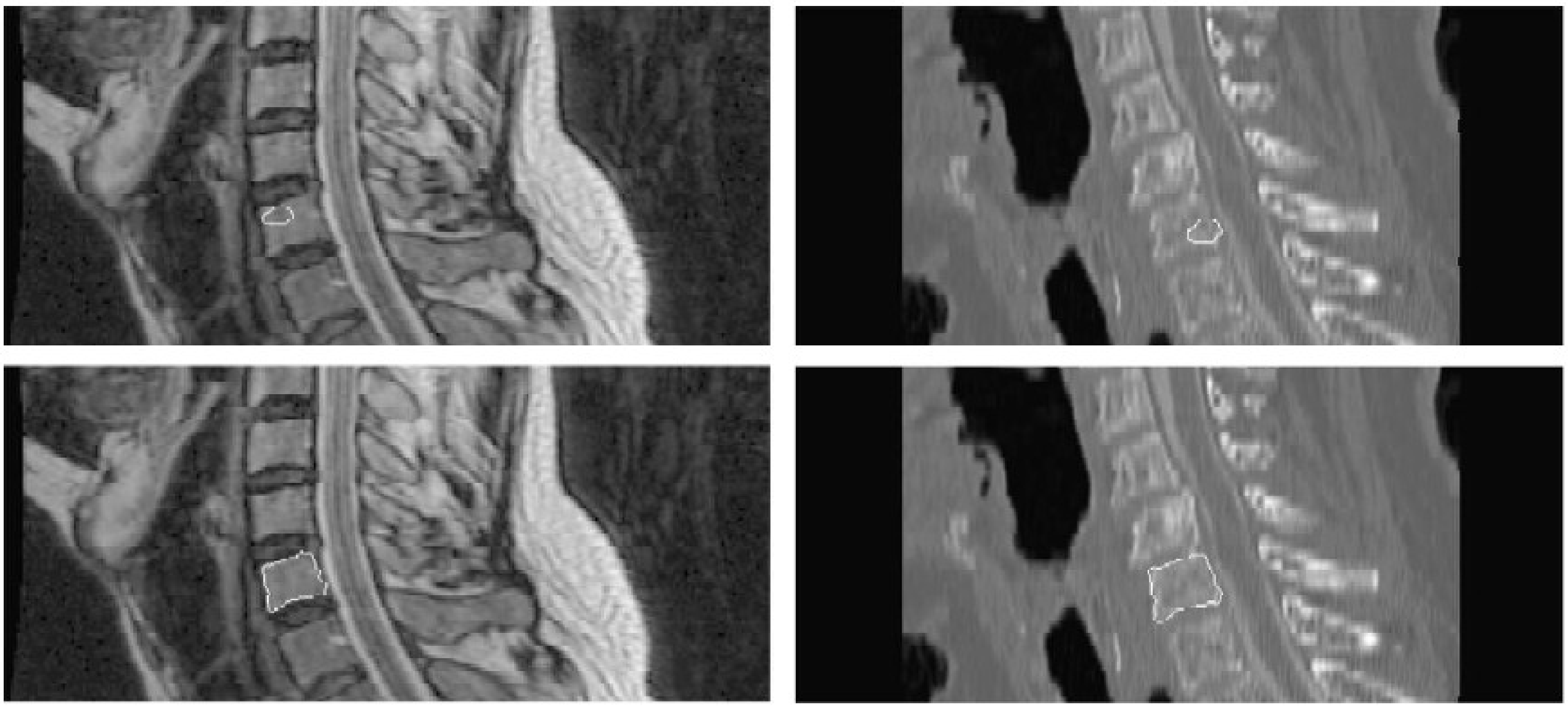
Paper Summary

- Use feature based energy constraints to simultaneously segment and register multiple images with active contours

- They tested this algorithm on
  - 2D MR-CT head images
  - 3D MR-CT spine, head and ventricle images
  - Synthetic validation images

MR / CT Spine Experiment

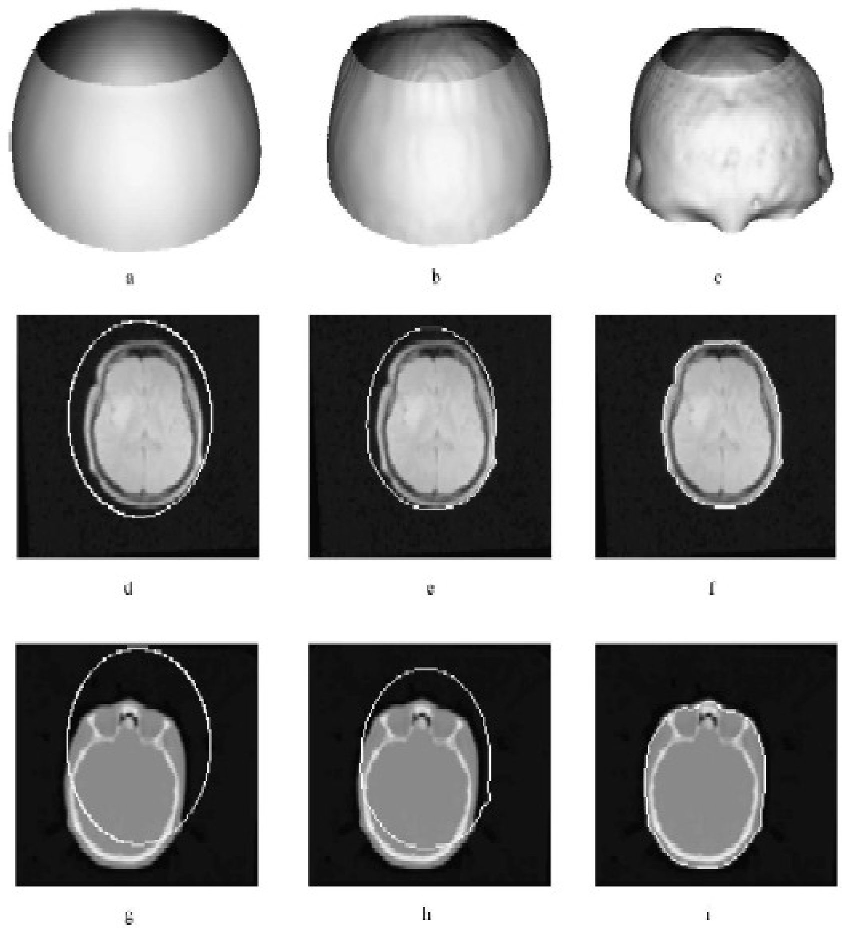
Top images: Initial step



bottom images: final step

Image from Yezzi, A. et al. *A variational framework for integrating segmentation and registration through active contours*.

3D MR/CT Head Experiment



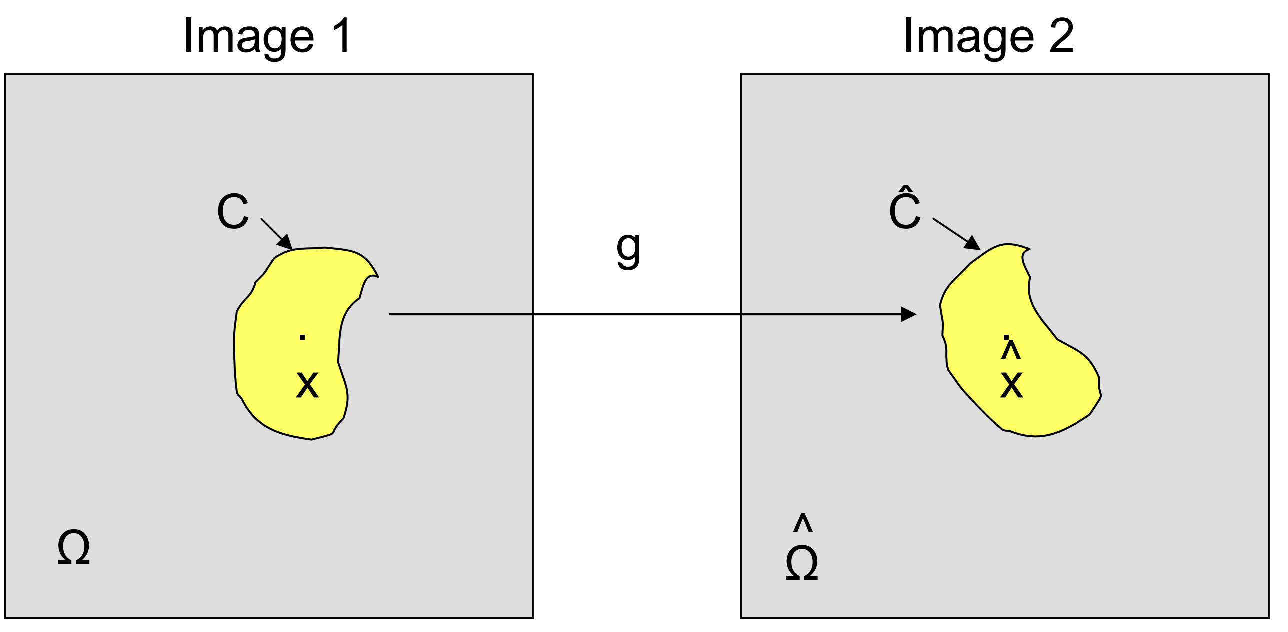
Initial Mid Final

Image from Yezzi, A. et al. *A variational framework for integrating segmentation and registration through active contours*.

Significance

- Registration depends on segmentation
  - Rigid and non-rigid transformations depend on segmentation results
- Segmentation may depend on registration
  - Higher level model-based segmentation methods require registering images on a model
- This method eliminates the dependency of one method's result on the other.

Algorithm Details



$$\hat{\mathbf{x}} = g(\mathbf{x}))$$

$$\hat{C} = g(C)$$

$$g(\mathbf{x}) = RM\boldsymbol{x} + D.$$

$$E(g, C) = E_1(C) + E_2(g(C))$$

$$= \int_{C_{\text{in}}} f_{\text{in}}(\mathbf{x})\, \mathrm{d}\mathbf{x} + \int_{C_{\text{out}}} f_{\text{out}}(\mathbf{x})\, \mathrm{d}\mathbf{x}$$

$$+ \int_{\hat{C}_{\text{in}}} \hat{f}_{\text{in}}(\mathbf{x})\, \mathrm{d}\mathbf{x} + \int_{\hat{C}_{\text{out}}} \hat{f}_{\text{out}}(\mathbf{x})\, \mathrm{d}\mathbf{x}.$$

Calculations

Where the region based energy functionals (f and f^) are defined as:

$$f_{\text{in}} = (I - u)^2, \quad f_{\text{out}} = (I - v)^2,$$

$$\hat{f}_{\text{in}} = (\hat{I} - \hat{u})^2 \quad \text{and} \quad \hat{f}_{\text{out}} = (\hat{I} - \hat{v})^2$$

Where u and v are the mean intensity values inside and outside the contour respectively.

Note that these functions are a variation of Gaussian Distribution

$$\phi(x; \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

Calculations Continued

$$E(g, C) = E_1(C) + E_2(g(C))$$

Rearranging the equation and writing Ĉ in term of C by using g provides:

$$E(g, C) = \int_{C_{\text{in}}} (f_{\text{in}} + |g'|\hat{f}_{\text{in}} \circ g)(\mathbf{x})\, \mathrm{d}\mathbf{x} + \int_{C_{\text{out}}} (f_{\text{out}} + |g'|\hat{f}_{\text{out}} \circ g)(\mathbf{x})\, \mathrm{d}\mathbf{x}$$

Calculations Continued

To describe how the contour changes with respect to time we can use the energy functionals:

$$\frac{\partial C}{\partial t} = (f_{\text{in}} - f_{\text{out}})N \quad \text{and} \quad \frac{\partial C}{\partial t} = (\hat{f}_{\text{in}} - \hat{f}_{\text{out}})\hat{N}.$$

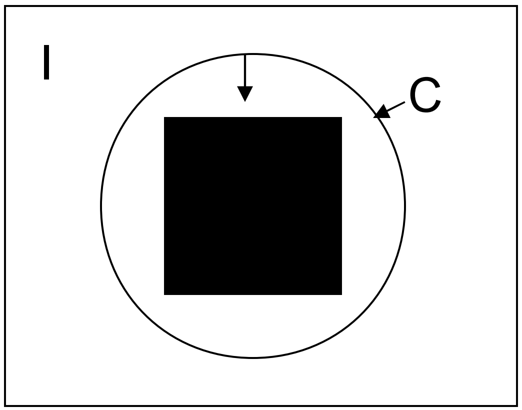
Combination of all the equations yield the necessary derivatives to calculate the contour line (C) and the affine transformation (g) at each iteration:

$$\frac{\partial C}{\partial t} = (f(\mathbf{x}) + m\hat{f}(g(\mathbf{x})))N - \kappa N,$$

$$\frac{\mathrm{d}g_i}{\mathrm{d}t} = \int_C \hat{f}(g(\mathbf{x}))\left\langle \frac{\partial g(\mathbf{x})}{\partial g_i}, mRM^{-1}N \right\rangle \mathrm{d}s$$

Illustrating How the Contour is Updated

$$\frac{\partial C}{\partial t} = (f_{\text{in}} - f_{\text{out}})N \quad \text{and} \quad \frac{\partial C}{\partial t} = (\hat{f}_{\text{in}} - \hat{f}_{\text{out}})\hat{N}.$$



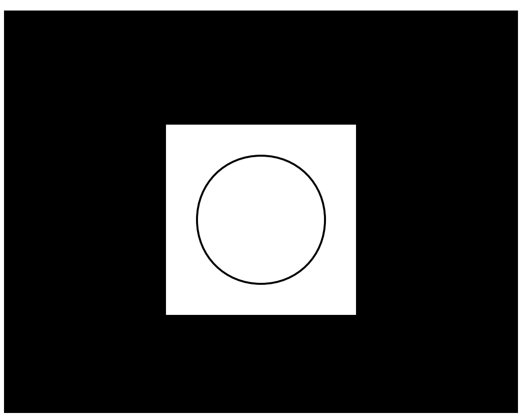
$f_{\text{in}} > 0$

$f_{\text{out}} = 0$

$(f_{\text{in}} - f_{\text{out}}) > 0$

$(f_{\text{in}} - f_{\text{out}})N$ points inward

Contour shrinks



$f_{\text{in}} = 0$

$f_{\text{out}} > 0$

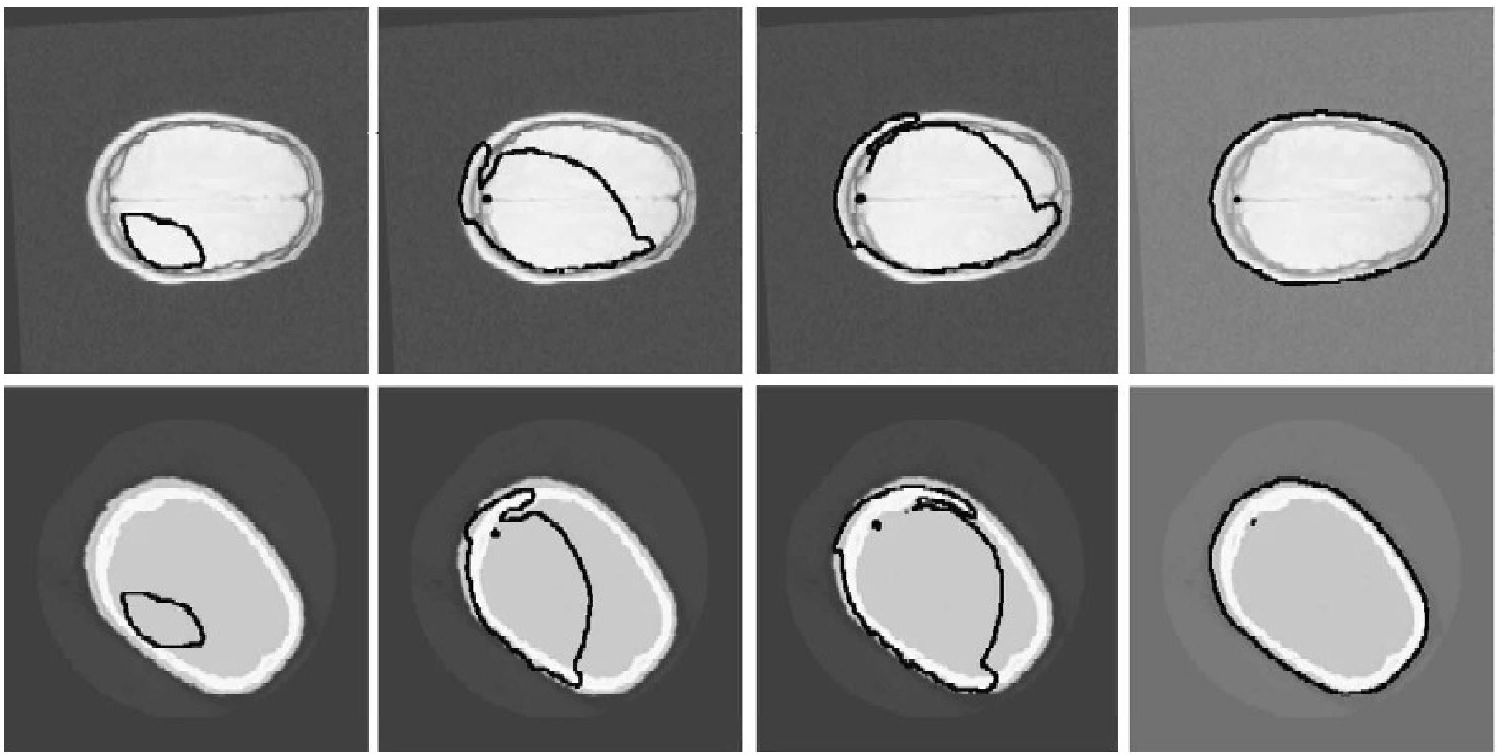
$(f_{\text{in}} - f_{\text{out}}) < 0$

$(f_{\text{in}} - f_{\text{out}})N$ points outward

Contour expands

Evaluation

- Solves segmentation and registration problems at the same time
  - Decreases the effect of error propagation



2D MR/CT head data

Image from Yezzi, A. et al. *A variational framework for integrating segmentation and registration through active contours*.

Evaluation cont.

- Robust against noise in the data
  - Assumes Gaussian distribution

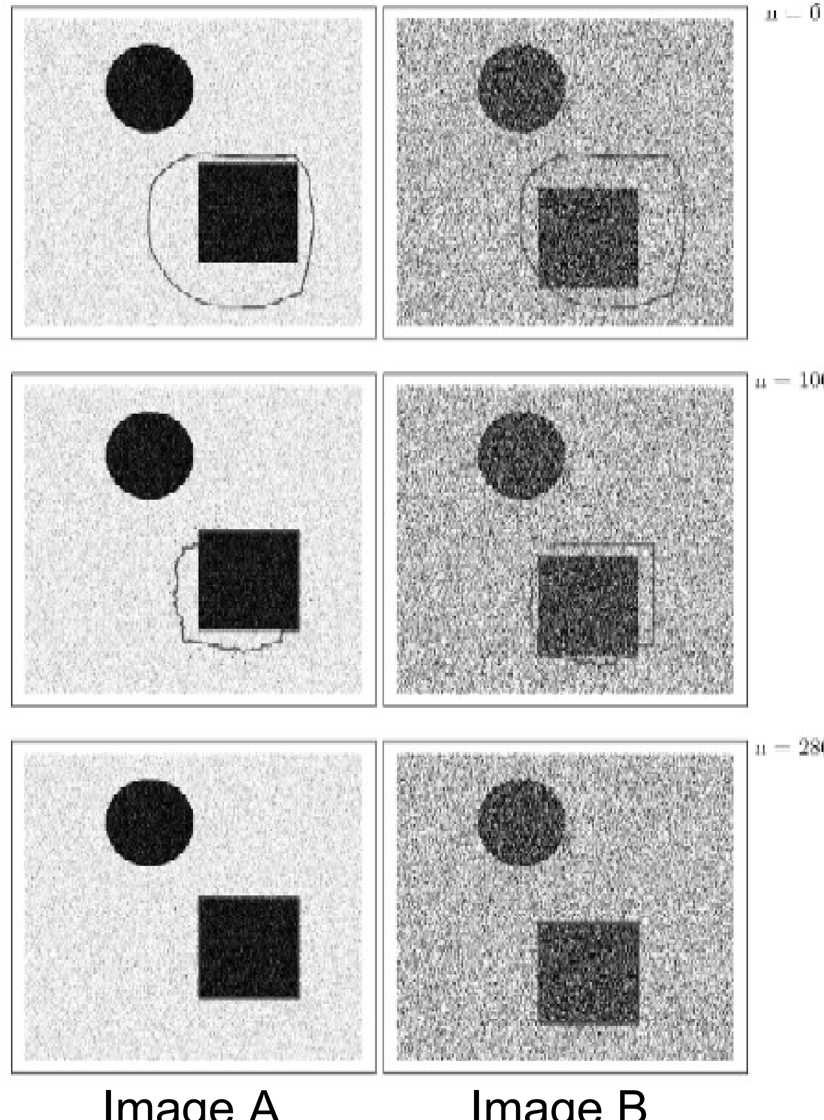
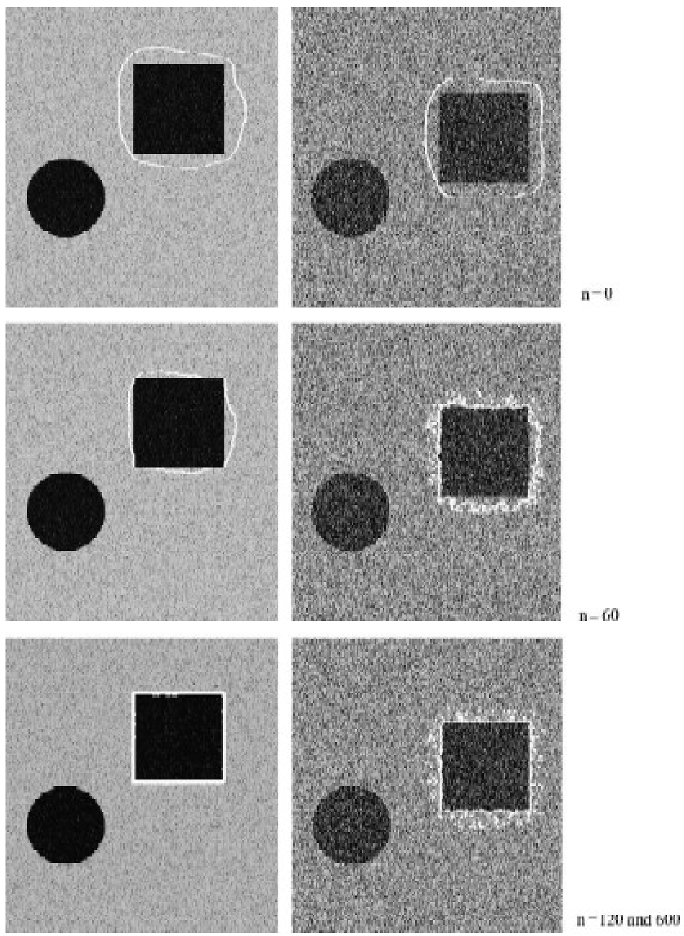
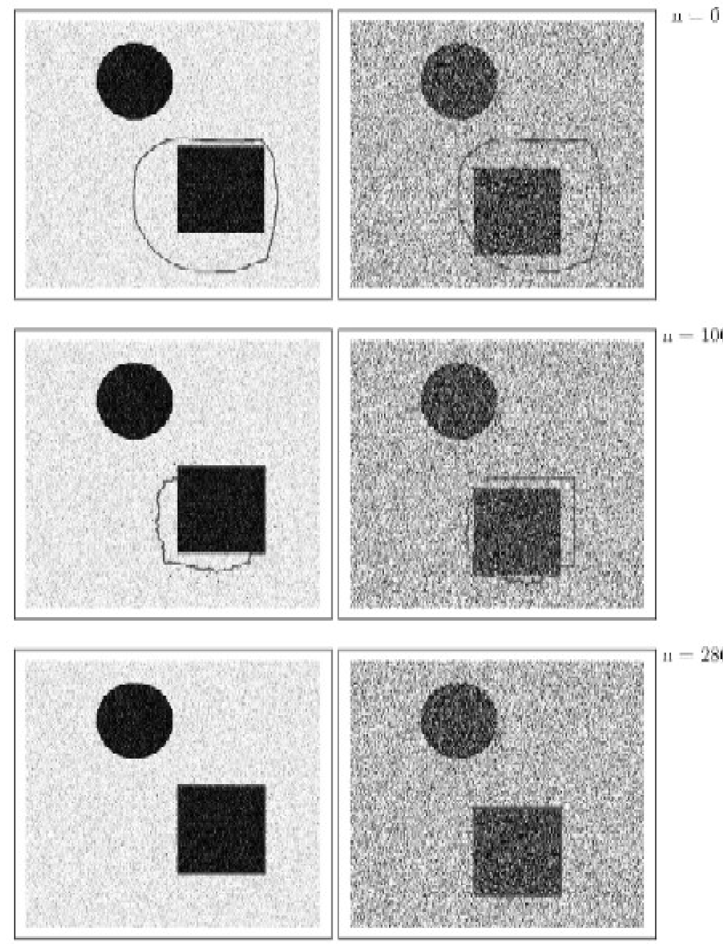


Image from Yezzi, A. et al. *A variational framework for integrating segmentation and registration through active contours*.

Something Suspicious..



Exp 1: Only segmentation



Exp 2: Developed Algorithm

Image from Yezzi, A. et al. *A variational framework for integrating segmentation and registration through active contours*.

Evaluation cont.

- Uses region based energy functionals
  - More applicable to medical data
- Can be generalized to work with multiple images
- Works with images from different imaging modalities

How can we implement this in our project?

Pros

- We can use it in the second step: model alignment
- Use segmented cadaver study to aid the segmentation of patient data
- Improve the knee atlas by using images from different modalities

Cons

- Algorithm assumes Gaussian distribution
  - The segmented volume has sigma=0
- We would be using the algorithm for different patients

Possible Improvements

- Generalize the algorithm for multiple images
- Use a weighted combination of E_1 and E_2 where one image would be easier to segment than the other

Bibliography

- Yezzi, A. Zollei, L. Kapur, T. A variational framework for integrating segmentation and registration through active contours. Medical Image Analysis 7 (2003) 171 – 185.

Questions?